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INSTITUTE
OF TECHNOLOGY
BULLETIN

REPORT
OF THE
PRESIDENT
1967

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PRESIDENT

I take pleasure in submitting my first report on the state of M.I.T. In an important sense the events of the last year should stand on their own and constitute in themselves a report of some interest to the several groups — the Faculty and the Corporation, the students and the alumni — who have a deep and understandable concern for our progress and our problems. The accounts of each school, written by my colleagues within the Institute, and which I submit with my report, well fulfill that requirement.

These accounts emphasize the nature of M.I.T.'s educational pattern: that this is a university where individuals who have accepted individual responsibility move forward on their own, toward their own objectives, in their own way; and that this is a university where the essential unit of measurement is the individual professor and the individual student working together in common cause. It is the professor relentlessly pressing for new understandings and new ideas, and it is the student setting for himself a high standard of imaginative performance and contributing in turn to the education cycle, that sets the Institute's pattern. The first function of this university, like others, is to turn out superbly educated men and women, and I hold this highly individualized responsibility that characterizes M.I.T.'s learning process to be the heart of the institution. The reports of the departments speak to this intensive individuality.

These events, however, assume added significance when viewed in the perspective of the whole history of M.I.T., for I believe they reflect the basic themes of the Institute and, as such, they reflect a continuation of the historic force that is M.I.T. These are the themes of a university centered on the advancement of science and its broadening applications and responsibilities, committed to the constructive use of technology,

dedicated to the liberal education of the best of our youth. The fine structure that supports these themes deserves examination.

It is appropriate, I believe, to take such a bearing on where we stand and where our community proposes to move this year, the next, and those that follow, so that we may judge better the worth and the cost of our goals. And it is precisely that kind of exercise in which many of my colleagues and I have been engaged this past year — in measuring where we stand, in reexamining our assumptions of size and purpose and direction, and in assessing our needs and expectations. No one needs to emphasize to those of us who undertook this effort, the difficulties of this kind of assessment and the inherent problems of projection in an institution that will measure its progress in ideas still without shape and in hopes that still are not understood. Yet a prudent look at our resources in combination with our evaluation of fields that most urgently require advancement makes elemental sense. The full range of M.I.T.'s aspirations emerges from this review. They express M.I.T.'s major concerns in science and technology; the nature of the physical environment; the nature of life and health; the quality of the living environment; the processes of communication; information and decision processes; the social, political and administrative problems of society; the humanities and the arts; the processes of teaching and learning; and the encouragement of undergraduate education. These are major commitments that relate our past and our future in the context of the current year, and they give us guidance in measuring what we can do and what we should not do. I propose to state those generalizations as we see them now, and to comment on them in the light of the year's events, recognizing always the impossibility of doing full justice to the many facets of a vigorous institution.

I

M.I.T. is a university with a primary focus on enlarging the horizons of science and the development of technology and its applications to our society. The enduring twin pillars of M.I.T. are engineering and science. It is important for one who seeks more than a superficial understanding of M.I.T. to understand the nature of their individual contributions, their unique beauty, if you will, and at the same time their intensive complementarity. It would be impossible in modern M.I.T. to have great engineering without great science; and to have great science without leadership in crucial applications of technology would not fit M.I.T.'s historic pattern. There is not only a harmony in supporting both, there is in fact a powerful requirement to do so. I believe that the vigorous strengthening

of each stream of our effort, together with the reinforcement of their crosscurrents, is both necessary and possible.

In science it is inconceivable that M.I.T. should be content with less than the first rank in the leadership of its several branches or in the quality of the education of our students. This year has shown that this obvious goal will not be achieved without vigorous and consistent effort. We have been gifted with a full complement of strong basic science departments since the days of Karl Compton. They lie at the heart of the teaching and research of the Institute, and their quality marks every part of the Institute. For, in addition to carrying a responsibility for education and research in the advanced sectors of these fields, the core science subjects are part of the education of every student. Now the time has come for further effort in all of these fields. With new opportunities in chemistry and physics, we can see next steps in the direction of strengthening basic science at M.I.T. The key to developing such new strength lies here, as everywhere, in the quality of faculty and students, and that is our first concern. But research funds and the facilities for effective work are necessities if the science fields are to move forward at a rate that matches both promise and need. Research funds are, of course, always a problem, but M.I.T.'s Alfred P. Sloan Basic Research Fund is an unparalleled base for start-up money in physical science research. In facilities, new steps are now under way. Construction on the new chemistry building, the Camille Dreyfus Building, has begun, and its coming to Eastman Court will mean a great deal to research and teaching in chemistry everywhere. Let us count our considerable recent blessings. The Dreyfus Building will join the already excellent facilities of the Cecil and Ida Green Building, which have made a wholly new level of work in earth sciences possible, and the Uncas and Helen Whitaker Building, which has permitted fresh progress in biology and its interconnections with chemistry and physics.

We have taken a good step forward this year in improving our facilities for theoretical physics. We hope to begin shortly the construction of a linear accelerator well off the campus, a useful country extension of a research facility that needs large spaces to be effective. Space on campus is one thing we do not have, but it must be said that we have unfinished business on the campus in providing facilities in physics and mathematics; and this will be one of our major preoccupations in the sciences for the years ahead.

In the same breath I turn to the second half of this primary commitment, the strengthening of our basic concern for improving technology. For M.I.T. this means engineering without equal. Most people, inside and outside M.I.T., take strong engineering at the Institute for granted. We dare not. First positions are precarious positions because there is no

place to go but down, and standings in education are no exception. Good progress was made this year in several of our engineering departments, but the men most deeply involved are the first to say that more remains to be done. A large part of the problem lies in the fact that technology moves forward relentlessly, and preparing men to lead it is a continually changing process, not only in content but in method. Yesterday's subject matter is obsolete, and yet if one goes too fast, too far, the constructive separation between applied science and technology becomes too wide. In almost every field of engineering, we ponder the question of how to continue to make old fields vibrantly new fields that still bear on the fundamental problems of engineering rather than science. These are always questions of balance, and the healthy debates I observe speak well for the level of concern and the level of performance.

Again, as a footnote, much of our hope of doing what we want to do well will depend on our ability to build new facilities. The immediate need is to produce a new electrical engineering complex. This is the largest and most sought-after Department among M.I.T. students, and the need is urgent. Chemical engineering is not far behind in its need, and its siting problems, for complicated reasons of campus geography, are more difficult. Within civil engineering, which has made such dramatic progress in educational advancement in the last few years, is the urgent need for an expanded laboratory for water resources. Naval architecture and marine engineering, borne in the rising tide of interest in all things oceanic, has had a new beginning, supported by our strong basic science work in oceanography. I add here that this supportive relationship between oceanography in the School of Science and ocean engineering in the School of Engineering is a classic case of M.I.T. science plus engineering producing a sum greater than the parts.

In brief summary, both the School of Engineering and the School of Science have compelling problems ahead, not the least of which is the need for major new resources over the next few years if their faculties and students are to achieve all they can and must. But no one can read the reports of the Deans of Science and Engineering without a feeling of grand movement and effectiveness during the year.

M.I.T. has a major concern with the nature of our physical environment and the means to explore and control it. It is impossible, of course, to separate this statement of concern and direction from the broader statement that has preceded it. It deserves emphasis because it bespeaks the special interests of professors and students of our science and engineering faculties in the atmosphere, in outer space, in the oceans, and in materials in general. Clearly, the effectiveness of our departments in

these areas has been advanced by the facilities of the Vannevar Bush Building, which houses the new Center for Materials Science and Engineering. Similarly, our work in oceanography will be strengthened by our close association with the Woods Hole Oceanographic Institution. The new joint doctoral degree in oceanography, initiated this year, opens laboratory facilities to our staff and students and offers increased theoretical strength to our Cape Cod neighbors. We believe that such regional extensions and collaborations are useful. In this light another major collaborative effort with several Northeast universities in the field of radio astronomy is being planned with the encouragement of the Corporation and with all of our hopes for the major federal funding it will require. It will join the Cambridge Electron Accelerator as well as our efforts at cooperation in more general regional associations. Finally, the completion of the Center for Space Research scheduled for the coming year will mean added opportunities to make contributions in this new frontier of science and engineering. These striking examples of strong theoretical work in association with strong applications bode well for the future of work in these fields.

I find this a reasonable place in my report, too, to note the continued achievement of our two large special laboratories, the Lincoln Laboratory and the Instrumentation Laboratory. They serve their primary purpose of providing major additions to the nation's operative defense and space programs, and, in another dimension, they provide appropriate problems for productive research by our students and faculty. Their purpose is a good one, and their process is productive for our scholarship.

M.I.T. has a major concern with the nature of life and health. Fully a third of the research projects under way at the Institute are directly in the life sciences or relate closely to them. Biology has been one of our most rapidly growing departments. Our work in nutrition and food science has become central to world interest in several of its areas; and the Department has changed the designation of some of its graduate degrees this year to Nutritional Biochemistry and Metabolism, to reflect both its revised scope and breadth. The number of undergraduates who have an interest in medical careers each year continues to grow. Our collaboration with medical faculties in the city, such as the Lahey Clinic and the Massachusetts Eye and Ear Infirmary, is in a healthy state. Early this summer a two-week study, sponsored by members of our Faculty and including a large number of distinguished visitors, sought to explore ways in which M.I.T. might organize our strong interests in the whole range of biomedicine. Related to this has been the appointment of several working committees representing the Harvard Medical School and M.I.T. to

explore cooperative efforts involving several aspects of engineering, physics, and medicine. It is difficult to overstate the high promise in education and research represented by these several moves. More work and more resources are called for. M.I.T. has a larger contribution to make in the health fields. We continue to seek its fuller expression.

M.I.T. has a major concern with the quality of our environment as it relates to the condition of our cities: the character of our structures, our transportation, our water resources, the pollution problems that mar the city's promise, and the management skills concerned with environmental problems. For years, M.I.T., through our School of Architecture and Planning, has had an important influence on the improvement of the aesthetic and economic process of the city and has left a distinctive mark on the way man relates to his environment. But now, we can observe generally an ever increasing awareness of the importance of the quality of our everyday life. The way in which man lives, the physical and psychological ways in which he relates to his fellows, determine in large part what he becomes. The problems that represent these concerns are systemic by nature and intimately related to our technology as well as our politics and economics. The answers, or even a methodology for arriving at holistic answers, are not yet clear. But M.I.T.'s concerns and intentions are clear. This year a faculty committee spent long hours planning a sharply upgraded effort in the field of urban affairs. It remains to be seen whether funds will be forthcoming to support the new personnel and new programs they have proposed. In a real sense M.I.T.'s habit of organizing to meet complex technical problems represents a distinct hope for achievement here. The work of several departments, in architecture and planning, in engineering, social science, and management are all involved in our concern for complex sociotechnical problems, and they will need program support.

M.I.T. is deeply interested in communication, information, and decision processes. Crossing school lines, in networks that are themselves complicated, are theoretical and applied interests of several departments in these areas, from electrical engineering to mathematics and physics, to civil engineering and management. Underlying these interests and extending to every department and laboratory, as well as the administrative framework of the Institute, is the ubiquitous computer, and the pervasive role of its science in vital extensions of information organization, retrieval, and analysis. There are now 20 computers on the campus, with an annual operating budget of about five million dollars, not including the two large special laboratories. This year we will complete a new

computer building, much needed in the service of these efforts. Project MAC, M.I.T.'s now famous advanced computer science project, continues to teach us all more about computers, beyond the significance of its original acronyms; and the work of Project INTREX, an imaginative set of approaches to making a reality of the automated library of the future, continues to make progress. Just as important, I believe, we must make more progress in the rational organization and allocation of our computation resources. M.I.T., from the time of Norbert Wiener and Vannevar Bush and before, has been a leader in the development of all of these fields. We propose to remain in the vanguard.

M.I.T. has a major concern with the social, economic, political, and administrative problems of our society and seeks to contribute to the body of knowledge aimed at their solution. Progress in the social and human relationships, whether at a world level or a community one, has been sadly slower than progress in areas of science and technology. At M.I.T. we believe that the two tracks relating to the human and technical sides of man's advancement need to be joined more effectively if real progress is to be made in the future in either area. The natural and effective growth of the social sciences and management at M.I.T. speaks for the way in which our faculty and students have seen this relationship. We have a good start in these fields, with distinguished economics, political science, languages and linguistics, and psychology, and I am glad to report continued progress in these fields during the year. Serious for the immediate future is the new fact that the Sloan School of Management is inadequately funded, given the sharply reduced level of the Sloan Foundation's support in recent months. This School, having so effectively emerged as a leading one in the field, now needs encouragement and support.

At an entirely different level of observation, but still related to M.I.T.'s long record of a concern with events that involve scholarship with national interest, I want to report on an important step in the complex problem of understanding classified research at M.I.T. It is almost impossible for the scholar not to be troubled by the presence on the campus of research or information or activity that is classified. Such work goes against the grain of the openness of intellectual dialogue and debate. Yet in a real world in which important work in some fields must have access to classified information, or, even more importantly, where the country may call on us for help in what we regard as appropriate extensions of our academic work, exceptions have been made, and in the future will be made again. To seek to understand the conditions under which M.I.T. will undertake these exceptions, a serious study of this

whole problem was undertaken by the Academic Council and by the Faculty Committee on Educational Policy. The statement of policy emerging from these studies was approved as a sense of the meeting of the Faculty and further endorsed by the Corporation. I include it here both for its intrinsic importance and as a piece of M.I.T. history.

M.I.T. affirms that the encouragement of research and inquiry into intellectual areas of great promise is one of the most basic obligations to its faculty, to its students, and to society at large. It affirms the profound merits of a policy of open research and free interchange of information among scholars as essential to this responsibility.

In the vast majority of research projects, the encouragement of inquiry wherever the research might lead is not in conflict with the principle of freedom of inquiry and open exchange of knowledge. However, M.I.T. is an institution that plays a unique role in important areas of science and technology that are of great concern to the nation. It recognizes that in a very few cases the pursuit of knowledge may require access to data or literature of a classified nature, or yield results whose immediate distribution would not be in the best interests of society. It affirms, therefore, that such activities are undertaken only when, after weighing the advantages and disadvantages for the academic program and for the nation, they are judged to be highly constructive. Since the implementation of classified research has some aspects which are detrimental to the academic environment of the Institute, it is essential that each project be reviewed and acted upon in the light of its impact on the Institute as a whole.

It is the policy of the Institute, therefore, that every research project within the academic structure of M.I.T. (excluding Lincoln Laboratory and the Instrumentation Laboratory) which requires a classification on the research process or on the publication of results receive the prior approval of the President or Provost, who shall seek the advice of the Committee on Educational Policy in cases that involve modification of the existing policy and will inform the Committee of all approvals.

Individual classified theses to be undertaken by undergraduate or graduate students must be approved by the Committee on Graduate School Policy before the work is begun.

II

I turn now to a guide for our aspirations that I consider to be one of the first orders of business for the next few years at M.I.T.:

M.I.T. will continue to strengthen the humanities and arts, recognizing their importance, within the context of a liberal university based on science, not only in providing a broader framework for understanding and directing the goals of science, but also in and of themselves. A fundamental purpose of the university is to generate new knowledge and new ideas. In a world dominated by technology M.I.T. can be regarded as a prime contributor in this regard. A second, less understood function is to evaluate and measure the progress of the world in the light of history — in short, to criticize it. For if the university does not criticize, what

social instrument will? Standing apart, somewhat less engaged in society's problems, the university is charged with providing a standard of value for society's actions. The most effective medium for both messages — contribution and criticism — is the student. We believe that in preparing the new generation of leaders which society will demand of us in the years ahead, the healthy interaction of contribution and criticism will make us stronger and more effective; and I mean to imply that a university like M.I.T. is perhaps uniquely equipped to function at an entirely new level of effectiveness in this role. So we turn to our progress in the humanities.

The work of our Department of Humanities is outstanding. But few if any students come to M.I.T. as undergraduates expecting to major in humanities, and few people outside M.I.T. are aware of our strengths in this field. We are now reasonably convinced that we pay a price for this, a certain parochial character in the balance that results. Just as science and engineering students need the breadth of humanities and arts, so could the humanities major of the future profit immensely by the addition of strong science in his course of study. The further promise of this relationship at a wholly new level is clear, but how we achieve this we are not yet sure. The work of this year, the potential association of our architecture, visual arts, and performing arts along with our humanities seems to promise another major step in our efforts to achieve the best possible educative opportunity for the men and women we propose to prepare for leadership and scholarship. Let me quote from a recent statement by Dr. Jerome B. Wiesner, the Provost:

As the scale of technical capabilities grows and becomes ever more pervasive and as M.I.T.'s faculty turns to an active involvement with the large social problems of society, urban development, nation-building, health care, environmental control and more effective education, we must constantly be reminded that we build for man; we must constantly strive to understand what this means. As the interaction with a strong scientific faculty in the years past transformed M.I.T.'s engineering from ingenious art to a rigorous discipline, so the presence of creative, humanistic scholars and artists probing the objectives of society, remembering the lonely human being, relating to the past and questioning the future, emphasizing the moral and esthetic and respecting the intuitive will insure that our great social engineering efforts reflect the best possible perception of man's real needs.

It would be a natural extension of M.I.T.'s progress in humanities for the past 20 years to take another large step. I hope that we will.

III

A final set of objectives that give us guidance for the future relates not to fields but to process, and finally to the style of education we propose to support.

M.I.T. is committed to research and improvement in the processes of teaching and learning. In every part of this university one can observe a vigorous effort at improving the teaching process. The impetus of more organized curriculum review efforts has had a beneficial effect most recently characterized by the effort of the faculty committee on curriculum development. Moreover, we are in a period of large-scale student interest in improving the methods of teaching and encouraging learning. We welcome all these good and continuing signs. The newly formed Education Research Center, growing out of the earlier Science Teaching Center, should help us further if we can support it adequately. At a time when the quality of college teaching has become a matter of national concern, I can say that from my view, the energy, interest and concern devoted to good teaching by members of M.I.T.'s Faculty is exceptional. But we worry about how we can do still better.

M.I.T. is strongly committed to undergraduate education. This statement has always been a cardinal point for us in the past; it remains so for the future. The undergraduates give the Institute a continuous cycle of new strength and vigor. They give us a wholeness and an integration that we would not achieve were we to concentrate mainly on the graduate side. We accept this important contribution, but to make it wholly effective will call for a great deal of work, including some bold experimentation.

For example, we intend to continue our effort at making the first year a productive and invigorating amalgam of the science and humanities purpose. We intend to continue our effort at making that introductory year an effective platform for movement to all our fields. We are doing a better job of understanding our problem here, thanks to the hard work of several of our most dedicated professors, but the whole answer to the organization of the science subjects and the steps beyond still is unclear. We want to continue and extend the effect beyond the first year.

I believe we are making more effective alternatives available to our students in the undergraduate years. The addition of the range of Wellesley College courses to our own expanding range should further improve the perspective as well as the view, and it is a natural extension of our undergraduate interests. To recall: In May the Faculties and the governing boards of both M.I.T. and Wellesley agreed to initiate an experimental program to make courses on each campus available to students of the other. A more detailed report of what we can expect from this experiment will be before us in another year. But I believe it speaks directly as an example of our interest in providing more effective and

more interesting diversity on our campus, and I for one am enthusiastic about its promise.

Also related to the undergraduate years, I note the initial studies by the Committee on Educational Policy on the authorization of pass-fail grading for an elective subject in the senior year. We shall see how that particular experiment turns out and hope to learn from it.

Beyond subject matter and method, two elements are worth mentioning that relate especially to undergraduates but, of course, affect our whole student group. The first relates to our interest in making the living environment more effective. We are now, as the Dean of Student Affairs points out in his report, a residential college. It is, I must emphasize, a different kind of residential college than those of cloistered halls, distant from reality, monastic in their isolation. Indeed, we seek to create a productive intellectual community of students, one in which they have responsibility as well as amenity. But our community, even as of old, must stay in touch with the active world outside the campus. This is not a new idea at M.I.T.; the fraternity men who trooped across Harvard Bridge and the Senior House and East Campus students all knew the process. Now we seek to strengthen it. The addition of the second half of McCormick Hall, the completion of the Eastgate Tower, a residence for married students on the Sloan Campus, and, to come, the reality of McGregor House, a new residence for undergraduates on Memorial Drive, give us strong assurance that we can make headway here. But the task is a difficult one. Resources are difficult to generate for these purposes. We will have to rely on those few who understand the strong contribution to learning made by the style of living and associations.

A second point related to our students is the pattern of responsibility thrust upon them by our system of student governance. The undergraduates take direct responsibility through their leaders for a large part of their lives while at M.I.T. It is a system that has been developed through generations of students, and it clearly has served the students and the Institute well. We propose to continue in this path.

IV

I turn now to the other side of our future. Beyond aspiration and beyond need lies the hard fact of cost. Can we afford those things which our departments and schools say are urgent over the next few years if we are to maintain and advance M.I.T.'s contribution to our world? In the final analysis the answer to that will be given by our friends and supporters,

but there can be no flinching from the magnitude of the costs associated with these brave goals.

It is Dr. Killian's judgment and mine that we should undertake no Second Century type of campaign to obtain the funds we need. Instead we will rely on a steadily growing Alumni Fund and on an unremitting solicitation of foundations, corporations, and individuals for the resources crucial to each project. We have just finished raising more than ten million dollars for our chemistry program with funds obtained from corporations, foundations, individuals, and government. We have just completed a two million dollar fund to modernize our engineering library, and this was made possible through a generous and large personal commitment by one of our alumni. In a similar manner we now propose to seek 14 million dollars for a new electrical engineering and electronics complex, 14 million dollars for faculty development (including endowed professorships), 6.5 million dollars for new student residences and the improvement of existing dormitories, and two million dollars for student aid. Thus, item by item, we propose to seek gifts and grants other than those required for normal operating budgets to meet urgent new capital needs. As we have discussed them with the Corporation Development Committee, the capital needs that we foresee for the next ten years total 135 million dollars. Future needs will require additions to this total, and M.I.T. must respond to these new needs as they arise. And let me add that, in these judgments, I acknowledge here with profound gratitude the timely advice and assistance of M.I.T. alumni during this first year of stocktaking. My own sense of the Institute's bearing and its future course has been quickened by an extraordinary round of discussions with alumni officers and groups in major cities and with individual alumni in leadership positions across the country.

I bring this overview of the past year to a close. Yet no account of mine could be complete without a note of admiration and a salute to the men before us who have made M.I.T. what it is today. This year alone nine remarkable men retired from the ranks of our professors. Their names add to the legend of great teaching, great research accomplishment, and, in the end, great human beings that marks the Institute. I need only name them: William P. Allis, Howard R. Bartlett, Alexander J. Bone, Jacob P. Den Hartog, Giorgio D. de Santillana, C. Stark Draper, Harold L. Hazen, Paul N. Rosenstein-Rodan, and Bertram E. Warren.

To that roster I add another name: Julius A. Stratton. We honor his achievement, we cherish his friendship, and all of us are in his debt.

PRESIDENT

Finally, among all the members of our Faculty who deserve recognition for assuming exceptional responsibility, I would like to name those men who have taken on new duties during the past academic year: Robert A. Alberty, Dean of the School of Science; Raymond L. Bisplinghoff, Head of the Department of Aeronautics and Astronautics; Milton U. Clauser, Director of Lincoln Laboratory; Alfred A. H. Keil, Head of the Department of Naval Architecture and Marine Engineering; John Ross, Head of the Department of Chemistry; Louis D. Smullin, Head of the Department of Electrical Engineering; and Victor F. Weisskopf, Head of the Department of Physics. I add Donlyn Lyndon, Head of the Department of Architecture; Boris Magasanik, Head of the Department of Biology; and Irwin W. Sizer, Dean of the Graduate School, who assume their new duties on July 1, 1967.

M.I.T. is a university that has sustained throughout its history an exceptional sense of relevance to its times. Concerned first with the soundness of its scholarship and with the education of its students, the Institute has nourished an innovative interest in the problems of society. And now, perhaps more than ever, it is appropriate that this be so. A century ago, in a society just emerging from a disastrous civil war, full of divisive problems, confronted with urgent pressures, and with a need to establish and reflect the ideals of a young country, William Barton Rogers' statement of the dignity of useful work and the relation of the ablest young people to the most difficult problems of the time was immediately important. In the years since then, that statement has been no less important. I believe that M.I.T.'s record of the year just past reflects these directions in a new form, with new purpose, and with continued relevance. It is in this sense and with this assurance that I submit this report on the state of M.I.T.

HOWARD W. JOHNSON

STATISTICS FOR THE YEAR

The following paragraphs report briefly on various aspects of the Institute's activities and operations during 1966-67.

REGISTRATION

In 1966-67 student enrollment was 7,567, an increase of 159 over the 7,408 enrolled in 1965-66. This total was comprised of 3,857 undergraduates and 3,710 graduate students.

Graduate students who entered M.I.T. last year held degrees from 291 colleges and universities, 184 American and 107 foreign. The foreign student population was 938, representing approximately 12 per cent of

PRESIDENT

the total enrolled. The foreign students were citizens of 73 different countries.

Degrees awarded by the Institute in 1966-67 included 872 Bachelor's degrees, 782 Master's degrees, 141 Engineer degrees, and 386 doctoral degrees — a total of 2,181.

STUDENT AID

This year 2,159 undergraduates, 56 per cent of those enrolled, received \$2,362,031 in scholarship aid and \$1,605,538 in loans. These two categories of direct aid thus totaled \$3,967,569, an increase of 27 per cent over the year before.

The planned use of M.I.T. operating funds in the amount of \$333,308 to augment our designated scholarship resources during the past year has helped to make possible this improved aid program. The scholarship assistance granted included \$1,061,934 from outside sources (an increase of \$174,617 from the previous year) and \$966,739 from M.I.T.'s own endowment fund. The endowment for undergraduate scholarships was increased by \$1,063,699 during the year. Total endowment now stands at \$15,528,876, reflecting a 7.3 per cent increase over 1965-66.

Of the loans provided during the past year, \$780,844 came from the Institute's Technology Loan Fund and \$647,027 from the National Defense Student Loan Fund. An additional \$176,267 in loan funds was received from other sources.

Besides the loan total recorded above, 79 students received \$57,089 under the Installment Credit Program, which permits a portion of the tuition fee to be paid over a ten-year period.

During the academic year 1966-67, the Institute made the following awards to graduate students: \$2,696,000 in fellowships, traineeships, and scholarships; \$916,000 in staff tuition grants; \$5,717,000 in staff salaries; and \$486,511 in loans, for a total of \$9,815,511.

Comparable figures for last year on a fiscal year basis were \$2,285,525; \$676,442; \$5,573,422; and \$457,872 respectively, for a total of \$8,993,261.

Fellowships awarded to our graduate students in 1966-67 by major outside agencies amounted to an additional \$1,874,000.

Figures 1 and 2 show the increases over the past decade in most of the foregoing categories of financial aid for both graduate and undergraduate students at the Institute.

PLACEMENT

A total of 412 companies, 35 government agencies and 18 graduate schools actively recruited in the Placement Bureau during the past year.

FIGURE 1

FINANCIAL AID TO UNDERGRADUATE STUDENTS
FROM ALL SOURCES, 1957-1967

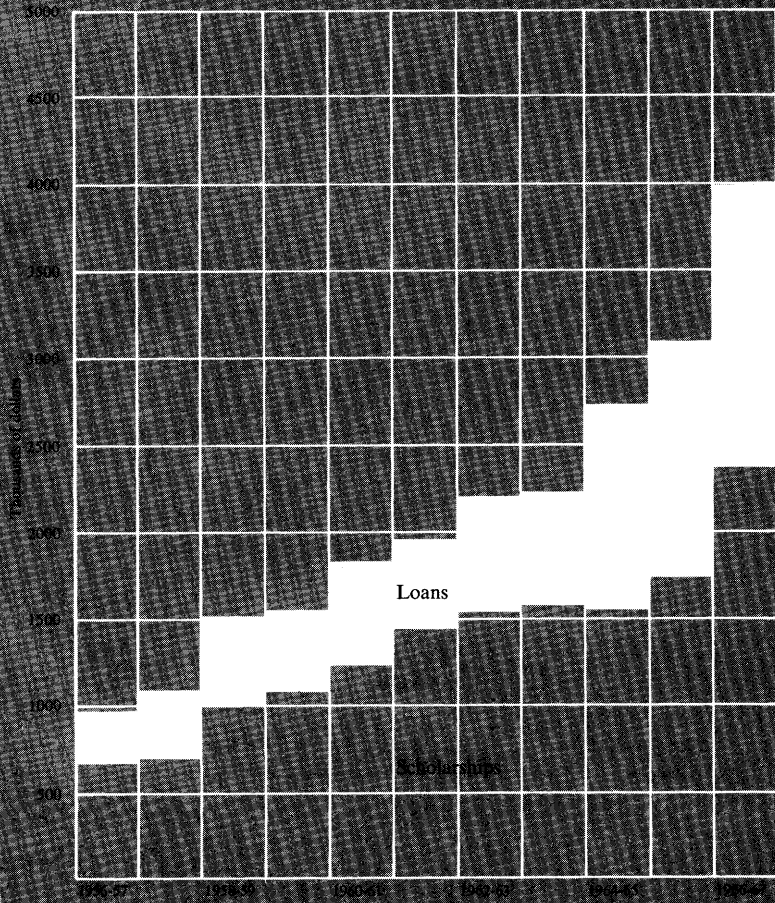
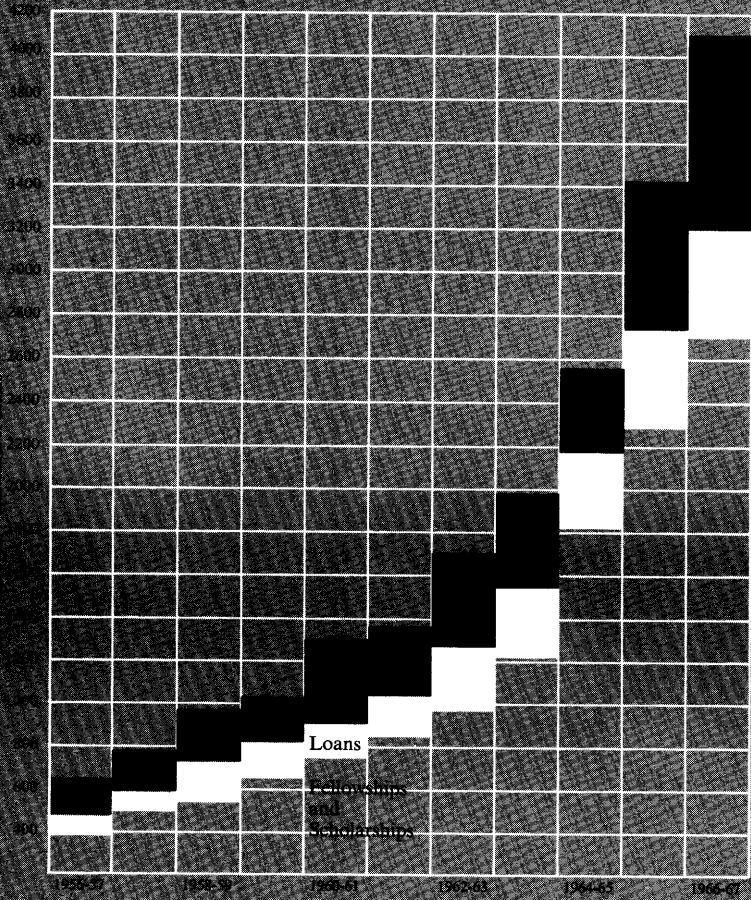


FIGURE 2

FINANCIAL AID TO GRADUATE STUDENTS
AWARDED BY M.I.T., 1951-1967



PRESIDENT

The 759 company and other representatives who participated in these visits interviewed a total of 1,554 students, who took 6,789 interviews.

Once again a rise was noted in the per cent of our total product (all degree levels) who entered business or industry. This amounted to 26 per cent. Among our graduating seniors, 77 per cent planned to go on to graduate school, with only 16 per cent entering business or industry.

Rising at approximately the same level as in recent years was the starting salary for our graduates. The median offer to this year's graduating seniors was \$720 per month; to Master's candidates, \$900; and to doctoral candidates, \$1,050.

An indication of the eagerness with which M.I.T. graduates are sought is that this year as many as 16,000 separate employment opportunities were received in our Alumni Placement Office.

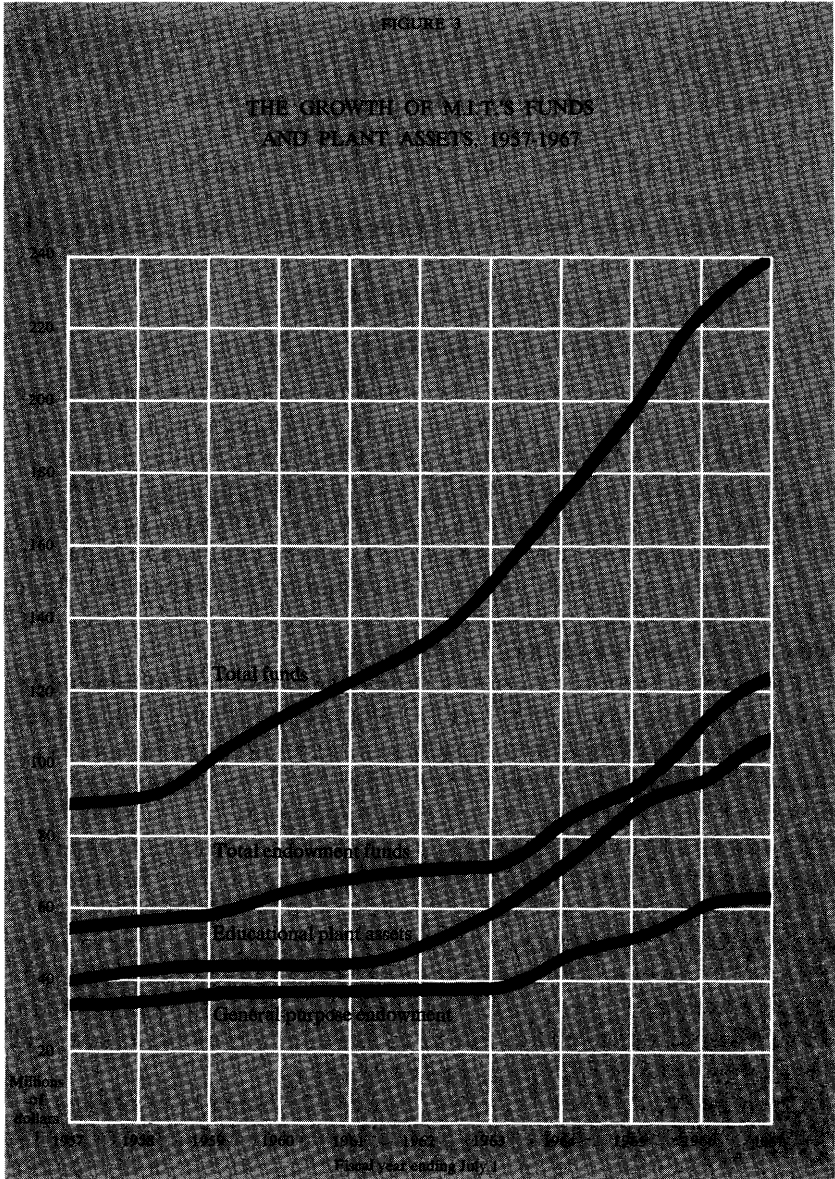
FINANCES

As reported by the Treasurer, the Institute's educational and general expenses — excluding the direct expenses of departmental and interdepartmental research and of the Lincoln Laboratory and the Instrumentation Laboratory — amounted to \$48,758,000 during 1966-67 as compared to \$41,666,000 during 1965-66. The Treasurer has pointed out that this increase in educational and general expenses was due, in part, to special programs such as the expansion of support for basic research, international programs, the curriculum development program, and extended computation and library services.

The direct expenses of general departmental and interdepartmental sponsored research increased from \$37,382,000 to \$41,621,000; and the direct expenses of major laboratories and special departmental research increased from \$93,972,000 to \$103,793,000. These changes represent increases of 11 per cent and ten per cent, respectively.

The large construction program of the Institute continued to make further progress in 1966-67, with the book value of plant facilities increasing from \$96,182,000 to \$107,871,000. Major additions to buildings in process of construction included the Eastgate facilities for married students and faculty, the Center for Space Research, the Center for Advanced Engineering Study, McCormick Hall — East, the central refrigeration plant, the computation center, the fourth parking garage and the initial expenditures for the chemistry building.

At the end of the fiscal year, the Institute's investments, excluding retirement funds, had a book value of \$232,151,000 and a market value of \$332,325,000. This compares to book and market totals of \$219,038,000 and \$317,544,000 last year. Endowment and other funds increased this year from \$229,118,000 to \$239,902,000.



PRESIDENT

Funds sharing in the income from the general investments earned 6.71 per cent, and five per cent was allocated to the endowment funds. There was also, as in the previous year, an extra distribution of one per cent to these funds.

Figure 3 shows the growth of M.I.T.'s fund and plant assets from 1957 to 1967.

GIFTS

Gifts, grants and bequests to M.I.T. from private donors totaled \$17,862,000 during fiscal 1966-67 as compared with \$40,740,000 for the previous year. The latter included \$1,546,000 in Second Century Fund pledge payments and unrestricted direct gifts to the Alumni Fund of \$696,000, which made up a part of the total of \$2,536,000 included in the Alumni Fund in 1966-67.

It is interesting to note here, from the report of the Treasurer, that during 1965-66 the bequest to the Institute by Alfred P. Sloan Jr., a large foundation grant, and the further receipts for the Second Century Fund combined to bring total new resources for the year to a peak level. Consequently, the gifts received in cash, securities, or other property in 1966-67 were lower at \$17,862,000 as compared with \$40,740,000 in the previous year.

PERSONNEL CHANGES FROM
OCTOBER 1, 1966 TO SEPTEMBER 30, 1967

CORPORATION

DEATHS

THOMAS D'ARCY BROPHY

APPOINTMENTS

GEORGE P. EDMONDS
Special Term Member

H. I. ROMNES
Special Term Member

ALBERT H. BOWKER
Alumni Term Member

RALPH F. GOW
Alumni Term Member

DONALD A. HOLDEN
Alumni Term Member

CHANGES OF APPOINTMENT

SEMON E. KNUDSEN
Life Member

ROBERT B. SEMPLE
Life Member

LUIS A. FERRÉ
Life Member

GWILYM A. PRICE
Life Member Emeritus

JAMES H. DOOLITTLE
Life Member Emeritus

ELECTION

GREGORY SMITH
President of the Alumni Association

PRESIDENT

FACULTY

DEATHS

FLOYD E. ARMSTRONG
Professor Emeritus in Economics

FRANCIS BITTER
Professor in Geology and Geophysics

RALPH E. FREEMAN
Professor Emeritus in Economics

RALPH G. HUDSON
Professor Emeritus in Electrical
Engineering

WALTER C. SCHUMB
Professor Emeritus in Chemistry

LAWRENCE S. SMITH
Associate Professor Emeritus in
Mechanical Engineering

THEODORE H. TAFT
Associate Professor Emeritus in
Mechanical Engineering

RETIREMENTS

C. STARK DRAPER
Institute Professor Emeritus

WILLIAM P. ALLIS
Professor Emeritus in Physics

HOWARD R. BARTLETT
Professor Emeritus in Humanities

JACOB P. DEN HARTOG
Professor Emeritus in Mechanical
Engineering

GIORGIO D. DE SANTILLANA
Professor Emeritus in Humanities

THOMAS B. DREW
Professor Emeritus in Chemical
Engineering

HAROLD L. HAZEN
Professor Emeritus in Electrical
Engineering and Dean of Graduate
School, Emeritus

PAUL N. ROSENSTEIN-RODAN
Professor Emeritus in Economics

BERTRAM E. WARREN
Professor Emeritus in Physics

ALEXANDER J. BONE
Associate Professor Emeritus in
Civil Engineering

RESIGNATIONS

Professors:

CHARLES H. TOWNES
Institute Professor

HOLT ASHLEY
Aeronautics and Astronautics

WARREN G. BENNIS
Sloan School of Management

CARVEL COLLINS
Humanities

DAVID A. HUFFMAN
Electrical Engineering

KENKICHI IWASAWA
Mathematics

ELTING E. MORISON
Sloan School of Management

PATRICK WALL
Biology

Associate Professors:

THEODORE M. ALFRED
Sloan School of Management

DONALD S. APPELYARD
City and Regional Planning

E. FARNSWORTH BISBEE
Civil Engineering
(to Research Associate in
Naval Architecture and Marine
Engineering)

CAPTAIN JOHN D. BLANKENSHIP
Military Science

GEOFFREY P. E. CLARKSON
Sloan School of Management

WILLIAM H. DENNEN
Geology and Geophysics

ALVE J. ERICKSON
Mechanical Engineering

ANTHONY F. GANGI
Geology and Geophysics

S. WILLIAM GOUSE JR.
Mechanical Engineering
(to Lecturer)

MARTIN GREENBERGER
Sloan School of Management

JAMES S. HEKIMIAN
Sloan School of Management

PHILIP G. HILL
Mechanical Engineering

WILLIAM D. JACKSON
Electrical Engineering
(to Lecturer)

WILLIAM L. LETWIN
Sloan School of Management
(to Senior Lecturer)

ELY MENCHER
Geology and Geophysics

PRESIDENT

GORDON C. OATES
Aeronautics and Astronautics

Assistant Professors:

GARY BERNARD
Electrical Engineering
(to Research Associate)

KENNETH W. BILLMAN
Physics

CARL J. BLACK JR.
Modern Languages and Linguistics

WALTER J. BORNHORST
Mechanical Engineering

NEAL A. BROWN
Naval Architecture and Marine
Engineering

RONALD A. BROWN
Metallurgy and Materials Science

EUSTRATIOS N. CARABATEAS
Mechanical Engineering

CLAUDE J. CAREY
Modern Languages and Linguistics

RAYMOND Y. CHIAO
Physics

LIEUTENANT ROBERT M. CLIFFORD
Naval Science

LIEUTENANT LEO H. CRAIGLOW JR.
Naval Science

HALDEAN C. DALZELL
Chemistry
(to Research Associate)

LEE W. DEAN III
Geology and Geophysics

LEONARD G. FEINSTEIN
Chemistry

WILLARD R. FEY
Sloan School of Management

JANIS Z. GABLIKS
Nutrition and Food Science

RICHARD J. GURSKI
Mechanical Engineering

KAARE HOEG
Civil Engineering (to Research Affiliate)

THOMAS H. JACKSON
Humanities

ROBERT E. KAHN
Electrical Engineering

JAN KUPERUS
Physics

HARRY B. LEE JR.
Electrical Engineering

ULRICH LUSCHER
Civil Engineering

WILLIAM W. MCKELVEY
Sloan School of Management

C. MICHAEL MOHR
Chemical Engineering

DUNCAN M. NELSON
Humanities

BOBBY J. PAYNE
Nutrition and Food Science

NORMAN PETTIT
Humanities

OTTO POENSGEN
Sloan School of Management

URI Y. SHAMIR
Civil Engineering

SAMUEL SHIBKO
Nutrition and Food Science

PEER O. SOELBERG
Sloan School of Management

GORDON R. SPARKS
Economics

GEORGE S. SPRINGER
Mechanical Engineering

JOSEPH E. STIGLITZ
Economics

GERALD M. STURMAN
Civil Engineering

JON R. VALBERT
Chemical Engineering

HEINRICH J. VOLK
Aeronautics and Astronautics

WILLIAM H. YOUNGREN
Humanities

*Assistant Professors and Postdoctoral
Fellows:*

JONNY ANDERSEN
Electrical Engineering

WILLIAM L. BLACK
Electrical Engineering
(to Lecturer in Mathematics)

FREDERICK K. BROWAND
Aeronautics and Astronautics

SHIOU-SHAN CHEN
Chemical Engineering

R. GORDON COOK
Mechanical Engineering

PHILLIP GOULD
Mechanical Engineering

MICHEL M. GOUTMANN
Electrical Engineering

PRESIDENT

JON R. KELLY
Mechanical Engineering
DAVID F. MARTIN
Electrical Engineering
RODNEY J. MASON
Aeronautics and Astronautics
LAWRENCE W. REHFELD
Aeronautics and Astronautics
PAUL B. SCOTT
Aeronautics and Astronautics
JOHN G. SIAMBIS
Electrical Engineering
BUD C. WONSIEWICZ
Metallurgy and Materials Science

PROMOTIONS

To Professor:

EUGENE BELL
Biology
FRANK BONILLA
Political Science
GENE M. BROWN
Biology
LYNWOOD S. BRYANT
Humanities
PRESCOTT D. CROUT
Mathematics
JEROME I. FRIEDMAN
Physics
ROBERT G. GALLAGER
Electrical Engineering
PAUL E. GRAY
Electrical Engineering
PETER GRIFFITH
Mechanical Engineering
FRANCIS B. HILDEBRAND
Mathematics
FRED C. IKLÉ
Political Science
HENRY W. KENDALL
Physics
ROBERT L. KYHL
Electrical Engineering
PATRICK LEEHEY
Naval Architecture and Marine
Engineering
JOHN D. C. LITTLE
Sloan School of Management
THEODORE R. MADDEN
Geology and Geophysics

G. HUBERT MATTHEWS
Modern Languages and Linguistics
LEO B. MOORE
Sloan School of Management
STANISLAW OLBERT
Physics
ERNEST RABINOWICZ
Mechanical Engineering
LAWRENCE ROSENSON
Physics
GEORGE P. WADSWORTH
Mathematics

To Associate Professor:

ARNOLD E. AMSTUTZ
Sloan School of Management
DONALD W. ANDERSON
Mathematics
CHARLES BATTERMAN
Athletics
DONALD L. M. BLACKMER
Political Science
ROGER W. BROCKETT
Electrical Engineering
HUNG CHENG
Mathematics
EDWARD B. CURTIS
Mathematics
ALAN DAVISON
Chemistry
ALVIN W. DRAKE
Electrical Engineering
HUBERT L. DREYFUS
Humanities
ARTHUR E. FARNHAM JR.
Athletics
LEONARD J. FEIN
Political Science
GORDON P. GARMIRE
Physics
ALAN HEIN
Psychology
THOMAS S. HUANG
Electrical Engineering
ROBERT S. KENNEDY
Electrical Engineering
JAMES L. KINSEY
Chemistry
LAWRENCE M. LIDSKY
Nuclear Engineering

PRESIDENT

CHUNG L. LIU
Electrical Engineering

SIMON C. MOSS
Metallurgy and Materials Science

JOSEPH PEDLOSKY
Mathematics

SHELDON PENMAN
Biology

FRANK E. PERKINS
Civil Engineering

DANIEL G. QUILLEN
Mathematics

DAVID B. RALSTON
Humanities

ADEL F. SAROFIM
Chemical Engineering

CARL M. SHAKIN
Physics

KARL SHELL
Economics

GERALD SILVERMAN
Nutrition and Food Science

KENNETH A. SMITH
Chemical Engineering

ROBERT E. STICKNEY
Mechanical Engineering

PETER TEMIN
Economics

M. NAFI TOKSOZ
Geology and Geophysics

DONALD E. TROXEL
Electrical Engineering

WOLF R. VIETH
Chemical Engineering

WILLIAM B. WATSON
Humanities

BRUCE D. WEDLOCK
Electrical Engineering

RAINER WEISS
Physics

WAYNE A. WICKELGREN
Psychology

AUGUST F. WITT
Metallurgy and Materials Science

LAWRENCE R. YOUNG
Aeronautics and Astronautics

THOMAS O. ZIEBOLD
Nuclear Engineering and Metallurgy
and Materials Science

To Assistant Professor:

WILLIAM H. BASSICHIUS
Physics

STEPHEN K. BURNS
Electrical Engineering

ERIC R. COSMAN
Physics

MARTIN DISKIN
Humanities

ROY E. FELDMAN
Political Science

JEROME I. GLASER
Electrical Engineering

GEORGE A. GORRY
Sloan School of Management

THOMAS J. GREYTAK
Physics

JAMES W. HARRIS
Modern Languages and Linguistics

MALCOLM M. JONES
Sloan School of Management

GORDON V. KELLY
Athletics

THOMAS J. LARDNER
Mathematics

JAMES P. MORAN
Aeronautics and Astronautics

JOEL MOSES
Electrical Engineering

DAVID N. NESS
Sloan School of Management

RONALD R. PARKER
Electrical Engineering

SERGEANT MAJOR DAVID J. PAWELSKI
Military Science

JOHN F. ROCKART
Sloan School of Management

DONALD C. ROYSE
City and Regional Planning

JOEL E. SCHINDALL
Electrical Engineering

DANIEL L. SMYTHE JR.
Electrical Engineering

CHRISTOPHER R. SPRAGUE
Sloan School of Management

CARL V. SWANSON
Sloan School of Management

GEORGE C. THOMAS II
Architecture

PREETINDER S. VIRK
Chemical Engineering

PRESIDENT

FREDERICK Y. M. WAN
Mathematics
MICHAEL L. WIEDERHOLD
Electrical Engineering

CHANGES OF APPOINTMENT

ARTHUR L. ANGER
Assistant Professor in
Electrical Engineering
ALAN H. BARRETT
Professor in Physics
JOHN M. BUCHANAN
John and Dorothy Wilson
Professor of Biology
ALBERT G. H. DIETZ
Professor in Architecture
EDWARD L. GLASER
Visiting Professor in
Electrical Engineering
CHARLES E. HUNT
Assistant Professor in
Nutrition and Food Science
URI RA'ANAN
Visiting Professor in
Political Science
JAMES K. ROBERGE
Assistant Professor in
Electrical Engineering
A. DANIEL RUBENSTEIN
Visiting Professor in
Nutrition and Food Science
GERALD E. SCHNEIDER
Assistant Professor in Psychology
ALBERT O. SEELER
Professor of Medicine, Medical
Department
RONALD C. SHANK
Assistant Professor in
Nutrition and Food Science
ANTHONY J. SINSKEY
Assistant Professor in
Nutrition and Food Science
JOSEPH H. STAFFORD
Assistant Professor in
Civil Engineering
KENNETH B. TAYLOR
Assistant Professor in Biology
RICHARD W. WERTZ
Assistant Professor in Humanities
CARL I. WUNSCH
Assistant Professor in
Geology and Geophysics

APPOINTMENTS

Professors:
W. CARLISLE BARBER
Physics
RICHARD L. CARTWRIGHT
Humanities
ALLEN FORTE
Humanities
MASON HAIRE
Sloan School of Management
RICHARD H. HOLM
Chemistry
GIAN-CARLO ROTA
Mathematics
GERALD E. SACKS
Mathematics
IRWIN L. SHAPIRO
Geology and Geophysics and
Physics
BENSON R. SNYDER
Psychiatry, Medical Department

Associate Professors:

JOHN P. APPLETON
Mechanical Engineering
CORRADO BAGLIONI
Biology
EUGENE GOODHEART
Humanities
KENNETH L. HALE
Modern Languages and Linguistics
ROBERT E. JONES
Modern Languages and Linguistics
MILES KENNEDY
Sloan School of Management
ALVIN C. KIBEL
Humanities
W. STEPHEN LEWELLEN
Aeronautics and Astronautics
JOHN N. NEWMAN
Naval Architecture and Marine
Engineering
CAPTAIN DAVID B. SMITH
Military Science
ABRAHAM SZÖKE
Physics
SAMUEL TING
Physics
Assistant Professors:
DAVID ADLER
Electrical Engineering

PRESIDENT

ROBERT C. BEARDSLEY
Meteorology

BORUCH A. BRODY
Humanities

JOHN J. DEYST JR.
Aeronautics and Astronautics

MATTHEW D. EDEL
Economics

LEONARD G. FEINSTEIN
Chemistry

THEODORE W. GAMELIN
Mathematics

STEPHEN GROSSBERG
Mathematics

ANDREW R. HAWLEY
Humanities

DAVID L. HOLT
Metallurgy and Materials Science

MICHEL Y. JAFFRIN
Mechanical Engineering

KEITH H. JOHNSON
Metallurgy and Materials Science

LANGLEY C. KEYES JR.
City and Regional Planning

ROSALIND E. KRAUSS
Architecture

WALTER H. G. LEWIN
Physics

RICHARD S. NAYLOR
Geology and Geophysics

STEVEN A. ORSZAG
Mathematics

GERALD A. POGUE
Sloan School of Management

RICHARD M. PRICE
Physics

WILLIAM K. ROSE
Physics

PAUL R. SCHIMMEL
Biochemistry and Chemistry

MARLAN O. SCULLY
Physics

STEPHEN D. SENTURIA
Electrical Engineering

ALBERT SOLBES
Aeronautics and Astronautics

JOHN B. SOUTHARD
Geology and Geophysics

LISA A. STEINER
Biology

JOHN M. THOMAS
Sloan School of Management

ORVAL F. THORSON III
Naval Science

PIN TONG
Aeronautics and Astronautics

VYTENIS M. VASYLIUNAS
Physics

JOHN R. WATT
Humanities

BRADFORD L. WRIGHT
Physics

ROBERT D. YATES
Electrical Engineering

Assistant Professors and Postdoctoral Fellows:

DAVID A. DIENER
Chemical Engineering

JEROME H. MILGRAM
Naval Architecture and
Marine Engineering

JOHN S. MOORE
Electrical Engineering

N. THOMAS OLSON
Nuclear Engineering

CHRISTOPHER K. W. TAM
Aeronautics and Astronautics

APPOINTMENTS OF VISITING FACULTY

Visiting Professors:

DAN AVNI-SEGRE
Ford Professor of Comparative History
(Humanities)

BENJAMIN CHINITZ
Bemis Professor of Economics in
City and Regional Planning

MILDRED S. DRESSLHAUS
Abby Rockefeller Mauze Professor
of Electrical Engineering

JOHN C. EVVARD
Jerome Clarke Hunsaker Professor
of Aeronautics and Astronautics

ERIC J. E. HOBBSAWM
Ford Professor of Comparative History
(Humanities)

THEODORE H. VON LAUE
Ford Professor of Comparative History
(Humanities)

SAMUEL I. WEISSMAN
A. D. Little Professor of Chemistry

PRESIDENT

- GEOFFREY WILKINSON
A. D. Little Professor of Chemistry
- JOHN H. ARGYRIS
Mechanical Engineering
- A. DOAK BARNETT
Political Science
- FRITZ BAUMGART
Architecture
- RICHARD S. BOWER
Sloan School of Management
- WALTER S. BRADFIELD
Naval Architecture and Marine
Engineering
- THOMAS J. BRIDGES
Electrical Engineering
- JOHN F. COLLINS
Sloan School of Management, Political
Science, and Civil Engineering
- GEORGE FEHER
Biology
- MARK P. FREEMAN
Chemical Engineering
- SERGIO P. FUBINI
Physics
- WOLFGANG K. GILOI
Electrical Engineering
- RICHARD N. GOODWIN
Political Science
- TAIZO HAYASHI
Civil Engineering
- CHARLES D. HENDRICKS JR.
Electrical Engineering
- HANS HÖRMANN
Psychology
- EDWARD H. JACOBSEN
Biology
- F. ALISTAIR JOHNSON
Physics
- HERBERT H. JOHNSON JR.
Metallurgy and Materials Science
- JEFFREY P. JONES
Aeronautics and Astronautics
- HEINZ LAMPERT
Economics
- JOSEPH C. R. LICKLIDER
Electrical Engineering
- YUKWENG M. LIN
Mechanical Engineering
- DAVID LOWENTHAL
Political Science
- HEINZ M. LUBASZ
Humanities
- FREDERIC MEYERS
Sloan School of Management and
Economics
- FRANK MORRELL
Psychology
- JIT I. NAGRATH
Electrical Engineering
- NORMAN L. OLESON
Nuclear Engineering
- SEYMOUR A. PAPERT
Mathematics
- MICHAEL M. POSTAN
Economics
- FREDERICK REIF
Physics and Biology
- EDUARDO SACRISTE
Architecture
- SHOICHIRO SAKAI
Mathematics
- ISRAEL SCHEFFLER
Humanities
- CHI-NENG SHEN
Mechanical Engineering
- GEORGE C. SHU
Electrical Engineering
- DONALD C. SPENCER
Mathematics
- J. FRITS STAAL
Modern Languages and Linguistics
- MICHAEL J. STEPHEN
Physics
- CARL C. VON WEIZSÄCKER
Economics
- ALAN A. WALTERS
Economics
- STEVEN WEINBERG
Physics
- LANCELOT L. WHYTE
Humanities
- RUDOLF WILLE
Aeronautics and Astronautics
- FRITZ WINCKEL
Humanities
- Visiting Associate Professors:*
- JEAN-MICHEL CHARUET
Architecture
- MICHAEL G. COOPER
Mechanical Engineering

PRESIDENT

GIAN-CARLO DECARLO
Architecture
G. AMOS EDDY
Meteorology
SOLOMON FEFERMAN
Mathematics
EUGENE GOODHEART
Humanities
YEHEKEL S. HALPERN
Biology
JANAK R. HANDA
Electrical Engineering
RICHARD W. HENRY
Electrical Engineering
HERMAN HERTZBERGER
Architecture
YUSING Y.-S. JUNG
Architecture
GERD KOPPELMANN
Physics
ALISTAIR H. LACHLAN
Mathematics
CHI C. LEE
Electrical Engineering
MORTON LOEWENTHAL
Electrical Engineering
GIUSEPPE MILLONIG
Biology
NEVILLE P. MORAY
Psychology
DEAN T. MORGAN
Nuclear Engineering
JAMES S. SHULMAN
Sloan School of Management
CHARLES W. SLATTERY
Biology
GERALD I. STILLMAN
Electrical Engineering
TSUNEYOSHI UYEMURA
Electrical Engineering
REINDER WERELDSMA
Naval Architecture and
Marine Engineering
JOSHUA ZAK
Physics
Visiting Assistant Professors:
DANIEL E. ATKINSON
Biology
T. ROY CHOUDHURY
Mechanical Engineering

ATHANASIOS E. EVANGELOPOULOS
Biology
MICHAEL T. HILLS
Electrical Engineering
JAEGWON KIM
Humanities
LAKSHMI MOHAN
Sloan School of Management
ERIC A. NORDLINGER
Political Science
ALBERT E. PREYSS
Aeronautics and Astronautics
K. L. V. RAMU
Civil Engineering
JOHN W. ROSE
Mechanical Engineering
CHANDER S. SHARMA
Mechanical Engineering
SHRI K. SHARMA
Physics
BARRY B. SPACKS
Humanities.

ADMINISTRATION

DEATHS

WILLIAM H. CARLISLE JR.
Manager of Student Personnel
CHARLES A. KALALIAN
Manager of Graphic Arts Services
JAMES N. MURPHY
Assistant Superintendent of
Building Services
DELBERT L. RHIND
Assistant Treasurer, Emeritus

RETIREMENT

FREDERICK G. FASSETT JR.
Dean of Residence

RESIGNATIONS

EDWARD S. ARENTZEN
Administrative Officer,
Department of Physics
RICHARD G. BROWN
Industrial Liaison Officer
WILLIAM W. BUECHNER
Head of Department of Physics
(still Professor in Physics)
JEREMIAH P. CALLAHAN
Personnel Officer for Professional
Personnel (to Instrumentation Laboratory)

PRESIDENT

JACK W. CHRISTENSEN
Assistant Director,
Industrial Liaison Office

FERNANDO J. CORBATÓ
Deputy Director, Computation Center
(still Professor in Electrical
Engineering)

ARTHUR J. FREEMAN
Associate Director, National Magnet
Laboratory

WILLIAM GARVIN
Assistant Planning Officer

ROBERT E. HOLZ
Associate Director, Office of
Institutional Studies

RICHARD J. HUNGERFORD
Assistant Director, Office of
Institutional Studies

JOHN P. KARLE
Administrative Officer, Department
of Nutrition and Food Science

M. STANLEY LIVINGSTON
Director of Cambridge Electron
Accelerator
(still Professor in Physics)

RICHARD L. SAMPSON
Administrative Officer,
Department of Civil Engineering

THOMAS YONKER
Director, M.I.T. Associates Office

APPOINTMENTS AND CHANGES

ROBERT A. ALBERTY
Dean, School of Science

C. FREDERICK BENTLEY II
Administrative Assistant,
Department of Nutrition and Food
Science

MORTON BERLAN
Communications Officer

JOSEPH BICKNELL
Executive Officer, Department of
Aeronautics and Astronautics

WILLIAM BJERSTEDT
Associate Director, Office of
Institutional Studies

DOROTHY A. BLAIR
Personnel Officer for
Office Personnel

GENE BROWN
Executive Officer,
Department of Biology

GERTRUDE E. BURNS
Administrative Officer,
Sloan School of Management

MAX M. BYER
Administrative Assistant,
Department of Electrical Engineering

EDWARD J. CAREY
Assistant Director of Placement

JAMES A. CARRIG
Assistant Director, Computer
Operations — Institutional Studies

JOHN H. CARTER
Institute Secretary

MILTON U. CLAUSER
Director, Lincoln Laboratory
Professor, Aeronautical Engineering

JOHN L. COCHRANE
Administrative Assistant,
Department of Nuclear Engineering

JOHN A. CURRIE
Assistant to the Vice President,
Operations and Personnel

ELMER W. L. DAVIS
Assistant Director,
National Magnet Laboratory

LEONARD V. GALLAGHER
Associate Director of Student Aid

SAMUEL A. GOLDBLITH
Deputy Department Head, Department
of Nutrition and Food Science

EARL GOODRICH
Administrative Officer,
Department of Chemistry

DANIEL H. GOULD
Administrative Officer,
Department of Physics

DAVID J. HARRIGAN
Assistant Fiscal Officer, D.S.R.

HAROLD L. HAZEN
Foreign Study Advisor

RICHARD F. HUGHES
Personnel Officer for
Professional Personnel

TROND H. KAALSTAD
Administrative Officer and Special
Assistant, Department of Civil
Engineering

PRISCILLA A. KARB
Associate Director, Executive
Development Programs,
Sloan School of Management

PRESIDENT

WILLIAM E. KELLEY
Assistant Comptroller

PHILIP J. KEOHAN
Assistant Comptroller

WALTER L. KOLTUN
Institute Secretary for Foundations and
Special Assistant in the Office of the
Vice President and Secretary of the
Institute

DONLYN LYNDON
Head of Department of Architecture

BORIS MAGASANIK
Head of Department of Biology

JOHN R. MARTUCCELLI
Administrative Officer, Department of
Aeronautics and Astronautics

SAMUEL J. MASON
Associate Director, Research Laboratory
of Electronics

ESTHER MERRILL
Assistant for Undergraduate Programs,
Sloan School of Management

RICHARD G. MILLS
Director of Information Processing
Services

JOSEPH F. O'CONNOR
Administrative Assistant to the Vice
President for Special Laboratories

H. STANLEY PALMER
Superintendent of Mechanical Services

HARRY P. PORTNOY
Senior Architect, Planning Office

PAUL QUINN
Administrative Officer,
Department of Nutrition and Food Science

RICHARD R. RANDLETT
Associate Registrar

DAVID P. RICHTMANN
Assistant Director, D.S.R.

DAVID H. ROBBINS
Director of M.I.T. Associates Office

M. ELIZABETH SCHUMACKER
Lecturer and Special Assistant,
Department of Civil Engineering

JOHN A. SEEGER
Assistant Director, D.S.R.

MIRIAM SHERBURNE
Assistant for Graduate Programs,
Sloan School of Management

IRWIN W. SIZER
Dean of Graduate School

RICHARD A. SORENSON
Assistant to Dean of Student Affairs

T. GUY SPENCER JR.
Associate Director, Alumni Fund

KARL STRAUCH
Director, Cambridge Electron
Accelerator

DAVID J. TOBIN
Institute Secretary for Charitable Trusts

PETER T. VAN AKEN
Special Assistant, Planning Office

VICTOR F. WEISSKOPF
Head of Department of Physics

JOHN M. WYNNE
Vice President, Organization Systems

SCHOOL OF ARCHITECTURE AND PLANNING

The attached departmental reports adequately record the major events of the year in the areas of enrollment, curricular development, research activities, and staff changes.

It has been a year of stock-taking and of planning for the future. Senior faculty in the Department of City and Regional Planning have made great investments of their energy in the work of the Ad Hoc Faculty Committee on Urban Studies. The Department of Architecture has been concerned with its contribution to the ten-year projection studies for the Academic Council and with preparation for new leadership under its newly appointed Department Chairman, Professor Donlyn Lyndon. All of these efforts have involved assessments of the future role of the two design professions, and of the capacity of the School to make significant contributions toward effecting that role.

Clearly architecture and planning are constantly approaching a difficult reorientation, reacting to massive shifts in the cultural and technological substructure. Until recently our professions thought of themselves as mediators between two sets of forces. On the one hand there arose through social interaction and growth a series of discrete problems (a regional high school here, a master plan for a community there). On the other hand one could identify the public and private effectuation agencies, including the building industry, waiting for instructions. The job of the professionals was to make the connecting bridges, and in the confidence of expertise, to facilitate the flow from needs to the appropriate realizations.

While this may still be in large part how the world works, there are sharp warning signals to indicate that the old idealization is too pat to

survive new dynamics. The problems posed by society are losing their clarity and designers are having to intervene more and more to discover or impose definitions of need. At the same time the effectuating agencies are increasingly subject to the constraints of their own processes, and these tend to dictate solutions that often override the problem formulations. What one can do under these restraints often determines what one can have, independently of what is wanted.

Thus the task of the designer is rendered far more difficult in regard to both ends and means. The entire train of events must be regarded as a complete system, and the role of the designer as catalyst in the system is being drastically revised. Designers need a perspective other than that dictated by day-to-day expediency, yet if such detachment implies a lack of involvement at some stage of the events, this may mean the end of effectiveness. Under the growing dominance of total environment, the architect and planner is dispensable unless he himself can become more fully involved.

Education for architecture and planning is in the process of increasing interaction with the disciplines that interpret urban social and political forces and also seeks deeper understanding and stronger links with industrial technology and the management arts. Increasingly it is realized that the educational task cannot be confined to skill development for trained professionals; there must be serious work at improving the effectiveness of efforts to design a better environment as measured in the field, and this must include an educational impact on other sectors of the over-all programming, effectuation, and evaluation system.

Planning for the future of the School involves appraisals of the need for opening new study areas, and of the problems of recruiting new staff and students. Projections of space needs and possible sponsorship for the planned programs also are included.

In the meantime the life of the School must go on. During the current year the School has planned for interim space changes to be carried out during the summer and fall of 1967. These will mobilize an additional 10,000 square feet of space in Building E21, so that all the design programs leading to the M.Arch. degree may be housed there, as well as the architectural research programs. This move releases space in Building 7, which will be largely used for the growing needs of the Department of City and Regional Planning.

In this Annual Report it seems appropriate to record the stewardship of the Albert Farwell Bemis Fund, which since 1954 has been devoted to a program of short-term visiting professors and lecturers in the School. The history of the Fund since that date is summarized in the appended report.

ALBERT FARWELL BEMIS FUND 1954-1967

It is now 13 years since the decision was made to use the income from the Bemis Fund for visiting professors and lecturers in the School of Architecture and Planning. This is a brief account of the most significant of these visitors to date.

The records show that a total of 42 individuals have held appointments supported wholly or in part from the Fund, and two more have been appointed for the coming year 1967-68. The appointments have varied in character; a few lecturers have come for only a single lecture or a short series, but most have been in full-time residence for at least a semester, and a few have held appointments in several successive years. About half of the visitors have served as visiting critics for one term in one of the classes of advanced architectural design. A few well-known figures have preferred to teach through lectures, seminars, and student conferences. The Fund has also been used to a limited extent for experiments in new subjects, often taught by promising young professionals.

Most of the architectural critics have been brought to M.I.T. from abroad, but there have been exceptions. One is Samuel E. Homsey of Wilmington, Delaware, who served for one term in the spring of 1955.

Another exception is Louis I. Kahn, who taught our masters' class in the spring term of 1956. A native of Philadelphia, Kahn had previously commuted to Yale but had not yet gravitated to his present post at the University of Pennsylvania. He was already known as a charismatic teacher, but he was only beginning to be prominent as a practising architect. At present his work is more admired by architects throughout the world than that of any other architect who is a product of the American culture.

A more recent American visiting critic was Gerhard M. Kallmann (German-born, English-trained) who taught advanced B.Arch. students in the fall term of 1963, 1964, and 1965. This appointment coincided with his move from New York to Boston as senior architect for the new Boston City Hall. Kallmann's firm had won the competition for this building; both he and his partner Michael McKinnell severed their connections with Columbia, the latter accepting a Harvard appointment.

Bernard Rudofsky came to the U.S. after a career as one of the innovators of modern architecture in Brazil. Instead of continuing to practice, he now writes and designs exhibitions affiliated with the Museum of Modern Art. He has made a study of the history of clothing, of the culture of Japan, and he recently published a photographic documentary of folk art: *Architecture without Architects*. His appointment at M.I.T. was in the fall of 1956.

During the first term 1958-59 Ludovico Quaroni served as visiting critic. Among the most social-minded of the Italian post-war architects, he was known for his design for new settlements at Matera, a program for the rehousing of troglodytic poor in Apulia.

The next year, in the autumn of 1959, Kenzo Tange taught our fifth-year architects for one term. He chose as a subject a new town on land made in Dorchester Bay; he used this as a way of exploring ideas that were in his mind in connection with a much larger project for expanding Tokyo into its bay which received wide publication a short time later. Already well known for his extraordinary public buildings in reinforced concrete, Tange came to even greater recognition as the architect of the magnificent enclosed stadiums for the Olympic Games of Tokyo.

In the spring of 1960 two extraordinary architects held appointments. Paul Nelson had lived as an expatriate in France since shortly after World War I. A pupil of Auguste Perret and a friend of many School of Paris painters, Nelson had designed a new kind of large medical center for the city of Lille. Its publication made a great impression, but the project was never executed and Nelson reverted to the creation of a series of paper projects, all strikingly innovative in character. His appointment here coincided with his effort to readopt his native country. He has now returned to Paris where he has organized a Franco-American atelier. The other spring 1960 visitor was Leonardo Ricci, eloquent and gifted architect and painter from Florence, and friend and admirer of the existentialist writer Albert Camus. Ricci returned again to give a lecture in 1962.

Zdenko Strizic, originally from Zagreb, came from the University of Melbourne to teach design at M.I.T. in the fall term of 1960, and this proved to be transitional step toward the tenure post he now holds at Braunschweig in West Germany. In the spring of 1961 Sven Markelius, the experienced and distinguished architect from Stockholm who had been one of the international consultants for the U.N. building (and later for the Kennedy Library), came for M.Arch. students, while Jane Drew of London taught B.Arch. candidates. Miss Drew, who in partnership with her husband Maxwell Fry (himself an ex-partner of Walter Gropius) had designed a series of buildings in the new tropical countries, was also involved in the design of Chandigarh, Le Corbusier's celebrated Indian capital.

Over most of the post-war period the Department of Architecture had arranged exchange teaching with the Royal Academy of Fine Arts of Copenhagen, and some of these have been supported by the Bemis Fund. Halldor Gunnløgsson, one of Denmark's best architects, came in the fall of 1961. In the spring of 1962 one of the visiting critics was Mario

Perez de Arce of the Catholic University of Santiago. Our faculty had become acquainted with him during an M.I.T. seminar in Chile sponsored by the Department of State. For the graduate students, we appointed during the same term J. T. P. Byhouwer, a landscape architect from Wageningen, Holland, who contributed significantly to the student project for a new town between Boston and Providence.

The following autumn, 1962, saw two Scandinavians teaching one fifth-year studio. The senior man was the late Viljo Revell, at that time engaged in supervising the construction of the Toronto City Hall. A native of Finland, Revell was the winner of the important international competition for the design of this project. Unfortunately he did not live to see it completed. Assisting him was a young Danish architect Nils Fagerholt, again from the Royal Academy. In the masters' class that term Charles Correa joined with two other instructors in the urban design section. Correa, who practices in Bombay, is one of a small handful of progressive young architects native to India. Born in Goa, he was from the first attracted to American culture, and came to the U.S. for his entire university education at the University of Michigan and M.I.T.

Following Gerhard Kallmann's three-year stint, the past year saw a new visiting critic, Herman Hertzberger, a sharp and enthusiastic young architect from Amsterdam. When the term opens this September, the visitor will be Giancarlo De Carlo of Milan, whose student dormitories at Urbino have attracted wide admiration and who has already visited M.I.T. while a visiting teacher at Yale University.

This completes the list of visiting critics in architectural design. We next indicate a number of visiting lecturers whose appointments have been in the Department of City and Regional Planning. Constantinos Doxiadis, widely known architect and planner from Athens, who has brought into modern usage a new word based on a Greek root, "ekistics" (the science of human settlements), lectured in 1957. Albert Mayer, prominent architect with extensive experience in city planning in India, occupied a professorship in the fall of 1958, and lectured again in the spring of 1961. In the spring of 1962 the Bemis Fund was used to bring Donald Appleyard, a young English-trained architect, to the Planning Department to start a new subject. Paul Opperman, an American city planner of distinction, was supported by the Fund during one term each year in 1963-64, 1964-65, and 1966-67.

Two very distinguished elder statemen each were here in successive years, and although their appointments were in the Department of Architecture, their area of concern was so broad as to contribute to the entire educational program of the Institute. Joseph Hudnut, following his retirement as dean of the School of Design at Harvard, was making

a new reputation for general education lectures at Bowdoin College when he was appointed Bemis Lecturer at M.I.T. in 1958-59; here he developed a subject for freshmen called *The Structure of The City* in which students went to look at functioning pieces of greater Boston and returned to discuss what they saw; the entire seminar benefited by Hudnut's penetrating knowledge of city development. The subject continued until Dean Hudnut was obliged to withdraw after 1961-62.

During the fall terms of 1957-58, 1958-59, and 1959-60, Lewis Mumford led three seminars. Living quietly in Amenia, New York, this renowned historian-critic intermittently frequents some university, where he is glad to share his current research materials with a handful of graduate students. We were fortunate to have this particular series, and our only problem was keeping the enrollment at manageable size.

Other writers have also used the seminar form during their Bemis appointments. In 1956-57 Robin Boyd, practising architect and popular writer on architecture in Melbourne, came to M.I.T. for the entire year, primarily for his own creative work. Edgar Kauffmann, American critic of art and architecture, held a lectureship in the spring term 1956. In 1959-60 Arne Korsmo, Norwegian architect and writer, came for part of the spring term.

One appointee came to develop his own capacities as a creative artist in a field close to architecture. The young Japanese painter Michio Ihara was three years a research associate, two of which, 1962-63 and 1963-64, were financed from Bemis funds. Ihara worked under the guidance of Professor Gyorgy Kepes, discovering his own kind of architectural sculpture. Of this he left many examples with local collectors, and one of his works remains in our Rotch Library.

Olav Hammarstrom, who came to the U.S. as an assistant to Alvar Aalto at the time of the construction of Baker House, was appointed during 1962-63 and 1963-64 to teach a special elective subject in architectural drawing. Peter Hornbeck, young American landscape architect, was a part-time teacher in that subject area in 1963-64, 1964-65, and 1965-66. The experienced Argentine professor and world traveler Eduardo Sacriste lectured in 1966-67 on the indigenous dwellings of many unfamiliar cultures. Carl Koch, Boston architect, was supported in spring 1966 in his subject *Industrialized Architecture*, and in the years 1962-63, 1963-64, and 1964-65, the fund contributed toward the support of Joseph J. Schiffer, who was then engaged in the development of a new subject on *Building Process* for the architecture curriculum.

The Fund has been used to fortify the Department of Architecture's concern for the structural aspect of building design, and it has reinforced our efforts to place students in contact with engineers whose creative

DEPARTMENT OF ARCHITECTURE

vision bridges the gap between their field and architecture. Pier Luigi Nervi, the great Italian designer, was brought to lecture in 1960-61. A. J. Harris, inventive structural consultant from London, has been a frequent visitor whose stay in April 1962 was made possible by a Bemis appointment. In 1961-62 the scholarly Turinese engineer Giulio Pizzetti held a lectureship, as did a local structural engineer, Howard Simpson. Both of these men worked primarily in the M.Arch. program. William J. LeMessurier, gifted and resourceful Boston structural designer (of Boston City Hall and many other outstanding structural realizations) was supported in 1962-63 as a lecturer and in 1963-64 as an associate professor. Frei Otto, a German architect with a passion for the development of suspended roofs, who is better known now as the architect (with Rolf Gutbrod) of the West German pavilion at Expo 67, lectured in November 1962. Waclaw Zalewski, Polish structural engineer (who is sometimes called the Nervi of Poland) was brought from Caracas, where he was practising, as a visiting professor in 1964-65 and again in 1965-66. In 1966 he accepted a tenure position on our faculty.

Norman Edwards (1963-64), an Australian architect, and Earl Flansburgh (1965-66) of Cambridge, were young appointees under the Bemis program.

As this account indicates, the decision in 1954 to use the Albert Farwell Bemis Fund as an endowment for visiting faculty in the School of Architecture and Planning, has facilitated an extensive program of important educational activities that could not have been carried out with general funds. It has brought outstanding professionals from the far corners of the world to the School for short periods, and it has helped the School to introduce new subject matter on a trial basis. It has served as an invaluable support for our need to look beyond our own resources and to maintain a continuing communication with new professional developments in all parts of the globe.

LAWRENCE B. ANDERSON

DEPARTMENT OF ARCHITECTURE

This marks the completion of the first year's operation under the new curriculum for the Bachelor in Architecture, in which this first professional degree is awarded only after at least two years of graduate study, following either M.I.T.'s new S.B. in Art and Design or some other baccalaureate program. Although in principle the new curriculum applied only to entering students, a number of advanced students who met the new conditions have been allowed to transfer to the new program,

and in June of this year the first award of the S.B. in Art and Design was made to Mrs. Ruth McDowell.

This year 14 students graduated with the degree B.Arch., 27 with that of M.Arch. Enrollment of professional majors in the department remains fairly constant. Candidates for the degree of B.Arch. have over the past eight years fluctuated from a low of 91 in 1964-65 to a high of 117 in 1962-63 (115 in both 1960-61 and 1966-67), whereas the registration for the second professional degree of M.Arch. grew, from a previous average of about 27, to 37 in 1966-67, owing largely to the new opportunities afforded by the inauguration of Section C under Professor Horacio Caminos.

It will be recalled that the Section C program, supported by the Ford Foundation, provides research and advanced education in housing and community design for developing areas. Eight students, including two returning U.S. Peace Corpsmen from Tunisia, a West European with experience in Senegal, and natives of India, Taiwan, and Thailand, prepared separate projects suited to the conditions with which they had direct experience. This was an auspicious year for these studies, and 12 graduate students are enrolled for the coming year.

Professor Waclaw Zalewski, who had already visited the department on a number of occasions, has now completed his first year on a full-time basis, as a professor of structures associated primarily with the M.Arch. program. Professor Zalewski offered structural consulting to all M.Arch. students and in addition inaugurated an advanced subject in architectural structures; this replaces the subject previously offered on a part-time basis by Paul Weidlinger.

Associate Professor Jan Lubicz-Nycz, a replacement for Professor Imre Halasz, was in charge of Section B during the current year. The theme of Section B in the M.Arch. program is urban design. In this section the emphasis was placed on the design of a new town tributary to Washington, D.C.

In Section A of the M.Arch. program, Professor Eduardo F. Catalano continued the study of construction systems, with particular assistance from Professor Zalewski.

The most advanced group studying for the first professional degree (B.Arch.) benefited from the teaching of Herman Hertzberger, a talented and enthusiastic young architect from Amsterdam, who served as visiting Bemis professor during the fall term.

Younger students in the same curriculum had a choice of studio activities under one of four teachers: Associate Professor John R. Myer, Assistant Professor Joseph J. Schiffer, and two new faculty members — Assistant Professors Chester L. Sprague and Robert Goodman.

Professor Sprague offered his students first the study of a school for the Washington Park Boston renewal area, then a cluster zoning study for Stonington, Connecticut. Professor Goodman concentrated on problems of architectural response to social change in public housing at Columbia Point, Boston.

Associate Professor Henry A. Millon was on leave during the second term to continue studies in Italy on the baroque architect Guarino Guarini. He was replaced by Professor Bates Lowry of Brown University.

The faculty noted with grief the death of Professor Emeritus Ernest N. Gelotte, who had given many years of faithful service to the teaching of structures to young architects.

During the year the department faculty engaged in a number of extra-curricular activities pertinent to the advancement of professional knowledge and their own skills. In the first term Professors Millon and Goodman, and Assistant Professor Stanford O. Anderson formed a team under the sponsorship of the Museum of Modern Art in New York for the study of eastern Harlem and the adjoining portion of the East River. Other teams, from Princeton, Columbia, and Cornell made parallel designs for other sections of the swath across Manhattan north of Central Park. The four projects resulting from these studies were exhibited in the Museum of Modern Art early in 1967, and focused public discussion on pressing problems of urban design in the New York area.

Department faculty under the leadership of Professor Stanford Anderson took responsibility for an interdisciplinary conference held early in the autumn at the Endicott House. The conference, called *Inventing the Future Environment*, was part of the A.I.A.-Princeton University program for research in innovation for architectural education which was co-sponsored by the Graham Foundation. Proceedings will become available under the editorship of Professor Anderson.

The Building Research Group continued work initiated in collaboration with the Department of Civil Engineering. Studies in Systems Analysis in Building Design, sponsored by the National Science Foundation, have been largely under the leadership of Professor Albert G. H. Dietz; a renewed program sponsored by the U.S. Steel Corporation on Design and Construction of Steel-framed High-Rise Buildings (directed by Professor Robert Hansen) has enlisted the efforts of Marvin E. Goody, Robert J. Pelletier, and Associate Professor William J. LeMessurier. Montefiore Hospital supports a program for the study of Programming Pre-Operative Unit Requirements under the guidance of Robert Pelletier. Leon B. Groisser and Nicholas Negroponte have been engaged in a project exploring three-dimensional graphic computer capability as a tool for the urban designer in the system they have named Urban 5.

Plans for the Center for Advanced Visual Studies, supported by grants from the Old Dominion Foundation and the Graham Foundation, are proceeding under the directorship of Professor Gyorgy Kepes. The architectural renovation of the old Harvard Cooperative Society's store (now in the Stratton Student Center) is nearing completion, so that studios for the first generation of fellows will be ready for the new academic year.

The public program for the visual arts, under the leadership of Professor Wayne Andersen, has asserted its place in the M.I.T. community during the year with a number of conspicuous exhibitions. (The Visual Arts Committee's program replaced the program of the old Museum Committee.) The faculty committee on the Visual Arts has also been activated and discussions are under way for a number of impacts on the physical environment.

Organization of the alumni of the Department proceeds a step at a time. Two meetings were held during the year, one in Chicago, the other in Boston, to organize the governing board, and they are now proceeding to the adoption of a constitution and bylaws and the election or appointment of the first officers of the new association, which will include the 2,400 alumni of the Department.

A very gratifying circumstance is the inclusion in this report of the record of the appointment of the new chairman of the Department, Donlyn Lyndon, effective July 1, 1967. Professor Lyndon, who will be responsible for subsequent annual departmental reports, will bring to M.I.T. the experience of other centers. Son of the well-known architect Maynard Lyndon, the new chairman studied at Princeton University, taught at Berkeley, spent a year in India, and served for three years as Chairman of the Department of Architecture at the University of Oregon before his appointment to this new post. Distinguished already in professional practice, and recognized for his contributions in criticism and theory, Professor Lyndon now assumes the responsibilities of chairmanship with every expectation that this will be the start of a new thrust by this century-old school of architecture, the first in the United States.

LAWRENCE B. ANDERSON

DEPARTMENT OF CITY AND REGIONAL PLANNING

The Department of City and Regional Planning has continued to grow in the numbers of its enrolled degree candidates, and also in the variety of its course work offerings. The change that is most important to the Department, however, is the heightened level of attention to urban problems and urban studies throughout M.I.T. This has increased, and will further increase, the capacity of our multi-disciplinary field to pre-

pare our graduate students to understand and to deal with the problems of the contemporary city.

In the Department this past year work has developed primarily in four directions: in city design, in planning for developing areas, in urban planning and social policy, and in quantitative methods. A major element has been the increase of research support in several of these areas. The Department is moving steadily toward a balance between research activity (with heavy involvement of graduate students), and course work study and teaching, that is approaching the normal M.I.T. graduate department pattern.

CITY DESIGN

City design concerns the shaping of the visual form of the city, not solely as an aesthetic exercise, but with equal regard for its social, economic, political, and psychological structure and function. Evolving from the pioneer work of Professor Kevin A. Lynch, it is a field still grappling with the problems of understanding phenomena of man-environment interaction and is not yet ready to prescribe solutions.

Research activity has expanded substantially. Associate Professor Donald S. Appleyard and Assistant Professor Stephen M. Carr have received support from Project TRANSPORT General Motors funds to explore highway-related aspects of the problem, building on beginnings financed by the Joint Center for Urban Studies. Professor Carr's project deals with "perception and memory of the view from the road." Professor Appleyard has been exploring aspects of "design of well-oriented, identified and aesthetically satisfying travel routes."

These researches are far from the word aesthetic in its everyday connotation of the superficialities of prettiness. Their thrust has been into social anthropology and the psychology of perception, and the need for further expertise has become evident. A psychologist with interests in these directions will join the Department staff next year, to aid in both teaching and research.

The aggregate of the Department's work in this field is evolving into an entity deserving the name of a city design laboratory, inventing and applying techniques of simulation necessary for experiment and evaluation. Expansion of these efforts is a main objective for the Department.

Several doctoral theses have been completed or nearly completed during the year in this area of specialization, each contributing small building-blocks to a still shallow foundation. Course work has not been increased in number (seven subjects in this field are offered by Professors Lynch, Appleyard, and Carr), but the content has been evolving with the progress in research.

DEVELOPING-AREAS PLANNING

The Department has had a long-standing concern with the planning problems of the developing countries of the world, under the primary leadership of Professor Lloyd Rodwin. This past year has seen the planning and organizing of a new program formally to be set in motion next year, financed in part by the Ford Foundation's grant to M.I.T. for international studies. Called SPURS (Special Program for Urban and Regional Studies in Developing Areas), it is aimed at middle-level technical and administrative personnel from developing areas who show promise of becoming policy-makers in their countries. Designed as a one-year curriculum (analogous to the Sloan Fellows program), it will involve several new subjects also available to regular graduate students interested in careers in this area, and a core seminar for the SPURS Fellows themselves.

Even in the absence of financial support for the Fellows, half a dozen have been enrolled for the coming year. The staff engaged in planning the program and the course work, in addition to Professor Rodwin, have been Lecturers Alexander Ganz, Lisa R. Peattie, and (joining M.I.T. in the fall) John F. C. Turner. All three participated in the Joint Center's highly successful Guayana Project in Venezuela.

This project is expected to grow and serve not only the urgent needs of the developing countries — a sufficient end — but also the professional-training goals of our regular students, of whom nearly one-fifth want to prepare for careers in overseas planning and development.

URBAN PLANNING AND SOCIAL POLICY

Concerned with the social impact of urban development problems and with applying social-science concepts and methods to the solution of planning problems, this special field is aimed at expertise in developing programs to cope with social needs (relocation, poverty, health, discrimination) in collaboration with other professionals. Associate Professor Bernard J. Frieden has spearheaded a successful effort to set up a joint program with the Department of Political Science, supported by a grant from the National Institutes of Health, for interdepartmental curricula leading to master's and doctoral degrees in either department. Professor Frieden's joint course work with the Florence Heller School at Brandeis has continued, as has research on health facilities planning jointly with Harvard administered through the Joint Center. Further research support is expected from the United States Department of Housing and Urban Development.

The work of Professor James M. Beshers in sociology is basic to this Department's activity in this area. In addition to his course work, he has

been engaged with faculty from the Department of Political Science in NSF-sponsored studies of large-scale social systems and in research in mathematical models of characteristics of intermetropolitan migration.

Another anchor of this special field is Mrs. Peattie's course work, which brings the discipline of anthropology to bear upon the nature of the cultures housed in the urban physical environment.

Half of the Master's theses in the Department this spring were within this area of social policy and planning, as well as two of the three doctoral theses completed during the term.

QUANTITATIVE METHODS

Though concerned with method, not subject, this is an area of special attention both because of its contribution to the subject-oriented components of urban problems and because it has potential as a specialized branch of the professions of urban studies and city and regional planning. The work of Professor Beshers mentioned above is an example; several of his advisees have stepped directly into very specialized jobs upon graduation.

Associate Professor Aaron Fleisher has devoted much of the year to designing and developing the Department's capabilities in dealing with the new mountains of data about the environment and its interaction with society — gathering, storing, retrieving, analyzing, and manipulating. Working with Technical Assistant Wren McMains and several programmers, Professor Fleisher has made it possible for graduate planning students with no prior computer training to use the computer in elementary classroom projects as well as in an increasing number of Master's and doctoral theses. This work has been partially supported by allocations of the IBM grant to M.I.T.

This aggregate of stored information and methods for handling it, like the city design studies, is beginning to evolve into a strong component of a Laboratory for Environmental Studies. Its primary functions are as a teaching tool and for academic research; but as it develops it becomes an essential element of the Department's capability for sponsored research. Substantial further development is both needed and expected.

OTHER AREAS OF TEACHING

Professor Jerome Rothenberg joined the M.I.T. Faculty this year, jointly appointed by the Department of Economics and this Department. In this Department he has offered two new subjects dealing with urban economics and supervised several theses. His direct contributions and the tie through him to economics are new points of strength. This De-

partment's share of his support is made possible by the generous grant of the Richard King Mellon Charitable Trusts.

Also supported by the Mellon grant was Dr. Ira S. Lowry, who was on leave for a year from the RAND Corporation. Dr. Lowry, urban economist and sociologist, has been a pioneer in the use of models in understanding and projecting urban phenomena. He taught several subjects as well as enlivening the intellectual atmosphere.

One of the most successful subjects of instruction again this year was this Department's participation in the interdepartmental so-called systems engineering subject, which for the third year dealt with an urban problem — the design of a flexible high-density unit of a big city. Lecturer Philip B. Herr represented the Department's faculty. Last year's project, Project Metran, was presented by students (including city planning students) at a session of the Highway Research Board's annual meeting in January.

The course work identified in previous pages makes up the leading edges of the Department's academic programs. All of the faculty named — without exception — also have been engaged in teaching the core subjects in our graduate curricula, along with the other members of the staff: Professors Frederick J. Adams and John T. Howard, Senior Visiting Lecturers Paul Oppermann and Lewis H. Weinstein, Visiting Lecturer Lawrence A. Sullivan, and Visiting Assistant Professor Daniel Weisberg.

Course work offered by this Department and required or recommended for undergraduates in the new S.B. program in the Department of Architecture has begun to build up a new workload in several subjects. Academically this is most welcome; but it has required a substantial increase in staff resources for next year.

OTHER AREAS OF RESEARCH

Project TRANSPORT has supported a number of research operations in the department in addition to those mentioned under city design. In addition to work in the SPURS program, Mr. Ganz has been engaged with several student research assistants on economic and demographic projections for U. S. metropolitan areas leading to projections of urban growth patterns, vehicle ownership and use, and transportation demand.

Professor Fleisher and Mr. Herr have been involved in the planning of further Project TRANSPORT activity, and are participants in the Summer Study Project. They will be the principals in a new project just approved by the Department of Housing and Urban Development to explore the relationships between transport access, job location, and poverty.

Professors Appleyard, Beshers, Fleisher, and Carr have all enjoyed partial support from the Joint Center for Urban Studies for their own research interests.

OTHER FACULTY ACTIVITIES

Service to the M.I.T. community has involved fulfillment of a number of non-routine assignments, including: Joint Center for Urban Studies, Faculty Policy Committee: Chairman, Professor Rodwin; member, Professor Howard; Community Service Committee: Chairman, Professor Lynch; Ad Hoc Faculty Committee on Urban Studies: Professors Howard, Lynch and Rodwin; Advisory Committee on Transportation: Professor Howard; Committee on Graduate School Policy: Professor Fleisher; Rotch Library Advisory Committee: Professor Beshers; and Foreign Scholarships Committee: Professor Beshers.

These and other members of the faculty have published books and articles, delivered papers at a number of technical and professional conferences, and served a number of outside professional organizations, as well as being involved in a wide range of professional consulting as in earlier years.

STAFF CHANGES

Mr. Paul Oppermann, Distinguished Visiting Bemis Lecturer in Metropolitan Planning, this year completes the three-year appointment which is the limit for Bemis Lecturers. His many years of professional field experience have contributed to our students' awareness of front-line problems.

Professor Appleyard has submitted his resignation to join the Faculty of the University of California at Berkeley. First a student, later a colleague of Professor Lynch, Professor Appleyard has been one of the pillars of the Department's work in city design and will be sorely missed.

Dr. Lowry's participation, though only for the one-year leave from RAND, contributed much in an area of great value. Professor Rothenberg's addition to our faculty has also been noted, with anticipation of strong future participation in this Department's development.

New appointments for the coming year include two assistant professors. Dr. Langley C. Keyes Jr. received our Ph.D. in February and returns after a brief stint with HUD to teach primarily in the area of planning and social policy. Donald C. Royse, due to receive our Ph.D. in September, will concentrate in the design area. Both will be involved in core teaching. Wren McMains has been appointed Instructor, and will teach course work in computer use.

SCHOOL OF ARCHITECTURE AND PLANNING

Dr. Mary C. Potter will join the staff as Lecturer in Psychology, and John F. C. Turner as Lecturer in Housing.

SPECIAL EVENTS

The Catherine Bauer Wurster Memorial Lecture Series, sponsored jointly by this Department and its Harvard counterpart, was completed this year by a lecture by Charles Abrams, formerly on this faculty and now head of the Columbia city planning program, and Martin Meyerson, formerly of the Harvard planning faculty and now President of the University of Buffalo.

Professor Adams again directed the two-week Special Summer Program of in-service training to planners — the first such program having been offered by him 30 years ago, in 1937. Bemis Lecturer Oppermann will direct a second Special Summer Program on Religion and Community Cooperation in Planning, Housing, and Architecture.

STUDENT ENROLLMENT

The growth of the graduate enrollment has continued, more slowly than the pressure for admission (which stands at eight applications for each place), but as rapidly as space and financial support permit.

The following figures compare last year, this year, and an estimate for next year. (Our quota for degree-candidate enrollment was 50, 60, and 70, respectively.)

	1965-66	1966-67	(Estimate for 1967-68)
Enrollment (February)			
M.C.P. Candidates	38	47	(45)
Ph.D. Candidates	15	16	(25)
Special Students	13	9	(12)
Total	64	72	(82)
(Foreign)	(16)	(10)	(20)
Degrees			
M.C.P.	14	22	(22)
Ph.D.	1	3	(6)
Total	15	25	(28)

The number of foreign students — largely one-year Special Students — has dropped this year, but is expected to rise again under the SPURS program.

Federal financial support for students has risen, with the new availability to our students of a few NIH and NSF traineeships and the new

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program of HUD fellowships, in addition to continued NDEA support. Research assistantships are a growing source of support. The department must still rely heavily, however, upon M.I.T. endowed-fellowship funds and the five-year grant (now completing the third year) from the Richard King Mellon Charitable Trusts.

THE FUTURE

The Department, having shared in the work of the Ad Hoc Faculty Committee on Urban Studies, has clarified and confirmed its hopes for further development and expansion, within the framework of an Institute-wide escalation of attention to urban problems. Our efforts to build new strength in a rapidly evolving field are encouraged and will be enhanced by this prospect.

JOHN T. HOWARD

SCHOOL OF ENGINEERING

Over the past several years, we have introduced the individual reports by the department heads of the School of Engineering with a brief synopsis of some of the principal activities as seen from the Dean's office. We have interpreted these activities in the context of engineering education as it is emerging specifically at M.I.T., and frequently we have discussed the role of engineering in society at large.

A quick scan of our remarks for the past several years discloses several issues that stand out as having had enduring consequences. For the year 1959-60, we commented at length on the importance of the grant received in the fall of 1959 from the Ford Foundation to undertake a comprehensive upgrading of the scientific content of our curriculum and to improve the laboratory programs associated with all aspects of our teaching. For the year 1960-61, we commented on these issues within the context of the celebration of the one-hundredth anniversary of the Institute's founding. That year, our remarks cited the pressures which arise within a four-year undergraduate program. We noted that, on the one hand, professors would like to provide their students with a body of knowledge that encompasses a significant fraction of the scientific and analytical background which, as engineering leaders of tomorrow, our students will require in order to cope with the increasingly complex programs of their day. On the other hand, professors would like to enmesh their students simultaneously in real-world engineering situations to broaden the student's horizons and to counteract their tendency to be preoccupied exclusively with the traditional disciplinary studies. This conflict grows increasingly intense as the body of scientific knowledge

grows, as the scope of engineering expands, and as technology interweaves more and more into the social and political facets of our society. Today it looms larger in our sphere of problems than when discussed in 1960, and becomes of supreme importance in relation to our desires, as mentioned in our last two Reports, to maintain a balance between our activities in the military-space sector of the economy and the civilian sector.

The 1960-61 Report noted also the expanding role of the Institute in world affairs, as witnessed both by the role of our Department of Civil Engineering in the Agency for International Development (AID) Program in Latin America, and our leadership in setting up the Indian Institute of Technology at Kanpur, India. During the intervening years, cooperative programs have been established with the Technical University of West Berlin and with the Birla Institute of Technology and Science in India. This broadening and deepening of our involvements reflects the growing concern of M.I.T. in the area of foreign affairs.

In later reports, we noted that the activities spurred by the Second Century Development Campaign and the curriculum changes in engineering fostered by the Ford Foundation grant had accelerated the movement toward an extensive re-evaluation of M.I.T.'s entire undergraduate curriculum. The Faculty Committee appointed by President Julius A. Stratton in 1962 to conduct this re-evaluation recommended changes in the curriculum of the first two years that resulted in a major break with tradition as recorded in our Reports for 1964-65 and 1965-66. Perhaps the most important change was to give students considerably more freedom in the structuring and sequencing of their program of studies than they had previously been offered. We comment on the present status of these changes in the next section of this report.

The increased choice which our students now have in designing their programs is, on the one hand, a manifestation of society's continuing search for freedom and advancement. On the other hand, it is a key element in promoting and accelerating the tempo and complexity of life on our campus. We are entering an era in which the number of distinct programs is becoming a significant fraction of the number of students rather than being only slightly greater than the number of our departments, as the casual observer might conclude. Within the last few years, much of our energy has been directed toward teaching and research activities that cut across departmental and school lines as our involvement in broad engineering programs carried out within the separate departments has increased, and as the Institute at large has moved to establish a number of interdisciplinary research centers.

During the last one and, at most, two years there have been stir-

rings on the campus in areas that present wholly new challenges and opportunities for our School. Many members of the faculty are expressing growing concern and are urging action relating to the issues generated by the problems of urban decay, population explosion, food shortages, and the unrest that is developing in regions wherein a significant number of people realize that many others in the world enjoy greater economic stability and live much better than they themselves do, and now are striving to achieve parity.

In this country, the Federal government is exerting considerable pressure on both universities and industry to be more concerned than they have been heretofore with problem areas such as transportation, air and water pollution, and the rebuilding of our cities. For an essentially technological or science-centered institution such as M.I.T., this challenge introduces new value systems, as these problem areas relate primarily to the civilian, rather than to the industrial, military, or space sectors of our society. We welcome these challenges, for in a sense they are responses to the concern we expressed in our remarks for the years 1964-65 and 1965-66 over the imbalance of our efforts in the various sectors of society. The technical aspects of the challenges have great significance, but frequently the social and political orientations are decisive in directing the form, the extent, and the timing of the application of technology. We must help our students to assess these matters so that as they pursue their careers they will better contribute to the expanding and evolving needs of society.

On our own campus, we note a bold building program, a seemingly insatiable demand for computer resources, a rapidly mushrooming involvement of students and faculty in new areas of research which cut broadly across previously defined disciplinary boundaries, and a wide and healthy diversity of opinion as to the appropriate course of action to be taken on almost any issue.

As we look back over the last year, we see many unanswered questions, many problems, and many steps toward partial solutions. We see less by way of long-term progress toward clearly defined goals than we would have hoped. It is now clear that our own actions themselves have been primary instigators of many of the extensive changes that are influencing education not only within M.I.T. but in many other institutions and at other levels of education, as well. Many of these factors — especially those relating to the changing role of M.I.T.'s School of Engineering as an education leader vis-a-vis many other outstanding engineering schools — were recorded in our introductory remarks to the School Report for the year 1965-66. M.I.T. is being, and will continue to be, influenced very greatly by these changes which, perhaps in oversimplified terms, reflect

the observation that the environment here is now both self-generating and open-ended and, by any reasonable standard of measure, enormous in the total range of its activities.

For the remainder of our remarks this year, we shall report briefly only on some aspects of our Freshman-Sophomore Program, on the expanding role of computers at M.I.T., on some aspects of our transportation-related research and teaching, and on the status of our new building and space-change program as we move to achieve improved housing of our activities and more efficient grouping of our faculty. Many other activities of the School are discussed in the individual departmental reports.

THE NEW FRESHMAN AND SOPHOMORE PROGRAM

Half of the undergraduates at M.I.T. have now experienced the new program as it was outlined in the introduction to our Reports for 1964-65 and 1965-66. We are encouraged by the results and have no desire to attempt to turn back the clock. We remain committed to the doctrine of increased flexibility, believing that it is a beneficial step forward. But we know now that we have yet to achieve a stable situation.

Our goal is to provide an intense and challenging educational experience for everyone whom we admit. However, we have yet to overcome many problems which stem from the extraordinary breadth of the spectrum of preparation and interests our students have when they enter.

Nonetheless, we are pleased to note that a review of the academic performance of freshmen leads us to believe that the increased emphasis placed on the role of Freshman Counselors and Instructors in the first-year subjects has significantly improved the extent to which individual freshmen adjust to M.I.T.'s pace and intellectual demands. Table I, taken from the Report of the Dean of Student Affairs for 1966-67, shows the marked reduction in the number of freshman disqualifications which is being achieved. For each of the past two freshman classes, the number of students who withdrew voluntarily prior to the end of the year was only about eight — less than one per cent of the class and substantially the same as the number who were disqualified.

Table I Incidence of Probation and Disqualification

Class	Probation in February	Probation in June	Disqualification in June
Average of 1966-68	51	43	23
1969	35	41	9
1970	35	52	8

VARIANT PROGRAMS

One feature of the new program is the reduced number of science-core subjects which each freshman is required to take. Consequently, there is an increased opportunity for him to adjust the grouping of core subjects to achieve a better match with his preparation and direction. Compared with the monolithic character of the first-year program prior to 1965, there is now more variety in the packages taken by the Classes of 1969 and 1970.

The Report of the Dean of Student Affairs also stated that the variant freshman programs group into three categories:

1. Students who defer nothing in the first term by taking all three core subjects: mathematics, chemistry and physics;
2. Students who defer chemistry in the first term, i.e., take only mathematics and physics; and
3. Students who defer physics in the first term, i.e., take only mathematics and chemistry.

All students are urged to begin their mathematics sequence immediately. Nearly all programs of individual freshmen include a core subject in humanities and one elective.

Table II shows the distribution of programs for the Classes of 1969 and 1970 at a point near the end of the first term: This tabulation thus combines in each category the students who initially deferred a subject with those who started with all three but later dropped one.

Table II Distribution of Variant Programs (Class of 1969 and 1970)

Class	Defer Nothing	Defer Chemistry	Defer Physics
1969	566 (59.7%)	194 (20.6%)	185 (19.7%)
1970	620 (69.0%)	130 (14.4%)	150 (16.6%)

We are not able to explain why the Class of 1970 appears to have regressed somewhat toward the old monolithic program. They benefitted from more extensive counseling by the Freshman Advisory Council. Furthermore, the first class appeared clearly to have benefitted from deferral. But we have learned from experience that students take counsel from several quarters. We know that our upperclassmen were advising their freshman friends not to defer science-core subjects on the grounds that the price — a potential restriction of later elective freedom, scheduling complexities, and potential second class citizenship — is not offset by improved academic performance. We disagree with this judgment. Also, admission into the upperclass programs of several departments had not

been opened up sufficiently to avoid imposing a penalty on a student who dropped behind in a prerequisite sequence because he deferred a science-core subject. The issue of the rigid structuring of prerequisites is still with us. Finally, there have been too few substantive electives which freshmen may use to fill the time made available by deferral of core subjects.

We are making progress on what now is as much a communications problem as a curriculum content problem. We have solicited the participation of student counselors of students and of upperclass student leaders, and have broadened their appreciation of these matters. All departments have now adjusted their second- and third-year programs so that students will be accommodated without a scheduling penalty even though they have not taken the normal prerequisites as a result of delaying either physics or chemistry during their freshman year.

THE FUTURE

There are stirrings within the faculty in the direction of changes that should, within the next few years, move us closer to our ultimate objective of effectively accommodating students with a spectrum of backgrounds, interests and desires. Specifically, there is recognition that

1. More substantive electives are needed for freshmen,
2. Alternative versions of the science-core subjects are needed,
3. Variations in the patterns of conducting the science-core subjects are needed, and
4. The grading and evaluation system needs an overhaul.

We agree wholeheartedly with the personal assessment of Dr. Paul E. Gray, Associate Dean of Student Affairs, on these matters when he notes (a) that an elective is truly available only if it is offered at a time when the class schedule of a freshman can accommodate it and only if it is tailored to a level for which the freshman has the appropriate preparation; (b) that the single versions of science-core subjects as now offered do not accommodate efficiently the broad range of background and preparation of our students; (c) the traditional pattern of lecture and recitation with uniform quizzes is of questionable value, especially during an epoch when so many novel procedures for enhancing the teaching-learning process are being explored; and (d) the traditional grading system which is based on short-run efforts may be a major factor in introducing tensions and pressures that lead to bad study habits and actually lengthen, rather than shorten, the distance between student and teacher. We certainly support the doctrine that, in the final analysis, some kind of measuring system is a necessity. However, we would like to be more certain than we are now that our grading system embraces and stimulates, rather than inhibits, the key elements in the realm of human learning.

THE EXPANDING ROLE OF COMPUTERS

Of all the developments coming down the pike at the present time, none threatens to alter the established order of the academic community more than the high-speed digital computer. The impact of the computer on all domains of campus life, its cost of operation, its penetration into the conduct of the teaching-learning process, its relation to the character of curriculum content, and the problem of its operation as an efficient service facility, all appear to have been underestimated.

Too often, the computer is viewed only as a device to perform calculations in scientific research rapidly, whereas actually it opens up a wholly new way to process vast quantities of information. It presents mankind with the opportunity to formulate and think through both old and current problems in new and different ways. It reacts back upon man's traditional cognitive processes in many amazing ways. It is crucial at this time that we master an understanding of the role of the computer in relation to the storage, processing, retrieval and presentation of vast quantities of information, and that we restructure our attitudes toward problem-solving and decision-making in almost every area of human activity.

The digital computer promises to alter the way of life of human beings within the next decade as much as, if not more than, Gutenberg's invention of printing from movable type has altered civilized man's way of life.

Much of the teaching process has been geared to the printed page in a textbook, or to the printed page in a professional journal. However, when one examines the inflexibility and delay inherent in this form of communication — which requires that a teacher draft his material, find a publisher, edit proof and wait for the final printed matter to be distributed — he recognizes that the process is both slow and rigid. The student has little or no opportunity to inject feedback into the system. But gradually we are developing the technology that will permit a person to do his thinking on-line with a computer in ways whereby he can interact quickly through the medium of questions and answers. The frame of reference is so changed that the student may ask questions that heretofore would not have made sense. Herein lies the potential for a revolution in the teaching-learning process that today can only be dimly perceived. It promises not only to change the content of what we teach to students, but also to revolutionize the methodology whereby we do it. The sanctity of the traditional classroom-lecture-quiz system is almost certain to be swept away.

But to exploit the full potential of these new processes, it seems essential that we have available not only the techniques for achieving rapid access to large stores of information and for processing data at high speed but also configurations of processor and storage and control equipment

that will permit simultaneous access by a multitude of users and the instantaneous sharing of the work of one user with many others. As our colleagues, Professor Peter Elias and Professor Charles Miller, point out, computers must now be viewed as generalized rather than specialized tools, and must be furnished with effective software to bring their most sophisticated capabilities within reach of a large community of users, rather than a small circle of experts. Then, with an appropriate administrative structure and with an imaginative distribution of input stations to give flexible remote access, computers hold the same type of promise for all areas of intellectual activity at a university as the ubiquitous support provided by paper, pencils, and books. Under these circumstances, the rigid monopoly of access associated with the traditional central computation facility, to which everyone must bring his problem, is intolerable. The analog of this situation would be a regulation requiring all reading and writing in a university to be done at only one location to which faculty and students would go to wait their turn at a reading booth or writing station. The present efforts in many research laboratories and industrial establishments to develop sophisticated time-sharing computer systems are pointed in the direction of providing the ease of access to computers that must be achieved if the potential which they offer is actually to be realized.

At the present time, computers are heralded by the teaching profession as marvelous developments. A close examination of the tasks which are invariably set for them shows, however, that in their direct application to the teaching-learning process they are used today only in the most primitive of fashions. Too often, an extremely expensive machine or procedure is being used only to computerize the job previously done by a skilled teacher. As so aptly phrased by our colleague, Professor Carl F. J. Overhage, the result is not unlike that which we would have achieved had we mechanized the movements of the horse rather than displacing it functionally by the automobile. To carry the analogy a step further, we might note that the world did not advance to the jet age in transportation merely by putting wings on the horseless carriage, but rather by introducing wholly new concepts and synthesizing knowledge within a new conceptual framework and from a number of areas, many of which offhand seemed quite unrelated.

We have abundant evidence before us which indicates an urgent need to uncouple our teaching-learning efforts from existing dogmas and methodologies. We must understand better the whole mechanism of human learning, we must study the human cognitive process, we must learn to exploit the potential in our teaching techniques for presenting a moving image or a pictorial display, as in a TV presentation, and we

should assess the importance of permitting the student to feed questions back into the teaching-learning process as knowledge is unfolded before him. In the vernacular of the automatic control engineer, this last requirement amounts to increasing the gain in the teaching-learning control loop. Happily, there are some initial moves in this direction as demonstrated by the way an on-line user may now partake in a dialogue with the computer, using some of the software systems that are now emerging.

The degree of excitement now apparent in the academic community over these issues is enormous, but unless we are careful we could easily run ahead of our supply lines. There is a strong urge to "computerize" existing subjects only to find that the process has not been carried sufficiently far and only a "mechanized" horse has resulted, or that what has been done in one "computerized" subject has made obsolete what has been or is being done in another. Also, we invariably find that the number of users who want simultaneous access to the computer saturates our present systems or that the amount of computer time that is needed is excessively expensive. We have before us a massive systems problem embracing technological, economic, and organizational issues. No segment of the academic environment escapes the impact of modern information-processing technology.

Achievement of the information-processing capability sought by so many would be utopian. Machines capable of doing the real job have yet to be constructed. The time-sharing computers currently in use cost too much for the service they render, and their operation is too slow. Their contribution has been to prove some of the basic conjectures and to point the way. The generation of computers about to come into use will significantly increase our capacity to cope with the situation but about all that we can expect for the next three to five years is a tangled web of efforts, a complex problem of coordination and evaluation, and great expense. Like many technological developments, this one has widespread sociological and psychological implications, and is far more revolutionary than most. Also, serious financial and legal questions must be resolved. The commercial market for textbooks is in jeopardy. New copyright laws are being considered and an equitable means for reimbursing authors must be developed or neither authors nor publishers will show enthusiasm toward converting to this new means for disseminating information.

Currently, several large computer activities exist at M.I.T. Among these are the Computation Center, which operates an IBM 7094 providing both batch-processing and time-sharing service, and a recently installed System/360, which includes a Model 65 and a Model 40 operating jointly in an Attached Support Processor configuration for batch processing. Project MAC operates a 7094, providing only time-sharing service to

selected users whose work contributes to the goals of the Project, and a GE 645 on which the MULTICS system for time-sharing and batch processing is being developed. MULTICS operation is expected to be made available on a semi-public basis in early 1968. For a more detailed discussion of these matters the reader is referred to the report by the Director of Project MAC included later in this document.

The Civil Engineering Systems Laboratory has operated a System/360, Model 40 for over a year with very good success and has recently added an IBM 1130 which operates as a stand-alone computer and ultimately may serve as a sophisticated terminal for the Model 40.

The Laboratory for Nuclear Science has saturated the IBM 7044, which it installed several years ago, and is converting to a System/360, Model 65.

The Sloan School of Management is in urgent need of more capacity than available from its IBM 1620 and believes that, in the absence of increased time-sharing service or remote-batch access to a large central facility, only a System/360, Model 30 will meet its needs. The Department of Aeronautics and Astronautics proposes to substitute an IBM 1130 for its IBM 1620 in the fall of 1967.

But these are only the most prominent computer systems at M.I.T. The Department of Electrical Engineering operates a TX-0 and a Digital Equipment Corporation PDP-1. The TX-0 is an experimental computer which was built by the Lincoln Laboratory and which subsequently became the forerunner of the PDP-1. Elsewhere at M.I.T. are about eight other PDP's in various configurations, some with connections to other large computers. Also dispersed throughout the campus and the neighboring community are about 230 typewriter consoles from which one may gain access to either of the IBM 7094's under the time-sharing system. As yet unclear is the demand that Project INTREX will exert, and the facilities that it will require. In addition, there are System/360, Model 30's in the Comptroller's Office and in the Office of Institutional Studies. The list is far from complete and the demand is far from satisfied.

Both of the IBM 7094 computers in current operation on our campus under the Compatible Time-Sharing Systems (CTSS) are overloaded. Both are expensive to operate and because of features inherent in their design, neither has the capacity for growth. They are, nevertheless, the most sophisticated time-sharing computer systems in existence anywhere. The MULTICS system being developed at M.I.T. by Project MAC under Advanced Research Projects Agency (ARPA) support has yet to demonstrate its capability although it looks very promising. The initial Time-Sharing System (TSS) under development by International Business Ma-

chines Corporation (IBM) for their System/360, Model 67 computer has yet to be proven.

There are many professionals in the computer arena who sincerely believe that the achievement of a reliable, inexpensive, and sophisticated time-sharing system is at least five or more years away, and may even be beyond the capacity of human development. At this time, there are pressures for increased capability in batch operation, and pressures to develop networks of computer interconnection to provide effective remote batch operation. All this confounds and complicates the task of the university administration which must set policy in these domains and finance and administer the facilities. A factor that greatly confuses the issue is that computer systems rarely become available until a year or frequently two years after decisions to acquire them have been made. Even then the newer systems almost invariably lack the software needed to make them really effective.

Central to these issues is the overriding fact that it is not the hardware but the software that provides the primary control and flexibility. The quality of the program that is written to organize the equipment and to establish the logic or algorithm whereby the machine handles the information fed into it is often the feature that distinguishes success from failure. Because of the number of corporations which today design and manufacture large computers and the absence of standardization among their products — even if we knew how to achieve standardization — and because of the multiplicity of groups developing software based on differing languages, and the desperate shortage of truly skilled manpower at all levels of the activity, we find ourselves somewhere in the midst of a jungle with little or no precedent to guide us and only a poor intuitive feel for what the future may bring.

Relevant here is the task facing the Department of Electrical Engineering, as discussed by Professor Louis D. Smullin in his report, of developing a curriculum that adequately fulfills both our present and future needs in the computer sciences. For the past several years, the Departments of Civil Engineering and Electrical Engineering have had to cope with the registration of hundreds of students each term in their introductory computer subjects. Nearly every student at M.I.T. now gains personal experience with the computer at some time or other in his program of studies. To meet their growing expectations, we must find ways to reduce the cost.

It is within this framework that we are working to optimize the use of our resources. We have concluded that rather than become preoccupied merely with computers and computer centers, we must realize that we are being carried along by the pressures of an open-ended, self-generating

campus-wide information processing program. The computer per se is the small part of it.

It appears that right within our grasp is a new conceptual movement which has a potential never before available for unifying the goals and purposes of the Institute. The common interest in the computer shown by scholars in disciplines so diverse that heretofore they never encountered one another, let alone shared knowledge and experience, is indeed amazing. The challenge we see ahead is to mobilize this common interest in ways that will convert this potential for greater unity of purpose into a reality — to achieve a different and better kind of university. We note that our faculty has experienced first hand, as no other faculty ever has, the potential offered by a time-shared computer capability. It wants more. Having seen gay Paris, our faculty no longer wants to go back to the old country farm.

We have responded to these challenges. A new six-story building is under construction to house the new equipment that will constitute the central facility of a large and complex campus-wide communications and data processing network with a multiplicity of kinds of input and output equipment. Our administrative structure has been strengthened by the appointment of Mr. Richard G. Mills, formerly Assistant Director of Project MAC, to a new post as Director of Information Processing Services to coordinate all computer facilities at M.I.T. While our faculty resources in the computer science and information processing domains are extensive, we are still grossly understaffed if we are to achieve the level and pace of activity in our total Institute-wide information processing program dictated by the needs of today, and by the demands that we know are just over the horizon.

TRANSPORTATION-RELATED RESEARCH

Our Report for the year 1964-65 mentioned the joint activities of a number of faculty in the School of Humanities and Social Science, and in the School of Architecture and Planning, as well as in the School of Engineering, in the broad-scale investigation of the potential for developing a high-speed ground transportation system to serve the Northeast Corridor of the United States. While our initial activities were limited by the sponsor, the Department of Commerce (now the recently-established U.S. Department of Transportation) to the Northeast Corridor Project, the enthusiasm engendered by this work showed clearly that within our faculty there existed the urge to develop an integrated effort covering all modes of transportation, and to embrace the research, development, and planning aspects of this crucial problem.

Following the initial work, the sponsor stipulated that our work under

the Northeast Corridor Project focus on purely technological studies. Nevertheless, these studies have involved faculty and students from the Departments of Civil, Electrical, and Mechanical Engineering in a broad spectrum of research. The Northeast Corridor Project has also supported the Department of Aeronautics and Astronautics in a related study of the potential offered by short-haul air transportation as a means for satisfying a portion of the transportation demands within the Northeast. Other events during the last two years have assisted us in moving steadily in the direction of developing a broad integrated activity in transportation.

Our research efforts were strengthened very substantially in July, 1965, by a grant of \$250,000 per year for a four-year period from the General Motors Corporation. The purpose was to fund a broad study of means for improving the efficiency and safety of highway transportation.

In each of the last three years, the existence of these activities under the Northeast Corridor Project and the G.M. grant has been a decisive factor in determining the topic chosen for study by the group of students in our interdepartmental subject in Systems Engineering. For the spring term of 1965, one section of the class was assigned the problem of designing a specific high-speed ground transportation system to handle passenger traffic demands of the Northeast Corridor in the 1980's. The following year, the class undertook the design of an evolutionary transportation system to meet the transportation needs of the Boston area. These students outlined a plan under which some new concepts could be introduced almost immediately while others would be phased into the system over a period of years. The students proposed a system utilizing an extensive network of automated highways, closely integrated with an automated capsule system for transport within the central business district which, by about 1990, would provide an efficient and flexible system for transportation within the whole metropolitan area.

This past spring, the student group examined the possibilities for developing a high-density residential and business area which would utilize innovative construction techniques to permit relocation of individual living units and even of complete large structures so that the area could evolve to meet new demands. An extensive transportation system formed an integral part of this design.

Each of these research and teaching efforts has involved a spectrum of faculty from other Schools at M.I.T., as well as engineers and representatives from both industry and government. Each has pointed clearly to the fact that the problems of transportation are inseparable from the broader problems of urban and regional development. As a result, many of those involved in these transportation efforts are working closely

with others at M.I.T. who are focusing their attention on one of the many other facets of urban and regional problems.

The development of a growing and broadening interest within M.I.T. in urban problems, and transportation in particular, has not passed unnoticed. Many of the faculty have been sought as speakers and participants in transportation studies carried on outside M.I.T. One of these studies, in which six of the M.I.T. faculty have participated along with approximately 70 others from industry and government with interests in various facets of the transportation problem, is undertaking a broad appraisal of the problems facing the airports of the country. The specific goal here is to outline steps that might be taken to permit airports to cope effectively with the problems of the late 1970's, a task they cannot fulfill without major changes in the present configurations, location, and coupling to the other segments of the transportation complex.

At this time, it appears that the Institute is well on its way toward developing a strong and broadly based effort in transportation. We can begin to look forward to graduating a significant number of students with a quite different blend of competence, motivation, and attitude from that of their predecessors. These students will be anxious to move into industry and government and put their broad training into practice. Over a period of years, their efforts should have a significant impact in improving the efficiency of the means whereby society will handle this aspect of its activity.

BUILDING ADDITIONS AND MODIFICATIONS

During the past year, considerable progress has been made under the Institute's program for providing additional space to house new and expanding activities and for reassigning and refurbishing space in existing buildings to provide more effective groupings for research and teaching. The opening of the Center for Materials Science and Engineering in the fall of 1965 afforded the opportunity for an extensive regrouping of the activities of the Metallurgy Department. A number of its activities were moved from Buildings 4 and 8 in the main group into the new Center, thereby freeing sufficient space to permit relocation into the main building group of all of the Department of Metallurgy activities formerly housed in outlying buildings. This change, which will not be completed until late in 1967, will leave the Department with its teaching and graduate research activities in first-class facilities and located conveniently around two neighboring foci.

Transfer of the metallurgy activities from Building 35 permitted reassignment of the top three floors of that building to the Electronic Systems Laboratory (ESL) of the Department of Electrical Engineering.

Although very extensive modifications of portions of Building 35, such as the old foundry laboratory, will be required to readapt it to the needs of ESL, the resulting space should serve the needs of the Laboratory much more effectively than did Building 32. This change will not be completed until the spring of 1968, and it is hoped that by that time the new building for the central computing facility will be completed so that the System/360, Model 65 computer now in Building 32 may be relocated, and Building 32 can be razed.

During the year, agreement was reached to proceed as rapidly as possible with the planning of a major new building complex to house much of the Department of Electrical Engineering and of the Research Laboratory for Electronics. Building 32 now occupies the site selected for this new complex and, consequently, there is considerable pressure to empty it and take it down.

In spite of the new construction added in recent years, and the refurbishing that has been accomplished, the complete lack of unassigned space at the Institute now makes it extremely difficult to accommodate new activities. It appears that this scarcity will continue even after the Center for Space Research is completed. Consequently, because it will be several years before a new Electrical Engineering building is available, we expect that a number of groups within the School will be forced to make the best of non-ideal quarters for several years. During this time plans can be laid for a reassignment of the substantial space in the main group which will be vacated by Electrical Engineering.

While some relief can be expected for the Department of Civil Engineering when the proposed addition to the Hydrodynamics Laboratory (Building 48) is completed, that Department and the Department of Mechanical Engineering must await the completion of the Electrical Engineering building to acquire any significant new space contiguous to their existing activities in the main group.

In addition to the problems mentioned above, we have a very pressing need to provide entirely new facilities for our Department of Chemical Engineering.

PERSONAL NOTES

Effective September 1, 1966, Professor Louis D. Smullin was appointed as Head of the Department of Electrical Engineering, succeeding Professor Peter Elias who had asked to be relieved of his duties as Department Head in order to resume personal research and teaching. Professor Smullin is a widely recognized authority on microwave engineering.

During the year, the following distinguished members of our faculty were elected to the National Academy of Engineering: Professor Manson

Benedict, Head of the Department of Nuclear Engineering; Professor Emeritus Jerome C. Hunsaker, Department of Aeronautics and Astronautics; and Professor Arthur T. Ippen, Ford Professor of Engineering in the Department of Civil Engineering.

Elected to the National Academy of Sciences were Professor Ascher H. Shapiro, Head of the Department of Mechanical Engineering, and Professor Raymond L. Bisplinghoff, Head of the Department of Aeronautics and Astronautics.

Professor Alfred H. Keil, Head of our Department of Naval Architecture and Marine Engineering, was honored on April 24, 1967, when he became the second recipient of the Gibbs Brothers Medal of the National Academy of Sciences. This medal is awarded for "outstanding contributions in the field of naval architecture and marine engineering." Professor Charles L. Miller, Head of the Department of Civil Engineering, was awarded the George Westinghouse Award of the American Society for Engineering Education for his "contributions to the improvements of teaching methods for engineering students." Professor Manson Benedict received the Founders' Award of the American Institute of Chemical Engineers.

Professor Claude E. Shannon of the Department of Electrical Engineering was awarded a National Medal of Science by President Lyndon B. Johnson in February, 1967; and Professor Norman C. Dahl of the Department of Mechanical Engineering was elected a Fellow of the American Academy of Arts and Sciences.

Three of our faculty members spent the 1966-67 year abroad at universities with which M.I.T. carries on exchange programs. Professor Robert L. Halfman of the Department of Aeronautics and Astronautics served as Program Director at the Indian Institute of Technology in Kanpur, India, and will remain in this position for the 1967-68 year also. Professors James E. McCune of the Department of Aeronautics and Astronautics and Peter J. Pahl of the Department of Civil Engineering spent the year as visiting faculty at the Technical University of West Berlin.

Professor Jack P. Ruina was appointed Vice President for Special Laboratories, effective July 1, 1966. Professor Ruina, a member of the Department of Electrical Engineering, had been on leave from M.I.T. serving as President of the Institute for Defense Analyses.

Two senior members of our faculty resigned during the 1966-67 year. They are Professor David A. Huffman of the Department of Electrical Engineering and Professor Holt Ashley of Aeronautics and Astronautics. Professor Huffman accepted a position as Professor of Computer Science at the University of California at Santa Cruz, while Professor Ashley

became a Professor of Aeronautics and Astronautics at Stanford University, Stanford, California. The services and companionship of these distinguished colleagues will be deeply missed by all of us.

Four distinguished members of our faculty retired at the end of the 1966-67 year. They were Alexander J. Bone, Associate Professor of Civil Engineering and an authority on the economics of highway planning and transportation; Dr. Jacob P. Den Hartog, Professor of Mechanical Engineering and one of the world's foremost authorities on mechanical vibrations; Dr. C. Stark Draper, Institute Professor and Professor of Aeronautics and Astronautics, a pioneer in the development of inertial navigation systems and a distinguished contributor of the highest order both to M.I.T. and to the broader engineering and scientific community; and Dr. Harold L. Hazen, Dean of the Graduate School, Professor of Electrical Engineering, and one of the nation's leading engineering educators. Dr. Draper will continue as Director of the Instrumentation Laboratory, which he founded more than 25 years ago; and Dean Hazen will assume the post of Foreign Study Advisor at M.I.T.

GORDON S. BROWN
WILLIAM W. SEIFERT

DEPARTMENT OF AERONAUTICS AND ASTRONAUTICS

The present report is written with the background of a year of intensive planning activities by the faculty of the Department of Aeronautics and Astronautics. These activities, together with the progress achieved during the course of the year, convey a feeling of optimism for the future of education in aeronautics and astronautics at M.I.T.

THE UNDERGRADUATE SCHOOL

The undergraduate school continues to set a challenging pace in enrollment and subject development. The enrollment above the freshman year was 215 in the spring term, 12 per cent above last year's figure. This places the Department's undergraduate enrollment second in the School of Engineering. A total of 62 Bachelor of Science degrees was awarded in the 1966-67 school year.

Increased flexibility and elective freedom in the undergraduate curriculum have made greater demands on the faculty. Many subjects are now offered in both terms. Several new electives were taught for the first time during the last year. Class sizes have increased in spite of the two-term subject availability. Three of the subjects had more than 80 students

enrolled in one term. Six subjects had between 40 and 55. Such enrollments require the best marshalling of the instructional resources of the Department. Suitable lecture rooms for large classes are a problem and will continue to be, even when the Center for Space Research is completed.

On the other hand, the staff that is teaching solid mechanics has divided up the recitation sections into small tutorial groups, increasing the demand for small conference-type rooms. Faculty offices with blackboards may be the ultimate solution to this problem.

As for new undergraduate subjects, Aerospace Engineering (16.82) was offered for the first time and was well received. This is an introductory overview of aerospace technology and is intended for first-year students. Aerospace Engineering was made up of a series of lectures given by Professors Raymond L. Bisplinghoff, Jack L. Kerrebrock, James W. Mar, Rene H. Miller, Edward S. Taylor, Leon Trilling, Wallace E. Vander Velde and H. Philip Whitaker. A new freshman seminar in air transportation was given in the spring term by Associate Professor Secor D. Browne. Small additional numbers of undergraduate students were encountered by the Department in Professor Joseph Bicknell's new Projects Laboratory (16.61) and in freshman seminars in flight guidance and fluid mechanics given by Professors Bicknell, Morton Finston, Winston R. Markey, Associate Professor Robert K. Mueller, and Assistant Professors Paul B. Scott and Sheila E. Widnall.

Participation of the Department faculty in freshman subjects included Professor Otto C. Koppen and Associate Professor Harold Y. Wachman. The former taught Flight Vehicles (16.81) and the latter a section of Chemistry (5.01).

Experimental Projects (16.62) continues as the focal point of undergraduate laboratory instruction. It demands large amounts of faculty time, but the general education, the opportunity to exercise and develop ingenuity while exploring the gap between classroom theory and the physical world have a sobering and maturing influence on the student. About 61 students carried out 46 projects during the year.

At the request of several of our undergraduates for more student-faculty meetings on an informal basis, during a series of cider hours, short presentations were made by the staff or invited guests. The presentations were followed by general discussion. At their conclusion, the students considered them well worthwhile and they will be offered again next year.

The students also requested a meeting room of their own and plans are in progress to provide one next year.

The Admiral Luis de Florez awards "for ingenuity and original think-

ing" were given to Robert Harmon Fall '67, Richard Warren Heldt '67, Wayne Robert Johnson '68, Stephen Howard Schroeder '67, and Greg Leon Zacharias '67. The awards were made on the basis of experimental projects and systems analysis and design.

The James Means Memorial Prize was awarded to John Bradford Ellenwood '67, and Harold Lee Jones '67, on the basis of superior systems analysis and design work.

The Henry Webb Salisbury award for outstanding academic performance in the Department of Aeronautics and Astronautics was given to Max Michael Polak '67.

THE GRADUATE SCHOOL

The graduate school enrollment continued at approximately the same level as that of the last five years — 175 regular students and 80 special students. By fields, the regular graduate school population was distributed as follows:

Instrumentation, control and guidance, including astronautics	80
Fluid mechanics and gas dynamics	45
Propulsion	20
Structures and aeroelasticity	20
Design and other	10

The distribution by means of support was:

Fellowships (mostly first-year graduate students)	45
Support by employer	15
Teaching Assistantships	4
Research Assistantships	105
Other	6

The distribution by degree candidacy was:

Doctor's candidates (including about 35 in instrumentation)	80
Master's candidates (including about three to five per year for the EAA degree)	95

This distribution pattern has been rather stable since 1962. The Department annually receives applications from 150 to 175 students, of whom 95 to 105 are admitted and 66 actually register. Of them, about 22 are M.I.T. undergraduates, 25 are from other U.S. schools and 13 are foreign.

During the course of the academic year, the Department administered qualifying examinations to 24 candidates, of whom 12 were admitted. In addition, ten general examinations and five thesis presentations were made. The number of theses presented is lower than usual this year, but

this is probably a temporary phenomenon. A total of 20 doctorates, 82 Masters of Science and nine Engineer degrees were awarded in the 1966-67 school year.

THE FACULTY

Dr. Raymond L. Bisplinghoff returned from his leave at National Aeronautics and Space Administration to succeed Dr. C. Stark Draper as Head of the Department. Dr. Draper was appointed Institute Professor and continued as Director of the Instrumentation Laboratory.

Other promotions included Dr. Winston R. Markey and Dr. Theodore H. H. Pian to Professor, Secor D. Browne and Dr. Laurence R. Young to Associate Professor, and Dr. Jacob L. Meiry to full-time Assistant Professor.

New appointments for the year are: Dr. Milton U. Clauser as Professor of Aeronautics and Astronautics and Director of the Lincoln Laboratory; Dr. W. Stephen Lewellen from Visiting to Associate Professor; and Dr. John H. Argyris to Visiting Professor, jointly with the Departments of Civil Engineering and Mechanical Engineering. Dr. Albert Solbes was appointed Assistant Professor. Dr. Robert G. Stern was appointed Lecturer. Paul E. Sandorff was reappointed Visiting Professor, to lead the group in Advanced Space Systems Design (16.74).

On leave during the year were Professor Robert L. Halfman to Kanpur, India, Associate Professors Myron A. Hoffman to the Laboratorio Gas Ionizzati in Italy, James E. McCune to the Technical University in Berlin, and Assistant Professor Walter M. Hollister to the Eidgenossische Technische Hochschule in Zürich.

Faculty leaving during or at the end of the year included Professor Holt Ashley to Stanford University, Associate Professor Gordon C. Oates to the University of Washington, and Visiting Assistant Professor Heinrich J. Volk, to the Max Planck Institute in Germany.

Ford Postdoctoral Assistant Professors completing their two-year fellowships and leaving are Frederick K. Browand and Paul B. Scott to the University of Southern California, Lawrence W. Rehfield to Georgia Institute of Technology, and Rodney J. Mason.

Almost all faculty members of the Department continued a high level of outside activities in connection with professional societies and government committees and boards. Honors accorded Department faculty members during the year included the Meritorious Civilian Service Award of the U.S. Army to Professor Rene H. Miller, election of Professor Emeritus Jerome C. Hunsaker to the National Academy of Engineering, and election of Professor Raymond L. Bisplinghoff to the National Academy of Sciences.

SPECIAL LECTURES AND SEMINARS

Captain Walter S. Diehl (USN, Ret.) presented the Lester D. Gardner lecture on May 3, 1967. Captain Diehl's subject was "Naval Aviation, Some Early Naval Aviation Papers Concerning Carriers, Airplanes, Organizations and People." It was well attended and enthusiastically received. The lecture was repeated in Washington, D.C., at the Smithsonian Institution.

Under the leadership of Professor Mar, the Department's Seminar Series sponsored 21 lectures by leaders in the various fields of aeronautics and astronautics. Five speakers were from outside the U.S.A., and three were from the Department. Following is a list of speakers, and their topics in the 1966-67 seminar series:

DR. RICHARD HEAD, NASA Electronic Research Center

"Triggering of Solar Proton Events"

DR. HERMANN SCHONE, Max-Planck-Institut für Verhaltensphysiologie

"Man's Orientation in Space with Relation to Gravity"

PROFESSOR W. STEPHEN LEWELLEN, Department of Aeronautics and Astronautics, M.I.T.

"Viscous Vortices and their Interactions with Solid Boundaries"

DR. YOSHIYUKI YAMAMOTO, University of Tokyo, Visiting Scientist in the Department of Aeronautics and Astronautics, M.I.T.

"Buckling of a Plate Subjected to End Thrusts and Lateral Pressure"

C. S. HOWELL JR., The Boeing Company

"The SST Development"

DR. JOHN MC CARTHY, North American Aviation, Inc.

"Post Apollo"

DR. GEORGE R. INGER, Douglas Aircraft Company, Inc.

"Boundary Layer Flows with Strong Blowing"

DR. F. A. LECKIE, Cambridge University

"The Rate Problem Applied to the Elastic and Plastic Stability of Shells"

PROFESSOR DOUGLAS H. SAMPSON, The Pennsylvania State University

"Approximate Methods for Treating Radiative Transport in a non-Grey Gas"

PROFESSOR EDWARD S. TAYLOR, Department of Aeronautics and Astronautics, M.I.T.

"A New Approach to Dimensional Analysis"

FRANKLIN J. DAVENPORT, The Boeing Company

"Aerodynamic Problems of VTOL Aircraft"

GEORGE MC LAFFERTY, United Aircraft Corporation

"Gaseous Nuclear Rockets"

FRANKLIN O. CARTA, United Aircraft Research Laboratories

"Aeroelastic Problems in Turbomachinery"

SCHOOL OF ENGINEERING

P. POISSON-QUINTON, O.N.E.R.A., Paris, France

"From Wind-Tunnel to Flight: The role of the Laboratory in the Development of Aircraft and Missiles"

DR. DANIEL E. ROSNER, Aero Chem Research Laboratory, Inc.

"Aerodynamic and Chemical Kinetic Aspects of the Ablation of Refractory Materials in Partially Dissociated Oxygen"

PROFESSOR SECOR D. BROWNE, Department of Aeronautics and Astronautics, M.I.T.

"Soviet Civil Transport Aircraft — 1967"

DR. ROBERT WEISS, Avco Everett Research Laboratory

"Theory of Hypersonic Near Wakes"

J. R. CLARK, Ling-Temco-Vought, Dallas, Texas

"Fundamentals of Aerospace Management with Examples from v/STOL Design and Development"

DR. H. OBREMSKI, Martin Company, Baltimore

"Transition in Oscillating Boundary Layer Flows"

PROF.-DR. ING. A. WALZ, Technical Highschool Karlsruhe

"Recent Advances in Turbulent Boundary Layer and Heat Transfer Calculation"

DR. OSCAR HOFFMAN, Lockheed Missiles and Space Company

"Research in Mechanics of Materials at Lockheed"

Professor Browne again organized a series of seminars dealing with the varied problems of flight transportation. They were attended by an audience drawn from the Institute and outside. The following distinguished outside speakers led seminars: John Borger, Chief Engineer, Pan American Airways; The Hon. Alan S. Boyd, Secretary of Transportation; Stuart G. Tipton, President, Air Transport Association; Oscar Bakke, Regional Administrator, Federal Aviation Agency; John R. Wiley, Director, Aviation Department, Port of New York Authority; Melvin A. Brenner, Vice President, Scheduling, American Airlines; and Jerome C. Lederer, Vice President and Technical Director, Flight Safety Foundation.

DIVISIONS OF INSTRUCTION

In order to deal effectively with the total range of subject matter in aeronautics and astronautics, the Faculty Policy Committee of the Department made the decision during the past year to divide the departmental academic activities into five divisions:

1. Aeronautical and astronautical systems.
2. Structures, materials and aeroelasticity.
3. Mechanics and physics of fluids.
4. Instrumentation, control and guidance.
5. Propulsion and power.

The activities during the past year of each division of instruction are described in the sections which follow.

AERONAUTICAL AND ASTRONAUTICAL SYSTEMS

The Aeronautical and Astronautical Systems Division of Instruction, with Professor Miller in charge, includes the following faculty members: Frank K. Bentley, Joseph Bicknell, Raymond L. Bisplinghoff, Secor D. Browne, Norman D. Ham, Jack L. Kerrebrock, Otto C. Koppen, E. Eugene Larrabee, Yao T. Li, Paul E. Sandorff, Robert W. Simpson, Edward S. Taylor, and H. Philip Whitaker.

The Department's subjects in Flight Transportation continued to attract increasing interest among the student body, with 26 students registered this year in 16.751 compared to 23 last year and 16 the previous year. This is an interdepartmental subject conducted with Courses I, VI and XV, although the participation of Courses I and VI dropped off this year. Interest on the part of Course XV students continued, with four students attending.

In the spring term, Assistant Professor Robert W. Simpson developed a new subject, Flight Transportation Operations Analysis, given as 16.60, but to be labeled 16.77 next year.

The Department continued to attract about 20 students each in its subjects in Space Systems Engineering (16.73 and 16.74). Approximately half of the students taking 16.73 elect the Advanced Space Systems Engineering subject (16.74). An additional 13 students took an aircraft-oriented systems engineering subject taught by Assistant Professor Norman D. Ham. Whereas the attendance in these subjects is reasonable for elective subjects at the senior and graduate level, it should be emphasized that only a small percentage of the total senior and graduate enrollment is exposed to the engineering concepts covered in the Systems Engineering subjects.

As has been customary for the past several years, students registering for the graduate elective subjects 16.74 and 16.362J combined to undertake the preliminary engineering design of a complex aerospace vehicle system. The Department's systems design subjects have roots that go back many years to the subjects in airplane design that were a required and integral part of the curriculum of the Department in its early years. Like the earlier design subjects, today's systems engineering subject (16.74) is concerned with the engineering solution of a real-world problem, a problem which cannot be solved in closed form, which requires simultaneous application of many scientific disciplines, and which has many solutions, none of them entirely satisfactory (all require compromising minor excellences to achieve an over-all optimum).

However, the systems engineering subject differs from the airplane design of the 1950's in several ways. The problems treated today are more complicated, and they involve more subsystems, all of which interact importantly with each other.

The design study is now carried out as a team effort, rather than by each student as a one-man project. The class is organized into groups, each of which is responsible for a major subsystem. The students work therefore as specialists, as is the case in industry. They contend not only with the technical problems, but with the problems of communication and coordination with other members of the team.

The design problem selected last year called for interception and diversion or destruction of the asteroid Icarus, which was assumed to be on a collision course with earth. This problem proved to be particularly well suited, not only because the topic attracted high student interest but because it involved many different subsystems and unusual trade-offs. The time constraints produced by the asteroid Icarus permitted the consideration of existing space hardware only. This led to firmer design, less effort on subsystem details, and more effort on system trade-offs.

The class of 21 included 13 graduate students and eight seniors. Two came from electrical engineering, two from nuclear engineering and the rest from Course XVI. Motivation this year was exceptionally high. Many of the students contributed more time than the credited hours and did much more work than was expected. Almost all were unusually good students in their fields of specialty. They formed some nine different subsystem groups. In some groups, the students took turns acting as group leader.

Professor Paul E. Sandorff was in charge of the subject, with support in Guidance and Control and in Orbital Mechanics from Professor Yao T. Li and Doctors Robert G. Stern and John J. Deyst. Professor Henri Fenech of the Department of Nuclear Engineering assisted the students from his Department. Lectures on special topics were given by Professor Louis D. Smullin of the Department of Electrical Engineering, and Drs. Charles E. Muehe and Herbert G. Weiss of the Lincoln Laboratory. Guest lecturers were Fred Whipple of the Smithsonian Astrophysical Observatory, Samuel Herrick of the University of the City of Los Angeles, and Jack Funk of the National Aeronautics and Space Administration (NASA) Manned Spacecraft Center. On May 22, the students gave an oral presentation of the results of their study to faculty and invited guests in the Little Theatre of Kresge Auditorium.

A high point for the students of Advanced Space Systems Engineering was a visit to Cape Kennedy on March 24. On this trip the students were the guests of the U.S. Air Force.

The Department continued to draw on industry participation in teaching systems engineering subjects, a practice which has been welcomed by both students and industry.

STRUCTURES, MATERIALS AND AEROELASTICITY

The Division of Structures, Materials and Aeroelasticity, under the leadership of Professor Mar, includes the following faculty members: Raymond L. Bisplinghoff, Louis L. Bucciarelli, John Dugundji, Theodore H. H. Pian, Paul E. Sandorff, Sheila E. Widnall, and Emmett A. Witmer.

Last year, the Division continued to conduct education experiments with 16.20, the subject in Solid Mechanics required of all the Department's students. This year more attention was devoted to trusses and beams, with less time devoted to the formal aspects of the anisotropic stress-strain relations. A start was also made toward the development of a new series of demonstration experiments to be used in the classroom. These experiments are to parallel the lectures and text with the objective of developing better physical insight into structural behavior.

Assistant Professor Louis L. Bucciarelli was responsible for both the fall and spring offerings of Solid Mechanics I (16.20). In an attempt further to enrich the subject matter, he introduced the class to selected topics on the historical development of the theories of strength of materials and elasticity. This took the form of five lectures, associated reading, and problems. From the response of the class, it was evident that a majority of the students felt that more emphasis on the history of science and technology would contribute to their professional development. On the invitation of Professor Anthony P. French, of the Department of Physics, Professor Bucciarelli related his experience in teaching the historical material and discussed the students' reactions at a seminar of the Science Teaching Center.

A review of the coverage of material last year revealed that insufficient time was being devoted by the division to flat plates, thermal stresses and stability theory. To fill this gap, a new subject will be introduced in the fall of 1967 bearing the number 16.21.

During the fall term, Professor Theodore H. H. Pian offered subject 16.25 with a major revision of the content. The revised content included 40 per cent on fundamentals of plasticity, 40 per cent on viscoelasticity and 20 per cent on creep and creep buckling.

During the spring term, the Department of Aeronautics and Astronautics and the Departments of Mechanical Engineering and Civil Engineering sponsored Dr. John H. Argyris as Visiting Professor. Professor Argyris taught an interdepartmental subject on Matrix Theory of Structures

SCHOOL OF ENGINEERING

and Solid Continua. There were 38 registered students, of which more than one-third were from Course XVI.

MECHANICS AND PHYSICS OF FLUIDS

The Mechanics and Physics of Fluids Division, with Professor Judson R. Baron in charge, includes the following faculty members: Holt Ashley, Joseph Bicknell, Frederick K. Browand, Eugene E. Covert, Morton Finston, Robert L. Halfman (absent), Marten T. Landahl, W. Stephen Lewellen, Rodney J. Mason, James E. McCune (absent), Paul B. Scott, Edward S. Taylor, Leon Trilling, Harold Y. Wachman, and Sheila E. Widnall.

Student interest in the mechanics and physics of fluids remained high during the year. Nearly one-quarter of the Department's regular graduate students specialized in fluid mechanics. Of them, one-third are qualified doctoral candidates. Of the Department's 21 seminars, seven were of fundamental fluid mechanics interest and four others dealt principally with aerodynamic applications and problems of specific flight vehicles.

Hydrodynamic Stability of Parallel Flows (16.60) was introduced for the first time as a graduate elective by Assistant Professor Frederick K. Browand. The graduate subject sequence 16.071-16.072, Aerodynamics of Wings and Bodies, taught last year by Professor Marten T. Landahl, had a record number of students — 25 in the first term and 12 in the second term, signifying a resurgence of interest in airplane aerodynamics.

Four faculty members of the Mechanics and Physics of Fluids Division left M.I.T. permanently during the past year. Professor Holt Ashley accepted a position at Stanford University at mid-year. The three current Ford Postdoctoral Fellows in the division completed their fellowships at the end of the year. Professor Browand, who has taught Viscous Flows (16.041) and Hydrodynamic Stability (16.60), and Professor Scott, who has taught the Experimental Projects Laboratory (16.62), are both taking faculty positions at the University of Southern California. Assistant Professor Rodney J. Mason, who has taught a section of Aerodynamics (16.02) is a candidate for the NASA Scientist-Astronaut Program.

INSTRUMENTATION, CONTROL AND GUIDANCE

The Instrumentation, Control and Guidance Division of Instruction with Professor Li in charge, includes the following faculty members: Ramon L. Alonso, Richard H. Battin, Milton U. Clauser, C. Stark Draper, Elmer S. Frey, Robert L. Halfman (absent), Norman D. Ham, John V. Harrington, Walter M. Hollister (absent), E. Eugene Larrabee, Winston R. Markey, Walter McKay, Jacob L. Meiry, Robert K. Mueller, James

E. Potter, Robert G. Stern, Wallace E. Vander Velde, H. Philip Whitaker, Walter Wrigley, and Laurence R. Young.

This division was formed during the last academic year by consolidating the Department activities in vehicle dynamics, measurements and instrumentation, data transmission and computing, control and guidance and man-vehicle systems. In this relatively large grouping of Department activities there are 26 subject offerings, of which three were offered for the first time this year. Eighty regular graduate students did their thesis work during the year under faculty members of the division. Of these students, about half were doctoral and half were Masters' candidates. In addition, 75 special graduate students elected subjects offered by the division.

Two programs are available for doctoral candidates. The first is the regular Department of Aeronautics and Astronautics doctoral program and the second is the interdepartmental instrumentation doctoral program. The ratio of the number of candidates involved in the two programs is about one of the former for three of the latter.

Among the new subject offerings during the last year in the Instrumentation, Control and Guidance Division was Life Support and Human Performance in Manned Vehicles (16.35J). The subject was offered jointly by Assistant Professor Laurence R. Young of the Department of Aeronautics and Astronautics and Associate Professor Thomas B. Sheridan of the Department of Mechanical Engineering. The subject was labeled 2.181J by the latter Department. This 12-unit graduate A subject was elected by ten students, most of whom were from Course XVI. Each student participated in an individual research project which formed an important part of his study, and his findings were reported at weekly meetings. The lecture material was devoted primarily to life support and secondarily to manual control, human factors, and displays.

Professor Vander Velde offered a new subject, Applied Optimal Control, (16.39T) for the first time in the spring term. This subject centers on computational methods of finding the solution to practical optimal control problems that are too complicated to admit analytic solutions.

PROPULSION AND POWER

The Propulsion and Power Division of Instruction, under the leadership of Professor Taylor, includes the following faculty members: Myron A. Hoffman (absent), Jack L. Kerrebrock, W. Stephen Lewellen, James E. McCune (absent), Gordon C. Oates, Albert Solbes, and Heinrich J. Volk.

Four subjects in Propulsion and Power were offered by the Division this year, two at the undergraduate level dealing with rockets and air-

breathing engines, and two at the graduate level, dealing with nuclear rockets and space power.

The undergraduate subject Rocket Propulsion (16.53) was taught in the spring term by Associate Professor W. Stephen Lewellen with the assistance of David B. Stickler. As in the past, it was well attended for an elective, with some 35 registered students. An additional ten students normally enroll during the summer, so that approximately two-thirds of the undergraduate students take this basic subject in propulsion, most in their junior year.

A smaller fraction of the students elected Aircraft Engines (16.54), taught by Professor Kerrebrock in the fall term. However, the enrollment of this subject has grown over the last three years from a low of about five to the present 15. This growth reflects a general renewal of interest in air-breathing propulsion.

During the fall term, Professor Lewellen discussed the present technology and future prospects for nuclear rocket propulsion in Astronautical Propulsion (16.561). The second term of this sequence, 16.562, was taught by Professor Kerrebrock and Assistant Professor Albert Solbes, and dealt with magnetohydrodynamic space power systems. To complement these Course XVI subjects, Professor Taylor offered three in Course II, one undergraduate and two graduate; they are Gas Turbines and Jet Propulsion (2.62 and 2.621) and Gas Turbines (2.622).

The staff of the Propulsion and Power Division was also deeply involved in instruction in related fields. Associate Professor Gordon C. Oates was responsible for Gasdynamics (16.03) in the fall term, Assistant Professor Heinrich J. Volk taught Advanced Topics in Plasma Kinetic Theory (16.58J) in the spring term, and Professor Kerrebrock participated in Space Systems Engineering (16.73) and Aerospace Engineering (16.82).

THE RESEARCH LABORATORIES

An important characteristic of the Department of Aeronautics and Astronautics is that, on the basis of his own choice, each faculty member may be associated with research work in either academic facilities or laboratories assisted by outside sponsorship. Experience and information gained from research is incorporated first in graduate subjects and later applied to all subjects offered by the Department. The laboratories also make it possible for undergraduate students, at all levels, and for graduate students and postgraduates to work with faculty members on a variety of advanced projects. Students assist with laboratory work, carry out special projects, and use laboratory facilities; they have the advantage of advice from the laboratory staff on undergraduate and graduate theses.

The Department is organized for research into two divisions. The Aerospace Research Division includes the Fluid Dynamics Research Laboratory, the Aerophysics Research Laboratory, the Aeroelastic and Structures Research Laboratory, the Wright Brothers Wind Tunnel Facility, the Space Propulsion Laboratory, the Experimental Astronomy Laboratory, the Man-Vehicle Control Laboratory, the Gas Turbine Laboratory, the Flight Transportation Laboratory and various facilities used for individual research by faculty members. The Instrumentation Division includes the guidance systems section, the guidance component section, and the guidance test facilities sections.

The Aerospace Research Division has equipment for research in all regions of flight, from hovering to interplanetary. The Instrumentation Division pioneers in the development of control and guidance equipment for aircraft, missiles and space vehicles. Inertial guidance receives special attention, and the Instrumentation Laboratory is equipped with advanced facilities for research on all phases of control and guidance.

FLUID DYNAMICS RESEARCH LABORATORY

The Fluid Dynamics Research Laboratory represents a confederation of the interests of Professors Landahl, Trilling, Wachman and Widnall. The laboratory is a somewhat informal group supporting the work of faculty members and graduate students, with few Division of Sponsored Research (DSR) personnel.

At present, there are two main branches of research activity in the laboratory. The first is research in rarified gas dynamics carried on principally by Professors Trilling and Wachman. The program consists of experimental and theoretical investigation into the behavior of rarefied gases at solid surfaces. There is particular emphasis on the nature of the gas-solid collision processes and the mechanism of energy and momentum exchange. In the experimental part of the program, measurements were made of the distribution of molecular velocities in argon gas following collision of an argon beam with heated platinum surfaces. The data are used to determine the mean speed and mean energy of reflected beam molecules as a function of angles of reflection at known incident angles. Values of differential energy accommodation coefficients are also derived from the data. Some emphasis has also been placed on studying gaseous sources for forming molecular beams. A new source which has been developed and used in the investigations gives a nearly monoenergetic beam of molecules.

Theory has been primarily directed at elucidating the mechanism of the collision process. Considerable emphasis has been placed on studying processes by which internal energy of excitation is exchanged with a solid.

A new experimental program has recently been initiated in support of this work.

The second branch of activity is carried out under the direction of Professor Landahl. This is a program of research on unsteady flow that has embraced a wide variety of problems from unsteady and steady boundary layers at low speeds to flow around bodies of revolution at high Mach numbers. Most of the effort during the present year has been devoted to continued exploration of application of the method of parametric differentiation to such diverse problems as the steady and unsteady flow around deforming bodies of revolution to incompressible boundary layer flows.

Also, research on the statistical properties of the fluctuations in a turbulent boundary layer has been continued.

AEROPHYSICS LABORATORY

The Aerophysics Laboratory, under the direction of Professor Finston, has continued a general line of activity similar to that of the past several years.

The Laboratory program revolves around the research interests of the faculty involved. In addition, ideas and supervision are provided by members of the DSR staff. The first group includes, in addition to Professor Finston, Professors Baron, Browand and Associate Professor Eugene E. Covert. Prominent in the second group are Doctors Laurence R. Boedeker, Charles W. Haldeman and Leon Schindel.

Because of earlier success with the development of a magnetic suspension system for wind tunnel models, the Laboratory was asked to provide designs for such systems for use with hypersonic tunnels at Wright-Patterson Air Force Base and at the NASA Langley Research Center. In addition to providing detailed drawings, a model of the new equipment was built together with a subsonic wind tunnel in which its use can be studied as a six-degree-of-freedom system. The staff members of the laboratory felt obliged to do this work because both agencies felt M.I.T. had the only qualified group in the country. As a by-product, the Laboratory now has a new and useful low-speed facility.

In addition to the important magnetic suspension work, other Laboratory "firsts" which can be singled out are:

Kuei-yuan Chien, under Professor Baron's guidance, predicted a precursor radiation in radiating gas flows of a magnitude hitherto unexpected. Experimental confirmation has recently been found.

Professor Browand led wake studies, using the magnetic suspension system. It was found that at small angles of attack ($\sim 0.4^\circ$) the near wake of a cone is very different than at 0° angle of attack. This finding

may materially influence the nation's present wake program.

Recently, Professor Covert showed that the problem of gravity simulation in the dropping of stores from aircraft could be studied using magnetic fields. Adaptation of this finding to wind tunnels at Tullahoma is being studied.

AEROELASTIC AND STRUCTURES RESEARCH LABORATORY

The research activities of the Aeroelastic and Structures Research Laboratory have continued in the pattern of previous years under the leadership of Associate Professor Emmett A. Witmer and with the active participation of Professors Landahl, Mar, Miller, Pian and Widnall, Associate Professor John Dugundji, and Assistant Professor Norman D. Ham, on contracts and grants from the federal government. The laboratory research involves problems of unsteady aerodynamics on re-entry vehicles and helicopters, non-linear vibrations, static and dynamic elastic and elastic-plastic analyses of simple and complex structures, buckling of shells and space-frame radomes, the mechanical behavior of metallic composites, and the development of blast-loads and blast-effects testing techniques.

Success has been achieved in developing a numerical method for predicting the blast-induced airloads experienced on a high-speed blunt body during an axisymmetric encounter with a blast. Numerical predictions compare favorably with experimental measurements. Effort is being devoted to extending the method to treat not only the region in the vicinity of the nose but also the entire vehicle. Separate investigations are being conducted to ascertain the effects on blast-induced airloads of the entropy layer and of ablation products within the shock layer. These efforts have been so successful that the blast airloads problem is regarded as "solved" for most practical purposes.

On the other end of the aerodynamic speed range, experimental and theoretical studies were made during the year to define and predict the fluctuating airloads on the tandem rotors of helicopters in high-speed flight and in transition during maneuvering. Experimental studies of vortex geometry, stall, and reversed flow are being made to clarify the flow behavior and to guide theoretical prediction.

Considerable effort has been devoted to the static and dynamic elastic and elastic-plastic analyses of simple and complex structures. The main approaches employed may be classed as finite-difference, and finite- (or discrete-) element methods. Using the finite-difference approach, a numerical analysis for the large general elastic-plastic deformations of impulsively loaded general shells has been developed and evaluated by applying it to the response of impulsively loaded cylindrical panels which

have been tested experimentally. Excellent theoretical-experimental agreement has been found.

Major efforts have been devoted to developing discrete-element (or finite-element) analyses for the static elastic and elastic-plastic behavior of shells of revolution. This very efficient method has been developed for the elastic analysis of isothermal and heated shells of revolution. An accounting of the effects of the elastic core in core-stiffened shells of revolution has been made by treating the core as a collection of discrete-element rings of revolution with triangular cross sections.

In order to evaluate the accuracy and reliability of numerical methods for predicting maximum-load-type buckling of space frame radomes, a 14-foot diameter space frame radome model with random beam-and-hub geometry was constructed. This model is being subjected to uniform radial loads in an attempt to produce general elastic instability.

Finally, the laboratory assisted the Air Force in developing techniques for conducting blast effects studies on re-entry vehicle structures using rocket-propelled sleds. Included are instrumentation and recording techniques, model launch and recovery schemes, and studies of the production and characteristics of blasts produced by high-energy explosives in Freon-filled expendable shock tubes.

EXPERIMENTAL ASTRONOMY LABORATORY

Under the direction of Professor Markey, the Experimental Astronomy Laboratory continued research in navigation system design and, through additional support, was able to provide thesis topics in the following three new areas:

1. Satellite geodesy
2. VTOL aircraft terminal guidance
3. Aeronautical and hydrographic charting system design

The third activity, sponsored by the United States Navy Oceanographic Office, involves the Departments of Naval Architecture and Marine Engineering, and Naval Science. In addition, Professors Harold E. Edgerton and Charles L. Miller are participating.

In addition to 12 doctoral candidates, the laboratory supports several Master's theses. The National Science Foundation continues to support experimental gravity research, and during fiscal 1969 additional support will be provided by the NASA Electronics Research Center.

SPACE PROPULSION LABORATORY

In addition to Professor Kerrebrock, who directs the activities of the Space Propulsion Laboratory, faculty members who take part in the

laboratory activities are Professors Lewellen, Oates, Solbes, and Volk, and Associate Professors Myron A. Hoffman and James E. McCune (both on leave). Apart from Professors McCune's and Volk's work on plasma physics, the major research efforts have been in magneto hydrodynamic (MHD) power generation, with smaller efforts on problems related to gaseous nuclear rockets and hybrid rockets. This year, seven doctoral candidates and five masters candidates were involved in the research.

As a logical consequence of small scale studies of non-equilibrium plasmas, a large non-equilibrium MHD generator has been constructed and operated. The program is being conducted with Air Force support, using the large plasma facility erected with support from the Center for Space Research. To date, the generator erected has given conclusive evidence of non-equilibrium ionization. This facility has also made possible an experimental study of the boundary layer that occurs on the insulator wall of MHD generators. Measurements carried out in a supersonic argon flow at 2000°K stagnation temperature indicate heat transfer rates several times those expected for a turbulent boundary layer. This result was expected from theoretical work, but is the first experimental evidence for large MHD effects. Basic theoretical studies of wave instabilities in MHD plasmas have been conducted, with the result that a general stability theory for such waves is now available.

Experimental studies of condensing plasmas have been extended to supersonic flow, and the theory has been improved, so as to account for non-isothermal effects on condensation.

This year a basic study of the dynamics of radiatively heated gases was begun. It has been found that when the power density is high, a phenomenon analogous to a chemical detonation wave is possible, if the absorptivity of the gas is strongly dependent on its temperature. An experimental study of this and related phenomena has been initiated. Swirling flow through nozzles is important for many propulsion applications, and is related also to the problem of "vortex bursting" on delta wings. Such flows are being studied both theoretically and experimentally.

A major step forward occurred with the successful formulation of a hypersonic liquid oxidizer-solid fuel combination which can be handled in the laboratory. The mechanism of combustion of this combination is now under study.

MAN-VEHICLE CONTROL LABORATORY

The Man-Vehicle Control Laboratory, under the direction of Professor Li, involves the collaboration of Professor Young and Assistant Professor

Jacob L. Meiry. Last year the personnel of the laboratory included 12 research assistants, one DSR staff member, and one secretary.

The Man-Vehicle Control Laboratory is supported entirely by two grants from NASA headquarters, one in the area of manual control and the other in the field of biotechnology for the investigation of vestibular characteristics. It is anticipated that funds from the United States Navy to support research in display techniques will be available shortly, and that a proposal for research on porpoise propulsion will be supported.

The scope of research work in the Man-Vehicle Control Laboratory during the last year covers the following areas:

1. Biological aspects of human sensors — Characteristics of the vestibular system; advanced eye movement model.
2. Psychological aspects of the human decision center — A mathematical model of the human learning process of a control task; a mathematical model of human adaptive process.
3. Man-vehicle coupling — Display of target (general display study, helicopter display system); correlation of motion cues and control performance of the pilot; optimum state space display.

Future activities now envisioned for the Laboratory will involve — in addition to continuation of the present programs — optimization studies of life-support systems for man in extended voyages, development of display systems for helicopters and deep sea submergence systems, and studies of the swimming characteristics of the porpoise.

GAS TURBINE LABORATORY

The Gas Turbine Laboratory under the direction of Professor Taylor continues to be supported by grants-in-aid from the General Electric Company and the Allison Division of General Motors Corporation. In addition, there are continuing contracts with the David Taylor Model Basin and the Power Branch of the Office of Naval Research. There is also a continuing contract with the National Science Foundation. The Laboratory's Annual Sponsors' Conference in December, 1966, attracted about 20 representatives of sponsoring organizations.

Included among the important research results during the year is the careful experimental work on the condensation of a number of different vapors in an expanding nozzle which showed the inadequacy of present nucleation and drop-growth theory. In addition, a theory which includes the effect of upstream history on turbulence intensity has been successful in showing agreement with measurements of a turbulent boundary layer in strong streamwise pressure gradients.

Included in the research in progress is a study of boundary layers in

favorable pressure gradients. This work is being extended to $M = 2$ and to high Reynolds numbers. It is applicable to the problem of cooled turbine blades in engines for supersonic transports and to the problem of cooling rocket nozzles. The study of the losses due to sound waves emanating from a transonic compressor is also being continued. The work is applicable to problems with current and future aircraft engines.

The study of a compressor blade of unconventional shape has given very promising results. This work has been revived after a time and is being vigorously pursued. It is applicable to all gas turbine compressors, particularly those of aircraft engines. The regenerative compressor is being studied. This type of machine is useful for special purposes where a pump of very low specific speed is required. The addition of swirling flow promises to shorten the mixing length of jets considerably. This subject is being studied for possible application to direct-lift engines and ejectors.

At the request of the United States State Department and under sponsorship of the Agency for International Development (AID) Program, Associate Professor Philip G. Hill of the Department of Mechanical Engineering participated in a summer institute held at Bengal Engineering College, Calcutta, India, during May and June, 1967. Professor Taylor continues to be active on the National Committee for Fluid Mechanics Films supported by the National Science Foundation. At the invitation of Professor Dr. Ing. Rudolf L. Wille and under sponsorship of the Ford Foundation, Professor Taylor spent a week at the Technische Hochschule, Hermann Foettinger Institut. During this trip he also lectured at Cambridge University at the invitation of Institute Professor William R. Hawthorne. Papers by Professors Hawthorne and Taylor presented at the General Motors Research Laboratory Symposium held in 1965 at Warren, Michigan, were published in *Fluid Mechanics of Internal Flow*, edited by Gino Sovran and published by Elsevier Publishing Company in 1967.

FLIGHT TRANSPORTATION LABORATORY

The Flight Transportation Laboratory, under the direction of Professor Miller and with the collaboration of Professor Simpson, is concerned primarily with research in air transportation systems. It consists of a small group of six research assistants working directly with Professors Miller and Simpson.

The laboratory is systems oriented and relies heavily on modern techniques of operational research. It is concerned more with total system management and operation than with details of aircraft design, although

the laboratory has pioneered in the development of computer programs for the parametric evaluation of transport aircraft configurations and maintains an updated library of programs that permit the rapid evaluation of various aircraft configurations and their optimization.

A major effort of the laboratory up to the present time has been the development of capabilities for analyzing and optimizing transportation systems themselves so that their efficient operation can be insured and so that suitable design requirements can be fed back to vehicle manufacturers. The laboratory continued its work during the year on the systems analysis of short-haul air transportation. A published report analyzed the potential of air transportation for satisfying the very large short-haul market and showed dominant factors in vehicle design and configuration, passenger and vehicle management systems, and network flow characteristics to optimize this market. This report received wide distribution and favorable comment. Five new reports published last year extended the scope of the original work and refined the analyses. Work is continuing with particular emphasis on the network structures and passenger flow in an attempt to optimize the system in the presence of a cyclic demand.

WRIGHT BROTHERS WIND TUNNEL FACILITY

The Wright Brothers Wind Tunnel Facility, under the direction of Professor Bicknell, was employed almost entirely for academic purposes during the past year. Two Master's theses covering dynamic wing stalling and dynamic loading of an aircraft tail section were carried out with a tunnel occupancy of about 16 weeks. A Bachelor's thesis studying the forces on a hull was completed and an investigation of sail aerodynamics was carried out using an additional 16 weeks of tunnel occupancy. A freshman seminar investigating the aerodynamics of an airfoil was conducted by Professor Bicknell in the tunnel over a three-week period. Finally, a short series of investigations measuring the drag forces on several skiers in racing crouch positions were carried out.

INSTRUMENTATION LABORATORY

Instrumentation Laboratory efforts expanded somewhat during the 1966-67 academic year with the U.S. Air Force, the U.S. Navy, the U.S. Army, the National Aeronautics and Space Administration (NASA) and the Federal Aviation Agency (FAA) as sponsors. Educational activities remained at a level substantially unchanged from that of previous years, with a total of some 400 individuals in all categories — from freshmen to graduates and special students — associated with the Laboratory in various ways. More than half of the 300 graduate students registered in the Department of Aeronautics and Astronautics took subjects associated

with work in the Laboratory or carried out thesis research, using its facilities and staff to provide equipment and supervision for 31 Master's theses and 13 doctoral theses. In recent years the graduate student population has shifted from 22 per cent military in 1962 to two per cent in 1966-67. This situation will continue in the future while the Laboratory can be expected to attract about the same number of students.

Many faculty members of the Department have served on the Laboratory staff and collaborated in teaching and research projects. Professor C. Stark Draper has been the Laboratory Director, Professor Walter Wrigley has been Educational Director, leading a faculty group that includes Professors Finston, Li, Markey, Meiry, Miller, Mueller, Vander Velde, Whitaker and Young, Associate Professor Walter McKay, and Assistant Professor James E. Potter. Staff members of the laboratory who have taken part as lecturers and given subjects for the Department are Drs. Ramon L. Alonso, Richard H. Battin and Elmer J. Frey. Forrest E. Houston, Ralph R. Ragan and Roger B. Woodbury were Deputy Directors of the Laboratory and Joshua B. Feldman was Executive Officer.

A number of Laboratory projects have reached the stage of operational testing during the past year. Design and engineering for the Apollo Guidance System have been completed. Manufacturing information has been documented. Equipments for NASA are being produced by the AC Electronics Division of General Motors Corporation. One of these units, operating in an unmanned Apollo Command Module, successfully guided the vehicle over a suborbital flight of some 18,000 miles without assistance from outside stations. Guidance systems are ready for the future lunar flights of Apollo as they are scheduled. The Laboratory has substantially completed its hardware obligations to Apollo but is still very much involved in the software research work of generating and verifying computer programs for various Apollo missions. With endeavors of this kind, problems of planetary exploration and requirements of advancing space guidance technology, the Laboratory certainly has very stimulating prospects in astronautical research ahead.

Stabilization, control, navigation and guidance systems in three regions of aeronautics have just reached the stage of operational demonstrations in the 1966-67 academic year: PACE, a high-performance system for navigation of Air Force spacecraft, has completed static tests and is now at Holloman Air Force Base for flight tests; SEAL, a research unit for accurately mapping radio and radar intensities of beams used in flight path control and landings, is now being given ground tests and will be installed for flight service during the next few months; and TAC, a development of systems for control and guidance to be used in vehicles without natural stability, has been designed and demonstrated in a helicopter for the U.S.

Army. The basic technology of this equipment is now being applied to systems for VTOL aircraft. Laboratory interests are not restricted to these areas but also cover systems for supersonic and hypersonic aircraft. Preliminary studies are now in progress with the hope that support for suitable projects may be acquired.

A very important activity of the Laboratory is that of pioneering advances in the technology of high-performance sensors and other components for stabilization, control, navigation and guidance systems of all kinds. Challenging projects sponsored by NASA and the U.S. Air Force are directed toward the engineering development and the generation of manufacturing information for third-generation gyro units and accelerometers. The project is an example of the way in which purposeful application of information to the realization of high-performance vehicle systems for the oceans, for the atmosphere, and for outer space serves as the primary motivation for the Laboratory. Theory and the technology of instrumentation are developed together by faculty, staff members and students who receive academic credit for freely chosen research work under authorized supervision. Material for new subjects is drawn from the practical laboratory experience of conceiving, engineering and reducing equipments to operational practice. Students and staff members with these subjects as components of their education often return to the Laboratory as degree-to-professional-practice interns and make significant contributions to new systems. Interactions of this kind have long been important for the healthy development of both the Department and the Laboratory and a continuation of present practices will surely lead to future progress even greater than that of the past.

For a more detailed report of current Instrumentation Laboratory programs and amplification of significant non-academic aspects of the Laboratory operations, see the section entitled Special Laboratories.

RAYMOND L. BISPLINGHOFF

DEPARTMENT OF CHEMICAL ENGINEERING

A major activity of the Department during the past academic year has been the detailed analysis of its undergraduate and graduate instructional programs, and significant changes in them will be made beginning in the fall term of 1967.

UNDERGRADUATE PROGRAM

The Institute Faculty over the last few years has made a critical evaluation of the core program in physics, chemistry, mathematics and humani-

ties, and major changes are being made in the subjects in these areas. The amount of time in required physics and chemistry subjects has been reduced, the mathematics requirement has been left essentially unchanged and the time in the humanities subjects has been increased. The decrease in the time allotted to physics and chemistry has been assigned to required electives in science subjects and laboratories. In order to match the undergraduate instruction with these changes it will be necessary to revise the subjects, the instructional methods and the curriculum in chemical engineering. An undergraduate chemical engineer at M.I.T. spends approximately two full years on the required science subjects: physics, mathematics and chemistry; the changes that are being made in these have a significant impact on his whole undergraduate experience. Beginning this fall the sophomore subjects in Chemical Engineering will involve an introduction to the use of the computer, taking advantage of the time-sharing computer console now available in the Department. The sophomore year, in addition, will include instruction on staged operations and chemical engineering thermodynamics. This will be followed by two new sequences in fluid mechanics and heat transfer with the choice being left to the student as to whether he is interested mainly in engineering and engineering science or in applied chemistry. The student will complete his program by taking subjects in materials, surface chemistry and physics, polymer chemistry, industrial chemistry, process design, catalysis and applied kinetics, project laboratories and thesis. Project laboratory instruction is now offered at the sophomore, junior and senior levels. These laboratories are modeled after the Chemical Engineering Practice School, and they give the students in small groups the opportunity to do experimental work of a research type that requires planning, laboratory work, close association with the senior members of the faculty, and oral and written reporting. The new undergraduate program will involve the development of several new subjects and the revisions of those previously offered. It will result in effective sequences for those who are planning to continue with graduate study, as well as for those who expect to enter industry after receiving their Bachelor's degrees.

GRADUATE PROGRAM

During the last five years the Department has developed several new subjects for the graduate students in the areas of polymer chemistry, applied chemistry, process dynamics and control, thermodynamics, catalysis and process design. The faculty is now examining the whole group of graduate subjects to determine how they should be revised and re-organized. The Department believes that it should continue to emphasize the Master's degree for those students who plan to do process develop-

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ment, process design, engineering, operation and management and to focus its doctoral program on those interested in research and teaching.

The Chemical Engineering Practice School continues to be a major component of our graduate instructional program and during the last year Practice School Stations have been operated at the Bound Brook, New Jersey, plant of American Cyanamid Company and at the Atomic Energy Commission (AEC) Oak Ridge National Laboratory. These two Stations complement each other well. At Bound Brook, students receive an intensive experience in process engineering, and in process research and development at Oak Ridge. The student enrollment in the Practice School has been increasing until now a high percentage of all our graduate students spend one semester at the Practice School with the time being divided between the two Stations.

STUDENTS

For the period July 1, 1966, to June 30, 1967, the Department awarded 36 Bachelor's degrees, 44 Master's degrees, five Chemical Engineer's degrees and 17 doctoral degrees.

Several of the students were given awards in recognition of their outstanding performance. Peter A. James was selected for a *Chemical Engineering News Award* for outstanding achievement and his picture was featured on the cover of the May 15, 1967, issue of *Chemical Engineering News*. Mr. James was also the recipient of the Hunneman Prize. The Haslam Cup for outstanding professional promise in chemical engineering was awarded to Thomas O. Maier. The American Institute of Chemists Award was presented to Frank A. March, and Robert C. Hewitt was awarded First Prize for his presentation at the Annual New England Conference of Student Chapters of the American Institute of Chemical Engineers.

FACULTY

During the last academic year the Department has had the benefit of the contribution of three distinguished visiting scholars. Dr. J. Theodoor Overbeek of the University of Utrecht, Holland, was a Visiting Professor of Chemical Engineering, and he worked with our faculty and graduate students making unusually valuable contributions in the areas of applied physical chemistry and colloidal chemistry. Dr. Dudley W. Coillet of the University of Sydney, Australia, and Dr. Vijay Shankar of the Birla Institute of Technology, Pilani, India, were Visiting Assistant Professors of Chemical Engineering.

Two Assistant Professors were appointed to the Department staff during the past year: Dr. Charles W. Selvidge and Dr. Preetinder Virk.

Professor Thomas K. Sherwood was on sabbatical leave and spent the fall term with the Chemical Engineering Department at the University of California, Berkeley.

Adel F. Sarofim, Kenneth A. Smith, and Wolf R. Vieth were promoted to Assistant Professors.

Professor Raymond F. Baddour was the recipient of an NSF Senior Postdoctoral Fellowship for the coming academic year and he plans to spend his sabbatical doing medical engineering research.

Professor Thomas B. Drew retires at the end of the present academic year and we are pleased that he will continue on a part-time basis as Emeritus Professor and Lecturer.

Assistant Professor Shiou-Shan Chen resigned to become Assistant Professor at Tufts University. Assistant Professor C. Michael Mohr resigned to take an industrial position with the Arthur D. Little Company and Assistant Professor Jon R. Valbert resigned to join the Scientific Design Company. The Department appreciates the contributions these colleagues have made as members of our faculty.

STAFF HONORS

Visiting Professor J. Theodoor Overbeek received an Honorary Degree of Doctor of Science from Clarkson College.

Assistant Professor Lawrence B. Evans was selected for the United Engineering and Constructors Preceptorship for 1967-68.

RESEARCH

HEAT, MASS AND MOMENTUM TRANSFER

Professors Edward W. Merrill and Harold S. Mickley, Associate Professor Kenneth A. Smith, and Assistant Professor Preetinder Virk, in collaboration with Professor Erik L. Mollo-Christensen of the Department of Meteorology and with the support of the Office of Naval Research, have been studying the extraordinary fluid mechanical effects which result from the addition of small quantities of very high molecular weight polymers to quite ordinary liquids. Of prime interest is the fact that turbulent pipeline flows of these solutions exhibit considerably less drag than do the solvents alone.

In this connection, it has been shown that polymer addition causes no change in the usual defect law for turbulent pipeline flow and that the value of Karman's constant in the law of the wall is also unchanged. Moreover, an onset hypothesis has been devised and this adequately correlates the occurrence of drag reduction. The asymptotic behavior under strongly drag-reducing conditions has been ascertained. Further-

more, it has been shown that drag reduction is associated with phenomena which occur in a region very close to the wall.

Other aspects of this investigation have shown that the reduction in the heat transfer coefficient is directly proportional to the reduction in the friction factor, and that the frequency of eddy shedding from a cylinder is profoundly affected by these additives. At present, light scattering is being employed to determine the elongation and orientation of drag-reducing macromolecules in the presence of an ambient shear field.

During the last year, Professor P. L. Thibaut Brian and Assistant Professor Samuel W. Bodman III have continued the study of heat transfer accompanied by a simultaneous reversible chemical reaction. In particular, attention has been focused on experimental measurements of the thermal conductivity of decomposing nitrogen dioxide gas at temperatures of 700° to 900°K and pressures up to 30 atmospheres. In this range of conditions, the chemical kinetics of the decomposition reaction limit the rate of energy transport. In addition to their intrinsic value, these data will be most useful in the interpretation of turbulent heat transfer results which are already available for the same chemical system.

When the walls of a container of liquid are heated, a natural convection circulation results. This circulation pattern can be divided into three regions: a boundary layer region near the wall in which the fluid heated by the wall rises to the surface; a core region where relatively cold fluid displaced by the warm fluid at the surface flows downwards in the vessel; and a mixing region at the top where the boundary layer fluid is deflected by the surface and mixes in some complex manner before entering the core region. The boundary layer and core region have been studied in M.I.T. thesis programs supervised by Professor Robert C. Reid and Assistant Professor Lawrence B. Evans. The mixing and surface regions are of primary interest and equipment has been constructed which is essentially a large rectangular cavity with heated side walls and adiabatic bottom and end walls. A two-dimensional flow pattern results. Temperature fields will be measured by thermocouples and velocity fields determined by streak photography. Simultaneously a theoretical study of the hydrodynamic flow and heat transfer is being made.

In many instances, heat transfer surfaces are degraded by the deposition of a solid deposit. One case of particular interest is the deposition of frost of water on the cold walls of a gas cooler. Professors Reid and Brian are investigating the mechanism of frosting and determining the density and thermal conductivity of the frosts. The data for frosts deposited from a humid nitrogen stream onto a cold plate, initially at 77°K, show an increase in frost thickness and density with time — and the heat flux decreases initially with frosting then levels off and becomes essen-

tially constant with time — even though frost continues to accumulate. A model has been formulated to describe this constant heat flux phenomena by noting that the densification leads to an increase in the thermal conductivity and thus to a compensation of the increased frost thickness. The densification results primarily from the internal diffusion of water in the frost. The rate of internal diffusion within the frost layer is a strong function of frost temperature. The partial pressure gradient that forces the water vapor diffusion can be thought of as a product of a temperature gradient and the slope of the curve of water vapor pressure versus temperature. The latter is an exponential function. Thus small changes in frost temperature result in large changes in internal diffusion; the net result is a high-gain feedback process whereby as more frost deposits and tends to raise the frost temperature, internal diffusion increases to raise the frost conductivity and negates the temperature rise. The model predicts that soon after frosting begins, the heat flux and surface temperature become nearly constant; this was confirmed experimentally. The model also predicts the variation in frost conductance for various independent parameters such as gas temperature and humidity.

Professors J. Edward Vivian and Brian are continuing their research on simultaneous gas absorption and chemical reaction. One study is concerned with the effect of a diffusional resistance upon the product distribution in sequential gas-liquid reactions. Many important chemical reactions involve the absorption of a gas into the liquid phase where the chemical reaction takes place. Often, several competing chemical reactions occur. Examples are the liquid phase chlorination of hydrocarbon and liquid phase oxidation of organic compounds. In such situations, if the kinetic rate of the reaction is quite rapid relative to diffusion rates within the liquid phase boundary layer, steep concentration gradients are required for the reacting species to diffuse together, and the chemical reaction takes place in a zone in which the reactants are severely depleted. But this is where the products of the chemical reaction are generated, and if they in turn react further with the dissolving gas, these diffusional effects result in over-reaction. The present study is directed toward a generalization of the theory of mass transfer effects upon selectivity and toward an experimental test of this theory.

Interfacial turbulence, which may be induced by the gas absorption process and which was demonstrated by a tracer technique in studies of the carbon dioxide-monoethanolamine system and the triethylamine system, continues to be an important research problem. Visual observation of this turbulence has recently been reported. A second study is currently under way to study the quantitative aspects of the phenomenon with a view to developing techniques for predicting these effects.

Dr. Roy N. Levitch, working under the supervision of Professors Mickley and Smith, has completed his investigation of the transpired turbulent boundary layer. His study involved a determination of the way in which the boundary layer responds to a step change in the transpiration rate. This response was found to be readily correlated by the ratio of the shear stress prevailing at the wall to that prevailing in the overlap region. More importantly, the correlation is of such a general nature that it may be applicable to other non-equilibrium situations such as those which occur in the presence of pressure gradients. In particular, the adverse pressure gradient data of Clauser have been found to satisfy this correlation and other data are now being examined.

Under the direction of Professors Thomas K. Sherwood and Smith, Dr. Patrick E. Fowles completed his study of turbulent structure in the immediate vicinity of a solid boundary. This problem is of major significance in the transport of heat or mass to a bounding surface, but it has heretofore posed extreme experimental difficulties. In this investigation, micron-sized tracer particles were tracked by means of stroboscopic light and dark background photography of the scattered component. The results showed that in the vicinity of a wall, the eddy viscosity is an order of magnitude higher than had been thought; and that the usual assumptions concerning the turbulent Prandtl number are, therefore, incorrect.

The stagnation pressures in dilute polymer solutions are being investigated by Professor Virk. It has been found that impact tubes placed in dilute polymer solution register a stagnation pressure significantly less than that corresponding to the kinetic energy at the flow velocity. Preliminary results indicate that the discrepancy depends directly on the strain rate at the stagnation point; the present aim is to relate this to polymeric parameters.

Professor Vivian and Assistant Professor Shiou-Shan Chen are supervising a program on the skin-friction and heat transfer characteristics of an axisymmetrical boundary layer by considering a power-law non-Newtonian fluid flowing along a cylinder. The main purpose is to investigate the influence of the transverse curvature on skin friction and heat transfer. The continuity, momentum and energy boundary layer equations have been transformed into a form more feasible to mathematical analysis. The resulting nonlinear partial differential equations are then solved by a method of series expansion. The zero-order equation is identical to the Blasius equation for a plate, the higher order equations represent the influence of the transverse curvature, which have been found significant for many cases of industrial importance. Numerical results are obtained with the M.I.T. IBM 360 computer.

Diffusion with concentration-dependent diffusivities and moving boun-

daries is being investigated with a numerical method involving variable-space network. The analysis developed by Professor Chen is useful for the understanding of processes such as the extraction of solvent from elastomer particles in which the diffusivity drops drastically as the elastomer concentration increases. The results indicate that steam distillation used in many solution polymerization processes becomes inefficient after the solvent concentration drops down to less than five per cent.

The surface migration of hydrogen chemisorbed on platinum was measured by Dr. Karl Sladek in a program supervised by Professors Raymond F. Baddour and Edwin R. Gilliland. The rate of hydrogen transfer through a porous platinum plug was measured and found to be significantly greater than would be predicted by the Knudsen relationship. These results indicate that even with the strong chemisorbed bond between the hydrogen and the platinum, there is still considerable mobility of hydrogen along the surface. The diffusivities for adsorbed flow as calculated from a two-dimensional Fick's law vary widely from about 10^{-3} , for weakly adsorbed molecules, to as low as 10^{-12} cm.²/sec. for strongly adsorbed systems. The strength and type of bonding of the adsorbed molecule to the surface appear to be the important factors in determining the magnitude of the diffusivity. Dr. Sladek developed a model for correlating the data of the systems with widely varying diffusivities that involves two main parameters: the heat of adsorption and the type of adsorption bond.

In most of the surface diffusion work involving the use of porous solids, a correction is made for the predicted Knudsen flow and this is frequently obtained by using helium as a test gas. The effect of pressure and temperature on the flow of helium through some of the porous medium gives results that are not in agreement with the Knudsen relationship. For this reason an investigation is now under way attempting to determine whether surface flow of adsorbed helium is a significant factor or whether the deviations observed are due to other phenomena.

CATALYSIS, APPLIED KINETICS AND REACTOR TECHNOLOGY

Professor Baddour and Assistant Professor Michael Modell are continuing their study of the fundamental surface phenomena that occur in catalysis by metals. The technique of combining kinetic studies with infrared spectra of adsorbed species is providing valuable insight into reaction mechanisms and changes occurring during break-in periods. In a study just completed, it was shown that different mechanisms, which result in the same over-all rate expression, can be distinguished by comparing experimental and postulated forms of the rate expressed in terms of surface

concentrations. Combined kinetic and infrared measurements provide the data required for the comparison. This technique is being used to study a given reaction on a series of metal catalysts in an attempt to define those parameters of the catalyst that influence the mechanism and rate of the reaction. The break-in period, during which the activity of a freshly prepared catalyst varies with time, has been investigated for carbon monoxide oxidation on a palladium catalyst. The activation energy decreased from 45 to 30 kcal/mole, while shifts in the infrared spectrum were observed corresponding to an increase in concentration of weakly bound CO at the expense of tightly bound species. Such changes are indicative of a decrease in the heat of adsorption of CO, which in turn would result in the observed decrease in the apparent activation energy. The changes observed during break-in are probably caused by a structural rearrangement of the exposed crystal faces of the palladium catalyst.

In theory, infrared spectroscopy can yield information as to the structure and concentration of all species adsorbed on a catalyst. In practice, however, there are experimental limitations that have yet to be overcome. In metal catalysis, the most serious limitation is the inability to observe absorption bands for all the surface species. Infrared spectra of adsorbed species are measured conventionally by transmission spectroscopy of finely dispersed metal particles supported on catalytically inert silica or alumina particles. Because the supports are opaque to broad regions of the infrared, the adsorbed species heretofore observed have been limited to those absorbing in the 2 to 10 μ region. In an attempt to extend the utility of the infrared method, Professors Baddour and Modell are investigating the reflection spectra using unsupported metal films. Preliminary results indicate that the weak signals inherent in reflection spectroscopy can be satisfactorily measured by multiplexscan interferometer spectroscopy. This technique would extend the applicability of surface spectroscopy to observation of metal-carbon and metal-oxygen bonds, which are thought to absorb in the 15 to 25 μ region.

Professors Baddour and Modell are continuing the study of the effect of visible and ultraviolet light on gas-phase, metal-catalyzed reactions. In earlier studies, it was demonstrated that light has an appreciable effect on the rate of carbon monoxide oxidation over a palladium catalyst. The effect was attributed to electronic excitation of a surface-adsorbate bond which, in turn, results in a change in the rate of desorption of surface species. The objectives of a study recently initiated are to determine the extent to which other systems can be similarly affected, and to investigate more thoroughly the mechanism of the photocatalysis. Monochromatic light of variable frequency will be employed to determine

which frequencies are photoactive. The study should provide information on the electronic structure of the bond between the adsorbed molecules and the surface atoms which can be used to interpret and predict the behavior of metal catalysts.

Professor Reid has been studying the reaction of hydrogen atoms with solid films of olefins at low temperatures. The reactions involved are free radical in nature, but there is little known about the actual physical and chemical mechanistic steps. There are several theories concerning the actual site of hydrogenation reaction. It has been suggested that all reaction occurs at the gas-solid surface, and that fresh reactant is supplied to the surface by olefin diffusion within the solid film. It would appear more probable that the hydrogen atoms can readily diffuse within the film and that most reaction occurs in "active" zones of higher temperature. These active zones result from hydrogen atom recombination. To determine diffusion rates within such films, an apparatus has been constructed whereby a thin layer of MoO_3 (yellow) is deposited by vacuum evaporation and subsequently covered with various thicknesses of olefin and alkane films at 77°K. Hydrogen atoms that penetrate the hydrocarbon film will react with the MoO_3 and reduce it to a lower oxide which is blue in color. The color change of the MoO_3 will be monitored by reflectance spectroscopy. By using different types and thicknesses of films, the diffusion rate of hydrogen atoms will be estimated.

In addition to the diffusion studies, the rate of reaction of hydrogen atoms with olefins at temperatures in the range of 65 to 90°K is being investigated. The olefins studied are propylene, 1-butene, and 1-pentene. Film thicknesses will be varied and different olefine-alkane mixtures used. Hydrogen atoms are produced in a microwave discharge and, depending on the experiment, allowed either to flow or diffuse into the cryogenic reactor cavity where a thin film of olefin has previously been deposited. Hydrogen atom concentrations in the reactor are monitored by electron spin resonance methods. After reaction, the residual hydrogen is pumped out mechanically and the reactor warmed to room temperature. The products of reaction are cryopumped to a sample tube and later analyzed on a gas chromatograph.

Professor Baddour and Dr. Peter H. Dundas have continued their work on promoting chemical reactions in low-temperature electric discharges and on elucidation of the electrical, electronic, and geometric factors which control these reactions. A program has been completed which had as its primary objective the determination of the importance of the frequency of the power source in the kilohertz-to-megahertz range on the performance of a plasma reaction. These results indicate, con-

trary to some published reports on the subject, in the pressure range of 10 to 100 torr that for the oxidation of hydrogen chloride in the gas phase, the frequency of the power source does not by itself appear to be an important design parameter.

Professor Baddour and Assistant Professor Max C. Deibert have investigated the influence of the interphase electronic interaction between the catalyst and the support. The catalyst under investigation is nickel supported on germanium. In this system the magnitude of the Volta potential difference and specific interphase charge transfer can be predicted using the Schottky analysis of metal-semiconductor contact. The variations in these parameters, brought about by changes in the type and concentration of impurities in the germanium, have been shown to influence the kinetics of formic acid decomposition on the supported nickel. Additional measurements are being made to determine if the kinetics of cyclopropane hydrogenolysis on the nickel catalyst is similarly influenced by support-catalyst electronic interaction effects. Measurements of total surface area and specific nickel surface area are being utilized to provide a more complete characterization of the nickel-germanium catalyst system. The kinetics of cyclopropane hydrogenation on pure nickel catalysts and specifically their time dependence are also under investigation.

A series of studies under the supervision of Professor Charles N. Satterfield has been directed at developing methods of predicting the effective diffusivity of catalysts from a knowledge of the pore size distribution and other information. Most studies reported in the literature have been obtained on porous masses prepared by pressing a powder into a die and the results have been analyzed assuming that the porous structure is uniform. However, recent studies on pellets three-eighths of an inch or one inch in diameter pressed from a hard chromia-alumina catalyst powder revealed that pellet heterogeneity, stemming largely from die-wall friction, can cause the local effective gas diffusivity to vary with position by a factor of as much as two-and-one-half. More recent studies with Boehmite (a spray dried alumina) showed that the variation of effective diffusivities of pellets pressed from this material likewise varied by a factor of as much as three or four with axial distance through the compact, and the results have been interpreted in terms of the density distribution patterns. Commercial pelleted catalysts, on the other hand, appear to be much more uniform, probably because of the use of lubricants in the catalyst mix and the fact that the pellets are usually subjected to a calcination treatment after pressing in which the gas that is evolved helps to modify anisotropies such as skin effects. A careful study of one widely used commercial pelleted catalyst, a nickel-based

steam-hydrocarbon reforming catalyst, showed that this was indeed the case. The diffusivity was sensibly invariant with direction of diffusion and with position and there was no significant skin effect on either the plane or curved surfaces. However, this conclusion is probably not valid for extruded or spherical commercial catalysts.

As one part of the development of predictive methods, the diffusivity characteristics of 17 different commercially manufactured pelleted catalysts and catalyst supports were measured by steady-state gaseous counterdiffusion methods. The results were analyzed according to a model which is most easily visualized by saying that the pores of various sizes are assumed to be in parallel and a tortuosity factor is invoked to account for deficiencies, in the assumption that all the pores are oriented in the direction of diffusion and that they are of uniform radius. Except for two materials that apparently had been calcined at very high temperatures, tortuosity factors all fell between three and seven. Studies with commercial methanol synthesis catalysts and several other commercial catalysts over the pressure range of 1 to 65 atmospheres and at ambient temperature showed little effect of pressure on the tortuosity factor for a given catalyst in the above model, even though the predominant diffusion mode shifts markedly from Knudsen to transition to bulk diffusion over this range. This lends confidence that from one experimental measurement at convenient conditions one can predict diffusion fluxes under far different conditions, even when dealing with the wide pore size distributions typical of most industrial catalysts.

Methods of predicting diffusion at elevated pressures in the presence of simultaneous forced flow were also developed from steady-state simultaneous diffusion and forced flow measurements, again using the binary system of nitrogen and helium at ambient temperature. Surface diffusion of nitrogen was found to make an increasing contribution to the total nitrogen flux with increase in pressure and at the highest pressure level it was of comparable magnitude to the volume diffusion flux. The surface diffusion flux was linearly related to the total pressure; and, applying values for the Henry's law constant previously reported in the literature, the effective surface diffusion coefficients were found to be in the range of 0.3 to 0.9×10^{-3} cm²/sec. The results of simultaneous diffusion and forced flow could be correlated well in terms of the "dusty gas model" of Evans, Watson, and Mason.

A study of the surface diffusion of chemisorbed hydrogen on nickel was made using steady-state flux measurements through a porous nickel disc. At 37°C. the surface diffusion coefficient for the system was found to be about 10^{-8} cm²/sec. At 62°C the permeability changed by about seven per cent per day. The surface diffusion flux was a substantial portion

of the total flux only at low pressure (e.g., 40 mm Hg). The value for the surface diffusion coefficient agrees within experimental error with the results of Gomer, Wortman and Lundy (1957), obtained by field emission microscopy, but is much less than that predicted by the indirect thermodynamic calculations of Sweett and Rideal (1960). With an activation energy of about 7 kcal/g. mole as reported by Gomer, and a surface diffusion coefficient of this magnitude, surface diffusion can make no significant contribution to the intraparticle flux in catalyst particles of typical dimensions of 1/10 to 1 centimeter, except when the temperature is high and the vapor pressure of the diffusion substance is very low — conditions seldom encountered in industrial catalysis. In multifunctional-catalysis, however, where path lengths may be of the order of 10-100 Å, the gas-phase concentration of intermediates may, indeed, be extremely low and surface transport can predominate over gas-phase diffusion.

The conversion of organo-sulfur compounds to hydrogen sulfide by hydrogenation is an increasingly important process in petroleum refining. The most common catalyst is so-called cobalt molybdate supported on alumina which is sulfided before use. Thiophene is a good model compound with which to study the characteristics of this reaction. The intrinsic kinetics of the hydrogenolysis of thiophene on industrial cobalt molybdate catalysts were studied in a differential reactor with recirculation at a total pressure of about one atmosphere and temperatures of 235-265°C. Retardation of the reaction by both thiophene and hydrogen sulfide was found to be significant and the rate of thiophene disappearance was correlated by a Langmuir-Hinshelwood type of kinetic equation. Butene is formed as an intermediate and its hydrogenation was found to be inhibited both by itself and by hydrogen sulfide. The forms of the kinetic expression obtained imply that the butene is not hydrogenated at the original desulfurization site.

The mass transfer characteristics of trickle bed reactors were studied in two doctoral thesis programs under the joint supervision of Professors Sherwood and Satterfield, using the hydrogenation of alpha-methyl styrene on a supported palladium catalyst as the model reaction. Studies of diffusion limitations within catalyst pellets were made in a well-stirred batch reactor at temperatures between 70 and 100°C. Studies on powdered catalysts were used to obtain intrinsic kinetic data. The intrinsic reaction rate was found to be first-order with respect to both the concentration of hydrogen and that of alpha-methyl styrene and showed an activation energy of 7.6 kcal/g. mole. With the pellets, the rate of reaction was limited by the diffusion of hydrogen and the experimental results could be brought into agreement with theory by applying an average value of the tortuosity factor of 3.9. The results show that the

theoretical methods developed for predicting catalyst effectiveness factor and used in the past primarily for gas-phase reaction can also be applied with confidence to liquid-filled catalyst pores using a reasonable value of the tortuosity factor for the catalyst.

Possible mass transfer limitations through the film of liquid outside the catalyst particles in a trickle bed reactor were studied with a model system consisting of a vertical row of spherical catalysts. The variation of the hold-up as a function of liquid flow rate and physical properties of the system was shown to agree well with a theoretical model based on the assumption that the flow around the spheres is laminar. For this particular system the catalyst effectiveness factor was found to be about 5.7×10^{-3} which indicates that only the outer skin of the pellets contributed significantly to the reaction. The tortuosity factor for the catalyst was about 7.5, a relatively high value. The mass transfer through the liquid film was analyzed in terms of several models. At least for this particular system, the mass transfer coefficient was only moderately greater than that which would be predicted by assuming the liquid film over the pellets to be stagnant. The rates of the reaction normally encountered in industrial hydrodesulfurization trickle bed reactors are substantially lower than the rates observed here, so that mass transfer limitations in the liquid film around the catalyst pellets are, in that case, negligible.

A series of studies on zeolites (molecular sieves) is being carried out under the supervision of Professor Satterfield, attention being directed both to the sorption and diffusion characteristics of zeolites as well as their catalytic properties. In the first case, studies are being directed to sorption and diffusion of vapors in mordenite, in conjunction with application of zeolites to environmental control systems in space capsules and similar isolated living units. The diffusion rates do not follow Fick's law closely and an immediate objective is to develop a more meaningful way of being able to describe results of diffusion studies. The catalytic studies, jointly supervised with Associate Professor Wolf R. Vieth, are focusing on the liquid-phase alkylation of benzene with propylene as the model reaction, with particular attention to the role of liquid-phase diffusion within small pores of the zeolite on the over-all kinetics.

Current developments in the understanding of enzyme activity, the separation and purification of enzymes, and preparation of "insolubilized enzymes" have given impetus to the study of these extremely efficient biopolymeric catalysts for chemical reactions. Recent studies under the supervision of Professor Vieth have examined a classic reaction, sucrose hydrolysis by invertase, for possible diffusional limitations, by carrying out the hydrolysis in a controlled-shear environment. Increases in hydro-

ysis rates as large as 50 per cent, relative to the unstirred reaction, have thus far been achieved by increasing shear rates. New models of the biocatalytic reaction mechanism are being developed concurrently.

A companion study is also under way, attempting to elucidate some aspects of the molecular constitution and geometry of the active site of the enzyme invertase which catalyzes the hydrolysis of sucrose. Salts in the lyotropic series were added to enzyme/substrate solutions and their effects on reaction rates determined. Polarimetric studies of substrate-free solutions of enzyme were carried out concurrently, seeking to sort out possible ion-enzyme interactions, again employing the lyotropic series. The data are being analyzed, in combination, in an attempt to elucidate the apparent size, shape and molecular constitution of the active site.

Techniques have been developed to investigate simultaneous changes in the activity and chemical composition of a catalyst surface. These methods have been used by Professor Baddour and Assistant Professor Charles W. Selvidge to study the interaction of clean germanium surfaces with ethanol. The results have demonstrated the failure of semiconductor theory to predict the nature of catalytic processes occurring at a germanium surface. A qualitative model based upon the surface electronic structure of germanium has been developed to interpret the experimental results. Research is currently under way to test this model on other reactant systems and to develop the model more quantitatively.

One of the major problems in chemical process design is scaling up the size of catalytic chemical reactors, especially when fluid beds or fixed beds with liquids are involved. Frequently the large plant reactors give poorer performance than the laboratory units and this is believed to be due to less effective contact between the fluid and solid as the size of the unit is increased. Research on the factors involved in contacting and the development of suitable design correlations have been limited by the availability of test systems with stable solid catalysts. Doctoral programs both on fluid-bed and fixed-bed reactors are in progress under the supervision of Professor Gilliland. Lee P. McMaster is investigating a liquid-phase heterogeneous catalytic reactor to determine the factors that contribute to deviations from the ideal models. The use of hydrogen ion exchange catalysis is being investigated in order to obtain a more reproducible catalytic system. A small surface layer of large plastic beads is converted into hydrogen ion exchange material and used for esterification reactions. Tracer techniques are used to determine the residence time function simultaneously with the catalytic reaction and the results are used to evaluate various models. Christian W. Knudsen is investigating the contacting in a small fluid bed with the first objective

being the development of a system that is reproducible with time. The particular test reaction under investigation is the hydrogenation of ethylene and, after trying a number of different catalysts, it is believed that copper deposited on microspheres gives reactivity stability satisfactory for evaluating the fluid bed performance. The evaluation is being made by performing both tracer and reaction studies.

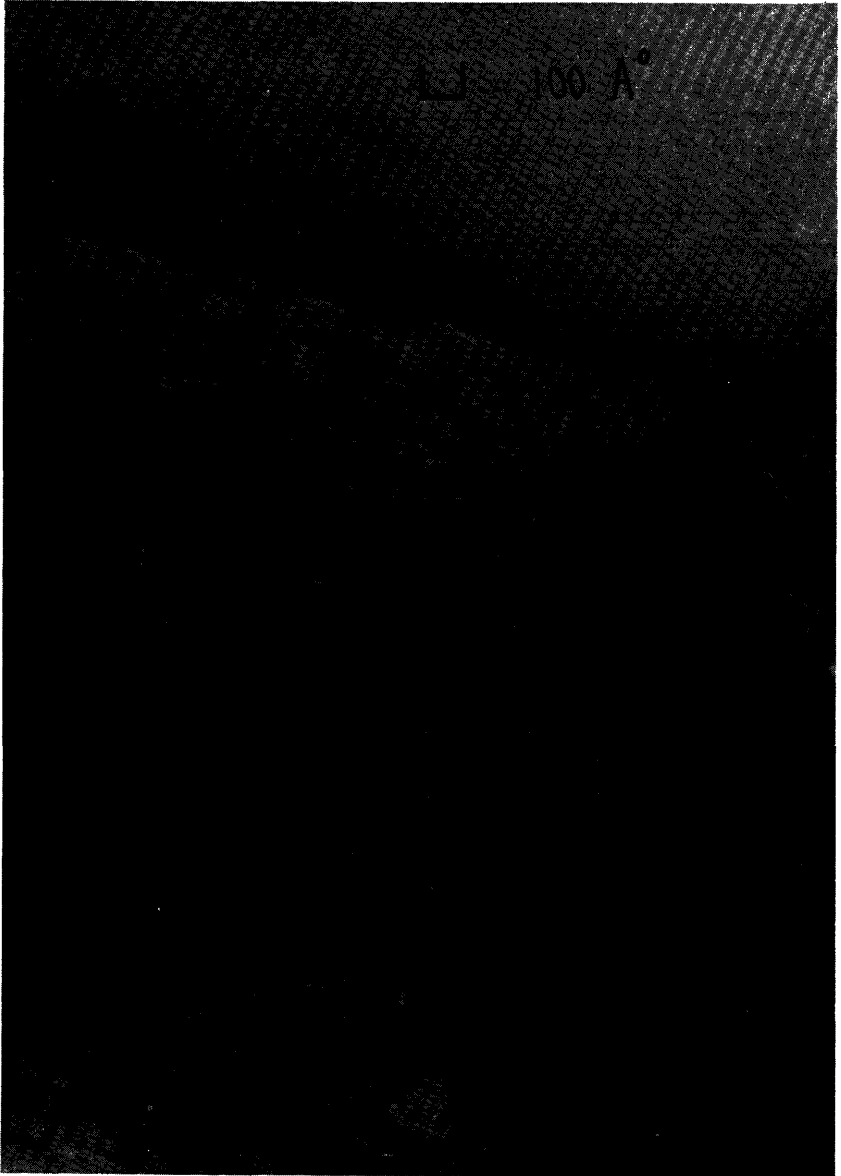
POLYMER CHEMISTRY AND PHYSICS

The investigation of the unusual temporary effects of intense radiation fields on the mechanical properties of polymers is continuing under the supervision of Associate Professor Allan S. Hoffman and Professor Gilliland. The study of the accelerated creep rate of polystyrene samples in a 3-Mev electron beam resulted in the hypothesis of a mechanism based on temporary accumulation of gases within the polymer during irradiation. Extension of the work to polymethyl methacrylate (PMMA) has led to a revised mechanism, wherein the act of gas generation supplies the necessary energy and local free volume to a particular chain segment. Then, when the radiation is terminated these gases diffuse to local voids or fissures where they are ineffective in accelerating creep further. This mechanism is being tested with polycarbonate polymer, by prepressuring the specimens to control the volume of and gas content of the void regions. Polycarbonate also exhibits an intriguing four- to five-minute induction period during irradiation under stress, before the onset of accelerated creep. This phenomenon is as yet unexplained, but should be elucidated by the effect of variations in free volume on the length of the induction period.

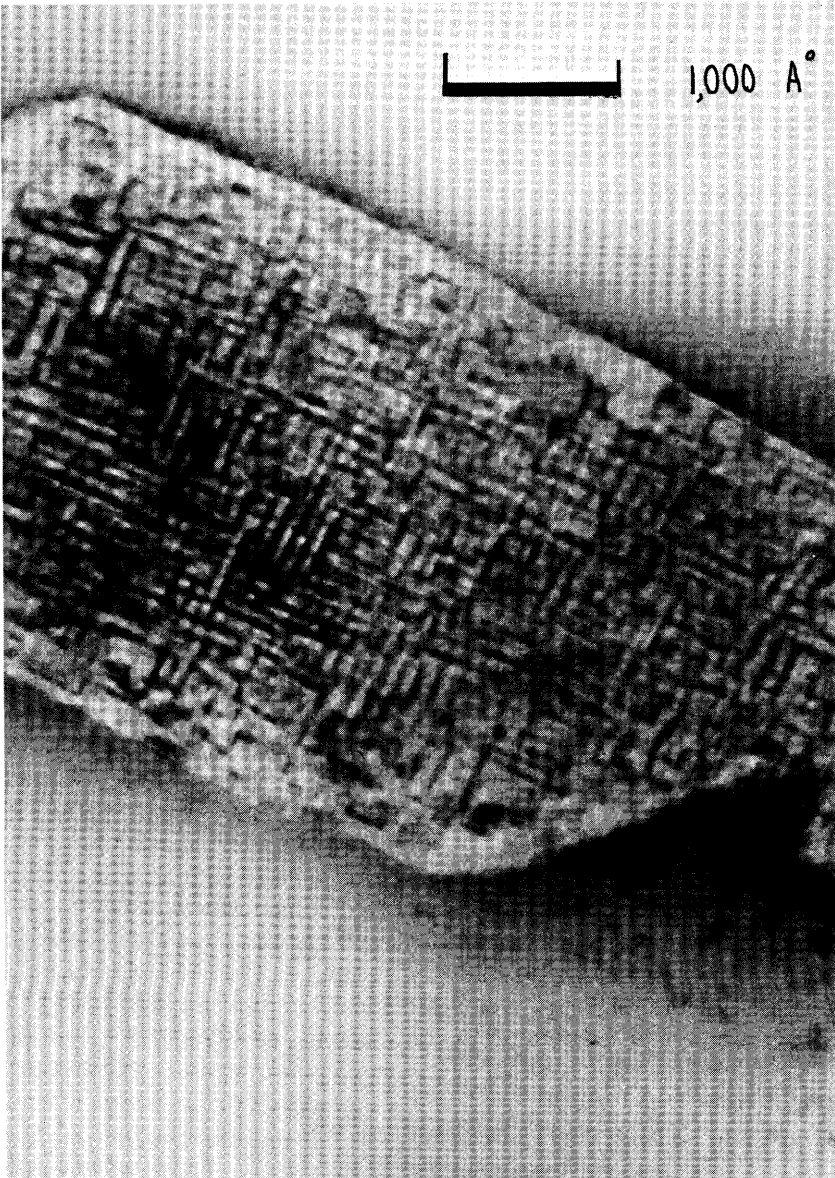
During the last year, several research programs under the supervision of Professor Vieth have been conducted in the areas of membrane transport and polymer morphology, including measurement of gas and liquid permeabilities of melt-quenched, solvent-annealed and dry-annealed films of polypropylene and their correlation with polymer microstructural properties (e.g., spherulite texture, amorphous phase density, amorphous glass transition temperature [T_g]); and development and characterization of highly specific, permeability-enhancing morphological alterations of polyethylene terephthalate, achieved by varying its thermomechanical history near the glass temperature. In addition to permeation measurements, polymer film studies were augmented by differential thermal analysis, high pressure sorption and electron microscopic examination.

These studies have added to an understanding of polymer microstructure in relation to its utilization in prediction and manipulation of membrane transport properties. In this regard, attention is called to several observations:

MICROCRYSTALLINE NETWORK MORPHOLOGY WITHIN
SPHERULITES OF THE ORIENTED POLYMERIC GLASS,
POLY (ETHYLENE TEREPHTHALATE)



GRID PATTERN OF LINEAR NETWORK ELEMENTS



1. Intraspherulitic paracrystallinity in polypropylene apparently controls the sorption and diffusion properties, as revealed by exceedingly careful gas-sorption measurements, and
2. The morphological alteration of polyethylene terephthalate achieved by stretching the polymer at low strain rates near T_g results in the development of an intraspherulitic network of microcrystalline linear elements approximately 30 Å wide and several hundred Å long which branch in a nearly orthogonal fashion.

These structures are prominent in the fringes of bushy spherulites which align themselves preferentially along slip planes, visible in the optical microscope. These structures are evidently the locus of the low activation energy pathways which result in permeability enhancements as high as 15-fold (for oxygen) relative to the unoriented polymer.

COMPUTER AND PROCESS DESIGN

Visiting Assistant Professor Dudley W. Coillet investigated the use of stochastic-decision making for optimization and dynamic simulation and applied the latter to realistic process designs for investigating the probable operating conditions and control layout. Computer programs were developed for the optimization of yields of chemical reactors in series in a number of configurations using a multivariate hill-climbing technique with appropriate tests for local and global maxima. Optimum temperature sequencing was established by dynamic programming.

Professor Evans and Associate Professor Leonard A. Gould of the Department of Electrical Engineering have investigated the use of optimal control theory for the design of a control system for a hypothetical fluid catalytic cracking process. Dynamic mathematical models of the process were developed by making material and energy balances around the reactor and regenerator. Semiempirical models of the reaction kinetics were derived from data available in the literature. Studies were made to determine the optimal control policy that restored the process from a perturbed state to its original steady state in a manner to achieve maximum profitability. The optimal control problem was formulated with air and catalyst rate as the control variables and was solved numerically by using Pontryagin's maximum principle and the method of steepest ascent of the Hamiltonian. The optimal control studies were used with the new approach to control system design to develop a feedback control for the process in which regenerator temperature is controlled by air rate and oxygen level is controlled by catalyst circulation rate. The new control system is different from that typically used in refinery operation in which reactor temperature is controlled by catalyst rate and oxygen level is controlled by air rate. The performance of the newly developed control scheme was

demonstrated by dynamic simulation to be better than the conventional scheme for controlling the hypothetical fluid cracking process.

Computer-aided chemical process design is being studied by Professors Evans and Gould to determine how the time-shared computer can be exploited most effectively for chemical process design. The work is focused on developing and experimenting with a prototype computing system which allows rapid and natural communication between the engineer and the computer in real time on an almost instantaneous basis. A systematic attack is being made upon the problems of developing such a computing system. The problems being investigated include representing an arbitrary chemical process within the computer in a convenient, flexible manner and carrying out the solution of the large systems of nonlinear equations which must be handled to complete heat and material balances for an interconnected process with recycle streams. An important goal of the research is to use the prototype system to ascertain the benefits that might be gained in chemical process design from a powerful man-machine combination.

The American Institute of Chemical Engineers recently analyzed the methods for the estimation of the physical and thermodynamic properties of gases and liquids and selected a program so that a computer could carry out the tedious route selection and arithmetical operations involved in such calculations. One serious drawback of this program is its inability to handle adequately property estimation methods of the so-called structural increment type. Many of the best (or only) methods to estimate critical properties, heat capacities, liquid viscosity, and other properties depend upon performing relatively simple arithmetical operations, such as the addition of contributions for each bond, or functional group, or combination of functional groups. The present computer program cannot accept as input data the structural formula of a compound and perform such operations. Professor Reid and Assistant Professor C. Michael Mohr are adapting existing automated search-and-match techniques for chemical structures, originally developed in the field of chemical information retrieval, to the problem of counting the number of atomic subgroups in the molecule whose properties are to be estimated.

One such technique is the "graph-theoretic" algorithm of Salton and Sussenguth, which treats the chemical structure as a "graph" of "nodes" (atoms) connected by "branches" (chemical bonds). This algorithm is being tested for use in a system of computer programs, which will accept structural information about the compound and produce the necessary information for estimating any required physical properties by various structural group contribution techniques. Investigation to date has focused on the Lydersen method for estimating critical proper-

ties. Success has been achieved with the Salton-Sussenguth algorithm in producing the Lydersen structural-group counts. Computation times on the IBM 7094 are of the order of 0.5 minutes per component, and work is in progress to reduce this time substantially. Some modification of the Sussenguth algorithm will be necessary when counting different bond types, as for example in the Dobratz method for estimating ideal-gas heat capacities and enthalpies.

COMBUSTION AND RADIATIVE HEAT TRANSFER

The Fuels Research Laboratory, under the direction of Professors Hoyt C. Hottel and Glenn C. Williams and in collaboration with Assistant Professors William H. Dalzell and Jack B. Howard, and Associate Professor Adel F. Sarofim, has continued its program on kinetics, heat transfer and flow in combustion processes.

Little information is available on the important variables, mechanism and rate controlling steps in the complex process of carbon black formation from residual fuel oils. A vertical-flow reactor capable of operating between 2000 to 2900°F has been constructed. A spinning-disk atomizer is used to generate a cloud of oil droplets with a very narrow particle size distribution in the range of 25- to 100 μ -diameter. These droplets are injected into the flow reactor where they are vaporized and pyrolyzed in a gas stream consisting of the hot combustion products of a natural gas-air flame. The pyrolysis reaction is quenched with steam, the carbon black collected on a sintered metal filter, and the gas stream analyzed on a gas chromatograph. This system leads to a quantitative evaluation of the effects of temperature, size of the oil droplets, gas composition, and residence time on the physical and chemical properties of the carbon black.

The kinetics of combustion of methane-air mixtures has been studied in a jet-mixed reactor and the performance of such a reactor was simulated on a digital computer. Over the range of temperatures from 1400 to 1800°K, pressures from 0.3 to 0.8 atmosphere and equivalence ratios from 0.5 to 0.8, the rate of methane disappearance could be correlated with a kinetic rate expression first order with respect to methane, half order with respect to oxygen and water vapor and with an activation energy of 56.6 ± 5.0 k cal/g mole. Under these experimental conditions methane burns to carbon monoxide which then burns to carbon dioxide. The rate of destruction of carbon monoxide could be correlated by a kinetic expression first order in carbon monoxide, half order in oxygen and water vapor and with an activation energy of 25.0 ± 5.0 k cal/g mole. A jet-mixed reactor in which a two-step reaction similar to that which occurs in the methane-air system was

modelled on a digital computer. The computer simulation predicted that rates of mass transfer and chemical reaction interact in a complex manner. For slow reactions with low activation energies, the jet-stirred reactor may be modeled as a perfectly stirred reactor. For fast reactions with high activation energies, however, the performance of a jet-stirred reactor depends strongly on equivalence ratio, inlet mole fraction of fuel, activation energy, and the location in the reactor at which measurements are made.

The use of the well-stirred reactor to test the validity of any proposed reaction scheme for predicting fuel burning rates in turbulent combustion systems was described in these reports several years ago, in application to the burning of carbon monoxide. The incompleteness of the reaction scheme then proposed and the key position of carbon monoxide in industrial combustion practice have caused the problem to be reopened. It now appears that the over-all consequences of some five separate reactions involved can still be approximated by a simple product of powers of the concentrations of carbon monoxide, oxygen and water vapor; but the power on carbon monoxide has changed from one to about five-fourths and the over-all activation energy has increased.

The development of predictive models for the propagation of free-burning fires has continued. Two types of steady-state, two-dimensional fires were considered: the first, a ground fire burning through compacted leaves and debris, the second, a brush fire. These were modeled mathematically by integrodifferential equations, the solution of which yielded the propagation rate as a function of preheating fluxes, fuel bed properties, and ambient conditions. In addition, experimental modeling studies were carried out in a 4.5-foot-diameter combustion wind tunnel, using shredded newsprint and wood excelsior to simulate, respectively, fuel beds in ground and brush fires. The shape of the ignition zone in compact brush fires was predicted by the mathematical model.

Research on the flammability of solid materials ranging from wood to plastics is being initiated. The object is to develop an understanding of ignition and flame spread that will enable the effective design of both flammability tests and techniques of flammability reduction. In preliminary work global properties such as ignition time and velocity of flame spread are being examined under well-defined conditions. The flammability behavior so obtained will be used to develop analytical models which can hopefully be used to extrapolate results on small scale tests to practical situations.

A study of turbulent boundary layer combustion was begun with em-

phasis on combustion in hybrid rocket motors under conditions where burning rate is controlled by fuel pyrolysis and chemical kinetics. The importance of oxygen at the surface of the pyrolyzing fuel is being evaluated by measuring both the oxygen concentration at the fuel surface at different burning rates and the increase in pyrolysis rate resulting from a given surface oxygen concentration. The two experimental techniques being used are the burning of flat plates of polymethylmethacrylate in oxygen streams of different velocity and the dropping of small fuel particles through a vertical reactor filled with hot gas in which the oxygen concentration is varied. In the first experiment, temperature and concentration profiles from the fuel surface through the turbulent boundary layer flame and total burning rate are measured; in the second, pyrolysis rate is measured.

The Department has continued its active research program on radiative transfer under the direction of Professors Hottel and Sarofim, with the collaboration of Professors Dalzell and Evans. The major emphasis has been on the development of methods for predicting radiative transfer in scattering media, radiative properties of surfaces, interaction of radiation and other modes of heat transfer, and heat transfer from luminous flames.

Allowance for multiple scatter in radiative transfer calculations is of importance to problems of temperature control of particulate matter in suspension in processing furnaces, heat transfer through fibrous or powder insulations, and rocket wall punishment from particle-cloud radiation. A method for the solution of the transport equation defining multiple scatter in a unidimensional system, based on the representation of the source function by a polynomial, has been developed. This method has been compared with several established procedures, including invariant imbedding, discrete ordinates, and that of Hartel. Comparison of computation times and accuracies has shown that there are ranges of optical thickness, albedo for single scatter, and peakedness of the scatter diagram in which each of the methods has distinct advantages.

The total-exchange area concept, which has proved to be so valuable in solving problems of interaction between radiation and other modes of heat transfer, has been extended to systems containing anisotropic scatterers. The complex multiple scatter problem for a system with fixed radiative properties needs to be solved only once to obtain total-exchange areas which provide a complete characterization of the radiative exchange between different parts of the system. Simultaneous radiative and conductive transfer in the system may then be calculated with little additional labor for a wide range of thermal conductivities and temperatures.

This method is particularly valuable in the calculation of radiative transfer through powdered and sintered insulators.

Experimental and theoretical investigations of particle suspensions and close packed particle coatings have yielded valuable information on the factors that determine the spectral and directional selectivity of surfaces. The method of discrete ordinates has been developed to calculate the reflection from pigment particles suspended in a clear matrix, with inter-particle spacing large enough to justify assumption of independent scatter. One result of major significance is that the neglect of reflection at the bounding surface (an approximation often introduced by other investigators) may lead to an underestimation of the surface absorptance by factors of three or more. When the particles are closely packed, however, the reflectivity cannot be predicted because of the complexity of the interface between the radiation scattered by neighboring particles. Measurement of the radiation scattered by a few well-defined systems has been used to develop simplified models. These indicate that scatter by close-packed non-absorbing particles can be adequately correlated by a multiple-scatter model in which the scattering centers are assumed to be the voids between the particles; and that, for highly-absorbing and -reflecting particles, the reflected radiation is primarily composed of radiation singly scattered by the surface layer.

Although conduction and radiation often both make significant contributions to the over-all heat transfer in systems of practical interest, such as that described in the preceding section, their individual contributions have usually been evaluated independently. This is in large measure a consequence of the fact that the non-linear equations cannot, in general, be solved analytically. The transient temperature and heat-flux distribution in optically-thick, one-dimensional, conducting-radiating media have been evaluated for different finite-difference schemes in order to provide a stable convergent method, which may be useful in the more complex two- and three-dimensional problems.

The natural circulation of absorbing-emitting fluids is of interest in the design of glass-melting furnaces, furnace convection, and atmospheric phenomena. Because the flow and heat transfer processes interact in such problems, their analysis necessitates the simultaneous solution of the energy equation and the equations of fluid motion as a coupled set. Finite-difference techniques have been developed to solve several such problems for fluids confined in two-dimensional enclosures. Significant improvements in finite-difference methods for the solution of the viscous Navier-Stokes equation, per se, have resulted from the investigation. Relative to previous work, these include a nominal five-fold reduction in computation time and an increase of at least a factor of ten in the

maximum allowable Rayleigh number for which stable solutions can be obtained. The behavior of the numerical schemes employed has been partially explained through stability analyses based on matrix iterative methods. Application of the methods to a two-dimensional enclosure heated from above and cooled at the sides predicts a flow pattern that is, as expected, bi-cellular, rising in the center. The rate of fluid circulation has been found to vary by as much as two-fold over the range of optical thickness studied, and to pass through a maximum.

No reliable values for the optical properties of soot have been reported in the literature. These optical properties, along with the mass concentration of soot, are needed to calculate the luminosity of flames. Soot pellets with optically smooth surfaces have been formed by compacting soot at very high pressures; and the reflectivity of these surfaces for polarized light has been measured over the visible and infrared wavelength regions (0.4 to 15μ). In the visible wavelength region ($0.4 - 0.8\mu$) the optical properties of soot with atomic carbon to hydrogen ratios of 4.5 to 15 to 1 can be adequately described by a refractive index of $1.55 - 0.50i$. At larger wavelengths (1 to 15μ) however, both parts of the refractive index increase rapidly with wavelength. A dispersion model, taking account of the physical structure of soot, is being developed to fit these data. By fitting these room-temperature data to a dispersion model it should be possible to predict the variation of the optical properties of soot with temperature.

In the calculation of radiative transfer in furnaces and hydrocarbon-fired combustion engines, allowance must be made for the contributions to the emissivity by carbon dioxide, water vapor, and soot. A detailed description of the spectral absorptivities of the carbon dioxide and water vapor is required in order to account for the spectral overlap of their emission bands and in order to allow properly for non-uniformity of temperature. Presently the parameters required in the Mayer Goody and Elsasser models of band emission are being determined, and it is planned to use this information in the calculation of temperature distributions in simple systems of interest.

ENGINEERING MEDICINE

A new study has been initiated by Professor Hoffman of the viscoelastic behavior of purified elastin, a major component of ligament and blood vessel walls in the body. The swelling behavior, stress relaxation and creep properties of this material will be measured in various aqueous salt and solvent solutions. Elastin is essentially a non-polar crosslinked rubber and the swelling and mechanical properties may be used to estimate the dimensions of the network structure, as well as to help

elucidate the nature of the crosslinks, which are still not clearly defined. Special interest will be placed on the effects of aging on these properties, especially as this relates to such diseases as arteriosclerosis and rheumatism. Assistant Professor Ioannis V. Yannas of the Department of Mechanical Engineering will be closely associated with this project. The advice and assistance of Drs. Franzblau and Sinex of the Boston University Medical Research Center, well-known for their work on elastin, have been invaluable.

Studies relating chemical engineering to medical and surgical problems are being carried out with the sponsorship of the National Heart and the National Arthritis Institutes and under the direction of Professors Merrill, Gilliland, Smith, and Evans and in collaboration with Dr. Gerald W. Austen of the Massachusetts General Hospital, Dr. Edwin W. Salzman of the Beth Israel Hospital, Dr. Endre Balazs, Director of the Retina Foundation, Boston, and Dr. Robert Replogle of the University of Chicago Medical School. These studies are:

RHEOLOGY OF HUMAN BLOOD A study of the non-Newtonian rheology of human blood with reference to the interaction of cellular elements and plasma proteins, and the physiological relevance of these rheological characteristics to mammalian microcirculation. Recent clinical studies by Dr. Replogle demonstrate remarkable therapeutic effects directly attributable to lowering of blood viscosity in polycythemia and hyperfibrinogenemia.

INTERFACIAL PHENOMENA RELATED TO PLASMA PROTEINS, LIPIDS, AND BIOLOGICAL POLYSACCHARIDES Studies of interfacial tension between saline solutions containing proteins, lipids, and/or polysaccharides, and air, immiscible liquids, and non-wetting solids. Emphasis has been placed on alveolar function and its abnormalities, as in hyaline membrane disease, and problems related to blood denaturation, as in direct oxygenation, divers' "bends" and evolution of cholesterol plaques.

MEMBRANE TRANSPORT/POLYMER STRUCTURE AND PROPERTIES Study of the permeability of cellulose and elastomeric membranes to oxygen and carbon dioxide, and to blood solutes such as urea, with special references to blood dialysis for chronic uremia (the artificial kidney) and to gas exchange during heart surgery (heart-lung machines).

ANTITHROMBOGENIC MEMBRANES AND SURFACES The chemical modification of surfaces, particularly membrane surfaces, so that human blood in contact with these surfaces is not denatured nor incited to clot by activation of either platelets or fibrinogen. The method for cellophane has been worked up to the point where experimental kidneys and oxygenators based on these membranes are being prepared for *in vivo* testing.

VISCOELASTIC PROPERTIES OF HYALURONATES A basic study is being carried out on the hyaluronates in steady and oscillatory Couette shear with reference to physiological function of hyaluronates in synovial fluid, vitreous humor and body tissues. Recent experiments on synovial fluid from young, elderly, and osteoarthritic humans demonstrate very significant differences in the relative elasticity of the fluid (high for young adults, low for the aged and arthritic).

FLUID MECHANICS/MASS TRANSPORT IN EXTRACORPOREAL BLOOD FLOW SYSTEM The application of fluid mechanics to the design of extracorporeal circuits for blood oxygenation and blood dialysis has led to two new concepts for promoting high mass transfer rates through blood in the artificial kidney and in the membrane oxygenator. One principle is to circulate the blood through a helical dialysis tube having a small radius of curvature, thereby generating secondary flow which increases mass transfer rates several-fold without inducing hemolysis. The second principle is to cause blood to flow outside of and normal to a bundle of tubular non-thrombogenic membranes which transport either oxygen or dialysis fluid, thereby obtaining high mass transfer rates in compact systems and avoiding the problems of plugging when blood is forced through tubular membranes of small diameter.

WATER DESALINATION

Professors Hoffman and Modell have received support from the Office of Saline Water to study desalination by reverse osmosis. Several new techniques are being investigated to prepare ultra-thin (100–3000 Å) membranes directly on relatively porous membrane substrates. In one method, the pores of the substrates are filled with a gel prior to deposition and polymerization of the membrane monomer. The gel can be removed after polymerization of the membrane, or if the gel resistance to permeation is small relative to that of the membrane, no further treatment will be necessary. A second method consists in blocking off the substrate pores (prior to admitting monomer) by deposition of a tightly packed protein monolayer onto the substrate. The ultra-thin membranes will be prepared by depositing a 100Å thick layer of monomer mixture onto the pretreated substrate surface, followed by rapid polymerization. Thicker films will be prepared by depositing subsequent thin layers of monomer mixture on the surface of the polymer membrane, polymerization following each addition of monomer. Since defects and pores are regions of high surface area (and possibly high surface-free energy), subsequent layers of monomers should tend to fill in imperfections.

The membranes are being characterized by salt and water contents as a function of salt concentration in solution, direct osmosis experiments

under atmospheric pressure, and reverse osmosis experiments at high pressure. The flow is then mathematically modeled and compared with the experimental data.

Professors Vieth and Hoffman have completed their supervision of an investigation of the mechanism of desalination in poly-electrolyte complex coacervate films. It has been found that water flux is linear in the effective pressure, $(\Delta p - \Delta\pi)$, salt flux is linear in $\Delta\pi$ and the normalized salt flux (salt flux/ $\Delta\pi$) is essentially independent of pressure and upstream salt concentration. These data have been interpreted as indicating that the transport of both salt and water is primarily diffusive in nature and that the contribution of pore flow (hydrodynamic flow) through pinholes is small.

A new reverse osmosis device, which should be particularly suited for desalination of brackish water, is being studied by Professors Modell and Hoffman. This system should be capable of utilizing high-flux moderately-selective membranes, such as the consolidated polysalt membranes. The device incorporates a well-mixed chamber of a strong polyelectrolyte solution downstream of the membrane. The presence of the polyelectrolyte counterions increases the activity of salt ions on the downstream side of the membrane, thereby decreasing the salt activity gradient across the membrane. In membranes that are relatively free of defects, the reduction of the salt activity gradient should result in a decrease in the salt flux. Since the activity gradient of water across the membrane will be increased by the presence of the polyelectrolyte, the rejection efficiency of salt should be increased substantially by the presence of the polyelectrolyte solution. The permeated water and salt are then separated from the polyelectrolyte by a simple dialysis step through a relatively porous membrane (50–100Å pores). The polyelectrolyte counterions will not pass through the dialysis membrane since electrical neutrality must be maintained. It is calculated that an over-all rejection efficiency of 94 per cent could be obtained for desalination of 5000 ppm NaCl by using a 1.6 ionic equivalent solution of a high molecular weight polycation with a membrane which has only 44 per cent rejection efficiency under normal conditions (i.e., under conditions of no polyelectrolyte downstream).

Professors Sherwood, Brian, Sarofim and Smith are supervising studies pertinent to the design and operation of crystallizers, wash columns, and melter-condensers in water desalination plants using the freezing process.

The growth and nucleation of ice crystals is being investigated with the objective of providing a more rational basis for the design of crystallizers in the freeze-desalting process. At present, the effects of undercooling, residence time, and agitation upon ice crystal size are poorly

understood. Batch crystallization studies by Shafik Sadek have indicated that the dominant nucleation mechanism is that of secondary nucleation induced by the growing ice crystals themselves and that the apparent rate of growth of the ice seed crystals is substantially lower than those predicted from kinetic measurements and mass transfer theories. In an extension of these studies, Geoffrey Margolis has developed a mathematical model that enables the determination of growth and nucleation rates in a continuous crystallizer from the concentration and size distribution of the crystals in the outlet stream. The data required by the model are obtained from photomicrographs of the ice slurry suspension leaving a laboratory-scale continuous well-stirred crystallizer. A separate investigation by Shantaram G. Kane is aimed at obtaining an understanding of the mechanism of secondary nucleation.

Heat and mass transfer from particles in a highly agitated tank has been investigated by Hugh B. Hales. Rates of heat and mass transfer were measured by melting ice spheres in water and in dilute sodium chloride solution and by dissolving similar pivalic acid spheres in water. Values of the Nusselt or Sherwood numbers calculated from the data could be correlated in terms of a dimensionless group containing the agitation power per unit volume, for a wide range of system geometries and stirring speeds, and the Prandtl or Schmidt number. The mass transfer rates for ice dissolving in brine, however, had to be corrected first for the effects on the mass transfer rate of the changing particle diameter and of the apparent transpiration at the surface which results from the solid-liquid density difference. Mathematical modeling of the process was successful in predicting the extent of these effects.

David L. Ritter is studying the problem of washing masses of ice particles so as to remove the adhering brine. This is achieved in a vertical column which is fed at the bottom with an ice-brine slurry and with chilled water at the top. A brine-wash water mixture is removed at an intermediate point and well-washed, compacted ice is removed from the top. The pilot plant required for this study is now fully operational and is yielding reproducible data of high quality. Data so far indicate that a rather simple one-dimensional treatment of the process will correctly model most of its essential features.

Lawrence W. Petri is studying the process of melting the compacted ice product obtained from such a wash column. Heat economy considerations virtually dictate that this be achieved by direct contact of the ice with a somewhat warmer, condensible vapor. This vapor may be either that of water or that of an immiscible organic refrigerant. In either event, the process involves flow of the vapor into the porous ice mass, condensation of the vapor, melting of the ice, and drainage of the

liquid. A preliminary analysis has provided strong evidence to the effect that resistance to vapor flow is the factor of over-riding importance.

Professors Baddour and Vieth and Assistant Professor Allan S. Douglas have continued the program to develop expanded glassy polymer membranes for use in the desalination of sea water. During the last year, the program has focused on two major areas: The development of promising new membranes, and characterization of previously developed membranes. Previous work indicated that the hydroxyl group content, polarity, and water swelling of the membranes were important factors in determining the semipermeability of a given membrane. Utilizing these and other concepts, the development program moved forward, significantly assisted by the addition of Dr. Rene Bloch, a visiting research associate from Weizmann Institute of Science in Rehovoth, Israel. Dr. Bloch's work has aimed at the development of methacrylate-based membranes of controlled water content. The polymers have been synthesized from mixtures of hydroxyethyl methacrylate and ethylmethacrylate. The water content of these films can be controlled by varying the fraction of the material which is hydroxyethyl methacrylate since the water sorption properties are determined by the hydroxyl content. Several successful films of varying composition have been prepared and initial screening tests using forward osmosis have shown that these films are potentially attractive reverse osmosis films. Tests in reverse osmosis have also been encouraging although severe pinhole problems have been encountered. Progress is also being made toward obtaining an asymmetric film of this material having an ultrathin barrier property.

In another major area of investigation, polyurethane membranes which are the reaction product of toluene diisocyanate and polyethylene glycol have been successfully prepared using glycols of molecular weight 350 and 550. These have shown salt rejections as high as 88 per cent and work is continuing on improving both the water flux and the salt rejection, as well as to provide elucidation of the transport mechanisms. Two new techniques have been developed for membrane characterization. They are membrane potential measurements and determination of diffusion constant by transient sorption techniques. The membrane potential measurements provide information that permits calculation of both the transport numbers for various ions in the membranes, as well as membrane fixed charge, as in the "polysalt" material. From the transport numbers it is possible to determine which ion of a particular pair is the pilot ion. This in turn provides insight into the mechanism of ion transport.

The rate of sorption of water vapor, at low relative humidities, by an initially dry polymer film has been related to the rate of liquid water

diffusion under a hydrostatic pressure driving force of 100 atmospheres by a modification of Fick's diffusion law. This modification takes into account the formation of immobilized clusters of water molecules which hinder the rate of equilibrium during the transient sorption. During steady state permeation only the mobile species contributes to the flux and in order to apply the results of the transient sorption experiments, subtle corrections must be applied. This technique has been used successfully to predict the rate of water transport during reverse osmosis in cellulose nitrate films of low water content where the rate of cluster formation is rapid. The equations are currently being extended to apply to the case where the rate of clustering is finite as is apparently the case with the polyurethanes. The advantage of this technique over others is that the predicted water transport rate is for a defect-free membrane, so that the ideal performance of a non-leaky film can be predicted.

ELECTROCHEMISTRY

Professors Herman P. Meissner and Deibert are conducting studies on the operating characteristics of fuel cell electrode systems. They are investigating the unexpectedly variable performance of the submerged flow electrodes. A determination of the effect of the electrode shape, the hydrodynamics of electrolyte flow and the presence of impurities on the operating characteristics of flooded electrodes is being made. Electrode systems under study include flow past cylinders and through tubes. In a study of gas evolution at electrodes of the type used in electropurification and rechargeable fuel cells, it was found that the incorporation of a teflon-bound silica layer on the electrolyte side of a membrane electrode is an effective means of capillary control of gas evolution. The maximum current density possible before the electrode became gas-bound nearly doubled when the silica layer was present.

A study of the rates of ion transfer through a porous membrane when voltage, pressure, and concentration differences are maintained across the membrane, and a hydrodynamic flow of electrolyte through the membrane opposes the electrical movement of cation (or anion) is being directed by Professors Gilliland and Evans. Ideally, for certain combinations of pressure and voltage differences, the bulk solution velocity should balance the ionic velocity of the cation (or anion) resulting in a minimum rate of transfer of cation (or anion) across the membrane. This balance point is expected to depend on the voltage difference, type of ion, pore size characteristics of the membrane, pressure difference, concentration difference, and the temperature of the solutions. Transient experiments have been conducted in an electrochemical cell in which the two compartments separated by the porous membrane have been

filled initially with sodium chloride solutions; electrolyte was supplied continuously to the cathode compartment and withdrawn from the anode compartment. Current was supplied to the cell through specially prepared silver-silver chloride electrodes. The objective of the study is to determine the relative importance of the hydrodynamical, diffusional, and electrical transfer processes involved by varying the voltage, concentration, and pressure differences across the membrane, the distribution of pore sizes in the membrane, and the types of ions used in the system.

SURFACE CHEMISTRY AND PHYSICS

The investigation of viscoelastic behavior of biocolloid-like complex coacervate systems continues under the supervision of Professors Hoffman and Meissner. Two different reaction products of oppositely charged polyelectrolytes are being studied. The swelling of such materials in salt solutions (e.g. NaCl, NaBr, NaI) reveals the increased significance of ion-binding of the halide ion to the quaternary polyion in the series $I^- > Br^- > Cl^-$. The salt and water contents of swollen films are being measured in these solutions. Mechanical studies of creep and stress-strain behavior of the coacervates immersed in these same salt solutions has led to attempts to correlate and predict the modulus as well as the viscoelastic response based on the swelling data. In a new study recently initiated, the polyelectrolytes are being synthesized from the monomers; the charge density in the backbone is being varied in a controlled fashion by copolymerizing with a non-charged monomer. Measurement of swelling data in these systems will also permit a revision and refinement of the equilibrium thermodynamic theory of complex coacervation.

The phenomenon of dilatancy (reversible shear hardening) has been investigated in aqueous kaolin suspensions in a program directed by Dr. Alan S. Michaels and Professor Hoffman. The critical shear rate for onset of dilatancy is being correlated with the solids volume concentration, particle size and shape, and sedimentation rate of the suspension in a centrifuge. The degree of dilatancy is estimated by the slope of a plot of $\log(\text{shear stress})$ vs. $\log(\text{shear rate})$ above the region where dilatancy begins. This also is found to correlate with the parameters noted above. Electron microscope photomicrographs provide a measure of the actual particle size and shape. Prediction of the dilatant behavior of synthetic mixtures of different particle fractions is currently being attempted.

EDWIN R. GILLILAND

DEPARTMENT OF CIVIL ENGINEERING

The teaching and research activities of the Department for the year 1966-67 represented an acceleration of the tempo of change that has characterized the Department in recent years. Because of the scope and magnitude of the many new activities that have been initiated during the year, in this report we must limit attention to selected examples of new developments. General discussions of the over-all academic programs are presented, followed by more detailed discussions of the activities of the technical divisions of the Department. All members of the faculty have contributed to the report, and many have participated in the writing of it.

ACADEMIC PROGRAM

As will be apparent from the division reports, the Department is dedicated to a research effort that is making substantial contributions to a rapidly evolving technology of civil engineering. Nevertheless civil engineering education remains our major concern, and the vigor of the academic program is greatly enhanced by its execution in an environment of significant research. All faculty members participate in the teaching program as well as in research. Conversely all graduate students and a large proportion of the undergraduate students participate in and contribute to the research effort. These circumstances, and a favorable faculty-student ratio, have produced a "climate for learning" that is valued by students and faculty alike.

Several years ago the Department introduced pioneering changes in its undergraduate professional curriculum. Major changes included a substantial reduction in the number of core subjects and increased flexibility in tailoring programs to individual student choices. We remain convinced of the logic of these changes. In a following section on Undergraduate Education there is a description not only of individual subject innovations that have occurred during the past year but also of the introduction of a new undergraduate curriculum which will be offered in addition to the regular Civil Engineering curriculum.

Because of the current rapid evolution of civil engineering technology, many young practicing engineers sense a need for further formal professional education. The need may be more depth, breadth, or education in an area that has developed since their initial educational experiences. Industry is beginning to recognize the importance of such advanced engineering study, and it can be assumed that able engineers will be encouraged in this direction in the future. Since 1965, the faculty of the Department have been discussing this need and planning an appropriate response. During the past years this discussion, led by Professor Myle

J. Holley Jr., and having the benefit of interactions with Professor Harold S. Mickley, Director of the Center for Advanced Engineering Study, has led to the definition of a new category of graduate student. This category, "Civil Engineering Affiliate of the Center for Advanced Engineering Study," will be used to designate young civil engineers entering our graduate program after demonstrating exceptional ability in practice. It is anticipated that normally they will be admitted for a period of two or three academic terms. Depending upon the extent of their prior academic experience, their period in this program may culminate in the degree of Civil Engineer. Each Affiliate will be associated with and receive guidance from a faculty member of the Department of Civil Engineering. In addition, he will participate actively in special subjects, seminars and other activities of the Center. We believe that this program can be of major importance and look forward to the possibility of early implementation.

UNDERGRADUATE PROGRAM

During the year, the Department continued to focus a major portion of its total effort on undergraduate teaching. The number of undergraduates taking their Bachelor's degree in the Department has continued to be about 30 per year per class. However, this statistic fails to indicate the extent of the Department's involvement with undergraduates. An average of about 150 other undergraduates enroll each semester in subjects taught by the Department. Many of these students enroll in basic computer subjects, yet other students also appear in all of the core curriculum subjects. In the six core curriculum subjects offered each semester, there is an average of 60 faculty contact hours per week in the classroom and laboratory, not counting individual interviews and unscheduled discussion sessions. In all of these subjects, teaching is done by faculty who also carry out extensive research and other professional activities.

Under the leadership of Professor Robert V. Whitman, the Department's Undergraduate Academic Officer, a new and additional undergraduate curriculum has been developed. This curriculum, especially suited for students whose interests cut across traditional departmental lines, leads to the degree of Bachelor of Science without departmental specification. To qualify for this degree, a student must (in addition to the Institute requirements) complete five specified subjects in information systems, differential equations, principles of uncertainty, engineering mechanics and engineering materials, plus an elective program of at least eight subjects, selected by the student with the approval of his faculty advisor and aimed at a well-defined educational goal. The existing undergraduate curriculum which leads to the Bachelor of Science in Civil

Engineering continues to be available to students desiring a basic and broad grounding in the design and construction of constructed facilities.

The subject, Civil Engineering Laboratory, was given this year for the first time, under the direction of Professor Arthur T. Ippen. Sophomore and junior students in this subject satisfy the Institute requirement for a subject which teaches and gives experience in the role of laboratory in engineering and research. Students worked in groups of four or five, and each group completed three projects using the facilities of the Structures Laboratory, the Materials Laboratory, the Soil Mechanics Laboratory and the Hydrodynamics Laboratory. Ten faculty members of the Department participated in the teaching of this subject, and hence the students became well acquainted with the faculty and with the research facilities of the Department. Two undergraduates, Robert Gladstone and Anthony Kettaneh, working in the Materials laboratory, initiated the development of a technique which uses the laser to weaken rock for easier and less costly tunnelling through rock. This widely publicized development has formed the basis for a major research project within the Department.

A new approach to the organization and teaching of the capstone senior subject, Civil Engineering, was undertaken this year. The class was divided into two groups, each of which was asked to organize itself as an engineering company, negotiate a design contract with a fictitious client, and prepare preliminary designs of a parking garage for a given site, advising the client of an appropriate design, including the foundation, structural system, mechanical and electrical equipment, operational policy, costs of design, construction and operation and, finally, the potential financial return to the prospective owner. The subject was structured in such a manner that the students had a minimum of guidance and a maximum chance to make their own decisions. Guest lectures were given concerning the organization and operation of an engineering firm, the considerations of a developer, and the financing of a commercial project. The student companies, which were in competition with each other, presented their results in report form and in a public meeting at the end of the semester. This major effort was headed by Professor Robert J. Hansen of the Structures Division, together with Associate Professor E. Farnsworth Bisbee of the Transportation Division and Professor Victor F. B. deMello of the Soil Mechanics Division.

Steady development has also taken place in the other undergraduate offerings of the Department. Further effort has gone into improvement of the project type experiments used in the laboratory portions of the subjects in fluid dynamics and soil mechanics. Laboratory work, including experimental observation of random phenomena and the use of

simulated experiments to solve problems, has been incorporated into the subject on principles of uncertainty. With the impetus provided by Assistant Professor Robert B. Williamson, there has been further development and use of the technique of programmed instruction. Textbooks are being written for use in teaching engineering geology, principles of uncertainty, and soil mechanics.

GRADUATE EDUCATION

In the 1966-67 academic year, the full-time graduate student enrollment was 190. This figure reflects a steady growth of approximately 10 graduate students per year as controlled by the Department's quota. However, these figures do not reflect a significant change in the graduate educational picture, namely, the number of doctoral candidates. In the last five years, the number of doctoral candidates has almost doubled. In 1961, doctoral candidates represented 23 per cent of the graduate student population, whereas in 1966 they had increased to 41 per cent. These numbers do not account for a sizeable number of graduate students who are currently Master's degree candidates and who intend to continue for the doctorate. Of the 125 United States universities offering a doctoral program in civil engineering, this Department is awarding approximately eight per cent of the degrees.

Approximately 130 graduate students are supported directly by the Department in the form of fellowships, teaching and research assistantships. In addition, many of the other students hold fellowships granted directly by government and industrial organizations.

During the current academic year, the department offered 80 subjects of instruction with 65 primarily for graduate students. In addition, numerous seminars and special study programs are arranged each term. The activity of the faculty during this academic year, in the revising, up-dating and the developing of new subjects of instruction, is shown by revised subject descriptions which were submitted for 15 graduate subjects. In addition, 11 new subjects have been added and five subjects have been dropped.

Mathematical optimization subjects within the Civil Engineering Systems area have been expanded by Assistant Professor Alan M. Hersh-dorfer into a three-semester sequence covering an introductory subject, an advanced subject and a special topics seminar treating dynamic programming and stochastic optimization. Assistant Professor Richard L. deNeufville has developed a new two-term sequence in Engineering Cost Effectiveness. These subjects develop systematic techniques for analysis and evaluation of engineering projects. Specific cases in the fields of transportation, water resources and structural engineering will be studied.

Assistant Professor Daniel Roos has revised the subject Computer Approaches to Engineering Problems into Civil Engineering Compute Systems Design with emphasis on the generation and processing of problem oriented languages. Assistant Professor Frank E. Perkins and Joseph M. Sussman have developed a subject in Computer Systems specifically for engineers in the Center for Advanced Engineering Study.

The subject Urban Highway Transportation Systems under the leadership of Associate Professor Alexander J. Bone has been broadened to multi-modes of urban transportation systems.

A seminar subject was given in the Soil Mechanics area by Professor Robert V. D. Whitman and Assistant Professor Ulrich Lüscher on Computer Approaches to Slope Stability. The students were encouraged to use existing computer programs to investigate the stability of earth slopes. Associate Professor Ronald C. Hirschfeld has developed a new graduate subject in Rock Mechanics.

An extensive revision of subject material has been undertaken by the Materials Division. Among the new graduate subjects are Structural Properties of Metals by Associate Professor Russel C. Jones, Cementitious Materials by Professor Williamson, and Structural Design of Pavements by Associate Professor Fred Moavenzadeh.

In the field of Structural Engineering, Associate Professor William A. Litle has developed two new subjects, Structural Models and Experimental Design of Shell Structures. In addition, computer-aided design techniques have been introduced into the advanced design subjects.

New subjects and subject revisions in the area of Water Resources include: increased emphasis on instrumentation and measurement techniques in the Experimental Hydromechanics sequence given by Professor Perkins; the new subjects Dynamic Hydrology and Hydrologic Analysis and Synthesis developed by Professor Peter S. Eagleson. The subject Waves and Coastal Processes, taught by Assistant Professor Ralph H. Cross III has been materially strengthened by the use of the book, *Estuary and Coastline Hydrodynamics*, by Professors Ippen, Donald R. F. Harleman, Eagleson and others. Professor Jacob Bear (on leave from The Technion, Israel) developed an extensive series of notes for graduate work in Ground Water Hydrology and Flow in Porous Media. Major changes in the subject Water Quality Control were introduced by Professor Harleman. These reflect recent analytical methods for predicting the distribution of pollutants in rivers and estuaries and thermal stratification and heat pollution problems. Associate Professor Ronald T. McLaughlin's class in Water Resource Systems organized as an engineering team and carried out a study of the upper Susquehanna water basin.

STRUCTURES DIVISION

For the past several years the research program of the Structures Division has been guided by two principal objectives: 1. To develop means for rapid, rational design of structural systems; 2. To extend the range of applicability of such means to analytically difficult structural types. Significant progress toward these objectives became possible with the advent of machine computation which permits rapid analysis of mathematical models of structural systems, and examination of the merits of alternative models according to prescribed criteria. However, this capability made glaringly evident the limitations of present design criteria and challenged both theoretical and experimental mechanics to provide more realistic models, for conventional systems as well as for those systems where no useful models previously were available. Thus there has developed a widespread interest in non-linear structural behavior, significant for most structural types and dominant in certain types. Correspondingly there has been a rapid development of finite element methods which permit the mathematical modelling of structural continua (e.g., plates and shells) in a form suitable for machine computation.

Concurrent with the development of better models of structural behavior, and their design implementation through machine computation, there is a demand for more sophisticated understanding of the uncertainties of loads and strengths, and their implications for safety and economy. It is likewise clear that major gains in structural efficiency will require study of fabrication and construction processes, which must be improved and more closely integrated with analysis and design.

During the last year, Professor J. Melvin Biggs continued to serve as Director of the Civil Engineering Systems Laboratory. Associate Professor Robert D. Logcher supervised the continuing development of the Structural Design Language, STRUDL, which is subsystem of the Integrated Civil Engineering Computer System, ICES. Under his direction substantial progress was achieved in developing a member design capability based on the selection of standard steel elements to satisfy arbitrary constraints and codes. Progress also was achieved in the addition of dynamic analysis capability in the computer system. Assistant Professor Gerald M. Sturman headed a group developing a bridge design capability in ICES.

Under the leadership of Associate Professor Jerome J. Connor Jr., substantial progress was achieved in the area of finite element analysis of structural continua. This group, which included Assistant Professor Ziad M. Elias and Carlos A. Brebbia, Kenneth J. Shepherd, and Agustin J. Ferrante, collaborated in the development of stiffness matrices for flat triangular bending elements, curved rectangular and curved triangular shell elements. Professors Connor and Logcher in collaboration with Mr.

Ferrante developed a general computer system for finite element analysis with ICES.

Professor Elias carried out extensive theoretical and applied research in the area of plate and shell structures. The theoretical portion of his effort dealt mainly with a new approach to the formulation of the basic equations of thin elastic plates and shells, emphasizing the duality between displacement and stress function methods. This duality allows the solution of physically different problems by a single set of equations. Professor Elias' theoretical research also dealt with the formulation of shell theory in cartesian coordinates which is of value for many shell forms of civil engineering interest. His applied research involved application of the above-mentioned analytical duality to finite element analysis of plates. A single computer program was developed to analyze stretching problems by the displacement method, and bending problems by the stress-function method.

Professor Litle devoted a major part of his effort to the continuing development of the Structural Models Laboratory. He supervised a research program having the objectives of documentation and advancement of the role of small-scale physical model experiments. The work of this laboratory has contributed significantly to a growing appreciation of the value of physical model studies in this country. During the last year particular progress has been made in the model analysis of non-linear behavior of structural frames and in the model analysis of the behavior of thin concrete shells.

Professor C. Allin Cornell has initiated new research in earthquake engineering. Interest lies both in broad-scale seismic risk of a site, as related to historical activity of neighboring faults, and in the small-scale questions of structural response to the chaotic ground motions resulting from earthquakes. Stochastic models of both problems are under development. Professor Cornell has been active also in the development of probabilistic methods and their application to structural design.

Professor Hansen continued to serve as Deputy Director of Project TRANSPORT. This interdepartmental research project, sponsored by the U.S. Department of Transportation, is concerned with the technological developments required for a high-speed ground transportation system. In addition, Professor Hansen supervised a Department of Architecture-Department of Civil Engineering joint research project directed toward the improved economy of high-rise steel-framed buildings.

The Division has a growing research interest in the total conception of design, fabrication, and construction of buildings, and during the last year Professors Hansen and Litle, Dr. Moneer F. Tewfik, John Clarkeson

and others formulated plans for relevant research to be initiated in the coming year.

Professor Holley, assisted by Dr. Tewfik and Elljarn I. Jordet, conducted research in model studies with the objective of developing new techniques to predict the effects of foundation settlement on stresses in arch dams.

Several members of the Division Faculty have assisted CAMROC (Cambridge Radio Observatory Committee) in the formulation of the governing equations of non-linear behavior for a proposed large space frame radome, and in implementing machine solution of these equations. Among the faculty members were Professor Connor, who worked on theoretical aspects of the problem; Professor Litle, who supervised verifying model tests, and Professor Logcher, who worked on computer programming aspects. It is of interest to note that the computer system STRESS, an earlier development of this Department, has proven to be adaptable to this complex problem in non-linear structural analysis.

Assistant Professor Peter J. Pahl who has been at the Technical University of Berlin (under the M.I.T.-T.U.B. Exchange Program) will return to Cambridge in September, 1967. During this year in Berlin, Professor Pahl has been developing numerical techniques for stress analysis of thick-walled concrete shells.

Assistant Professor Jose M. Roesset, who has spent the last 16 months in Chile, associated with the University of Chile and the Catholic University under the M.I.T.-Inter-American Program (IAP) will return to Cambridge in September, 1967. His research has been concerned with programming methods in structural analysis and implementation on the new computer at the University of Chile. In addition, he has worked with Professor Arias of the University of Chile on stochastic models for earthquakes.

Professor Albert G. H. Dietz, in collaboration with Professor Hersh-dorfer, Lavette C. Teague Jr., Barry L. Gerken, and William F. Sommerfeld Jr., conducted research in the application of systems methods to building design.

The faculty continued to contribute substantially to the work of professional engineering societies and similar technical groups. Professor Hansen served as a member of the Executive Committee, Advisory Committee on Civil Defense, National Academy of Sciences. Professor Biggs served as President of the Boston Society of Civil Engineers. Professor Dietz continued as a member of the Executive Committee of the Building Research Advisory Board (BRAB) and served as Chairman of a BRAB Committee to advise the U.S.A. Corps of Engineers on policy for research in overseas construction. Professor Litle served as Chairman

of the American Society of Civil Engineers (ASCE) Subcommittee on Structural Model Analysis and as a member of the American Concrete Institute (ACI) Committee on Structural Models. Professor Logcher served on the ASCE Committee on Electronic Computation. Professor Cornell served as a member of ACI and ASCE Committees on Structural Safety, and as a member of the control group of the latter. He also has become a consultant to the National Bureau of Standards for the planning of a statistical survey of building loads. Professor Sturman served as a member of the ACI Committee on the Use of Computers. Professor Holley served as a member of the ACI Committee on Structural Safety and the ACI Committee on Nuclear Reactors. He also served as Chairman of the Radome Panel of the CAMROC Project.

MATERIALS DIVISION

Our new approach to civil engineering materials teaching and research is well launched and the early results are encouraging. Because civil engineers are the largest users of materials in the world today, they bear a special responsibility: They must understand behavior and properties of materials, and be perceptive in identifying and analyzing new needs and new opportunities for materials to contribute to the profession. These are the guides to our efforts in the Division.

In both our teaching and research, we concentrate on three principal points, which form the nodes of a completely interactive loop system:

1. Understanding how the macroscopic mechanical properties of structural materials derive from their composition and from their internal structure or microstructure.
2. Given a set of mechanical characteristics possessed by a material, how can these be most accurately and rigorously represented for use in structural analysis and design?
3. Given the need for a combination of material properties in a class of structural applications, how can presently available or new substances be synthesized or enhanced to meet such a need best?

Responding to the first point — the relationships between properties, composition and internal structure — we have continued to strengthen our teaching and research resources. Large laboratory space in the basement of Building 1 has been completely modernized. Major items of new equipment include a second, more powerful and modern electron microscope, a microfocus x-ray diffraction apparatus and a very high-quality optical microscope. All of these are used in the freshman elective subject, Introduction to Electron Microscopy, which is being presented in both academic terms because of the substantial student demand for it. Also

used in this subject is the instruction program which Professor Williamson and his former associates at Harvard developed to teach the fundamentals of crystallography. Our success with this method of teaching has led Professor Williamson to develop a second instruction program on elementary dislocation mechanics, in collaboration with Professor Chalmers of Harvard.

The freshman elective is an example of the interactions possible between teaching and research. Using modern, sophisticated scientific equipment is gratifying to the motivated undergraduate who has just entered the Institute. Such equipment requires and facilitates a fundamental approach to materials, quite unlike the conventional treatments most civil engineering students usually receive. Within half a term, the student has developed skills in microscopy which render him an attractive research partner to faculty and graduate students. He has become a useful collaborator and several of our research papers, reports and projects have benefited from the findings these young men have made, either while enrolled in the subject or subsequently as a laboratory assistant. We have also placed a number of them in summer jobs in industrial laboratories where their microscopy talents have been used.

Enhancing the teaching-research interaction has occupied a great deal of our thought and effort during this last year. Several graduate subjects have been terminated and replaced by others more aligned with our faculty's research strengths; three research projects were also suspended because of their dubious educational contributions, while others, more satisfactory in this respect, were initiated in the areas of concrete microstructure, brittle fracture mechanisms and fibrous composites.

We have also profited from outside help in the planning and execution of our research. This help has taken two forms. First, we retained a consultant to meet with us periodically to review our work and to comment upon it. Dr. Warren F. Busse, who recently retired after a brilliant career as a Research Associate in the E. I. duPont Research Laboratories, combines a unique background in physics and chemistry with a lifelong interest in learning processes as related to teaching. The experiment of having his advice and counsel has been so profitable to us that we are considering another similar arrangement in a second area of our research interests.

The second form of help has been more conventional. During the last year we have held a weekly materials seminar and about a third of the speakers have been distinguished teachers and researchers from other organizations. Each spent a complete day with us, hearing about our work and describing his own. At the end of the day, the guest presented his formal talk to an audience of students and faculty. Out of these dis-

cussions have come many valuable exchanges and relationships and we propose to continue the seminars in the future.

Because we are taking a new approach to civil engineering materials teaching and research, we are conscious of the desirability of informing our colleagues at other schools about our work and getting their advice and comments. Toward this end, copies of selected reports describing our research projects have been sent to all departments of civil engineering in the United States and Canada. These have elicited positive and useful reactions and mutually helpful relationships have been so engendered. We have also planned a Civil Engineering Materials Workshop for approximately 30 professors from other schools in North America for a two-week period in July, 1967. During this period we anticipate a full exchange of ideas, techniques and objectives, building associations which can have long-term professional benefits.

In the area of professional activities, Professor Jones served as a member of the Executive Council, Division of Materials Science of the American Society for Testing and Materials (ASTM), and as a member of the Executive Committee of the Massachusetts Section of ASCE. Professor Moavenzadeh served on four committees of the Highway Research Board (HRB) and ASTM, and Professor Frederick J. McGarry served on two committees of the Society of Plastics Industry.

SOIL MECHANICS DIVISION

During the academic year the Soil Mechanics Division, under the leadership of Professor T. William Lambe, made an evaluation of its research program, especially in the light of the important and timely problems facing civil engineers. The staff of the Division selected the Integrated Soil Engineering Project as the backbone of its soil mechanics research program. This is research on engineering and its key features are "evaluate" and "integrate." In general, the Integrated Soil Engineering Project consists of the following eight steps:

1. Select an appropriate civil engineering structure for study;
2. Predict some aspect of the performance of the structure on the basis of soil tests (laboratory or field or both) and theory;
3. Instrument the actual structure before and during construction;
4. Observe the behavior of the structure both during and after construction;
5. Evaluate the performance of the structure and the techniques used for predicting the performance;
6. Improve existing techniques and develop new techniques of analysis, testing, and construction as ideas spawn from the evaluation;
7. Use the results of the study to help in the engineering of the structure

under consideration and in the planning of the nature, location, and method of constructing future structures;

8. Undertake fundamental research on those topics shown to be in most need of investigation.

The evidence indicates that the Integrated Soil Engineering Project is making a major contribution to the profession, the educational program at M.I.T., and other research activities within the Department of Civil Engineering.

Projects being studied under the Integrated Soil Engineering Project include:

1. Building foundations on the M.I.T. campus (sponsored by M.I.T. Physical Plant Department);
2. Braced cut at North Station (sponsored by the Massachusetts Bay Transportation Authority);
3. An embankment of soft foundation (sponsored by the Massachusetts Department of Public Works);
4. A harbor breakwater (sponsored by Esso Libya);
5. A load test on hydraulic fill (sponsored by Toa Nenryo of Japan);
6. A load test of soft valley deposits (sponsored by the Government of Turkey).

Under Professor Whitman's direction, the division continued to develop a strong effort in earthquake engineering. Professor Cornell of the Structures Division is cooperating in this work. Several structures under the Integrated Soil Engineering Project were studied for earthquake effects. Research projects have been launched to back up these engineering studies. Professors Whitman and Lüscher started an investigation into the densification of sands by vibrations. These studies are aimed at determining the relative roles of accelerations and stresses in causing sand densification. Professor Whitman initiated a theoretical and experimental study of soil-structure interaction. Both of these research efforts were supported by the Inter-American Program in Civil Engineering in cooperation with the University of Chile and the National University of Mexico. Professors Lambe and Whitman visited Japan, Mexico, and Turkey in connection with earthquake engineering studies.

Faculty of the Division conducted fundamental research to back up the engineering research. Associate Professor Charles C. Ladd, and Assistant Professors Anwar E. Z. Wissa and Leslie G. Bromwell conducted soil behavior research; Professor Hirschfeld continued his research in engineering geology and rock mechanics; and Assistant Professors John T. Christian, Kaare Höeg, and Lüscher continued their work in theoretical soil mechanics, highlighted by Professor Christian's work on the finite element technique in soil mechanics analyses.

The faculty of the Soil Mechanics Division continued active in professional societies. Professor Lambe served as Chairman of the Executive Committee of the Division of Soil Mechanics and Foundations, ASCE, and Chairman of an Organizing Committee. Professor Whitman is Chairman of the Research Committee for the ASCE Soil Mechanics and Foundations Division. Professor Ladd was elected Chairman of the Structural Section of the Boston Society of Civil Engineers. Professor Hirschfeld is Secretary of the U.S. National Committee for the International Society of Soil Mechanics and Foundation Engineering and Chairman of the Geology Committee of the Soil Mechanics Division, ASCE.

Professor Lambe presented a paper at the Annual Meeting of the ASCE held in Seattle and one at a Boston Society meeting. Professors Lambe and Whitman, and Dr. L. Anthony Wolfskill presented papers to the ASCE Specialty Conference on Stability and Performance of Slopes and Embankments held at Berkeley in August, 1966.

WATER RESOURCES DIVISION

The teaching and research activities of the Water Resources Division cover a wide spectrum ranging from basic hydrodynamic principles, new applications to engineering design, and systems analysis of technical, economic and social factors. The most significant development during the academic year has been the announcement of a third and fourth floor for the Hydrodynamics Laboratory. The existing laboratory was completed in 1950 and for several years has been inadequate for the teaching and research activities of the division. Approximately one-third of the faculty and research assistants are presently housed in Building 1. The addition of 22,000 square feet of space will permit research and instruction in hydrodynamics, hydrology, and water resources to proceed in close conjunction with each other.

Professor Ippen continued research in the mechanics of transport of solid particles in the pipe lines and in cavitation inception near rough surfaces. A significant new criterion was established which relates the beginning of cavitation to the dimensionless resistance coefficient of the surface. Professor Ippen and Assistant Professor Chiang C. Mei conducted experimental investigations of surface wave motion in shoaling areas and internal wave motions in density-stratified fluids.

Professor Harleman supervised analytical and experimental research on the design of offshore structures in deep-water random waves. Computer programs using the explicit finite difference technique have been developed for the calculation of tidal currents and elevations in estuaries and canals. A special study for the prediction of tidal currents in the proposed Panama Sea-Level Canal was completed. The investigation in-

cluded cross sections using both conventional and nuclear excavation methods. The study of thermal stratification and heat dissipation using models represents a relatively new area of experimental fluid mechanics. Several graduate students, working under Professor Harleman's supervision, are studying transient temperature distributions in lake and reservoir models. Mercury vapor and infrared lamps are used to simulate solar radiation effects in the laboratory. Thermal recirculation and heat dissipation studies in connection with condenser water discharges from nuclear power plants are also in progress.

Professor McLaughlin has investigated unsteady free-surface flows in sewer and storm drainage systems. A computer program was developed to analyze unsteady flow in branching channels with lateral inflow along the channels.

The development of problem-oriented computer languages in the water resources field has been under the leadership of Professor Perkins. A HYDRA subsystem under the ICES project has been designed to analyze pipe network systems, highway drainage and hydrologic data. Professor Perkins has also made a theoretical study of the numerical stability of finite difference schemes used in unsteady, free-surface flow problems. An unexpected result was the finding that frictional damping could make some finite difference schemes less stable numerically even though the damping contributes to the physical stability of the flow.

Assistant Professor Uri Y. Shamir has developed computer methods for dealing with the complex dispersion equations which describe the mixing and movement of water recharged into ground water aquifers.

Basic research on turbulent flow near porous boundaries has been directed by Assistant Professor Lynn W. Gelhar. This work relates to the sedimentation process in rivers where turbulence near the bed may be affected by the porosity of the bed. Professor Gelhar has also obtained an analytical solution for the secondary flow generated between concentric rotating cylinders which is found to agree with observed flow patterns.

Professors Ippen, Harleman, and Cross have continued research on the salinity and sediment problems in the Straits of Maracaibo. In connection with this project, Professor Cross has undertaken some basic studies of the erosional and depositional behavior of cohesive sediments.

Professor Ippen was active in the planning, organization, and administration of two international educational efforts of the School of Engineering as Chairman of the Council of International Affairs. These include the Faculty Exchange Program with the Technical University of Berlin and the development program with the Birla Institute of Technology and Science. Both programs are under Ford Foundation sponsorship.

Professor McLaughlin participated in a committee review of the an-

nual report of the Office of Water Resources of the Department of the Interior.

TRANSPORTATION SYSTEMS DIVISION

The Department has a long history of involvement in transportation. As pointed out in last year's report, research activities in transportation extend throughout the Department. One of the unique characteristics of the Department's efforts in transportation has been the emphasis on multi-mode transportation systems. By the beginning of the year, the scale of research and educational programs in transportation systems made the establishment of a new Transportation Systems Division desirable.

The focal point of the division's research and educational program in transportation is on multi-mode transportation systems in their social and economic contexts. In the analysis of urban, megalopolitan, national, and military transportation problems and those of developing countries, the transportation system is treated as a mix of modes and mode interfaces, each with its unique technical and economic characteristics. Particular emphasis is given to the non-physical aspects of transportation — its impact on economic, social, and institutional structures. The program also has close interaction with the Department's Systems program. The educational program builds on a core of systems subjects, including economics, probability theory, mathematical optimization, computer applications, and decision theory; and this emphasis is also a strong feature of the research program.

Research activities in transportation systems cover a wide spectrum. Professors Bisbee, Siegfried M. Breuning, de Neufville, and Assistant Professor Marvin L. Manheim of the Division have participated in the interdepartmental research program of Project TRANSPORT. Professor Breuning has been serving as Acting Director of the Highway Transportation program (supported by the General Motors grant) of Project TRANSPORT. With Professor Ernst G. Frankel of the Department of Naval Architecture and Marine Engineering, Professors Bisbee, de Neufville, Manheim, and Assistant Professor Joseph H. Stafford have initiated a program of research in the analysis of multi-mode transportation systems, supporting the systems analysis program of the Special Assistant to the Joint Chiefs of Staff for Strategic Mobility in the Department of Defense. This has provided a unique viewpoint of transportation systems which is complementary to the Department's other research in urban, megalopolitan, and developing country transportation systems. Topics being investigated include procedures for dynamic routing and scheduling in multi-mode networks, value of information in a transportation management

system, analysis of multi-mode terminals, off-loading of cargo from ship to shore, the transportation planning process, as well as several exploratory efforts.

Professor Roos has done research on computer dispatching and scheduling of small mass transportation vehicles, illustrating the technical and economic feasibility of such a system. With support of the Massachusetts Department of Public Works, Professor Bone has done research on demand for urban transportation which influenced the development of ICES subsystems for transportation planning. Earl R. Ruiter, William F. Johnson, Wayne M. Pecknold, John H. Suhrbier, and John C. Prokopy are participating in the development of these subsystems.

With support from the new federal Department of Transportation, research is being conducted by Professors Manheim, de Neufville, and Stafford into the process of transportation systems analysis in such contexts as megalopolitan transportation studies.

Professors Breuning, de Neufville, and Hershendorfer participated in the interdepartmental systems subject on the design of a dense city core. Professor Breuning, who served as coordinator for the subject, also conducted the transportation systems design subject which developed a complementary transport system for the dense city designed in the interdepartmental subject.

A particularly interesting experiment was the introduction of a case study using the ICES computer system into the first subject in transportation systems. In a sequence of integrated problems, ranging from network analysis to detailed facility design, several different subsystems of ICES were used.

Faculty of the Division have also had a long interest in urban affairs, with several degrees in city planning represented. Professors de Neufville, Hershendorfer, and Manheim participated in deliberations of the Institute's role in urban affairs by an Institute-wide "Junior Faculty" committee. As independent consultants to the city, these faculty members and Professor Roos provided assistance in the development of the "Model Cities" proposal by the City of Cambridge to the Department of Housing and Urban Development.

The faculty of the Division have also played a major role in professional activities. Professor Hershendorfer organized and was appointed first chairman of the Special Interest Committee on Civil Engineering, Architecture, and (City, Regional, and Transportation) Planning (SICCAP) of the Association for Computing Machinery, and organized its quarterly newsletter, the SICCAP Bulletin. Professor Manheim chaired the annual meeting of the Transportation Research Forum (TRF) designing a program of 30 papers to outline the scope of transportation systems

analysis, and was elected to the Council of the TRF. Professors Breuning, de Neufville, and Manheim participated in the Highway Research Board of the National Academy of Sciences through service on a number of committees and departments. Professor Manheim has been invited to serve as a Regional Editor for the new international Journal, *Transportation Research*. Professor Breuning served on the Requirements Sub-panel of the Department of Commerce Panel on Electric Cars.

To summarize, this first year of the Transportation Systems Division has been marked by a broadening of the educational and research programs, and expanded participation by the faculty in professional and community activities.

CIVIL ENGINEERING SYSTEMS LABORATORY

The systems approach to civil engineering has received increasing attention over the past few years. This represents an overdue recognition of the fact that civil engineering involves large projects, which should be engineered in total and not segmented into the traditional discipline areas. The Civil Engineering Systems Laboratory (CESL) is playing a leading role in this development.

CESL is a unique organization. It has no rigidly defined structure and cuts across the conventional boundaries of interest within the Department. Its purpose is to provide a focal point for the general interest in systems and a vehicle for the interchange of ideas in this area. Under the directorship of Professor Biggs, faculty and students from all divisions of the Department participate in what has become a very stimulating activity.

Although academic programs are primarily a divisional responsibility, CESL is directly involved in offering those subjects that are clearly intra-departmental in nature and provide a foundation in systems for the whole Department. Subject areas in this category include: Computer Systems (Professors Roos, Logcher, Perkins and Assistant Professor Jay R. Walton), Numerical Methods (Professors Elias and Christian), Mathematical Optimization (Professor Hershendorfer and Felipe Ochoa-Rosso), Decision Theories (Professor Manheim), Simulation Methods (Professor Walton and Mr. Sussman), Probabilistic Systems (Professors Bisbee and Cornell), and Civil Engineering Projects (Professors Hansen, Bisbee and deMello). The faculty is pioneering in this field and new approaches and subject offerings are constantly being developed. Professor Logcher will present a new subject on information processing in the structural design field; Professor Cornell is experimenting with the use of laboratory sessions in the teaching of stochastic processes; and Professor Roos introduced a new subject on computer usage in civil engineering

from a professional viewpoint. Professor Perkins and Mr. Sussman have assisted the Center for Advanced Engineering Studies (CAES) in developing a computer facility and teaching a subject on the facility for CAES participants.

As a result of the expanding influence of the systems concept on the civil engineering curriculum, an increasing number of doctoral students are placing a major emphasis in this area. Such students retain an identification with one of the divisions of the Department representing their application area of interest. However, the activities of CESL have resulted in a broadening of doctoral programs in civil engineering.

The major CESL research effort during the past year has been the development of ICES (Integrated Civil Engineering System) which is a large scale computer system encompassing the engineering process at the project level. More than a collection of computer programs, ICES represents not only a new concept in computer usage but a new approach to the practice of engineering. It consists of a framework of systems programs that monitor an unlimited number of subsystems, each dealing with a particular problem area. Thus the system is potentially applicable to a wide range of engineering problems. In keeping with CESL objectives, ICES will utilize the power of the computer more effectively as an information processor, as well as a calculator, thus enabling the engineer to realize the benefits of the systems approach.

The ICES system design has been accomplished by a special task force under the chairmanship of Professor Roos; it includes Professor Logcher, Professor Walton, Professor Hershdorfer, Mr. Sussman, Richard V. Goodman, Alden T. Foster, Ronald A. Walter, and M. Elizabeth Schumacker. This effort required fundamental research in computer technology and the development of new programming techniques.

Under the general supervision of Professors Charles L. Miller and Biggs, the ICES project involves a large number of faculty and students from all units of the Department. It provides a vehicle for those interested in computer systems to develop applications in their area of interest and to make the results readily available to the profession. In the field of structures, Professors Logcher, Sturman, and Cornell, and Leland C. Albertson Jr., are developing subsystems that encompass the entire structural design process. Professors Miller and Bone, and William F. Johnson, Thomas N. Harvey, Mr. Suhrbier and Mr. Ruitter are creating ICES components for highway engineering, including roadway location and design, traffic studies and transportation network analysis. In the field of water resources Professors McLaughlin and Perkins are extending ICES to include hydrologic systems. Professor Hershdorfer and Mr. Ochoa-Rosso are developing a mathematical Optimization Subsystem

applicable to all engineering fields. Professors Whitman and Christian and Carl A. Schiffman are utilizing ICES to apply the computer to problems in soil mechanics. The systems approach to architectural design, including the interface with engineering disciplines, is being explored through ICES subsystem development by Professors Hershendorfer, Dietz, and Mr. Teague. William H. Linder and others are developing a construction scheduling subsystem for use by the Massachusetts Bay Transportation Authority.

The CESL staff has presented a series of conferences and seminars on ICES, including a summer session jointly sponsored by the Center for Advanced Engineering Studies which was attended by more than 100 engineer-administrators from all parts of the country. Widespread interest in the ICES concept is evident. All indications are that ICES will have a significant impact on the civil engineering profession.

The CESL computer facility has continued to expand during the past year. It now consists of an IBM S/360, Model 40 (256K core and three disk drives), and an IBM 1130. This facility is used extensively by students and has become an important and integral part of the academic program in civil engineering. The IBM 1130, and a time-sharing terminal are located in the computer classroom, which continues to be an effective environment for engineering instruction.

In addition to software system development (e.g., ICES), the CESL staff is interested in the adaptation of the latest hardware for engineering design purposes. Professor Walton has developed a teleprocessing system utilizing remote teletypes on the Model 40. In addition, he and Mr. Foster have incorporated the 1130 into this system, thus providing a more powerful remote terminal suitable for an engineering design office.

As of July, 1967, Professor Roos will become Director of CESL. It is expected that under his leadership the laboratory will continue to grow, to contribute to the advancement of civil engineering practice, and to stimulate further progress in the systems area within the Department.

THE INTER-AMERICAN PROGRAM IN CIVIL ENGINEERING

Perhaps the most exceptional aspect of the IAP at this time is that it is no longer regarded as unusual; it has become an integral part of the activity spectrum of the Department and it continues to evoke strong support at the working level. Thirteen projects are under way, with collaborating groups in Mexico, Chile, Venezuela, Brazil, Argentina and Colombia. Each of the five divisions of the Department is involved, representing an aggregate of approximately 75 persons, none on an exclusive basis. The research being done is in all respects comparable to that performed under more conventional support; in fact, no distinc-

tion is drawn. Technical reports are published by each project at logical points in the work and quarterly progress reports presenting a summary of the entire Program are also issued.

A new kind of international cooperation in technical education has evolved in the IAP. By concentrating on the principle of Latin and M.I.T. individual educators performing research together, it is possible to bypass many of the institutional constraints that have generally weakened overseas programs. By not requiring the M.I.T. faculty member to be absent from the Institute for prolonged periods of time, and by making research the principle component, we are able to enlist our best talents in the Program. By avoiding formal commitments with the Latin schools, we circumvent administrative delays and retain an operational freedom which would be difficult under other circumstances. In many instances our projects have continued to function productively through political unrest and upsets which have totally stopped other, more formalized cooperative relationships. And by working with gifted and motivated Latin engineering professors, we are able to strengthen their capacity to achieve and contribute in their own professional environment, better insulated from the digressive influences which frequently dissipate their resources.

Many of these points can be shown better by a specific example. For several years we have had a very productive set of relationships with men in the School of Engineering of the University of Chile in Santiago. Materials, water resources, structures, computers and transportation have been the areas involved. A number of their people have been at the Institute earning graduate degrees, participating in research programs, or serving as visiting faculty. Many M.I.T. personnel, faculty and students, have been in Santiago, some for periods of many months. More than a year ago Project Camelot, which was an attempt to study certain internal Chilean affairs, was seized upon by radical elements in Chile as a prime example of U.S. intervention. Considerable turmoil ensued, but through it all our research went on without interruption. The Camelot affair had literally no effect on the IAP projects there.

The professional calibre of our associates at Santiago and their motivation can be illustrated well by another event of a far different nature. For some time, the ICES effort has commanded significant amounts of our Department's research resources. It is a sophisticated system that will have an effect on the practice of civil engineering in the decades ahead. Now operational at M.I.T., it was just recently made functional at the Computation Center of the University of Chile. In one week they "got the system up" and performing satisfactorily. Later, a group from M.I.T. led by Professor Biggs joined a similar group from the Center

to present a one-week workshop on ICES to a large number of Latin participants, from Chile and from other parts of South America. The men at the University of Chile evoke our respect for their accomplishment.

So the Inter-American Program continues to function and continues to encounter situations that are novel, challenging and productive. We anticipate no significant changes in the coming year but we remain alert to new opportunities should they arise. The flexibility of the Program will permit us to exploit them, if they do.

HONORS AND AWARDS

The outstanding work of the faculty of the Department was recognized by numerous honors and awards received during the year.

Professor Ippen was elected to membership in the National Academy of Engineering and honorary membership in the Venezuelan Society of Hydraulic Engineers. The Technical University Karlsruhe, Germany, awarded Professor Ippen an honorary doctor's degree.

Professor Harleman was awarded the Desmond Fitzgerald Medal of the Boston Society of Civil Engineers. Professor Jones received the Collingwood Prize of the American Society of Civil Engineers. Professor Hansen received the Transportation Section Award of the Boston Society of Civil Engineers.

Professors Biggs, McGarry, and Miller and undergraduate students Robert Gladstone and Anthony Kettaneh were cited in the *Engineering News Record* annual "Men Who Made Marks" editorial and were honored at the Construction Man of the Year dinner in New York.

Professor Miller received the 1966 George Westinghouse Award of the American Society for Engineering Education.

Professor Manheim received the Army Commendation Medal for his work in systems analysis in military transportation while on active duty with the U.S. Army.

FACULTY AND STAFF

Professor Bone retires this year after 34 years on the staff of the Department. The Department is indebted to him for his long and loyal service as one of our most dedicated and hard-working teachers. Professor Bone's many friends and former students will be pleased to know that he is in good health and plans to continue as a Senior Lecturer in the Department.

We were honored to have Dr. Victor F. B. deMello of Brazil and Dr. Jacob Bear of Israel as Visiting Professors for the year. Dr. deMello held the National Science Foundation (NSF) Senior Foreign Scientist

DEPARTMENT OF ELECTRICAL ENGINEERING

Fellowship at the Institute for the year. Dr. John C. Scrivener of New Zealand joined us as Visiting Associate Professor early in 1967 and will be with us for the year.

After many years of affiliation with the Department, Professor Dietz will be full time in the Department of Architecture at the Institute starting with the next academic year. Professors Lambe and Eagleson have been on sabbatical leave for one term during the past year.

Professors Pahl and Roesset will be returning from assignments in West Berlin and Chile respectively and Assistant Professor Kenneth F. Reinschmidt will be returning from military leave. Professor Sturman has resigned to accept a position as Assistant to the President of Parsons, Brinckerhoff, Quade, and Douglas. Professor Bisbee has resigned to accept a research position with the Department of Naval Architecture and Marine Engineering at the Institute. Professor Lüscher has accepted a position with Woodward, Clyde, Sherard and Associates, consulting engineers and geologists, and Professor Höeg is returning to Norway.

We were pleased to have Professors de Neufville, Bromwell, Christian, Cross, and Roos join us as new members of the faculty during the year. John Clarkeson, well-known consulting engineer, joined us as Visiting Engineer and will continue during the coming year as Senior Lecturer. Mr. Trond H. Kaalstad was appointed Administrative Officer of the Department. Henry Bruck and Miss M. Elizabeth Schumacker have been appointed Lecturers in the Department.

CHARLES L. MILLER

DEPARTMENT OF ELECTRICAL ENGINEERING

THE UNDERGRADUATE PROGRAM

During the 1966-67 academic year the three undergraduate classes in Course VI had enrollments of 218 sophomores, 213 juniors, and 212 seniors. Of these 643 students, 460 were in VI-1 (Electrical Engineering) and 183 were in VI-2 (Electrical Science). The cooperative program, VI-A, had a total undergraduate participation of 72, drawn from both the VI-1 and VI-2 programs.

Electrical engineering disciplines such as electronics, control, and computer programming and theory have become basic background material for many other departments. As a result, nearly half the enrollment in our undergraduate subjects consists of non-electrical engineering students.

In a field that is changing as rapidly as electrical engineering, the question of how to organize the undergraduate curriculum is under con-

stant discussion. Within the four-year undergraduate span, the subject material available to the student must meet the following conflicting needs: provide a cultural and a general scientific background, provide the foundation in the relevant engineering sciences, and give the student some skills in current engineering design and practice. In electrical engineering, we have depended since 1954 on a common core curriculum to provide the basic engineering sciences. The undergraduate electives available to the student permitted him either to broaden his scientific background, or else to acquire more specific knowledge and understanding of some narrow field of specialization.

During the last two years our curriculum has been the subject of careful re-examination. This has been motivated by two distinct problems. First, the present core curriculum is basically one in electrical science. However, the recent rapid growth in the computer sciences has made it clear that for a substantial number of students, the transformation laws for symbols and information are at least as important as are the conservation laws for matter and energy. And second, even for those students whose concern is with engineering devices and systems, the computer has become an essential tool not only for numerical problem solving but for helping to visualize and understand complex phenomena.

With these problems and the general objectives of an undergraduate education in mind, the Department is proceeding along three courses of action. First, a sequence of three subjects — Programming Linguistics (6.231), Computational Structures (6.232), and Basic Issues of System Complexity (6.233) — in the area of computational science are being developed under the leadership of Professor John M. Wozencraft, Associate Professor Jack B. Dennis, and Professor Fernando J. Corbató. Initially, these subjects will be regarded as an elective sequence whose purpose is to provide students with a solid background in the fundamentals of computational sciences. The faculty developing this particular sequence of subjects envisions its development into a core curriculum for students whose major interests are in the field of computer science. The first of these subjects was taught for the first time to a group of about 20 students during the second term of the 1966-67 academic year. The other two subjects will be taught for the first time during the 1967-68 academic year.

The second course of action along which the department is proceeding is a resynthesis of the present core curriculum. Two objectives are in mind here. First, the time allocated for the various divisions of subject matter will be redistributed in an attempt to make the core somewhat more representative of the Department's interests. And second, material on the use of the computer as both a tool for numerical problem solving

and as an aid to the visualization and understanding of complex phenomena will be included.

The third course of action represents the development of a number of elective sequences. The recent revisions of the Institute requirements make available a number of time slots which could be filled by either additional Department requirements or additional electives. The Department has decided that these additional time slots could be put to best advantage by the student if good elective strings were available to him. To this end, a number of sequences of electives are now being developed. In addition to the computer science sequence mentioned above, the following sequences are being developed:

1. Two classroom and two laboratory subjects are the goal of a sequence on digital systems and logical design which is being developed by Assistant Professor James D. Bruce, Associate Professor F. F. Lee, Assistant Professor Richard N. Spann, and Associate Professor Donald E. Troxel. This sequence will be offered for the first time in the 1968-69 academic year.
2. An elective subject in Continuum Electrodynamics and Waves (6.58) which uses 6.07 as a prerequisite has been developed by Associate Professor Abraham Bers in association with Professors Hermann A. Haus, Associate Professor James R. Melcher, Associate Professor Frederic R. Morgenthaler and William B. Lenoir from the electromagnetics and electrodynamics areas. Even though this subject is offered as a first-year graduate subject, it will serve our seniors.
3. A sequence of subjects in the control area is being planned by Associate Professors Roger W. Brockett and Leonard A. Gould. This sequence of subjects will introduce to the undergraduate curriculum a number of the concepts of modern control theory now taught in graduate subjects offered by the Department.
4. Also in the planning stage is a sequence of electives in the materials area.

With an ever-increasing emphasis on theoretical understanding, it is important to keep the laboratory subjects stimulating both to students and faculty. With this aim, the Department's laboratory requirements have been modified to give the student a greater range of subjects from which to choose. Only one specific laboratory subject, Experimental Electronics (6.70), is now required. An additional 18 units must be accumulated from among a number of subjects, including the project laboratories listed below which were offered for the first time this year.

Digital Systems Project Laboratory (6.711)

Bioelectronics Project Laboratory (6.712)

SCHOOL OF ENGINEERING

Communication Systems Project Laboratory (6.713)
Electronic Light Measurements Project Laboratory (6.714)
Electromechanics Project Laboratory (6.715)
Particle Optics Project Laboratory (6.716)
Audio Frequency Communication Project Laboratory (6.717)
VHF Circuits Project Laboratory (6.718)
Semiconductor Devices and Circuits Project Laboratory (6.719)

Some feeling for the type of projects done by the students in these laboratories can be obtained by considering the titles of several projects which received awards. J. Payne Freret Jr. received the first-prize award for his project titled, "Automatic Control Via Touch-Tone Telephone," in the competition for the Electrical Engineering Open House Award. This competition was sponsored jointly by the Department Stu-Fac Committee and the Institute's Eta Kappa Nu Chapter. The Morris J. Levin Awards were presented to James S. Cornell, Ellis E. Eves II, and Mark H. Johnson for their joint project, "Quadratic Equation Display," and to William H. McCandless for his project, "Synchronous AM Detector.

In addition to its large student body, the Department of Electrical Engineering also has an Institute-wide influence through the large number of out-of-department students registered in electrical engineering subjects. Registration statistics for the 1966-67 academic year are shown in Table I.

An undergraduate curriculum can be effective only if the entire faculty is concerned continually with the relevance of the material taught and the methods of teaching it. Table II presents some statistics showing to what degree the Department's faculty is involved in the teaching of undergraduate lectures and recitations. This table compares the number of recitations and lectures taught by the various components of the Department faculty and staff for the 1966-67 academic year. It is interesting to note that since there are approximately 100 faculty members in the Department (not counting regular faculty on leave or visitors), on the average every faculty member teaches one recitation section of some undergraduate subject per academic year.

THE GRADUATE PROGRAM

The graduate enrollment of the Department was 406 regular and 152 special students during the past year. Of them, 16 were instructors, 121 held fellowships, 92 held teaching assistantships, and 116 held research assistantships. In September, 1966, there were 222 enrolled for the Master of Science degree, 30 for the Electrical Engineer degree, and 154 for the Doctor of Philosophy and Doctor of Science degrees.

The doctoral qualifying examination is a perennial problem everywhere; it is probably even more troublesome in a department as large and diversified in interests as is ours. The following paragraphs describe our most recent attempt at providing a meaningful examination system that would fulfill the dual roles of screening students and of providing diagnostic-corrective information for the individual students.

Table I Student Registration in Course VI Undergraduate Subjects for the 1966-67 Academic Year

	Course VI students	Non-Course VI students	Total
Core Curriculum subjects	1269 (80%)	315 (20%)	1584
Computer subjects			
6.47	104 (11%)	810 (89%)	914
Other computer subjects	280 (45%)	344 (55%)	624
Sub-Total	384 (25%)	1154 (75%)	1538
Laboratory subjects	521 (87%)	77 (13%)	598
Elective subjects	543 (57%)	407 (43%)	950
Total	2821 (51%)	2763 (49%)	5584
Total not including 6.47	2717 (58%)	1953 (42%)	4670

Table II Tabulation of the Undergraduate Teaching Activities of the Faculty and Staff of the Department of Electrical Engineering 1966-67 Academic Year

Taught by	Recitation	Lecture
Faculty	105 (51%)	22 (79%)
Lecturers and Instructors	30 (15%)	4 (14%)
Teaching Assistants	41 (20%)	2 (7%)
Other	29 (14%)	0
Total	205	28

All new regular graduate students with an electrical engineering background — regardless of level or degree objectives — take a preliminary written examination in February of their first year of registration. This examination consists of four three-hour closed-book sections on successive days, of which two must be selected by each student. The current titles of the four sections are:

1. Circuits, Signals and Dynamic Systems
2. Electromagnetics and Dynamics
3. Electronic Material devices and Circuits
4. Computation and Logical Design.

The preliminary written examination is designed to probe knowledge that is contained in most undergraduate electrical engineering curricula

(at least, if electives are included). The examination is graded and the results are discussed in detail with each student. No attempt is made to establish a passing grade for the examination as a whole and the examination usually cannot be repeated, but students whose grades fall in roughly the bottom quarter are generally discouraged from planning to seek the doctorate.

After a student interested in the doctorate has completed two to three terms of graduate study including a Master of Science thesis or equivalent project, he may apply for an Oral Qualifying Examination. His application is assigned by the Graduate Committee to one of (currently) seven area committees. Each area committee is composed of five to seven graduate counselors and other senior faculty members with common or related research interests. To preserve flexibility, the boundaries between the domains of the area committees have intentionally been kept vague, and any attempt to associate uniquely each member of the Department with one area committee has been resisted.

In most cases the student's application for an Oral Qualifying Examination is assigned for evaluation to that Area Committee which most closely matches the student's future area of specialization. The Area Committee schedules an oral examination that is intended to explore both the applicant's preparation for research as well as what he has learned from his graduate studies to date (including S.M. thesis). Taking into account all the evidence available — including the quality of the S.M. thesis and such personal impressions as the faculty may have gained, as well as the results of the Oral Qualifying Examination and the Preliminary Written Examination — the Area Committee then recommends to the Graduate Committee (in favorable cases) that the student be considered qualified for doctoral study. The Oral Qualifying Examination may be repeated, but no student may remain registered as a candidate for the doctorate beyond two years unless he is qualified.

The Area Committees have direct responsibility for the programs and oral examinations of all doctoral candidates in their area of research. The Area Committees also assist the Graduate Admissions Committee in evaluating applicants for admission with advanced degrees or non-electrical engineering backgrounds.

The procedure for selecting new graduate students has evolved over the past few years into its current pattern. Each year, we receive about 705 applications, 110 are from present (or recent) M.I.T. undergraduates, 330 from other U.S. and Canadian schools, and 265 from foreign countries. In 1966-67 we finally registered 164 as new students: 66 from M.I.T., 69 from other U.S. and Canadian schools, and 29 from foreign countries.

An admissions group consisting of Frederic H. Fairchild and a faculty committee reviews each application and rank orders them for admission and for financial aid. In general, admission is to the Department as a whole rather than to a particular area (computers, solid state, etc.), and no internal quotas of new students are allotted to these groups. However, each major research group is represented on the admissions committee and is thus able to identify applications of special interest to it.

RESEARCH ACTIVITIES

The bulk of the research in the Department of Electrical Engineering is carried on within the framework of several laboratories. The distribution of departmental manpower among these labs is indicated in Table III. Because there are separate sections of this report dealing with each of these laboratories, their activities are only summarized here; and, in addition, a few highlights are dealt with separately.

RESEARCH LABORATORY OF ELECTRONICS (RLE)

In this interdepartmental laboratory, faculty and students from a dozen academic departments conduct basic research in three broad fields — general physics, plasma dynamics, and communication sciences and engineering.

The research in general physics includes a variety of topics such as molecular beams, microwave spectroscopy, radio astronomy, solid-state microwave electronics, optical and infrared spectroscopy, noise in electron devices, electrodynamics of media, and physical optics of invertebrate eyes.

Table III Electrical Engineering Staff on DSR projects

	Energy Space Center	Research Laboratory of Electronics	Project MAC	High Voltage Laboratory	Materials	Electronic Systems Laboratory	Operations Research	
Faculty	4	2	52	14	1	18	11	1
Research Associates	0	—	7	1	0	3	0	0
Research Assistants	1	4	28	13	4	21	22	3
DSR	0	—	18	43	4	13	39	0
Teaching Assistants and Instructors	9	—	40	2	0	11	5	4
Graduate students	5	—	65	6	0	19	16	6
Guests and postdoctoral fellows	0	—	10	2	0	2	11	0

The research on plasma dynamics includes studies of the basic properties of plasmas as well as engineering applications such as controlled nuclear fusion for energy conversion. Intensely ionized plasmas are being

produced both by high-power electron beams and by microwave radiation. Plasma phenomena in solids are being studied theoretically and experimentally.

The research on communication sciences and engineering includes studies related to signal generation, transmission, processing and utilization in man-made and living systems. The major areas of research are circuit and system design, communication theory, information processing and transmission, linguistics, speech communication, cognitive information processing, communications biophysics, and neurophysiology.

A combined research and training program in communications bio-engineering has been initiated recently. The program will be based on the research in speech communication, cognitive information processing, communications biophysics, and neurophysiology. The program will provide increased opportunity for doctoral training of electrical engineering students in areas related to the life sciences, as well as postdoctoral training for biological or medical scientists.

The Department of Electrical Engineering is the largest participant in the research activities in RLE. Currently, about 52 of the Department's faculty, 10 postdoctoral research staff, 133 graduate students and 36 undergraduates are engaged in a variety of projects spanning most of the research categories mentioned above.

During the last year, 13 doctoral, seven Engineer, 32 Master of Science and 30 Bachelor theses in electrical engineering were based on research supported by the Laboratory.

A more detailed report on the Research Laboratory of Electronics, covering some of the year's research accomplishments, appears elsewhere in this volume.

ELECTRONIC SYSTEMS LABORATORY

Faculty and staff members of the Laboratory conducted a diversified program of research, with active participation by 70 students at the graduate level and 31 at the undergraduate level. A total of 48 theses were completed, and degrees earned were as follows: four at the doctoral level, five Electrical Engineer, 24 Master's and 15 Bachelor's degrees. John E. Ward, Assistant Director of the Laboratory since 1959, was appointed Deputy Director; to assume a considerable part of the Laboratory administrative responsibilities and to permit Professor John F. Reintjes to devote more of his time to Project INTREX.

Students and staff working with Professor Reintjes, Associate Professor Alfred K. Susskind and Assistant Professor James K. Roberge on computer-oriented information-transfer systems for Project INTREX have greatly expanded their research program. Their objective is to

develop an experimental storage and retrieval system for selected area of the materials science and engineering field. Included in their project is a plan to develop an enriched catalog of 10,000 documents which will be placed in computer store and which can be read through use of special computer consoles being developed by the group. They are also investigating techniques that will provide guaranteed rapid access to the full text of the documents through use of wide-band communication links and soft- and hard-copy display devices. The system will be evaluated experimentally in the M.I.T. Engineering Library.

The spacecraft radar group under Professor Reintjes is concentrating its efforts on a forthcoming flight-test program. The group is developing a radar instrument for measuring the electromagnetic reflection coefficients of planetary bodies. The flight tests, scheduled for October, 1967, are expected to yield useful information on reflection coefficients of selected types of terrestrial surfaces as well as an engineering evaluation of instrument performance. In another radar research program under Lawrence R. Swain Jr., and Godfrey T. Coate, a real-time "direct" processor for airborne mapping radars is being studied, involving a novel cathode-ray tube. The tube has been fabricated by an industrial vendor, and a demonstration of feasibility should occur during the coming year.

The Display Group under John E. Ward and Robert H. Stotz continued work in display systems for man-computer interaction. A PDP-7 buffer computer was added to the ESL Display Console at Project MAC to investigate techniques for future remote operation of such consoles. A second ESL Display Console was placed in operation at the M.I.T. Computation Center to make displays available to a wider segment of M.I.T. students and staff. Good progress was made in the development of a low-cost storage-tube display console with both alphanumeric and graphical capability. This can be driven by telephone lines, and it is planned as an eventual replacement of teletypewriters as terminals for time-shared computer systems. A prototype was installed in the Center for Materials Science and Engineering; two more are being made for the Lincoln Laboratory and the Center for International studies.

Assistant Professor Michael L. Dertouzos and the students working with him completed plans for CIRCAL-II, a second-generation program for on-line circuit design, which combines the features of the previous programs CIRCAL-I and AEDNET, and provides many additional features. Implementation is continuing, and a substantial effort is planned in using CIRCAL-II for circuit design practice within M.I.T., and in cooperation with the National Aeronautics and Space Administration (NASA) and the Lincoln Laboratory. Closely related to CIRCAL-II is research being con-

ducted in mathematical foundations for efficient on-line design with two main approaches: solution of non-linear networks by functional inversion, and techniques for "tearing" networks for solution "a piece at a time." The group is also investigating threshold-logic network synthesis and computer-aided system analysis and simulation.

The Computer-Aided Design Project under Douglas T. Ross and Clarence G. Feldmann, aided by 12 visiting staff members from industry, continued research on the AED (Automated Engineering Design) family of computer languages and systems. Preliminary versions for the IBM 7090-series computers are in substantial use within M.I.T. and in about 20 companies cooperating in the program. Present work is aimed at translating AED to several newer computers (IBM 360, Univac 1108, and GE 645) by the end of the year, and applying the techniques to specific mechanical design areas.

The interest of faculty and students in control-related activities continues at a high level, and there is considerable coupling with the academic program. Registration in ten subjects totalled 286 students — 35 undergraduates and 251 graduates. Of the theses previously mentioned, one doctoral, 17 Master of Science and/or Engineering, and eight Bachelor's theses were in the control area under the supervision of a staff of six faculty members, one instructor and three assistants. A total of 21 graduate students in control received support as Research Assistants or full-time staff members through seven contracts and grants within the Electronic Systems Laboratory (ESL). The research topics of these contracts and grants are reviewed below.

In cooperation with the Department of Chemical Engineering, Professor Gould and his students have continued their investigation of problems in chemical process control and distributed systems. Attention has been focused on input-output stability of chemical reactor cascades; profit-optimal control of recycle plants and the fluid catalytic cracker; modal analysis and control of the TVA ammonia reactor, the Lamont boiler, and a heated rod; and preliminary studies of computer graphics and system organization for Computer-Aided CHEmical Engineering design (CACHE).

Professor George C. Newton Jr., Associate Director of the Laboratory, and associated staff and students are studying problems in the guidance and control of underwater vehicles. A real-time simulation on the PDP-1-X computer is being used to evaluate the performance of guidance systems in which the allocation of tasks between manual and automatic equipment and the effectiveness of computer-generated displays are being studied. Theoretical studies are also under way on "optimal control against multiple target sets."

Associate Professor Michael Athans, Professor Brockett and a team of graduate students continued their research in the fields of non-linear systems, stability theory, and optimal control. New results, related to the circle criterion for the stability of non-linear systems and the optimal control of strings of vehicles, have been obtained. New research on computational algorithms and suboptimal control of complex dynamic systems was started.

A number of other research projects are in progress but only can be mentioned here. Associate Professor Fred C. Schweppe has been studying signal design for communications using optimal control theory; Professor Newton, Dr. Richard W. Bush, and John O. Silvey are developing a new form of rate gyroscope. In addition, real-time simulation is being studied in relation to the automobile driving task.

Both faculty and staff were active in presenting the results of their research at various meetings of the professional societies. Professor Newton served as Chairman of the Education Committee of the American Automatic Control Council, and John E. Ward as past President of the Council. Professor Athans is Chairman of the Non-linear and Optimal Systems Committee of the Institute of Electrical and Electronic Engineers (IEEE) Automatic Control Group, and Professor Brockett is Chairman of the Stability Theory Committee of the same group.

During the year, the first phase of the move of the Laboratory from Building 32, its home since 1941, to Building 35 was completed. Additional space is being renovated, and it is expected that all elements of the Laboratory will be housed in the new quarters by the end of the year.

Details of individual research programs are reported separately in the Annual Report of the Laboratory.

PROJECT MAC

The Department of Electrical Engineering provides the largest faculty and student participation in Project MAC, an interdepartmental research laboratory in the computer sciences. Project MAC is directed by Professor Robert M. Fano and is housed presently in an office building adjacent to the M.I.T. campus. During the last academic year this research community included 14 members of the Department faculty, five Lecturers, 13 Research Assistants and seven fellowship students. In addition, 19 other members of the Department faculty and 25 Research Assistants and graduate students were associated with Project MAC for the purpose of exploring the use of its time-sharing computer system in other branches of electrical engineering.

Professor Corbató and Associate Professor Edward L. Glaser are leading the development of the Multics time-sharing system, which is expected

to be in useful operation in early 1968. This system, which embodies the results of research carried out over the past few years, will provide a very useful test bed for future system research as well as much more powerful and flexible facilities for work in other fields.

Professor Marvin L. Minsky is leading a research project aimed at developing a visually controlled manipulator. Most effort during the last year has been devoted to hardware and software instrumentation, and is turning now to more basic problems of automatic scene analysis.

Professor Dennis' group on computing structures is concerned with such topics as asynchronous parallel processing, organization and addressing of virtual memories, and table-driven compilers.

The work of Professor Wozencraft's group on computer linguistics is concerned with the theoretical and conceptual foundations of computer languages. This research is related intimately to the development of a first subject of an undergraduate program in the computer sciences.

The work of Associate Professor Joseph Weizenbaum and his group is aimed at developing conversational programs capable of constructing models of reality on the basis of unstructured information provided in natural language. This research has a direct bearing on computer-aided instruction; a classroom experiment will be conducted next fall in conjunction with the introductory computer subject offered by the Department.

A more detailed report on Project MAC appears elsewhere in this volume.

STROBOSCOPIC LIGHT LABORATORY

Dr. Jurgen Krochmann, of the Technical University of Berlin, was a Visiting Professor for one year in the Stroboscopic Light Laboratory beginning about February, 1966. During his first term he attended Associate Professor Parry Moon's lectures on illumination and the scheduled meetings of 6.202 (Electronic Light Measurements). Professor Krochmann taught 6.202 during the fall term, changing the form of the subject to fit his interests in illumination.

Shortly after Professor Krochmann departed for Germany in January, 1967, a Visiting Professor from the University of Tokyo arrived for a one-year stay. Dr. Tsuneyoshi Uyemura brings to the Laboratory a long experience with high-speed cameras.

Fred Centanni Jr., served as the teaching assistant during the 1966-67 school year.

Professor Harold E. Edgerton spent the summer of 1966 in Greece and Israel with sonar research equipment for geological and archaeological studies. He also took a sabbatical leave (from September, 1966

to January, 1967). Part of his time was spent in Germany and Greece. A sonar study of part of the Bay of Corinth was conducted with Professor Spiro Marinatos of the University of Athens. The search was for a city, Helice, which disappeared in 325 B.C., according to ancient historical accounts. Further sonar and excavation studies are required. It is proposed that a sediment pump or air lift be arranged to move some of the sediment that overlays objects that produce subbottom sonar echoes. This activity would have been under way now (aboard the R. V. *Calypso*) except for the Israel-Arab war which held up the *Calypso* in her voyage through the Suez Canal from the Red Sea.

Funds for an elapsed-time underwater camera and a plankton camera have been made available by the Research Committee on the National Geographic Society. As of June 22, 1967, two 50-foot rolls of film have been exposed in Boston Harbor, near Boston Light, after several test runs were made in the M.I.T. swimming pool and the dock area of Boston Harbor. The movie films at Boston Light were taken at 70-second intervals. A vane in the field of view shows the direction of the currents.

The elapsed-time motion picture films showed the motion of many star fish on the bottom, and the activity of the tidal currents at a depth of about 40 feet. Both dirty and clear water surged back and forth during the 30 hours that the gear was on the sea bottom. The motion picture method seems to be of great promise for the study of long-time seabottom activity. Other studies with this equipment are under way.

During the spring term, a freshman seminar group considered stroboscopic circuit design and performance. Each student presented reports on each of the pioneers in short-flash photography. The research material was obtained from historical books, magazines, and reprints.

HIGH VOLTAGE RESEARCH LABORATORY

The High Voltage Research Laboratory, under the direction of Professor John G. Trump, continued its activities in two related areas:

1. The use of megavolt x-rays and electrons in the control of malignant disease in humans, and in certain biological and physical studies, and
2. Investigations directed toward increasing the voltage-insulating capability of high vacuum and of compressed gases.

In the past these studies on vacuum and compressed gas insulation have contributed to the development of compact Van de Graaff electrostatic particle accelerators for research in nuclear structure physics and for improved x-ray therapy in medicine. During the last two years these studies have had additional motivations. Compressed-gas-insulation possesses properties that seem uniquely suitable for the underground

installation of high voltage electric power transmission lines. Experimental studies on short lengths of gas-filled concentric transmission lines provided further strong support for this proposition. A paper was presented at the 1966 Annual Conference on Electrical Insulation and Dielectric Phenomena by Dr. Sanborn F. Philp and Professor Trump on "Compressed Gas Insulation for Electric Power Transmission" and one by Professor Trump at the 1967 National Particle Accelerator Conference on "New Developments in High Voltage Technology."

The second International Symposium on Insulation of High Voltages in Vacuum, under the chairmanship of Professor Trump and the joint sponsorship of M.I.T. and the University of Illinois, was held in Kresge Auditorium on September 7 and 8, 1966. A report was presented by Chathan M. Cooke on "Residual Pressure and Its Effect on Vacuum Insulation."

Further research in vacuum insulation with high voltage gradients and total voltages up to 70 kv has been carried out to study the effects of dielectric coatings to suppress field emission from cathode surfaces. Studies have also been conducted on the problem of the production of microbeams and the resultant anode heating under high voltage gradients. It is expected that these programs will aid in the attainment of stable operation at higher voltage gradients.

The physical-clinical investigation program which has the cooperation of the medical staff of the Lahey Clinic Foundation, especially Drs. Magnus I. Smedal and Ferdinand A. Salzman, continued with its development of advanced methods of applying penetrating x-rays and electrons to a wide variety of deep-seated and superficial malignant tumor problems. At the 1967 meetings of the American Radium Society Dr. Salzman presented a paper entitled "A Technique of Renal Protection Using Two Mv Rotational Radiotherapy." A special teaching course on new techniques of radiation therapy was given by invitation for the fifth time by Dr. Smedal and Kenneth A. Wright at the December meeting of the Radiological Society of North America.

The Laboratory has had a pioneering role in the direct application of megavolt electrons for the control of extensive areas of tumor on or just below the skin. A new program has been started, initially using a 100 per cent ambient oxygen atmosphere to study possible beneficial enhancement of the radiation effects in certain selected patients who are undergoing electron therapy for cutaneous disease. Safety studies were carried out prior to clinical application. These programs continue to make the physical, biological, and clinical studies with megavolt electrons an important and rewarding part of the Laboratory's activities.

During the last year three Master's theses were completed and two

Master's and two doctoral candidates have been doing thesis research.

In addition to Institute support, the work of the High Voltage Research Laboratory was made possible by grants for specific research from the National Science Foundation, the National Institutes of Health, the Lahey Clinic Foundation, and the Damon Runyon Memorial Fund for Cancer Research.

SYSTEMS ENGINEERING AND OPERATIONS RESEARCH

About 350 students from many departments participated in the program of subjects which includes Probabilistic Systems Analysis (6.28J-15.09J), Systems Engineering and Operations Research (6.536J-15.594J), Statistical Decision Theory (15.095), and Mathematical Programming (15.59 and 15.592). Related thesis and research work is performed at the Operations Research Center, in which the Department of Electrical Engineering is represented by Associate Professor Alvin W. Drake, Associate Director of the Center.

A textbook, *Fundamentals of Applied Probability Theory*, representing the Probabilistic Systems Analysis subject, was published in February. The Systems Engineering and Operations Research subject was revised this year to condense the presentation of introductory material on Markov processes, allowing time for more general discussions of dynamic programming and advanced probabilistic models.

Established research programs, mostly of a theoretical nature, continue in areas such as probabilistic models, decision analysis and mathematical programming. There has been a rapid increase in interest and research activities in the area of operations research for non-military public systems.

With support from the General Motors Corporation, the U. S. Public Health Service, and the National Science Foundation (NSF), this Center has established research programs in topics such as vehicular traffic flow and control, scheduling of public transportation systems, regional blood-banking systems, allocation of scarce medical resources, and operational aspects of the criminal justice system. A special summer program on such applications was initiated in September, 1966, and will be presented in a more developed form in September, 1967.

In July, 1966, the M.I.T. Operations Research Center began publication of an Annual Report. This document discusses in some detail our educational and research programs in systems engineering and operations research.

POWER AND ENERGY

During the year, Professor Herbert H. Woodson initiated some educational and research activities in power system engineering. He was as-

sisted in these efforts by Alexander Volk, Visiting Associate Professor. A study was started to learn more about the physical processes that lead to contamination flashover of outdoor insulation, a problem that is becoming more important as transmission voltages are increased. A second study is directed toward improving the quality of power-system simulation. Two approaches are being taken:

1. The use of cryogenic technology to make more accurate physical scale models of some of the more crucial components such as turbo-generators;
2. The careful study of analog and digital models to assess the quality of simulation under abnormal conditions.

A third study is concerned with the application of superconductors to produce magnetic fields in large synchronous machines. The continuing demand for larger turbogenerators and synchronous condensers has pushed conventional technology to the point where machine parameters may induce stability problems, efficiency is less than desired, and economies of scale are not so readily realized. Initial theoretical studies of the use of superconducting field windings in these machines have indicated a possibility of significant improvement on all counts. During the year, these research activities involved one doctoral student, two Master of Science candidates, four Bachelor of Science thesis students, and one junior doing a 6.715 laboratory project. One Master of Science thesis and four Bachelor of Science theses were completed this year.

Under the title of 6.241, Engineering Problems, Professors Volk and Woodson taught an elective subject on power system engineering during the spring term.

As part of the plans for a modest expansion of these activities, Assistant Professor Gerald L. Wilson went on leave this year and has been working with the American Electric Power Service Corporation on a Ford Foundation Residency. The experience he gains will enhance the quality of the group effort.

CONTINUUM ELECTROMECHANICS

The major emphasis of the Continuum Electromechanics Group, supervised by Professor Melcher, continues to be on the basic aspects of electrohydrodynamics, with applications such as the storage and handling of cryogenic liquids in the zero-gravity environment of space, power generation, fluid pumping and flow measurement, and industrial processing. Contributions have been made during the past year in four areas where investigations have developed a close tie between theory and experiment:

1. Electrohydrodynamics of thermally stressed fluids where static and

traveling-wave electric fields have been used to create ordered or turbulent motions of slightly conducting fluids;

2. Stability of polarized fluids in situations where field gradient effects are dominant, including a new "bang-bang" mechanism of stabilization that has been demonstrated to be an order of magnitude better for some purposes than previously known effects;

3. Traveling-wave electrohydrodynamic energy conversion, where new classes of pumps and generators have been demonstrated;

4. Continuum feedback control of electromechanical systems, including effects of spatially and temporally quantized feedback.

CHARGED PARTICLE OPTICS LABORATORY

Several projects are under way in the charged particle optics laboratory of Assistant Professor Charles K. Crawford and his students. A program has been set up to explore the feasibility of using small-diameter electron and ion beams as current sources to test microcircuits. These beams would be focused on small circular contact pads built into the microcircuits, which could be much smaller than the test pads presently contacted by mechanical probes. Problems concerning stability, secondary emission, intrinsic brightness, and methods of injecting positive currents, are being considered.

Another project under way is the designing of ion sources suitable for the ion implantation fabrication of semiconductor devices. There is a need for sources that are stable, compact, reliable, require little power, that produce ions only of the desired species, and that can be switched simply from element to element. Ion sources that are to be used to implant by image optics (to make very large numbers of components in one operation, simultaneously and to reduce their size) must have high intrinsic brightness and a narrow energy spread. One promising idea appears to be the use of ions from the plasma produced by the impact of a laser beam on a solid. Problems to be solved include space-charge spreading, recombination within the plasma, and the perveance limit of the extraction geometry.

Work is continuing on the measurement of electron ionization cross sections using a large quadrupole mass spectrometer. A new technique for measuring cross sections which uses two electron-impact ionization chambers stacked in series on a single atomic beam is being perfected. The first chamber modulates the beam while the second chamber detects this modulation, thus allowing the simultaneous absolute determination of the cross section and the number density in the beam. The technique is potentially powerful because, when combined with the mass

spectrometer, it would allow the instantaneous measurement of cross sections and flow rates in a fluctuating multicomponent atomic beam.

Cross sections for single and double ionization of metal vapors, obtained by an atomic-beam-trap weight-gain method, are being published.

A new ultra-high vacuum system has been set up and is in use for the study of space charge neutralization in electron ionization chambers.

A program has been initiated to develop high-intensity atomic-beam sources that are free of charged particles. The major sources of these unwanted particles are the Knudsen-cell bombardment-heating electrons generating ions from background gas, the bombardment electrons themselves, the emission of ions from hot surfaces by surface ionization, and the emission of Auger electrons from electrode surface bombarded by ions. By use of various suppression electrodes, it is possible to obtain neutral beams with all of these effects suppressed to below 10^{-10} amps; further improvement is expected.

CENTER FOR SPACE RESEARCH

The last year has witnessed an increased involvement of the Department in the activities of the Center for Space Research, especially in the area of space communications.

Department faculty participation includes Professors John V. Harrington and Wilbur B. Davenport Jr., and Associate Professor Robert S. Kennedy. Additionally, two lecturers from the Department are responsible for the solar radar and solar plasma probe programs in the Center. Growing student interest is evidenced by the acceptance of five research assistantships in the Center's Laboratory for Space Experiments. Also in residence at the Center through the Department, are a postdoctoral fellow under the sponsorship of the European Space Research Organizations and NASA, a visiting engineer from Japan, and a graduate student under Air Force sponsorship.

The main areas of activity have been the study of space communications, analysis of phased array antennas, and electronic design associated with the Sunblazer experiment. Two recently completed Master of Science theses deal with the problem of communications through a dispersive medium. The phased-array antenna efforts include analysis of the combined effects of random phase errors and quantization effects.

Present indications suggest an increased interaction between the Department and the Center as the expected growth of the Center will provide additional areas of interest for graduate study.

THE READING MACHINE

A machine which will reliably reproduce written text in spoken form is the aim of a project at M.I.T.'s Research Laboratory of Electronics.

Work toward this goal provided a highlight of RLE's Annual Research Review in early May.

The project undertaken by Professors Samuel J. Mason, Lee, Troxel and Murray Eden and Kenneth R. Ingham of RLE started in January of last year. The group hopes eventually to produce portable units which will scan printed pages and read their contents to the blind.

The machine consists of three basic parts. A character recognizer scans printed English text, and translates it into individual letters and punctuation marks. These signals pass into a translator, whose function is to convert the printed letters into the fundamental units of speech, known as phonemes, and to put the phonemes into the context of the sentences in which they appear. The phonemes, with appropriate stresses and pauses added, then pass into a speech synthesizer, which utters the speech through a loudspeaker.

The group completed the character recognizer a year ago. At the RLE Research Review, Professor Lee reported on two new developments in the speech synthesizer and part of the translation unit.

The translator consists of two parts. The first — a grapheme-phoneme translator — converts letters received from the character recognizer into phonemes. This input then passes to a syntax analyzer, which introduces the pauses and stresses necessary to give the listener clues to the context of the speech and hence aids comprehension of the output from the speech synthesizer.

So far, only the first half of the translator has been implemented. In these tests an electric typewriter has been used to provide the input to the translator, thus bypassing the character recognizer, in the interests of saving computer time. Output from the translator is fed into the speech synthesizer, which produces the corresponding machine speech.

In view of the absence of the syntax analyzer, the group is very pleased with the performance of the machine. A number of visitors to Open House recently had the opportunity to hear the machine's performance at first hand.

The development of the syntax analyzer will greatly improve the machine's speech. To this unit will fall the tasks of distinguishing between such possibilities as "refuse" (noun) and "refuse" (verb), of translating "quadruped" as a noun rather than a past participle, and of emphasizing the "e" at the end of words such as "apostrophe" and "recipe." Although English speakers treat these linguistic quirks as natural parts of their cultural heritage, machines have to learn them from scratch.

SOLID-STATE MICROWAVE ELECTRONICS GROUP

Associate Professor Robert P. Rafuse, Dr. Donald H. Steinbrecher and their students in RLE have been working on various problems in communi-

cation-system circuits and components. The Computation Center's time-shared IBM 7094 is being used to do computer-aided design of microwave circuits for varactor multipliers and parametric amplifiers. Precision measurement data on non-linear devices can be processed on the computer to obtain models for devices and processes that are virtually independent of the measurement fixture. A combination of such circuit design and model generation, together with previously derived non-linear circuit analysis allows the design of active microwave, solid-state circuits which are finished, complete and operating, once assembled. Such a "fixed-tuned" approach is necessary if high-efficiency, low-noise, solid-state circuits are to be built at frequencies much above 3 GHz. The technique is the only way in which high-performance millimeter-wave circuits can be obtained. Presently under development, for example, is a low-noise 23.5 GHz parametric amplifier.

Another area of interest in the group is low-noise, high dynamic range circuits. Using MOSFET devices, mixers and phase detectors have been built from dc to HF with dynamic ranges of 120 to 140 db. Work is in progress to develop new receiver techniques around such circuits and devices, with the goal of obtaining receivers virtually invulnerable to high level, out-of-band interference.

LABORATORY FOR INSULATION RESEARCH

The dielectric measurements group of the Laboratory under William B. Westphal continues to develop advanced techniques for high-temperature and high-pressure dielectric spectroscopy from d.c. to the millimeter region and to evaluate — as a public service — materials required by modern technology. Technical Reports 201 and 203 summarize some of this work.

Professor Arthur R. Von Hippel is studying water, ice, solid and liquid electrolytes, and the properties of interfaces, with the aim to create a clearer molecular basis for the understanding of biological problems. The first two reports of a new series have been released. Professor Von Hippel, in addition, continues to serve as a senior consultant of the Office of Naval Research (ONR).

MATERIALS SCIENCE CENTER

The following material highlights the work of the Electrical Engineering faculty and students in the Materials Science Research Center. In addition there have been several students working at the Lincoln Laboratory with Professor Alan L. McWhorter on problems of phonon-plasma interactions in solids, and two students did research at the National Magnet Laboratory on super-conductivity and on lasers.

CRYSTAL PHYSICS LABORATORY

The Crystal Physics Laboratory under the direction of Professor Alexander Smakula is engaged in fundamental research on crystal growth and the physical properties of crystals. The laboratory also provides crystals to other groups at the Institute and elsewhere on a cooperative basis.

Facilities are available for growing crystals by various techniques, including aqueous solution, high-temperature solution, Czochralski, Bridgman, flame-fusion, and hydrothermal synthesis. The laboratory has research equipment for ultraviolet and infrared spectrophotometry and fluorescence spectroscopy, high-precision lattice constant determination, high-precision density determination and dielectric measurements. Other research is concerned with the preparation and study of various oxides, fluorides and halides in the pure and doped state. Low-temperature ferroelectric transitions in perovskite mixed crystals are being studied by various techniques. The influence of temperature and crystal symmetry on the luminescence of perovskites doped with rare earth ions is another topic of study. A study of new optically-pumped laser crystals in the blue and near-infrared regions of the spectrum is in progress.

SEMICONDUCTOR MATERIALS AND DEVICES GROUP

The general theme of the work undertaken here is the relationship between electronic device capabilities and limitations, and the materials employed. These capabilities and limitations may stem from the material itself, or from technology associated with device fabrication. Our work covers both aspects.

Located primarily in the Center for Materials Science and Engineering, the group has developed and expanded from the former Energy Conversion and Semiconductor Devices Group. With the addition of Professor Robert H. Rediker to the faculty a year ago, significant new research effort commenced in three directions: Optical and radiation-detection devices in the lead salts PbSe and PbTe; ion implantation of impurities in semiconductors (in collaboration with the Lincoln Laboratory); and electrical and electro-optical properties of heterojunctions, especially with attention to hot-electron phenomena.

The entire group now comprises Professors Richard B. Adler, Paul E. Gray, Rediker, Associate Professor David H. Navon (Visiting), Associate Professors Arthur C. Smith, Richard D. Thornton and Bruce D. Wedlock, and Assistant Professors Floyd O. Arntz, John N. Churchill, John S. Moore, Daniel L. Smythe Jr., James N. Walpole, Stephen D. Senturia, one DSR staff member, and one guest. Thirty-one graduate students are participating in the program, and the degrees granted during

the year have included six Bachelor's, eight Master's, and four doctorates. External support has come from the Advanced Research Projects Agency (ARPA), NASA, ONR, U. S. Army Electronics Command, U. S. Department of Commerce, NSF Fellowships and Ford Fellowships. In addition to the new research topics described above, the group has continued its activities in the following areas: Interaction between successive diffusants in silicon integrated-circuit technology, including the role of stress and dislocation development in these phenomena; electro-optical (Franz-Keldysh) effects in TiO_2 , CdTe and GaAs, as well as very high-frequency forms of these and related non-linear optical effects; thermal instability and secondary breakdown in transistors; analysis of high-injection phenomena in semi-conductors; development of high-power transistors for use in new kinds of high-power, high-frequency motors of large power-to-weight ratios; design of efficient p-i-n thermophotovoltaic cells to function at high illumination levels; limitations on the close matching of integrated differential transistor pairs; Knight-shift of Pb^{207} and Te^{125} nuclear resonances in PbTe, as a function of conductivity type and carrier concentration (in cooperation with the Materials Theory Group); Hall-effect determination in very high-resistivity materials; theory of junction potentials in wide-gap p-n structures with partially-ionized impurities; and use of computers in circuit design, with a view eventually toward the special problems of integrated circuits.

MATERIALS THEORY GROUP

Under the direction of Professor George W. Pratt Jr., the group has been active in the area of semiconductor lasers, energy band theory, the magnetic properties of narrow band materials, and the theory of equations of state. The laser work has centered about the frequency modulation of a GaAs laser by ultrasonic waves. A signal has been successfully sent and detected on an optical laser FM channel. Work is underway with PbS lasers attempting to establish two separate inverted populations in the same semiconductor cavity. A theoretical treatment is being carried out of the dielectric constant, impurity levels, and photoemission in the Pb salts. A theory of the lattice vibration spectrum for the Pb salts has been evolved, treating successfully the large coupling of the phonons to the electromagnetic field in the solid.

The investigation of correlation in narrow bands has revealed, by a new technique, the presence of a metal-insulator transition and shown under what circumstances the system is ferromagnetic. This treatment has been generalized to yield an equation of state whose ultimate purpose is the description of solid-liquid transitions.

MICROWAVE AND QUANTUM MAGNETICS LABORATORY

The Microwave and Quantum Magnetics Group in the Materials Science Center, directed jointly by Professors David J. Epstein and Morgenthaler, is carrying out basic studies on the linear and non-linear propagation and mutual interaction of magnons, phonons, and photons in magnetic crystals. The studies are being carried out with particular emphasis on their relevance to the development of microwave devices, especially those capable of generating coherent photons and phonons, and to the control of magnetic losses.

The group's interest in magnetic loss processes encompasses a range of loss from very high to very low. For many magnetic devices, efficient performance is synonymous with low loss. On the other hand, substantial amounts of controlled loss are required in microwave absorbers.

Losses that occur in magnetic switching were previously studied in "picture-frame" crystals of silicon-doped yttrium-iron garnet (YIG) and progress has been made in extending these studies to silicon-doped yttrium-gallium and erbium-iron garnets. The latter is of particular interest because Er is known, from microwave resonance work, to be a slow-relaxer and no one has yet studied its influence on domain wall damping. Measurements of permeability dispersion in the garnets as a function of excitation field strength are aimed at clarifying switching loss mechanisms as are our high-temperature linewidth studies.

A detailed theoretical study of the Kerr magneto-optical effect with special emphasis on its use to observe magnetic domain structure under dynamic conditions has been completed. Preliminary experiments with YIG crystals employing carbon arc or laser illumination have not yet been successful.

The ultrasonic spectrometer previously used to measure anelastic and first- and second-order magnetoelastic constants at room temperature has been modified to allow measurements to be performed as a function of temperature. The improved system has been used to measure the first-order magnetoelastic and second-order elastic constants of YIG in the 80-296°K range. Magnetoelastic studies of manganese-doped YIG are commencing; several excellent crystals already have been grown for this purpose.

A phonon traveling in a ferromagnet or antiferromagnet generates an effective magnetic field that can couple parametrically to magnons. This process of "phonon-pumping" with ultrasound has been successfully carried out in gallium-doped YIG and is being studied in depth. Our experimental facilities for fabricating thin film ultrasonic transducers have been substantially improved.

The frequency of a magnetoelastic wave propagating in a ferromagnet can be altered by suitable time variation of the bias magnetic field, and the character of the wave converted from magnon-like to phonon-like (or vice versa) by appropriate time and/or space variation of the bias magnetic field; such frequency and/or mode conversion can be utilized in fundamental spectroscopy as well as in the field of microwave ultrasonic devices. The experimental program employing YIG has been successful and has included preliminary studies of pulse compression and variable delay line applications.

Theoretical studies of magnetoelastic wave propagation have continued and general small-signal power and stress-momentum theorems have been formulated. The complete set of small boundary conditions has been deduced and applied to the study of direct coupling of magnetoelastic and electromagnetic waves at a material interface.

Our continuing interest in the antiferromagnet RbMnF_3 is still very great. During the last year, non-linear resonance experiments were carried out in order to determine magnon relaxation rates and subharmonic generation was attempted. Progress has been made in the development of a theoretical model for the decline of the high power susceptibility. As preparation for an experimental study of the coupled electronic and non-linear resonance modes in RbMnF_3 , a preliminary theoretical investigation of the relevant mode spectra has been completed.

PERSONNEL

Several members of the Electrical Engineering faculty have been on leave this year.

Professor David J. Epstein spent both terms at the Danish Technical University in Lynghy, Denmark. Professor Peter R. Gray worked both terms at General Atronics Corporation in Philadelphia. Associate Professor Frederick C. Hennie III spent the second term at the University of California at Berkeley. Assistant Professor Robert E. Kahn spent both terms at Bolt Beranek & Newman, Inc., in Cambridge. Associate Professor Paul L. Penfield Jr. spent both terms at the Imperial College of Science and Technology in London. Assistant Professor Gerald L. Wilson worked for both terms at the American Electric Power Corporation in New York.

We have had the pleasure of the following visitors in the Electrical Engineering Department during the past year: Robert K. Brayton, Visiting Associate Professor from International Business Machines Corp., who did research work in the Electronic Systems Laboratory and taught a section of 6.60 (Introductory Control subject) and 6.602; Thomas Bridges, Visiting Professor from Bell Laboratories, who worked

with Professor Haus in the laser laboratory; Harry D. Huskey, Visiting Professor from the University of California at Berkeley, who did research at Project MAC; Jurgen K. F. Krochmann, Visiting Associate Professor from the Technical University of Berlin, who worked with Professor Edgerton in the Stroboscopic Laboratory and taught 6.202 (Electronic Light Measurement); Peter J. Landin, Visiting Lecturer from Univac (England), who was involved in the computer science curriculum development and Project MAC research; Joseph C. R. Licklider, Visiting Professor from International Business Machines, who did research on Project INTREX and taught a graduate seminar in the spring; James L. Massey, Visiting Associate Professor from the University of Notre Dame, who did research work in the RLE Communications Group; Erik Mortensen, Visiting Associate Professor from the Royal Technical University of Denmark, who taught a section of 6.01 (Introductory Network subject); David H. Navon, Visiting Associate Professor from Transitron, whose research activities centered around semi-conductor devices and integrated circuits; Fred C. Schweppe, Visiting Associate Professor from the Lincoln Laboratory, who did research in the Electronic Systems Laboratory and taught graduate subject 6.609; George C. Shu, Visiting Professor from National Taiwan University; Tsuneyoshi Uyemura, Visiting Associate Professor from the Institute of Industrial Science of the University of Tokyo, who is an authority on mirrored cameras and did research in the Stroboscopic Light Laboratory with Professor Edgerton; Alexander Volk, Visiting Associate Professor from American Electric Power Service, who taught a section of 6.01 in the fall and carried out research; Terry J. Wagner, Visiting Assistant Professor from the University of Texas, who worked in the RLE Communications Group; Karl Zander, Visiting Associate Professor from the Technical University of Berlin, who did research on applications of computer-aided design techniques, and on the relationships with model descriptions of semi-conductor active components in cooperation with Professor Reintjes in the Electronic Systems Laboratory.

The new appointments over the year included the appointment of Robert H. Rediker as professor.

Appointed Associate Professors were Edward Lewis Glaser, William B. Kehl, Francis F. Lee.

New Assistant Professors are Richard J. Briggs, John N. Churchill, John J. Donovan, Arthur Evans, Jr., Robert R. Fenichel, William L. Henke, Zvi Kohavi, Donald E. Nelsen, Bruce H. Pomeranz, James K. Roberge, Jerome H. Saltzer, Stephen D. Senturia, Donald L. Snyder, Richard N. Spann, and James N. Walpole.

LOUIS D. SMULLIN

DEPARTMENT OF MECHANICAL ENGINEERING

Two matters of general import concerning the character and development of the Department will be reported upon before entering into the details of departmental activities.

Mechanical engineering as a field of endeavor has become increasingly comprehensive in the range of its activities. The disciplines and topics with which it deals are perhaps more ramified than those of any other branch of engineering. Broadly speaking, mechanical engineers are concerned with the behavior and processing of a wide range of materials — solids, liquids, gases, and plasmas; with the utilization of energy and information in many forms; with the understanding, synthesis and control of complex systems; and with the design process which assembles them into useful and economic form for human use. This great breadth on the one hand precludes as clearly identifiable a departmental focus, and image, as we might wish to have. On the other hand, this very characteristic of generality makes for a special role which we must make the basis for our appeal.

For the last 20 years the Department has been organized loosely into professional divisions as a means of identifying academic groupings and responsibilities and of dealing with administrative matters of staff appointments and advancement, of space and equipment allocation, and so on. As the scope of the Department's activities increased, what started as five divisions grew to a total of some 15 entities comprising academic divisions and so-called independent laboratories. The natural competition among organizational entities inevitably injects a centrifugal character into departmental deliberations. While competition is healthy, it is felt that the welfare and future development of the Department will be better served through a smaller number of divisional entities, each larger in size than the present ones. Fortunately, the present structure is to a large degree arbitrary, having been created by historical expediciencies. Moreover, a simplified structure suggests itself, one based on natural intellectual interests, content, and professional motivation. During the last year we have been operating informally on this new structure; beginning next year it will be our formal plan of organization.

The Department will be organized into three major divisions. They and the types of activities encompassed are as follows:

Mechanics and Materials

Elasticity, plasticity, rheology

Dynamics, vibrations, acoustics

Surface physics, wear, lubrication, friction

Materials processing

Fibers, polymers, textiles

Thermal and Fluid Sciences

Thermodynamics, kinetic theory, statistical mechanics

Heat transfer, mass transfer

Gas-surface interactions

Fluid mechanics, plasma dynamics

Cryogenics

Power generation and transmission

Systems and Design

Systems modelling and analysis

Control theory, control devices

Man-machine systems

Electromechanics

Computer-aided design and analysis

Information storage and retrieval

Bioengineering

Power generation and transmission

Urban problems: transportation, crime control, health service systems

As before, these divisions will comprise a very loose departmental structure, there being no intention to create subdepartments. Within each major division smaller groups will continue to work together on the basis of natural affinity. The advantages expected from the three-division structure are, first, a more rational basis for planning and for making decisions affecting the well-being of the Department as a whole, and second, more closely related activities of the departmental faculty.

The second general item concerns a continuing trend away from research engendered by defense and aerospace problems, and toward industrial and societal problems. The glamour of some industries now appears to some as gloss, and many technological areas thought to be mundane are taking on a glamour of their own.

In the two-and-a-half decades since the end of World War II, engineering education and engineering schools have undergone revolutionary changes. These changes were catalyzed largely by the defense and aerospace programs. The availability of large government funds for research, the excitement of new vistas at the scientific frontier of engineering, the realization of the importance of technological capability to national security and pride — all these motivated an enormous growth in graduate education and engineering research, as well as remarkable changes in the spirit and content of undergraduate curricula. M.I.T. has been a leader in these developments.

More recently, other values have begun to assume their due share of attention. In the last decade many faculty members became dissatisfied with the prospect of expanding our technology mainly in directions stimu-

SCHOOL OF ENGINEERING

lated by defense and aerospace needs. Concentration in these directions, by forfeit, tended to steer our best people and our best efforts away from the civilian economy and from those elements that determine the character of human life. Powerful elements of idealism among our students have expressed themselves in similar feelings. A significant number of faculty members, with their students, has turned its attention to such areas as biomedical engineering, inter- and intra-urban transportation, desalination and air pollution. It is now the mood of the country, a mood we share, to make up for the unbalanced efforts of the past and to repair our neglect of those areas in which the well-being of people is the primary concern.

Within the Department of Mechanical Engineering we have for some years had strong activities in man-machine systems, in sensory aids for the blind, in prostheses for handicapped people, and in transportation problems. This trend is now advancing rapidly: The scope of activities in biomedical engineering is growing, urban transport is receiving enlarged attention, and new and important work has begun in the areas of air pollution and water desalination.

UNDERGRADUATE PROGRAM

REGISTRATION

Our undergraduate enrollment (sophomores, juniors and seniors) increased from a total of 156 in 1965-66 to a total of 174 in 1966-67, according to the following breakdown:

	1965-66	1966-67	Change
Sophomore	44	60	+16
Junior	67	50	-17
Senior	45	64	+19
Total	156	174	+18

Whether the increase of about 10 per cent in the total is significant or merely a statistical fluctuation remains to be seen. Our objective continues to be an advance to a total of about 270, which we believe we can handle more efficiently and with a better balance among the various elements comprising the entire academic community of the Department.

BACHELOR OF SCIENCE DEGREE, UNDESIGNATED

This year the Department offered the degree of Bachelor of Science without designation of field, in addition to the degree of Bachelor of Science in Mechanical Engineering. The new degree program recognizes that the older professional boundaries have been blurred and that many excellent

curricula can be designed — suited to individual interests — that cut across accepted patterns and which differ from a curriculum associated with a degree in an identified field.

The new program has a reduced number of specified required subjects, and has a new category of “planned electives.” They are subjects to be agreed on between an individual student and a special departmental advisor so that the entire program of a student is coherent and in pursuit of a clearly defined objective. For instance, students may design a program with a strong element of biology and physiology as a foundation for work in bioengineering; or with a strong element of electrical fields, circuits, and devices, as a foundation for work in electromechanics; or with a strong element of computer sciences as a foundation for work in systems control and automation; or with a strong element of mathematics as a foundation for work in applied mathematics; or there may be substantial specialization in materials, thermodynamics, fluid mechanics, continuum mechanics, or vibrations. Students electing this degree program must so advise the Department by the beginning of the junior year in order that there be adequate opportunity for planning the complete curriculum.

In its first year, the program attracted about 15 per cent of the entering sophomore class in the Department and it is anticipated that in subsequent years this percentage will rise. The typical student in the program is aiming for a career in law or medicine, or else he plans to enter a family business based on technology; a few are interested in scientific fields (e.g., oceanography) which straddle the borders between the traditional academic disciplines. Professor Ernest Rabinowicz is faculty advisor for students enrolled in the program.

UNDERGRADUATE SUBJECTS

Much of the work in subject development continues to be in response to the new General Institute Requirements, necessitating new Science Distribution subjects and Undergraduate Laboratory subjects suitable for sophomores, with a shift in pattern from typically nine-unit to 12-unit subjects.

The introductory sophomore subject, Mechanics of Solids (2.01) was shifted over this fall by Professor Norman C. Dahl to Mechanics of Solids (2.012) with an increase in units. The extra time was used to incorporate more material on rigid body mechanics, which is no longer emphasized in freshman physics, to develop the concept of a tensor, and to introduce the viscous continuum and some simple rotationally symmetric elastic problems.

Professor Stephen H. Crandall and Associate Professor Dean C. Karnopp, with the help of Dr. Edward F. Kurtz Jr. and Dr. David C.

Pridmore-Brown, completed a revised soft-cover edition of their text, "Dynamics of Mechanical and Electromechanical Systems," for the junior subject, Dynamics (2.03).

The whole range of control systems subjects was examined carefully for possible improvement and better coordination, and considerable changes were initiated to strengthen the subjects and to reduce overlapping. Associate Professor Forbes T. Brown and Assistant Professor William R. Ferrell revised and expanded Control System Principles (2.14), and Man-Machine Systems (2.18) was also expanded. Associate Professor Herbert H. Richardson, with the help of Professor Peter Griffith and David N. Wormley, continued the development of Introduction to System Dynamics (2.022), which was given for the first time in the spring of 1967 as a Science Distribution subject under the new curriculum. It has been increased to 12 units with a two-lecture, two-recitation per week format together with free use of computer and physical demonstrations. A closed-circuit television between the analog computer and the lecture room was used on an experimental basis during the spring semester. Some experimentation was also carried out on the use of analog computer projects as teaching aids. Results were favorable and further development along this line is planned for next year. Professor Richardson was also responsible for a successful proposal to the National Science Foundation for equipment, used in several laboratory subjects, which includes operational manifolds and a TV tape recorder and monitor system. It is expected that use of TV recording will constitute a most interesting experiment when employed to evaluate lectures, to record physical demonstrations and as a self-evaluation medium for student projects.

Professor Richardson and Mr. Wormley, with the collaboration of Professor Charles Kingsley of the Department of Electrical Engineering, offered a pilot version of the new 12-unit Electromechanical Components and Systems (2.13J-6.48) during the fall term. This new subject builds on the sophomore core subject, Introduction to System Dynamics (2.022), to cover the concept of a field, relations between lumped elements and field configurations, energy and forces in material media, and energy conversion and modulation systems. In emphasizing both basic field theory and its application to actual electromechanical devices, the subject stresses a design approach. Last semester the lecture material was based on a set of notes prepared by Professor Henry M. Paynter; they will be extended by Professors Paynter and Richardson with the support of a Ford Foundation grant.

The Department, which has been an innovator and leader in the development of design and laboratory instruction, introduced a project

laboratory subject, Design and Experiment (2.67), for students at sophomore level. This year the class used the general theme, "Technology in Developing Nations," as a vehicle of instruction. A series of ten lectures open to the entire M.I.T. community was presented by such authorities as William G. Saltonstall, former ambassador and Director of the Peace Corps in Nigeria, George C. Lodge, former Director of the International Division of the Harvard Business School, Dale B. Fritz of the Volunteers for International Technical Assistance, and a number of professors of political science, economics, education and management — all with experience related to developing nations — from the Boston academic community. After a round of assigned preliminary experiments, students organized themselves into small groups and defined investigations which they carried through for the remainder of the term. Among their investigations were: A comparative study of low-cost linings for irrigation canals; the feasibility of an all-bamboo wheelbarrow; a low-cost surveying transit; and more general studies of the introduction of new technology into developing nations and the teaching techniques appropriate for developing nations. Interestingly enough, and consistent with the intent of the teaching faculty — Professors Robert W. Mann and Frank A. McClintock, Associate Professors S. William Gouse Jr. and David G. Wilson, and Assistant Professors Joseph Gerstmann and Ernest G. Cravalho — all but two of the students are, or intend to enroll, in departments other than Mechanical Engineering.

In Engineering Design and Manufacture (2.861), of which Associate Professor Deane Lent is in charge of the design portion, 48 sophomores addressed themselves to the problem of improving the fishing gear used on North Atlantic trawling vessels. Through the cooperation of the Bureau of Commercial Fisheries at Gloucester, students were taken out on fishing expeditions on two occasions on which they personally witnessed the hazards of personal injury, together with the loss of fish and fishing time, inherent in current trawling gear. In response to this awareness, they individually devised and designed a number of devices and systems, some of which are sufficiently novel and potentially practical to have been taken under consideration by the Bureau of Commercial Fisheries.

In Engineering Design (2.731), coordinated this year by Assistant Professor Igor Paul with Professors Mann, McClintock, Richardson and Paul and Associate Professor Thomas B. Sheridan supervising the sections, 45 students addressed themselves to the theme, "Engineering in Crime Prevention, Detection, and Law Enforcement." Guest speakers from local and national law enforcement agencies and industrial concerns dealing in related products and services lectured on various aspects of the problem. At a final formal presentation, students reported on their

term projects, which ranged from the mechanical design of new locking and alarm devices to the design of complete law enforcement systems for yet-to-be-planned cities.

Professor Paul's subject, Introduction to Engineering Systems (2.00), was expanded from a six-unit to a 12-unit subject this year, and emphasis was placed on an introduction to engineering and engineering sciences. Students were introduced to systems and design engineering activities, including project planning and economic considerations as well as the basic premises of the engineering sciences, including the behavior of materials, solid and fluid mechanics, thermodynamics including heat transfer, electromechanical devices and control theory. Applications of these principles were demonstrated in the laboratory where the students planned and executed experimental projects. Material for an "Introduction to Engineering" text has accumulated over the last three years of teaching experience in 2.00.

In the senior design elective, Design Concepts (2.732), Associate Professors Dwight M. B. Baumann and Richardson placed emphasis on the technological problems of underdeveloped countries.

Professor Griffith was in charge this year of the junior projects laboratory subject, Experimental Engineering (2.671T), in which most of the experiments were completely replaced with new ones.

Professor Joseph H. Keenan and Dr. George N. Hatsopoulos completed preparation of a syllabus for the Science Distribution subject, Elements of Classical and Statistical Thermodynamics (2.42), which is an introduction to classical and statistical thermodynamics using a generalized approach.

There was considerable discussion in the weekly thermodynamics seminar of methods for making the first subject in thermodynamics more effective. A poll of students at half term indicated a general lack of appreciation for both the fundamental aspects of the subject and its current applications. Part of the difficulty arises because it is impossible in the limited time available to cover adequately both fundamental and applied aspects. It was suggested that two parallel sequences might be developed to deal with the problem: One which would emphasize practical applications, and the other fundamentals. This will be tried on an experimental basis in 1967-68. The applied sequence will be Thermodynamics (2.403), which is being revised by Associate Professor Joseph L. Smith Jr., assisted by Professor Cravalho, to cover a limited number of topics selected to give students best the thermodynamics necessary for advanced thermodynamics and other subjects, followed by Heat and Mass Transfer (2.50) or Applied Thermodynamics (2.60); the fundamental channel

will be Elements of Classical and Statistical Thermodynamics (2.42), followed by Statistical Mechanics and Kinetic Theory (2.404).

As an experiment in the more effective teaching of Mechanical Behavior of Materials (2.30), Associate Professor Ali S. Argon, assisted by Associate Professor Regis M. N. Pelloux, spent half of the spring term using a carefully selected collection of case studies as a vehicle for discussing mechanical phenomena important to mechanical engineers. Results indicate that this procedure not only stimulates students more but also makes lecturing a pleasanter task for the instructor.

The new project-type laboratory subject, Physical Measurement and Analysis (2.654), was taught by members of the Materials Processing group and the Surface Laboratory. Student enrollment was eight the first term and 18 the second; a majority of the students came from outside the Department and seemed to enjoy the exposure to mechanical engineering. Another new project laboratory subject was Manufacturing Project Laboratory (2.86).

Assistant Professor Ioannis V. Yannas, working with Professor Allan S. Hoffman, of the Department of Chemical Engineering, presented an undergraduate seminar which will be continued next fall as a joint Science Distribution subject entitled Polymer Materials Science (2.901J).

Fiber Processing Dynamics (2.904) was experimentally modified from a lecture presentation to a project form so that each student treated a separate subject in greater depth than was possible in the past. Results of the term experiment show considerable promise of this technique as a teaching vehicle for future students, and illustrate the benefits of the information retrieval system developed in the Department for textile documentation.

Planning has been completed and the funds are now available to equip a new polymer physics laboratory oriented toward the systematic determination of viscoelastic coefficients, as well as of optical and spectroscopic parameters of synthetic and naturally occurring polymers. The new facility is expected to become available for teaching and research during the fall of 1967.

UNDERGRADUATE SEMINARS

We continue to be one of the most active departments in offering Undergraduate seminars for freshmen. The list for 1966-67 is as follows:

Fall Term

Douglas P. Adams — Birth and Care of a City; Modern Marvelous Mechanical Motions

William R. Ferrell — Human Decision-Making in Vehicle Guidance

SCHOOL OF ENGINEERING

August L. Hesselschwerdt Jr. and John S. Maulbetsch — Environmental Control Techniques

Arthur R. Kantrowitz — A Survey of Engineering and Medicine

Jon R. Kelly — Combustion and Propulsion

Igor Paul — High Speed Ground Transportation

Brandon G. Rightmire — Solid-Solid Interfaces

Augustus R. Rogowski — Engineering and Research in Piston Engines
Spring Term

Augustus R. Rogowski — Engineering and Research in Piston Engines

William R. Ferrell — Human Decision-Making in Vehicle Guidance

Ioannis V. Yannas and Allan S. Hoffman, Department of Chemical Engineering — The Science of Giant Molecules

ENGINEERING PROJECTS LABORATORY

The laboratory, under the chairmanship this year of Professor Wilson, with William L. Verplank as Coordinator, has grown in size and scope as individual members and groups of the faculty have found it advantageous to make use of the laboratory's resources in personnel and equipment. The present position of the laboratory is reflected in the following table:

	1964/65	1965/66	1966/67
2.67 students (Design and Experiment)			18
2.67 experiments			9
2.671 students			
(Experimental Engineering)	54	72	51
2.671 experiments	10	14	16
Bachelors' theses completed	20	18	41
Masters' theses completed	41	37	31
Doctoral theses completed	11	14	25
Number of faculty involved	23	22	32

A new laboratory facility, the Acoustical Vibration Laboratory, developed by Professors Crandall and Patrick Leehey, of the Department of Naval Architecture and Marine Engineering, became associated with EPL. The Student Shop was rearranged, repainted, and partly re-equipped, and some new procedures were introduced, so as to serve the EPL community better, and an attempt was made to maintain the laboratory in a more presentable condition by providing storage drawers for loose equipment. Display panels have been mounted on all tables and equipment so that full details of all experiments in progress may be shown.

A full series of EPL Colloquia were arranged and attracted good attendances and stimulating discussions throughout the year.

GRADUATE PROGRAM

ENROLLMENT

In September, 1966, 245 students were enrolled in the Graduate School of Mechanical Engineering. Of this number, 120 students held Institute appointments as Instructors, Teaching Assistants, or Research Assistants. Sixty-four received fellowships or industrial support.

Of the students who enrolled in September, about 24 per cent were citizens of foreign countries: 20 students were from Asia, ten from Canada, England and South Africa, and the remainder from South America, Europe and the Near East.

About 58 of the enrolled students had received their undergraduate degrees from M.I.T. Forty-seven students had degrees from foreign universities. The remaining students had degrees from the following universities in the United States and Canada: Stevens Institute of Technology (five); Rensselaer Polytechnic Institute, Drexel, Purdue, U.S. Naval Academy (four each); U.S. Military Academy, Lehigh, Maryland, Minnesota, Princeton (three each); College of the City of New York, Cooper Union, Duke, Lowell Technological Institute, Missouri, Northeastern, New Hampshire, Newark College of Engineering, Notre Dame, Queens University, Stanford, Worcester Polytechnic Institute, Yale (two each); and other universities including Brown, California Institute of Technology, Case, Carnegie, Harvard, Johns Hopkins and Cornell.

DEGREES AWARDED

In February, the Department awarded eight Doctor of Philosophy and 14 Doctor of Science degrees, five Mechanical Engineer's degrees, and 14 Master of Science degrees.

In February, 220 graduate students registered in Mechanical Engineering and of them, four received Ph.D. degrees, seven received Sc.D. degrees, six received the Mechanical Engineer's degree, and 21 received S.M. degrees in June. Of the students remaining in the Graduate School, 82 have passed the Qualifying Examination and are working, or will start, on their doctoral programs.

In September, approximately 20 students should receive their Master of Science degrees in Mechanical Engineering. Since the Department does not allow doctoral thesis presentations in the summer term, doctoral students completing their degree work in the summer will officially graduate in February, 1968.

SCHOOL OF ENGINEERING

DEPARTMENTAL COMMITTEE ON GRADUATE STUDIES

It has hitherto been the practice of the Department to require for the degree of Mechanical Engineer a comprehensive written and oral examination. This examination was essentially the same as the qualifying examination for entering doctoral research. By vote of the Department faculty, the comprehensive examination was removed as a requirement for the degree of Mechanical Engineer, beginning with the spring term 1967. Thus, this degree is now awarded upon completion of 162 units beyond the bachelor's degree, plus the completion at M.I.T. of a satisfactory thesis.

SUBJECTS

In Continuum Mechanics (2.085) Associate Professor Charles A. Berg introduced automated computer programs for the solution of a general class of elasticity problems. Students made use of existing working programs to solve significant problems of their own selection. They were not responsible for the programming details but used the existing programs as tools to extract meaningful engineering relations from complex elastic systems.

Dr. John H. Argyris, Visiting Professor of Structural Mechanics, gave a well-attended special graduate subject in the Departments of Mechanical and Civil Engineering and Aeronautics and Astronautics, entitled Matrix Theory of Structures and Solid Continua (2.099J).

Evolution of basic subjects in control systems and an increase in the level of preparation of new graduate students led to a complete reorganization of the graduate subject structure. Three subjects were dropped and two new subjects were developed. System Dynamics and Control (2.141) and Analysis and Design of Engineering Systems (2.161) and (2.162) thus are replaced by Modelling and Simulation of Dynamics Systems (2.141T), and Life Support and Human Performance in Manned Systems (2.181J). The latter is a joint effort of Professor Sheridan and of Professor Laurence R. Young, of the Department of Aeronautics and Astronautics, and will be offered for the first time in 1967-68.

Professor Karnopp developed new material for Advanced Automatic Control Systems (2.151), which is now being taught more in the fashion of a seminar with students encouraged to submit term papers relating to recent advances in automatic control in lieu of a final examination.

Professor Brown continued the development of Distributed Systems (2.153) now in its second year and a significant amount of general text material has been prepared.

Professor Shih-Ying Lee continued the revision and improvement of Fluid Power Controls (2.171). During the last few years the new field

of technology, fluidics, has attracted worldwide attention and this subject has been revised to include increasingly greater proportions of this new technology. A number of laboratory projects were devised to give students better understanding and insight into the subject.

Instruments for Measurement and Control (2.173) was upgraded by Professor Lee with more emphasis put on understanding the basic principles of instruments, control elements and components.

In the interdepartmental subject, Special Studies in Systems Engineering (2.191J), Professor Baumann, with Dean William W. Seifert of the Department of Electrical Engineering, Professors Siegfried M. Breuning and Richard L. de Neufville of the Department of Civil Engineering, and Philip B. Herr of the Department of City Planning, supervised a study of the development of a residential community for 70,000 people with 30,000 jobs on Thompson's Island in Boston Harbor. One of the design criteria was the building-in of adaptability as a mechanism for avoiding obsolescence. For example, floating foundations were proposed not only for support but to permit buildings to be moved into new locations; modular construction was explored, and a unified transportation system was studied.

In Computer-Aided Design (2.726), Professor Baumann and Dr. Richard P. Parmelee supplemented the formal lecture program with a requirement that each student undertake a project on computer-aided design hardware and/or software.

Two new advanced subjects, Kinetic Theory of Gases and Plasmas (2.261) and Reaction Kinetics of Gases and Plasmas (2.262), were offered by Professor James C. Keck with the objective of acquainting students with the basic properties of high-temperature gases and plasmas necessary to deal with them as working fluids in a variety of modern engineering problems. These subjects combine and extend the material previously covered in Kinetic Theory of Ionized Gases (2.26) and Atomic and Molecular Kinetics (2.292 and 2.293), which are no longer offered.

A new subject, Two Phase Flow and Boiling Heat Transfer (2.57), was developed and taught by Assistant Professor Arthur E. Bergles and Professor Gouse, as a natural outgrowth of extensive research in this area carried out in the Heat Transfer Laboratory over the last 20 years. Classroom lectures were complemented by a weekly film series which attracted Institute-wide interest. Another new subject, Vehicle Environmental Control (2.647) was developed and taught by Associate Professor August L. Hesselschwerdt and Assistant Professor John S. Maulbetsch.

Academic offerings of the Fibers and Polymers Division were changed radically in content during the last year. The introductory subjects,

Physics of Fibrous Materials (2.905 and 2.906), were given by Professor Yannas. The first was devoted entirely to the mechanics and optics of polymers; the second concentrated on the principles of macromolecular physics. Subject matter relating to Applied Mechanics of Fiber Assemblies (2.913 and 2.914) was presented separately in seminar form by Professor Stanley Backer.

SPECIAL SUMMER PROGRAMS

Again the departmental faculty made strong contributions toward the Special Summer Programs of the Summer Session. The following programs are offered in the summer of 1967; Photoelasticity and Moiré Techniques, by Professor William M. Murray, with experts from industry and universities; Strain Gage Techniques: Lectures, and Strain Gage Techniques: Laboratory, by Professor Murray and outside authorities; Non-destructure Testing, by Professor Murray; Physical Measurement and Analysis, coordinated by Professor Nathan H. Cook and Associate Professor Ernest Rabinowicz, with members of the Materials Processing and Surface Laboratories and guest lecturers; Two-Phase Gas Liquid Flow and Heat Transfer, under the direction of Professors Griffith and Gouse with members of the Department and outside lecturers; Physical Dynamics, directed by Professor Karnopp and Assistant Professor Ronald C. Rosenberg with the help of other members of the Department; and Modern Kinematic Developments, by Professor Adams with outside authorities.

Through a special grant from the Ford Foundation, Professors McClintock, Argon, Berg and Pelloux presented a Special Summer Program on the Mechanical Behavior of Materials to 26 faculty participants from other universities; the Program dealt with developments in teaching and laboratory procedures of this subject as taught to juniors in Mechanical Engineering at M.I.T. Discussions of the content of the subject and methods of teaching proved very useful both to M.I.T. people and participants from other universities.

RESEARCH

APPLIED MECHANICS

Under the direction of Professors Crandall and Leehey, the new Acoustics and Vibration Laboratory began operation this year. Much of the effort was devoted to building and installing equipment but a few theses and 2.671 projects were completed. The laboratory now has a low-turbulence acoustic tunnel whose test section is in a chamber that can be converted to either reverberant or anechoic operation. The other major piece of

equipment is an electromagnetic shaker with a 1,500-pound force rating. Accelerometers, impedance heads, microphones, hot wire anemometers and strain gages are used as transducers, and several instrumentation chains for the analysis (and production) of vibratory and acoustic signals have been installed and calibrated.

Professor Berg studied non-linear creep and plasticity in connection with problems of forming, fracture, and free surface motion, as well as with the mechanics of seismic faulting, convection in the earth's mantle, continental drift and mountain building. His studies indicate that the main mechanism of deformation in the mantle is plastic deformation rather than viscous creep.

Professor Dahl made progress on the development of a computer program that will facilitate the design (not simply the analysis) of thin shells of revolution.

Assistant Professor R. Gordon Cook made a study of factors affecting waiting times along an MBTA (Massachusetts Bay Transportation Authority) bus route. He examined techniques for decreasing the mean and the variance of the waiting time.

Assistant Professor Allan D. Pierce embarked on a three-year study of infrasonic atmospheric wave propagation. He concluded a study (with A. B. Friedland) on the reflection of acoustic waves by ambient fluid velocity gradients.

THERMODYNAMICS DIVISION

Professor Keck and his students continued theoretical investigations in the fields of non-equilibrium reaction rates, ionic recombination and scattering of gases from surfaces. He also collaborated with Professors Tau-Yi Toong and Kenneth N. C. Bray and Associate Professor Augustus L. Rogowski in preliminary studies of air pollution from internal combustion engines which is intended to complement the studies of Professor James A. Fay and Associate Professor David P. Hoult on air pollution caused by stack gases.

Research on electrical discharge machining was initiated this year by Assistant Professor Robert E. Stickney with the principal objective of understanding the metal removal mechanism in sufficient detail to be able to minimize the rate of tool wear. Professor Stickney also continued research on surface problems relating to thermionic energy conversion, momentum and energy transfer in gas-solid interactions, and surface catalysis.

Dr. Hatsopoulos and Assistant Professor Walter J. Bornhorst carried out both theoretical and experimental studies of liquid-vapor transition. Concepts of irreversible thermodynamics were employed to establish a

general formulation for the energy and mass rate processes occurring at a phase interface. The corresponding transport coefficients were measured for a liquid-vapor mercury system, yielding for the first time an experimental value of the coupling transport coefficient.

Most of the weekly thermodynamics seminars were devoted to a general survey of interface phenomena and phase change. These areas form a common focus of interest for many faculty members in the Department, and it is our hope to develop special competence in them. Among the topics discussed were vaporization, the triple interface, scattering and adsorption of gases on solids, dissociation and recombination, catalysis, and thermionic energy conversion.

CRYOGENIC ENGINEERING LABORATORY

The Cryogenic Engineering Laboratory, under the direction of Professor J. L. Smith, is cooperating with Professor Herbert H. Woodson of the Department of Electrical Engineering in a major commitment, now in the exploratory and planning stage, to investigate the application of cryogenics to large-scale electric power generation and utilization. Professor Gerstmann's continuing investigation of forced-convection heat transfer to super-critical helium became part of this effort.

Professor Cravalho is building a large, pumped-liquid-helium facility for experiments below 1°K. The first project planned for this facility is an engineering study of refrigeration in the millidegree range with He³-He⁴ mixtures.

A project was started on the freeze-out of impurities from the gas stream passing through a thermal regenerator. Professor J. L. Smith also cooperated with the Department of Nuclear Engineering in obtaining a large 4.2°K cryogenic facility for the M.I.T. reactor.

Continuing projects are a thermodynamic analysis of the Stirling engine, pool-boiling heat transfer to liquid helium, and the application of metal bellows to cryogenic refrigeration engines. Projects were completed on the spontaneous thermally induced oscillations in liquid helium lines, and on the effectiveness of a thermal regenerator with a packing having large variations in specific heat.

The facilities, equipment and experience of the Cryogenic Engineering Laboratory continue to be available to and are broadly utilized by the M.I.T. community.

FLUID MECHANICS DIVISION

In addition to continuing research mentioned in previous reports, many new projects were initiated last year. They cover research on aortic balloon assist pumping for cardiac patients (Professor Ascher H. Shapiro

and Dr. Colin Clark), measurement of pulsatile flow by thermal dilution (Dr. Clark), fluid flow in the separation column of a desalination plant using the vacuum-freeze distillation process (Professor Ronald F. Probst), acoustic waves in reactive flows (Professor Toong), chemionization and chemiluminescence in gaseous detonations (Professor Toong and Assistant Professor Jon R. Kelly), plasma wind tunnel and shock tube experiments simulating ionospheric plasmodynamics (Assistant Professor Ain A. Sonin), aerodynamics of turbulent buoyant plumes (Professors Hout and Fay), magnetically balanced arc (Associate Professor Martin D. Cowley and Professor Fay and Drs. Yeshaiahu Y. Winograd and Marvin E. Goldstein), free surface instability of ferromagnetic fluids (Professor Cowley), Hartmann flows (Professors Cowley and Fay), vibrational relaxation in expanding flows, NO formation in rapid expansion of combustion products (Professor Bray), and rarefied gas flow shock structure (Professor Probst and Dr. Goldstein). Continuing research touches aspects of high temperature gas dynamics, chemically reacting flows, plasma dynamics and magneto-hydrodynamics, and the fluid dynamics of biological systems.

Research activities were reported in 18 papers published during the year and 13 presented at technical meetings. In addition, lectures or seminars were presented by various members of the laboratory at Brown, New York, Harvard, Cornell, Columbia, Princeton, and National Taiwan universities, the University of California at San Diego, the Technical University of Berlin, M.I.T., and the National Aeronautics and Space Administration (NASA), Lewis, Avco-Everett, and United Aircraft research laboratories. With W. Hayes, Professor Probst co-authored Volume I of "Hypersonic Flow Theory" and co-edited Volume I of the translation of the Zeldovitch and Raizer treatise, "The Physics of Shock Waves and High Temperature Hydrodynamic Phenomena."

MATERIALS DIVISION

Professor Egon Orowan examined the conclusion of M. Ewing and his collaborators (based on the discovery of Lower Miocene microfossils close to the crest of the Mid-Atlantic Ridge) that crustal movements must have ceased there at least 20,000,000 years ago. Professor Orowan showed that this conclusion depended upon a discontinuous-flow model of mantle convection that is mechanically impossible and, further, that a plausible continuous-flow model reconciles the observations with the widely assumed movement of the oceanic crust away from the ridge with a velocity of the order of 1 cm/year at points not too close to the crest.

Professor Orowan found that "fracture parabolas" in Plexiglas are

sites of overlapping cracks in two slightly different levels. Room-temperature creep fracture in Plexiglas showed the abundant formation of cracks branching away from the main crack plane. The interference colors are not due, as hitherto assumed, to the alignment of molecules by sliding in a thin layer at the surface of fracture, but rather to fracture of van der Waals bonds between chain molecules in this "craze" layer.

Professor Orowan and his students are also studying the macroscopic extrusion-intrusion phenomenon on torsion-cycled tin crystals, the absence of yield points in strain aging when the deformation is opposite to that before aging, and, with Professor Berg, the physical basis of adhesion — in particular, the problem of the high peel strength of brittle adhesives, which is orders of magnitude above that to be expected with the strongest atomic bonds if the crack propagation occurs in a smooth surface.

Professor Argon and his students continued their research on the strain hardening of single crystals.

A study of the rate mechanism of plastic deformation in pure sodium chloride single crystals revealed that the stress and temperature dependence of the plastic strain rate cannot be explained by the dynamics of individual dislocations, but requires understanding of interactions between dislocations. A companion study of the birefringence at large plastic strains in sodium chloride established that all birefringence bands are kink bands situated normal to the active slip system and are in a state of simple minaxial stress. From this it was concluded that their observable long range stresses play no role in strain hardening.

Experiments of initial yielding in copper single crystals deformed by single slip showed that the retained dislocations strongly associate into dipolar and multipolar clusters free of long-range stress. Tension experiments on pre-twisted single crystals accompanied by sectioning and etching experiments showed a direct relationship between the shear strength of the primary slip plane and the square root of the forest dislocation density. A statistical theory of single slip based on probabilities of formation and inactivation of dislocation sources indicates that the strain hardening results from a decrease of dislocation flux on the primary planes due to growth of multipolar clusters with strain, while the plastic strain rate is primarily governed by the thermally activated intersections between primary dislocations with forest dislocations.

In a joint study of fatigue of lithium fluoride crystals at elevated temperatures, Professors Argon and Orowan observed the formation of wide-spread fatigue damage in the form of pore formation. Although strong extrusion and intrusion formation is found on the surface, cracks are formed by the accumulation of pore damage at deformation-induced

tilt boundaries or boundaries separating two regions with differing slip systems. By studying the temperature dependence of the rate of pore formation it was concluded that although diffusion could play a role, extensive cross slip is an essential requirement of pore formation.

In a study of beryllium, Professor Argon found that the micro-yield strength of beryllium can be raised sixfold by alloying it with one per cent iron followed by an aging treatment.

Professor McClintock and his students continued a variety of studies directed toward understanding fracture in more or less ductile materials. At the atomic scale, experiments on bubble rafts under biaxial tension and cyclic loading show that, even with stress levels low enough so that fracture does not occur spontaneously, holes can be nucleated by the interaction of dislocations.

At the microscopic level, application of the theory of the growth and coalescence of holes indicates that a critical stage in fracture is the reduction of the strain-hardening rate to the point where thin bands of deformation can occur, so that the theory for homogeneous growth of holes represents only an upper bound to the ductility.

In fatigue, an analysis of the growth of spherical holes under cyclic loading, using the stress-strain relations that have been found to describe the Bauschinger effect in aluminum alloys, shows a growth process with no mean load. Crack propagation and striation markings can be predicted successfully from macroscopic plasticity in large, fully plastic specimens of soft aluminum. A technique for taking low-power stereo-micrographs of fractured surfaces was developed and revealed the large part that hole growth plays in fracture of even relatively brittle materials, such as 7075-T6 aluminum alloy and hydrogen-embrittled steel. Experiments with notch specimens exposed to atmospheric hydrogen, however, show that the role of hydrogen is not limited to internal pressures in the holes.

Calculations of the plastic flow around cylindrical inclusions under longitudinal shear show that there is a negligible reinforcing effect, and that the deformation in the matrix tends to be confined to a region of very high shear strain close to the surface of the inclusion. The stress concentration within the inclusion is of the order of 3, although the yield strength of the inclusion required for the full reinforcing effect is only about 1.3 times that of the matrix.

In the Mechanics area, an analogy from available Mode III calculations seems to predict the instability of fracture in the ordinary cup and cone fracture that terminates a tensile test in a fully plastic material.

A theory was developed for crack growth in fully plastic specimens for repeated blunting which concentrates the strain in front of the crack, but experiments showed that the classical analysis on which the theory

was based was incorrect in predicting blunting. Instead the cracks tend to remain sharp or become flat-bottomed, as apparently shown by a more careful analysis.

HEAT TRANSFER DIVISION

Professor Warren M. Rohsenow continued research in condensation and boiling of liquid metals. Analysis predicted rather well the large variation in wall temperatures and bubble frequencies in boiling of sodium. Investigation of forced-convection film boiling of nitrogen led to an analysis that predicted the magnitude of the significant vapor superheat and the liquid droplet sizes.

Research on metal-to-metal contact resistance continued under the direction of Professor Rohsenow and Assistant Professor Borivoje Mikic and covered aspects of waviness influence, plating effects, transient behavior and the effect of non-uniform distribution of contact spots. Experiments were initiated to measure contact resistance between a liquid metal and a solid surface.

Professor Griffith initiated research on the mechanism of deterioration of heat transfer in supercritical pressure water and also in mass transfer associated with the fuel cell process. He continues work in two-phase flow and non-Newtonian fluids.

Professor Gouse completed his study of boiling in long tubes and continued work on flow oscillations in parallel heated channels and deceleration of flow in two-phase flow diffusers. A new project designed to determine the acoustic velocity in two-phase flow mixtures was initiated. In addition, a study of the similarity criteria for model testing of solid propellant rocket nozzles is under way. He also participated in a study of alternative heat engines for automotive vehicle propulsion, the design of a one-horsepower solar-powered steam engine for use in developing nations, and the study of the total energy processing and utilization system of an urban area.

Professor Bergles continued work with the National Magnet Laboratory on cooling of high-power magnets, with emphasis on flow boiling. A study of flow surface boiling was completed which produced a method for determining the nucleation properties of surfaces, data relating to the effect of surface finish on heat transfer, and an assessment of the thermocapillarity effect on hydrodynamics and heat transfer. Tape-induced swirl flows were considered in another completed investigation. A general correlation was developed for heat transfer and pressure drop in the non-boiling case, and the hydrodynamic and heat transfer characteristics for the subcooled flow with boiling were determined for the first time. A project was initiated which is concerned with an evaluation of

the heat transfer characteristics of dielectric fluids used for computer cooling.

Professors Maulbetsch and Hesselschwerdt initiated work on a program to correlate data and develop design procedures for refrigerant condensers; to investigate boiling of aqueous lithium-bromide solutions for solar energy systems; to study fluid flow and heat transfer in porous media such as wicking material for application in zero-gravity evaporators; to investigate frothing condensers; and to investigate oxygen reclamation from carbon dioxide by electrolysis for spacecraft application.

Assistant Professor Leon R. Glicksman continued research on glass forming, in particular the interaction of radiation and convection in low-speed flows with variable fluid properties. He developed an approximate technique for calculating radiation in absorbing and emitting media.

Professor Wilson developed a design method for heat exchanger inlet headers.

MATERIALS PROCESSING DIVISION

The program on Computer-Aided Manufacturing Planning is taking on substantial form. The goal is to provide a system within which manufacturing decisions can be made, both on a large, plant-wide scale, and on a small, machine-operation scale.

Work on electrochemical machining is promising in that specific metal removal rates have been obtained considerably in excess of those obtained commercially (approximately five times as fast).

Continuing research is in progress in the general area of cutting-tool wear. The description of high-temperature tool wear as a thermally activated mass diffusion transfuse from tool to chip is progressing satisfactorily.

SYSTEM DYNAMICS AND CONTROL DIVISION

An active program was continued in the area of fluid power control and fluidics. Work under Professor Richardson's direction included development of fluid acceleration sensors, investigation of a pneumatic transformer, studies of frequency-modulated pneumatic systems, and studies of pure fluid valves based on vortex action. A limited study was also made by Professor Richardson in cooperation with the NASA Cambridge Laboratory dealing with fluid attitude control for space vehicles. Activities under the direction of Professor Lee included basic studies of turbulence amplifiers, development of a pneumatic stepping motor, development of a tri-stable fluidic control valve, studies of electro-fluid signal conversion technique, and study of a new fluid metering principle.

Professor Brown initiated a program of research in fluidics aimed at modelling and computer simulation of fluid jet amplifiers and of complete fluidic systems over a broad frequency band. Professor Brown also continued his studies on the absorption and dispersion of acoustic waves in turbulent fluid lines.

Professors Brown and Rosenberg are continuing the application of the bond-graph language for systems modelling and simulation initiated by Professor Paynter. Professor Brown probed the logical development and implications of the language, added new primitive elements, and applied a procedure to the area of distributed systems. Professor Rosenberg developed efficient digital simulation schemes. Professor Karnopp worked on improving the reliability of sensor output data, on the response of time-optimal servomechanisms with random noise inputs, on parameter space reduction techniques for adaptive controllers, and on the optimization of the vibration characteristics of flexible-body attitude controllers and active vehicle suspension systems. Professor Rosenberg continued development of ENPORT-2 (a digital computer program for the simulation of the dynamics of multiport engineering systems).

FIBERS AND POLYMERS DIVISION

Research was initiated by Professor Yannas toward an understanding of the molecular basis for yielding in polymers. This work will benefit in many ways from the phenomenological insight which was gained from the recently concluded three-year project on the yielding behavior of glassy, amorphous polymers. Exploratory research was also initiated which aims at the incorporation of collagen, an abundantly occurring animal fiber, into the area of polymer science and engineering.

Dr. Emery I. Valko conducted research on the effect of the degree of crosslinking of cotton cellulose on the absorption, equilibrium and diffusion of dyes. Dr. Gerhard Egbers studied the effect of mechanical history on the tensile modulus of fibrous materials.

Professor Backer's research continued to emphasize the role of friction during bending of fiber assemblies in fabric form and during drafting of fibers in various stages of textile processing. A major effort is under way to complete the development of an information storage and retrieval system. This program includes the formulation of extensive computer programs to permit maximum flexibility in posting, filing, and searching for pertinent documents. The computer developments were undertaken by a group of student programmers headed by Robert Sheldon. The textile information system provides for on-line computer searching from a distance. Its working mode was demonstrated to the textile industry in April through an information searching dialogue between New York

and Cambridge. A similar demonstration between Manchester, England, and M.I.T. is planned for July, 1967.

DESIGN DIVISION

PROJECT TRANSPORT In the general area of transportation, departmental faculty supervised research and graduate student thesis investigations in the areas of high-speed ground transportation and traffic safety.

Under Department of Commerce support of high-speed ground transportation, Professor Paul continued research investigations on active vehicle vibration isolation, feasibility of at-speed passenger transfer, and stresses and strain in rolling contact.

Professor Gouse continued studies of the aerodynamic drag on high-speed ground transportation vehicles in enclosed guideways. The work was extended to include the effects of guideway wall porosity and guideway end conditions on the over-all drag coefficient of spherical and cylindrical vehicles.

Professor Baumann continued investigation of computer-organized information retrieval mechanisms for systems engineering decision-making.

Professor Richardson's research was concerned with the dynamics of high-speed vehicles, especially fluid-suspended vehicles. Studies were completed of the dynamic modelling of fluid suspensions and of the quasi-static pressure-flow displacement behavior of fluid suspensions, using a scale model at superambient pressure in a large-scale water tunnel. Work dealing with the dynamics of suspended vehicles moving over irregular guideways including consideration of passenger comfort, guideway accuracy, and suspension characteristics was also finished. Objectives of this research are to develop basic understanding and the ability to predict dynamic behavior at the design stage for advanced vehicle suspension concepts. Of particular significance is the potential use of controlled flexibility of the fluid suspension to optimize dynamic performance and thus to relax the necessary guideway accuracy requirements.

Professor Wilson continued work, initiated last year by Professor Suo, on applying the hydraulic analogy to the passing of high-speed trains into tunnels. Results thus far show that the forces encountered are such that they must be taken into account in the design stage, particularly as they affect train stability.

Under the General Motors grant to support research related to highway safety, Professor Wilson supervised several economic analysis and resource allocation studies directed toward optimum distribution of nationwide highway safety funds. Results of these cost benefit analyses

are encouraging and may very well influence government decision-making. In another investigation, Professor Wilson supervised the study of the over-all economics of automated inspection procedures for present-day vehicles and future high-speed and automated vehicle systems, with concentration on automated inspection of difficult areas such as the tire carcass, where it was shown that the dynamic response of the tire is sufficiently affected by the presence of flaws in the casing to provide a basis for an automatic inspection method.

Professor Baumann and his students completed an investigation of the optimal merging strategies for networks of automated vehicles.

Professors Sheridan and Ferrell are concerned with the man-machine interaction in the context of highway safety. Professor Ferrell emphasized the modelling of human behavior in controlled situations similar to vehicle driving. Investigations were made of the effect of restricting the ability to see ahead and of the pressure of time on decision-making and of the question whether being in active control affects the quality of decisions. Professor Sheridan completed the first phase of a theoretical and experimental study of human preview control, using a driving simulator to collect data and optimum control theory to establish a base line against which to measure human performance.

SENSORY AIDS The Braille translating and embossing system of Professors Mann and Baumann and Mr. John Dupress of the M.I.T. Center for Sensory Aids Evaluation and Development passed several new milestones and continues to be a center of effort. This fall, M.I.T. Braille embosser consoles will be deployed in several Boston area schools to permit blind children and their teachers to obtain "instant" Braille from English input at keyboards at the school, by means of English-to-Braille translation at the M.I.T. computer over telephone company connections. Telephone-computer interfacing and buffering equipment was developed and is in readiness for this experiment in computer-aided instruction for the blind.

The holographic, laser-driven, associative memory researched by Daniel W. Kennedy in his doctoral thesis was shown feasible for many applications including the direct Braille translation for which it was originally intended. Among novel applications is automatic fingerprint identification, an S.B. thesis study supervised by Professor Baumann.

Activity on the Braille project was accelerated by a substantial grant from the John A. Hartford Foundation in New York City to continue development and evaluation of the Braille embosser. With respect to the wide-scale deployment of technologically assisted Braille, including the recommended establishment of national centralized facilities, a

Master's thesis investigation by Louis H. Goldish in the Sloan School of Management, supervised by Professor Mann, was very well received and will be published in quantity by the American Foundation for the Blind, New York City.

Professor Ferrell continued research on an auditory display for a reading machine for the blind.

LIMB PROSTHESES Collaboration continued among Professor Mann, orthopedic surgeons at the Massachusetts General Hospital, and the staff of Liberty Mutual Research and Rehabilitation Centers on the electromyographically controlled arm. A mechanical redesign simplified and lightened the limb. The electronic control circuitry was integrated into the forearm and the limb, and these, together with an upper arm socket, were fitted to an amputee. Concurrent electromyographic testing of the prospective patient population yielded much data on control propensity and variability, training and fatigue. This summer a group of amputees will be fitted with the limb and subjected to laboratory, then clinical, and ultimately everyday evaluation of the device. The doctoral investigation of David Alles under Professor Mann demonstrated that a satisfactory cutaneous display of limb position to the amputee can be provided by means of two fixed-location, vibro-tactile stimulators in the upper arm socket. By relating time of onset of vibration of the stimulators to the angle of the elbow the subject perceives a phantom cutaneous vibration whose position between the stimulators correlates with elbow angle.

OTHER RESEARCH In the Man-Machine Systems Laboratory, Professor Sheridan demonstrated laboratory manipulator systems under various kinds of "supervisory control" in which the human operator inputs the sub-goal using a compiler-type language and the computer directs the machine manipulator using an optimization algorithm. Space and under-seas applications of such "supervisory control" manipulators are anticipated. Professor Ferrell continued investigations of the use of teletypewriter keyboards for conveying geometrical information to a computer for the positioning of a manipulator.

Professor Wilson and Professor Henri Fenech of the Department of Nuclear Engineering supervised an investigation, which resulted in a patent, of a helium-water mixing cycle for energy production whose advantages in capital costs may outweigh low efficiency. Professor Wilson also supervised a special study on mixed power-plus-process-steam plants and an investigation of power recovery in coke-oven plants.

Professor Richardson completed a study of the physics of face seals.

Dr. Parmelee extended the Computer-Aided Design research in two directions, an expansion and further evaluation of the computer program for stress analysis and studies into the design of a flexible input-output system to be used as a basis of a computer-aided design system.

Professor Adams supervised several thesis students on kinematic and nomographic investigations.

GAS TURBINE LABORATORY

Careful experimental work, under the direction of Associate Professor Philip G. Hill, on the condensation of a number of different vapors in an expanding nozzle showed the inadequacy of present nucleation and drop growth theory.

Under Professor Edward S. Taylor of the Department of Aeronautics and Astronautics, theoretical work which includes the effect of upstream history on turbulence intensity showed agreement with measurements of a turbulent boundary layer in strong streamwise pressure gradients. The study of boundary layers in favorable pressure gradients was extended to $M = 2$ and to high Reynolds numbers. This work is applicable to the problem of cooled turbine blades in engines for supersonic transports and to the problem of cooling rocket nozzles.

Study of the losses due to sound waves emanating from a transonic compressor was continued. The work is applicable to current and future aircraft engines.

The study of a compressor blade of unconventional shape gave very promising results and is being vigorously pursued. It is applicable to all gas turbine compressors, particularly those of aircraft engines.

The regenerative compressor was studied. This type of machine is useful for special purposes where a pump of very low specific speed is required.

A study indicated that the addition of swirl to the flow promises to shorten the mixing length of jets considerably, and may have application to devices such as direct-lift engines and ejectors.

SURFACE LABORATORY

Under the direction of Assistant Professor Phillip Gould, a project to study energy dissipation at clamped interfaces was started. This is of interest to the airplane industry, because such interfacial damping helps to get a rotationally accelerating jet engine safely past its resonance frequencies.

Under the direction of Professor Rabinowicz, an investigation of mechanical reliability continued with the aim of predicting the performance of mechanisms under normal operating conditions by running

tests under accelerated stress conditions and extrapolating the results of these tests. Special attention is being paid to methods applicable to mechanisms that have been run under normal conditions in the field for part of their working lives, and then are brought back to the laboratory so that failure can be induced under accelerated conditions.

Professor Rabinowicz continued his study of the polishing process. An analogy was established between material removal from a solid during sliding, as mechanical energy is fed into the solid, and material removal from a liquid as thermal energy is fed into it. Just as the liquid has an evaporation mode in which the surface stays smooth, and another mode in which bubbles form and the surface becomes rough, so does the solid have a polishing mode producing a smooth surface and a severe wear mode producing a rough surface.

Professor Rightmire worked on the stability under mechanical stress of matter adsorbed at a solid-solid interface. Experiments on liquid alcohols at room temperature indicate that, provided the normal stress is not too high, a stable state can be attained. To reach such a state within a reasonable time, however, some kind of relative motion appears to be necessary. In particular, slow, oscillatory sliding has been found effective. Thus the approach to equilibrium is controlled primarily by the applied stress and motion, thermal activation being unimportant. An equilibrium theory of interfacial adsorption was developed which predicts the maximum normal stress for which stability is possible. Measurements of electrical conductance at an interface between crossed wires are being used to test the theory.

Assistant Professor Walter D. Syniuta is carrying forward rolling-contact-fatigue research with the objective of discovering where dangerous cracks start. Techniques of electron fractography are used on fatigue-fractured surfaces to determine the direction of crack propagation leading to failure. Hydrogen embrittlement is suspected as a cause of early failure in the presence of some lubricants known to contain moisture. Polarized testing is under way to check this view. Professor Syniuta also started work in the area of electro-chemical and electric-discharge machining.

SLOAN AUTOMOTIVE LABORATORY

Research under the direction of Professor Rogowski was concerned with the influence of mechanical factors in ignition and the early stages of flame propagation, the rapid and efficient burning of lean mixtures and the mechanics of fuel spray core break-up and droplet shattering. Professor Kelly continued work in non-equilibrium ionization and radiation in shock and detonation waves. It is noteworthy that significant contribu-

tions to this research were made by undergraduate thesis students from both the Department of Physics and the Department of Mechanical Engineering. Both Professor Rogowski's engine group and Professor Toong's combustion group are planning active participation in the air pollution research program of the Department.

SENSORY AIDS EVALUATION AND DEVELOPMENT CENTER

Principal areas of investigation include:

1. the conversion of United Press International (UPI) news on compositors' tape to Grade 2 Braille;
2. the interaction of dotsys (a computer system to generate Grade 2 Braille from a wide variety of inputs) with a manually-operated typewriter input and Grade 2 Braille print-out in real time;
3. the conversion of textbook material on teletypesetter tape to Grade 2 Braille;
4. the fabrication, preliminary evaluation and redesign of monaural and stereophonic ultrasonic mobility aids intended to supplement the use of a long cane by a blind traveller;
5. a basic research project on length and distance concepts in congenitally blind children, with cooperation from Perkins Institute and the Massachusetts Commission for the Blind;
6. cane balance experiments with Boston College, Graduate Department of Education, Peripatology Program, and the Department of Psychology at the University of Louisville, and
7. cooperative projects with the University of Canterbury, New Zealand, to combine a collapsible long cane and an ultrasonic mobility device, with the Royal National Institute for the Blind in England to use a small computer for Braille translation, and with the Library for the Blind in Denmark to use a 7094 for Braille translation.

STUDENT ACTIVITIES

AMERICAN SOCIETY OF MECHANICAL ENGINEERS

The program organized by the M.I.T. student section of the American Society of Mechanical Engineers (ASME) included meetings held at about three-week intervals devoted to technical presentations and career discussions, as well as two staff-student cookouts. A new development was the formation of an ethics committee which brought to the M.I.T. community a lecture by Mr. Ralph Nader, followed by a panel discussion on the topic of the engineer's responsibility to society. David F. Cahn took over the chairmanship from Raymond J. Giglio, and plans further widening in ASME's activities in the coming year.

AWARDS

Awards were announced and prizes presented at the annual Awards Dinner, organized by Professor Lent, which was held May 25.

The de Florez, Wunsch Foundation and Lubrizol awards, totalling \$2400, were divided among 23 students.

The de Florez award for outstanding ingenuity in mechanical engineering was won by G. Reid Marsh III, Joel P. Robinson and John A. Swaim. Honorable mention was given to Robert H. Sturges, William Hsu, James D. McGill, Glenn A. Wanek, Gregory D. Wight, David R. Berry and J. Edward Snyder.

Silent Hoist and Crane Company Materials Handling Awards were given by the Wunsch Foundation for the best papers or theses submitted on subjects in the field of production, materials handling, or machine design related to materials handling; they were awarded to Lawrence W. Hill, Donald E. Uhl, Jeffrey L. Ellison, Bruce A. Enders, Bruce I. Nappi and George C. Slusher.

Lubrizol Awards, given to sophomore students in the subject Engineering Design and Manufacture, were received by Robert A. S. Lee, William D. McLaughlin, Ora E. Smith, Kenneth R. Hules, Stanley B. Limpert, Donald T. Scholz and Robert L. Jacobus.

The Scott Paper Foundation Leadership Award for 1967 was won by William M. Mack Jr. This award of \$1,500 toward senior-year tuition plus \$1,500 toward tuition in the first year of graduate study, is presented to an engineering student in his junior year in recognition of demonstrated high character, actions on behalf of the welfare of his colleagues, and potential for making outstanding contributions to the professional aspects of engineering in business and industry.

An American Society of Mechanical Engineers certificate for outstanding efforts and accomplishments in behalf of the M.I.T. Student Section of ASME was presented to David F. Cahn.

American Society for Testing and Materials (ASTM) Certificates which confer membership in the Society for 1967 in recognition of demonstrated interest and meritorious work in subjects relating to the activities of the ASTM were won by Edward D. Riley and Robert Hodges.

STAFF

NEW MEMBERS OF THE FACULTY

Dr. David P. Hoult, formerly Associate Professor in the Department of Aeronautics at Pennsylvania State University, joined the Department in January as an Associate Professor of Mechanical Engineering. His major field of interest is fluid mechanics in which he is continuing his recent

work in ionospheric fluid mechanics while initiating research in the atmospheric dispersion of pollutants.

Dr. Ernest G. Crvalho, whose major interest is thermodynamics, joined the Department as Assistant Professor after completing his Ph.D. at the University of California, Berkeley; he is presently working in the Cryogenic Laboratory.

Dr. Allan D. Pierce, formerly Senior Staff Scientist, Space Science Department, AVCO RAD, and a lecturer in the Physics Department at Northeastern University, was appointed Assistant Professor. He is working with Professor Crandall on acoustics.

Dr. Ioannis V. Yannas, whose major interest is fibers and polymers, was appointed Assistant Professor after receiving his Ph.D. from Princeton University.

New Assistant Professors include two former Research Associates — Dr. Joseph Gerstmann, heat transfer, and Dr. Ronald C. Rosenberg, computation. Appointed Assistant Professors after receiving M.I.T. degrees were: Dr. Borivoje Mikic, heat transfer, Dr. Pangal N. Nayak, materials processing, and Dr. Walter D. Syniuta, lubrication.

New Research Associates and their areas of concentration include Dr. Colin Clark, biomechanics and the cardiovascular system, Dr. Richard P. Parmelee, computation, and Dr. Yeshaiahu Y. Winograd, plasma dynamics.

Mr. Nicholas P. Negroponte, a Research Fellow in the Department of Architecture, was a Lecturer in Mechanical Engineering last year. His major fields are architecture and computer-aided design.

RETIREMENTS

Professor Jacob P. Den Hartog, one of the best known names in mechanical engineering and internationally famed as an expert in mechanical vibrations, came to the age of retirement this year. He is no less famous for his lectures and, with Mrs. Den Hartog, for his befriending of foreign students the world over. Professor Den Hartog came to M.I.T. as Professor in 1943 but served on leave with the U.S. Navy until 1945. He was Head of the Department from 1954 to 1958. Since 1962 he has held a joint appointment in the Department of Mechanical Engineering and The Department of Naval Architecture and Marine Engineering. We are fortunate that Professor Den Hartog will continue to teach with a half-time appointment as Senior Lecturer.

LEAVES OF ABSENCE

Professor Den Hartog was on leave the spring term before his retirement, writing new editions of his two texts, lecturing, and travelling in the United States and Japan.

Professor Paynter spent his year of leave in Vermont reading and writing to lay the groundwork for new activities which he and his colleagues can later pursue.

Professor Toong spent the year writing a book based on his graduate subjects on the dynamics of chemically reacting fluids, doing research and giving lectures.

Other leaves of absence include Professor Steven A. Coons who spent the fall term working at Project MAC and writing a monograph on the shape-descriptive mathematics he has been working on during the past few years, and in the spring was a Research Fellow at Harvard's Aitken Center doing research in computer graphics; Professor Carabateas, who continued on leave for the third year on an educational project for the Ministry of Coordination, Athens; and Professor Adams who was on sabbatical leave this spring term, devoting most of his time to translating a definitive work on kinematics by U.S.S.R. Academy member I. I. Artobolevskii.

RESIGNATIONS

Two associate professors who made valuable and long-lasting contributions to the Department resigned this year. They were Alve J. Erickson and S. William Gouse Jr.

We also regret the resignations of Assistant Professors Eustratios N. Carabateas, R. Gordon Cook, Phillip Gould, Richard J. Gurski, Jon R. Kelly, Walter J. Bornhorst, George S. Springer and Research Associate Marvin Goldstein.

VISITING STAFF

Once again the Department had an unusually large number of visiting staff.

Dr. John H. Argyris, Professor at Imperial College of Science and Technology, University of London, and Director of the Institut für Statik und Dynamik der Luft und Raumfahrtkonstruktionen, Technische Hochschule Stuttgart, held an appointment as Visiting Professor of Structural Analysis in the Departments of Aeronautics and Astronautics, Civil Engineering, and Mechanical Engineering for the spring term.

Dr. Kenneth N. C. Bray, a Reader in Aeronautics at The University, Southampton, spent a sabbatical year as Visiting Professor with the Fluid Mechanics group of the Department.

We had three visitors from the Technical University of Berlin. Two of them spent a month here in the fall as Visiting Professors — Ernest Fiala, with Professor Sheridan in man-machine systems, and Theodor Gast, with Professor Lee in systems dynamics and control. Dr. Hans

Hermann Fernholz spent the year as a Visiting Associate Professor in the Gas Turbine Laboratory.

Dr. Martin D. Cowley, a Lecturer in the Engineering Department at Cambridge University, was a Visiting Associate Professor with the Fluid Mechanics group while on sabbatical leave.

Mr. Michael G. Cooper, also a Lecturer in the Engineering Department at Cambridge, spent his sabbatical year in the heat transfer division, during the fall as a Research Associate and during the spring as Visiting Associate Professor.

Dr. Regis M. N. Pelloux, Chief of the Materials and Processes Unit, Turbine Division, The Boeing Company, was a Visiting Associate Professor. He worked with Professors McClintock and Argon in the materials group.

Dr. Andreas Boehringer was a Visiting Research Associate from April, 1966, to April, 1967, working on automatic controls and engineering systems, power systems and electromechanics. He is a Teaching and Research Assistant at Technische Hochschule Braunschweig, Institut für Elektrische Antriebe.

Dr. Hisayoshi Sato, an Assistant Professor on leave from the Institute of Manufacturing Technology, Tokyo University, spent the year as Visiting Research Associate working with Professors Nathan Cook and Crandall on machine-tool vibration problems.

Professor Borisas Cimbleis, Head of the Mechanical Engineering Department at the University of Minas Gerais, Belo Horizonte, Brazil, was a Guest of the Department in the thermodynamics group from February to May. He has a strong interest in the history of thermodynamics.

Dr. Jaciej J. Zgorzelski, an Assistant Professor of Physics at Warsaw Technical University, was a Visiting Scholar in the thermodynamics group, working with Professor Stickney. He is interested in the problems of thermionic energy conversion and carried out a theoretical study of the non-equilibrium ionization in converters.

Dr. Helmut W. Huff, who received his Ph.D. in 1966 from the Technische Hochschule Darmstadt, was a Visiting Research Fellow in the materials group on a NATO (North Atlantic Treaty Organization) fellowship.

Walter Greaves, a Ph.D. candidate at the University of London, was here on a Kennedy Memorial scholarship with the rank of Research Fellow. His interest is thermodynamics.

Mr. Oscar L. Bowie, a staff consultant at Watertown Arsenal, was a Visiting Research Fellow in the materials group.

Dr. Gerhard Egbers, from the Textile Institute of Aachen Institute of Technology, was a Visiting Engineer in the fibers and polymers group.

Mr. Mark Schoenberg, who received his S.B. from the Department of Aeronautics and Astronautics at M.I.T. and who is now a student at New York University Medical School, was appointed a Visiting Engineer. He worked with Professor Shapiro in the fluid mechanics of the cardiovascular system.

Mr. Yuri A. Bondarenko, a graduate student at Leningrad Polytechnical Institute, was a Visiting Scientist in the Gas Turbine Laboratory.

STAFF ACTIVITIES AND AWARDS

Professor Den Hartog received two honorary degrees: D. appl. Sc., doctor in de toegepaste Wetenschappen ad honores, from the University of Ghent, in February, 1966, and D. tech. Sc., doctor in de technische Wetenschappen honoris causa, from the Technical University of Delft, Holland, 1967. He was Conference Chairman of the Vibrations Conference held in Boston March 29-31 under the auspices of the Machine Design Division of the American Society of Mechanical Engineers. Professor Crandall was chairman at the same meeting of the subcommittees on random vibration and non-linear vibration.

Professor Crandall served as chairman of the Publications Committee and Professor Berg was a sponsor for non-linear fluids within the Applied Mechanics Division of the American Society of Mechanical Engineers. Professor Crandall is also serving as a member of the Navy ad hoc Committee on Dynamic Analysis for Shock.

Professor Probststein served as a member of the American Institute of Aeronautics and Astronautics Fluid Dynamics Technical Committee and the Commission on Physics of Comets of the International Astronomical Union.

Professor Fay continued his membership on the executive Committee of the Fluid Dynamics Division of the American Physical Society and of the NASA Fluid Dynamics Advisory Committee. He served as chairman of the American Institute of Aeronautics and Astronautics Plasmadynamics Committee. He also served as a member of the subcommittee on air pollution of the Cambridge City Council.

Professor Shapiro was elected a member of the National Academy of Sciences, a Fellow of the American Institute of Aeronautics and Astronautics, and a Fellow of the American Society of Mechanical Engineers. He was appointed a Councilor of the American Academy of Arts and Sciences. He served as a member of the Editorial Committee for the new publication, *Annual Review of Fluid Mechanics*, and continued active work in educational film production as a member of the National Committee for Fluid Mechanics Films.

Professor Dahl was elected a Fellow of the American Academy of Arts and Sciences. He is serving as chairman of an ad hoc Committee on Teaching appointed by the Committee on Educational Policy. Last summer Professor Dahl visited the College of Petroleum and Minerals at Dhahran, Saudi Arabia, for two weeks and reported on the problems of the establishment of engineering education at the college. He also attended a UNESCO meeting in Paris to discuss a world congress on engineering education to be held in 1968.

Professor C. Richard Soderberg was elected an Honorary Member of the American Society of Mechanical Engineers.

Professor Keck became a member of the Physics Panel of the Air Force Office of Scientific Research.

Professor Keenan served as Visiting Professor of Mechanical Engineering at Stanford University and at Purdue University. He presented a graduate subject in thermodynamics during the winter quarter at Stanford.

Professor Stickney served as editor and co-chairman of the Physical Electronics Conference held in March at M.I.T. In addition, he was a member of the steering committee of the Thermionic Conversion Specialist Conference.

Professor Rightmire continues active as a member of the Research Committee on Lubrication of the American Society of Mechanical Engineers.

Professor E. S. Taylor continued his work with the National Committee for Fluid Mechanics Films. At the invitation of Professor Dr. Ing. W. R. Wille and under sponsorship of the Ford Foundation, Professor Taylor spent a week at the Technische Hochschule, Hermann Foettinger Institut. During this trip he also lectured at Cambridge University at the invitation of Visiting Institute Professor William R. Hawthorne.

At the request of the U.S. State Department and under sponsorship of the Agency for International Development program, Professor Philip Hill participated in a summer institute held at Bengal Engineering College, Calcutta, India, during May and June, 1967.

Professor Toong was invited by the National Tsinghua University and the Academia Sinica to lecture at the National Taiwan University. He also lectured at the Chinese Institute of Engineers and the Technical University of Berlin. He continues his membership on the Propellants and Combustion Committee of the American Institute of Aeronautics and Astronautics.

Professor Hoult became a member of Commission III of the Union Scientific Radio International.

Professor Lee served as Chairman of the Fluid Control Session at the American Society of Mechanical Engineers meeting in December, 1966. He also served as a Session Chairman for the Joint Automatic Control Conference in June, 1967.

At the invitation of the Advisory Group for Aerospace Research and Development of the North Atlantic Treaty Organization, Professor Lee participated as the co-chairman of a special group which gave lectures on modern developments in fluid power in Turin, Brussels and London.

Professor Richardson organized a technical session entitled, Vehicle Guideway Suspension Interactions, to be held in August, 1967, at the Second International Symposium on Transportation under the joint sponsorship of the New York Academy of Sciences, the American Society of Mechanical Engineers, and the Institute of Electrical and Electronic Engineers.

The Fluidics Committee of the American Society of Mechanical Engineers, under the chairmanship of Professor Brown, held its first symposium, which was attended by 500 persons working in this area.

Professor Karnopp served as Session Chairman at the Canadian Conference of Applied Mechanics in May, 1967.

Professor Rogowski is active in several national professional society committees including one on revision of the ASME power test code.

Professor Wilson was appointed to the Comité Scientifique et Technique of the French magazine, *ENTROPIE*, devoted to power and propulsion. He is past Vice-Chairman and upcoming Chairman of the Process Industries Division of the ASME and Program Chairman of the 1968 Annual Conference of the Gas Turbine Division of the ASME. He has also been elected to the Board of Directors of the Volunteers for International Technical Assistance, and is Chairman of their Boston chapter.

Professor Hesselschwerdt has taken on additional duties of advising the Physical Plant on refrigeration, heating and air conditioning as these facilities at M.I.T. are expanded. He has been elevated to the grade of Fellow in the American Society of Heating, Refrigerating and Air Conditioning Engineers.

During the past year Professor Nathan Cook continued to serve actively as an advisor to the Birla Institute of Technology and Science, Pilani, India. In conjunction with this effort, a joint research program has been established, initially in the general area of machine tool wear.

Professor Backer was re-elected for a second term to the Board of Trustees of the Textile Research Institute. He is also serving on the American Panel of the British Textile Institute, as well as on the Executive Committee of the Textile Engineering Division, American Society of Mechanical Engineers.

Dr. Valko served last year as a member of the Governing Council of the Fiber Society, and was chairman of the International Fiber Society Conference on Fine Structure Fibrous Polymers. He is also a member of the American Panel of the British Textile Institute.

Professor Sheridan continued as Editor of the Institute of Electrical and Electronic Engineers (IEEE) "Transactions on Human Factors," while Professor Ferrell continued his service on the editorial board of the Man-Machine Systems group of the IEEE.

Professor Baumann was a member of the Summer Study on Science and Urban Development sponsored at Woods Hole, Massachusetts, by the Department of Housing and Urban Development. With students of the interdepartmental systems subject in the spring of 1966 who prepared Project METRAN, Professor Baumann visited and made presentations to executives of the General Motors Corporation and the Ford Motor Company, as well as a presentation at the Annual Meeting of the Highway Research Board of the National Academy of Sciences.

Professor Mann continued as Chairman of the Sensory Aids Subcommittee of the Committee on Prosthetics Research and Development of the National Academy of Sciences – National Research Council. The activities of the Subcommittee have expanded to the point where a recommendation has been made to upgrade the Subcommittee to full committee status as the Committee on Sensory Aids of the National Academy of Sciences – National Research Council. For a week in the spring semester Professor Mann lectured in the Mechanical Engineering Department at Auburn University in Alabama and in the nearby Tuskegee Institute on the subject of engineering design.

ASCHER H. SHAPIRO

DEPARTMENT OF METALLURGY AND MATERIALS SCIENCE

In 1939 the Department of Metallurgy became an entity of its own, dropping its affiliation with mining. There followed a period of 27 years of growth and development, particularly in terms of a broadened outlook towards materials in general, rather than metals alone. The last year has seen the culmination of this development with the formal recognition of a change in name to "Department of Metallurgy and Materials Science."

It should not be thought that this was a precipitate or even novel decision. It is the result of a gradual evolution in the interests of the Department throughout the past ten years. In fact, the desirability of changing the name of the Department was discussed with the Visiting

Committee in 1961, but it was then felt that the interests of other departments in the School of Engineering were not sufficiently well established to make a decision that might have had the effect of weakening their own materials programs. In the intervening years, such fears have been shown to be groundless; most other engineering departments have developed strong programs in materials engineering geared to their own particular needs. Interaction with the activities of this Department has been good. It is also fair to say that, in 1961, it was not perfectly clear that materials science would emerge as a unifying field. The impetus given to broad studies of structure-property relationships in materials by programs such as those of the Advanced Research Projects Agency of the Department of the Defense have — together with the interest of many progressive industrial corporations in coupling metallurgical and other skills in the study of composite materials — insured that the field would emerge in its own right.

Materials science has not been a province exclusively of the metallurgist but it is fair to say that metallurgists have contributed most to the field and have been ready to accept the responsibility of applying metallurgical techniques to materials such as ceramics and polymers.

The danger with such a departmental title is that it may be too vague and all-encompassing. It is sensible, therefore, to read into it some restrictions as to scope. The concern of departments such as our own is with materials that are useful for structures, machines and devices and these are generally metals, ceramics and polymers. Metallic materials still constitute by far the largest class of useful materials, but the study of metals and alloys alone gives an unnecessarily restrictive view of the broader field.

In some other universities, materials science and engineering have emerged as graduate programs, after the students have taken an undergraduate degree in metallurgy or mechanical engineering. It is more satisfying, conceptually, that the initial introduction be to the field of materials in general, and particularly to the structure-property theme, and then for specialization to come in the graduate school. Such specialization is not the aim of every graduate student. Some, with backgrounds in physics or chemistry, are attracted to the kind of research that is done in a metallurgy department but are not willing to concentrate on metallurgy. Their research work, in particular, is much better described as materials science.

The main advantage that the Department will gain from this change in name is that students will be aware that we deal with a field which is not narrowly oriented. It is clear, from course choices, that students are attracted to the basic sciences, because these are well known to them,

or to the broader engineering fields, because these also are familiar names. But metallurgy is not a familiar name, unless a student encounters it through his family or his location.

In retrospect, it might have been more satisfying to an M.I.T. department to pioneer this change in name, but no one can say now that we have not given the subject enough study. Along with the change in name, it should be noted that the Bachelor's degree is now given in Metallurgy and Materials Science and that a Doctor of Philosophy or Doctor of Science in Materials Science may be awarded to graduate students.

UNDERGRADUATE EDUCATION

Experience with the unified curriculum in metallurgy and materials science suggests that the basic concepts are sound but that some further work on subjects needs to be done. A small faculty group has been meeting with representatives of the Student Metallurgical Society to review the curriculum and the teaching of individual subjects. The comments of the students have been constructive and helpful and will bring about some changes. For example, it is clear that a curriculum in which more than 20 per cent of the subjects are unrestricted electives demands a better information and counseling system. The M.I.T. *General Catalogue* is simply not a sufficient guide to a student looking for a logical sequence of electives, particularly if the sequence involves subjects in other departments.

Professor Thomas B. King and Assistant Professor Derek J. Fray taught 3.02 (Chemistry of Materials) for the first time and encountered a not-entirely-unexpected difficulty — the varying background of students in chemistry. The traditional approach through electronic structure and periodic properties is, for most of our students, treated in high school. Subsequent exposure to the problems of how substances react tends to be from the viewpoint of physical chemistry and thermodynamics. A “feeling” for chemical behavior is, therefore, difficult to impart, since the student no longer has the intensive background of the periodic table and periodic properties.

Professor Walter A. Backofen and Assistant Professor Bud C. Wonsiewicz taught 3.11 (Mechanics of Materials) for the first time, and managed — with some success, according to student comment — to combine the traditional continuum view of elasticity and plasticity with an awareness of the important effects of structure on mechanical properties.

Professor Robert E. Ogilvie and Assistant Professor Bernhardt J. Wuensch introduced another new subject, 3.12 (Principles of Crystallography and X-ray Diffraction) which deals less with diffraction techniques and provides a much stronger foundation in crystallography.

The fourth new subject, 3.01 (Thermodynamics and Statistical Mechanics) was taught by Professor Clyde M. Adams Jr. and Associate Professor Robert M. Rose. It has not been easy to reconcile, in the minds of students, the classical and statistical approaches to thermodynamics.

Professor John F. Elliott, with the aid of a new computer console in Building 8, was able to introduce more complex problems on equilibria into 3.00 (Thermodynamics of Materials) an innovation which proved to be popular among the sophomores. A study group, with Professors Elliott, Adams, Fray and Rose will develop further problems next summer under a grant from the Dean of Engineering. The console in Building 13 has seen further service in the teaching of 3.15 (Materials Science II) taught by Associate Professors Roy Kaplow and Simon C. Moss. The former, with the help of Dr. John W. Brackett, has made further progress in the development of MAP, a system for on-line mathematical analysis, and a manual has now been published.

Associate Professor Merton C. Flemings has made considerable modifications to the laboratory in 3.141 (Engineering Materials) which is now much closer to a project-type laboratory. Handling about 150 students in such a laboratory is a real problem but the results so far make it worthwhile.

Associate Professor Robert L. Coble brought his knowledge and experience in glass and ceramic forming processes to bear in a new approach to 3.18 (Materials Processing).

The sophomore laboratory subjects, 3.04 and 3.05 (Materials Research Laboratory) attracted 12 students in the first term and 28 in the second. Students met with Professor Harry C. Gatos once a week for orientation and discussion sessions while they did laboratory work under the supervision of an individual professor. All students were exposed initially to x-ray and metallographic techniques. In general, they were enthusiastic, particularly those who were able to come up with a specific research contribution. Some, however, might have preferred more traditional laboratory instruction.

Undergraduate seminars were presented by Professor Nicholas J. Grant and Dr. Bill C. Giessen (Ultrafast Quenching Experiments), Assistant Professor Donald R. Uhlmann (Rapid Quenching of Non-metallic Materials), Professors John Wulff and Rose (Superconducting Alloys), Professor Herbert H. Uhlig (Corrosion of Metals), Professor Gatos and Associate Professor August F. Witt (Semiconductor Crystal Growth) and Professor Ogilvie (X-ray and Electron Optics).

Enrollment remained disappointing, at 50 students, though student quality is higher. The Department graduated 15 seniors with the Bachelor's degree.

The Dow Chemical Company prize for the best undergraduate thesis was awarded to Andrew M. Sherman (first prize) and William A. Brown and Alexander D. Wilson (joint second prize). The Metallurgy and Materials prize for the outstanding junior was presented to David C. Hill at a meeting of the Boston Section of the American Institute of Mining, Metallurgical and Petroleum Engineers which sponsors the award.

GRADUATE INSTRUCTION

The recommendations of Professor W. David Kingery's committee, with regard to general departmental subjects, have now been implemented.

Graduate enrollment during the year averaged 158 regular students (down from last year, because of research-funding problems) with about 120 students registered for the doctorate degree. Advanced degrees awarded from September, 1966, through June, 1967, totalled 24 Master's, two Engineer's degrees and 40 doctor's degrees (a record).

The Colloquium Series, organized by Professor Cyril S. Smith and a small committee, dealt with the "Many Faces of Metallurgy." The Williams Lectures, delivered by Professor Smith, can be described only as fascinating.

A notable first for the Department was the award of the Goodwin Medal, for conspicuously effective teaching, to John W. Hafstrom, a teaching assistant with Professor Wulff (who might be regarded as an apt mentor).

GRADUATE RESEARCH

PHYSICS OF SOLIDS

Research in this group deals with the application of solid-state physics to problems of interest to the metallurgist and materials scientist. The general areas of research are the scattering of x-rays, electrons, and neutrons from solids and liquids, the electronic structure of metals, alloys, and semiconductors, order-disorder phenomena, and the study of local environments in metals and alloys.

Professor Benjamin L. Averbach has continued work on spin correlations in antiferromagnetic oxides by neutron scattering. Similar effects to those already reported for MnO are observed in cobalt and nickel oxides. The data are coupled with susceptibility measurements in a study of the mechanisms involved in the antiferromagnetic transition. Spin arrangements are also being investigated in iron-silicon and iron-vanadium alloys in the vicinity of the Curie temperature. Strong ferromagnetic local order is observed above the transition, and this is being investigated as a function of temperature.

Professor Averbach and Assistant Professor David J. Sellmyer have installed a high-homogeneity, superconducting solenoid in a low temperature cryostat to study the electric and magnetic properties of metals and alloys down to 0.8°K and in fields up to 45 kG. An apparatus for measuring de Haas van Alphen oscillations has also been constructed and used to measure areas of several third-zone pieces of the Fermi surface of pure lead. This work has already been reported, but the effect on the electronic structure of the crystalline potential, as varied by alloying, is being studied in the lead-indium system.

The high fields available at the National Magnet Laboratory can be used to investigate the Fermi surfaces of metals with relatively short relaxation times at low temperatures — for example, dilute solid solutions and transition metals that are difficult to purify. Quantum oscillations in the resistivity of antimony in a field modulation experiment up to 100 kG have been observed. The maximum frequency was 6×10^6 .

An apparatus has been constructed for measuring thermoelectric power and resistivity of single crystal rod samples from 4.2°K to 300°K and a vibrating sample magnetometer for use in the longitudinal field of a superconducting solenoid has also been built. This apparatus will make it possible to measure the susceptibility of metals and alloys from liquid helium temperatures to room temperature.

Professor Sellmyer has been studying the Fermi surfaces of Hume-Rothery electron compounds; a more detailed understanding of the effects of electron concentration on phase stability can be achieved. The measurements are of high field magnetoresistance, in fields of 150 kG, at the National Magnet Laboratory. Ordered alloys, on which preliminary data have been obtained, include silver-zinc, gold-aluminum, gold-gallium and gold-indium alloys. The gold-aluminum crystals, which have resistance ratios of 500, show very sharp open orbit effects. The Fermi surfaces of these fluorite-structure compounds seem to have similar topologies.

Professor Moss has modified an electron microscope to incorporate X-Y scanning of the electron diffraction pattern obtained from a sample mounted in the high-resolution diffraction chamber. The instrument has been used in research as well as a teaching tool. Professor Moss has mounted an electrostatic velocity filter below the final slit to determine an energy window of ± 0.5 volts. It is intended to examine phase transitions in crystalline and non-crystalline solids, and other quantitative electron-scattering phenomena. In principle, it will also be possible to examine plasma losses in pure metals and dilute alloys.

The work of Professors Moss and Averbach on ultrasonic studies has continued, with further measurements on gold-nickel alloys. The initial

findings were reported last year and the work on elastic constants has been combined with thermodynamic data of other workers to recalculate the temperature suppression of spinodal decomposition in the system. It was found that the true, coherent spinodal has a maximum at about 40 atomic per cent nickel whereas the chemical spinodal occurs at 70 atomic per cent nickel. This calculation supports the electron diffraction evidence for a shift in the peak of the spinodal to about 40 atomic per cent nickel.

Professor Moss, in collaboration with Dr. P. C. Clapp of the Ledge-mont Laboratory of Kennecott Copper Corporation, has continued his theoretical study of order-disorder transitions in binary alloys.

Professor Averbach has been interested in the gold-nickel alloy system in the low temperature range and this system has been studied in detail using transmission electron diffraction. Decomposition in this system is related to the spinodal mechanism and, in agreement with the calculations of Moss and Golding, the peak in the coherent miscibility gap shifts to approximately 40 atomic per cent nickel because of elastic interactions.

Professor Kaplow has obtained further confirmation of the structure of amorphous B_2O_3 , in which the triangular units, typical of the previously determined structure of crystalline B_2O_3 , are retained, but half the boron atoms are contained in the center of oxygen triangles while the remaining boron atoms are bonded to only two oxygens and connect the BO_3 triangles together into a network structure. Work has also been instituted by Professors Kaplow and Averbach on the atomic arrangements in selenium. The reduction of the diffraction data for obtaining distribution functions and for consideration of models for the amorphous phase has been facilitated by computer programs, in conjunction with newly designed automatic data recording equipment.

Professor Kaplow has developed further techniques in diffuse diffraction analysis, in an attempt to eliminate experimentally the incoherent photons resulting from inelastic scattering. Lithium fluoride crystal monochromators, placed after the specimen, can remove nearly all the Compton component, and high-resolution diffuse intensity analyses with specimens of low atomic number become possible.

Professor Moss has been experimenting with a Kratky camera and a Kiessig low-angle film camera. These have been used to investigate possible clustering in sputtered and annealed foils from dilute solutions of iron in gold. It is intended eventually to make investigations of the rates and extent of decomposition in one or two simple phase-separating glasses.

Professor Moss, in cooperation with Professor Morris Cohen, has made further studies of static atomic displacements in martensite and iron-car-

bon alloys. The displacement of iron atoms in the so-called distortion dipole has been estimated to be 0.53 Angstrom units. The effects of strain tempering on the static displacements in martensite have also been studied and an investigation is under way on atomic displacements in the solid solution of oxygen in zirconium.

Professor Kaplow has continued Mössbauer spectroscopy in iron-carbon and iron-nitrogen alloys, with particular emphasis on transformations caused by thermal treatment.

PHYSICAL METALLURGY

STRUCTURE AND TRANSFORMATIONS Further work on strain-enhanced self-diffusivity in metals — for example, gold and iron — has been concentrated on the simultaneous diffusion of slow and fast tracers during plastic deformation. The experiments are really designed to distinguish between a model of strain-induced diffusion involving migration along moving dislocations and one involving mechanical mixing by random motion of small glide packets. The quantitative findings favor the moving-dislocation model, with high diffusivities along short-circuiting paths.

Professor Cohen has continued his work on martensitic transformations, extending this to alloys in the iron-nickel-manganese system. Measurements of martensitic plate sizes, during the course of transformation, have given further information on the rate of the process of martensite formation. In addition, the chemical free-energy changes accompanying the martensitic reactions have been calculated, using a regular-solution model. Carbon and manganese have a more pronounced influence on the nucleation kinetics than can be explained by driving-force considerations alone, so that it is possible that these elements play a direct role in controlling the potency of the embryos. It has not yet been found possible to detect such embryos with transmission electron microscopy.

In collaboration with Professor Kaplow, Professor Cohen has continued Mössbauer investigations of interstitial phases, such as carbon and nitrogen, in austenite and martensite. The Mössbauer measurements give direct information on the clustering of carbon atoms on dislocations, as in strain-tempered martensite. Mössbauer analysis is also being applied to the unusual iron-carbon and iron-boron phases produced by splat-quenching. In collaboration with Dr. Giessen, Professor Cohen has applied splat-quenching to a wide range of iron-carbon and ternary alloys. A new, hexagonal close-packed phase has been produced, containing carbon from 15.6 to 18.7 atomic per cent, approximately half the concentration in epsilon iron carbide. It has also been determined that some of the splat-quenched phases previously thought to be amorphous are, in fact, microcrystalline.

Professor Cohen has also continued work on strain-hardening at very high strain. It has already been shown that strain-hardening of iron can be directly related to the transverse dimensions of the subgrains produced by deformation as severe as that in wire-drawing. Carbon was thought to stabilize subgrain boundaries, but experiments with iron-titanium alloys show that even here, where the carbon is tied up by titanium, the rate of strain-hardening remains about the same. It is, therefore, likely that the nature of the body-centered cubic deformation process is more significant than the interaction of interstitials with sub-boundaries.

Thermomechanical treatments, such as the ausforming of iron-carbon-nickel alloys, reveal substantial increments of strengthening, which are accounted for by the high dislocation density in ausformed martensite and the pinning of such dislocations by interstitial atmospheres during subsequent tempering.

In collaboration with Professor Moss, Professor Cohen has studied the static displacements of iron atoms in iron-carbon martensites. Studies such as this have been extended to hexagonal close-packed zirconium-oxygen and titanium-oxygen solid solutions.

Assistant Professor John Breedis has been studying deformation and transformations in alloys, particularly iron-ruthenium and iron-ruthenium-nickel alloys. Darkfield electron microscopy on foils is being used to reveal the character of lattice defects after deformation or quenching. Professor Breedis has also investigated the strengthening of titanium alloys to establish the dependence of strength on solid-solution hardening and on the structures developed through plastic deformation and phase transformation. Transmission electron microscopy is being used to relate structure to properties. The defect structure of martensite in iron-ruthenium alloys is also being studied; of particular interest is the defect structure associated with the body-centered cubic and hexagonal close-packed structures. Diffraction contrast effects in thin foils are the main experimental technique.

PHASE TRANSITIONS IN SOLIDS Professor John W. Cahn has been examining the massive beta-to-alpha transformations in brass, using a capacitor-discharge pulse-heater to give heating rates of 10^7 degrees C per second. Quenched-in beta transforms to alpha in the limited temperature range corresponding to the single-phase, alpha region of the phase diagram.

Professor Cahn has made further studies of the mechanism of phase separation within the spinodal. This work is essentially theoretical, though experimental work is contemplated. The theoretical aspects of liquid-liquid separation in glass, both by nucleation and growth and by

spinodal decomposition, have also been considered and detailed predictions about kinetics and morphology have been made. Both mechanisms seem to occur in silicates and in borosilicate glasses. The theory of particle coarsening, during exposure to high temperatures of precipitation structures, has also been studied.

Professor Cahn has also undertaken theoretical studies on exsolution textures in minerals, which resemble metallurgical textures, and ordering in disordered alloys, particularly the topology of the domain structure that can be seen by transmission microscopy.

Professor Cahn and Assistant Professor Kenneth C. Russell have begun a comprehensive experimental and theoretical study of nucleation in condensed phases. Metals, glasses and ceramics will all be included, and nucleation in metastable phases will be looked at in the hope that rigorous version can be developed to replace Oswald's law of stages.

Professor Russell has also collaborated with Associate Professor Philip G. Hill of the Department of Mechanical Engineering in a study of nucleation in supersonic nozzles. There are many competing theories of nucleation which attempt to describe the behavior of vapors and it is hoped to determine which, if any, of these theories will apply.

Professor Russell has also studied the electron irradiation of body-centered cubic metals at 4.2°K in order to identify the nature of the damage and to study the kinetics of annealing.

THERMODYNAMICS IN METALLIC SYSTEMS Professor Michael B. Bever's calorimetric measurements have confirmed the existence of a new, high-pressure indium antimonide phase. The heat of formation of this phase and of other forms of indium antimonide have been measured. The phase boundaries between the various forms and the relative positions of the triple points have been calculated.

The heats of formations of various compounds such as In_3SbTe_2 , InSb and InTe have been measured. The heats of solution of silver, gold and platinum in lead at 623°K have also been studied as functions of concentration. The concentration dependence of these heats cannot be explained by theories which assume that the solute-solute interaction does not change on the formation of a dilute solution, but can be accounted for if a non-zero value is assigned to the relative strength of the solute-solute interaction.

In collaboration with Professor Grant and Dr. Giessen, Professor Bever is studying the thermodynamic properties of metastable phases produced by the splat-cooling technique. Gold-antimony alloys and silver-platinum alloys have been investigated and preliminary values of the

heat of formation of metastable $\text{Au}_{0.86}\text{Sb}_{0.14}$ and $\text{Au}_{0.25}\text{Sb}_{0.75}$ at 273°K have been obtained.

Professor Bever has also worked on the derivation of the exact relationship between the interaction parameters and the heat of solution of mechanical mixtures of solutes in a liquid solvent. It is shown that the values of the interaction parameters can be obtained from the heats of solution of mechanical mixtures of elements and their solid solutions.

HIGH TEMPERATURE METALLURGY

Professor Grant and his co-workers have a long history of work on alloy-strengthening by fine, oxide particle dispersion. Recently, the mode of deformation and fracture of internally oxidized, copper-alumina alloys has been studied, using transmission electron microscopy. Beryllium oxide dispersions in an iron matrix have been produced by internal oxidation rather than selective reduction, enabling alloys to be produced in sufficient quantities for creep rupture tests.

Copper-alumina alloys have been produced by the SAP technique, and studies of oxide particle size and morphology have been continued as functions of internal temperature and depth of penetration in these and in nickel-base alloys. Studies have also been made of the stored energy of deformation in copper-alumina and copper-silica alloys.

Copper base dispersions with various strengtheners, such as metals, oxides and intermetallics, are being produced from ultrafine copper powder produced by the reduction of the oxide. The blends are sintered and extruded, at low extrusion ratios, to provide structures which are not cold-worked.

The effect of cerium oxide, formed in a titanium matrix by internal oxidation, is also being investigated. There is a noticeable increase of rupture life in 50 per cent cold-rolled specimens, showing that internal oxidation is a feasible technique.

Studies of deformation and fracture have continued, and an investigation of wrought and cast nickel-base superalloys has defined the optimum strain and strain rate necessary to bring about grain refinement and enhanced hot plasticity. Molybdenum alloys are also being looked at to determine how the deformation and fracture mechanisms are influenced by strain, strain rate, and temperature. Work on high-strain-rate testing of metals undergoing phase transformations has been concentrated on iron and titanium. Incremental strains, at high strain rates and temperatures, followed by a recovery or recrystallization period, give a refined grain size leading to fracture ductilities of 250 to 300 per cent. A study of the hot plasticity of iron-carbon-niobium alloys shows that low strain

rates result in decreased hot plasticity, causing press forging problems. High strain rates, on the other hand, lead to enhanced hot plasticity at hot-working temperatures.

Significant progress has been made in using the splat-cooling technique. Professor Grant and Dr. Giessen have worked on the copper-silicon and copper-beryllium systems and the solubility ranges of intermediate phases have been considerably enhanced. Metastable, intermediate phases have been found in the zinc-gallium, cadmium-indium, cadmium-tin and cadmium-bismuth systems, and an amorphous metastable phase has been found in the platinum-antimony system. A splat-atomizing unit, designed to atomize and rapidly quench metal quantities up to ten pounds, which uses a continuous shock-wave generator, has been constructed.

Finally a study of deformation and fracture in an aluminum-zinc alloy under axial load and low cycle fatigue has been completed.

ELECTRON OPTICS AND X-RAY DIFFRACTION

Professor Ogilvie has been using the electron microanalyzer in an extensive study of diffusion in the copper-silver-gold ternary system. Activity measurements have also been carried out in this ternary system, using a zirconia, solid-state galvanic cell. The object of the two types of measurement is to confirm the correctness of Onsager's extension of Fick's law to multicomponent diffusion, and the dependency of the diffusion flux on the atomic mobility and chemical potential.

Further modifications have been made to the scanning electron microscope and it is now being used to study the nature of fractured surfaces and, in particular, the deformation bands and cracks developed during fatigue. The scanning microscope has the desirable feature that it is not necessary to replicate the surface. An electron diffraction unit has also been modified so that the diffraction patterns can be displayed on an x-y recorder or an oscilloscope. This unit has been used to follow the crystallization kinetics of amorphous films, and the formation of an ordered structure in gold-palladium films.

Work has been completed on the pseudobinaries $\text{ReSi}_2\text{-TiSi}_2$, $\text{TiSi}_2\text{-TiSb}_2$ and $\text{ReSi}_2\text{-ReAl}_{12}$, in an attempt to elucidate the factors that control the formation of particular structures in such pseudobinaries.

Research has continued on the role of pressure, temperature and time on the formation of the Widmanstätten pattern in metallic meteorites. A cooling model with low internal pressure has been proposed for the development of structures found in such meteorites.

Hypervelocity-impact experiments have been carried out with the purpose of studying crater formation. Metal transport from projectile to tar-

get material and the metallographic features of the deformed material around the crater are being studied. Projectiles traveling at speeds up to 19.2 kilometers per second have been examined.

PROCESS METALLURGY

Professor Elliott has completed a study of the standard free energies of formation of a number of sulphides, using a reversible EMF cell with calcium zirconate as the electrolyte. Mixed sulphides are also being studied and the possibility of using a metallic sulfide as an electrolyte above 1000°C is being examined.

Since many of the metal oxides show suboxides that are volatile, the possibility that a similar situation exists in metallic sulfides is being studied. In this work a mass spectrometer-Knudsen cell system is being used.

Professor Elliott is also continuing work on the thermodynamics of alloy systems, a study that is of interest to Professor Emeritus John Chipman. Professor Chipman has extended his work on the interpretation of the behavior of carbon in alloyed, liquid iron to the equivalent behavior in alloyed, solid austenite. He has also derived a method for treating solutions, introducing a molar ratio as the concentration parameter rather than a mole fraction.

Work with the high-temperature solution calorimeter has been suspended for the moment after a successful study of iron-silicon, iron-aluminum and iron-copper alloys at 1600°C. This is the highest temperature at which a solution calorimeter has ever been operated. Work on the vapor pressure of aluminum over aluminum-nickel and aluminum-iron alloys, using a transpiration technique, is being carried out, and it is hoped to establish the thermodynamics of these systems by this method.

Helmut Hadrys, on leave from the Technical University of Berlin, has completed an analysis of the measurements he has made on the thermodynamic properties of chromium and phosphorus in liquid iron-chromium-phosphorus and iron-chromium-phosphorus-carbon alloys.

Dr. Shiro Ban-ya, visiting from Tohoku University, is studying the equilibrium conditions at 1550°C in binary and multicomponent iron-sulphur alloys.

Professor Elliott has continued his work on the distribution and composition of the inclusions that form in iron-silicon-oxygen alloys during solidification. The results lend support to the argument that the interfacial free energy between liquid iron and the inclusion can serve as a barrier to nucleation. A detailed analysis of the nucleation process in iron-aluminum-oxygen alloys has also been completed. A levitation melting sys-

tem for the study of iron-sulphur-oxygen alloys is now in use; Professor Flemings is also involved in this work.

Professor Elliott has made further developments in dynamic analysis with a study of the effect of the physical properties of graphite on the temperature distribution in an electric furnace electrode. He is also beginning a study of the influence of convection in the residual liquid on the structures produced during dendritic solidification.

Professor Fray has completed his work on phosphate melts; the surface tensions and densities of molten phosphates have been measured as functions of temperature and composition and these properties have now been correlated with the results of paper chromatography studies which reveal the anion structure of such melts.

Professor Elliott, Professor Chipman, and Dr. Olga Repetylo are completing a critical evaluation of the thermodynamic data on liquid metallic solutions and molten oxides. The best formalism to be used in correlating the data is still in question.

Professor King has completed his work on the interaction of carbon monoxide with liquid iron. It has been shown that, while the gas-metal reaction involves a slow surface step, the similarity to the nitrogen reaction is not complete in that the melt surface composition is affected by the composition of the gas phase. Another difference is that the slow surface reaction is specific to oxygen as a surface-active solute.

Professor King, with Barry H. Rosof, has also been working on the theory of coupled reactions. Mr. Rosof is developing a theory based on an analogy between mechanical and chemical systems which is yielding interesting results, possibly more general than the present applications of irreversible thermodynamics.

SURFACE CHEMISTRY

Professor Philip L. de Bruyn has continued his work on the influence of the structure and composition of clean, solid surfaces on the nature and behavior of solid-fluid interfaces. A study of the interface between crystalline zinc oxide and an aqueous electrolyte solution shows that the addition of an acid or base to the suspension leads to a rapid change in pH followed by slow decay with time. This drift in the pH of an oxide suspension appears to be quite general and has been shown also for titanium oxide, iron oxide and aluminum oxide. The slow step may be attributed to an ion exchange mechanism or the alternative process of a slow diffusion of protons into or out of the lattice.

The adsorption of anions on zinc oxide has been observed to increase in the order — chlorate, nitrate, iodide, bromide, chloride. This is the re-

verse, at least for the halide series, of that observed on mercury, and may be explained by the strong orientation of water on oxide surfaces and the order-disorder effects of ions on the water structure. An analysis of fast adsorption isotherms on rutile showed specific adsorption of ions to increase in the following order — iodide, chloride, cesium, sodium, lithium. This is the same order as that found for zinc oxide. The anhydrous rutile is assumed to be covered by tightly-bonded OH groups and a second layer of strongly hydrogen-bonded water, the dissociation of which results in the formation of the surface charge.

Professor de Bruyn has also continued work on the spreading of liquids on high-energy solids under controlled interfacial conditions. A contact angle apparatus, involving a captive bubble, is used to measure the spreading behavior. Organic acids, esters, phosphates and alcohols have been allowed to spread on aluminum, anodized aluminum and nitralloy, in the presence of air. In general, the implications are that when an autophobic liquid covers a solid in the absence of air a different molecular configuration is present at the surface from that present when air displaces the liquid. In order for air to displace the liquid, the complex arrangement of the liquid molecules near the surface must be broken down into a monolayer, a process that requires an induction period. Spreading behavior depends on the relative magnitudes of the surface tension of the solid surface, covered with a monolayer of adsorbed organic liquid, and the surface tension of the organic liquid. A finite contact angle will be established only if the former surface tension is less than the surface tension of the organic liquid.

CORROSION

Professor Uhlig's activities are concerned currently with the measurements and interpretation of critical potentials for corrosion pitting of stainless steels and other passive alloys. In particular, environmental and metallurgical variables are being considered.

Critical experiments are also being carried out to differentiate between the electrochemical theory of crack propagation in metals and an alternative theory based on reduction of surface energy by adsorbed ions. These theories are applied indiscriminately at present to explain the mechanism of stress corrosion cracking. The mechanism of hydrogen cracking is also being studied on carbon and alloy steels. The effect of cold work on the susceptibility of 301 stainless steels is being looked at and, in the carbon steels, the variables include the metallic impurities, inclusion count, and metallographic structure, as well as cold work.

The mechanism of corrosion fatigue is being studied on 1015 carbon

steel subjected to reverse stress cycling at 1,850 cycles per minute. The control variables include the oxygen concentration, the chloride ion concentration, the pH, and temperature.

Passivity in copper-nickel alloys is also being studied. Passivity begins at or above 38 atom per cent nickel. Additions of zinc, which contributes two electrons per atom, raise this critical nickel content to predictably higher values. Ternary alloys of other electron donors — aluminum and cadmium, for example — are being investigated in order to establish the mechanism of passivity by alloying.

Work on the initial oxidation kinetics of metals in the thin-film region has also been continued. It has been shown that gaseous pretreatment of copper leads to surface faceting which, depending on the gas and crystal face, has a major effect on the oxidation behavior.

MINERAL ENGINEERING

Professor Antoine M. Gaudin has completed an experimental study, using radiotracers, of the ball-milling of albite. The size distribution of particles that break down during milling can be followed closely by this technique. A combination of volume radioactivation of particles and surface marking, by adsorption of tracer, provides a powerful tool for tracing the detailed history of particle comminution.

CERAMICS

KINETICS OF PHASE CHANGES Professor Wuensch has started a program on grain boundary diffusion in polycrystalline ceramic bodies. There have been few direct investigations in oxides or ionic materials but diffusion is an important mechanism in development of microstructure. Impurity cation diffusion has been studied, with the aid of microprobe analysis near the grain boundary, in bicrystals. Thallium, which is quite soluble in potassium chloride, is the solute ion, chosen on the basis that boundary enhancement of diffusion should be greatest for ions of high polarizability. Normal lattice diffusion rates will be categorized first, before proceeding to experiments with bicrystals.

Professor Coble is making further studies, by a different technique, of oxygen diffusion in single crystal sapphire. A thin layer of aluminum metal is evaporated onto the surface of the sapphire crystal, then oxidized in a 92 per cent O^{18} atmosphere. After a diffusion anneal in nitrogen, the O^{18} is activated by protons in the cyclotron.

Professor Coble is continuing his work on the development of microstructure in sintering and pressing. It has been found that there are a number of processes that govern the development of microstructure and

elimination of pores during sintering, but the mechanism of material transport is not well delineated for most materials. Experimental work is being carried out on zinc oxide and aluminum oxide.

Professor Coble has also studied the kinetics of vapor deposition of titanium nitride. Depending on the temperature, the rate limiting step of the deposition process could be the surface reaction or a gas-phase reaction, though at lower temperatures the kinetics are more complex.

Professor Uhlmann has studied crystallization and melting kinetics in glass-forming systems, using silica and germanium oxide. Other work on sodium disilicate has been carried out over a range of undercooling from 6 to 298 Centigrade degrees. In particular, the crystallization kinetics have been studied and, even with the largest undercooling, a faceted interface morphology has been observed, with no evidence for a transition from a lateral growth mechanism to one of continuous growth. Professor Uhlmann has examined these processes also at high pressure. The catalytic effect of water, previously observed in connection with the crystallization of silica, is being studied further on boric oxide and albite.

STRUCTURE-PROPERTY RELATIONS Professor Wuensch has been investigating the crystal structures of a number of complex phases, especially those which show complex superstructures based on a simpler atomic array. Sulphur compounds, in particular, show such superstructures. Professor Wuensch is also studying the crystal chemistry of glass-forming sulphides, such as antimony and arsenic sulphide. Many of these complex phases have interesting properties and it is necessary to develop rules for the formation of these phases and to examine the complex structures to see why some particular compositions are not stable. For example, the iron-sulphur system exhibits complex magnetic properties that are still incompletely understood. There is a series of defect structures deficient in iron. Stoichiometric FeS is now known to be antiferromagnetic but, near the composition Fe_7S_8 , there is an ordered vacancy arrangement and ferromagnetic behavior is observed. Structure determinations on this phase are proceeding.

Professor Kingery has performed creep tests on polycrystalline ice in tension. At low stresses, ice behaves in a viscous manner — that is, the strain rate is proportional to the stress, and the viscosity is found to vary with the square of the grain size. The behavior is consistent with the diffusional creep model of Nabarro and Herring. However, it is presumed that diffusion must be enhanced near the grain boundaries because of an increased number of defects. At higher stresses, the strain is proportional

to a power of the stress; a deformation model originally developed by Friedel can explain such results.

The creep deformation of high-purity, polycrystalline alumina also has been studied, at temperatures between 1650°C and 1830°C. Impurity content has been shown to influence the creep rate and the controlling diffusion coefficient.

Professor Coble has been studying dislocation dynamics in calcium fluoride; the mechanical behavior is explained by a model that gives a qualitative explanation for the transition from ductile to brittle behavior which can be observed in calcium fluoride.

Professor Coble has been working also on nitrogen solubility in silicon carbide, the conductivities of single crystals of calcium fluoride as a function of temperature, and the solubilities of magnesium oxide, titanium oxide, and hydrogen in aluminum oxide as functions of temperature. These subsolid equilibria are of interest in ceramic processing. Professor Coble also has examined the creep and fracture behavior of polycrystalline silicon carbide. Creep occurs by a diffusional process and grain boundary diffusion is shown to be the rate-controlling mechanism for the creep of the polycrystalline material.

Professor Kingery has studied the effect of neutron irradiation, at low temperatures, on aluminum oxide and magnesium oxide. There is a lattice expansion and density decrease in both oxides. The solid solution behavior of impurities in high-purity, single-crystal alumina is also being studied. The addition of chromium oxide to alumina is expected to cause an increase in density and it is planned to develop crystals with various impurities and then make precise determinations of density and lattice parameters. Another program is being initiated to prepare high-purity polycrystalline aluminum oxide. One technique is based on the corrosion of pure aluminum metal in a mercuric chloride solution.

STRUCTURE AND PROPERTIES OF NON-CRYSTALLINE SOLIDS Professor Kingery has studied the structure of aluminum oxide thin films, deposited by electron beam evaporation on room temperature substrates. As deposited, the material is amorphous but the films crystallize to a fine-grained, randomly oriented mixture of two forms of alumina at 330°C. The films have a system of fine pores open to the surface and the porosity increases if the vacuum in the preparation system is poor. Water vapor is not necessary for the development of the amorphous structure.

Nickel ferrite thin films have also been prepared by reactive sputtering. Electron-microscopy and electron-diffraction studies show that films deposited on substrates at temperatures below 0°C are amorphous,

whereas films deposited at temperatures above this are polycrystalline, the size of the crystallites increasing as the temperature is increased. The amorphous films show paramagnetic behavior and the micro-polycrystalline films show superparamagnetic behavior. Ferrimagnetism is found only in films prepared at 400°C and above. Non-crystalline thin films of silicon carbide have also been formed by physical sputtering, using a single-crystal, hexagonal silicon carbide cathode. Electron-microscopy and diffraction studies indicate that films heated to temperatures above 800°C undergo a transition to polycrystalline cubic silicon carbide. Boron and aluminum have been identified, by mass spectrometry, as the major impurities present. Hot-probe measurements show that both amorphous and crystalline films are p-type semiconductors. Annealing of the amorphous films over the temperature range 200°C to 600°C causes irreversible changes in electrical conductivity. The dielectric properties of a ferroelectric material, barium titanate, in the amorphous and crystalline forms are also being studied.

Professor Uhlmann has been working with the alkali borate glasses. Property measurements are being combined with electron microscopic observations to evaluate the effect of submicrostructure on properties. Professor Uhlmann also is studying flow and relaxation processes in simple, glass-forming liquids. Measurements of viscous flow in alpha-phenyl-ortho-cresol have been carried out using both beam-bending and falling-sphere viscosimeters. Professor Uhlmann has also examined the anomalous flow in the glassy state at high stress levels in inorganic oxide glasses. Fibers of a borosilicate and rubidium silicate glass have been tested at temperatures between 20 and 50 degrees of their respective strain points. Measurements on the borosilicate glass for periods up to weeks have indicated the absence of any anomalous flow. Measurements on the rubidium silicate glass have not yet been completed. The objective is to see whether the phenomenon is general for polymeric materials.

Professor Uhlmann also has completed the equipping of a high-pressure laboratory and has been studying the effect of high pressure on glasses. One investigation is concerned with the electrical properties of simple silicate glasses in which alkali and alkaline-earth atoms have been partially substituted for cesium. A mixed alkali effect has been observed and this has been shown to occur in the absence of observable phase separation.

Splat cooling is being used to study materials, as glasses, which cannot normally be obtained in the amorphous solid state. Initial work has been concerned with some simple standard salts and molecular liquids and glass formation has resulted in nearly all cases. The strength of some

simple inorganic glasses is being investigated also as a function of the microstructure and preparation history. Professor Uhlmann is also working on the effect of microstructure on the electrical properties of arsenic-selenium-tellurium glasses.

Professor Uhlmann has also initiated a program on the crystallization and properties of polymers at high pressure. A Bridgman anvil device and a 200,000-psi gas apparatus are being used, while a large-volume, solid-medium press is being completed. Contrary to experience with inorganic oxide glasses, preliminary results on polymethyl-methacrylate have indicated the absence of any pronounced permanent densification resulting from high pressure treatment.

MATERIALS PROCESSING

CASTING AND SOLIDIFICATION Professor Flemings has responsibility for the metal crystal growth facility which serves the Center for Materials Science and Engineering. Some new equipment has been installed, including a Bridgman furnace for growing crystals up to a 1700°C melting point in vacuum, a laboratory arc-melting unit, and a zone-melting unit for vacuum crystal growth of materials of up to a 2,000°C melting point.

Professor Flemings' research on the effect of fluid flow on the structure of metal crystals has been continued. It has been found that the inhibition of convection by application of a magnetic field is a most effective way to reduce segregation. This result is in agreement with previously developed theories of microsegregation. In related work, two-phase alloys are being grown under steep temperature gradients, at a slow rate, and it has been shown that two-phase composite structures can be produced in which the second phase is lamellar or rod-like. These resemble eutectics but can be grown from compositions far removed from the eutectic composition. This work has obvious importance for the development of composite materials.

The effect of large degrees of undercooling, up to 300°C, on the structure and solute redistribution in metallic alloys is a continuing study. One aim of this work is to develop improved methods for producing non-equilibrium structures by rapid cooling of melts. Presently, samples of about 100 grams can be undercooled in glassy containers. Levitated metal droplets can also be studied. The levitated droplets are undercooled and dropped between two rapidly closing metal platens before nucleation takes place. A significant feature of the research is the demonstration that coarsening, or as it is sometimes known, "ripening," significantly alters solidification structures even at very rapid solidification rates. A companion study on the growth of dendrites is directed at understanding the

mechanism and relating it to the dendrite morphology, as determined by heat and mass flow, surface energy, and interface kinetics.

Work on solute redistribution and on microsegregation has continued. Computer programs have been of great help in determining the extent of solid-state diffusion to be expected during growth of binary alloys. Experimental and theoretical work is now under way in more complex systems, including ternary alloys. A general expression has been obtained for segregation caused by flow of solute-rich liquid to feed solidification and thermal contractions. It is shown that inverse segregation and center-line segregation can be understood as limiting cases of the analysis, and that other types of segregation, including macroscopic bonding, can result from the fluid flow. The direction of fluid flow with respect to the solidification isotherms is of major importance and this has not been previously considered.

A new program has been initiated on the formation, growth, and final morphology of inclusions in iron-base alloys. This work is proceeding in conjunction with the chemical metallurgy group under Professor Elliott.

WELDING AND JOINING Professor Adams has started a program, in cooperation with the Oral Science Laboratory of the Department of Nutrition and Food Science, to apply laser heat sources to the welding of dental structures. Extremely fine laser welds have been applied to external, orthodontic structures and future work will attempt to develop welding techniques that will not require removal of the structure from the mouth.

Continued heat flow studies have resulted in an analytical characterization of the welding arc as a moving heat source; the associated thermal cycling and metallurgical transformations can be calculated.

Rapid solidification studies on low alloy steels have been carried out to reveal the details of microsegregation, particularly the composition and morphology of low-melting intergranular material that often causes poor properties. Companion studies on aqueous solutions, with different objectives, have concentrated on the effects of convection, including work in centrifugal systems at accelerations up to 100G.

A method has been developed to determine accurately the residual stress distribution in and near welds on high-strength steels.

A process to promote flow and wetting during brazing involves vacuum metallization techniques, and is now being applied in practice. Studies of the plastic behavior of some brazed joints have revealed superplasticity in composite joints consisting of high modulus base materials.

DEFORMATION PROCESSING Professor Backofen and his group have refined the theory of superplasticity and have demonstrated superplastic

behavior in a number of different alloys. Although this part of the work is perhaps exciting most attention, the group has many other studies in progress, including important work on the plastic behavior of the hexagonal, close-packed metals, such as magnesium, beryllium and titanium, which are vital space-age materials.

ELECTRONIC MATERIALS

Professors Gatos and Witt have studied compound semiconductor surfaces, particularly InSb, although some attention has been paid to GaAs and CdS. The last compound is interesting, because it may serve as a bridge between covalent compounds and ionic or refractory materials. Interesting observations have been made of the effect of large-signal AC on the behavior of the A and B(111) surfaces of indium antimonide. Anomalies have been found in classical field-effect experiments on indium antimonide when fields perpendicular to the surface have been applied.

A low-energy electron-diffraction apparatus has been designed and constructed for a concurrent study of electrical properties and structural characteristics of surfaces. Preliminary experiments have been done on germanium and silicon surfaces.

A crystallochemical approach to the specification of new superconductors and semiconductors has been devised and a large number of new superconductors, involving the compounds of niobium, beryllium, ruthenium, molybdenum, platinum, zirconium, and iridium, have been made up. Addition of a third platinum group metal to a binary alloy either weakens (Pt to MoRu) or strengthens (Ir to NbPt) the superconducting interactions. Magnetic susceptibility and electronic specific-heat measurements are being planned.

AB_3 phases in the compounds of rare earth metals with gold have been synthesized and their crystal structures established as the orthorhombic $TiCu_3$ type. The superconducting behavior of these gold-rich phases is being examined. Studies on superconductivity of transition metal carbides have been pursued and a variety of new carbides with the β -Mn structure have been prepared and their transition temperatures have been determined. Work has been initiated to dope Nb-Ti-V alloys with enriched uranium and irradiate them with thermal neutrons to cause structural damage by internal fission and to relate the damage to changes in superconducting properties.

Work on semiconductors has concentrated on using the average heat of atomization to correlate the composition and temperature limits of stability of the sodium chloride type structure in the IV-VI and related compounds. Some solid solutions with this structure have been synthe-

sized in the PbTe-PbSe-SnSe system and await optical characterization. Development of infrared transmitting materials in the 2-25 μ range with good thermal stability up to 500°C has been aided by looking at average heats of atomization. Vitreous semiconductor compositions in the Cd-Ge-As system have been synthesized. Many glasses in these systems have useful infrared transmission capabilities. This work is being extended to thin films of CdGeAs₂ and solutions between this compound and InAs. Work is being done on vitreous semiconductors containing rare-earth ions.

A study of thermodynamic instability in compound semiconductors under reduced pressures is being carried out with silver oxide and copper oxide as substrate materials. These are produced by vapor depositions onto quartz flats, of the appropriate metal and oxidation at low oxygen pressures.

Professors Gatos and Witt have also been interested in studies of the distribution of impurities in semiconductor materials. Interference-contrast microscopy and polarization interferometry are both used and they result in the resolution of impurity striations with a spacing of less than one micron. Transmission electron microscopy does not show that the striations are associated with structural defects, such as dislocation loops or precipitates. A simple mechanism of crystal growth has been proposed, which explains some of the striations found in rotated crystals. An analysis of rotational crystal growth under thermally-asymmetric conditions shows that microscopic growth rates in the off-core region vary periodically and may even assume negative values that lead to partial remelting. The growth rate of the core is unaffected by thermal asymmetry and is the same as the imposed pulling rate.

A new etchant for revealing impurity distribution has been applied and has distinct advantages over other etchants, because pitting is completely absent. Striations can be revealed with very high resolution. From studies of growth rates in single crystals, it is more and more evident that crystal-line perfection is intimately related to microscopic rates of growth. Localized micro-growth rates can be measured by introducing constant-frequency vibrations into the melt, during crystal growth. These vibrations will be reflected in the form of very sharp impurity striations superimposed on the regularly appearing impurity heterogeneities. From the known frequency of the vibrations and the separation of the resulting striations, we can determine the microscopic rates of crystal growth.

Studies of semiconductor growth have continued, with attempts to grow single-crystal films of lead selenide, gallium arsenide and zinc oxide in a modified vacuum evaporator. A radio-frequency-heated silicon pulling furnace has been completed and a second evaporator up-graded to

serve as a unit for contact evaporation and the formation of glassy semiconductor films by flash evaporation. A program has been started to grow highly-perfect single crystals of lead salts, using a Bridgman technique on high-purity starting materials pre-reacted in vacuum. Experimental arrangements have also been constructed for the growth from the vapor phase of InAs, GaAs and their alloys. So far only polycrystalline growth on InAs substrates has been observed, but good epitaxial growth has been obtained on GaAs. Epitaxial growth of silicon carbide on silicon substrates produced polycrystalline overgrowth of preferred orientation. The object of this study is to produce epitaxial layers of controlled resistivity.

The metallurgical character of heterojunctions in Ge-GaAs, and Ge-InSb and similar systems has been investigated. Systems including germanium as one component form eutectics but heterojunctions between III-V compounds do not exhibit eutectic formation. A double strip hot stage has been used to produce relatively good regrowth of the lower-melting-point semiconductor. The regrowth is a continuous single crystal matrix containing a small number of twins. Studies of dislocation and strain distributions in the regrown layers are now being carried out.

High-pressure studies, under Professor Gatos and with the cooperation of the Lincoln Laboratory, have been continued on the metacinnabar-cinnabar transformation in the mercury selenide-mercury sulfide system. Thermal analysis and resistance measurements have been used to investigate the hysteresis between forward and reverse transformations.

SUPERCONDUCTING MATERIALS

Professors Wulff and Rose are continuing their work on the effect of low-temperature aging of cold-worked Nb-Ti alloys on the superconducting critical current density. The optimum aging temperatures are shown to be a function of the oxygen content of the alloy; the response to aging is quite rapid in the temperature region of 400 to 500°C. In higher titanium alloys, the effects of cold work and oxygen content on the superconducting properties are being established. Plastic deformation is found to enhance J_c only at relatively large levels of cold work. Oxygen is found to be without effect on J_c , when it is in solution, but is effective on subsequent aging.

Basic exploration of the superconducting properties of niobium-copper composites has continued, using a recently constructed vibrating-sample magnetometer and an adiabatic demagnetization apparatus. Professor Rose has continued his work on heterogeneous nucleation effects in superconducting niobium. Manipulated microstructures are used, and the role of oxygen in fluxoid pinning and the nature of the oxygen distri-

bution, at very low concentrations, are being examined. The data on superconducting properties conflict with the presently accepted picture of the oxygen distribution. Somewhat similar work is under way on superconducting vanadium.

Professor Rose is also studying electron tunneling into single crystals of niobium, using thin-film and point-contact techniques. Basic theoretical work on magnetic properties and magnetic impurities is being conducted, with experimental techniques of high sensitivity for magnetization measurements.

STAFF

It is with regret that we record the completion of Professor Chipman's formal association with the Department as Senior Lecturer. Fortunately, he will continue to take an interest in the research of the chemical metallurgy group and has agreed to be available for consultation during the summer and fall terms.

Assistant Professor Ronald A. Brown left to join the physics faculty of Kent State University and will leave an energy gap as the resident theorist in the physics of solids group. Assistant Professor Bud C. Wonsiewicz also resigned to take up a research position with the Bell Laboratories. His contribution to the development of Mechanics of Materials (3.11), is much appreciated. Replacements have been found in Dr. Keith H. Johnson, from Professor John C. Slater's group in Florida, and Dr. David L. Holt, from General Motors Defense Research Laboratories.

It is a pleasure to record the promotions to Associate Professor of Dr. Witt and Dr. Moss.

Professor Bever spent a sabbatical year at Harvard University in the Division of Engineering and Applied Physics, and returned with many fresh viewpoints on research and teaching. Professor Chipman spent his usual two months in the winter at Berkeley and Professor Gaudin undertook both a survey of South African mining and a review of the U.S. Bureau of Mines Laboratories. Members of the faculty visited Japan, the U.S.S.R., and Scandinavia in numbers that make recording difficult but that reveal their interest in keeping abreast of developments abroad.

Dr. Gunnar Bartsch, from the Technical University of Berlin, spent the year here, under the Ford Foundation program, and managed to find the time to engage in significant research. Other visitors included Dr. Frank Gardner, from the Office of Naval Research, as Research Affiliate, Dr. Shiro Ban-ya, from the University of Tohoku, as Research Associate, Dr. Henryk Matya, from Poland, also a Research Associate, Dr. Olga Repetylo, from IRSID (Institut de Recherches de la Siderurgie)

France, as Research Associate, Dr. Harumasa Nakamura, from the National Research Institute of Metals in Tokyo, as Visiting Scientist, Dr. H. F. Harnsberger, from Chevron Research, as Guest of the Institute, and many others, whose visits were more fleeting but whose contributions are remembered.

THOMAS B. KING

DEPARTMENT OF NAVAL ARCHITECTURE AND MARINE ENGINEERING

The Department of Naval Architecture and Marine Engineering, which is by far the best and largest graduate school in this field in the United States and which provides two-thirds of the advanced degree graduates in the country, has pioneered in the broadening and expanding of the scope of its naval architectural education since it was established more than 70 years ago. Now it is in the process of taking another major step forward in order to give its graduates the breadth needed in the future. To see this step in proper perspective, it is necessary to review briefly the development of education in naval architecture and marine engineering.

Naval architecture and marine engineering has traditionally concentrated on ship design; that is, on the problem of how to make sure that a ship is designed well. The naval architectural profession was therefore one of the first to practice systems engineering because ship design requires the efficient integration of many, many subsystems. The education of naval architects and marine engineers consequently concentrated on the factors controlling the design process; that is, hydrodynamics of hull shape, strength of hull structures, efficiency of ship propulsion, and process of accommodating a set of requirements in a ship design.

The impact of rapidly advancing research during and after World War II broadened the basis for ship design. This resulted in a special emphasis on ship hydrodynamics and a realization that ship acoustics, ship structural mechanics and materials research play an important and often a crucial role. The trend required expansion of the education of naval architects during the last two decades by providing a broader basis in the respective engineering sciences.

During the last few years it has become eminently apparent that the basis for ship design and shipbuilding must be broadened further. Ships must be viewed in the context of their missions as part of over-all systems. The shipping industry, for instance, must consider ocean transportation not just as moving cargo from one port to another. The development of container shipping and the growth of supertankers shows

the impact of systems approach and market analysis in the commercial sector. For the Department of Defense shipbuilding program the analysis of naval warfare systems established the requirements for concept formulation as a step now necessary to justify the naval shipbuilding program. Modern computer technology has provided further a heretofore unavailable link between basic engineering disciplines and design, and between design and the actual shipbuilding process.

During the last year the Department has also become the focal point for the new Ocean Engineering Graduate Program of the Institute, which was planned this year and will be offered beginning in the fall of 1967. In this program, extensive use will be made of existing strength in selected ocean engineering areas at M.I.T. Within the Department the rapidly growing demands for ocean engineering require emphasis on special surface vehicles, submerged vehicles, stationary floating platforms and structures, support of ocean mining and oil drilling, engineering support for ocean fisheries, engineering aspects of ocean explorations, engineering aspects of oceanographical research, and support for ocean-bottom stations.

The traditional fields of naval architecture and marine engineering must therefore be extended or supplemented to cover the widened scope of the Department.

The educational process, in order to be responsive to the broad new needs in ocean transportation, naval engineering and ocean engineering, must develop in the student required background knowledge in the engineering sciences and the engineering attitudes necessary to apply this background in finding meaningful solutions to practical problems; that is, to view engineering tasks within the framework of the respective systems and objectives, to design creatively, and to analyze thoroughly.

The necessary expansion of the Department resulting from this requirement for broadening the educational basis was planned in detail. The Visiting Committee for the Department was briefed on the new objectives and present plans. Implementation of the plan has started.

UNDERGRADUATE PROGRAM

The Department decided to strengthen its undergraduate program by preparing, under the Ford Foundation grant, a sophomore subject, Hydrospace Vehicles and Their Use, which will also be available for science distribution credit to freshmen. This subject serves two purposes. First, it will expose the student to the engineering and the related scientific challenges of the ocean; and secondly, it will give undergraduates, early in their studies, an opportunity to become familiar with concepts of engineering and engineering attitudes, to recognize the difference between

scientific and engineering approaches, and to appreciate the interface between science, engineering, economics, and society.

Preparation has also started for reshaping the content of the basic introductory subject of the Department, Principles of Naval Architecture.

The Freshman Seminar in Sailing Yacht Research continues to attract many students.

GRADUATE PROGRAM

GENERAL PROGRAM

The graduate enrollment remained at the same level of 120 as in 1965, with 70 students in the XIII-A curriculum for Naval Engineering. The subject offering was expanded mostly with the help of Ford Foundation funds.

Associate Professor Justin E. Kerwin prepared a new subject, Computer Applications to Naval Architecture Problems, in the spring of 1967. This subject was aimed at introducing our students, in a systematic manner, to the use of computers in the solving of problems in our field. The new subject was extremely successful and will be continued on a regular basis.

Dr. Bernard W. Romberg was a visiting lecturer for the spring term for the subject, Computer Systems Applications to Naval Architecture and Marine Engineering. This subject is aimed at clarifying the broad potential of computer systems, especially for ship design and construction, and how this potential can be utilized. This subject also will be offered on a regular basis.

Associate Professor Ernst G. Frankel (though still on leave of absence) has organized two one-week special summer programs. The first, on ocean transportation, demonstrates the full scope of effort which has to go into systematic consideration of ocean transportation systems — that is, the ship system and its interface with land transportation and the points of interfaces of the harbors and terminals, and terminal operations. The second program, on ship production, identifies the steps which appear most relevant toward more economic ship construction, such as integration of design and production engineering, the application of computer techniques and the use of numerically controlled tools.

Assistant Professor Neal A. Brown offered a new subject, Unsteady Hydrodynamics, during the fall term, covering unsteady propeller and hydrofoil theory, transient response, hydrodynamic effect in ship vibration and motion, and hydroelasticity. Such unsteady and transient phenomena are becoming of increasing importance for modern naval architecture.

The Department is increasing its emphasis on creative design as part of graduate engineering. Associate Professors S. Curtis Powell and Sher-

man C. Reed again successfully combined Propulsion Hydrodynamics (13.02), Ship Propulsion (13.21), and Naval Ship Propulsion (13.22) into joint class lectures in which the application of engineering judgement and reasoned approximation could be brought to bear on practical engineering problems covering the entire propulsion field. The very large enrollment of 41 civilian, foreign, and naval officer graduate students provided an excellent opportunity for exchange of diverse engineering views during about 15 one-week design projects which covered selected aspects of marine engineering. The role of the marine engineer in concept formulation was introduced both by lecture and design project example. In this connection, emphasis was placed on problems of powering revolutionary systems in comparison to normal design evolution, so that the student would be better prepared for the challenges of ocean engineering. Sharply increased emphasis was given to the evaluation of the costs and worth of engineering alternatives. Similar emphasis was given to the creative solution of marine engineering design problems with the aim of emphasizing an analytic and creative balance in each student. Where a latent creative impulse could not be found, the student was exercised in the value of seeking and using the creativity of others, particularly those of diverse backgrounds. Strong emphasis was given to determining the bounds of unbounded engineering problems including careful system definition as an aid to design. Finally, the heuristic approach to marine engineering problems was given increased emphasis to give the student confidence to make necessary engineering decisions where empirical data is insufficient to develop probabilistic, much less deterministic, decisions.

As a direct outgrowth of a spar ship study conducted by three graduate students during the academic year, Professors Philip Mandel and Reed have developed a three-term approach to exploring and developing new concepts in ocean vehicles. Initiated in the summer term of 1967 under a special problem number, 13.91, three naval officer graduate students have selected for a project the possibility of broadening the applications of mobile column-stabilized ocean platforms, which have been developed for oil drilling and Project Mohole. It is intended that these students will gather all pertinent factual information, define additional concept applications and current feasibility, and define unknowns preventing wider application. Industry interest and information support has been solicited and the response has been excellent. It is anticipated that successful conclusion of the summer term project will result in three different thesis topics all relating to the concept to be pursued by those students during the fall and spring terms of 1967-68. Under consideration is the possibility of bringing

the three students together again in Preliminary Design (13.46), to select a new application and engineer the concept for this specific application. Not only will this educational approach provide a cohesive yet wide-ranging academic exercise for the students, but it is anticipated that a useful start will be made toward a departmental library of concepts to be researched and developed for use by other students. This approach will also greatly increase the relevancy of the student's thesis topic to his total education and thus deepen his commitment to his thesis.

XIII-A CURRICULUM

The Naval Construction and Engineering Curriculum has remained essentially the same with changes as necessary to meet the needs of naval engineering and to take advantage of new subject offerings. Changes have reflected increased emphasis on the analytic and creative tools needed by the naval engineer to meet and anticipate the challenge of current and future development in the whole shipbuilding and design fields. These changes continue to be within the framework of a curriculum leading to a broad professional degree in naval engineering with a specialization in hull design, marine propulsion, or electrical-electronics recognized by the appropriate Master's degree.

The recent graduating class of 19 officers is one of the smallest in recent years. However, the numbers of current and anticipated entering classes indicate that future graduating classes will average between 25 and 30. The graduating class was awarded 17 professional Naval Engineer degrees and designated degrees of Master of Science as follows: ten in Naval Architecture and Marine Engineering, six in Mechanical Engineering, and four in Electrical Engineering.

The increase in emphasis on computer applications continued with general enrollment appropriate to background in Computer Approaches to Problems in Naval Architecture and Marine Engineering (13.50), newly offered within the Department. The numbers of thesis topics selected in the field of computer application also reflect increasing student interest.

In Preliminary Design (13.46), under Professor Robert E. Stark, assisted by Professor Reed, further changes have been made to exercise the graduate student officers as groups in a design project prepared to challenge to the fullest the new analytic and creative tools provided in the curriculum. In particular, "What to design?" was a major question for each of these groups. The largest group worked on a project to develop landing-force-support-ships. The problem was strongly flavored with the results of operations analysis in probabilistic form. Results of the concept exploration phase were required to be in cost-

effective form. Because the group had been subdivided into competing teams, rivalry added considerable incentive. A concept selected from the results of concept exploration was then developed by smaller competing teams into preliminary design.

As a second project within 13.46, four students worked on Project HYSURCH under the joint sponsorship of the Experimental Astronomy Laboratory and this Department. These students worked on the selection of a ship system for the task of high speed mapping of large water areas contiguous to land. In general the problem provided an excellent interdisciplinary exercise.

As a third project within 13.46, and at the suggestion of Professor Alfred A. H. Keil, three students undertook the reverse of concept formulation, seeking a use for a concept rather than a concept for a use. The concept explored was that of the spar of flip ship. This project proved particularly successful and resulted in a number of quite interesting applications from which one was selected for a more normal preliminary design. The selected system-purpose was Perpendicular Object Search and Recovery Systems (POSARS), whose features included a tethered manned submersible as a search subsystem with a 6,000-foot capability and an object recovery subsystem with an eight-ton object recovery capability to 2,000 feet. Extensive pertinent literature was obtained and research problems well defined.

OCEAN ENGINEERING

The Department proposed and the Institute approved the initiation of a new graduate program in ocean engineering leading to the Master of Science degree and the doctorate in Ocean Engineering and the professional degree of Ocean Engineering. This program will be offered beginning with the fall term of the 1967-68 academic year. It has its focus in the Department of Naval Architecture but draws strongly on existing subjects related to ocean engineering in many departments of M.I.T. as well as research and development projects throughout the Institute, including the Instrumentation Laboratory. It establishes close cooperation with ocean engineering efforts at Woods Hole Oceanographic Institution and complements the joint graduate oceanography program of M.I.T. and W.H.O.I.

In order to provide a comprehensive curriculum, new subjects have to be prepared to supplement existing ocean engineering-related subjects. Preparation for four new ocean engineering subjects was started in spring 1967 with Ford Foundation support as follows: Ocean Engineering Structures and Control of Ocean Vehicles (in this Department), Materials Engineering for the Ocean Environment (in the Department

of Civil Engineering), and Law, Politics, and the Oceanic Realm (in the Department of Political Science). Additional support is expected from the National Science Foundation under Sea-Grant Projects.

SEMINARS AND SYMPOSIA

The weekly departmental seminars were based on the theme, "The Broadening Perspectives for Naval Architecture and Marine Engineering." They concentrated on ocean engineering aspects, such as the need for ocean engineering, design studies for a saturation diving facility, ocean engineering salvage, a series on deep sea vehicle design (six seminars), underwater towing, oceanographic surveys in river deltas, application of deep-sea vehicles for surveys, and field observations of air and sea interactions; on ship-related subjects such as development of aircraft carrier characteristics, computer applications to preliminary design, studies of segmented ships, computer-aided ship design, and key development efforts for large surface effect ships; and on basic engineering science subjects such as high speed propulsion, panel response to pressure fluctuation of a turbulent boundary layer, analysis of ocean waves and Aeolian tones associated with resonant vibrations.

The Industrial Liaison Office Symposium held in April, 1967, was planned also to demonstrate the expanding scope of naval architecture and marine engineering. The presentations by faculty members covered the spectrum from engineering science and new facilities to ship concepts, design, and production as indicated by the following titles of the presentations: "Control of Deep-Sea Vehicles," "Mooring and Towing Mechanics," "Propeller Excitation of Ship Vibrations," "Acoustics and Vibration Research," "Water Tunnel Research," "System Design Consideration," "Concept Formulation in Naval Design," "Parametric Studies on Hull Structures," and "Production, Control and Management."

The Department sponsored a Symposium on Sailing Yacht Research which drew an attendance of more than 300 persons. It provided a forum for discussion of the latest research in this field.

RESEARCH FACILITIES

Modern facilities are instrumental for a strong program in teaching and research. The Department therefore continued its determined efforts to improve present facilities and add new ones.

SHIP MODEL TOWING TANK

The Ship Model Towing Tank has experienced an increase in both activity and diversification during the last few years in serving as an effective, up-to-date instructional and research laboratory. The per-

formance of a recently installed novel beach consisting of a 12-foot-thick sloped beach of stainless steel shavings coupled with the white-noise technique of generating purely random irregular waves provides a unique facility for testing ship models in realistic seaways in order to determine maximum motion and loading responses. These new tank items, like other tank equipment and capabilities, are readily used in research and laboratory instruction.

To the capability of conducting resistance, maneuvering, seakeeping, and yacht testing has been added recently the additional apparatus and technique for conducting wake surveys at the hull stern, determining the propeller induced hydrodynamic vibrating forces on a model, and determining stability coefficients for ship models by a "step response technique." The experience in testing surface ship models (such as aircraft carriers, cargo ships, trawlers, boats, destroyers and hydrofoil boats) has been augmented in the last few years to include tests on catamarans, deep-submergence rescue vehicles, ground effect machines, mooring systems, buoys, amphibious craft, mother ships for submersibles, oceanographic vehicles, and other special types.

With the capability of conducting such a variety of testing on models of such diverse vehicle types comes the development and acquisition of modern and special instrumentation. Although the towing tank is modest in size (100 feet by 8½ feet by 4 feet), it contains probably a very dense concentration of instrumentation. Some of this instrumentation is currently being updated and amplified under a Ford Foundation grant.

Even with the great variety of research instrumentation and techniques which have been developed in the towing tank over the years since its modest beginning, the two fundamental concepts in the towing tank are still essentially maintained. These are:

1. Top priority is given to student instruction, laboratory, and thesis — followed by research, with last priority given to commercial testing.
2. Instrumentation and testing techniques should be developed so that only one man (albeit with some difficulty) can be able to conduct a test from the operations room.

The demands on the towing tank during the last term required operating many days until midnight and sometimes beyond.

A great portion of the data acquired at the tank is in a form to be readily reduced and analyzed by computer methods using programs specially developed for such analysis.

ACOUSTICS AND VIBRATION LABORATORY

The Acoustics and Vibration Laboratory completed its first full year of active operation. It was set up with the joint participation of the De-

partments of Mechanical Engineering and Naval Architecture and Marine Engineering under the Engineering Projects Laboratory. This year saw completion of a low-turbulence, low-noise wind tunnel and the placing of this facility in active operation on research projects. This tunnel was specifically designed for flow noise research and is one of the very few of its type in the country. It is a single pass tunnel with a 15 by 15-inch square cross section in the test duct. The test section may be used in either open-jet or closed-duct modes. The test section is housed in a concrete test chamber that may be fitted either as an anechoic chamber or as a hard-walled reverberant chamber. A true boundary layer flow is developed on the test section walls with a thickness of approximately one inch. A turbulence level of .05 per cent at 130 feet per second was achieved throughout the uniform mean flow regime. The maximum tunnel velocity is 200 feet per second. The purpose of this facility is to permit the study of triple point problems involving the interactions of hydrodynamic shear flows, structural vibration, and acoustic radiation. It is being used in both boundary layer and periodic wake studies.

A second major Laboratory facility was placed in operation this year. This is a 1,500-pound shaker system that can be programmed for either discrete-frequency or shaped-spectrum excitation. It is installed on a large concrete block floated on air springs.

An integrated instrumentation system for the Laboratory has been acquired and placed in operation with substantial support by the Alfred P. Sloan Foundation. Various transducers and their associated power supplies and preamplifiers have been acquired — including microphones, accelerometers, structural impedance heads, and constant-temperature hot-wire anemometers. Analysis capability has been developed which now permits the determination of power spectral density (in two forms — constant narrow band width and constant percentage band width), cross correlation, shock spectrum, structural impedance, and vibratory power flow.

The laboratory contributed directly to the academic program this year. Four Master's theses were completed and one doctoral thesis was commenced. In addition, the laboratory participated in the 2.671 project subject with two student groups carrying out experimental studies. Demonstrations were also given in the laboratory in conjunction with 13.95 and subjects in the Mechanical Engineering Department.

PROPELLER TUNNEL

The Propeller Tunnel, as originally built in 1939, was intended primarily for the measurement of the steady-state performance characteris-

tics of conventional ship propellers. In recent years it has become evident that a more versatile water tunnel would better serve the educational and research needs of the department. A program of conversion was started in November, 1965, and it is expected that the laboratory will be back in operation in the near future.

The re-built tunnel will have greatly improved flow characteristics, a longer and more accessible test section and new electronic instrumentation. Special provisions have been made to permit rapid change-over from one experiment to the next.

Experiments which we expect to be made in the next few years include dynamic measurements of oscillating supercavitating hydrofoils, vibratory force measurements on a variety of propeller-hull combinations, flow visualization studies, acoustic measurements — including cavitation noise and boundary layer excitation of plates, and a variety of free-surface flow studies.

STRUCTURAL LABORATORY

Plans are being prepared to expand the Structural Laboratory, especially by adding facilities pertinent for ocean engineering projects.

RESEARCH HIGHLIGHTS

Extensive participation by graduate students in the research projects of the Department continues. A few highlights are summarized below.

SHIP HYDRODYNAMICS

The research recently and currently carried out in the Department concerns hydrodynamics and dynamics of ship motion and control. It covers the entire spectrum of principles, practical aspects, experimental investigations, and theoretical studies.

The investigation of surface wave phenomena, under the Office of Naval Research (ONR) sponsorship, which just a year ago resulted in the analysis, development, and construction of a model of an active beach, has been extended to investigation of wave water spouts emanating from a container on impact. The results from tests involving high speed photos of experiments involving liquid containers on impact have been compared with the results of theoretical hydrodynamic analysis.

With the development of the technique of white noise generation of random waves which are effectively eliminated at the tank end by the new beach, a series of tests involving a destroyer model has been carried out in order to determine the maximum response (such as pitch, heave, acceleration, bending moment) in several sea states of increasing severity. By this means it can be determined in what sea states and at

what speeds such a vessel can avoid structural failure. This project is under ONR sponsorship.

For about five years, the U.S. Maritime Administration has sponsored a research program in seakeeping at M.I.T. with the aim of improving ship speeds at sea. Under this program, a theoretical approach was developed last year to calculate the motions and loadings of segmented ships, either hinged or linked, in a seaway. Computer programs are being developed for calculating these seaway responses for a finite and infinite number of segments. Model tests on barge trains of a varying number of segments are being made in waves in the towing tank for comparison with theory. Data from these tests will provide information as to the feasibility and competitiveness of such hinged ships from a seakeeping point of view. Also, an insight as to the loads on the hinges helps to determine the necessary strength for design of such joints. Part of the speed loss of ships at sea results from the added drag of ships in a seaway. The theoretical calculation of such added drag has been successfully programmed on the computer. This calculated added drag agreed rather well with that measured on a model. This success provides another step toward the goal of being able to predict the speed made good of any ship in a given seaway due to both voluntary and involuntary loss of speed. Recent results of this program predicted the measured 10 to 15 per cent advantage in drag of a specific V-form hull over a specific U-form hull in a seaway.

Under sponsorship of the U.S. Marine Corps, a general theoretical and experimental look at the stability of amphibious landing craft in shallow water and surf is being conducted. It is hoped to determine in what type of surf and wave conditions a craft can properly beach without broaching while using its available control forces — or what control forces are necessary to be operational under certain specified conditions. Model tests of the amphibious craft in waves onto a sloping beach are being carried out.

The deep-submergence program of the U.S. Navy involves several special-purpose submersibles whose design and operations push the state of the art. Of these, the deep-submergence rescue vehicle is under design. The research in our Department involves the hydrodynamic aspects of such vehicles as they pertain to motion stability and control. Sophisticated motion control of these vehicles is critical for accomplishing their missions and the challenges of a more general and accurate hydrodynamic modeling are being pursued.

The motion responses and speed loss in a seaway for a new design of icebreaker are under investigation through model testing in regular

and irregular seas and through use of theoretical methods as programmed for the computer. The sponsor, the U.S. Coast Guard, hopes to improve range and speed through reduced motions. In addition, we hope to get an estimate of the increase in operational time of the helicopter assigned to the icebreaker, resulting from reduction of ship motion.

Our research also included the following projects concerning motions that are critical to the operations of the various vehicles involved:

1. Ground effect vehicle in waves.
2. Motion response of oceanographic submarine and mother catamaran in waves and the relative motion of the two in recovery position.
3. Motion responses of an unloading ramp attached to a ship and a barge in a seaway in proximity to the ramp.
4. Research on the optimization of the stabilization of a submarine in near-surface operation.

Graduate student Research Assistants participate in depth in our research, and this involvement is a major contribution to their total education. The student is motivated and stimulated by the technical challenge and the variety of the research projects; he works closely with the faculty supervisor, and he is encouraged to make use of his professional talents through individual opinions and efforts.

PROPELLER VIBRATION

A rotating propeller is a major source of mechanical vibration and radiated noise. Research in a number of aspects of this problem is being carried out in the Department. A method of calculating the rotating pressure field of a propeller in uniform flow has been developed as an extension of the propeller design computer program. Methods are under development to compute the unsteady forces on a propeller operating in a non-uniform flow field. The problem of measurement of the non-uniform wake behind a ship model has been studied, and equipment has been developed to generate wake surveys rapidly by digital conversion and processing of test data.

A technique for the measurement of propeller vibration forces on a ten-foot self-propelled model has been developed. In order to avoid the need for construction of a new model for each hull form to be studied, an aluminum skeleton has been built on which outer shells constructed of fiberglass-reinforced plastic and foam can be attached.

The combination of this work should lead ultimately to the development of propulsion arrangements with greatly improved vibration characteristics.

PROPULSION

A design theory for marine propellers has been under development for a number of years. A computer program has been developed which provides essentially all dimensional information needed to build a propeller with specified performance characteristics. The accuracy of the method has been verified for a wide variety of propeller types by model experiments conducted by the Naval Ship Research and Development Center.

This work is now being extended to include heavily loaded propellers, and propellers with extremely large hubs. More accurate water tunnel wall interference corrections are also being computed, using similar theoretical techniques.

SHIP STRUCTURE

Research on the optimization of ship structures has now been directed toward the selection of materials. Sponsored investigations related costs and weights, using a variety of steels and encompassing a parametric family of frame spacings and framing systems. Until the development of a complete methodology made possible the extensive computer-aided midship-section structural-design program now in use at M.I.T., such a thorough and rational approach to the design of primary structure was not possible. It is now planned to extend the work to include a greater variety of material characteristics and possibly to forecast optimum properties required for the future.

Other structural research has investigated the relationship of total hull weight to the midship section structure in the hope of deriving an accurate method of weight estimation for incorporation into a master computer-aided design system for over-all ship concept formulation.

In a third project, the STRESS computer language was given a limit test of suitability in a three-dimensional study of the elaborate compound-truss structure found in icebreaking vessels.

SHIP ACOUSTICS

The first phase of an investigation of noise from steam reducer valves was completed and a second more detailed investigation of the causes and correction of discrete frequency noise in these valves is under way. Two experimental tasks have been under way this year in the low-noise, low-turbulence wind tunnel. The first is an investigation of the acoustic radiation from a cylinder excited resonantly by a periodic vortex wake. The second is a study of sound radiation from panels excited by turbulent boundary layer wall pressure fluctuations. The former of these tasks produced the very interesting result that the intensity of acoustics

radiation increased by the twentieth power of the stream velocity as the vortex shedding frequency approached the third resonant frequency of the cylinder from below. This is at wide variance with the previously accepted sixth-power velocity law. It appears that this phenomenon is principally related to a 100-fold increase in the root mean square sectional lift coefficient over the Reynolds number range involved, but is not identified with any significant structural vibration influence upon the wake.

SHIP DESIGN

This year saw the successful application of an exponential random search technique to the ship design procedure by Professor Mandel and Reuven Leopold. This was a pioneering achievement that has aroused widespread interest in the naval architecture profession. With support from the United Aircraft Corporation, we are now developing the design model for gas-turbine-powered, large-size, high-speed container ships, and are using the random search technique to generate optimized designs for a given set of owner's requirements. An extension that also will enable optimization of the owner's requirements was discussed at the Department's Industrial Liaison Office Symposium in April and work on this is currently being pursued.

In recognition of the fact that all engineering systems should be useful and desirable to society, the optimization criteria used in this work are not the traditional engineering measures of efficiency; rather the criteria are economic ones. Among those used are the least-cost (amortized building cost plus annual operating cost) criterion and the required-freight-rate (for a specified return on investment) criterion.

Another major report completed this year shows the effect of systematic variation in hull dimensions and geometry on five responses (heave motion, pitch motion, relative vertical bow motion, relative vertical bow velocity and stern vertical acceleration) in a series of realistic irregular seas. This is the first time that broad seakeeping data applicable to a very broad family of designs has been presented.

FRANCIS RUSSELL HART NAUTICAL MUSEUM

In approaching the end of his fourth year of duty, William A. Baker, the curator of the Hart Nautical Museum, can report that his work of the last year has been more curatorial and less janitorial than in the previous three. There has been a steady flow of questions to be answered, from visitors as well as by telephone and letter; the cataloguing of the large plan collections has continued; the Fogg Museum has cleaned and repaired an oil painting which now hangs in the President's office along with another restored in a previous year; and the photographic

record of the museum's property and major loans has been expanded.

Donations to the museum last year were limited to a few books and plans. Roderick Matheson, the new shop man, has constructed two half models of well known sailing yachts of the 1930's; others of this type are planned to up-date the yacht collection. Because of the change in the shop, a model of a fishing trawler of about 1930, started in September, 1964, and left unfinished in June, 1966, was completed by a model maker in Duxbury and is now on display. A one thirty-second-inch-scale waterline model of the large U.S.-built tanker *Manhattan* is under construction in New Jersey to augment the group of models now on loan from Mrs. E. L. Cochrane.

Special displays during the year have included "Sailing by Computer," the "M.I.T. Propeller Tunnel" and "The Yacht *America*." Special exhibits were installed for the Open House in April. Work is under way on new display facilities following the retirement of an unsatisfactory case from the museum. An eye-level case will replace the present substantial small boat case in the south room and a wall case will replace the two 30-by-40 inch frames at the foot of the stairs in the corridor just outside the museum. The first exhibit in the latter will feature ocean engineering vehicles.

As in previous years, requests for reproductions of plans from the Haffenreffer-Herreshoff Collection outnumber those for the work of other designers. The curator and the museum's facilities continually provide researchers with ship information ranging from plans for simple models to data for the full size reproduction of Cartier's *La Grande Hermine* of 1535, which is a feature of EXPO 67 in Montreal. U.S. Navy photographers spent two full days photographing models and prints of old ships to be used in the production of training films.

Not directly a part of the museum's work, the curator selected the paintings and prepared the catalogue material for "The Clipper Ship" show in Hayden Gallery, November 14 to December 2, 1966. Included were one painting, several plans, some sailing cards, and a model from the museum's collections. This show, which received much favorable comment and publicity, honored the Department of Naval Architecture and Marine Engineering and its catalogue had a foreword by the Department's new head, Dr. Alfred A. H. Keil.

Other events during the year which kept the Department and M.I.T. in the public eye were guided tours for school groups, a visit by the Bay State Historical League, a short interview on WHDH-TV concerning the Norsemen-versus-Columbus feud, listings in various "museums to visit" brochures, and a reception for elementary school principals in connection with a book on early voyages to America.

Visits to other museums as far south as Washington have maintained and expanded the necessary professional contacts and the curator has continued to serve as a member of the U.S. Coast Guard Working Group studying stability and subdivision.

FACULTY

During the last academic year, Dr. Patrick Leehey received a tenure appointment and was promoted to full professor. He had joined the Department in 1964 after a successful career in the U.S. Navy where he developed a deep insight into the research and engineering aspect of ship acoustics.

Dr. Alfred A. H. Keil joined the Department on July 1, 1966, as Professor of Naval Architecture and Head of the Department; formerly he was Technical Director of the Navy's David Taylor Model Basin.

Commander Sherman C. Reed, USN, replaced Commander William R. Porter as Associate Professor of Naval Engineering.

Dr. Bernard Romberg, Director of Computer-Aided Ship Design of the Navy-supported projects at Arthur D. Little, Inc., was appointed part-time lecturer for the new subject, Application of Computer systems to Naval Architecture and Marine Engineering.

L. R. Doyon, Manager of the Reliability/Maintainability Engineering division of Raytheon Corporation was appointed part-time lecturer for the propulsion system reliability subject.

ALFRED A. H. KEIL

DEPARTMENT OF NUCLEAR ENGINEERING

The most significant development affecting the Department of Nuclear Engineering which took place during the last year was the acceleration in the rate of adoption of nuclear power stations by electric utilities. In the United States, in the year preceding July 1, 1967, more nuclear generating capacity was ordered than had been ordered in all previous years. Similar notable advances took place in Western Europe and Japan. These developments are due in part to the continued reliable operation of first-generation nuclear power stations, in part to realization that nuclear power plants do not contribute to atmospheric pollution, but most of all to the low cost of second-generation nuclear power plants and their associated fuel cycle, which permits them to generate electricity at lower cost than plants burning fossil fuel anywhere in the world except where fuel is very inexpensive.

Nuclear power plants being built in the United States are of the light-water type, which convert to energy no more than one per cent of the

energy latent in natural uranium, because they utilize primarily the scarce isotope uranium-235 instead of the abundant uranium-238. The rapid introduction of nuclear power plants in the United States, which the Atomic Energy Commission (AEC) now estimates may be generating 150,000 megawatts of electricity by 1980, has focused attention on the fact that present U.S. reserves of uranium ore will be exhausted within a few decades unless reactors which make more efficient use of uranium can be developed. This has led to expanded efforts in the United States, the U.S.S.R. and the countries of Western Europe to develop fast breeder reactors, which in principle are capable of converting all of natural uranium to energy by first transmuting uranium-238 to plutonium and then utilizing plutonium as a nuclear fuel. If power plants using breeder reactors can be made economic, the world will have a practically inexhaustible supply of energy.

One of the main objectives of the Nuclear Engineering Department has been to educate men to make effective professional contributions to the development and commercial utilization of these types of nuclear power systems. Student interest in careers in the nuclear power field remains high, and the demand for men trained to deal with the problems of nuclear reactors, which has been substantial for many years, is increasing. Power equipment manufacturers continue to seek men with this type of training both in connection with designing and building light-water power plants and to develop improved breeder reactors. The national laboratories need additional staff to attack the problems of breeder reactors and to assist the Atomic Energy Commission in formulating and evaluating its over-all reactor development program. The Atomic Energy Commission is expanding its staff of nuclear engineers, both to administer the national reactor development program and to provide skilled technical evaluation of new reactor projects in connection with safety review and other aspects of reactor licensing and regulation. An especially significant new development has been the decision of electric power companies to add nuclear engineering graduates to their staffs. It seems clear that the growth of nuclear power will provide professional opportunities for men with nuclear engineering training for many years, and will provide technical problems to challenge them both while doing research at school and in subsequent professional employment.

The interests of the Department of Nuclear Engineering extend beyond nuclear power, however. The Department is active in other related areas of advanced technology, including applied nuclear physics, energy economics, radiosotopes, radiation effects on materials, nuclear rockets and other nuclear energy systems for space application, thermionic direct-conversion devices and applied plasma physics. About one-fourth

of the Department's activity is devoted to applied plasma physics because of its relevance to controlled thermonuclear power.

If a feasible controlled thermonuclear reactor can be developed and if a power plant based on it can be made economic, the world will have another practically inexhaustible energy source, rivaling the breeder reactor. The technical problems of a controlled thermonuclear reactor are much more intractable than those of a breeder reactor. During the last year a special panel of the President's Science Advisory Committee assessed the U.S. program of controlled thermonuclear research and recommended an increased national effort, including more work at the universities. The ultimate attainment of economic thermonuclear power was recognized as being both uncertain and distant, but the national effort was held to be justified both because of the tremendous potential value of this new energy source and because of the scientific interest and derivative practical value of the research on plasmas which is necessary in order to understand the problems of controlled thermonuclear systems.

Through its program of instruction and research in applied plasma physics, the Department of Nuclear Engineering is making significant contributions to the national effort on controlled thermonuclear research. Students graduating from this program are filling responsible positions in plasma research laboratories. Faculty and students in the Department of Nuclear Engineering constitute a major participant in the Research Laboratory of Electronics' applied plasma research program, undertaken with support from the Atomic Energy Commission and the National Science Foundation. The results of this research, both experimental and theoretical, are helping to understand the complex behavior of plasmas and to suggest means to improve their confinement in thermonuclear systems.

STUDENTS

During the preceding year 28 students received the degree of Master of Science in Nuclear Engineering, 11 the degree of Nuclear Engineer and 22 the Doctor's degree. The number of students receiving the Nuclear Engineer degree is greater than the total number of men receiving this degree in all previous years, and the number of Doctor's degrees awarded is 50 per cent higher than in any previous year. This increase in the number of more advanced degrees is indicative of the more advanced state of nuclear technology, which makes it advantageous for students to pursue a more extensive program of graduate study. The greatly increased student interest in the Engineer's degree program is especially gratifying, as the Department has felt that there is a need for men trained for careers in creative engineering design, which is the primary objective of this pro-

gram. Of the 61 degrees awarded, 49 were in the Department's fission technology option and 12 in the applied plasma physics option.

The September, 1966, enrollment in the Department was 122 regular students and six special students, three less than in the previous year. The number of U.S. students applying for admission is somewhat lower than in previous years, and the number of foreign students markedly higher. Foreign student enrollment is being kept at about 25 per cent of the total.

The demand for nuclear engineering graduates remains very high. A specific effort is being made to train students for responsible technical positions with electric utilities, who are now seeking to employ more M.I.T. nuclear engineering graduates than are available for such positions.

FACULTY

The department faculty now comprises 18 men. Dr. Elmer E. Lewis joined the faculty as Assistant Professor and Postdoctoral Fellow in Engineering. Dr. Lewis is a nuclear engineering graduate from the University of Illinois who had been serving as an officer of the U.S. Army's Fort Monmouth Electronics Laboratory. His research interests are in reactor physics and fission product transport.

As part of the exchange arrangement between M.I.T. and the Technical University of Berlin, Dr. Klaus Johannsen, Privat-Dozent in Nuclear Engineering at that school, spent the year at M.I.T. as Visiting Associate Professor of Nuclear Engineering. Dr. Johannsen carried out theoretical research on heat transfer in flow channels of nuclear reactors and presented an informative series of lectures on this topic.

Dr. Kunmo Chung resigned his position as Research Associate to accept appointment as Associate Professor of Electrophysics at the Polytechnic Institute of Brooklyn. During his two-year appointment at M.I.T., Dr. Chung made valuable contributions to our research program in plasma physics and ably assisted the faculty in directing student research.

Professor Edward A. Mason is leading a summer project for the Atomic Energy Commission at Oak Ridge National Laboratory on agro-industrial complexes using low-cost energy from nuclear reactors. The object of the project is to study the economic feasibility of using the low-cost heat and electricity which it is hoped will be obtainable from very large nuclear reactors to desalt sea-water and produce chemical fertilizer for agricultural purposes and to use by-product electricity for such energy-intensive industries as aluminum reduction. Favorable combinations of processes are to be identified and the conditions under which such projects would be economically justified are to be determined.

Professor Elias P. Gyftopoulos is taking a year's leave of absence in which he is writing a book on thermionic conversion and is collaborating with a local hospital and engineering firm in developing a radioisotope-powered artificial heart.

INSTRUCTION

During the last year the Department's instructional program was modified and expanded to keep pace with new developments in nuclear technology and the Department's broadening interests. To provide a more complete treatment of modern nuclear reactor physics, Professor Irving Kaplan has organized a series of lectures in Advanced Reactor Physics in place of a former series of student-presented informal seminars on this subject. Assistant Professor Sidney Yip prepared notes and presented lectures for the first time on Neutron Physics and Applications. The primary purpose of this subject was to acquaint students with the principles of neutron interaction with matter and with theoretical methods for obtaining neutron cross sections for use in nuclear reactor design and in investigating material properties by neutron scattering.

Three new subjects were introduced to reflect new developments in the engineering aspects of nuclear reactors. Professor Theos J. Thompson presented a series of lectures on Nuclear Reactor Operations which dealt with the principles of reactor operation, operating and maintenance experience with existing reactors, reactor safety analysis and the prevention of reactor accidents. Students are shown how the M.I.T. Reactor is operated and are taken to visit a nearby power reactor. Professor Manson Benedict presented a series of lectures on the Economics of Nuclear Power, which treated accounting principles used by electric utilities, current costs of generating electricity, nuclear plant costs, uranium resources and costs, nuclear fuel management, nuclear fuel cycle costs, and the economics of light water and breeder reactors.

In the fall term, Professor Thompson organized a new subject, Fast Reactors, which described the principal fast reactor concepts, presented design methods for them and discussed their development problems. Students in this class were organized into three teams, each of which prepared a detailed report on one of the three principal fast reactor concepts, the sodium-cooled, steam-cooled or helium-cooled type. These reports were in the form of a proposal for development and construction of a demonstration reactor generating 500 megawatts of electric power. At the end of the term each student team presented its reactor proposal to a panel of engineers and economists, and gave arguments in favor of building a demonstration plant based on its reactor concept. This competitive series of hearings stimulated student interest in fast reactors and

provided realistic experience in presenting engineering reports. In the following spring term Associate Professor Henri Fenech's class in Nuclear Reactor Design carried out detailed design studies and an economic optimization of the design of three different versions of a sodium-cooled fast reactor, making use of principles and design methods presented in Professor Thompson's class. In the coming year, a similar sequence of classes will be offered dealing with thermal reactors, with reactor concepts and design principles being taken up in the fall term and detailed design studies and economic optimization in the spring.

In the summer of 1966, Professor Thompson directed an intensive two-week subject in Nuclear Power Reactor Safety. The two-volume compendium, *The Technology of Nuclear Reactor Safety*, recently published by Professor Thompson and his collaborators, was used as a text, and lectures were presented by authorities on reactors from M.I.T., the principal reactor manufacturers and the AEC. The subject was very well attended by 94 men from the United States and a number of foreign countries, representing research organizations, manufacturers, power companies and government regulatory agencies. The opportunity afforded for diverse groups to exchange views and discuss reactor safety was extremely valuable. The subject is being repeated in 1967, with equally large attendance.

M.I.T. RESEARCH REACTOR

The M.I.T. Research Reactor continues to be a major Institute asset and research facility and an essential element in the Department's program. It is used extensively as a radiation source for research by the Departments of Nuclear Engineering, Physics, Chemistry and Metallurgy and Materials Science and to a lesser extent by other M.I.T. departments and outside organizations. It supports about 40 student research projects and is used for instruction by classes in reactor operation, reactor experiments, neutron diffraction and nuclear chemistry.

The reactor continued its record of safe and relatively trouble-free operation, thanks to the skill and dedication of the reactor staff headed by Professor Thompson, Director; Lincoln Clark Jr., Associate Director; Edward J. Barnett, Assistant Director for Engineering and Design; and James W. Gosnell, Assistant Director for Operations.

Productive reactor time per week has held up very well in spite of the increasing age of the reactor and the consequent need for more frequent major repairs. In the spring of 1967, leaks in the heat exchanger tubes presented a major maintenance problem. It was necessary to take out of service first one and then the other of the two primary heat exchangers and to operate at two megawatts during March, April and May, while the leaks were being located and repaired. Only

the diligence of the reactor operating and maintenance staff kept operating interruptions to this low level. During the rest of the year operation was maintained at five megawatts five days per week. A spare heat exchanger is now on hand.

M.I.T. is very appreciative of an action by the Atomic Energy Commission — lending to the M.I.T. Reactor a helium refrigeration unit no longer needed at the Cambridge Electron Accelerator. With partial funding from the Sloan Fund for Basic Research and the National Science Foundation, this equipment is being moved to and installed at the M.I.T. Reactor. There it will provide refrigeration for an in-pile cryostat in which materials are to be irradiated at liquid-helium temperatures and for a second cryostat in the thermal column which will provide a source of cold neutrons for physics experiments. This new facility makes possible a substantial increase in the research potential of the reactor.

Funds received by the M.I.T. Reactor from users of its facilities and charges for operating the reactor are compared below for the two past academic years.

Year	1965-66	1966-67
Receipts	\$317,930	\$289,100
Charges	\$348,229	\$277,134
Difference	— 30,299	11,966

Receipts were lower last year than in the previous year because of termination of some research contracts and cutback in others, owing principally to reduced availability of federal research funds. Charges were lower last year than in the previous year because the reactor was relieved of charges for M.I.T. overhead. Next year it will be difficult to increase receipts from reactor users, despite the new projects which will use the helium refrigeration equipment, because of further cutbacks in existing projects using the reactor. Charges will increase because of unavoidable escalation. Consequently, the reactor will probably again operate at a deficit. Intensive efforts are being made to stimulate new research projects, and another attempt is being made to obtain more satisfactory financial support for university reactors from federal agencies than is available in the present system of piecemeal funding through individual research contracts.

RESEARCH AT THE M.I.T. REACTOR

The Reactor Lattice Project uses well-thermalized, high-intensity neutrons from the M.I.T. Reactor to generate neutron flux distributions in subcritical lattices of slightly-enriched uranium metal or uranium dioxide

rods in heavy water moderator. Larger, critical lattices of this type would be used in power reactors moderated by heavy water. From measurements of the flux distribution, conclusions can be drawn about the reactivity of lattices of a specified size and the ratio of conversion of uranium-235 to plutonium. This project has been conducted for the U.S. Atomic Energy Commission since 1959 and is currently directed by Professors Thompson and Kaplan and Assistant Professor Michael J. Driscoll. It has developed a number of new experimental techniques for measuring the properties of thermal reactor lattices and, with the aid of theoretical correlations developed by the project, has provided improved means for predicting the properties of uniform heavy-water lattices. The project has provided worthwhile topics for thesis investigations by more than 40 students. Five sets of uranium metal rods have been studied, each for three different lattice spacings. Three lattice spacings using oxide fuel have been studied, and two more will be completed before termination of this phase of the project when its present contract expires on September 30.

A proposal has been submitted to the Atomic Energy Commission for continuation of the project, using facilities and techniques already developed to study the reactor physics of fast reactor blankets such as would be used in breeder reactors and non-uniform clustered uranium dioxide fuel such as is being used in Canadian heavy-water reactors.

In the Organic Coolant Project, with financial support from the Atomic Energy Commission, Professor Edward A. Mason and his students have been determining the effect of neutrons and gamma radiation in the M.I.T. Reactor on organic fluids which have been proposed as coolants for the Heavy-Water Moderated Organic Cooled Reactor. This is one of the types of advanced converter reactors which has been of interest because it is potentially capable of generating electricity at lower cost than light-water reactors and makes more efficient use of natural uranium than they do. In the M.I.T. Organic Coolant Project, various mixtures of terphenyls have been circulated through a loop installed inside a fuel element in the reactor. The extent of decomposition of terphenyl, and the nature and amount of decomposition products and change in physical properties of the coolant have been determined as functions of the dose rate of fast neutrons, dose rate of gamma radiation, temperature, duration of exposure and isomeric content of terphenyls. Correlations have been developed which relate results obtained at M.I.T. to results obtained in other laboratories working on organic coolants, in Canada and Europe. Because of a decision of the AEC to terminate development of the organic cooled heavy-water reactor, this project is to be concluded by June 30, 1968.

Associate Professor Thomas O. Ziebold and his students are designing and building a cryogenic chamber inside a fuel element of the M.I.T. Reactor in which materials will be irradiated with fast neutrons while refrigerated with helium and held at any temperature between ambient and the boiling point of liquid helium, at 4.2°K. This facility will make use of the helium refrigeration unit lent M.I.T. by the AEC and is being funded in part by a grant from the National Science Foundation, as mentioned earlier. The unique value of conducting irradiations at low temperatures is that primary radiation damage effects are preserved in the specimen and are not annealed out, as would occur if irradiations were conducted at ambient temperatures. Professor Ziebold and his students will use this facility to study the microstructure of radiation defects induced by fast neutrons in structural metals, and will correlate changes in microstructure with changes in the fracture mode of the materials. This work is being supported by the Naval Research Laboratory, whose facilities in Washington will be used to examine the irradiated specimens. Several members of the Department of Metallurgy and Materials Science faculty also plan to use this low-temperature irradiation facility.

To obtain data needed for design of this facility, Professor Ziebold and his students have been studying the effect of fast neutron irradiation on heat transfer from a metal to boiling liquid helium. They have found that the reduction in thermal conductivity of a metal caused by neutron irradiation reduces the maximum heat flux which can be tolerated by boiling helium without occurrence of film boiling.

Professor Thompson, Mr. Barnett and their students are designing the second helium-refrigerated facility to be installed in the M.I.T. Reactor. This will consist of a block of moderator material in the thermal column, cooled with liquid helium, to serve as a source of cold, low-velocity neutrons. Low-velocity neutrons will be conducted selectively from this source to facilities outside of the thermal column by internal reflection in bent, polished copper tubes, in which low-velocity neutrons are reflected internally very much as light is in a light-pipe.

Professor Clifford G. Shull of the Department of Physics has conducted experiments on fundamental properties of the neutron at the M.I.T. Reactor. He has demonstrated that the electric charge of the neutron is less than $\pm 2 \times 10^{-18}$ times the charge on the electron, a result about one million times more precise than previous measurements. This tends to refute a theory held by some cosmologists that the expansion of the universe may be due to a slight difference in charge between the proton and the electron. He showed that the electric dipole moment of the neutron is no more than one-fifth as high as the limit set by pre-

vious measurements. He has shown that neutron beams can be focused by inhomogeneous magnetic fields.

Professor Shull and groups from the Department of Metallurgy and Materials Science and outside laboratories have used neutron crystal spectrometers at the M.I.T. Reactor to study crystal structure and the distribution of magnetic centers in solids. Work on neutron scattering by plastics and liquids is being initiated and is being interpreted theoretically by Professor Sidney Yip.

Professor Norman C. Rasmussen and students have perfected techniques for producing large (40 cm^3) crystals of lithium-drifted germanium to be used for precise measurement of gamma-ray energies. With these crystals the gamma and x-ray spectrum of spent fuel from the M.I.T. Reactor was measured and used as a non-destructive measure of the content of fission products, uranium and plutonium. With further development this technique should be useful to power reactor operators and fuel reprocessors in providing means for assaying spent fuel before reprocessing and should also be valuable in the international control of transactions in fissile materials.

With support from the U.S. Air Force, Professor Rasmussen and his students are also using these detectors to measure the energy of gamma rays emitted when thermal neutrons are captured by natural elements. Measurements on 75 natural elements represent the most complete study available to date, and will soon be published as a compilation.

Associate Professor Gordon L. Brownell, working in association with staff from the Massachusetts General Hospital, has been in charge of biomedical research at the M.I.T. Reactor. In a continuation of previous work on neutron capture therapy, through theoretical studies and experiments on phantoms which simulate tissue, it has been found that epithermal neutrons provide a better distribution of neutrons than the thermal neutrons formerly used in therapy. Medical applications of activation analysis have been extensively explored, using both thermal neutrons and bremsstrahlung to activate biological materials. It has been found possible to measure as many as 20 trace elements simultaneously in blood, hair or other tissues. Attempts are being made to correlate trace element levels with disease occurrence.

RESEARCH WITH ROCKEFELLER ACCELERATOR

The 3.5-Mev Rockefeller van de Graaf accelerator is being used by Dr. Leon E. Beghian, Assistant Professor Franklyn M. Clikeman and their students, under a National Science Foundation research grant, to measure fast neutron inelastic scattering, the slowing down of fast neutrons, and the spectra of gamma rays emitted during capture of resonance neutrons.

The capability of this accelerator to deliver neutrons of controlled energy in intense, short pulses of a few nano-seconds duration, coupled with use of high-resolution lithium-drifted germanium gamma-ray detectors, makes possible very precise determination of nuclear energy levels involved in inelastic scattering of neutrons. The same combination of capabilities is being used to follow the variation of neutron flux with time, space and energy during the slowing down of a pulse of fast neutrons to resonance energies in indium, cadmium or gold by water or graphite.

With support from the M.I.T. Center for Space Research, these men are studying the effectiveness of iron and paraffin shields to degrade and attenuate 14-Mev neutrons. Neutrons are generated in the Rockefeller accelerator and are detected in a stilbene-crystal proton-recoil scintillation spectrometer. The spectrum of neutrons after passage through the shield is inferred from the pulse-height response of the detector and its pulse-height response in separate calibration experiments with mono-energetic neutrons. This technique and the computer code used to interpret the detector pulse-height response represent a new departure in neutron shielding experiments.

REACTOR ANALYSIS

Professors Kaplan and Driscoll and Associate Professor Kent F. Hansen and their students have been engaged in developing analytical methods for treating the neutronic behavior of fast reactors, in place of the machine-computational multi-group methods ordinarily used for this purpose. These analytic methods provide more direct physical insight into the behavior of fast reactors and facilitate the teaching of fast reactor principles. Critical mass and relative nuclear reaction rates in fast critical assemblies predicted by these analytic methods are in good agreement with experimental measurements.

Professor Elias P. Gyftopoulos and his students have continued theoretical studies of reactor dynamics and stability. Emphasis has been placed on the space-time dynamics of large reactors such as are being used in current nuclear power stations. Topics dealt with include rapid transients, interpretation of oscillator tests and analysis and experimental interpretation of flux tilting. The last is the tendency of very large reactors to experience slow, periodic shifts of neutron flux from one region to another, owing to an instability associated with the growth and decay of fission product xenon-135. Prediction of potential flux tilting and design of control measures to prevent it is an important practical application of reactor dynamics theory.

Assistant Professors Elmer E. Lewis and Sidney Yip and their students have been conducting research in transport theory. A new method for

solving the Boltzmann equation for neutron transport has been developed and is being applied to interpretation of the neutron slowing-down experiments being conducted at the Rockefeller accelerator. Professor Lewis has extended his investigation of fission product transport in thin sections of fissile material such as might be used in fuel elements for a chemo-nuclear reactor or fission detectors for neutrons.

Professor Hansen and his students have continued research on development of improved computational methods for designing and predicting the performance of nuclear reactors. Work has been completed on development of a rapid, stable and accurate numerical method for solving the one-dimensional multigroup time-dependent equations for neutron flux; this is a notable advance, as no general-purpose production code of this type has heretofore been available. Methods are now being developed for the numerical solution of three-dimensional time-dependent neutron flux calculations in such a way as to be within the capability of today's computers.

RESEARCH ON PLASMAS AND CONTROLLED FUSION

Professors David J. Rose and Gyftopoulos and Associate Professors Lawrence M. Lidsky and Thomas H. Dupree and their students undertake research on plasmas and controlled fusion as part of M.I.T.'s interdepartmental plasma research program in the Research Laboratory of Electronics, with financial support from the Atomic Energy Commission, the Department of Defense and the National Science Foundation. The Department of Nuclear Engineering has the two objectives of contributing to the eventual development of a practical fusion reactor and of providing a better understanding of plasmas.

It is now generally agreed that a practical fusion reactor will have to provide stable confinement for a relatively dense plasma of tritium and deuterium ions held at a temperature of around ten million degrees for a time long enough for the fusion reaction between deuterium and tritium, which produces helium and 14-Mev neutrons, to occur. The hot plasma must be contained inside a refractory vacuum wall and be prevented from physically contacting the wall by a confining magnetic field, shaped in special ways. All of the energy produced by the fusion reaction would pass through the vacuum wall in the form of 14-Mev neutrons, x-rays and heat. A blanket must be provided outside of the vacuum wall to recover the energy and to use the neutrons to produce additional tritium and regenerate that consumed in the fusion reaction.

Work continues at a modest pace on energy recovery and tritium regeneration in the blanket. To the original concept of using a fused salt in the blanket as coolant, neutron moderator and tritium regenerator

has recently been added the suggestion by Los Alamos that liquid metals might also be used for these purposes.

The material requirements for the vacuum wall are completely beyond present experience. Thermal stresses would be high, and the integrated dosages of x-rays and 14-Mev neutrons would be without precedent. Professor Ziebold is starting experimental work on radiation damage by 14-Mev neutrons at the lower fluxes obtainable from the Department's present accelerators. Professor Lidsky and his students have conceived a novel source of high intensity 14-Mev neutrons consisting of a windowless deuterium gas target flowing from a hypersonic jet nozzle across a beam of tritium ions from an accelerator. Preliminary design calculations indicate that a flux of 10^{14} 14-Mev neutrons per cm^2 per second could be obtained from 32 grams per-second of deuterium flowing at Mach 8, with expenditure of about one megawatt of electric power. Oak Ridge National Laboratory has expressed interest in such a facility.

The crucial problem of a fusion reactor is stable confinement of the required dense, hot plasma, and most of the Department's research in the fusion area is concerned with contributions to a better basic understanding of plasmas. The Department has developed a hollow-cathode gaseous-arc plasma generator and has built a number of these units to study the properties of plasmas in the laboratory. During the last year, experiments were completed on this generator which provide an understanding of the processes which permit a current of as much as 100 amperes to flow from a three-millimeter tantalum hollow cathode.

One gaseous arc plasma generator with a plasma column three meters long and a few centimeters in radius is being used for a study of unstable waves, anomalous diffusion and turbulence in plasmas.

Density fluctuations in plasmas produced in another generator of this type are being studied by scattering of a laser beam. Because the intensity of the scattered radiation is only about 1×10^{-12} of the input, it is necessary to use elaborate precautions to detect the scattered signal in the presence of the input beam and radiation from the plasma. By using a 120-watt CO_2 -nitrogen laser as source and doped germanium at 4°K as a solid-state detector, and using synchronous detection techniques, it has been possible to detect scattering from collective plasma fluctuations rather than from individual electrons.

Apparatus has been built to study a hot-electron plasma confined in a minimum-B magnetic field. Such a field configuration, in which a region of minimum magnetic intensity is surrounded on all sides by regions of increasing field intensity, is known to suppress many of the gross instabilities which limit the confinement of plasmas. Measurements are being made of the electron density, velocity distribution and life-time in

cusped, mirror and stuffed-cusp geometry in an effort to understand the instabilities present in each case.

In order to study not only non-adiabatic motion of charged particles in magnetic fields, but also certain important interactions between particles and plasma waves, Professor Lidsky and his colleagues have completed two experiments on the trapping of electrons in specific magnetic field structure. In one case, an electron beam is trapped in a toroidal system that resembles a stellarator in shape but not in function. The circulating electrons are scattered from designed field perturbations, and the effect of many transits through weak perturbations has been measured. In the other case, a beam is trapped in a straight magnetic mirror, using a field perturbation for both injection and subsequent loss. Both experiments have confirmed specific predictions of kinetic theory regarding the scattering of charged particles in electromagnetic waves (here, the field perturbation represents the wave in a suitably moving coordinate system). The experiments also have direct bearing on confinement of charged particles in the Van Allen belts and in some proposed nuclear fusion devices.

Professor Dupree and his students are continuing theoretical research on plasma kinetic theory and turbulence. A new perturbation theory has been developed which is capable, in principle, of solving exactly the equations descriptive of plasma fluctuations and which predicts new types of instabilities and diffusion phenomena that can be compared with available experimental data. Professor Dupree has been invited to give an account of some of this work at the Symposium on Shock Waves in Plasma, in Novosibirsk.

Professor Gyftopoulos and his students have extended their theoretical research on fundamental phenomena in thermionic converters. A novel and unorthodox physicochemical model has been developed for analyzing electron emission from surfaces of pure metal crystals, either uncoated or partially coated with adsorbed atoms. Predictions of the model regarding the dependence of electron work functions and desorption energies on crystal orientation and nature and coverage of adsorbed atoms are in excellent agreement with experiment. Student papers on different aspects of this fundamental research on thermionic converters have won the 1966 Mark Mills Award of the American Nuclear Society and the Nottingham Prize of the 1967 Physical Electronics Conference.

OTHER RESEARCH

Professor Yip and his students have expanded their theoretical research on the statistical mechanics of gases and liquids, with financial support from the U.S. Army Research Office and the National Science Founda-

tion. The primary aim of this work is to develop methods for evaluating correlation functions which describe space-time fluctuations in the density and particle velocities in liquids or dense gases. These correlation functions permit calculation and interpretation of such diverse properties of dense fluids as the spectrum of inelastically scattered slow neutrons, the spectral distribution of scattered light, infrared absorption spectra of molecular liquids, and the viscosity of liquids. This work has stimulated experimental work at M.I.T. and elsewhere on these topics and has shown how seemingly quite different experimental results may be interrelated.

With support from the M.I.T. Center for Space Research, Professor Mason and his students have started design of a radioisotope power source for the Sunblazer space probe which the Center will use to measure radiation fields while in orbit around the sun. With support from the same source, Professors Mason and Hansen are continuing computer-aided design calculations on a hydrogen-fueled nuclear rocket. Topics under current investigation include transient temperature and stress distributions during startup, and the prediction of power peaks at temperature discontinuities.

In his subject in Radioisotope Applications, Professor Brownell directed student design studies of radioisotope-powered heat engines which might be implanted in the body to drive an artificial heart. The relative merits of different radioisotopes as heat sources and different energy conversion systems were evaluated.

Professor Thompson directed a number of student theses related to reactor safety. A theoretical model for predicting how void formation in a water-cooled reactor provides a mechanism for shut-down after a rapid power excursion has been shown to be in good agreement with experiment. New containment and emergency cooling concepts have been developed for limiting the consequences of a severe reactor accident, which it is hoped will make more feasible urban siting of nuclear power plants. A study is being made of means for making less positive the coolant void coefficient in heavy water reactors.

Professor Henri Fenech and his students have continued research on a number of reactor engineering topics. The technique of dynamic programming has been applied to optimization of fuel management in a three-zone reactor with two fuel enrichments and to optimization of management of control rods during fuel irradiation. The optimum gradient method has been applied to a design study for minimizing the mass of the shield for a shipboard reactor. A study has been completed of refined statistical methods for allowing for the effect of uncertainties in design parameters on reactor performance. Experimental studies have been made of two-phase flow of air-water mixtures in a vertical tube to

contribute to the understanding of entrainment of liquid and heat transfer in reactors cooled by a mixture of steam and water. An experimental program has been initiated on vibration of reactor components induced by high-speed coolant flow.

Professors Benedict and Mason and their students are completing their work on fuel cycles for nuclear reactors under AEC contract. A general parametric study of conversion ratios in a reactor moderated by heavy water and fueled with thorium dioxide and recycle uranium dioxide showed that conversion ratios above unity can be obtained, so that breeding in such a reactor would be possible, in principle. This would require operation at such a low specific power and such a high ratio of heavy water to fuel that power costs in a reactor which breeds would be substantially higher than in an economically optimized system. Studies are nearly complete of the effect of the presence of uranium-236 on the value of uranium when used as feed for heavy-water or light-water reactors. Every gram of U-236 present in the feed for a light water reactor would reduce the value of uranium by about \$10 if neptunium-237 had no value, but would increase the value of uranium by about \$2 if neptunium-237 could be sold for \$60 per gram. Neptunium-237 is produced when U-236 absorbs a neutron; it is an intermediate in the production of plutonium-238 which is in demand as a long-lived radioisotopic power source.

CONCLUSIONS

In its program of instruction and research, the Department of Nuclear Engineering focuses attention both on the technology of current or near-term nuclear power systems and on fundamental principles of applied physics which will be relevant as technology advances. In this way, graduates of this program will be able both to contribute to solutions of today's problems while being prepared to participate in future developments. The ability to keep abreast of new developments is especially important in this field because it is growing so rapidly and changing in ways which are not altogether predictable.

Research is an essential part of this program of graduate education in nuclear engineering. To be meaningful and relevant, research in nuclear engineering calls for facilities that are expensive to build and to operate, such as the M.I.T. Reactor, accelerators, and plasma research equipment. One of the major problems faced by the Department is funding the costs of research, especially at a time when federal support for research is diminishing because of other more urgent demands on the federal budget. As the nuclear power industry becomes established and profit-

able and as its need for graduates in nuclear engineering becomes even more apparent, it is hoped that a measure of private support in the form of fellowships and research grants can be secured.

MANSON BENEDICT

CENTER FOR ADVANCED ENGINEERING STUDY

During the year 1966-1967 the third group of senior engineers and scientists from industry, government, and education completed the Practicing Engineer Advanced Study Program. Summer programs in Experimental Solid-State Physics and in Civil Engineering Computer Systems were offered. The development of a new format for on-the-job continued education was started.

In the past year the Center has occupied the fourth and fifth floors of Building 24. Within this space are the offices of the administrative and professional staff of the Center, seminar rooms and classrooms, and informal lounges and individual studies provided for the men attending the programs of the Center.

The new building to house the Center is now under construction. Scheduled for occupancy in the fall of 1967, this modern air-conditioned educational facility will support the growing activities of the Center.

THE PRACTICING ENGINEER ADVANCED STUDY PROGRAM

The Practicing Engineer Advanced Study Program is designed for men who have supplied and are expected to continue to provide the initiative, leadership, and accomplishment that catalyzes technical progress. Although a relatively small fraction of the technical population, they form a critical group whose efforts have widespread effects. The Practicing Engineer Advanced Study Program provides a way for these key people from industry, government, and education to broaden and deepen their technical competence and thereby to enhance and prolong the most fruitful period of their professional careers.

This program involves residence at M.I.T. for one or more school terms. During this period the men and their families move to houses in the vicinity of M.I.T. Ninety per cent of those attending the program spend the full academic year at M.I.T. All participants in the program are experienced engineers or scientists who have demonstrated high-order professional capability and who are marked to play important future roles in their organizations.

The median age of the 40 men who have completed this program in the past three years has been 39. The majority of the participants have

been employees of industrial firms but the U.S. Navy, the Federal Aviation Agency, The Massachusetts General Hospital, and the University of Brasilia have also sponsored fellows.

The formal education backgrounds of the men attending this program have encompassed aeronautical engineering, applied mathematics, chemistry, chemical engineering, civil engineering, electrical engineering, mechanical engineering, metallurgy and physics. As fellows of the Practicing Engineer Advanced Study Program, these men were able to broaden and/or deepen their understanding of areas relevant to the interests of their employers, areas in which they were chosen to play leading roles.

The study programs followed were tailored to meet the specific objectives of the individual. No two study programs were identical; each was designed as an optimum experience in the light of the background and future plans of each fellow. This flexibility was achieved by drawing on all of the educational resources of M.I.T. and, in the rare case where greater scope was indicated, arrangements were made to include work at other educational institutions in the metropolitan Boston area. No constraints were placed on the areas pursued. A fellow was not restricted by disciplinary bounds but could engage in work at any level in any discipline provided only that his program was commensurate with his background and objectives. The program of a fellow of the Center often combined very advanced work in one area with studies at a basic level in another area. Some participants carried a substantial load of formal classroom subjects; others dug deeply into research frontiers, following and digesting emerging technology and evaluating its relevance to their home organization.

The regular undergraduate and graduate subjects, seminars, colloquia and research offered by M.I.T. departments were available to the fellows of the Center. In addition, the Center offered subjects that were designed specifically to meet the needs of the mature professional. These subjects were:

CALCULUS REVISITED, PROFESSOR HAROLD S. MICKLEY A six-week development of the first two years of modern calculus. It is given in the late summer just before the opening of the fall term, and the student devotes his entire time to it. It is designed for men who have had at least two years of calculus previously but who have grown rusty in its use. This opportunity to resharpen mathematical tools has greatly facilitated the process of fitting men at the Center into the mainstream of M.I.T.

PROBABILITY THEORY AND RANDOM PROCESSES, PROFESSOR WILBUR B. DAVENPORT JR. A development of the theory of probability and of ran-

dom processes with engineering applications. Its aim is to enable men with no prior background to attain rapidly the understanding requisite to advanced specialized subjects, the literature, and applications.

MODERN PHYSICS AND THE SOLID STATE, PROFESSOR ARTHUR C. SMITH
A presentation of the fundamental concepts of quantum mechanics, with emphasis on the interpretation of the theory and of the insight it provides into phenomena associated with the solid state. Designed for men with no background in quantum mechanics, it provides the foundation needed for applications and advanced work.

COMPUTER SYSTEMS, JOSEPH M. SUSSMAN, INSTRUCTOR IN CIVIL ENGINEERING
A treatment of the computer as part of a system. In addition to developing programming facility, the subject seeks to develop understanding of the role of the computer in real systems and the impact it will have in the future. Extensive experience in using the computer in both batch and time-shared modes to solve problems posed by the student is a key feature of this subject.

These were all intellectually demanding "full-bore" subjects. Although few in number, they have dramatically demonstrated both the need for and the value of expansion in this direction. The Center is striving to reach the stage at which, on the average, a man will be able to follow a program in which his formal subjects are about equally divided between regular M.I.T. offerings and those provided within the Center.

In order to help the new fellow design his program and to provide a focus for interaction with the M.I.T. staff, a "partnership" was arranged between each participant and a member of the M.I.T. Faculty. This association, based upon common professional interests, frequently resulted in a rapport that continued after the fellow had completed his work at M.I.T. and had returned to his job.

The chief thrust of the members of the Practicing Engineer Advanced Study Program was to develop a thorough understanding of areas of primary importance to their future responsibilities. As a complement to these in-depth intellectual activities, the Center offered special weekly seminars. The purpose of the seminars was to provide perspective on developments in a spectrum of fields that might be relevant to the future.

The subjects of the seminars encompassed oceanography, geophysics, biomedical engineering, computer sciences, neurophysiology, modern communications, optimal control, industrial dynamics, management of research and development, psychology and political science.

The scope and variety of the programs followed by members of the

Practicing Engineer Advanced Study Program are indicated by these examples of the activities of recent fellows:

A chemical engineer whose career has been concerned with combustion, drying, heat transfer, fluid flow, and particle size reduction pursued studies in combustion and high temperature phenomena, properties of polymers, the physics and chemistry of surfaces, and computer technology. He developed a computer program for solving high temperature reaction problems.

An electrical engineer whose recent professional responsibilities have largely been concerned with engineering management (direct responsibility for several hundred technical people) had a broad knowledge in the areas of radar and data processing, as well as in the systems in which they are used. While at M.I.T. he expanded and developed his knowledge in new management techniques and studied the theoretical and analytical aspects of systems engineering and operations research. He also spent a significant part of his time gaining a better understanding of time-shared computer systems.

A chemical engineer's recent responsibilities included coordinating and directing programs for improving existing methods and equipment, developing new methods and facilitating the use of computers within his company. At M.I.T. he attended subjects in chemical engineering, electrical engineering and management and extended his proficiency in computer programming and computer-aided design. He also participated in research using a hybrid computer to simulate equipment and processes.

A mechanical engineer concerned with mechanical properties and materials behavior in the design of pressure vessels, piping and process equipment attended subjects in shell structures, advanced mechanics, advanced heat transfer, fracture, and advanced calculus. He also spent some of his time learning to apply computer technology to help him solve his problems.

The professional responsibilities of another recent participant have been concerned with the testing and evaluation of electronic components, the development of reliable packaging systems, and the design of power supplies for satellite programs. While at M.I.T. he concentrated on improving his knowledge of solid-state technology and semiconductor electronics by attending subjects offered by the Departments of Metallurgy and Materials Science, Electrical Engineering and Physics.

The experience of the past three years has shown that the Practicing Engineer Advanced Study Program successfully meets the needs of the technical manager who wishes to understand those developments which bear directly on his problems, the engineer or industrial scientist who

seeks competence in depth at a technological frontier, and the professional who desires to strengthen and expand his technological base.

SHORT INTENSIVE PROGRAMS

During the summer of 1966 the Center offered two short, intensive programs, Experimental Solid-State Physics and Civil Engineering Computer Systems. In each case the participants represented a mixture of college faculty, industrial, and government employees.

The purpose of the five-week solid-state physics program was to provide an opportunity for participants to widen the scope of their experimental competence.

Although lectures were given, the main feature of the program was the experimental work in the laboratory. Fourteen projects were available and suggestions as to the nature of possible experiments were made to the participants. Each participant carried out eight experiments with a different partner for each experiment. The group consisted of nine faculty participants and ten participants from industry and government.

The purpose of the one-week Civil Engineering Computer Systems Conference was to give faculty members of other civil engineering departments and civil engineers from industrial organizations, consulting firms and government agencies an opportunity to gain experience in the latest M.I.T. developments in computer-based engineering systems.

The principal subject was the Integrated Civil Engineering System (ICES), a comprehensive programming system, implemented on the IBM System/360, which is now under intensive development within the Department of Civil Engineering. In addition to ICES, sessions also dealt with the use of time-sharing computers for on-line design, computer-controlled plotting and automatic drafting, the use of scope and light pen for input and output, and computer techniques for the teaching of civil engineering.

Although some lectures were given for the entire group (109 participants), most sessions involved groups of less than 20 participants. The group was varied, with regard both to technical areas of interest and computer competence. Consequently multiple, concurrent sessions were held. Each session dealt with a particular subject matter or objective.

ON-THE-JOB CONTINUED EDUCATION

The Practicing Engineer Advanced Study Program aims to provide an optimum educational experience for a selected set of "high-leverage" individuals. It has been and is likely to remain an opportunity afforded only to a small fraction of the professional population. A way to provide

continued education for a larger segment of professionals is to expand the scope of on-the-job continued education activities.

On-the-job continued education opportunities currently fall into the following categories:

ESSENTIALLY UNORGANIZED SELF-STUDY For a few, this is completely satisfactory; for the majority, it is ineffective. Motivation is often lacking, but even when it exists, the efforts of the individual are frustrated by other factors. Of these, the question of how to begin and the lack of self-study texts, auxiliary learning aids, and opportunities for tutorial help are the most serious.

IMMEDIATE NEED SUBJECTS ORGANIZED BY A COMPANY TO PROVIDE HOW TO IN A SPECIALIZED AREA The electronic firms, for example, have used this approach to introduce their vacuum people working with tubes to solid-state device terminal behavior. This kind of approach is apparently successful. It does not develop deep understanding, but it does impart new skills. It does not appear to be an activity in which M.I.T. should be involved.

REGULAR FUNDAMENTAL SUBJECTS DESIGNED TO DEVELOP UNDERSTANDING These are replicas of similar college subjects and use the classroom routine of the university. They perform a valuable service and their role will expand as remote television transmission of regular university classes develops. However, they do not service that large fraction of professionals whose need for continued education is most pressing. Instead, their clients are degree-oriented young men only a few years out of the university. They do not attract the seasoned professional. This is a result of the restrictions imposed by the standard classroom approach. The standard classroom is a lockstep operation imposing fixed meeting times, uniform pace, relatively uniform background requirements. In the university it is an acceptable compromise, although scarcely optimum. As an approach to continued education for mid-career professionals it has serious deficiencies. The spectrum of backgrounds, learning rates, objectives, and time available for study vary so widely at the working professional level that a flexible system is imperative. Because of local crises, temporary job reassignments, business trips, home and community responsibilities, a fixed schedule of classroom meetings excludes a large fraction of those who seek continued education.

THE MISSING SUBSYSTEM

The present system of continued education is not able to respond to the needs of a large fraction of working professionals. In order to do this,

a subsystem which bridges the standard classroom and unorganized self-study approaches is needed. The Center has been exploring this problem and believes that a solution resides in the following educational format:

1. The organization and preparation under the auspices of the Center of what would ultimately become a set of core subjects. At roughly first-year graduate level, their aim would be to provide the background and stimulus needed for more advanced study.
2. Each subject would be designed for use in the student's home environment on a guided self-study basis. This would provide flexibility of pace, background, study time. The central elements are: (a) a special text, produced by the Center and written for self-study; (b) a set of lecture-demonstrations keyed to the text and using audio tapes and sound motion pictures. These devices are designed to replace attendance at formal lectures or recitations and would be packaged for use by individual students at times convenient to them. They provide both an aural and visual learning experience. They would be produced by the Center in cooperation with WGBH and the Education Development Center; and (c) a tutor. Wherever possible the tutor is to be drawn from the organization employing the student. He would spend part of his time as an educator and the remainder in his normal professional activities. He has three primary roles. He helps the student over personal road blocks. He is the vehicle through which real situations, germane to the organization's activities, are introduced by means of problems, examples, and projects. He keeps track of the student's progress and urges him on.

The special subjects that we have been developing and teaching in the Center were selected with this purpose in mind. We now have enough experience with one subject — namely, Professor Davenport's Probability Theory and Random Processes, to undertake the development of a version for home study use. A first draft of the text is well along and we hope that in the fall of 1968 we shall be ready to test the format in cooperation with industry.

HAROLD S. MICKLEY

COMPUTATION CENTER

During 1966-67, the Computation Center continued to face a rapidly increasing volume of requests for computer services from all segments of the Institute community. In order to meet them and, simultaneously, to provide an appropriate research environment for faculty

and students, the equipment configuration and support staffs of the Center were expanded significantly.

In July, 1966, the Center installed an IBM System/360, Model 65, its first computer of the System/360 series. During the summer and fall of 1966, considerable effort was exerted by the Center's staff toward the development for this machine of an operating system which would be both efficient and effective in meeting the Institute's needs. As the Model 65 was one of the first computers of this type to be installed, progress was at first quite slow. By January, 1967, use of the Model 65 by other than Computation Center personnel had risen to about 30 hours per week and in June, 1967, this level of use stood at 60 hours per week.

Discussions held during the year led to the decision to install a System/360, Model 40 in July, 1967, for use with the Model 65 in an Attached Support Processor (ASP) configuration. It is expected that this configuration will improve significantly the efficiency of the System/360 installation.

Significant changes were also made during the year to the Compatible Time Sharing System (CTSS) which is operated on the IBM 7094 at the Center. These changes make available greatly increased storage space for user files and increase the efficiency with which the system is utilized. Use of CTSS grew significantly during the year and the system is now a valuable tool in a large number of instructional and research programs.

During the year, construction of the new building to house the Center's staff and the central computer facility was started. This building, currently scheduled for completion in early 1968, will provide some 40,000 net square feet of space for the computation Center. It is anticipated that an IBM System/360, Model 67 will be installed in this new building as soon as construction has been completed.

The reader is referred to the section on the Expanding Role of Computers of the Report of the School of Engineering by Deans Gordon S. Brown and William W. Seifert for a more extensive discussion of these issues.

PHILIP M. MORSE

PROJECT INTREX

Project INTREX (Information Transfer Experiments), a program directed toward the functional design of new library services, is continuing its activity under the direction of Professor Carl F. J. Overhage. The project has been established with the twofold objective of finding long-term solutions for the operational problems of large libraries and of developing competence in the emerging field of information transfer engineering.

Experiments are being prepared for tests involving library users in two areas recommended for first attention by the participants of the Planning Conference that inaugurated the project. These experiments — the augmented catalog experiment and the text access experiment — are being planned and developed in the Electronic Systems Laboratory (ESL) under its Director, Professor J. Francis Reintjes. As the experimental equipment is proven ready for use, it will be placed in the Engineering Library, the operating environment for the project.

The research program to create and test an augmented, machine-stored, remotely accessible catalog of library holdings is sponsored by The National Science Foundation. The purpose of this experiment is to learn from the users of the catalog their preferences for types and formats of catalog information and to discover the catalog elements that are required by a reader in order to reach a decision to seek or not to seek the cataloged document in the library. A successful experiment should give much helpful information to those who will attempt larger machine-stored catalogs and to those who seek a standard entry format of wide utility for library catalogs.

Preparation of this catalog is going forward in three groups within ESL — the catalog input group, the software group, and the hardware group.

This year the catalog input group has obtained the cooperation of a faculty and research team in the Center for Materials Science and Engineering, identified the literature of interest to them, developed the catalog entry elements and the catalog entry formats, written a cataloger's manual, implemented a work flow program for catalogers and typists, and cataloged 1,500 items of the initial 10,000 planned for this experiment.

The software group has designed the storage and retrieval system and completed and implemented many of the basic computer programs that will be needed for in-house trials of the augmented catalog. In addition to the routines for creating the magnetic record from the punched paper tape, this group has written and, in some cases, tested and debugged the programs and subroutines for creating and updating the inverted files that will be the main data storage units used for search and retrieval; they have also planned the inquiry and response dialogue patterns and given consideration to the problems of file and user supervision and of recording of user activity. This first statement of the programs is Phase 1 of a three-phase plan to permit early testing of system components by INTREX personnel before an evolution to enable all library users to exercise the system takes place. User aids and refinements of the system are to be added in Phases 2 and 3.

Specification of requirements and design criteria for the catalog console

have been the concern of the hardware group. They have developed a list of minimum requirements and of desired characteristics for this console and evaluated available commercial equipment with regard to these qualities. Since no available unit meets requirements, this group has proceeded to the detailed analysis of components that precede construction of a satisfactory device. Procurement of components—some of them entertainment-type television subassemblies — is now in progress while the machine logic for the console is being studied. This group has had heartening news for the project in terms of achieving a very suitable console within the \$5,000 target price for a manufactured copy of what will be constructed.

In the other experimental area, the text access group is attacking the problem of providing the library user with guaranteed access to the materials in the collections. The emphasis in this work, as in the augmented catalog program, is to learn from the user how the library and the information system can best meet his needs. Access to a displayed (or soft) copy is being studied along with access to a printed (or hard) copy. Economic considerations weigh heavily in each area with fast response time invariably seeming to be more expensive. Early analysis has led to the exclusion of computer storage of full text from the first experiments because of problems with input, cost of storage units, graphics, color, and search and retrieval. Instead, this group is planning tests of a microform store of documents. Under laboratory conditions, they have demonstrated transmission of black and white and color images from microfiche to a remote screen with acceptable clarity. The group has been working on the problems of image storage and control at the remote console and also the problems associated with the tradeoff between time and bandwidth in a campus-wide system of the type they have postulated and demonstrated. Unsolved problems of retrieving, positioning, and refiling the microfiche in the storage unit lie ahead. The activity in this area is funded by a grant from the Council on Library Resources.

Other experiments in the INTREX program await the larger funding that will make the effort possible. Meanwhile, under partial sponsorship by the U.S. Office of Education, the Engineering Library is about to undergo a thorough renovation to make it suitable for the dual roles of a traditional library of high quality and an experimental facility for Project INTREX. The architects have faced the challenge of providing this unusual coupling of activities and have provided solutions that show high promise of viability. As the planning documents reach the bidding stage, the library staff has been preparing to meet the special challenges of providing good service during the construction period of 15 to 18 months.

CARL F. J. OVERHAGE

SCHOOL OF HUMANITIES AND SOCIAL SCIENCE

The bulk of this report consists of the individual departmental accounts. The department heads have not been regimented to produce any uniformity of style or content; and this, I think, is as it should be, since styles and emphases do differ from one department to another in this wide-ranging and variegated School. The departmental reports are also the most natural means of conveying what has been going on, since the department is the most significant operating unit for our primary activities of education and research.

There are, however, some further perspectives that can be presented about the School as a whole, including some comparisons among its parts. With the aid of some tables (pp. 273-277), descriptive and interpretive comments will be offered as to both the growth of the School and certain relative shifts involving its constituent parts. This essentially quantitative exercise also leads into the more philosophical questions as to where we think we are going and why.

Our quantitative review will be organized according to the three levels of instruction offered by the School: (1) humanities and social science subjects available primarily as general education to all undergraduates; (2) the undergraduate majors in economics (Course XIV), political science (Course XVII), and humanities (Course XXI); and (3) the graduate programs, mostly for the Ph.D., in economics, linguistics, philosophy, political science, and psychology.

GENERAL EDUCATION

Although, as we shall see in the next section, there has been a substantial percentage increase in the numbers of our own undergraduate majors in

recent years, the majority of students enrolled in our undergraduate subjects are drawn from the Institute at large. That enrollment, including students registered in subjects in the visual arts (which is a field eligible for the junior and senior humanities requirement, though manned by faculty of the School of Architecture and Planning), is shown in Table I.

The total such registration for the fall and spring terms of 1966-67 was 11,438, representing an increase of 770 over the previous record figure of the year before. This means that the 3,857 undergraduates enrolled at M.I.T. last fall took about three such term subjects per year on the average. Even allowing for the fact that our own majors, representing almost ten per cent of all undergraduate majors, took perhaps six such subjects per year on the average, it is clear that undergraduates throughout the Institute are taking appreciably more subjects in our area than the two per year that are required.

The trends in these figures in recent years appear from the following tabulation of (1) the registrations in humanities, language, and social science undergraduate subjects for both terms, (2) total undergraduate enrollment at the Institute in the fall, and (3) the ratio showing the average number of such subjects taken per year per undergraduate:

	1963-64	1964-65	1965-66	1966-67
Undergraduate registrations	9,524	10,495	10,668	11,438
Total undergraduates	3,612	3,640	3,755	3,857
Ratio of (1) to (2)	2.64	2.88	2.84	2.97

For the two years prior to those shown, our undergraduate registrations had an almost exactly level trend; so the increase since then, mainly in two sizable spurts, are all the more interesting. It is clear, too, that over this four-year period our registrations have been growing more rapidly (6.4 per cent per year) than the undergraduate body (2.2 per cent per year).

Within the past few years, we have been departing more and more from the pattern of a common core of humanities subjects in the freshman and sophomore years. As a reflection of this, Table I shows the comparative registrations in the disciplinary options for the sophomore year. One term of either literature or philosophy is required, and so is one term of either history or social science. It may or may not be significant that the former choice is more popular in the fall and the latter in the spring. A comparable set of alternatives has been introduced experimentally in the freshman year; but that breakdown is not shown because students could not be given a free choice at the outset.

Our junior and senior program, which has long provided students with a wide choice among ten fields of humanities and social science, has been

further expanded this year to include a special set of interdisciplinary subjects. These are offered by the Department of Humanities, as a part of a program of curriculum enrichment supported by the Carnegie Corporation. The registrations in all of the junior and senior electives appear in Table I; and their percentage distribution is shown in Table II, not only for the current year but for five preceding years as well.

The four social science fields (economics, psychology, political science, and labor relations) attract slightly more juniors and seniors than the other seven fields (the five offered by the Department of Humanities plus foreign literature and visual arts). The social sciences reached a peak of 53.8 per cent of these choices four years ago; and since then that percentage has fallen off to 51.6.

Economics and psychology have vied for first place in the recent past. It was a dramatic shift in 1963-64 when psychology spurted into first place, a position that economics had held by a wide margin for many years. Part of the explanation for the decline of economics at that time was that its special advantage of being required by some departments was reduced by some departmental rule changes. At the same time, Professor Hans-Lukas Teuber's popular lectures in introductory psychology and the further enrichment of the undergraduate curriculum as a by-product of the newly established Ph.D. program in psychology contributed to increased registrations in that field. After two years in first place, psychology has again moved down to second in the past two years.

Among the other fields, there have been notable increases of registration over the past four years in history and visual arts. Since history also has the highest sophomore registration, this represents a much heavier teaching load in that field than in the past.

Where there are increases of relative share, there must also be decreases; and the sharpest have been in philosophy and foreign literature. In contrast to our experience in psychology, the introduction of a Ph.D. program in philosophy has been followed by a decrease in junior-senior registrations; but this must also be looked at in the light of the newly available study of philosophy in the sophomore year.

The decline in foreign literature enrollment to less than one-third of what it was six years ago is more alarming, especially because there is a similarly unfavorable trend in the study of foreign languages. The latter registrations, shown at the bottom of Table I, have fallen off in each of the past four years and have suffered a cumulative decline of almost 25 per cent over that interval. This is partially offset — and at least partially explained — by an increase in the numbers of units per subject in that area; and the trend has also been affected, as Professor William F. Bottiglia comments, by the new freshman and sophomore scheduling pat-

terns. Next year we hope to strengthen and broaden both our modern language instruction and our foreign literature offerings. We shall also be moving further away from the purist ideal of the past to limit literature subjects in the Department of Modern Languages to those in the original language. There will be some branching out into German and Russian literature subjects to be conducted at least primarily in English.

Tables IV and V show the extent to which undergraduates majoring in different schools have different tastes as to their junior-senior subjects in the humanities and social sciences. The single biggest relative concentration is of architects in the visual arts, despite the fact that certain subjects in that field, being professional electives for architects, cannot be counted by them as a part of their humanities requirements. The broader generalizations are that engineers incline toward the social sciences almost as strongly as the scientists incline toward the humanities, while the management and humanities students are evenly divided between those two broad areas.

These relationships have not been particularly stable. Since 1963-64, for example, the architects have sharply increased their preference for the visual arts; engineers have reduced somewhat their preference for the social sciences; scientists have increased somewhat their preference for the humanities; management students no longer have a strong preference for the social sciences; and humanities students no longer have a strong preference for other humanities.

Lest this discussion of students' choices be given too sharply competitive an interpretation, let it be said that the numbers enrolled — while easiest to measure — are by no means the only, nor the most important, criterion of whether the teaching is strong or weak in a given field. If enrollments fall because intellectual demands on the student are being raised from undesirably low previous levels, that is usually all to the good. Conversely, if enrollments rise because reading assignments are softened and high grades are more cheaply bestowed, that is not what we wish to encourage. Fortunately, on the other hand, there are abundant instances in many fields where the challenge of solid material excellently taught meets with favorable student response.

UNDERGRADUATE MAJORS

This is the last year that we shall tabulate the numbers of undergraduate and graduate majors in the traditional form of Table III. On the undergraduate side, the table goes back to the founding of Course XXI, at which time Course XIV had already been awarding undergraduate degrees for seven years. Through 1964-65, Course XIV maintained its original character as a double major in either economics or political sci-

ence and a field of science or engineering. After that date, not only did the Department of Political Science become a separate entity as Course XVII, but its undergraduate major and that in economics became single majors — with a marked reduction in the amount of study required in science or engineering in the junior and senior years, but with no reduction in the amount of such study that the individual student may elect. During the present year, Course XXI has followed that example to some extent. Without setting aside its traditional double majors, it has added the option of a more whole-hearted major in a field of humanities, with greatly reduced requirements in science or engineering.

Without doubt, the new single majors in economics and political science have proved to be more popular than the programs they replaced. Though enrollments had been on an upward trend for four years, more than doubling from the low point of 35 in 1960-61 to 78 in 1964-65, they have almost doubled again in the past two years. As for the composition of the combined enrollment in social science, this has stayed fairly close to half economics and half political science in recent years. As Professor Teuber comments, we hope to be able to add an undergraduate major in psychology in the not too distant future; but this will require expansions of both staff and laboratory facilities.

Although social science majors outnumber those in humanities this year for the first time since the inauguration of Course XXI, the humanities majors are also more numerous than ever before.

For the School as a whole, the rate of increase of undergraduate majors has been especially sharp over the past four years. From 1963-64 to the present, the average annual rate of increase has been 19.4 per cent. Expressing the numbers of our majors relative to the total numbers of undergraduates who have selected majors, we find that the majors in this School have increased from 6.1 per cent in 1963-64 to 9.7 per cent this year.

That phenomenon is all the more significant in view of the fact that only the merest handful of entering freshmen come here with the intention of majoring in a field of humanities or social science. To some extent, it should be frankly acknowledged, our majors include students who have become disillusioned with their initial ambitions in science or engineering. Given the unusually high basic intellectual ability of any student admitted to the Institute, however, we are confident that even our "rescue" operations are, in by far the largest part, an eminently worthy service. Beyond that, of course, there are also gratifying numbers of students who find their way into our departments with more positive motivation and with strong academic credentials in mathematics and science as well as in at least one of our own fields. Since students with

scientific predisposition and aptitude have something special to contribute to the humanities and the social sciences, it is all the more constructive to be able to offer them the widened choice of majors that we have developed.

There is also a growing opinion in many quarters that it is in the long-range interests of M.I.T. to build the role of the humanities and social sciences. We have long since established a consensus that technical education alone is not enough, and we have also come a long way toward establishing our own disciplines as of coordinate importance and excellence along with the scientific and engineering fields, rather than as underprivileged, subsidiary activities. Yet it can also be argued persuasively that we can go a good deal further toward an even greater degree of balance among the, not two, but n cultures. Such a development promises not only greater contributions to the disciplines to be expanded, but also an enrichment of the educational and research opportunities in the technical fields as well.

GRADUATE PROGRAMS

The righthand side of Table III summarizes the expansion of our enrollments of graduate students, almost all of whom are candidates for the Ph.D. At the beginning of the period covered by the table, our only graduate program was in economics. We then added Ph.D. programs in political science in 1958, in linguistics in 1961, psychology in 1962, and philosophy in 1964.

The doubling and quadrupling of graduate students since 1955-56 reflects both the contributions of the added fields and also the growth of the oldest and largest one, economics. Thus economics, having expanded from 52 graduate students to 117, still represents about two-fifths of all the students in the School's five graduate programs. Since the social sciences are now organized in three separate departments, instead of the one that existed as recently as three years ago, future versions of Table III will show that division more explicitly. To show the historical growth, however, we present Table III in its traditional form for the last time. The graduate enrollment in the Department of Humanities is now exclusively in philosophy, just as the linguistics enrollment accounts for all in the Department of Modern Languages and Linguistics.

Allen M. Cartter's study for the American Council on Education, *An Assessment of Quality in Graduate Education*, which was published in 1966 and based on a questionnaire solicitation in 1964, provides the best objective evidence as to the distinction of those of our Ph.D. programs that were operating early enough to be included in the survey. Cartter's respondents, a sample of scholars in each discipline, were asked to rate departments as to "the quality of graduate faculty" and "the effective-

ness of the doctoral program." Answers to the first question of "distinguished" were worth 5 points, "strong" 4 points, "good" 3 points, and so on; and answers to the second question of "extremely attractive" were worth 3 points, "attractive" 2 points, and so on.

In economics, Harvard and M.I.T. each enjoyed a first place on one question and second place on the other. In quality of faculty, Harvard's 4.82 nosed out our 4.80, with the third-place department a fair distance behind at 4.57. In effectiveness of graduate program, however, M.I.T. was first with 2.70, while Harvard was second with 2.60. As to the absolute scores, the economics faculty rating of 4.80 was the highest single one at M.I.T., being closely approached only by electrical engineering's 4.78; and the economics graduate program rating of 2.70 was also the highest at M.I.T., where the second highest was chemistry's 2.50.

The fine print also revealed some further comfort to M.I.T. economics. Thus, when the respondents' ratings of their own Ph.D. and employing institutions were removed, M.I.T. moved slightly ahead of Harvard even on the faculty rating. A supplementary polling of a small "select panel" also gave slightly different results. In the faculty rating, M.I.T. moved ahead of Harvard but was also tied by Yale for first place; and as to the program rating, Yale moved into first place while M.I.T. fell to second and Harvard to fourth. With 173 economics respondents in the basic survey and 12 in the select panel, we are obviously dealing with small differences. As Cartter once said to me, M.I.T. economics might have done even better if one of our distinguished colleagues had seen fit to answer his questionnaire.

Since our graduate program in political science was still in a formative stage when Cartter polled 165 scholars in that field, and since our department differs in several important respects from the more traditional ones, its ratings were creditable. As to quality of faculty, M.I.T. political science was tied for seventh place, with a rating of 3.77; and it was also seventh as to program effectiveness, with a rating of 2.07. The select panel of 12, however, moved the faculty rating up to sixth and the program rating up to a tie for second with Harvard, behind Yale.

The small field of linguistics was not included in Cartter's original survey, but a select panel of 13 was polled later. In view of the newness of the M.I.T. program, its showing was remarkable. It was rated in first place as to quality of faculty and tied for second, with Yale and behind Cornell, as to effectiveness of graduate program. Since only two doctorates had been awarded in linguistics at M.I.T. by 1964, the effectiveness of the program would undoubtedly gain even more support today, when an appreciably larger number of our Ph.D. alumni are out in the world.

A critical question that we face over the near and longer-term future is how far and how fast we should continue to extend graduate work in this School. The doctoral programs that we already have are in the fields where creative activity takes the form of research, often as a team effort, rather than just individual scholarship; and it is in these fields that graduate programs are the more important, if not absolutely necessary to attract a faculty of best quality. Furthermore, we are not disposed to start graduate programs just on general principles. Rather, only when we see a chance to make some kind of constructive new departure in a field, preferably complementary to other activities already established at the Institute, do we generate enthusiasm about a new field of graduate work.

There are several fields where these conditions may be fulfilled. Literature, with a strong relationship to linguistics, is one. The history of science and technology is another; and there are further possibilities in still other aspects of history. Music may also be an eligible field, especially in its newly unfolding relationships to electronics and the computer. Whether these gleams in our collective eye will lead to more tangible actualities, we shall have to wait and see.

HONORS

It is fitting to close this portion of the annual report with a bow to those of our distinguished faculty members who have been singled out for unusual honors. A somewhat selective list is given, and still other activities are commented upon in the various departmental reports. I content myself with citing only one rather special set of simultaneous honors. When the University of Chicago celebrated its 75th anniversary last May, four honorary doctorates were awarded to members of the M.I.T. faculty; and, of these, three were members of our School. Professor Noam A. Chomsky, our leading young linguist, was one; and the other two were economists, Professors Franco Modigliani and Robert M. Solow — the former of whom we also share with the Sloan School of Management. Since Professor Paul A. Samuelson had previously been honored by the same university, the cumulative total of three such doctorates from Chicago probably sets some sort of record for economics departments.

ROBERT L. BISHOP

SCHOOL OF HUMANITIES AND SOCIAL SCIENCE

Table I Registration in Humanities, Languages, and Social Science Undergraduate Subjects 1966-1967

	Fall	Spring
Freshman program	948 ¹	959 ¹
Sophomore program		
Literature	427 ²	215 ²
Philosophy	280	99
History	298 ³	354 ³
Social Science	95	228
History	240	366
Philosophy	227	235
Literature	345	395
Music	194	288
Interdisciplinary	188	155
Total humanities electives	1,194	1,439
Economics	641 ⁴	818 ⁴
Political science	282	358
Labor relations	59	73
Psychology	523	679
Total social science electives	1,505	1,928
Foreign literature ⁵	70 ⁶	74 ⁶
Visual arts ⁷	190	255
Thesis		
Economics	19	16
Political science	11	21
Course XXI	45	30
English composition	11	13
Senior Seminar (XXI)	45	—
Science writing	7	6
Elementary, intermediate, and advanced modern languages	307	349
Grand Total	5,452	5,986

¹ Includes registration in special humanities subjects in French (28 in the fall, 23 in the spring) and in German (18 in the spring).

² Includes registration in comparable subjects in French (21 in the spring) and in German (15 in the fall).

³ Includes registration in comparable subjects in French (25 in the fall) and in German (nine in the spring).

⁴ Includes registration in Economic Principles I (14.01) (fall, 292; and spring, 374).

⁵ Exclusive of 656 registrants in elementary, intermediate, and advanced languages.

⁶ Includes undergraduates in graduate linguistic subjects.

⁷ Taught by faculty of the School of Architecture and Planning.

Table II Percentage Distribution of Junior and Senior Electives in Humanities, Languages, and Social Science by Fields, 1961-67.*

	1966-67	1965-66	1964-65	1963-64	1962-63	1961-62
Economics	21.9	22.8	19.9	19.7	24.8	28.0
Psychology	18.1	16.6	20.2	21.4	14.8	11.4
Literature	11.1	12.7	12.5	12.5	14.4	13.3
Political science	9.6	9.2	9.3	10.4	10.5	8.4
History	9.1	10.2	8.5	5.6	5.9	5.5
Music	7.2	7.7	8.9	8.2	7.8	7.8
Philosophy	6.9	9.3	9.1	13.2	12.0	12.7
Visual arts ¹	6.7	6.4	4.8	3.1	2.8	3.0
Interdisciplinary subjects	5.2					
Labor relations	2.0	1.9	2.1	2.3	3.0	3.2
Foreign literature ²	1.9	2.7	4.3	3.5	4.0	6.7

* Omitting registrations in the underclass required core subjects, 21.01, 21.02 and 21.03T or 21.031 or 21.04T, and 21.05T or 21.06T or 17.01T, and the miscellaneous registrations following Visual Arts in Table I.

¹ Taught by faculty of the School of Architecture and Planning.

² Exclusive of elementary, intermediate and advanced language subjects; includes undergraduates in graduate linguistics subjects.

Table III Majors in the School of Humanities and Social Science.*

	Undergraduates				Graduates			Grand Total
	Social science	Humanities	Total	Social science	Humanities	Modern languages	Total	
1955-56 ¹	40	19	59	52	—	—	52	111
1956-57	38	32	70	69	—	—	69	139
1957-58	41	67	108	74	1 ²	—	75	183
1958-59 ²	46	75	121	81	1 ²	—	82	203
1959-60	38	64	102	105	2 ³	—	107	209
1960-61	35	93	128	114	—	—	114	242
1961-62 ⁴	55	88	143	129	—	7	136	279
1962-63 ⁵	65	85	150	145	—	22	167	317
1963-64	71	87	158	165	4	31	200	358
1964-65 ⁶	78	109	187	190	15	36	241	428
1965-66 ⁷	110	114	224	197	24	34	255	479
1966-67 ⁸	149	121	270	222	29	42	293	563

* As registered in the second term of academic year 1955-56 to 1966-67 (omitting freshmen)

¹ Course XXI initiated.

² Graduate degree in political science initiated.

³ Special program in teacher training.

⁴ Graduate degree in linguistics initiated.

⁵ Graduate degree in psychology initiated.

⁶ Graduate degree in philosophy initiated, with small preregistration in 1963-64.

⁷ Social science undergraduates: 50 in economics and 60 in political science. Social science graduates: 111 in economics, 63 in political science, and 23 in psychology.

⁸ Social science undergraduates: 76 in economics and 73 in political science. Social science graduates: 117 in economics, 79 in political science, and 26 in psychology.

Table IV Distribution of Registrants in Undergraduate Electives by Schools and Fields (by numbers), 1966-67.

School	Subtotal in the										Grand Total		
	Economics	Labor Relations	Political Science	Psychology	Social Sciences	History	Literature	Music	Philosophy	Interdisciplinary Subjects		Visual Arts	Foreign Literature	Subtotal in the Humanities
Architecture	29	0	5	10	44	6	8	2	3	2	147	2	170
Engineering	609	90	181	391	1,271	214	181	173	71	86	93	28	846
Humanities	257	24	273	156	710	145	240	33	131	77	55	23	704
Management	19	8	57	63	147	38	27	14	15	26	22	5	147
Science	268	7	99	313	687	170	266	169	223	136	98	45	1,107
Unclassified ¹	277	3	25	269	574	33	18	91	19	16	30	22	229
Totals	1,459	132	640	1,202	3,433	606	740	482	462	343	445	125	3,203

¹ This includes all students who have not yet made Course designations, plus a handful of unclassified graduate students.

DEPARTMENT OF ECONOMICS

Table V Relative Distribution of Registrants in Undergraduate Electives by Broad Fields and by Schools insofar as They Can Be Identified, 1966-67.

School-Field	Visual Arts	Foreign Literature and Linguistics	Other Humanities	Social Sciences
Architecture	.69	.01	.10	.21
Engineering	.04	.01	.34	.60
Humanities	.04	.02	.44	.50
Management	.07	.02	.41	.50
Science	.05	.03	.54	.38

ROBERT L. BISHOP

DEPARTMENT OF ECONOMICS

UNDERGRADUATE PROGRAM

The number of registrants in the undergraduate program increased again this year over last, bringing us to the largest number that we have ever had. The modest but persistent expansion in the number of economics majors necessitated a reconsideration of the relationship between the subjects offered for the humanities program and those offered to economics majors. Since most of the non-technical undergraduate subjects have been included in the humanities program, their prerequisites necessarily have been limited to the introductory economics subjects — 14.01 and 14.02. The result has been that the economics background of the students in these subjects has varied significantly. While the present number of economics majors appears to make possible an obvious solution of special sections for these subjects, the scheduling problem makes this infeasible. A committee has been at work this year under the chairmanship of Assistant Professor Duncan K. Foley to reexamine these offerings, to make recommendations for a more satisfactory cumulative program for majors, and yet to provide adequate breadth and depth in the humanities program. They will be reporting shortly, and revisions of subject offerings will undoubtedly be called for.

Further steps were taken this year to improve student-faculty relations. An Undergraduate Economics Association has been initiated. It has provided a structure for feedback on teaching and on changes in content of subjects discussed above. Professor Everett E. Hagen is in charge of the undergraduate major program for this coming year, to advise Faculty Counselors and to work with the Undergraduate Economics Association.

GRADUATE PROGRAM

Maintaining a position of eminence is difficult in these days of sharp competition — both for staff and students. It was gratifying to be placed

at the top with Harvard in quality of faculty and in quality of graduate instruction by the American Council of Education in its recent rating of graduate schools. But we have felt an aggressive response by other institutions in the financial support offered to graduate students and in the retention and expansion of faculty. We can take pride in the permanence of our faculty in the face of highly attractive offers from outside, but we must be on guard to see that academic conditions here are at least the equal to those in any other place.

Our graduate student body continues to be first-rate. We do not envisage, at the present time, the need or desirability of major expansion. In response to moves by other major institutions, we have increased our commitment to long-run support for entering students. We face one important change in the termination next year of Woodrow Wilson Fellowships, of which we have always had a substantial number. These have been converted to substantial institutional grants by the Ford Foundation for, generally, four-year support of graduate students. The fact that M.I.T. as an institution was not included among the ten to receive these grants will undoubtedly weaken our attraction of entering students unless similar funding can be secured.

An elaborate appraisal of subject matter, teaching, and thesis supervision was undertaken this year with the active participation of the Graduate Economics Association. An almost complete response from the present graduate student body was achieved. Analysis and tabulation of their replies is now underway, and will provide a fruitful beginning for revisions of the graduate program.

PERSONNEL CHANGES

Visiting us again this year were Professors Michael M. Postan from Cambridge University and Michael Bruno of Hebrew University. Our new visitors were Professors Kenneth J. Arrow of Stanford University, Alan A. Walters of Birmingham University, and Assistant Professor John H. Williamson of York University.

Last year I reported a number of new regular appointments, primarily at the assistant professor level, that were to begin this year. In addition, Professor Jagdish N. Bhagwati will take up residence beginning in 1968-69. He comes from Delhi University and will help to make up the loss we sustain in international economics and economic development through the retirement of Professor Paul N. Rosenstein-Rodan. Professor Rodan has had a distinguished career as an academician, as a participant in and director of research, and as an economic advisor to many governments. He served for several years as one of the "nine wise men" of the Alliance for Progress. Happily, his relationship to the De-

partment and the Center for International Studies will continue, albeit on a part-time basis. We will also be losing Assistant Professors Gordon R. Sparks and Joseph E. Stiglitz, one to the Central Bank of Canada and Queen's University, the other to Yale University.

Professor Franklin M. Fisher was on leave this year, primarily in England, under a Ford Foundation Faculty Research Fellowship; and Professor Evsey D. Domar spent the year at RAND Corporation on research on foreign aid.

RESEARCH AND OTHER ACTIVITIES

The faculty continues to be deeply involved in research and public service, and only a highly selective coverage of these activities can be given. A major effort is going forward in the study of capital and economic growth — theory, policy, and quantitative estimation — both for developed and underdeveloped economies. Participants in this research were Professors Robert M. Solow, Charles P. Kindleberger, and Richard S. Eckaus, Assistant Professors Karl Shell, Pranab Bardhan, C. Duncan MacRae, Miguel Sidrauski, and Stiglitz. A substantial number of papers on this general subject were published: a monograph by Professor Kindleberger, *Europe's Postwar Growth: the Role of the Labor Supply*; and a set of essays by staff members and graduate students under the editorship of Professor Shell, *Essays on the Theory of Optimum Economic Growth*. Professor Eckaus' study, *Planning for Growth*, will be published this year; and he now plans to extend this model, used for India, to Chile.

Professor Max F. Millikan edited *National Economic Planning*, a volume resulting from a conference of the Universities-National Bureau Committee on Economic Research, in which several members of the staff took part. Professor Charles A. Myers was editor of *The Impact of Computers on Management*, a subject to which he has devoted a major portion of his time over the past year. Professor Jerome Rothenberg continued research in urban economics; and his monograph, *Economic Evaluation of Urban Renewal*, is in press.

Professor Franco Modigliani was on leave this year to conduct research sponsored by the Board of Governors of the Federal Reserve System on the linkage between monetary policy and economic activity. Assistant Professor Sparks has been associated with this project. Professor Edwin Kuh is directing a research effort into the time-sharing use of the computer in econometrics and the development of a data bank. Associate Professor Peter A. Diamond and Assistant Professor Foley have received a National Science Foundation grant for studies in the pure theory of public finance.

Professor Paul A. Samuelson, while extending his list of important research papers in economic theory, has brought out the seventh edition of his historic textbook, *Economics*, a work now translated into 15 languages.

Participants in the administration of professional societies have been Professor Hagen as President of the Association for Comparative Economics, Professors Kindleberger as Vice President and Modigliani and Solow as members of the Executive Committee of the American Economic Association, Professor Samuelson as continuing President of the International Economic Association, and Professor Millikan as President of the World Peace Foundation.

It would be a lengthy list that encompassed all of the government agencies and Congressional committees that have benefited from the advice of department members. They have made significant contributions at the state, federal, and international level with a not inconsiderable expenditure of time.

Richly deserved honors came to Professor Kindleberger in the award of the Docteur honoris causa by the University of Paris, and to Professors Modigliani and Solow of the LL.D. from the University of Chicago.

It is with profound sorrow that the death of Professor Emeritus Ralph E. Freeman is reported. He was long-time Head of the Department — from 1933 until his retirement 25 years later — and it was under his leadership that it grew from a service department to one with a graduate program and faculty of world-wide reputation. As a wise counselor, selfless administrator, and warm friend, he leaves us with a sense of deep personal loss.

E. CARY BROWN

DEPARTMENT OF HUMANITIES

After extended debate in 1965-66, the Department decided to abandon the long-standing practice of offering a single or common subject to all freshmen in the core curriculum. The addition of two new subjects in the fall of 1967 to the sequence introduced by Professor Harald Reiche in 1960 reflects several important considerations. One is the diversity of interests in the Humanities faculty itself; this lies unused so long as a single subject prevails. Another is the increasing diversity of taste and aptitude in any given freshman class, which can generate its own discontent when denied a measure of choice. A third is a growing sense that the core curriculum itself is excessively rigid, an opinion that has often been expressed by highly qualified applicants who have declined acceptance of admission to M.I.T. in the past.

The two new subjects for freshmen were developed by Professors Albert R. Gurney and Hubert L. Dreyfus in one case and by Professors Arthur R. Steinberg and William I. Thompson in the other. Although revisions have been made in each subject, both enjoyed a career of remarkable success with the Class of 1970. We suspect that the core curriculum in Humanities ought to be regarded not as a structure that is periodically rebuilt, but as a process that appropriates new energies from one year to the next.

The task of developing a curriculum for undergraduates in science and engineering was considered on a wider scale at a conference sponsored by the Department in August, 1966, supported by its grant from the Carnegie Corporation. Representatives from 11 institutions (California Institute of Technology, Carnegie Institute of Technology, Case Institute of Technology, Drexel Institute of Technology, Harvey Mudd College, Illinois Institute of Technology, M.I.T., Newark College of Engineering, Polytechnic Institute of Brooklyn, Rensselaer Polytechnic Institute, and Stevens Institute of Technology) met for a week at Endicott House for a critical review of their common problems, drawing these into the perspective of colleagues in engineering and science. Professors Gordon S. Brown, William W. Seifert, Jerrold R. Zacharias and Arnold B. Arons (Amherst) were guest participants in the conference, whose elaborate program was largely the achievement of Professor E. Neal Hartley. A second national meeting was held in the early summer of 1967, with the agenda taken from reports of recent studies of science and engineering students at M.I.T., and from comprehensive research on the contemporary undergraduate developed by Dr. Martin Trow at Berkeley.

Carnegie funds also made it possible for the Department to sponsor a program at Kresge Auditorium during the winter season of last year; it included a lecture-concert in October by Whitney Balliett of *The New Yorker* with Red Allen and Pee Wee Russell; a special performance of *Marat/Sade* by the Theatre Company of Boston; a concert featuring the music of Elliott Carter performed by the Dorian Wind Quartet and the Lenox String Quartet; and a series of dramatic readings in January by Sir John Gielgud and Miss Irene Worth.

At a meeting with the Visiting Committee in May, the Department offered a survey of current efforts in the core curriculum, together with reports by Professors Louis Kampf, Bruce Mazlish, James F. Thomson, Klaus Liepmann and Roy Lamson of their several programs. These reports are elaborated below.

Confronting the Department as a whole are two problems that appear recurrently in any consideration of the immediate future. One is the need to widen the base of the departmental budget through the increase of

non-categorical funds. We intend no ingratitude for the gains we have enjoyed from grants provided by the Carnegie Corporation over the past ten years, because without such support, efforts of the kind reported above could scarcely have been attempted. The Old Dominion Grant, moreover, has provided a unique resource in the career of younger colleagues in the Department. And the recent Ford Grant that Professor Mazlish treats below has offered wholly new prospects for the teaching of history at M.I.T. At the same time, however, a department responsible for the education of over 3,000 students each semester requires funds that are not provided either in the general budget or from foundation grants. A faculty of 80 — representing a wide variety of disciplines, teaching and research — faces many of the same contingencies that confront a small college in areas of curricular experimentation, the support of faculty research, sponsorship of special lectures and colloquia, support of publication, contributions to extracurricular projects and a whole range of initiatives that can seldom be planned or anticipated for the enrichment of a department's contribution to the life of undergraduates and the Institute as a whole.

The second problem of common concern is an acute shortage of office space, brought on by the growth of this faculty in recent years; and a long-standing shortage of classrooms appropriate to the teaching of humanities. The great majority of our subjects are conducted through the discussion of texts in classes of 30 students or less. But virtually all the classrooms assigned to us were designed for lectures and recitation, so that students are seated to face the professor rather than one another. The increasing use of films, slides and audio material in humanities subjects adds to the pressing need for 20 new classrooms. We should like to think that this space, together with 85 offices, might be combined in a new building complex, specifically designed for humanities and the arts. The urgencies of a more experimental curriculum, adequate classrooms and discretionary funds are closely joined together.

PERSONNEL

Professor Howard R. Bartlett retired in June, 1967, after a career of 38 years in the Department. Of these he spent 25 as its Head in a period that spanned the adversities of the depression, the pressures of wartime, and the problems of post-war expansion in a department whose structure was radically changing. One can scarcely imagine a more difficult time in the history of the Institute in which to hold together and to build a department of liberal arts in a university of engineering and science. But just as Howard Bartlett could not choose the time in which he presided over this Department, so too could he not change his style as a colleague and

chairman. His integrity, loyalty and his fairness have dignified and added decency to every task he undertook. We are pleased to know that he will return to teach during the fall term.

Giorgio Diaz de Santillana also became Professor Emeritus in June, retiring from a distinguished career in the history and philosophy of science which began when he received his doctorate at the University of Milan in 1925. He has taught and lectured at the University of Milan, the Sorbonne, Brussels, Harvard, the University of Florence, the University of London, Frankfurt and Venice. A colloquium in his honor, entitled "Unpopular Views and Unfair Criticisms on the History of Science," was held on May 2. The participants included Jerome B. Wiesner, Professor Noam A. Chomsky, I. Bernard Cohen (Harvard), Robert Cohen (Boston University), Professor Jerome Y. Lettvin, Everett Mendelson (Harvard), and Professors Philip Morrison, and Cyril Stanley Smith. Goliard, *umanista*, historian and philosopher, Giorgio de Santillana now goes on to serve as director of a new international center for the history of ideas, sponsored by UNESCO and the Italian government in Venice. As Professor Emeritus, he will return to M.I.T. to teach part-time.

Professor Kampf succeeded Professor William C. Greene as chairman of the Literature Section in February, 1967. During the last year he published an article in *College English* on "The Permanence of Modernism," and contributed reviews to *Confrontations*, *History and Theory*, and *College English*. His book, *On Modernism: The Prospect for Literature and Freedom* was published by the M.I.T. Press in May, 1967. Professor Kampf also lectured at Wesleyan and the University of Buffalo, and served as a member of the Woodrow Wilson Fellowship Selection Committee.

Professor Lamson, Director of Course XXI, served on the Committee on Educational Policy, the Committee on Academic Performance, and the Premedical Advisory Committee at M.I.T. He was also chairman of the M.I.T. Advisory Committee to Oklahoma City University and chairman of the Regional Marshall Scholarship Committee.

Professor Liepmann conducted the M.I.T. Choral Society in performances of the Verdi *Requiem* and *The Seasons* by Haydn, with 48 members of the Boston Symphony Orchestra at each performance. He conducted the M.I.T. Glee Club in performances of Purcell's *King Arthur*, Milhaud's *Les Choéphores*, and Hindemith's *Apparebit Repentina Dies*. In December Professor Liepmann spoke at a panel discussion on "Cross-fertilization of Controversy and College on the American Campus" at the Ninth Annual Meeting of the College Music Society in New Orleans.

Professor Mazlish was elected a Fellow of the American Academy of

Arts and Sciences and received a Social Science Research Council Faculty Fellowship for 1967-1968. He was also a member of the Steering Committee of the Group for the Study of Psycho-Historical Process; consulting editor for *History and Theory*; a member of the working party on "Values and Rights" of the American Academy's commission on the year 2000; and delivered a paper at the Conference on the Future sponsored by the Department of Architecture at M.I.T.

Professor J. F. Thomson was a panelist and critic at a December meeting of the American Philosophical Association in Philadelphia and presented another paper at Cornell University in May. He has also been invited by the Addison-Wesley Publishing Company to edit a series of analytical texts in philosophy. He represented the Department of Humanities on the Graduate School Policy Committee for the second year.

RICHARD M. DOUGLAS

COURSE XXI

Course XXI began the fall term with the addition of a new curriculum known as XXI-B, Program 2. Based on the Institute Requirements in science, humanities, and social sciences common to the freshman and sophomore years, the curriculum offers in the junior and senior years a major or concentration in history, literature, philosophy or music, providing for undergraduate study in the humanities on the same basis as in the programs in management and in architecture. It is similar to current undergraduate programs in economics and in political science. The curriculum differs from XXI-A and XXI-B, Program 1 in requiring greater concentration in breadth and depth in a single field of humanities chosen by the student and further study in a second field of humanities, social science, visual arts, modern foreign literatures, or linguistics. With the intellectual groundwork of the Institute Requirements in science, this new curriculum should provide students an education rigorous and yet flexible and innovative, general but with the opportunity for meeting the requirements and standards of graduate study in the humanities. Program 2, open this year to the sophomore class, has enrolled ten students.

By adding this new curriculum, Course XXI now consists of a double major in humanities and engineering, and in humanities and science, and a concentration in a selected discipline in humanities, with supporting study in further humanities and social science disciplines, in visual arts, and in linguistics.

This year Course XXI enrolled 117 students in three classes (50 seniors, 38 juniors, 29 sophomores). The total is the same as in 1965-66. The choices of humanities disciplines were literature 66, philosophy 22,

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history 19, and music 2. Eight sophomores were undecided about their fields. As in the last four years, the life sciences have led the science concentration with 26 students, many of whom plan to go on in medicine. Nineteen chose mathematics; 17, electrical engineering; nine elected physics, 11 less than last year. The psychology-humanities program increased from ten to 21 students.

The Class of '67 fell just a tenth of a point under last year's class, gaining a cumulative average of 3.6, with a strong upper quarter. Of the 27 students who have announced their plans for next year, about 75 per cent will pursue graduate study:

Medicine	6	Sociology	1
Philosophy	3	Dentistry	1
Comparative Literature	2	History	1
Education	2	Social Psychology	1
Linguistics	2	Secondary School Teaching	3
Theology	1	Armed Forces	2
Far Eastern Studies	1	Industry	1

Of the students who will teach, one, who also has a second S.B. degree in physics, is our second holder of a Teaching Fellowship at Phillips Andover Academy; another will teach English in India. Graduate schools chosen include Brown, Cincinnati, Columbia, Gordon Divinity School, Harvard, Heidelberg, M.I.T., New School for Social Research, New York University, Stanford, U.C.L.A., University of Pennsylvania, and Wesleyan.

The Senior Seminar, the most experimental yet attempted, dealt with time and its relation to science, history, the arts, and philosophy. Visiting Lecturers for the term were Professor David A. Park and Julius T. Fraser. Members of the Institute from several departments and from Yale and Princeton lectured and also led the five small discussion groups. Without students grounded in science and knowledgeable in the humanities, such an interdisciplinary seminar would not be possible. Student response was made concrete in an unusual number of excellent papers, three of which were given as public lectures in the second term.

The Senior Thesis offers the best opportunity for an individual, student-teacher relationship, and most students have benefited greatly from this experience. In past years, however, some students have not availed themselves sufficiently of the supervision offered and have occasionally pursued unrewarding research and poor methods of study. A special effort this year was made by supervisors to keep theses from being over-long or too large in scope, and this effort will be continued. Several theses derived from initial studies in the Senior Seminar; some combine

experience and training in both the Department of Humanities and other departments of the Institute. Twelve theses dealt with literature and literary criticism; 12 with history and history of science; seven with philosophy. Two theses dealt with psychology; two novels were accepted as theses. The following titles may at least illustrate the range of subject matter: "The Gurus of the White Dynasty: Lives and Teachings"; "A Critique of Heidegger's *Being and Time*"; "Faith and Reason in the Works of Pascal"; "Two-Dimensional Geometric Optical Illusions"; "Elements of Success in Modern Chinese Peasant Movements"; "Naturalism and *In Cold Blood*"; "The Contrapuntal World of Aldous Huxley"; "A Study of the Poetry of Robert Graves"; "A History of Semi-conductor Research"; "A Guide to the American Car Cult."

Course XXI Society conducted two colloquia with students and faculty, sponsored three student lectures, three lectures by national and foreign writers and teachers, and four poetry-reading sessions in Ash-down House. The colloquia at Endicott House, day-long affairs arranged and moderated by students, dealt with "The Social Relevance of Philosophy" and "The Avant-garde Movement in Art." The latter was illustrated with films made by a former XXI student and by an improvisational musical ensemble. The Society also assisted effectively in Open House and Freshman Orientation.

It is rewarding to observe the activities of some Course XXI graduates of five and six years ago. They are making their mark mainly in the academic world in teaching and research, in medicine, and in industry.

ROY LAMSON

LITERATURE SECTION

The last year has seen the beginning of a major transformation of the literature curriculum. The transformation is necessary, for the traditional staples of college English courses — formal explication and literary history — clearly have not met the needs of students at M.I.T. This failure indicates a larger problem: the traditional English curriculum has become irrelevant to the realities of our culture.

Students at M.I.T., being oriented toward engineering and science, will not take the importance of the literary tradition for granted. This attitude, rather than putting us at a disadvantage, offers a singular opportunity. Our students are simply being honest about the plain fact that literature is no longer reverently accepted as an important element of our lives. Once we put literature's cultural pretenses aside — and our students have done so already — we are able to bypass the moribund and empty formalisms of the profession of English. Since we cannot depend on the students' familiarity with the categories of literary criti-

cism and analysis, any subjects we design must meet issues that are central to the students' lives, to their intellectual and cultural concerns. Only in these terms can literature be a meaningful part of the curriculum at M.I.T. — or anywhere else.

A proper model for this refurbishing of the curriculum is to be found in M.I.T.'s interdisciplinary laboratories. Having been forced out of their own fields and having been confronted with the demands of other disciplines, workers in these laboratories found themselves dealing with meaningful scientific problems, rather than trying to live up to the canons of their professions. And in facing problems that were real, they elicited the enthusiasm of students. For literature, the challenge derives from the students' scientific background and from the interdisciplinary work we expect to do with anthropology, philosophy, psychology, history and linguistics. All these will address themselves to elucidating the relation of literary forms to the experiences of men in society.

As a beginning, we have introduced a new sophomore literature subject during the past year. This subject attempted to have students relate examples of high literature to various popular forms; in doing so, we hoped they would be led to assess a substantial part of the range of literary experiences — from a pulp magazine and a low-grade movie to the plays and poems of the advance guard. The objective was to make students freely appropriate the materials (past and present) of the various literary cultures available to them. By the end of the semester, it was assumed, their reactions and evaluations would be richer, more complex, and more meaningful to their general experience.

Several electives of a similar nature — often cutting across chronological, national and disciplinary lines — were also offered. The members of the section have been planning more subjects of a similar nature. Ultimately, we expect the entire literature curriculum to concern itself with basic human issues, rather than with categories of literary history and criticism.

PERSONNEL

Professor Carvel Collins has resigned to accept an appointment at Notre Dame; Assistant Professor Duncan M. Nelson is going to the University of Massachusetts at Boston; Assistant Professor William H. Youngren will go to Smith. Assistant Professor Thomas H. Jackson resigned to take a position at Brandeis; Assistant Professor Norman Pettit is going to Brown.

New appointments include Associate Professors Alvin C. Kibel and Eugene Goodheart, Assistant Professor Andrew R. Hawley, and Instructor Michael B. Folsom.

Publications and Professional Activity: Professor Robert Adolph's book, *The Rise of Modern Prose Style*, has been accepted for publication by the M.I.T. Press. Professor Gurney's play, *The Rape of Bunny Stuntz*, has been published by Samuel French; Professor Gurney has received the Baker Award for Teaching. Professor Warren J. MacIsaac's essay, *Richard II*, has been accepted by the *Shakespeare Quarterly*. Professor Pettit's *The Heart Prepared: Grace and Conversion in Puritan Spiritual Life* has been published by Yale. Professor Thompson's *The Imagination of an Insurrection: Dublin, Easter 1916* has been published by Oxford; his essay "Collapsed Universe and Structured Poem: an Essay in Whiteheadian Criticism" was printed in *College English*. Professor Theodore Wood has been appearing regularly on television, lecturing on American literature, history and folk music.

LOUIS KAMPF

MUSIC SECTION

The current year has seen the American composer Elliott Carter as Visiting Professor of Music at M.I.T. Professor Carter taught a subject, Trends in Contemporary Music, and also gave a series of four lectures for the general public on various aspects of music. His "Piano Concerto" was given its world premiere by the Boston Symphony Orchestra in January; and the Abramowitz Memorial Lecture, also in January, consisted of an all-Carter concert in Kresge Auditorium.

Professor Klaus Liepmann conducted the M.I.T. Choral Society in performances of the Verdi *Requiem* and *The Seasons* by Haydn, with 48 members of the Boston Symphony Orchestra at each performance. He conducted the M.I.T. Glee Club in performances of Purcell's *King Arthur*, Milhaud's *Les Choéphores*, and Hindemith's *Apparebit Repentina Dies*. The topic of his Harvard Extension Course was the Choral Music of J. S. Bach. In December Professor Liepmann spoke in a panel discussion on "Cross-Fertilization of Conservatory and College on the American Campus" at the ninth annual meeting of the College Music Society in New Orleans.

Professor Gregory Tucker gave a concert of twentieth-century piano music, including a work of his own, at the DeCordova Museum in Lincoln, and prepared several concerts for the summer.

Associate Professor David M. Epstein was guest conductor with the Czech Radio Orchestra last July and with the Berlin Radio Symphony Orchestra in January. He was also a guest conductor-composer with the Baltimore Symphony Orchestra at the Rockefeller Foundation Symposium on Contemporary Music in May. Professor Epstein's "String

Trio" and "Sonority-Variations for Orchestra" were accepted for publication by MCA Music, Inc., and will be issued shortly. Currently he is working on a new composition for winds, brass and percussion and a book on musical form and structure, as well as continuing his research project in Swedish orchestral music.

Again this year John Cook worked with the Stratford Shakespearean Festival of Canada, for which he was commissioned to write music. Throughout the year he has continued his position as organist and choirmaster at the Church of the Advent in Boston.

Ercolino Ferretti and Michael Lay have given many lecture-demonstrations on computer music, the analysis of musical sound, and waveform analysis to various high schools, junior high schools and business organizations in the Boston area.

John Buttrick, who came to M.I.T. at the beginning of the second semester, has given piano recitals in New England and New York and was soloist with the New Symphony Orchestra of New York in November and April. He is teacher and instigator of the pilot program, "A Workshop in Musical Ideas," now in progress at the Boston Music Center for studying professional musicians. Mr. Buttrick is preparing for his fifth concert tour in Europe (scheduled for the middle of 1968) under United States and Dutch management.

I am particularly happy to announce the appointment of Allen Forte, a foremost music theorist now at Yale University, as Professor of Music. Professor Forte will come to M.I.T. in the fall of 1967 and will teach two of the three new theory subjects to be added to the music curriculum in the fall. Professor Forte has worked extensively with computers and music and plans to continue his research in this field at M.I.T. The M.I.T. Press will publish two of his books, *The Study of Musical Structure*, and *Snobol Primer*, an introduction to a programming language for music analysis.

At the risk of sounding repetitive, it must be stated that the famous and customary need for additional staff and space has become critical. We are offering 15 subjects in music — several of them requiring two to four sections each — and we have only *six* instructors in our music section. All of the music subjects are given in inadequate rooms and widely dispersed locations: in the Music Library Seminar Room, in the Rehearsal Rooms of Kresge and in 2-190. Three properly equipped music classrooms, which might double as rehearsal rooms, are urgently needed. They should be equipped with piano, phonograph, tape deck and music blackboard.

KLAUS LIEPMANN

PHILOSOPHY SECTION

This year the decision was made within the Department to recommend the creation of an autonomous Department of Philosophy in 1969. We look forward to this apotheosis with pride, regret, and some trepidation.

UNDERGRADUATE STUDIES

Since its inception in 1964, the subject, Introduction to Philosophy: Classical and Contemporary Problems, has been one of the most frequently chosen by sophomores to fulfill part of their humanities requirement. Although the details of this subject are revised constantly, it is and will remain a problem-oriented subject; it seeks to give students a sense of the most profitable ways in which to approach the problems of philosophy. We have always taken the view that this subject is a major responsibility of the whole section, and we have adopted the principle that every faculty member teach at least one section of the subject every year, even though the subject represents a considerable expenditure of our scanty resources.

This year upper-class electives were scheduled for undergraduates, and in addition a number of undergraduates were allowed to register for graduate classes.

GRADUATE PROGRAM

Our graduate program is now three years old. We have 28 students in residence; six of these will probably complete their studies next year. One of our students is already teaching at Columbia University and another at the University of Michigan. A third has accepted a post at the Chicago campus of the University of Illinois.

This year saw the inauguration of a special pro-seminar for graduate students. All second- and third-year graduate students participate in this seminar. Interested first-year students are invited to attend. The object of the seminar is to get students to undertake independent research on problems of their own choosing at an early stage in their studies, and incidentally to help them find a topic for their dissertation. It also provides students already working on their dissertation with an opportunity to present and discuss their drafts and to defend their ideas. This year the seminar was directed by Associate Professor Sylvain Bromberger and was attended regularly by a number of other members of the staff as well. It became a focus of the graduate program and promoted a sense of scholarly community that had been somewhat lacking. Students' reaction was generally very favorable and their papers and discussions often reached professional levels. This year the seminar met only during the spring semester, but it will meet during both semesters in 1967-68.

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In attracting new students we find ourselves in competition with the most prestigious and richest universities in the country. As a result we also find ourselves hampered by lack of endowed scholarships.

PERSONNEL

On leave this year were Professor Huston C. Smith for the fall term, visiting at the University of California at Santa Barbara; Associate Professor Irving Singer, who has spent the last two years at Villa I Tatti, Florence, on Guggenheim and I Tatti fellowships; Associate Professor Abner E. Shimony, who had an NSF fellowship; and Assistant Professor Dreyfus for the spring term, visiting at the Berkeley campus of the University of California. Professor Singer is working on a second volume on the philosophy of love, to succeed *The Nature of Love: Plato to Luther*, which was published in 1966 by Random House. Professor Shimony is collaborating with Professor Wendell Furry, Professor of Physics at Harvard, on conceptual problems in quantum mechanics.

In September our ranks will be joined by Professor Richard Lee Cartwright and by Assistant Professor Boruch A. Brody. Professor Cartwright comes to us from Wayne State University and is a graduate of Oberlin (B.A. 1945) and Brown (Ph.D. 1954). Professor Brody, now at Hunter College, City College of New York, is a graduate of Brooklyn College (B.A. 1962) and Princeton (Ph.D. 1967).

These appointments bring the total faculty members to 14. Associate Professor Jerry A. Fodor, however, continues to give half his time to the Department of Psychology, and Associate Professor Jerrold J. Katz remains an active member of the Research Laboratory of Electronics. We look forward to making at least three new appointments at the senior level and two appointments at the rank of Assistant Professor.

JAMES F. THOMSON

HISTORY SECTION

The section moved toward a sharper definition of its aims by both a revision of the history curriculum and the start of its program in comparative modern history, the latter supported by a grant from the Ford Foundation, made in 1966.

The curriculum was revised by the design of 13 new electives, many in comparative modernization and others in comparative civilizations, and by their grouping under new headings intended to provide a clear rationale for a given sequence of subjects. Some subjects, in turn, were dropped. The sophomore subject, Revolution, War, and 'Totalism,' was revised, and a new printing of the book of readings was put into effect. Plans were also made to revise the other sophomore subject, Society and Consciousness, during the course of next year.

While continuing to stress the undergraduate program, the section also moved a step closer to projecting a graduate program in history. Approval has been given in principle within the Department to a small and specially oriented effort in comparative modern history, emphasizing the interests especially associated with M.I.T. The details of this effort, however, need to be worked out carefully during the next few years.

The section also sponsored a series of seminars in conjunction with its program in comparative modern history. Bernard Cazes led a discussion on "Americanization: A Synonym for Modernization?;" Hannah Arendt on "The Role of Ideology in Revolution;" Eric J. Hobsbawm on "Social Banditry Reconsidered;" J. P. Nettl on "Revolution and Cultural Change;" and Dankwart Rustow on "Revolution and Elites: The Turkish Example." Members of the History Section, of course, participated, as did guests from the Departments of Political Science, Economics, Sloan School of Management, and the Center for International Studies at M.I.T. as well as from surrounding universities. Research grants for work in the areas of comparative revolution and comparative industrial impacts were made to some members of the section, and more are anticipated. In addition, Professor Theodore H. Von Laue, of Washington University (St. Louis) will be Ford Visiting Professor of Comparative History, and Vladimir Dedijer, formerly of the University of Belgrade, will be a Carnegie Visiting Professor in the fall of 1967-68.

During the spring semester, we were honored by the presence of Eric J. Hobsbawm, of Birkbeck College, University of London, who served with distinction as the first Ford Visiting Professor of Comparative History, and who, in addition to participating vigorously in seminars and other section activities, offered a subject, Industrialization and Social Protest Since 1850.

PERSONNEL

Associate Professor Lynwood S. Bryant served again as Master of McCormick Hall. Professor E. Neal Hartley became Institute Archivist, and also served as Secretary of the Faculty. Assistant Professor Robert E. Herzstein received the Founder's Day Award for Outstanding Scholarship, New York University, and read a paper, "The Phenomenology of Freedom in the German Philosophical Tradition: Kantian Origins," at the Conference on Value Inquiry, April 14, 1967. Assistant Professor Arthur D. Kaledin delivered a paper at the Conference on Early American History, held at the State University of New York at Albany, April 8, 1967, and was appointed to the New England Advising Committee for the Atlantic Colleges. Professor Thomas H. D. Mahoney, a member of the Cambridge City Council, also served as Chief Consultant for the

Special House of Representatives Committee on Elections, U.S. Congress, in December, 1966. Assistant Professor Nathan Sivin has received a two-year grant from the National Science Foundation. Professor Smith was awarded the Leonardo da Vinci Medal by the Society for the History of Technology. Assistant Professor William B. Watson received a Fulbright Research-Lectureship to Spain, and was also the recipient of an American Philosophical Society Grant.

Lynwood S. Bryant was promoted to Professor. David B. Ralston and William B. Watson were promoted to Associate Professor. Professors Mazlish and Sivin will be on leave next year, and Professor Steinberg will be on leave for the spring semester under a grant from the Old Dominion Foundation. Professor Hartley becomes Acting Chairman of the section, and Associate Professor Robert E. Macmaster Acting Director of the Ford Project.

BRUCE MAZLISH

DEPARTMENT OF MODERN LANGUAGES AND LINGUISTICS

GRADUATE PROGRAM IN LINGUISTICS

Professor Noam A. Chomsky returned to the Institute in the spring term after spending the fall term on leave at the University of California at Berkeley. On May 5, 1967, he received an honorary degree from the University of Chicago.

Dr. James H. Sledd of the University of Texas is completing a one-year appointment as Visiting Professor of Linguistics. During the first term he taught subject 23.733, History of the English Language.

In the fall of 1967 Dr. Kenneth L. Hale, currently Associate Professor of Anthropology at the University of Arizona, will join our faculty as Associate Professor of Linguistics, and Dr. J. Frits Staal of the University of Amsterdam will come here for one year as Visiting Professor of Linguistics. The former is a specialist in the Oceanic languages and in anthropology; the latter, in Indic philology. These appointments reflect the deliberate gradual broadening of our linguistics research program.

In addition to recent publications listed elsewhere in this Report, the following works in progress exemplify the breadth of activity which already characterizes that program: *The Sound Pattern of English* (Professor Chomsky and Professor Morris Halle), *On the Evolution of English Stress* (Professor Halle and Samuel J. Keyser), *Handbook of Phonetics* (Professor Halle and Kenneth N. Stevens), *The Abstractness of Underlying Structure* (Assistant Professor John R. Ross and George

Lakoff), a textbook on the algebraic properties of grammars of natural languages and language-like systems (Associate Professor G. Hubert Matthews), a monograph on analysis by synthesis with respect to natural languages and its application to automatic language translation and information retrieval (Professor Matthews), a full-length study of English grammar (Associate Professor Edward S. Klima), and a comprehensive historical Greek grammar (Assistant Professor René P. V. Kiparsky).

GRADUATE PROGRAM IN LANGUAGES

After a number of deliberations, the Committee on Graduate School Policy has decided to revise the doctoral foreign language requirement. Henceforth a graduate student may meet that requirement in either of the following ways:

1. by demonstrating to the Department of Modern Languages and Linguistics his ability to read and translate the scientific literature of his field of specialization from two modern foreign languages into English; or
2. by demonstrating to the Department of Modern Languages and Linguistics that he has attained intermediate competence in speaking and reading one modern foreign language.

In all cases the language or languages chosen must be acceptable to the Department in which the student is enrolled.

In connection with option 1 the Department of Modern Languages and Linguistics will continue to offer one-term subjects in German (fall term), French (spring term), and Russian (spring term). The Department will give written examinations in these languages four times a year, and will arrange for written examinations in other languages approved by the various departments in individual cases. The Department will also give credit for graduate examinations of at least equal difficulty passed elsewhere by transfer students, and for language subjects with a reading stress taken at college through the intermediate level with a grade of C or better.

In connection with option 2 the Department of Modern Languages and Linguistics will offer two-term subjects (4-0-8 units per term) on a pass-fail basis in French, German, Russian, and Spanish, and will arrange for examinations in other languages approved by the various departments in individual cases. The Department will also give credit for language subjects with a speaking and reading stress taken at college through the intermediate level with a grade of C or better. This includes any third-term language subject passed with a grade of C or better in our own undergraduate program.

Option 1 is centered on languages containing a sufficient amount of important and pertinent technical literature; option 2, on field languages.

UNDERGRADUATE PROGRAM IN LITERATURE AND LANGUAGES

Starting in the fall of 1967, the Department will add to its literature offerings, which are now conducted wholly or largely in the foreign language, six subjects to be conducted in English and based on readings in translation. These subjects, two in German literature and four in Russian, are designed for students interested in such literature but not equipped to read the original language or to speak it. The Department will also add two subjects in Spanish literature to the two introduced this year in order to make possible an upperclass concentration in that field.

Dr. Claude J. Carey, Assistant Professor of Modern Languages, has resigned to accept a position at Brown University. Mr. Carl J. Black, Assistant Professor of French, has resigned to accept a position at Bard College. Professor Robert E. Jones of the University of Pennsylvania will join our faculty in the fall, and, in addition to participating in our Humanities in French program, will be in charge of our French literature offerings.

Professor Martin Dyck, whose book *Die Gedichte Schillers* was recently published in Europe, is continuing his research on Schiller. Professor William F. Bottiglia is nearing completion of his Voltaire volume for Prentice-Hall's Twentieth Century Views series. Associate Professor Krystyna Pomorska's book *Russian Formalist Theory and Its Poetic Ambiance* is at the press in The Hague, and she is now working on an anthology to be entitled *The Last Fifty Years of Russian Prose*. Professor Jones's book *La Nouvelle Critique en France: 1940-1966* is at the press in Paris, and will also appear in an English version on this side of the Atlantic. He is currently preparing full-length studies on Nerval and Giraudoux.

In 1964-65, the last year of the old curriculum, our language and literature enrollments in French, German, and Russian totaled 1,001. This year they have dropped to 809. A breakdown of these figures reveals that French has held its own, rising in fact from 262 to 275. Russian has fallen, though not too badly, from 226 to 193, while German has plummeted from 513 to 341.

If French continues to prosper, the reasons are: (1) that beginners can master it more easily than they can German or Russian, and (2) that there is a greater supply of students with a background in French for our intermediate and advanced subjects to attract. As for the general decrease, it has at least three causes. One is the proliferation in recent years of elective subjects in the School of Humanities and Social Sci-

ence, plus the introduction of Freshman Seminars, with no appreciable increase in the total number of undergraduates. Another is the expansion of our language subjects from 8 to 12 units, so that they can be less comfortably fitted into our students' crowded schedules. Finally, there is the problem of required subjects in the freshman year under the new curriculum: two terms of mathematics, physics, and humanities, and one term of chemistry (normally taken in the fall term). This program makes possible only one term of language, save for freshmen able and willing to shoulder a considerable overload. The 1966-67 enrollments in French, German, and Russian clearly reflect this situation: first term, 55 freshmen; second, 132.

HUMANITIES IN FRENCH AND GERMAN

This year the Humanities in French program was deliberately reduced to one section on both the freshman and the sophomore levels in order to ensure top quality classes and professionally competent instruction. The number of highly qualified freshmen continues to increase each year. The class of 1971 includes 179 students who have done superior work, and 88 who have done good work, in three or more years of secondary school French. A reexpansion to two sections seems wise, therefore, as soon as we can find an upper-echelon professor capable of handling this kind of material in French.

The Humanities in German program is now completing its second year and appears to be consolidating itself as a part of the Department's regular curriculum, with enrollments per section being held to about 15. The prospects for next year are promising, since the entering class numbers 82 freshmen who have done superior work, and 37 who have done good work, in three or more years of secondary school German.

WILLIAM F. BOTTIGLIA

DEPARTMENT OF POLITICAL SCIENCE

THE PAST TEN YEARS

The political science program at M.I.T. is approximately ten years old. In 1956, the Faculty authorized an S.B. degree in Economics, Politics, and Engineering. In 1958, the Faculty voted to authorize the Ph.D. in Political Science. In 1965, a separate Department of Political Science was created. In this decade M.I.T. has acquired one of the top such departments in the country.

As is often true when one starts from a low level, the rate of growth of this Department has been rapid: in about six years the number of

both students and faculty has doubled. Since 1961-62, the number of graduate enrollments in political science subjects has grown from about 150 to about 250 per term. The sharpest increase, however, has been in undergraduate enrollment. The number of undergraduate registrations per term has risen from about 200 to about 500. The annual increase in the number of graduate students is normal for a new department, running at about nine per cent; this rate is subject to control by admissions policy and is certain to decrease. The rise in undergraduates, however, reflects the appeal of a strengthened department to M.I.T. students who came here without a specific interest in political science. To a very large extent, it is the result of increased registration in general education courses, especially the introductory social science course. The number of political science majors is now 61, accounting for at most 150 to 200 of the 500 undergraduate registrations. It should be noted that this undergraduate growth does not represent net growth of the Institute, but rather a shift in interest among undergraduate students. It thus represents a problem, but not the same problem as if it were sheer net growth. Since it represents free election of subjects, it is not as controllable, though there is of course a saturation point. The undergraduate registration has been growing at the rate of 16 per cent per year. Combining graduate and undergraduate students results in a growth rate of 12 per cent per annum, exactly the same rate as the growth of the department faculty during the past six years. The rate of faculty growth in the past three years has already been cut in half.

The Political Science Department, in ways typical of M.I.T., is an interdepartment. Its parent, the old Department of Economics and Social Science, made a home for sociologists, anthropologists, psychologists, and political scientists who were needed both for purposes of general education and for certain of the Institute's research programs. Today, since Political Science and Economics have separated, the Department of Political Science has become the home of the residual social sciences. It might better be named the Department of Political and Social Science, as was indeed the Department's preference at the time of its formation. Teaching in the Department are two professors with doctorates in psychology, five whose doctoral work was in sociology, two economists, one whose work was in management, two in mathematics, two in electrical engineering, and one whose former career was in journalism.

From the beginning, the Political Science Department has sought to establish bridges to the School of Engineering and to other parts of the Institute. This is not an easy process, but it can be fairly said that it is succeeding. The bridges are of many kinds. The growing role of the

Department in undergraduate general education has been noted above. We may also note the work of the Department in the field of science and public policy under the direction of Associate Professor Eugene B. Skolnickoff. A number of cooperative activities are taking place between this and other departments. Courses on political-technical problems have been developed jointly, or are in the process of development, by this Department and City Planning, Civil Engineering, and Ocean Engineering. There has been one Ph.D. granted jointly by Political Science and Civil Engineering; there has been extensive participation in Project MAC activities by the Department, not simply as a user, but in the development of interactive man-machine systems relevant to the social sciences. Members of this Department are engaged in the General Motors Traffic Safety Program, the Transportation Research Program, and the Center for Space Sciences. This Department took the initiative in the creation of the interdepartmental committee on systems analysis, which is developing curriculum in this field and which is inaugurating a special program for mid-career government people to be housed in the Center for Advanced Engineering Studies. M.I.T.'s Political Science Department is probably unique in the extent to which it seeks to link analysis of the social and technical aspects of current political problems.

THE PAST YEAR: INSTRUCTION

During the last year, nine graduate students completed the Ph.D. requirements in Political Science; five others earned master's degrees; and eighteen received the S.B. degree.

The completion of 14 programs of graduate study this year is a significant milestone. Until this year our program was getting under way and growing. As a result, each year we admitted substantially more students than completed their degrees. The pipeline was slowly filling up. This year we have admitted 17 new students for graduate study to start in September, while 14 are going on their way with degrees completed. Considering the inevitable attrition each year of a few students who start and drop by the wayside, these numbers represent a stable flow.

As it must to all stable organizations, the time has come for reevaluation. We are proud of our curriculum; it was given kudos by the American Council on Education Survey of American Universities, in which a special panel of experts rated this Department as tied for second place with Harvard in effectiveness of graduate instruction. Nonetheless, we are not satisfied. As noted in last year's annual report, we feel there is need for improvement in our undergraduate curriculum. We also feel that the time has come to reevaluate the structure of our graduate school curriculum.

The Department has launched, therefore, a comprehensive review of both curriculum and teaching methods. A committee consisting of ten members of the Department under the chairmanship of Associate Professor Donald L. M. Blackmer is spending a substantial part of the summer in this review. It will report to the Department in the fall. The committee is charged with looking at the curriculum at all levels: the introductory subject, the undergraduate offerings, and the graduate offerings. It will also include consideration of pedagogical devices to be used to speed up and improve the learning process, including team-teaching, short courses, video tape, audio-visual aids, and field experience. Committee members will also reconsider the organization of our discipline into fields. The six fields which we have offered are likely to be supplemented in the near future by additional fields such as urban politics and mathematical methods and models. With growth in the number of fields, the present rules covering the general examination and degree requirements became inappropriate and need reconsideration.

Our students also have been involved in this discussion of curriculum. Several meetings have been held with both graduates and undergraduates to elicit their suggestions and evaluations. These will be continued. We have had a graduate student organization for some time. Our undergraduates have now formed a Course society. When the number of undergraduate majors was very small, this was not necessary. Now, such an organization fills an important need.

One measure of the progress of the Department is the work done by its alumni. M.I.T.-trained political scientists are now found on the faculties of a number of major institutions. In the past year, our alumni have been appointed to the faculties of the University of Michigan, the University of Pennsylvania, Yale University, Brandeis University, Michigan State University, the University of Chicago, and the University of Minnesota.

RESEARCH

The research projects of most members of this Department are covered in the annual report for the Center of International Studies. We shall not attempt to duplicate that report. Three projects, however, deserve special mention here, because of their intimate relation to the teaching process.

THE M.I.T. SOCIAL SCIENCE DATA ARCHIVE

For two years we have had a small experimental social science data archive which was developed with the support of a National Science Foundation Grant. The archive was set up to permit experimentation

with time-sharing computer methods for the analysis of social science data. The archive and the associated ADMINS data handling system have been used extensively and increasingly by our students.

In the past, social scientists typically have taken the cards or tape arising from a single study and subjected them to statistical analysis. Published articles reporting on previous studies might be alluded to in the write-up, but the raw data collected in any one study was essentially dead once that study was reported. Now that computers with large bulk memories exist, social scientists are becoming increasingly aware of the mine of data collected in earlier studies in which they could find answers to many of their questions. New methods are needed to permit the social scientist to work over libraries of data rather than over single studies. The ADMINS system developed by Stuart D. McIntosh and David M. Griffel provides such methods. It is a highly flexible system for managing data files and for analyzing their content. It is being used for the processing of public opinion survey data in the Political Science Department and for the processing of urban data in City Planning. It will be used to experiment with health-information systems under the auspices of the Joint Center for Urban Studies, and for an international crisis data system at the Center for International Studies. The National Science Foundation has just renewed the grant for the development of the ADMINS system for two years.

The important aspect of the system for our students is that it provides them with a new kind of library and the facilities to work in it. We now have in the archive the equivalent of approximately a million and a quarter cards from a variety of social surveys. We have three consoles, and we are about to install a scope so that the students can work efficiently on this data on line. For the next two years, the perpetuation of this archive as an educational as well as a research facility is guaranteed by the NSF grant. Beyond that point it will be necessary somehow to assimilate it into the Institute's normal educational facilities, perhaps in the library system.

NIMH FELLOWSHIPS IN URBAN POLITICS

Last summer this Department applied to the National Institute of Mental Health for a \$700,000 training grant to permit the training of four new Ph.D. candidates in the field of urban studies each year for seven years. The initiation of this program has now been approved by NIMH, and the first four students will start next September. This project was initiated by Associate Professor Leonard J. Fein and then made a joint project with the Department of City Planning, with whom we will share these fellowships. The focus of the program will be on the psycho-

logical and social problems of urban life. All students will take some courses in urban politics, some courses in city planning, and some courses in the sociology of the city. This grant represents a major opportunity for this Department, especially in the light of the Institute's new commitment to the urban studies field, and in the light of Professor Robert C. Wood's interest.

HUMAN FACTORS IN DEVELOPMENT

Professor Frederick W. Frey is just launching a very considerable comparative study of human factors in development. Some years ago he directed a survey in 450 Turkish villages on social and psychological conditions for modernization. Then, more recently, a similar survey was conducted by him and the Center for International Studies in Venezuela. He now proposes repeating this operation perhaps in four more countries.

We mention this Center for International Studies project in the present report because it will provide an important educational opportunity for quite a few of our graduate students who may be expected to do their dissertations as part of this program.

Our Department has always had a substantial number of graduate students doing field research overseas. This year nine students worked on their dissertations abroad, almost all of them in developing countries. Under a Carnegie grant received a few years ago, and under the more recent Ford International Relations grant, we have been able to support a number of these students. Others have won Ford Foreign Area Training Fellowships, Fulbright Fellowships, or secured other means of support. In general, we have been able to maintain a practice whereby students in the field are in contact with members of our faculty at some point during their overseas stint. Considering the tensions and tribulations of field research, that has sometimes proved quite useful. Such contact has proved possible because members of our faculty have also been abroad in the developing areas. Professor Frey's project represents an opportunity for maintaining such training activities in the developing areas. Political development has been the strongest field in our Department and the one attracting the largest number of students. We look forward to maintaining our preeminence in this field.

During the year a number of members of the Department have been on leave. Professor Myron Weiner spent the year in Europe studying agricultural modernization in Eastern Europe in the nineteenth century. His primary specialization has been on India in recent years and will continue to be so. He desired, however, to look at the European modernization to help shed light on similarities and differences from that in India.

Professor William E. Griffith spent the year in Germany, studying the problems of contemporary Germany and Central Europe. Professor Fein took a partial leave in the spring term at the Joint Center for Urban Studies, and Professor Fred C. Iklé took a leave in the spring term at the Kennedy Institute.

The Department made an arrangement with the Ford Foundation at their request but with our strong support whereby Professor Frank Bonilla will spend half of his time in Latin America during the next five years. This arrangement will not only support Professor Bonilla's research, but also will provide an opportunity for him to maintain continuing contact with students who do field work in Latin America.

A major new program in which this Department has taken the initiative has been in systems analysis. At our suggestion, and with the endorsement of President Johnson, an interdepartmental committee was constituted last fall under the chairmanship of Professor William W. Kaufmann and with representatives from Management, Economics, Civil Engineering, Operations Research, City Planning, and the Center for Advanced Engineering Education.

The purpose of the committee was to design curricula in systematic policy analysis both for regular M.I.T. students and for mid-career people who might come to the Institute for this purpose. New courses have been added in systems analysis both in this Department and in others. The first major accomplishment of the committee is represented by a contract with the National Institute of Public Affairs at the instance of the Bureau of the Budget for the training of mid-career fellows. This contract has been undertaken jointly by the Center for Advanced Engineering Studies and the Political Science Department, and the program is being organized jointly by Professors Kaufmann and Harold S. Mickley. The incoming group of 14 students are drawn from almost as many different parts of the government, in response to our insistence that this training program not be focused solely on the defense application of systems analysis.

Participation continues by members of this Department in the Center for Space Sciences, the Transportation Program, and similar joint programs. Professor Skolnikoff and Assistant Professor Harvey M. Sapolsky have been working with the Center for Space Sciences and have played a major role in the development of a faculty seminar on science and public policy. Associate Professor Alan A. Altschuler and Assistant Professor Frank C. Colcord Jr. have been working with the Transportation and General Motors Public Safety programs. Next year we will be adding Matthew A. Crenson to work in the latter area.

OTHER FACULTY ACTIVITIES

A number of members of the Department have published books during the past year. Among them we may note Professor Skolnikoff, *Science, Technology, and the American Foreign Policy* (Cambridge: M.I.T. Press, 1967); Professor Harold R. Isaacs, *American Jews in Israel* (New York: John Day Co., 1967); Professor Fein, *Politics in Israel* (Boston: Little, Brown, and Co., 1967); Professor Griffith, *Sino-Soviet Relations, 1964-1965* (Cambridge: M.I.T. Press, 1967); Professor Weiner, ed., *Modernization* (New York: Basic Books, 1967); Professor Daniel Lerner (with Wilbur Schramm), ed., *Communication and Change in the Developing Countries* (Honolulu: East-West Center Press, 1967); Professor Norman J. Padelford, *The Dynamics of International Politics*, revised edition (New York: Macmillan Co., 1967); Professor Lincoln P. Bloomfield, *The United Nations and U. S. Foreign Policy*, revised edition (Boston: Little, Brown, and Co., 1967).

Members of this Department continue to be active in a variety of contributions to public affairs. Significant activities in public affairs include the following:

Professor Altschuler served as consultant and prepared a study paper for the Committee for Economic Development's committee on wage-price policy.

Professor Bloomfield, who just completed a study of the control of local conflict for the Arms Control and Disarmament Agency, has been helping that agency in the use of his research in current conflict situations.

Professor Bonilla has been consulting for the Ford Foundation with the School of Political Science at the Federal University of Minas Gerais, Brazil.

Professor Fein has worked with the research program of the Massachusetts Commission against Discrimination.

Professor Everett E. Hagen is president of the Association for Comparative Economics and on the executive committee of the Southeast Asian Development Advisory Committee of AID. He has also served on an advisory committee to the Policy Planning Council of the U.S. Department of State, as has Professor Max F. Millikan.

Professors Iklé and Ithiel de S. Pool have been members of the Commission on the Year 2000 of the Academy of Arts and Sciences.

Professor Kaufmann has continued to consult for the Office of the Secretary of Defense.

Professor Millikan is president of the World Peace Foundation and is a member of advisory committees to AID on Economic Development and on Research.

Professor Padelford is chairman of the board of editors of *International Organization*.

Professor Pool was in charge of the convention program of the American Political Science Association in 1966, and has been engaged in research in Vietnam for the United States government.

Professor Lucian W. Pye is a member of the board of directors of the Council on Foreign Relations, the Asia Foundation, and the Asia Society. He is now chairman of the Committee on Comparative Politics of the Social Science Research Council and a member of the State Department panel on China and the State Department panel on the Far East. He is also a member of the advisory committee for economic development of AID, and of the Ad Hoc Committee on Army Psychological Operations, of which Professor Millikan is also a member.

Assistant Professor John S. Saloma has continued his activities in the Ripon Society and has submitted a report on the job of the congressman to the American Political Science Association's study of Congress.

Professor Skolnikoff is secretary of the section on social sciences of the American Association for the Advancement of Science.

ITHIEL DE SOLA POOL

DEPARTMENT OF PSYCHOLOGY

Psychology at M.I.T. has completed its first three years as a department, its first five as a doctoral program. At a rapidly growing institution, we are no longer the youngest department, though we continue to be one of the smallest, by the standards of departments around the Institute. The faculty in psychology has remained the same for the last two years: 11 members at the different professorial ranks, aided by a slowly increasing number of lecturers, research associates, visiting investigators, and research staff (24 in 1965-66; 26 in 1966-67). At the same time, however, commitments to research and teaching have grown: the departmental laboratories are getting more and more crowded, and the enrollment in psychology has taken a further leap since it rose from 1,013 undergraduate and graduate students for the year 1965-66, to the highest level thus far, a total of 1,314 students for 1966-67, the year under review. Of these, 118 were enrolled in the ten graduate seminars and laboratories offered in 1966-67; the remaining 1,196 distributed themselves over 13 undergraduate subjects. The census in the doctoral program during the year was 24; with departures and arrivals, this figure is expected to rise to 28 in 1967-68.

It is evident that we must continue to grow, but we are resolved to control this growth. The directions are clear: we should slowly increase

the faculty to keep pace with growing teaching commitments, while adding to essential portions of our departmental research program. We must search for an orderly response to the many requests for an undergraduate major in psychology. As we pointed out in our last annual report, this development presupposes additional staff and laboratory facilities for undergraduate training, still conspicuously absent. Assuming that such additions can be made, we shall have to find ways of keeping such an undergraduate curriculum within bounds. These matters are under active exploration within the Department.

BASIC PLAN

Irrespective of these developments, the Department remains firmly committed to its plan, which requires selective emphasis on three major areas of modern behavioral science: brain and behavior (physiological psychology); perception and learning (experimental psychology); and early development and group interaction (social-developmental psychology). The three areas of this program have continued to be major growing points for the Department in teaching and research. It is this essential structure, first sketched out seven years ago when the major effort in psychology was launched, that has provided the framework for all other developments. As we said in last year's report, the main concern in the course of future growth will have to be for continuing symmetry among the three principal lines of the program. We say this, fully knowing that the lines are at times hard to tell apart.

In the organization of our teaching on the undergraduate and graduate levels, there is little difficulty in maintaining the tripartite arrangement: in the Course IX sequence, as now constituted, the first series of decimals, from .01 to .29, indicates subjects in physiological psychology; the second, from .30 to .59, subjects in perception and learning; and the last third, from .60 to .89, those in social and developmental psychology. Such symmetry is harder to discern for the research programs, although our progress reports continue to show a natural grouping of projects under each of the three major headings. Yet, in substance, the lines of research are interlaced; and that is, we think, not at all undesirable.

ADVANCES IN RESEARCH

BRAIN AND BEHAVIOR

Our ongoing studies of brain-behavior relationships are concerned with the often subtle changes in perception after penetrating brain wounds, with changes in motor control or in memory. Increasingly, these observations on man (several hundred cases in Boston and New York) are complemented by studies of the behavior of single cells in the brain of

animals, since current techniques permit us to record such unit-activity through microelectrodes in animals that are awake and show no discomfort. In this fashion we have found cells in the frontal lobes (in the so-called frontal eye fields of the monkey) that discharge vigorously when the eyes have reached a particular end-position, following a spontaneous shift in gaze (Bizzi). This discovery is of considerable importance to us in our attempts at a more convincing interpretation of the role of the frontal lobes in behavior. These vast structures are clearly neither sensory nor motor in function; they are involved, we believe, in a process that presets other parts of the central nervous system for the expected consequences of voluntary action.

Such unorthodox views of function call for correspondingly unorthodox connections within the structures of the forebrain — not only from sensory to motor centers, as has always been assumed, but in reverse. It is therefore of great moment to us that Professor Walle J. H. Nauta's group in the Department has developed a new technique for staining degenerating nerve terminals (the Fink-Heimer modification of the Nauta stain) that enables one to see differentially so-called anterograde and retrograde degeneration following experimental interruption of neuronal pathways. It is already clear that the supposedly established "wiring diagrams" for large sectors of the brain will have to be reexamined with this new and much more powerful technique. Under the electron microscope, the method distinguishes degenerating from intact end-feet in synaptic fields, opening possibility for a microdissection of these regions where the crucial changes during learning may well occur.

Meanwhile, physiologic studies of perception and learning in the departmental laboratories have raised hopes of delineating certain late-appearing waves that distinguish reaction to expected from unexpected visual patterns (Chorover, Schiller) in the computer-averaged evoked potential from the human brain; and there is mounting evidence (Richards) that the rescaling in the perceived size of objects as they approach or recede (so-called size-constancy in perception) may be mediated by those motor-to-sensory discharges in the brain that we have postulated earlier in our interpretations of frontal-lobe functions.

At the same time, radioisotope techniques have been employed (Altman) in surveying the effects of rearing animals in enriched or impoverished environments. These differential treatments at critical stages of development can lead to definite changes in the number of small neurons (microneurons) in different parts of the animal's brain. Similar reductions in microneurons can be observed after short-time, low-level x-irradiation. Some of these experiments were performed in collaboration with M.I.T.'s High Voltage Laboratory.

PERCEPTION AND LEARNING

In general experimental psychology, one of the novel observations has likewise been concerned with early development and special conditions of rearing: confirming preliminary results obtained last year (1965-66), it is now established that young animals (kittens, monkeys) cannot use their limbs under visual control, if they are raised in such a way that they are prevented from seeing their own limbs (Held, Hein, Bauer, and others in the departmental laboratories). Thus, baby monkeys raised in padded chairs where they can move their limbs normally under a large opaque bib, but cannot see their limbs, show great surprise when first permitted to look at their own hands, say, eight weeks after birth. For a number of days, the hand is useless to them as long as they are in the light; they misreach for objects, until their own motor apparatuses have been appropriately mapped into their visual systems. Silent film strips of these experiments were shown at the International Psychological Congress in Moscow in the summer of 1966 and made their point without requiring translation. Such problems of origin and maintenance of spatial order in perception, and of the basis for voluntary motor control, in animal and man, remain a central concern of our laboratories.

The same is true for the fundamental aspects of memory and learning. The experiments just described indicate the surprising extent to which such seemingly elementary achievements as pattern vision and voluntary reaching can interact in early development, and the extent to which they depend on early experience. Yet, the mechanism of such perceptual-motor learning, or the mapping of one system into another, remains as elusive as are higher levels of learning such as those involved in the acquisition of language and concepts.

The rudimentary state of our knowledge becomes apparent if we consider the difficulties of demonstrating such seemingly straightforward phenomena as the rate of decay for short-term memory (Wickelgren), or if one investigates the baffling cases of "anterograde amnesia" in those men in whom injury to the undersurface of the brain has apparently disrupted the transition from short-term memory (which is intact) to long-term storage of learned material (Milner, Wickelgren and others).

SOCIAL-DEVELOPMENTAL PSYCHOLOGY

It is evident how much the three areas of the departmental program overlap. There are, however, distinctive issues in the third area — that of early development and acquisition of forms of social interaction — which are as salient as some of the recent work in the other two parts of the program. To cite again only two or three major aspects: there is a

new way of looking at the child's acquisition of syntax and other cognitive structures (Fodor, Bever, Mehler, Garrett and others in the Department). The young child is often said to have an amnesia not too different from that of adults with brain lesions of the sort just described; he exhibits short-term memory but fails to build up long-term, continuous trace-systems. Yet, normal children, and even many severely retarded ones, do show an uncanny capacity for learning linguistic structures, the phonemes and morphemes of their language, and its different syntactic rules. Obviously, their amnesia is material-specific: they can remember certain things (such as the elements of language) much better than adults, while they forget other things, such as complex sequences of events, perhaps simply because one cannot remember what one does not comprehend.

The child's acquisition of language is peculiar: it had been assumed that different syntactic structures (e.g. active vs. passive constructions) are acquired in sequence, the child being able to understand an active sentence long before a passive one. But it turned out in recent work during the last year that very young children laugh or balk at passive sentences that contain a logical absurdity ("The policeman has been eaten by the apple"), and they can be shown to engage in complicated logical operations long before traditional views of child-development would permit them to do so.

Equally intensive work proceeds on the acquisition of social norms and values (Saltzstein and others). Many of these experiments take the familiar form of asking young boys and girls to judge the numerosity of dots presented to them on a large surface covered with more dots than they can count, and to provide suggestions as to how many dots there are. Such social influence turns out to be much less effective for boys than for girls, the former resisting these (induced) distortions of their spontaneous judgments. Yet, curiously, the relation is reversed, if one now re-tests for persistent effects of social influence, in later sessions: now some of the boys show a form of delayed compliance while the girls revert to their own way of judging the situation.

This rather cursory description of selected topics in this year's research program may serve to indicate the diversity of themes together with a rather considerable unity of underlying concepts. No graduate student is permitted to impale himself on only one prong of the program for the duration of his stay, and the continual cross-visiting by the staff in offices, laboratories, seminars and research meetings results in frequent interchanges and regroupings all the more useful for being entirely unplanned.

COOPERATION WITH OTHER GROUPS AT M.I.T.

The same can be said for the numerous collaborative arrangements with laboratories and centers elsewhere at M.I.T. During the last year, these arrangements outside the Department have included joint efforts with the Department of Biology (in work on the biochemistry of learning) and with the Department of Chemical Engineering (with which we shared electron microscope facilities). The cooperation with the High Voltage Laboratory (for work on behavioral effects of short-term irradiation) has already been mentioned. As before, we have shared with other departments in the use of the Clinical Research Center, where Professor Hans-Lukas Teuber and Doctors Suzanne H. Corkin and Thomas E. Twitchell of our Department continue their studies of behavior after brain injury in children and adults.

Equally intense was the collaboration with the Linguistics Section of the Research Laboratory of Electronics and the Department of Modern Languages and Linguistics, in connection with our work on normal and abnormal language development; this concern in psycholinguistics took the form of several joint staff appointments. In the same area, Associate Professor Jerry A. Fodor continued to divide his teaching between the Philosophy Section of the Department of Humanities and our own Department, where he is carrying out his psycholinguistic research. Meanwhile, closer ties are being worked out with the new Educational Research Center, where Professor Teuber serves as advisor, and where one or two joint appointments with psychology are planned, provided the appropriate persons can be found.

In a similar fashion, Professor Richard M. Held has maintained some links with the Committee on Sensory Prostheses, and both Professors Held and Teuber have an active interest in the new Center for Visual Studies. Professor Nauta, in turn, is serving on the Institute's Animal Care Panel, and on the Ethics Committee, which reviews all experiments involving human subjects. He is also an associate of the Neurosciences Research Program.

We list these arrangements and appointments in some detail in order to indicate the many ways in which a small department such as ours gets involved in other activities within the Institute. In this respect we are certainly not different from other groups at M.I.T., where interdepartmental contacts are frequent. We value the opportunity for these contacts.

The hazards are equally clear: there is the threat of continual distraction, and the embarrassment of having to draw lines and say "no" to yet another request for some new collaborative venture. Yet, so far, the climate has been bracing, though we sometimes wish that the squalls would not rise quite so often.

SPECIAL REPORTS AND ADDRESSES BY STAFF MEMBERS

It remains to cite some of the honors and special invitations that have come to members of the Department. To start with the invitations: five of us were invited to the International Psychological Congress last summer (1966) in Moscow, where Professor Held and Assistant Professor Alan Hein took part in the Symposium on Perception and Early Development, and where Professor Teuber chaired the Symposium on the Frontal Lobes and participated in another Symposium on the Role of Psychopathology in the Study of Behavior. He also gave a paper, as proxy for Thomas G. Bever, Dr. Merrill F. Garrett, and Professor Fodor, in the Section on Psycholinguistics, while Dr. Gerald E. Schneider attended the Congress under a special travel award from the American Psychological Association. Just prior to the Congress, Professor Teuber took part in a one-week meeting at Oxford University on Current Studies of Brain Function. Soon after the Congress, Dr. Corkin and Professors Fodor and Teuber presented papers at the XIIth International Neuropsychology Colloquium, which was held in Greece. In September Professor Teuber gave the Presidential address to Division 6 (Physiological and Comparative Psychology) of the American Psychological Association at its Annual Convention. Associate Professor Joseph Altman and Professor Nauta participated in the 1966 Summer Conference of the Neurosciences Research Program in Boulder, Colorado, and this June Professor Nauta visited the Sarkisov Institute in Moscow as a guest of the Soviet Academy of Sciences.

SERVICE ON NATIONAL PANELS AND ADVISORY BOARDS

In addition to these international activities, members of the Department continue to serve on national panels and advisory committees: Professor Held continued to serve as chairman of the Experimental Psychology Study Section of the National Institutes of Health; Professor Nauta served on its Selection Committee for Career Investigators; and Professor Teuber on the Neurology Study Section, as well as on the Bio-sciences Committee of NASA, and on the Research Advisory Board of United Cerebral Palsy; he also joined the Board of Directors of the Foundations' Fund for Research in Psychiatry. Associate Professor Stephan L. Chorover took part in the evaluative program of the National Institutes of Health for its new "Health Sciences Advancement Centers."

PROFESSIONAL HONORS

The Department and its graduate students were delighted when we learned in the spring of 1967 that Professor Nauta had been elected to the National Academy and that Professor Held had become a member of the American Academy of Arts and Sciences.

VISITORS

As in previous years, the Department was host to a number of guest investigators and visiting faculty members. During the summer of 1966, Dr. Anne Pick and her husband, Dr. Herbert Pick, from the University of Minnesota, worked intensively with Professor Held and his group on problems of perceptual learning. During the academic year, Dr. John Hay from Smith College worked on problems of sensory-motor adaptation as a guest of the Institute, also under Professor Held's sponsorship.

In Professor Nauta's laboratory, Dr. Anthony H. M. Lohman from the University of Nijmegen, Holland, spent eight months as a visiting investigator; and Professor Teuber acted as host to Professor Hans Hörmann, Director of the Psychological Institute at the Free University of Berlin, who was a Visiting Professor in the Department from February through April, 1967.

For the coming year, we expect to see Professor Frank Morrell from Stanford University as Visiting Professor during the fall term in the Department; his main base will be the Neurosciences Research Program at the American Academy as a guest of Professor Francis O. Schmitt. Professor Morrell's wife, Dr. Lenore Korke Morrell, will work for the same time with Professor Teuber on physiological bases of perception and learning, an area to which both Morrells have devoted much of their careers.

Other visitors will include Dr. Kenneth Ian Forster from Australia, who will join our psycholinguistics group, to work primarily with Professor Fodor and Dr. Garrett. Dr. John R. Frederiksen will participate as a research fellow in some of the work on behavioral alterations after brain injury in children and adults; this will be his second postdoctoral year, the first having been spent at Harvard after receiving his doctorate in mathematical psychology from Princeton. Dr. Neville P. Moray, senior lecturer at the University of Sheffield, England, will be at the Institute as a Visiting Associate Professor under a joint arrangement between the Research Laboratory of Electronics and the Department of Psychology. He is primarily interested in computer simulation of certain perceptual phenomena. In Professor Nauta's laboratory, Dr. Hans Zeier, a young zoologist from the University of Zurich, Switzerland, will spend about one year in work on bird behavior, in close contact with Dr. Harvey J. Karten, who is continuing his intensive studies of the avian brain.

PROMOTIONS

Besides these impending arrivals, and the departures of those guests we have listed, there are no staff changes to report; but it is with great satis-

faction that we note the recent promotion, to take effect on July 1, 1967, of two of our younger faculty members, Alan Hein and Wayne A. Wickelgren, to the rank of Associate Professor.

COLLOQUIA

The departmental colloquium program, now a solidly established tradition, continued as actively in 1966-67 as in previous years, with a total of 43 speakers. Sixteen of these came from abroad, the same figure as in 1965-66.

FUNDS

The general departmental budget from all sources increased slightly during the year under review; these fiscal matters and the innumerable domestic details of our daily lives continue to be under the prudent care of our business administrator, Robert I. McElroy. The most gratifying financial news was the assurance received in the middle of June, 1967, that the second five-year round of our training grant from the National Institute of General Medical Sciences would be paid starting in July, 1967, essentially at the level of support we had requested.

Still, we are faced with several major needs: our departmental library has only partial support. Beyond that, we will have to find new funds if we want to move in the direction of undergraduate laboratories and an undergraduate major. No matter how we restrict the scope of such an additional venture, it is patent that it will require new effort and thought.

HANS-LUKAS TEUBER

CENTER FOR INTERNATIONAL STUDIES

What follows is a summary of the Center's research program under the four general headings of economic and political development, international communication, foreign policy and defense studies, and international communism. The present brief account does not pretend to be a complete record of research in progress, nor can it convey the full flavor of the Center's varied activities. Those interested in a more detailed description are invited to write for the Center's *Research Report* and cumulative publications list.

PROBLEMS OF ECONOMIC AND POLITICAL DEVELOPMENT

As in the past, much of the Center's research effort has been devoted to studies on problems of economic and political change in developing

countries around the world. One of the major products of the Center's long association with India was completed this year, a book by Professor Richard S. Eckaus and Dr. Kirit S. Parikh entitled *Planning for Growth: Multi-Sectoral, Inter-Temporal Models Applied to India*. This study rests on the premise that economic planning can be significantly improved by employing modern computer techniques to evaluate theories of development and to test the effects of alternative policy choices. Linear programming models have been designed to analyze the mobilization and optimum use of resources, taking explicit account of intersectoral and intertemporal relationships. While primarily a pilot study of the potentialities of linear programming techniques in development planning generally, the book also provides new insights into Indian economic policy by applying the models specifically to the Indian case. Also published in the Center's series on economic development in India were Stephen A. Marglin's *Public Investment Criteria*, and *Investments for Capacity Expansion: Size, Location, and Time-Phasing* by Alan S. Manne and several collaborators.

Although the Center intends to maintain an active interest in Indian matters, our economic development research over the next several years will deal primarily with Chile. Plans have been laid for a long-term research program to be carried out in collaboration with the Chilean Office of National Planning. Work will be done on a variety of problems relevant to Chilean economic growth, including further research by Professor Eckaus on the planning models described above. Also centrally involved will be Professors Max F. Millikan and Paul N. Rosenstein-Rodan, both of whom travelled to Santiago during the spring for consultations with Chilean officials. In addition to the research program, several Chileans are expected to come to Cambridge each year for research and training.

This new Chile study is a further sign of the Center's growing interest in Latin America. Published results have now begun to appear from a series of studies on social and economic change in Venezuela which have been conducted in collaboration with the Centro de Estudios del Desarrollo (CENDES) of the Central University of Venezuela in Caracas. Three volumes are in preparation, all concerned with one or another aspect of the feasibility and relative social cost of alternative strategies of development for Latin American transitional societies. The first book, by Associate Professor Frank Bonilla and José A. Silva-Michelena, is entitled *A Strategy for Research on Social Policy* and will appear in the fall. It contains the diagnosis of Venezuelan problems on which the study was based, an explanation of the research strategy devised to analyze these problems, and information on how the research design was implemented.

Professor Bonilla has been writing the second volume of the series, based on interviews with 200 leaders of Venezuelan business, political, and cultural life; the result will be a detailed report on elite formation and elite functions in transitional social systems. The third study is being written by Silva-Michelena, who has been analyzing the data gathered from survey samples of 35 groups in the Venezuelan political culture; this analysis is aimed at identifying and classifying sources of alienation and antagonism within the society.

Under the direction of Professor Frederick W. Frey, the Center has taken the first steps in a major comparative analysis of the attitudinal and behavioral dimensions of the modernization process. The initial stages of what is expected to be a five-year study have been devoted to collecting bibliographical and other background material and to working on the selection of the five countries in which comparative surveys are to be made. Professor Frey and James L. Dorsey, Administrative Officer of the Center, spent several weeks in Europe and in Asia discussing the project with individual scholars and representatives of research organizations. By selecting countries for maximum diversity of size, cultural homogeneity, and economic development, the project hopes to analyze those specific behavior patterns that distinguish the relatively "modern" individual, the attitudes and orientations that lie behind such behaviors, and the background and experience that shape these attitudes. Among the objectives of the project are to provide accurate, cross-culturally comparable information on fundamental attitudinal, behavioral, and social structural processes of social change and "modernization"; to provide country-specific information based on large national population samples in several important nations; and to establish a baseline for additional cross-national comparisons.

Mention should also be made of individual studies on aspects of development being carried out by other Center political scientists. Professor Lucian W. Pye has completed the manuscript of a book on *The Spirit of Chinese Politics*, a psycho-cultural study of Chinese political culture that focuses particularly on the attitudes most relevant to determining the successes and failures of the Chinese Communists in modernizing their country. In exploring the authority crisis he believes to underlie China's development problems, Professor Pye has called upon his broad comparative understanding of the development process as well as his specific knowledge of communism and of the Chinese scene. Another specialist on Asian affairs, Professor Myron Weiner, has turned his attention this year to Europe. As part of a wider theoretical and comparative study of political participation and political organization in the development process, he has been examining the writings of earlier Euro-

pean social theorists and relating their ideas, and some hypotheses derived therefrom, to historical data from the evolution of western and eastern Europe. Professor Weiner's book on the Indian Congress Party, *Party-Building in a New Nation*, is to be published in the fall.

Two other Center-sponsored books on development problems are in press. Professor Millikan and David Hapgood have collaborated on *No Easy Harvest*, a book based on the report of a summer study conference on agricultural productivity organized by the Center. This conference brought together 45 individuals of different academic disciplines from governmental and international agencies and from major operational programs of agricultural development in the developing countries to explore the problems of agricultural development. The book is essentially a tool of analysis — a method of approaching agricultural policy — and if the response to the conference report is any indication, it will be received with interest by international and governmental planning agencies.

Dr. Archibald Callaway's study examining the Nigerian educational system as an integral aspect of development planning has resulted in a coauthored report (with A. Musone) — titled *Financing of Education in Nigeria* — which will be published in Paris by UNESCO's International Institute for Educational Planning. Dr. Callaway has also continued his work on the related problem of school-leavers and employment opportunities in Nigeria.

STUDIES IN INTERNATIONAL COMMUNICATION

A gradual shift in emphasis from study of the Soviet communication system to that of China and other parts of Asia has been taking place in the program on communication and international security being conducted under the direction of Professor Ithiel de Sola Pool. The most important accomplishment of the past year has been completion of the programming of a computer model that permits quantitative and qualitative estimates of the spread of information in a country, including an identification of which groups of people are reached by the communications networks and what things they choose to believe.

The computer model has been extended to handle statistical analysis of communications during crises; intensive analyses have been made, for example, of messages received by the Soviet population during the Cuban missile crisis and after the Kennedy assassination. A number of monographs on mass media communications — radio, television, movies, and newspapers and magazines — in Communist China and in the Soviet Union, as well as on computer simulations of these communication systems have already been completed, and others are currently under way.

An experiment in computer methods for handling large social science data files, also under Professor Pool's direction, has resulted in the successful development of a data analysis system called ADMINS, constructed by Professor Pool, Associate Professor James M. Beshers, Stuart D. McIntosh, and David M. Griffel. This system permits social scientists to work simultaneously on data from a whole library of data, rather than on single studies. One of its major advantages is that it permits social scientists who do not know computer programming to work on-line on the computer. The system is already in operation and is being used to analyze data compiled in several Center-sponsored studies.

Professor Daniel Lerner has been putting into the ADMINS system the data gathered from his ten-year comparative survey of French, German, and British elites as well as his 1965 survey of the top administrative staff of the European Communities. He is now in the concluding phase of this project and has begun to draft the final reports. One volume will be a detailed analysis of all the data, to be written jointly by Professor Lerner and Dr. Morton Gorden; another will contain the data base of the project. The analyses of the shifting consensus and dissensus within and among the major European allies of the United States, projected into the future, should be relevant to the interpretation of current political difficulties and should give a better understanding of the interaction between attitude change and changes of policy.

Professor Harold R. Isaacs has continued his series of books on group identity and political change with the appearance of *American Jews In Israel*. This study was preceded by *India's Ex-Untouchables* and will be followed by reports on the Chinese in Malaya and on Filipinos. A further case study along the same lines, of the Chinese in the United States, was begun this year by Dr. Ai-li Chin who will work in cooperation with Professor Isaacs. Dr. Chin will examine the current experience of Chinese in this country, focusing especially on generational patterns and family life as they reflect shifts of identity patterns that are both Chinese and American.

STUDIES IN FOREIGN POLICY AND DEFENSE

Professor Lincoln P. Bloomfield and Amelia C. Leiss have completed a major two-part report on the problems of controlling local wars within and among developing countries. This study brings together a body of research on the political problems of these areas and the insights offered by studies of arms control. The first part is a design study which develops a model of local conflict and identifies the phases of conflict and the varieties of control techniques that might be used in these phases. The second part contains case studies of recent conflicts, in each instance

applying the theoretical model to an analysis of the development and outcome of the conflict, particularly as it relates to the United States' interest. Professor Bloomfield and Miss Leiss have begun work on two related arms control projects — the first, a study of the effect on developing nations of arms transfers, and the second a study, through the use of political-military gaming techniques, of policy dilemmas posed by the control of local conflict. A third related study, to be conducted by Professor Emile Benoit of Columbia University with the collaboration of Professor Millikan, will examine the effect of national defense programs on the economies of developing nations.

In the course of the past year Professor William W. Kaufmann and Associate Professor Fred C. Iklé have continued to develop a training and research program dealing with political-military problems of the United States. In this connection, the Center sponsored a conference at Endicott House on the state of the art in defense analysis, concerned mainly with the role of systematic analysis in government policy and the relationship between military estimates and various aspects of foreign policy. Three papers stemming from this conference have been published so far. First steps have also been taken to develop case studies and other materials for strengthening the teaching program in defense studies. Work has been carried out by graduate students on RAF calculations before World War II about the outcome of a German air attack on England, on the evolution of a Multilateral Nuclear Force for NATO, on analyses of nuclear propulsion for the surface fleet, and on fast deployment logistics of ships. Professor Kaufmann has written several papers on various aspects of defense research.

Professor Iklé is engaged in a study on war termination and has also begun an analysis of the role of intuitive judgments in policy analysis. This latter study is designed to explore how analytical reasoning and intuition fit together, what the different forms of intuitive reasoning are, and how the combination of analysis and judgment is affected by bureaucratic forces within the government.

STUDIES IN INTERNATIONAL COMMUNISM

The Center's program of studies on international Communist affairs has continued to focus on the implications of the Sino-Soviet dispute, and especially its impact on Communist parties around the world. Ten books have now been published in this series, including four during the past year. In *Sino-Soviet Relations, 1964-1965*, Professor William E. Griffith, director of this research program, provided a detailed analysis and documentation of the recent history of the dispute. Three other volumes dealt with the Communist movement in other parts of the world: Douglas

Pike's widely reviewed study of the Vietcong, François Fejto's book on the French party, and Stephen Fischer-Galati's analysis of the political dimensions of Rumania's new independent stance. Two other studies are in press, by J. M. Montias on the Rumanian economy and by Assistant Professor Donald L. M. Blackmer on the Italian Communist party. Published recently was *Cuba: Castroism and Communism 1959-1966* by Andrés Suárez.

Ernst Halperin, author of an earlier book on Chile, spent most of the year in Brazil working on a study of nationalism and communism in that country. Professor Griffith was based in Munich doing research on West German relations with East Germany and the other East European states. In residence at the Center were Professor Uri Ra'anan, studying Soviet relations with the third world, and Francis J. Rendall, who is writing an analysis of the origins of the Sino-Soviet dispute.

MAX F. MILLIKAN

EXTRACURRICULAR ACTIVITIES

DRAMA

During the 1966-67 season Dramashop presented two one-act plays on four occasions. These one-act productions, increased by popular demand to two evenings, were directed, designed, and entirely produced by students, presented free to the M.I.T. community and followed by audience critique with the entire company on stage. The one-act plays are generally selected from among contemporary playwrights. This year's program included: W. B. Yeats' poetic dance drama, *At the Hawk's Well*; Thornton Wilder's *The Long Christmas Dinner*; a Ferlinghetti happening, *Servants of the People*; the Don Juan in Hell scene from Shaw's *Man and Superman*; Harold Pinter's *The Lover* with Murray Schisgal's *Windows*; and lastly, Terence Rattigan's *The Browning Version* and *The Chairs* by Eugene Ionesco.

The major production of the first semester, presented in December, was G. B. Shaw's *Heartbreak House*, produced and directed by Professor Everingham. In April, Dramashop presented Maxim Gorki's *The Lower Depths*.

At the request of the Religious Counselors, a small company of Dramashop actors formed The Chapel Players and performed a series of dramatic readings of modern plays at the M.I.T. chapel in conjunction with regular Sunday morning religious services.

The Director and his staff have given informal support and assistance to M.I.T. theatrical productions organized by students, including the

annual Tech Show, the Gilbert and Sullivan Society program, and various performances by students who present theatrical pieces in their own dining halls and lounges.

The Celebrity Series this year was limited to the presentation of two performances of contemporary dance which Dramashop cosponsored with the Dance Circle of Boston. The program included new dances by Gus Solomons (M.I.T. '28, who is now a professional dancer in New York), M. Remy Charlip, and Mrs. Anne Tolbert.

During the past year approximately 150 students participated actively in all departments of production sponsored by the Dramashop.

JOSEPH D. EVERINGHAM

MUSIC

A great number of concerts took place at M.I.T. during the last season. They were sponsored by various organizations and ranged from internationally famous artists to student ensembles.

Groups that performed in the M.I.T. Humanities Series, coordinated by Professor Gregory Tucker, were the Drolc Quartet, the Hungarian Quartet, the Borodin Quartet, the New York Chamber Soloists and the Beaux Arts Quartet.

Artists who performed in the Organ Series in Kresge Auditorium were Peter Hurford, St. Alban's Abbey, England; Robert Anderson, Southern Methodist University; Anthony Newman, St. Gabriel's Monastery, Brighton; Robert Baker, Union Theological Seminary, New York; André Marchal, Paris; and Francis Jackson, York Minster, England. André Marchal performed two Handel organ concertos with members of the Cambridge Festival Orchestra conducted by Klaus Liepmann.

The monthly Sunday afternoon series of organ recitals in the M.I.T. Chapel was dropped this year, since attendance had been very poor for the last few years. Instead John Cook established as an experiment a series of weekly concerts at the noon hour on Thursday. The programs naturally focused on the use of the organ, but they also included instrumental ensembles and vocal performances; much use was made of the M.I.T. harpsichord. Admission to these concerts was free, and most of the performing was done by music students at M.I.T. and in the Boston area. The series was a great success and will be continued in 1967-68.

The Chamber Music at M.I.T. concerts (formerly the Library Concerts) were held in the Sala de Puerto Rico in the Student Center and were coordinated by Professor Gregory Tucker. Artists who performed in these concerts were Sonya Monosoff, violin, and Gregory Tucker, piano; Jean and Kenneth Wentworth in works for piano, four hands, by contemporary American composers; the Pacific String Trio; Thomas Simons, piano; Joan Trachtman, soprano, with Phillip Oliver, piano;

John Sandor, piano, Erica Brown, violin, and Karl Kornacker, cello; Kai Moser, cello; and Paul Matthen, bass-baritone, in Schubert's *Die Winterreise*.

The Lenox String Quartet, members of the Dorian Wind Quintet, Paul Jacobs, harpsichord, and Michael Rudiakov, cello, all performed in a concert of the music of Elliott Carter, Visiting Professor of Music at M.I.T. The works played were *Eight Etudes and a Fantasy for Wood-Wind Quartet* (1950); *Sonata for Flute, Oboe, Cello, and Harpsichord* (1952); and *String Quartet No. 2* (1959). The Abramowitz Memorial Lecture Series presented this concert.

The birthday of J. S. Bach was celebrated with an all-Bach harpsichord recital by Gustav Leonhardt of Amsterdam, Holland.

In May Professor Tsai-Ping Liang of Taiwan and his daughter Miriam Liang, an information chemist at M.I.T., gave a concert-lecture on the cheng, a zitherlike stringed instrument originating in China in 221 B.C.

The M.I.T. Symphony Orchestra, conducted by David Epstein, gave two concerts this year. Its first program in December consisted of the Boston premiere of Johan Helmich Roman's *Drottningholms-Musique*, the Boston premiere of Leos Janacek's *Sinfonietta*, and Beethoven's *Violin Concerto*, with Joseph Silverstein, concertmaster of the Boston Symphony Orchestra, as soloist. The second program, which was also played on tour at Goucher College in Baltimore and at Douglass College in New Brunswick, New Jersey, consisted of Bach's *Brandenburg Concerto No. 4*, the Boston premiere of Roberto Gerhard's *Dances from Don Quixote*, and Dvorák's *Symphony No. 4* in G major.

Under the direction of Klaus Liepmann, the M.I.T. Glee Club gave several concerts both at M.I.T. and at other colleges and universities. Works performed were Purcell's *King Arthur* at Vassar, Hindemith's *Apparebit Repentina Dies*, and Milhaud's *Les Choéphores* with Smith.

The M.I.T. Choral Society, also under the direction of Klaus Liepmann, gave two concerts this year. The first was a performance of the Verdi *Requiem* and the second a performance of Haydn's *Seasons*. In both concerts the Choral Society sang with soloists and 48 members of the Boston Symphony Orchestra.

The M.I.T. Concert Band, conducted by John Corley, gave several concerts both at M.I.T. and away. Most of these concerts featured contemporary American music written for concert band.

Participants in the Sixth Spring Festival of Music were the Glee Club, the Choral Society and the Concert Band. Works performed in the Festival have been mentioned above.

The Baton Society presented the Chamber Symphony of Philadelphia.

KLAUS LIEPMANN

ALFRED P. SLOAN SCHOOL OF MANAGEMENT

If I were to select one dominant characteristic of the School over the last year, it would be a spirit of confident self-examination. The School now completes its 15th full year of operation. All who are associated with it take pride in its achievement during this comparatively brief period under the leadership of my predecessors, Edward P. Brooks and Howard W. Johnson. Good fortune, as well as wisdom, played some part in our progress, for the School was launched just in time to catch the new wave in management research and education generated by the application of discipline-oriented, rigorously analytical methods to management problems. So much for the good fortune; the wisdom lay in sensing this movement and in bringing together a quality faculty and providing them with freedom and encouragement to pursue their individual research interests. It may be useful at this point to identify and attempt some classification of these interests as a means of appraising where we now stand.

One major cluster of our faculty concentrates its research efforts on the broad problems of organizational effectiveness. This is an able group of men, internationally distinguished for their contributions to organization theory. The planning of change, the transfer of knowledge across organizational and cultural boundaries, organizational influences on attitudes and values of young managers, and the whole range of issues involved in "the human side of enterprise" are being illuminated by the work of the behavioral scientists in the School. A new but important area in the organization field and one central to M.I.T.'s interest as a whole is the research in progress on the management of science and technology. Within this broad area projects have been focused on fac-

tors influencing the effectiveness of individual researchers, of project teams, and of laboratories.

A second important cluster of faculty are those whose focus is the field of finance. This group is clearly a distinguished one. Its interests are broad, ranging from portfolio management of financial institutions to the impact of monetary policy on demand, and including work in capital budgeting, structure of capital markets, measurement of the cost of capital, and the interaction of corporate policy and the national tax system.

A third group are those men who have been distinguished for their work in industrial relations and manpower development. A principal current focus of their interests is on the implications of technological change and automation for the structure of the work force and the organization of the enterprise.

A fourth cluster consists of those faculty members whose interests are in management controls, information systems, and operations management. Aided by M.I.T.'s powerful computer facilities, they have been involved in pioneering work in the application of the computer to management systems. They have provided an important stimulus to the development of new tools and analytical techniques for control and for managerial decision making.

A fifth major group includes those men who are in the vanguard of a new approach to the study of marketing, again through the application of quantitative methods and computer techniques. Particularly promising is research in the development of marketing-oriented management information systems and the effective use of the computer in the simulation of market behavior.

These are the groups within the faculty concerned with the problems of immediate interest to management. Sources of great strength in the School, however, are those members of the faculty who concentrate on applied mathematics and statistics, on industrial history and industrial economics. They lay a groundwork for our students in the disciplines underlying decision making and instill a breadth of view of our economic and social institutions that is invaluable.

I began this report with the comment that the dominant characteristic of the last year has been one of self-examination. My primary purpose in identifying our faculty strengths and interests is to give some qualitative indication of where we stand now, 15 years after the founding of the School. This description is more than my personal assessment, however. It is one of the products of a faculty review of the School's teaching and research programs, begun during the last year. Although this exercise is not yet finished, it has already indicated that the basic strategy which

the School has been following is sound. We shall continue to search for faculty members of exceptional quality and to make constant effort to provide them with an environment in which they can do their best work. We shall continue to ground our research and teaching on the fundamental disciplines, and we are convinced that the computer and rigorous analysis will play an increasingly important role in research, in teaching, and in management decision making.

Nevertheless, our self-examination of the last year does suggest that it is appropriate for the School to broaden its interests and competences at this time. A number of considerations suggest that the School should modify its commitment to the problems of industrial management. First, it is becoming clear that the management of hospitals, educational institutions, cities, government agencies, and other non-industrial organizations is an increasingly visible and important problem in our society. Second, it is also becoming clear that the basic approach to problem solving developed in the context of industrial management problems is to a considerable extent applicable to more general management situations. Third, career opportunities in management are beginning to develop in non-industrial organizations; these will require and deserve men of the quality of Sloan School students with good training in management. And fourth, research opportunities in non-industrial organizations are beginning to attract and hold faculty interest. For all these reasons, the educational and research objectives of the Sloan School over the coming years will be somewhat different from those of the past.

None of these considerations should be interpreted to mean that the Sloan School will reduce its interests in the problems of industrial management. This field continues to stimulate important research work. It provides, and will in all likelihood continue to provide, the best base on which to construct a management curriculum. And, at least at present, industrial organizations are better prepared (largely as a result of the inputs of schools of management) to accept the conclusions of management research and to utilize the talents of graduates of the Sloan School than are their non-industrial counterparts.

The field of industrial management continues to evolve and reveal new problems. Thus, even if the School were to limit its interests to this area, some changes in its operation would be required during the coming years. But because a revision in basic strategy is also planned, it is difficult to imagine any aspect of its operation that will not require substantial modification if the School is to maintain the position of leadership in the field of management research and education that it has earned during the first 15 years of its existence.

UNDERGRADUATE PROGRAM

In my last report, I described the extensive and imaginative changes proposed by the Undergraduate Program Committee, chaired by Associate Professor Edward B. Roberts, for Course XV, the School's program for undergraduates. A new curriculum incorporating the proposed changes was approved this year, and it was implemented with the Course XV sophomore class. The core of the new curriculum is a group of four required subjects covering the fundamentals of management: Introduction to Management, Managerial Economics, Managerial Psychology, and Business Environment. Beyond this core, each student chooses one of four optional paths for career development: Behavioral Science in Management, Management Science, General Management, or the flexible Special Programs in Management. Each option comprises a combination of required and elective subjects that permit the student to study some area relevant to management in depth.

The entire curriculum was designed to emphasize flexibility in meeting the educational goals of individual students and to create a high level of motivation among both the students and faculty. In particular, the Special Programs option charges the student with prime responsibility for designing his own educational program and for recruiting a faculty advisory group to work with him. This option is designed for the student with high motivation for self-development and is intended to develop an entrepreneurial orientation.

Throughout the new program the thrust has been toward a rethinking of traditional ideas about management education. New subjects have been designed for the core curriculum as well as for each of the optional educational paths. For example, during the last year Professors Billy E. Goetz and Roberts joined in a "team teaching" experiment in the sophomore introductory course, itself experimentally based on a business policy text usually taught to seniors. Associate Professor Paul W. MacAvoy has been preparing for fall term implementation of a major redesign of his managerial economics course. In addition, Assistant Professors Thomas J. Allen and Irwin M. Rubin have designed a series of undergraduate subjects in behavioral sciences, working under the leadership of Professor Warren G. Bennis. In the areas of operations research, computers, and management science Professor John D. C. Little, and Associate Professors Donald C. Carroll and Gordon M. Kaufman have integrated materials from their previously separate elective subjects into a comprehensive package, supplemented by new subjects designed especially for the Course XV undergraduates. Finally, in the general management area Professor Thomas M. Hill, Associate Professor Leo B. Moore, and Herbert Goodwin have been able to combine formerly separate

functional subjects and strike out on new ground in their plans for subject work to link management theory and practice more closely.

Another innovation embodied in the new curriculum is an emphasis on development of effective communication skills, in recognition of the importance of such skills to the future manager. During the spring term Sanford Kaye, jointly appointed as Lecturer in the Schools of Management and Humanities and Social Science, worked with the new sophomore class in developing its writing capabilities. Further emphasis on written and oral communication is planned in the coming year.

The cumulative effect of all these changes is twofold. To the School's faculty and students alike, they represent a reinforced commitment to the importance of the undergraduate in Course XV. The educational resources of time, attention, and money being devoted to undergraduate management education should reassure Course XV's large and successful alumni group that we shall continue to take a leading role in M.I.T.'s undergraduate life. Increased sophomore enrollments, 40 students compared to 33 the year before, and greater attendance at Course XV's departmental undergraduate presentations suggest that we are on the right track, and lend us optimism for the future of Course XV.

THE MASTER'S PROGRAM

The year just past has been a good one for the School's Master's Program. Eighty-two degrees in all were granted. More applications were received — over 600 — than ever before for the 100 places in the first-year class. The quality of our students by all measures continues to be very high. One of those measures certainly is the demand for their services by American industry, whose representatives visited the School in record numbers and offered salaries at record highs. The scientific or technical undergraduate education possessed by most of our students, combined with the Master's degree in management is a powerful educational combination that meshes well with the rising corporate interest in management information systems, computer applications, and advanced quantitative approaches to managerial problems.

Our Master's Program continues to be, in comparison with most such graduate degrees in management, a highly flexible one. While we require a core understanding of the principal disciplines underlying managerial decision making, the economic and social environment in which those decisions are made, and the relevant theory in the business problem areas, we do not require that the student learn it "our way." If he comes to us already prepared in a particular area, he can move on to more advanced work. Nor are we overly specific about the sequence in which the student must take his subjects, and we give him wide

latitude to elect a program most relevant to his long-term interest from the whole range of subject offerings at M.I.T. for which he may qualify. We encourage the Master's student to associate himself with the research of the faculty, perhaps through his choice of a thesis topic or, for those who qualify, through appointment as a research assistant.

The Master's Program is strong by all the measures we can find, but it has become what it is because we have worked hard on its design. In order to assure its continued strength, we began to evaluate some of these questions during the past year: Are we overemphasizing the quantitative solution to the exclusion of the intangible, non-quantifiable elements in the problem? Are we appealing sufficiently to the student with entrepreneurial interests? Are we educating potential managers, or management specialists? Are we involving and exciting our students too much with the research of the faculty, to the exclusion of an action orientation? What attitudes and values, apart from knowledge and skills, are we or should we be imparting to our students? Are we teaching our subjects as discrete packages of knowledge, leaving too much of the integration to the student? Are we failing to involve the student sufficiently in the life of the School so that he has a sense of identity, participation and commitment here?

The answer to all these questions, of course, may be that in our best judgment we are on exactly the right track and should continue our efforts. To stimulate the search for an answer, I have asked Assistant Professor Arnold A. Amstutz to assume the leadership of the Committee on the Master's Program and to devote substantial effort with that Committee over the next year in a careful examination of every facet of our Master's Program, including admissions, curriculum, faculty-student interaction, and student environment. I plan to report next year on the outcome of the work of the Committee, confident that it will make a major contribution to the quality of this program which is central to the School's interest.

THE DOCTORAL PROGRAM

Since the beginning of the Doctoral Program in Management at M.I.T. in 1960, 35 degrees have been awarded. Of these, 13 were granted this year. It is expected that another 25 students will complete all their work toward the degree by September of this year. After the long years of buildup, we believe we have now reached the position where the annual output of men with the Ph.D. in management should approximately equal the annual input, less, of course, the voluntary and involuntary attrition. The major fields of the men receiving the degree this year give some indication of the breadth of the School's interests. They include management information systems, managerial organization, operations

research, computer science, corporate finance, operations management, international business and the management of research and development. The majority of these men are joining university faculties. Stanford, Harvard, Purdue, U.C.L.A., and M.I.T. are among the institutions at which these men have accepted appointments. A few are joining companies or consulting firms.

Twenty-two new doctoral students will enter the School in September, a number somewhat larger than planned, but the quality of the applicants was so high that we found it very difficult to draw the line below this number. Of those admitted, nine will be entering from the Sloan School Master's Program. Some 60 per cent will have had backgrounds in engineering and the physical sciences, with the balance scattered among economics, law, and the liberal arts.

Doctoral candidates in residence were highly successful in fellowship competitions this year, with eight receiving Ford Foundation Fellowships, one winning a National Science Foundation Fellowship and another the Richard D. Irwin Fellowship.

Given the large numbers of our doctoral students whose career goal is membership on a university faculty, one of our continued objectives must be development of teaching skills on the part of our doctoral students. This presents a problem, because the road to the doctorate in preparation for general examinations and completion of the thesis is a long one. Nevertheless, well over half of those receiving their degrees this year have assumed full responsibility for teaching one or more graduate subjects, and we are confident of being able to increase this proportion.

The School continues to emphasize the interdisciplinary character of its Ph.D. All entering students are expected to have or to acquire the broad knowledge of the business process as represented in the first year's work in our Master's Program. They must have a familiarity with the principal theories and the literature of the major disciplines underlying the study of business management. This year marks the introduction, as well, of required doctoral seminars in the disciplines, which are designed to develop the student's capacity for research across field boundaries. Thus the basic structure of the School's interdisciplinary doctoral program is now well established.

Within this framework, of course, the student is expected to select a major applied field representing his primary research and teaching interest. The number of such options open to students will continue to grow as new fields emerge and as faculty strength grows. This year, for example, Professor Jay W. Forrester and his colleagues have evolved within the structure of the Sloan School Ph.D., an option to develop a

high order of competence in research in the applications of industrial dynamics.

In addition, the School intends always to be sufficiently flexible to accommodate the needs of able doctoral students whose interests bridge the traditional fields, and who are prepared to take on a rigorous program of study tailored by the faculty to meet those interests.

Finally, let me note that beginning with degrees awarded in February of this year, the Ph.D. earned within the Sloan School is a Ph.D. in Management. "Industrial" has been dropped from the specification of the degree as an unnecessary and misleading modifier. The School's interests embrace substantially more than industrial enterprises; we are persuaded that the theories, tools and skills being developed here and in other comparable schools have relevance to the management of a wide range of enterprises — commercial, industrial, governmental, educational — and that we should broaden our curriculum and open our doors to students with matching interests.

THE SLOAN FELLOWSHIP PROGRAM

Under the vigorous direction of Dr. Peter P. Gil, Associate Dean for Executive Programs, the Sloan Fellowship Program continues to attract applicants from an increasingly diverse group of organizations. In recent years both the content of the Program and the composition of the student class have widened in scope as the proportion of Sloan Fellows from public-sector and international organizations has increased. The 46 Sloan Fellows receiving their Master's degrees in 1967 represented 43 organizations from six countries, including seven men from public-sector organizations.

The backgrounds of the 1967-68 class of Sloan Fellows are equally diverse, nine countries and 41 organizations are represented, including ten men from the public sector. The number of applications for the Program continues to grow, and the quality of applicants continues to be of a very high order. Of this incoming group of Sloan Fellows, more than a third have Master's degrees and two have Ph.D.'s.

During the last year the Sloan Program Evaluation Committee, chaired by Stanley M. Jacks, performed a thorough review of the Program to seek ways for maintaining or improving its already high quality. As a part of this review, the Committee interviewed a group of Sloan Fellow alumni from the classes of 1957 to 1963 to obtain feedback on the Program from their vantage points. The feedback was both reassuring and helpful, and it encouraged several members of the faculty to explore further systematic means for drawing upon the Sloan Fellows alumni as part of the Program evaluation process.

An important innovation introduced during the year was a subject to develop the writing skills of the Sloan Fellows as a preparation for the writing of their theses in the spring term and as a part of their broader education.

An effort was made in developing the subject to avoid the superficial and to deal with written communication at the conceptual level. The subject, introduced experimentally last year, taught in a problem-solving, decision-making framework, seemed effective in meeting the Sloan Fellow's needs. It will be incorporated, with some improvements, in the 1967-68 Program.

The schedule for the spring term was made more flexible this year, permitting the Fellows a wider choice of electives and an opportunity to pursue topics of special interest. The Fellows have used this opportunity well, taking elective courses not only at the Sloan School but also at Harvard and elsewhere within M.I.T.

Sloan Fellow Robert F. Calman of Mobil Oil Corporation was this year's winner of the E. P. Brooks Prize for the outstanding Master's thesis, the third Sloan Fellow so honored in the past eight years, for his thesis entitled "Cash Alpha: A Linear Programming Approach to Banking Relations."

PROGRAM FOR SENIOR EXECUTIVES

The Program for Senior Executives, now celebrating its tenth year, is directed toward the seasoned executive whose decisions will affect the policies and direction of his organization substantially. The Program provides the opportunity for a "Senior" to re-examine his ideas and attitudes on management, decision making, and policy issues through an intensive nine-week period of interactions with faculty members, policy makers in governmental positions, and with other Seniors of diverse backgrounds. The Seniors attending the sessions of fall, 1966, and spring, 1967, ranged from 37 to 52 years in age, and represented nine countries, 25 industries, and 50 organizations. Over a third of the roughly 27 men in each session had advanced degrees, seven in the fall session were Ph.D.'s. The three-day trips to Washington, D.C., an important innovation of last year, were continued this year. The Seniors again responded enthusiastically to the rugged schedule of meetings in Washington with government leaders in the Cabinet, the Congress, advisory groups, and regulatory agencies. The School is grateful to the Brookings Institution in Washington for arranging these meetings and for helping to prepare the Seniors for them. The Program remains strong, and the number of applications for the limited openings continues to mount. As a result, the calibre of the participants continues to increase, but allocation of open-

ings in the Program, held at about 27 openings per session, the size of working group we consider optimal, is becoming more difficult, and loyal supporters of the Program must sometimes be disappointed.

THE GREATER BOSTON EXECUTIVE PROGRAM

This year marked the tenth anniversary of the Sloan School's participation in the Greater Boston Executive Program, a joint venture conducted annually with our Boston neighbors to provide executive development opportunities for mid-career executives. Currently, the Program consists of 15 full-day sessions held once each week during the spring. Enrollments have been limited to 25 men, typically ranging from 30 to 50 years of age. A committee of six of Boston's leading executives administers the Program, with Dr. Gil acting as Program Consultant. In addition to Dr. Gil's services, the School provides faculty members and facilities for the Program. Applications for the Program continue to grow, evidence that the Program is addressed to a real need in the community. The Sloan School is pleased to assist in meeting this need.

SUMMER PROGRAMS

The Sloan School was again an active participant in the M.I.T. Summer Session, offering five two-week courses in management subjects. For the fourth consecutive year, Professor Zenon S. Zannetos and Associate Professor James C. Emery of the University of Pennsylvania presented their program, Concepts of Management Planning and Control Systems: Theory and Technology. Other programs repeated were Advanced Industrial Dynamics, presented by Professors Forrester and Roberts, and Assistant Professor Willard R. Fey; and Management of Research and Development, presented by Professors Roberts and Donald G. Marquis. Offered for the first time were the programs in On-Line Computation and Simulation, presented by Associate Professor Martin Greenberger and Malcolm M. Jones, James H. Morris Jr., and David N. Ness; and Computerized Simulation of Market and Competitor Response, organized by Professor Amstutz, assisted by Professor Little and Christopher R. Sprague. In addition, Assistant Professor Leon S. White was a co-director of the program, Introduction to Probabilistic Systems, offered by the Department of Electrical Engineering.

These summer session programs provide valuable opportunities for the interchange of ideas and research findings between our faculty and practitioners outside the academic world. The interchange subjects our work to a healthy scrutiny and allows us to transmit the results of faculty research in a most efficient manner to a select group of persons with the capabilities and influence to test and apply these ideas. We are pleased

with the continuing popularity of the School's summer session programs, and we plan to expand their number in the future.

ALUMNI AFFAIRS

The Graduate Alumni Association of the Sloan School of Management, formed for graduates of the regular Master's and doctoral programs of the Sloan School, was officially recognized by the Institute last fall, the culmination of several years' efforts by a small group of dedicated alumni. Last fall the Association held a workshop/banquet at the Sloan School, where they elected Mr. Arthur Alexander, S.M. '58, President, and Mr. Samuel Appleton, S.M. '57, Editor. They have since published a directory and the first edition of their bulletin.

The Society of Sloan Fellows, organized for the alumni of the Sloan Fellowship Program, successfully completed its fund drive to provide the total financial support of the Alfred P. Sloan Fellows Chair.

MANAGEMENT RESEARCH

Research on the problems of management is a vital underpinning to education for management. Research, teaching, and professional service to the community — the three major tasks of the School — are highly complementary activities. Research provides the content and the conceptual tools for compressing knowledge and expanding understanding. For example, the impact of systems analysis has provided a new language and a unifying conceptual framework for understanding a welter of diverse phenomena. Education is a complex process that cannot be confined to the classroom; the interaction of students and faculty involved in a research partnership is a most valuable educational adjunct to more formal instruction. Research nourishes fruitful contacts with the professional community and keeps our work relevant and tested. Equally important are the interactions among the faculty members themselves, which are encouraged by the research process. With these comments on the contribution of research to the vitality of our teaching, let me report on our research in progress.

ORGANIZATION STUDIES

An important segment of the School's research continues to be concentrated in the area broadly classified as organization studies. The spectrum of research conducted within this area is wide, ranging from studies of the individual and the determinants of his behavior to the design of organizations and the effects of alternate organizational structures on organizational effectiveness.

Assistant Professor David A. Kolb and William W. McKelvey studied self-directed change and the roles of goal setting and feedback in this process. Professors Bennis and Rubin directed studies of the process of transmitting aid, ideas, and practices across political and cultural boundaries; they based the studies in part on data from the M.I.T. Fellows in Africa and Latin America Program. Professor Mason Haire and James R. Miller substantially have completed a computerized simulation model of personnel flow in organizations to aid research on the management of human resources. Professor Edgar H. Schein is conducting research in several areas of direct concern to the School itself. He has studied the attitudes of the Sloan School faculty and the effects of the School's programs on the attitudes of students at the graduate and senior executive levels, has conducted a student-faculty seminar on the role of the faculty, and has conducted other research on educational dynamics. Assistant Professor Peer O. Soelberg completed his research of unprogrammed decision making and focused on the implications of organization theory as applied to management information systems. Professor Leo B. Moore and Herbert F. Goodwin pursued research on the management of improvement. They collaborated as editors of *Management Thought and Action in the Words of Erwin H. Schell*, a collection of the late Professor Schell's works, which was published this year.

MANAGEMENT OF SCIENCE AND TECHNOLOGY

A second major effort within the field of organization is the Research Program on the Organization and Management of Science and Technology, directed by Professors Marquis and Roberts and supported by grants from the National Aeronautics and Space Administration and other sources. Professor Marquis continued his research on group decision making under conditions of risk and uncertainty. He also joined Assistant Professor William H. Gruber on an interdisciplinary study of human factors in the transfer of technology, worked with Professor Rubin on analysis of the relationships between project organization and project performance, and continued his analysis of Project Hindsight data in search of variables influencing technological innovation. Professor Roberts, assisted by Herbert Wainer, continued his productive application of industrial dynamics techniques to the analysis of research and development (R & D) management, focusing on R & D contract award decision making and project performance, and on the formation and growth of new technical enterprises "spun off" from parent R & D efforts. Professor Allen conducted research on organizational aspects of information flow in science and technology. Assistant Professor George F. Farris studied the process of organizational problem solving, and the

relationships between the organizational factors related to the R & D function within a firm and the success of the firm's operations.

While the results of this group's research are far from definitive, their findings have challenged the "folklore" surrounding several of the techniques currently employed for contract awarding and project management and have revealed some issues for further investigation.

MARKETING

Research in marketing is progressing well on several fronts. Professor Amstutz continued his work on computer simulation of market and consumer behavior, focusing on development of a multiregional marketing game for use as a teaching device. Professor Little has undertaken design of an adaptive control system for use by marketing management and is developing mathematical models for the selection of advertising media. Assistant Professor David B. Montgomery conducted research on the application of probabilistic models for analyzing consumer behavior, and Assistant Professor Glen L. Urban has developed normative models for marketing decisions regarding new products and marketing mixes of existing product lines.

FINANCE

In finance, an active faculty continued a strong research program. Professor Franco Modigliani was on leave to pursue full-time research at M.I.T., directing, with Professor Albert Ando of the University of Pennsylvania, a project sponsored by the Board of Governors of the Federal Reserve System on the links between monetary policy and economic activity. Associate Professor Donald E. Farrar was also on leave as a recipient of a Ford Foundation Faculty Research Fellowship, pursuing his study of patterns of corporate financial behavior. Professor Edwin Kuh continued his work on econometric methods, including work on computer software for econometrics, and completed his study on the behavior of wages. Professor Daniel M. Holland continued his studies on the effects of taxation of land and of personal incomes of high-salaried individuals. Professor Paul H. Cootner continued his work on debt portfolios and hedging, and Assistant Professor Stewart C. Myers pursued his research on the effects of uncertainty on the valuation of securities.

MANAGEMENT OF OPERATIONS

Management research continues to be heavily influenced by the advent of today's large-scale computer systems, which have enabled the researcher to analyze increasingly complex systems and have facilitated an integrated approach to the management of operations. During the

last year several faculty members in this area extended their exploration of possible applications of computer technology to management problems. Professor Carroll continued his research on systems design for operational planning and control, collaborating in part with Professor Zannetos, who expanded his work on adaptive information systems. Assistant Professor Michael S. Scott-Morton examined the use of visual display terminals to permit the manager to communicate directly with a computer system and selectively retrieve and display combinations of stored data for decision making. In addition, Professor White further developed his simulation model of flow shop operations; Assistant Professor Wallace B. S. Crowston worked on decision network applications and scheduling problems; and Assistant Professor John F. Pierce continued his work on carrier dispatching models. Assistant Professor Jay R. Galbraith structured research problems in production smoothing and organization design.

The prospects for continued progress in this area were greatly buoyed recently by the receipt of a major grant from the Boeing Aircraft Company for research in operations planning and control systems. The research, to begin this summer, will be conducted as a team project with Professor Carroll as principal investigator.

INDUSTRIAL RELATIONS

A major interest in the area of industrial relations continues to be the impact of automation and technological change on organizations and the structure of the work force. During the year Professor Charles A. Myers published in book form his report of an M.I.T. conference on the Impact of Computers on Management and collaborated with Frazier Kellogg on a study of computer-based job-man matching systems. Assistant Professor David P. Taylor continued his study of the effects of worker displacement by a major urban renewal project. Professors Douglass V. Brown and Abraham J. Siegel worked on a new industrial relations textbook, and Professor Theodore M. Alfred further developed his study of staffing practices of U.S. corporations.

QUANTITATIVE METHODS

From its inception, the Sloan School has been characterized by a quantitative orientation toward management studies, and the use of quantitative techniques is now well established in all areas of the School's research. Work in the quantitative methods area is concerned with expanding and refining the arsenal of quantitative techniques available to colleagues in other areas of research. This year such work included Professor Greenberger's development of on-line simulation capabilities

for time-shared computer systems, Professor Kaufman's research on problems of estimation and inference by Bayesian methods, Assistant Professor Jeremy F. Shapiro's work on mathematical programming, and Professor Sidney S. Alexander's investigation of theorem proving by computer.

OTHER RESEARCH

In addition to the research mentioned above, faculty of the School conducted research in business economics and history, international management, policy, and other areas. Professor MacAvoy explored the design economics of desalting plants and nuclear power systems, Assistant Professor Peter Temin studied the economic and political histories of the United States and Britain during the 1830's, and Professor Alexander probed some issues in the economic foundations of public policy. In the international area, Associate Professor J. Daniel Nyhart continued his research on development banking, Dr. Richard Robinson studied international joint ventures, and Associate Professor William P. Travis studied the European industrialization process. Associate Professor James S. Hekimian and Assistant Professor Otto H. Poensgen collaborated on a study of the relationship between organizational form and operating performance in business firms, and on a study of investor rationality during stock market downturns. Research continued on applications of industrial dynamics, and Professor Forrester worked on a new introductory textbook for the subject.

Last year I noted our research on education. This research continues on a small scale. Professors White and Zannetos are investigating applications of computers to curriculum design and programmed learning. And, as I mentioned earlier in this report, Professor Schein has conducted research on student and faculty attitudes, on the changes in attitudes of students passing through the School's programs, and on the sometimes conflicting roles of a faculty member. This research has raised some perplexing questions, but we feel the exercise has been worthwhile, and we will continue our studies of the educational process.

INTERNATIONAL PROGRAMS

The School's programs in other countries continued to evolve this year in response to changes in opportunities and commitments. For example, our direct participation in the development of the schools of management in London and Calcutta is being replaced by more informal collaboration among our faculties as these schools continue to mature. While program directions change, the orientation of the School clearly remains international. Before reporting in detail on these programs, let me touch briefly on some of this year's developments.

It is particularly gratifying for me to note the graduation of the first Master's class at the Indian Institute of Management, both as an event of great promise to India, and as an occasion to pay tribute to Professor Hill, Dean John M. Wynne, former Dean Howard Johnson, and the other individuals here and in India whose foresight and enterprise over the past several years have brought this important milestone to fruition.

Our Fellows in Africa and Latin America Programs have matured and will terminate in 1968 with the return of the last class of Fellows in Latin America. Studies are now under way to assess the impact of the programs on both the Fellows and their host countries. Concurrent with the maturation of these programs, however, there has been exploration and growth in other areas. Under the direction of Professor Nyhart we have undertaken a new program jointly with the National Bank for Economic Development (B.N.D.E.) in Brazil to strengthen the developmental banking system there. During the year we also sought and evaluated opportunities for several future international undertakings.

Our informal relationship with Colombia continues, and was manifested in a number of ways this year. Some of the first group of Fellows in Colombia have remained there to carry out new assignments developed through their own initiative. An active group of Colombian alumni of M.I.T. is making significant contributions to the progress of Colombia and is maintaining communication within the group. We are particularly pleased to note that a recent alumnus is serving as a special assistant to the President of Colombia. Also we were pleased to have the distinguished industrial leader, Manuel Carvajal, President of Carvajal & Cia, as our guest at the School this year.

LONDON GRADUATE SCHOOL OF BUSINESS STUDIES

The Sloan School continued its informal association with the London Graduate School of Business Studies and was host to two members of its faculty visiting here this year. The London School began its first two-year Master's Program in September, 1966, with a class of 36 students. Over 700 applications have been received for the 45 places available in September, 1967. The School's goal is to work up to 150 students in each of the two years, and to increase its faculty from the current size of 23 to 50. The London School has developed two programs for executives, offered annually: a six-week program for 20 senior executives and a 12-week program for 50 middle-management executives.

An Alfred P. Sloan Fellowship Program, supported by a grant from the Sloan Foundation and patterned on the lines of the Sloan Fellowship Program at M.I.T., will get under way in June, 1968, with 15 young

executives from the United Kingdom and the Commonwealth. The Director-elect of the London Sloan Fellowship Program, Charles Handy, spent a full 12 months at the Sloan School understudying the job of the M.I.T. Sloan Program Director. Enrolled as a Sloan Fellow during that period of time, he completed his course of studies successfully and was awarded a Master of Science degree in management this June.

Professor Marquis spent the fall term at the London School teaching organization theory, and we expect that exchanges of faculty between the two schools will continue.

INDIAN INSTITUTE OF MANAGEMENT

The Sloan School continues its collaboration, begun in 1961, with the Indian Institute of Management at Calcutta. The Institute, supported by the Government of India and the Ford Foundation, is one of two graduate schools created to meet India's growing needs for trained managers. Three M.I.T. faculty members are now on long-term assignment in Calcutta. Two will return this summer. The third, Associate Professor Barnard E. Smith, will remain for his third year of service and will be joined by another visiting professor from the United States.

The main emphasis of the Institute is on its two-year program comparable to the Sloan School Master's Program. The first class of 40 students graduated last year; a second group of 60 students will complete their two years this spring. The majority of these have been placed effectively in Indian firms. One hundred students will be accepted from about 1,600 applicants to begin the Program in the 1967-68 academic year thus providing a total two-year enrollment of 180 students.

In addition to the Master's level program, the Institute runs a 13-week program for middle management twice each year with an average enrollment of 30 per session. It has a number of short courses for executives in such areas as marketing, finance and accounting, operations research, and human relations. In addition, the Institute is responsible for the Advanced Management Program for senior executives of Indian firms, conducted in collaboration with the All India Management Association. Professor Hill and I will serve on the faculty of this Program in Kashmir this summer.

While the Sloan School has been and continues to be quite active in its collaboration with the Institute, this collaboration gradually is being reduced, and the responsibility for assignment of full-time faculty will probably end within two years. It is anticipated, however, that the informal ties between the two Institutes will continue to be strong long after the formal arrangements have been terminated.

INTERNATIONAL FACULTY FELLOWS

Joining us as International Faculty Fellows for a year of work at the School were several men associated with schools of management in India and the United Kingdom. They were Suresh Srivastva of the Indian Institute of Management in Calcutta; Bryan L. Davies of the Manchester Business School in England; Charles B. Handy, Director-elect of the London Sloan Fellowship Program at the London Graduate School of Business Studies; and Eric Newbigging, also of the London School.

M.I.T. FELLOWS IN AFRICA AND COLOMBIA

The M.I.T. Fellows in Africa Program was intended to place capable young Americans in positions of substantial responsibility in African governments in order to bridge the gap between the departure of large numbers of British Colonial Service officers and the education of African university graduates to fill such positions. In all, since 1963, 63 young men, many with families, have spent two years on a variety of assignments in 12 countries stretching from Sierre Leone on the west to the island of Mauritius on the east. The last group returns in the summer of 1967.

Two years ago we concluded that the gap would soon be filled by Africans and we should bring this unique program of technical assistance to an end before M.I.T. Fellows began to find themselves competing with Africans for the limited number of key positions in the ministries of finance, economic planning, commerce and industry, and development banks. The M.I.T. Fellows had become widely recognized for their standard of high-quality managerial performance in the public service.

Although each man contributed significantly to the government he served, the most enduring result of this whole exercise is the development and maturation of the M.I.T. Fellows themselves. Eight of the former Fellows are at work in the World Bank family of international development institutions. Several others are in the international departments of American firms. Altogether they are a remarkable group of young people, whose growth was accelerated greatly by their African experience.

In 1965 we started a smaller program in Colombia — one in which Fellows served in development banks or special government corporations. A second class of five Fellows went to Colombia in 1966, and with their return in 1968 this program will terminate. The economy of Colombia is, of course, far more advanced than any in Africa, and Colombia has been politically independent for nearly 150 years. After intensive instruction in Spanish, M.I.T. Fellows have moved into Colombian organizations, found useful applications for their managerial training — or failing that, have moved on their own initiative to more interesting

assignments. Two of the first class of four are making special studies for the Office of the President and for the Mayor of Bogota, himself an M.I.T. alumnus. The rapid development of the M.I.T. Fellows in the basically different Latin culture will produce some highly qualified young men to serve either in the United States or in Latin America. As these programs were drawing to a close, we felt a need for a critical evaluation of the whole exercise. Happily, several members of our faculty, sparked by the enthusiasm of Professor Bennis, have become interested in making such an evaluation. Begun about a year ago, this research should lead to a book at the end of 1968.

STUDENT AWARDS AND HONORS

I am pleased to note the following awards and honors achieved by students of the Class of 1967. The Brooks Prize in Industrial Management for the best thesis submitted for the degree of Master of Science in Industrial Management was awarded to Sloan Fellow Robert F. Calman for his thesis, entitled "Cash Alpha: A Linear Programming Approach to Banking Relations." Professor Cootner was the faculty chairman of Mr. Calman's thesis committee. Larry L. Constantine received the Sloan School of Management Senior Award for an outstanding senior in the field of management with high scholastic standing, leadership, and professional promise.

The President of the Graduate Management Society elected for the fall term was Paul Konnersman, and for the spring term, Tom Riesing.

The editors of the *Industrial Management Review*, chosen each year from among the second-year graduate class on the basis of high scholastic achievement, were Paul Bergsteinsson, Richard Daniels, and John Reid. Associate editors were William H. Byrn Jr., R. Douglas Hulse, Harry C. Lucas Jr., William Wade Jr., and Walter F. Zwick.

STAFF PROMOTIONS AND CHANGES

I am pleased to announce the promotion of John D. C. Little and Leo B. Moore to the rank of Professor, and the promotion of Arnold E. Amstutz and Otto H. Poengen to the rank of Associate Professor. Promoted to Assistant Professor were G. Anthony Gorry, Malcolm M. Jones, David N. Ness, John F. Rockart, and Christopher R. Sprague.

We are especially pleased to report that Professor Haire has joined our faculty as Professor of Organizational Psychology and Management, and will lead our organization studies group. Professor Haire has spent the past year as a Visiting Professor at the Sloan School, on leave from the Department of Psychology at the University of California at Berkeley.

Rejoining us during the year was Professor Marquis, who was on leave

for the fall semester as a Fulbright Senior Fellow and Visiting Professor at the London Graduate School of Business Studies. He returned this spring to resume, with Professor Roberts, direction of the School's Research Program on the Management of Science and Technology.

Several of our faculty spent the year on leaves of absence. Professor Farrar was on leave as a Ford Foundation Faculty Research Fellow. Professor Kaufman spent the spring term as Visiting Associate Professor at the Center for Operations Research and Econometrics, Université Catholique de Louvain, Belgium. He will rejoin the quantitative methods group in September. Michael J. Bower, Assistant Professor of Industrial History, spent the year as Visiting Professor of Political Economy at the Universidad del Valle in Cali, Colombia.

We look forward to having Professor Frederic Meyers with us next year as Visiting Professor of Industrial Relations, and Professor James S. Shulman as Visiting Associate Professor of Management. Professor Meyers will be on leave from the University of California at Los Angeles, Professor Shulman from Northeastern University. Joining us as Visiting Professor of Management will be Mrs. Lakshmi Mohan, on leave from the Indian Institute of Management in Calcutta.

Returning next fall from assignments at the Indian Institute of Management will be Miles Kennedy, Associate Professor of Management, and John M. Thomas, Assistant Professor of Organizational Psychology and Management.

Joining us this fall as Assistant Professor of Finance will be Jerry A. Pogue from the Carnegie Institute of Technology. Mr. Sanford Kaye has been appointed as Lecturer jointly with the Department of Humanities. This fall will also see the arrival of several newly appointed Instructors in Management. They are Gary L. Bergstrom, Kenan E. Sahin, Richard Schmalensee, and James W. C. Tomlinson. All are enrolled in the School's doctoral program except Mr. Schmalensee, who is working for his Ph.D. in the M.I.T. Department of Economics.

Completing their appointments here this year are Visiting Professor Charles H. Savage, who has accepted a post at the Harvard Business School, and Visiting Assistant Professor Wilbur G. Lewellen, who returns to the Herman C. Krannert Graduate School of Industrial Administration at Purdue University.

Several of the faculty have resigned their posts and, while we will miss these colleagues, they take with them our very best wishes for continued success and satisfaction in their new work. Professor Bennis will assume the duties of Provost of the Social Sciences and Administration at the State University of New York at Buffalo this fall. Professor Bennis served as head of the organizational studies group this year and directed

research on the Fellows in Africa and Latin America Programs. His contributions to this School and to the cause of the "human side of enterprise" have been many; we will miss him and the enthusiasm he engendered in others, and we wish him well in his new post. Professor Alfred has accepted a post as Professor of Management at Western Reserve University in Cleveland, Ohio. Professor Hekimian will become Dean of the College of Business at Northeastern University. Associate Professor Geoffrey P. E. Clarkson will join the Manchester Business School in Manchester, England, as a Professor. He was a visiting professor at the London School of Economics this past year. Professor Greenberger will join the faculty of Johns Hopkins University next fall as Professor of Computer Science and Director of the University Computing Center. Professor Poensgen has accepted the Chair of Business Administration at Universitaet des Saarlandes School of Law and Economics in Saarbrucken, Germany. Professor Fey has become a member of the Technical Staff at the MITRE Corporation. Professor Soelberg has accepted the post of Professor of Management at the University of Wisconsin. Professor McKelvey will join the faculty of the Graduate School of Business Administration at the University of California at Los Angeles. Professor Temin will become an Associate Professor with the Department of Economics at M.I.T. Professor Elting E. Morison has elected to remain at Yale University, where he was on leave last year as Master of Ezra Stiles College. William L. Letwin has resigned as Associate Professor to accept an appointment with the London School of Economics. He will continue a part-time association with the Sloan School as Senior Lecturer.

ADMINISTRATION OF THE SCHOOL

This year much effort was devoted to planning, both to determine the directions of growth for the School and to assure that the necessary resources would be on hand at the proper time to facilitate this growth. To aid me in this task, I called upon senior men representing our several teaching areas to work with me as the School's Policy Committee, requesting that they advise me on the goals and needs of their colleagues and assist me in evolving over-all statements of direction and resource requirements for the School.

Serving on the Committee last yere were Professors Alexander, Bennis, Brown, Forrester, Hill, Holland, Little, and Carroll L. Wilson, as well as Dean Wynne and Dr. Gil. We made substantial headway, for which I am grateful to these men. Much remains to be done, however, and I anticipate further contributions from the Policy Committee in the coming year.

John M. Wynne served the School with distinction as Associate Dean, and I am particularly grateful to him for his assistance and counsel during this first year of my administration. His efforts enabled the School to maintain its direction and momentum throughout a period of major organizational change, and for this we are in his debt. Dr. Gil, who as Director has administered the School's executive development programs with imagination and effectiveness, became Associate Dean for Executive Programs. Miss Priscilla A. Karb became Associate Director for Executive Programs. Continuing their distinguished records of service to the School and its students were Miss Miriam Sherburne, Assistant for Graduate Programs, and Miss Esther Merrill, Assistant for Undergraduate Programs. Miss Gertrude E. Burns, who as Administrative Assistant has controlled the School's finances effectively for a number of years, became Administrative Officer for the School. In an attempt to practice what we preach, we have experimented with some quantitative analyses of the School's own operation, and the results are most promising. As a Research Associate, J. David Raney will continue to work with me on these and other projects relating to planning and administration of the School.

Let me conclude by thanking all of my colleagues for their hard work and unfailing cooperation, which have made my first year as Dean a very rewarding one.

STAFF ACTIVITIES AND AWARDS

Professor Allen served on a panel for the evaluation of grant proposals submitted to the Office of Science Information Service of the National Science Foundation.

Professor Amstutz served as Special Assistant to the Secretary of the Navy.

Richard Beckhard served on the Board of Directors of the National Training Laboratories.

Professor Bennis was elected vice chairman of the National Training Laboratories Board and Chairman of the Executive Committee. He was invited to participate in the American Academy of Arts and Sciences Panel on the Year 2000. In addition, he continued his editorship of the following journals: *Journal of Applied Behavioral Sciences*, *Administrative Science Quarterly*, *Organizational Behavioral and Human Performance*, *Trans-action*, and *Journal of Humanistic Psychology*.

Professor Brown continued his service as a member of the Executive Board, Industrial Relations Research Association.

Professor Carroll served as secretary-treasurer of The Institute of Management Sciences' College on Simulation and Gaming, and as Program Chairman (College and Contributed Papers) for its National Meeting in Boston.

Professor Cootner became an associate editor of the *Journal of Finance*, the journal of the American Finance Association.

Professor David Durand completed his third year of service as associate editor of the *Journal of Finance*.

Professor Farrar served as a consultant to the Economic Development Administration of the Department of Commerce.

Professor Farris was awarded the Certificate of Excellence for the Marquis Dissertation Award in the Department of Psychology at the University of Michigan.

Professor Forrester was elected to membership in the National Academy of Engineering, and served as a member of the National Inventors Council.

Professor Galbraith received the 1966 McKinsey Award for Dissertations for his doctoral thesis, "Motivational Determinants of Worker Performance."

Professor Goetz was program vice chairman of the Engineering Economy Division of the American Society for Engineering Education. He served as a member of the Academy of Management's screening committee for selecting the best management books of the year, and as an editorial consultant for the *Journal of the Academy*. He is also a review editor for the *Engineering Economist*, and is a member of the Committee on the Taylor Key Award of the Society for the Advancement of Management.

Mr. Goodwin continued as a national governor for the Boston Chapter of the Society for the Advancement of Management. He also served as director of the Executive Conference on Managing Improvement, conducted at Cape Cod. During the past year he was elected a trustee of the International Work Simplification Institute.

Professor Greenberger was elected a Fellow of the American Association for the Advancement of Science, and was invited to be a national lecturer of the Association for Computing Machinery. He served as chairman of a conference session on simulation at the National Meeting of the Association for Computing Machinery in Los Angeles.

Professor Haire served on the Defense Service Board of the Department of Defense, was a member of the Board of Trustees of the Foundation for Research on Human Behavior, and was a member of the Advisory Council of the American Foundation for Management Research. He also presented the second Douglas McGregor Memorial Lecture at M.I.T. this spring.

Professor Holland served as a consultant to the Assistant Secretary of the Department of Housing and Urban Development. He continued as editor of the *National Tax Journal* and served as Chairman of the

Pension Funds session at the 18th National Conference of the Tax Foundation.

Mr. Stanley M. Jacks served as secretary-treasurer of the National Shoeboard Conference, Inc., a trade association.

Professor Kuh continued on the Advisory Committee of the Econometric Model Project at the Brookings Institution.

Professor Kolb served as a trustee on the Science Committee on Psychological Experimentation.

Professor Little served as chairman of the Marketing Session of the Fourth International Conference on Operational Research, held at Cambridge, Massachusetts, in September, 1966. He is a member of the Organizing Committee of the College of Marketing; the Institute of Management Sciences; the Computers in Marketing Committee of the American Marketing Association; and the Education Committee of the Operations Research Society of America.

Professor McKelvey was awarded a Summer Faculty Fellowship at the NASA Langley Research Center.

Professor MacAvoy served as a consultant to the Department of State on a proposal to construct a nuclear desalting plant in Israel. He also served as a member of the Ad Hoc Committee of the United States Bureau of the Budget to evaluate low-flow augmentation for pollution control, and as a member of the Academic Consulting Committee of the New England Council.

Professor Marquis served as chairman of the Sesquicentennial Symposium on Computers and Society at the University of Michigan, and was a member of the Panel on the Challenge of Population Growth in the Year 2000 at the M.I.T. Alumni Day, June, 1967. He served as a member of the U.S. National Commission for UNESCO, the Council of American Arts and Sciences, the Program Committee for the 20th National Conference on the Administration of Research, and the Program Committee of the American Institute of Chemical Engineers.

Professor Modigliani was on leave during the 1966-67 academic year on full-time research directing a joint project with the Board of Governors of the Federal Reserve System on the links between monetary policy and economic activity. He served on the Publication and Executive Committees of the American Economic Association and on the Board of Directors of the Social Science Research Council. He also served on the Social Science Research Council's Committee on Economic Stábilization, and its Subcommittee on the Monetary Mechanism. This year Professor Modigliani received an LL.D. from the University of Chicago.

Professor Montgomery served as chairman of the Organizing Committee of the Marketing College of The Institute for Management Sciences

(T.I.M.S.), was elected vice chairman of the newly formed college, and served as chairman of the Marketing College Session at the American Meeting of T.I.M.S. held in Boston this April. He was appointed to the Education Committee of the American Marketing Association for 1967-68, and he represented the Sloan School at the conference, "Education for International Business," sponsored by the Association Internationale des Etudiants en Sciences Economiques et Commerciales in Lausanne, Switzerland, in July, 1966.

Professor Moore continues as director of public relations for the American Institute of Industrial Engineers. He also serves as the vice president for research of the International Work Simplification Institute, as chairman of the Research and Education Committee of the Standards Engineers Society, as a member of the Board of Directors of the Society for Advancement of Management, and as a member of the Creative Leadership Council of the Creative Education Foundation. He also serves on the editorial boards of the *Standards Engineering Magazine* and the *Journal of Creative Behavior*.

Richard S. Morse served as chairman of a Federal study panel dealing with the auto industry and air pollution. The study was sponsored by the Departments of Commerce; Defense; the Interior; Health, Education, and Welfare; and Housing and Urban Development. He served as the United States delegate to the European Industrial Research Management Association meeting held in Sweden, and served as a member of the Department of Commerce Technical Advisory Board, and its subpanel on "Technological Innovation: Its Environment and Management." He was a consultant to the Department of Defense.

Professor Charles Myers served as a member of the National Manpower Policy Task Force.

Professor Nyhart acted as a consultant on development banking to the Development Centre of the Organization for Economic Cooperation and Development, serving as editor of the *Global Directory of Development Finance Institutions in Aid Receiving Countries*. He also served as consultant on development finance to the United Nations, working with the Fiscal and Financial Branch on the study, "Financing of Economic Development — Promotion of Private Foreign Investment in Developing Countries." He was elected president of the Boston Chapter of the Society for International Development, having served last year as its secretary.

Professor Pierce served as secretary of the Operations Research Committee of the Technical Association of the Pulp and Paper Association, and served as session moderator at the National Meeting of The Institute of Management Sciences in April, 1967.

Professor Poensgen was Visiting Professor of Business Administration at the Universitaet des Saarlandes, Saarbrucken, Germany, last summer.

Professor Roberts was appointed to memberships on the Air Force Scientific Advisory Board Panel on Psychology and Social Science, and the Department of Commerce Technical Advisory Board. He continues as Director of Operations of the College on Research and Development of The Institute of Management Sciences, and was elected to membership in their National Council for 1967-68.

Dr. Robinson served as chairman of the Program Committee for the Association for Education in International Business, as associate editor of *European Business*, as a member of the Editorial Review Board of the *Academy of Management Journal*, and as a member of the Finance Committee of the Middle Eastern Studies Association, Inc.

Professor Schein served as a consultant to the Internal Revenue Service.

Professor Abraham J. Siegel continued to serve on the Labor Panel and the Education Panel of the American Arbitration Association, and as a member of the Interstate Conference on Labor Statistics of the U.S. Department of Labor's Bureau of Labor Statistics. He was appointed associate of the Institute by the International Institute for Labour Studies in Geneva, Switzerland, and was named to the Panel of Arbitrators and Fact-Finders of the Massachusetts Board of Conciliation and Arbitration, Department of Labor and Industries.

Professor Taylor was appointed as a consultant to the United States Employment Service.

Professor Temin served as a member of the Program Committee for the 1967 meetings of the Economic History Association.

Assistant Professor Glen L. Urban received Honorable Mention in the McKinsey Postdoctoral Fellowship competition on the basis of his Ph.D. dissertation.

Professor White served as vice chairman of the Boston Chapter of the Institute for Management Sciences, as arrangements chairman for the 1967 National Meeting of that organization, and as associate editor for *College News for Management Science*, Series C. He also served as president of the M.I.T. Chapter of the American Association of University Professors.

Professor Wilson served as a member of the Research Advisory Committee to the Agency for International Development, the Science Organization's Development Board of the National Academy of Sciences, and the Advisory Council to the Bureau of African Affairs in the Department of State. He also is a member of the Advisory Committee to the

Economic and Social Council of the United Nations, and he chaired the working group of the committee on a study of sources of edible protein. He continued as the United States delegate and elected chairman of the Committee on Research Cooperation of the Organization for Economic Cooperation and Development. He also serves as trustee, member of the Executive Committee, and consultant to the Director of the Woods Hole Oceanographic Institution.

Professor Zannetos served as vice president of the College of Measurements in Management of The Institute for Management Sciences, as a member of the Research Group for Managerial Models of the American Accounting Association, as a member of the Advisory Council of the Hellenic University, and was made a member of the Board of Editors of the *Accounting Review*.

THE ADVISORY COUNCIL

We are grateful once again for the guidance that we have received from the distinguished group of men who comprise our Advisory Council. In particular, we thank Mr. Elisha Gray II, Chairman of the Whirlpool Corporation, who served this year as chairman of both the Advisory Council and the Visiting Committee. Under his able direction we adhered to a tight agenda at our annual meeting and achieved a highly productive exchange of ideas. The terms of several members of the Council drew to a close this year. They are George M. Bunker, President of Martin Marietta Corporation; J. Erik Jonsson, Honorary Chairman of the Board of Texas Instruments Incorporated; and Cyrus R. Osborn, former Executive Vice President (retired) of General Motors Corporation. We of the Sloan School greatly appreciate the unflagging interest and support of these men.

SUMMARY

As I mentioned in my introduction to this report, the last year has been a period of self-examination for the School, and appropriately so, as it was the first year of a new administration. We have attempted to assess our current strength, our problems, and our opportunities. We have found the position of the School to be strong. For this we owe a great debt to all those who have been associated with the School over the past 15 years and to the foresight and sustained encouragement of the late Alfred P. Sloan Jr. in particular. We have also found both challenge and opportunity as we seek to broaden our interests and competences. And we have continued to build the plans and policies that will lend direction to our efforts in the coming years.

A great deal of our planning was concerned with maintaining and revitalizing current programs, and this necessary work must continue. But much of the excitement of this past year has been in fashioning the plans for new undertakings. I look forward to reporting next year on the progress of these and other of our endeavors.

WILLIAM F. POUNDS

SCHOOL OF SCIENCE

When I arrived February 1 to take over the responsibility for the School of Science from Dr. Jerome B. Wiesner, I found a strong School moving vigorously ahead to improve its programs and develop new ones.

It was good to find that the new chemistry building was completely funded and that construction was to start in the spring. It was good to find that an agreement had been reached with the Woods Hole Oceanographic Institution to develop joint graduate programs in the oceanographic area, that remodeling funds had been arranged for the development of a Theoretical Center in the Department of Physics, that the Laboratory for Nuclear Science was moving ahead with the new LINAC to be installed at Middleton, and that a number of other important developments were in process.

As a new dean I have enjoyed getting acquainted with the staff of the School of Science and learning about the interesting research programs and curriculum development programs. There is a lot more going on than I, as an admirer of M.I.T. from a distance, had even realized.

For the Dean's Office one of the major activities of the spring term was the development of a ten-year building program. It was evident from this study that a number of the science departments are poorly housed in terms of the size of the faculty and the total number of people and their teaching and research responsibilities. The necessary increase of space is greater than the expected growth of faculty because of the decompression needed. The concept of a science campus, which had been under development by Dean Wiesner, formed the basis of the ten-year plan. The development of this plan in such a short time would not have been

possible without the able assistance of Joel Orlen, the Administrative Officer of the School of Science.

The number of graduate students enrolled in the School of Science increased 4.2 per cent (from 1,040 to 1,084) between September, 1965, and September, 1966. The Department of Biology again showed the largest increase (from 98 in 1965 to 127 in 1966). The second largest increase was in the Department of Nutrition and Food Science (from 99 to 110). These increases are partly a result of the fact that September, 1966, began the first full year that the Whitaker Building had been occupied. Between September, 1965, and September, 1966, the undergraduate enrollment in the School of Science as a whole showed no significant change. The undergraduate enrollment increased ten per cent in the Department of Biology and six per cent in the Department of Chemistry and was constant in the other courses, except the Department of Mathematics, which showed a seven per cent decrease.

Interest in the composition and operation of the required core subjects in chemistry, mathematics, and physics remains high, both from the standpoint of the departments involved and the Institute as a whole. In view of the fact that these subjects are taken by all freshmen, it is hard to overestimate their importance in the undergraduates' experience at M.I.T. and the role they have in underlying subsequent courses. The Class of 1970 was the second class to experience the new undergraduate curriculum at M.I.T. The Freshman Council Feedback Committee Report pointed out that the questionnaire filled out January 8, 1967, identified Physics 8.01 as the most popular of the freshman subjects, with 41 per cent of those who took the subject indicating it as their first preference, and Mathematics 18.02 as the second most popular subject. Physics 8.01 was taught by Professor Anthony P. French, and Mathematics 18.02 was taught by Professor David J. Benney. Freshman Chemistry 5.01 was taught by Professor William R. Moore, Professor Walter R. Thorson, and Professor David K. Roe; and Mathematics 18.01 was taught by Professor Arthur P. Mattuck. In teaching these key required subjects, these men undertook a very important responsibility for the Institute as a whole. I am happy to report that they all undertook them with enthusiasm and all introduced further improvements and innovations.

Most of the departments in the School of Science have developed project laboratories to replace the older undergraduate laboratories. In these laboratories a student develops a project which allows him to have an experience much more like research and gives him far greater depth of understanding of experimental work. These new and well-equipped laboratories are popular with both the students and the staff. We would like to increase the amount of instruction of this type, but it is of course

expensive so that increased resources, human and financial, are required.

Federal funds continue to be very tight, and there has been difficulty in carrying certain programs ahead as we hope to do. This situation has also made it very difficult to start new programs, and we feel that a number of improvements and new developments will have to be postponed until adequate funding is available. One of the consequences of the present situation is that higher percentages of the funds are going into salaries, so that decreasing percentages are going to replace and improve equipment and facilities.

During the spring it was announced that Professor Irwin W. Sizer, Head of the Department of Biology, was to become Dean of the Graduate School upon the retirement of Dean Harold L. Hazen on July 1. Professor Sizer had been Head of the Department of Biology for 12 years and had seen it through a period of dramatic growth, new housing, and the development of research and instructional programs that had attracted world-wide attention. The search for a new head led to Professor Boris Magasanik, who had joined the Department from Harvard in 1960. Professor Magasanik's research has been in the field of microbiology, and he has made major contributions to the understanding of control mechanisms. He will be joined in the administration of the Department by Professor Gene M. Brown, who will act as Executive Officer.

During the spring it was announced that the John and Dorothy Wilson Chair was being created and that the first occupant would be Professor John M. Buchanan of the Department of Biology. Professor Buchanan has brought distinction to himself and the Institute in his research in biochemistry and has built up this area of the Department of Biology to be one of the leading centers.

This year more students majoring in other departments have elected Biology subjects, and we expect this trend to continue. At the Summer Study on Life and Health Sciences it was estimated that 25 per cent of the research at the Institute could be classified in the life and health sciences area.

During the year the Department of Biology lost one senior member, Professor Patrick D. Wall, to the University of London.

Professor John Ross joined the Department of Chemistry as Head on July 1, 1966. He brought his experimental and theoretical research programs in molecular beams and irreversible processes in gases from Brown University. During the spring term construction started on the new chemistry building, which is to be called the Camille Dreyfus Building. The building will parallel Building 6 in the Eastman Court and will be attached to the Dorrance and Whitaker Buildings at the north end. This will afford ready communication with the Department of Biology, a

convenient arrangement, since the Departments of Biology and Chemistry are planning several joint appointments, the first being Professor Paul R. Schimmel, who will arrive in September, 1967. Construction of the Camille Dreyfus Building is expected to be completed by the spring of 1969.

The Department of Chemistry has been studying and changing its undergraduate and graduate curricula. The flexibility of the graduate program has been increased, and this will facilitate the training of graduate students with some interest in areas that interface with chemistry.

A chemistry electronics shop has been set up during the year, and a joint chemistry-geology shop is being developed.

The Department of Geology and Geophysics, under the chairmanship of Professor Frank Press, has moved to develop programs jointly with the Woods Hole Oceanographic Institution (W.H.O.I.), the Lincoln Laboratory, and the Instrumentation Laboratory, as well as the Center for Space Research. Members of the staff of the Departments of Geology and Geophysics and Meteorology are already participating in scheduling ships and obtaining joint grants with the staff at W.H.O.I., and W.H.O.I. scientific staff are participating in instructional programs at M.I.T. Dr. Irwin I. Shapiro, of the Lincoln Laboratory staff, has joined the staff of the Department in a joint appointment with the Department of Physics. The Large Aperture Seismic Array in Montana, which is managed by Lincoln Laboratory, is of help to research in the Department of Geology and Geophysics.

The Department of Mathematics, under the chairmanship of Professor William Ted Martin, has continued to develop new areas of mathematics research and instruction. This Department carries a very heavy responsibility for teaching students majoring in other courses and has 303 undergraduate majors of its own. Thus it has the third largest number of undergraduate majors in the Institute. In order to develop a closer rapport with students the Department of Mathematics sponsors afternoon teas once a week, and these are continuing successfully. The program of C. L. E. Moore Instructorships has attracted an even larger number of very strong applicants this year.

The Department of Meteorology, under the chairmanship of Professor Henry G. Houghton, is also very much involved with the new cooperative arrangements with the Woods Hole Oceanographic Institution. Oceanographic studies involve meteorology, and the circulation of the oceans has much in common with the circulation of the atmosphere. The Department has been very much involved in the World Weather Watch and the Global Atmospheric Research Program, major new international programs that reflect the increasing practical importance of meteorology.

DEPARTMENT OF BIOLOGY

The Department of Nutrition and Food Science, under Professor Nevin S. Scrimshaw, was host for two very successful conferences during the year. The first was on world protein problems and the second on malnutrition, learning, and behavior. The 12-bed Clinical Center, operated by the Department for the use of the entire Institute, has now been in successful operation for two years; and the clinically qualified regular faculty was increased to five during the year by the addition of Dr. Richard J. Wurtman and Dr. Edwin D. Bransome Jr. The Department was the recipient of two fine gifts: a mass spectrometer was presented by the Campbell Soup Company and a new pilot plant in food technology was presented by Mr. Stephen P. Mugar.

Professor Victor F. Weisskopf became Head of the Department of Physics during the fall, taking over from Professor William W. Buechner, who had been Head for six years. Under Professor Weisskopf's direction the organizational structure of the Department has been changed as he describes in his annual report. The remodeling of the Theoretical Center, mentioned above, is to be completed by the time classes start in September. A new series of graduate fellowships in physics, the Karl Taylor Compton Fellowships, has been inaugurated. The Department of Physics is participating actively in the development of a proposal to build a large (440-foot diameter) radio telescope, which is described in Provost Wiesner's report.

The first building priority of the School of Science is to provide space for the Department of Physics and the Laboratory for Nuclear Science, for decompression, growth of present programs and development of new programs. These organizations are presently spread throughout 14 buildings, and it would be highly desirable to construct a single building to house most of these activities. The physics undergraduate program is the second largest in the Institute; the graduate program is the third largest.

Members of the School of Science received so many honors during the year that it is not possible to list them here, but it is worth noting that three members of the School of Science became members of the National Academy of Sciences this spring: Professor F. Albert Cotton of Chemistry, Professor Norman Levinson of Mathematics, and Professor Francis E. Low of Physics.

ROBERT A. ALBERTY

DEPARTMENT OF BIOLOGY

During the past year the Biology Department has continued to grow rapidly in numbers of students registered in Course VII. It now has 134

undergraduates, which makes it one of the larger teaching departments at M.I.T. In addition, its role as a service department has increased, since students from most departments commonly elect subjects in the Biology Department. To take care of the increased number of majors, a special counseling system has been set up in which all members of the Biology faculty participate. Each professor is assigned four or five undergraduate tutees for the academic year and, even though this is very demanding of faculty time, this advisory system is working out extremely well. Also, a special Institute committee, under the chairmanship of Dean Emily L. Wick has been set up this year for giving advice to premedical students.

CURRICULUM

A new two-semester graduate biochemistry subject (7.71, 7.72) was offered for the first time in the fall of 1966 not only to serve graduate students in the Department of Biology but other students, especially those from the Departments of Chemistry and Nutrition and Food Science.

Professor Alexander Rich has reorganized his seminar subject on Molecular Configuration in Biological Systems (7.99); much of this spring's subject was devoted to the construction and interpretation of a model of the enzyme lysozyme.

Professor Cyrus Levinthal has developed a new subject for graduate students in biophysics on biological applications of the computer.

TEACHING AND RESEARCH FACILITIES

Teaching facilities of the Department have been improved greatly during the last year. Several of the research laboratories on the fourth floor of the Dorrance Building have been completely remodeled and converted into teaching laboratories. A number of the large laboratories on the first floor of the Dorrance Building have been converted into lecture and seminar rooms. A large part of the unfinished basement of the Whitaker Building has been utilized for a General Biology Projects Laboratory (7.02) with special facilities for teaching neurophysiology to beginning students. Much of the equipment for this laboratory was purchased through a grant from the National Science Foundation.

Research facilities for experiments involving animals have been greatly improved by the renovation of the animal quarters and the construction of aquariums for salt and fresh water animals as well as by the development of a special room for growing embryos.

PERSONNEL

Professor Irwin W. Sizer will leave the Department to become Dean of the Graduate School and will be replaced as Head of the Department by Professor Boris Magasanik.

Professor John M. Buchanan has been appointed to the John and Dorothy Wilson Chair as Professor of Biochemistry.

Professor Gene M. Brown has been promoted to the rank of Professor and Executive Officer of the Department of Biology.

Dr. Eugene Bell has been promoted to the rank of Professor and Dr. Sheldon Penman has been promoted to the rank of Associate Professor.

Professor Patrick D. Wall is leaving the Department to accept a position at the University of London.

New appointments include Associate Professors Corrado Baglioni and David Baltimore. At the level of Assistant Professor the Department has appointed Dr. Paul R. Schimmel (jointly with the Chemistry Department), Lisa A. Steiner, and Kenneth B. Taylor.

During the coming year Professors Vernon M. Ingram and Kurt S. Lion, and Professor Rich have been granted sabbatical leave to carry on research in laboratories abroad.

RESEARCH

Although the Biology Department continues to concentrate its research activities in molecular and cell biology, it is also developing new areas to broaden the research base and apply fundamental concepts to problems of living organisms at various levels of complexity. In cooperation with the Chemistry Department, the area of physical biochemistry is being developed with reference to kinetics of fast enzyme reactions. The subject of immunology is also undergoing a major development with special emphasis upon the synthesis and structure of immunoglobulins. Investigation is being made of the embryology of many different organisms, especially the chick, tadpole, sea urchin, and clam, utilizing the techniques of biochemistry and molecular genetics.

Closely associated with this program in development is a study of cell division in tissue culture. The role of several organelles such as the nucleolus, nucleus, ribosome, polysome, chromosome, and cell membranes are being investigated with reference to protein and nucleic acid biosynthesis and cell division.

Control systems which play a key role in living organisms are being investigated with special consideration devoted to the way in which enzymes are synthesized and their activities regulated. Also being investigated are control systems in living organisms at all levels of complexity from bacteria and viruses to the central nervous system of man.

Electrical signals obtained by the implantation of microelectrodes into individual nerve cells are particularly useful in elucidating the mechanism of action of such control systems.

There continues to be major interest in the structure and function of enzymes at the molecular level. Information is being obtained on the conformation of the active site of enzymes and the role played in enzyme catalysis by vitamins, coenzymes, and trace metals.

Techniques of electron microscopy and x-ray crystallography and new applications of the computer have made possible considerable insight into the structure of certain of the nucleic acids. Appreciable progress on this problem has also been made by the biochemists who have been determining the sequence of nucleotides in the RNA molecule.

The research work of the Department of Biology is now summarized in an annual publication entitled *Research Summaries*, which is available at Department headquarters.

IRWIN W. SIZER

DEPARTMENT OF CHEMISTRY

Forty-one undergraduates were awarded the Bachelor of Science degree in chemistry during the past year. Of these, 38 applied for and were admitted to graduate schools as candidates for the degree of Doctor of Philosophy. The remaining graduates took positions in industry. The Department had 40 graduates with the doctoral degree. Of these, six accepted academic positions; 15, industrial positions; 16, postdoctoral appointments; and three entered the services as officers to fulfil military commitments. To date the Chemistry Department has graduated a total of 1,027 doctorates.

There are in residence in the Department 108 predoctoral fellows, 64 research assistants, 62 teaching assistants, and a total enrollment of 240 candidates for a doctoral degree. In addition, there are 75 postdoctoral fellows and research associates in the Department.

CURRICULUM

A number of changes have been put into effect in the undergraduate and graduate curricula.

The first year of chemistry in the undergraduate curriculum has received considerable attention in the past few years. During the past academic year the Department has made a number of recommendations regarding the first year which were approved by the Faculty Committee on Educational Policy and by other departments in the Institute. It has been recognized for some time that it is of importance to present the

principles of chemistry during the first year of chemistry, illustrated with well-chosen examples of descriptive chemistry. The curriculum has been arranged to present in the first semester the elements of atomic and molecular structure and the elementary principles of kinetic theory and chemical kinetics. During the second semester, equilibrium in chemical reactions is discussed on the basis of the laws of thermodynamics. The laboratory subject associated with the first year will be discontinued. In its place, a project laboratory, to be elected for three or six hours per week, will be offered. Past experience with project laboratories in the Chemistry Department and in other departments has proven their effectiveness. These curriculum changes will provide more flexibility and choice in the first-year program.

The graduate program has been revised to provide maximum freedom of choice to each student. The thesis research plays a central role and is guided by a member of the faculty who, for each student, is aided by a thesis committee. There are no formal course requirements; a program of subjects is designed for each individual student by consultations between the student, the research supervisor, and the thesis committee. The qualifying examinations given to entering students and minor requirements have been dropped. A series of one-hour written examinations is scheduled in each semester and each student must pass six of these examinations, three of which must be in one field of specialization and the remaining three may be in any field of chemistry.

The graduate program is highly flexible and particularly well suited for students and staff whose interests are in the broadening border areas between traditional fields of chemistry and between chemistry and the other sciences.

PERSONNEL

Professor F. Albert Cotton was elected to membership in the National Academy of Sciences.

Professor Richard H. Holm joined the Department in June of 1967. Professor Holm received his Ph.D. degree from M.I.T. in 1959 in inorganic chemistry. He was at Harvard University from 1959 to 1965 and at the University of Wisconsin from 1965 to 1967. His research area of interest is inorganic chemistry and he has published widely on transition metal chemistry.

Associate Professor Glen E. Gordon was on sabbatical leave for the academic year in residence at the University of California at San Diego.

Professor Richard C. Lord was on sabbatical leave for the spring term. He attended research conferences in India and Australia and devoted the remainder of his leave to his research program at M.I.T.

Professor Irwin Oppenheim was on leave of absence this year, and was in residence at the University of California at San Diego for the first term. He was invited to be the van der Waals Professor at the University of Amsterdam for the second term.

Dr. Paul R. Schimmel has accepted a joint appointment in the Departments of Biology and Chemistry as Assistant Professor. Dr. Schimmel received his Ph.D. degree at M.I.T. in the Biology Department and for the past year was a Research Associate at Stanford University. His research interests are in experimental and theoretical studies of biological macromolecules.

Professor John C. Sheehan was on sabbatical leave for the spring term. He participated in discussions and formal lectures at Stanford University, at Berkeley, and at universities in Australia, Japan, and Switzerland.

Professor David P. Shoemaker was on sabbatical leave for the second term in residence at the Laboratoire de l'Electrostatique et du Physique du Metal at Grenoble, France.

Professor Clark C. Stephenson was on sabbatical leave for the second term. He devoted his time to his research program at M.I.T.

Professor Geoffrey Wilkinson of the Imperial College of Science and Technology, London, was an Arthur D. Little Visiting Professor. He lectured on the chemistry of rhodium and some aspects of homogeneous catalysis.

Professor Samuel I. Weissman of Washington University, St. Louis, was also an Arthur D. Little Visiting Professor. He lectured on principles of measurements of rates by spectroscopic methods and applications to electron and atom transfer reactions.

FACILITIES

For the past few years, planning and design for a new building for the Chemistry Department has been under way. Plans were completed during the spring, and construction of the building has begun. The building will be called the Camille Dreyfus Building in recognition of generous financial support from the Camille and Henry Dreyfus Foundation. A substantial grant from the National Science Foundation and contributions from industry and individuals completed the financing of the building.

When completed, the new chemistry building will be occupied by organic and inorganic chemists of the faculty of the Department, their postdoctoral research associates, and graduate students. The building will also house Chemistry Department Headquarters.

Most of the research space presently occupied by the Department will be reallocated for use by physical, biophysical, and analytical chemists.

Plans are being made for renovating and modernizing the existing laboratories and offices, some of which are much as they were 50 years ago.

A joint Chemistry-Geology machine shop is under construction in the basement of Building 6 to provide modern facilities for the two departments. When the new chemistry building is completed, the machine shop will be expanded by 50 per cent into adjacent areas now being used for research.

A chemistry electronics shop has been set up in the Department to design, service, and maintain electronic equipment needed for instruction and research.

RESEARCH

The faculty of the Department of Chemistry is active in research in all areas of chemistry. There follows a description of a few of the research programs which are representative and indicative of the wide range of research interests.

Professor Klaus Biemann and his associates are concerned with the development and refinement of the use of mass spectrometry for the solution of problems in organic chemistry.

Much of the work is aimed at the determination of the structure of organic compounds, particularly natural products of biological significance, such as alkaloids, peptides, hormones, and nucleosides. Major emphasis is placed on the exploration of the potentialities of high resolution mass spectrometry and has led to the design of highly sophisticated data-acquisition and data-processing systems using a medium-size computer on-line with some of the experiments.

The large volume of highly precise data thus produced (accurate mass and thus elemental composition of all the ionic species formed by electron impact of an organic compound) demands the involvement of the computer in the interpretation of the data. The direct, real-time communication of the chemist with the computer is accomplished, using the facilities of Project MAC.

The high sensitivity and structural specificity of mass spectrometry makes it one of the most promising methods for the detection and characterization of organic compounds in extraterrestrial materials. A considerable research effort is devoted to the development of experimental techniques required to analyze samples from the surface of the moon (and later perhaps of other planets) for organic substances.

Several aspects of organometallic chemistry have been receiving attention by Professor Dietmar Seyferth. Most fruitful has been an investigation of the reactions of phenyl(trihalomethyl)mercury compounds, PhHgCX_3 . These reagents have been found to be potent CX_2 -transfer

agents. They add CX_2 to olefins to form *gem*-dihalocyclopropanes; they insert CX_2 into C-H, Si-H, Ge-H, O-H, B-C, Si-C, Si-Hg, Ge-Hg, Sn-Sn and metal-halogen bonds; they react with triphenylphosphine to form Wittig reagents, with amines to form trihalovinylamines; their C-X bonds undergo free radical reactions. Kinetic studies have shown that their reactions with olefins and silicon hydrides involve free dihalocarbene intermediates. Studies with $PhHgCHX_2$ and $Hg(CH_2X)_2$ compounds showed these to have similar reactivity.

Other studies have been concerned with the use of organometal-substituted acetylenes (such as $Me_3SnC \equiv CSnMe_3$ and $Me_3SiC \equiv CSiMe_3$) in Diels-Alder reactions. The resulting products with vicinal organometal substituents have been shown to be useful intermediates in further conversions, since the metal-carbon bonds are cleaved easily by a variety of reagents. Furthermore, it appears that photochemical transformations of such vicinal di-metal compounds is a potentially interesting area of investigation.

A newer area of research is concerned with a study of functional diazoalkanes and carbenes. Reagents, such as Me_3SiCHN_2 and $(MeO)_2P(O)C(R)N_2$ and the carbenes derived from them are very useful for the introduction of such functionality into organic and organometallic structures.

Associate Professor Glenn A. Berchtold is concerned with a general program of organosulfur chemistry and with an understanding of the photochemistry of molecular systems in which a sulfur atom may interact with another chromophoric group in the excited state or may serve to stabilize the excited state of the molecule. It is open to question whether this effect determines the product distribution or whether the weakening of bonds at certain positions in the molecule due to the presence of the sulfur functionality controls the product distribution. Product studies so far have established some interesting new reactions, many of which occur in sufficient yield to be attractive for synthesis.

The ultraviolet spectra of cyclic γ -keto sulfides, for example, show evidence for sulfur-carbonyl interaction in the excited state. Irradiation of such compounds in an inert solvent leads to the elimination of ethylene and subsequent formation of the corresponding thiolactone. This reaction also occurs in alcoholic solvents, but it is complicated by photoreduction and by ester formation resulting from ketene intermediates via α -cleavage.

Assistant Professor George M. Whitesides has research in progress in the area of organometallic chemistry, with particular emphasis on the role of transition metal organometallic compounds as intermediates and cata-

lysts in organic reactions. A number of practical syntheses of σ -bonded organocopper(I) species have been developed and the synthetic applications of these compounds in carbon-carbon bond-forming reactions are being exploited. These reagents show particular promise in effecting reactions which resemble the Ullman and Sandmeyer reactions but which involve only unactivated alkyl groups. At the same time, a detailed study of the mechanisms characterizing the thermal decomposition of copper(I) and silver(I) organometallic compounds has demonstrated the existence of a complicated group of competing pathways, utilizing free-radical, hydridic, and concerted steps to mimic the products of a simple free-radical reaction.

The oxidation of organolithium reagent aggregates has been shown to involve at least two distinct paths: one apparently involving initial one-electron transfer from the lithium reagent to oxygen, followed by dissociation of free alkyl radicals from the resulting cluster radical cation; and a more complicated reaction path in which the metal atom cluster remains intact. These studies, in which the rate of the initial electron transfer reaction is faster than the rate at which the structure of the cluster can reorganize, promise to provide a clearer understanding of the mechanistic significance and kinetic stability of these clusters than has been possible from examination of other relatively slower reactions.

The study of collisions of molecules and their interactions by molecular beam techniques is of interest to Professors Isadore Amdur and John Ross and Assistant Professors James W. Dubrin and James L. Kinsey. From the study of elastic collisions, information about intermolecular forces may be obtained which is then useful in the study of a large number of equilibrium and non-equilibrium properties such as the equation of state and transport properties. Energy transfer between various degrees of freedom takes place by inelastic collisions. Their study is of importance in chemical kinetics, transport properties and gas dynamics. The technique of molecular beams makes possible a detailed study of chemical reactions. Under study are the measurements and determination of threshold energies and distances for chemical reaction, probability of reaction given initial conditions, the total reaction cross-section, the angular distribution of reaction product and the disposition of the energy change during the reaction.

Assistant Professor Robert J. Silbey and his research group are primarily interested in theoretical studies of the excited electronic states of molecular crystals. Current research topics include the study of the effect of the interaction of radiation with such crystals; the investigation of the effect of crystal size and shape on the absorption spectrum; and the study of the effect of molecular vibrations on the spectrum. Work is beginning

on the interaction between phonons and excitations in such crystals in order to understand the nature of energy transfer in these systems.

Assistant Professor Jeffrey I. Steinfeld has been investigating the exchange of molecular vibrational and rotational energy with translation during collisions. A molecule, such as diatomic iodine vapor, is selectively excited by monochromatic optical illumination, and the fluorescence analyzed by high-resolution spectrophotometry. Experiments are under way to determine the degree of reorientation of the molecular axis in a collision, by exploiting the polarization properties of a laser excitation source, and also to explore chemically reactive collisions by an extension of this technique. The vibrational relaxation data obtained from these studies can be interpreted in terms of current inelastic scattering theories, but the rotational energy transfer cannot yet be adequately predicted. A related approach to these problems is being undertaken in collaboration with Professor Ali Javan of the Physics Department, using the high power density at a selected infrared frequency available from a carbon dioxide laser to disturb the equilibrium populations in the energy states of a polyatomic molecule. These population deviations are detected as a double resonance in the optical absorption spectrum. This technique can be used to facilitate analysis of complex molecular spectra, and as a very general source of energy relaxation information.

Assistant Professor William B. Walters' research in nuclear chemistry includes the study of β and γ decay of radioactive nuclides as well as the study of positron annihilation in condensed phases. The recent studies of β and γ decay of isotopes of tin, antimony, tellurium, iodine, and xenon have yielded considerable information about the structure of odd-mass nuclides in that area. Because antimony and iodine have one and three protons respectively outside of a closed shell, the structures of these nuclides have been the subject of several theoretical investigations. He has been able to compare his experimental data to the results of various theoretical descriptions of these nuclei to determine the strengths and weaknesses of the various calculations. He has established the presence of a number of hindered β transitions between nuclei in this area. The γ -ray decay pattern in antimony nuclides has revealed several changing transition rate ratios. Also under investigation are the decay schemes of several odd-odd nuclear isomers that have been observed recently.

The study of positron annihilation rates in condensed phases has been initiated in order to characterize the chemical effects upon these rates better. The anomalous annihilation properties of the liquid water—solid water equilibrium are under study as are the properties of several organic liquids and solutions.

JOHN ROSS

DEPARTMENT OF GEOLOGY AND GEOPHYSICS

The environmental sciences are in a state of flux all over the country. New fields are replacing old ones; new departments are being created where none previously existed; old departments are being strengthened. Traditional geology departments are being transformed to include geochemistry, geophysics, planetary physics, oceanography. To an increasing extent faculty and students are being drawn from the fields of chemistry, mathematics, physics, and engineering to work in these developing fields. The activities in the Department of Geology and Geophysics in 1966-67 reflect the changing directions, the growth and excitement in the fields.

Our program in oceanography (which we share with the Department of Meteorology) received new momentum with the agreement of M.I.T. and the Woods Hole Oceanographic Institution to organize a joint degree program in oceanography. Although formal implementation will begin next year, M.I.T. faculty have already participated in scheduling ships and obtaining joint grants with Woods Hole staff members. Our faculty and students have made use of Woods Hole facilities and ships to a larger extent than heretofore. The Woods Hole scientific staff have joined us in the educational process by participating on admissions committees, by providing assistantships and fellowships, by giving lectures, and by serving on thesis committees.

Student interest in oceanography continues to grow, but the pressure has been somewhat relieved by the Woods Hole relationship. We are still expanding our faculty in oceanography. Assistant Professor Carl I. Wunsch is joining the staff in physical oceanography. He will be working on internal waves, midocean tides, and the application of information theory to oceanographic experiments.

In the past year, research in oceanography stressed marine geophysics, oceanographic geodesy, and chemical oceanography. The flow of heat from the sea floor was observed on the mid-Atlantic ridge, the Mediterranean Sea, and the Red Sea. Gravity data is being acquired to elucidate the structure on the western margin of North America and the island arc structures of the Caribbean Sea. A marine gravimeter, based on the principle of the vibrating string accelerometer, is being developed.

The development of instruments to measure the direction of gravity at sea as a means of navigation and as a means of determining the slope of the sea surface continues. An array of thermometers and pressure recorders is being installed off Bermuda to measure internal waves in the ocean and, in cooperation with the Environmental Science Services Administration, tide gages will be installed on key Pacific islands for precise analysis of a number of lines in the midocean spectrum.

A study of chemical exchanges that take place at the sea-air interface, using data gathered from surface ships and light airplanes, is under way with particular emphasis on volatile organic constituents.

Geology is the parent science in the history of the Department, and it is the intention of our faculty to keep our effort in this field strong. Associate Professor David R. Wones has just arrived and is establishing a laboratory and curriculum in experimental petrology. Joining us in a few weeks will be Assistant Professor Richard S. Naylor, who works in the field of geology-geochemistry, and Assistant Professor John B. Southard, whose research interests are in sedimentary and marine geology. Associate Professor William H. Dennen is leaving us to join the faculty of the University of Kentucky, and Associate Professor Ely Mencher is moving to the City College of New York.

An outstanding research result of the geology-geochemistry group has been the demonstration by rubidium-strontium age dating that the complex sequence of age provinces along the Atlantic coasts of Africa and South America match. This is a significant piece of new evidence in support of continental drift and also offers the interesting practical application of performing geological exploration in Brazil based on what is known in Africa.

The workers in the rock mechanics laboratory have found large changes in electrical resistivity that accompany the fracture of rocks. This phenomenon may serve as the basis of an earthquake prediction scheme.

One of the most powerful techniques for elucidating the physical-chemical properties of complex compounds is to work out their crystal structure. In the past year, the crystal structure of pharmacosiderite, parawollastonite, and polluate have been carried out.

In the field of geophysics and planetary physics, most of the faculty are new at M.I.T. and are busy establishing their laboratories and acquiring students. Work in high pressure geophysics, heat flow, regional geophysics, seismology, rock magnetism, geophysical fluid dynamics is actively underway. Dr. Irwin I. Shapiro has accepted a professorship in our Department and will take the lead in organizing our planetary physics program. His research interests in planetary and radar astronomy and celestial mechanics as well as cosmological physics provide an important extension of the Department's coverage. The geophysics group has been extremely successful in attracting students and support for its work.

Among the research contributions this year are the following:

1. It was shown that the jet stream excites gravity waves in the atmosphere which in turn influence the upper atmosphere.
2. It was shown that the world-wide properties of the ionosphere can

be observed by measuring the low-frequency electromagnetics resonances as excited by lightning.

3. It was shown that the properties of the earth's mantle under continents, oceans, and orogenic belts differ in each case, probably because of differences in temperature with depth under these regions.

4. A technique for determining the stress drop in earthquakes from distant observations was devised. The surprising result that major earthquakes are accompanied by stress drops of only a few tenths of atmospheres emerged.

5. A number of experiments have been carried out using the Large Aperture Seismic Array operated by the Lincoln Laboratory in Montana. The 600 seismometers and the 25 subarrays have been used to obtain precision derivatives of the travel time function that, in turn, have been used to infer anomalous changes in physical properties of the mantle at great depths. "Numerical seismographs" have been constructed in the computer using LASA data to form the equivalent of rotational seismographs, strain seismographs with physical extent of 200 miles.

6. It was also shown that the upper mantle under Japan contains partially molten zones that may be the source of volcanism.

7. The atmospheres of Jupiter and Saturn, when viewed through telescopes, show certain prominent features such as bright cloud zones separated by dark belts and, in the case of Jupiter, a great red spot. The motion of these irregular markings is observable. An attempt to explain these features in terms of basic fluid dynamics has been made. It has been suggested, for example, that the great red spot of Jupiter represents a "Taylor Column" associated with a topographic feature. An analogy between the rapid equatorial currents in these planets is made with the equatorial Cromwell current of the Pacific Ocean. These problems are being attacked with experimental models as well as with theoretical techniques.

8. The history of the earth's magnetic field is important because it reveals processes taking place in the earth's fluid core and because it may reveal relative displacements between continents and oceans. The existence of radiation belts and the amount of solar particulate energy reaching the surface is, of course, dependent on the earth's magnetic field. The fossil magnetism of rocks has been used to recover the position of ancient magnetic poles and the direction of the field at different points on the earth's surface. It has been found that in the Tertiary the reversal of the earth's field has followed a completely irregular schedule, the changes occurring at time intervals from ten thousand to fifty million years. Attempts are now being made to measure the intensity of the ancient fields as well as their direction.

The preceding is not an exclusive list of research results in the Department in the past year. It is a selection made to indicate the range of interests of the Department.

Some other highlights of the year are as follows:

1. Three faculty members were selected by NASA to function as principal investigators in the analysis of lunar rock return by the Apollo program.
2. A grant was received from the National Science Foundation to acquire modern geophysical equipment including a gravimeter, a nuclear precession magnetometer, and seismic refraction apparatus for undergraduate instruction in geophysics.
3. During the year a number of faculty members and students have been engaged in a study sponsored by NASA to plan a series of geophysical experiments on the moon following the Apollo program. This study has led to several specific proposals to conduct magnetotelluric experiments on the lunar surface, to construct a lunar gravimeter and a lunar passive seismic system, and to conduct heat flow experiments on the lunar surface.
4. The geophysics curriculum of the Department has been reorganized, and major changes have been instituted so that graduates of the Department have strong backgrounds in mathematics and physics and have a reasonably broad view of the entire field together with expert knowledge of their field of specialization. We will next undertake a study of the geology-geochemistry and oceanography curricula to see what changes are necessary.
5. The Department notes with some satisfaction that the grade point average of entering graduate students improved ten per cent over the preceding two years. This is the largest improvement among all of M.I.T.'s departments and signifies to us a new interest of bright science students in the earth and planetary sciences.

FRANK PRESS

DEPARTMENT OF MATHEMATICS

The number and over-all quality of undergraduate mathematics majors remain at a high level. With the large number of such majors, the Department has taken certain steps to increase the personal contact between the majors and individual faculty members and other steps to coordinate the work of the various faculty counselors. This year the Department inaugurated a series of weekly teas to which mathematics majors and faculty members were invited. These occasions afforded a pleasant opportunity for informal discussion by students and faculty, and the De-

partment plans to continue them next year. Following a suggestion from the recently established Departmental Student-Faculty Liaison Committee, a number of members of the faculty volunteered to serve as informal advisors in their individual fields of specialty and to confer with students concerning specific subjects, plans for graduate work, and other pertinent topics. To help in coordinating the work of the faculty counselors, the Department established an office for undergraduate mathematics majors under the direction of Associate Professor George P. Wadsworth. In this capacity, Professor Wadsworth works closely with individual faculty counselors. The office also has material available to undergraduates about placement and graduate work in other universities. These various steps have enabled the Department to know better its large group of undergraduate majors and to work more closely with them on their academic programs and their future plans.

As the secondary school curriculum in mathematics in various parts of the United States has improved, the mathematics program for our entering freshmen has been changing. At the same time, it has become necessary to devote special attention to the ten to 15 per cent of the entering class with the least favorable preparation in high school mathematics. The freshman calculus class regularly meets for two lectures and two recitations per week. This year the students in this special group met in very small recitation sections and attended the regular lectures. On the basis of this experiment, next year the Department plans to handle this group with the same lecture system but with special recitation sections of varying sizes, a special syllabus, and an especially designed set of exercises. The hope is that in this manner the great majority of the freshmen can proceed with the regular program, and that the few who have less mathematical aptitude or background will be provided with a program to fit their needs and, at the same time, prepare them for later work at M.I.T.

In response to a request from President Howard W. Johnson for a long range plan for the development of the Department of Mathematics, the Departmental Policy Committee held a number of special meetings to discuss the matter, and members of the Committee did a great deal of work between meetings. The result of the study was an imaginative, stimulating, and forward-looking plan which described a challenging opportunity for the Department. I quote from the introduction to the Policy Committee's report, which influenced significantly my own:

"During the past several decades, the Department has grown from a small 'service' department into one of the world's major centers of research in mathematics. This does not mean that the distinguished mathematicians who have been in this Department over the years ever

thought of themselves as 'servants,' nor does it mean that the present members can forget or ignore the great teaching obligation which mathematics incurs by virtue of being the language of science. But it does mean that the center of gravity of the Department's activities has shifted. At the same time that enrollment in its undergraduate subjects has hugely increased and that the number of its undergraduate majors has become the third largest at the Institute, the Department has also become committed to the various responsibilities of a major research center, including the development of a broad graduate program, and, inevitably, a substantial concern with postdoctoral training. All this has placed greatly increased burdens on the Department and especially on its faculty.

"In the years to come, the Department's primary goal must be the development of a superior faculty which represents all of the diverse aspects of mathematics, not only the traditional subjects in pure and applied mathematics, but also those new branches in which mathematicians of high quality are to be found. It must strive to improve the quality of education which it provides at all levels. It must be responsive to the changing needs of the undergraduates, to the demands of a continuously improving graduate program, and to the obligations of postdoctoral training. Quality of faculty must be of paramount concern, because the Department can hope to cope with its educational commitments only by bringing to M.I.T. gifted mathematicians with a broad range of research interests.

"A mathematics department of the breadth and quality which M.I.T. needs has never existed before — but then, neither has the truly great scientific and technical University which M.I.T. is becoming. It is perhaps only at M.I.T. within this context of the leading scientific and technical University, that the opportunity to build such a department exists. The Department of Mathematics is convinced that the opportunity does exist here, and that its realization is essential for the continued scientific and educational well-being of the Institute."

RESEARCH

Almost all of the full-time staff is active in research. Research is being carried out in abstract analysis, algebra, algebraic geometry, astrophysics, theory of automata and heuristic programming, differential equations, differential geometry, elasticity, hydrodynamics and applications of mathematics to magneto-hydrodynamic waves, mathematical logic, number theory, numerical analysis, probability, and topology. Research activities are too numerous to mention individually, but the work of some of the full professors serves as illustration.

Professor Michael Artin has been studying applications of methods of

commutative algebra to the theory of non-commutative rings. This has resulted in a clarification of the nature of the finite-dimensional representations of such rings, and in an internal characterization of Azumaya algebras. In continuation of joint work with Associate Professor Barry Mazur of Harvard University on cohomology of schemes, previous results for number fields in the étale topology have been extended to the more general context of cohomology with values in flat group schemes. From this a duality of the Poincaré type for arithmetic surfaces has been deduced.

Professor Sigurdur Helgason has worked on a geometric Fourier transform theory on symmetric spaces. Some unexpected connections with classical analysis have emerged, for example, that the Poisson formula for harmonic functions and the inversion formula for the Mehler transform are special results within Fourier analysis on the non-euclidean plane. Some new integral representations or general eigenfunctions of the Laplacian have been obtained.

Professor Kenkichi Iwasawa has continued to study algebraic number theory. Recently he has found a relation which exists between the so-called Jacobi sums and the class numbers of a certain type of cyclotomic fields.

Professor Chia-Chiao Lin has continued work on the dynamical theory of galactic spirals. The work has now entered a deeper phase, that is, the working out of rather detailed predictions and their comparison with observations. For example, radio observations of galactic rotation curves show variations previously explained by the rather artificial assumption of the absence of hydrogen gas from certain parts of the galaxy; now they can be explained in terms of the presence of a gravitational field whose existence is an integral part of the formation process of the spiral pattern. Indeed, the distribution of the gravitational potential can be mapped out with the aid of the observed gaseous arms. Other observed phenomena are being studied in terms of the present theory, for example, the past migration of the stars now in our vicinity. Attempts to understand the dynamical mechanism have also entered a more refined stage.

Professor James R. Munkres has been continuing to investigate the concordance problem for differentiable structures on manifolds.

Professor Eric Reissner has established an unexpected class of explicit solutions of large deformation shell theory, of interest in dislocation theory and in the theory of curved beams.

Professor Hartley Rogers Jr. has obtained a more unified framework for theories of the arithmetical and analytical hierarchies of recursive function theory, and he has obtained substantially simplified versions of some of the more complex priority arguments.

Professor Richard D. Schafer (in joint work with Dr. Kevin M. McCrimmon, a C.L.E. Moore Instructor) has extended to non-commutative Jordan algebras the structure theory developed by Nathan Jacobson for those commutative Jordan algebras which satisfy minimal conditions on quadratic ideals.

Professor Irving E. Segal has worked mainly in three directions. One is the global theory of non-linear relativistic equations, where he has shown the existence of the dispersion operator in a strong topology for a fairly broad class of equations. Another is the theory of group representations in special relation to elementary particle models, where he has shown the existence (and relative rarity) of positive energy models embodying mass splitting and suitably integrating internal and external symmetries. Finally, he has worked toward the construction of relativistic non-linear quantum field theories, and he has shown in particular that such local theories showing typical divergences can be described in terms of hamiltonians which can be applied to dense domains of vector states, and have self-adjoint extensions.

PERSONNEL

One of the positive moves which the Department makes in support of research is a system of leaves for members of the faculty and the related policy of bringing to the Department visitors from other universities or from industry or government. During the past year Professors Nesmith C. Ankeny, Kenkichi Iwasawa, and Eric Reissner and Associate Professor W. Gilbert Strang were on leave for the entire academic year; and Professors Daniel M. Kan, Bertram Kostant and Franklin P. Peterson were absent for one term. Professor Ankeny spent the year at the University of California at Berkeley and Professor Iwasawa at the Institute for Advanced Study. Professor Reissner served as Visiting Professor of Applied Mechanics at the University of California at San Diego during the winter quarter and spent the rest of the year in the Cambridge area. Professor Strang spent the year at Oxford University on an Alfred P. Sloan Jr. Research Fellowship. Professor Kan spent his leave in this area, while Professor Kostant was at the Institute for Advanced Study with partial support from an Alfred P. Sloan Jr. Research Fellowship. While he was on leave during the spring term, Professor Peterson visited the University of Chicago and the University of Kyoto, the latter on a Fulbright Grant. In addition, Professor Warren Ambrose spent the latter part of the spring term on leave as Visiting Professor at the University of Chile.

The Department was fortunate to have Dr. Leslie C. Woods of Oxford University as Visiting Professor, and Dr. Ching-Sheng Wu, Scientist Specialist, Jet Propulsion Laboratory of the California Institute of Tech-

DEPARTMENT OF METEOROLOGY

nology as Visiting Associate Professor; both visited during the fall term. Professors Carlo Cercignani of the University of Milan and Gerald Sacks of Cornell University were in residence as Visiting Associate Professors for the entire academic year. Professor Edwin E. Moise of Harvard University spent the fall term with us as a guest, and Professor Louise Hay of Mount Holyoke College spent the academic year as a National Science Foundation Postdoctoral Fellow.

The Department is pleased to report that, beginning July 1, 1967, Professor Gian-Carlo Rota of Rockefeller University, a member of our faculty from 1959 to 1965, will return as Professor of Mathematics, and that Professor Sacks will join our faculty as Professor of Mathematics. Other new faculty members joining our Department on that date are Assistant Professors Steven A. Orszag and Stephen Grossberg. In addition, Dr. Thomas J. Lardner and Dr. Frederick Y. M. Wan, who have been serving as instructors in the Department, will join the faculty as Assistant Professors on July 1.

The Department is sad to report that Professor Iwasawa resigned effective on June 30 to accept a professorship at Princeton University. Professor Iwasawa, who joined our faculty in 1952, has made many distinguished contributions to research and to our teaching program. The entire Department will miss him.

In April Professor Norman Levinson was elected to membership in the National Academy of Sciences; Professor Segal and Assistant Professor Edward B. Curtis were awarded John Simon Guggenheim Memorial Fellowships; Professor Hartley Rogers Jr. won a National Science Foundation Senior Postdoctoral Fellowship; and Assistant Professors Donald W. Anderson and Daniel G. Quillen, were awarded Alfred P. Sloan Jr. Research Fellowships.

WILLIAM T. MARTIN

DEPARTMENT OF METEOROLOGY

The most notable event of the year was the approval by the Faculty and the Corporation of a joint degree program in oceanography with the Woods Hole Oceanographic Institution. Legislative action by the Commonwealth of Massachusetts has provided the necessary legal basis for this unique joint program. The successful and rapidly growing program in oceanography developed during the past few years in cooperation with the Department of Geology and Geophysics has an urgent requirement for the ready access to the oceans provided by the research ships and shore facilities of the Woods Hole Oceanographic Institution. The com-

bined staffs and facilities of the two institutions offer unparalleled opportunities to graduate students in oceanography. On their part, the Woods Hole Oceanographic Institution is convinced that the stimulus of direct participation in education and the close cooperation with our faculty will strengthen and broaden their own programs.

The size of the Department, both in staff and students, was essentially unchanged from the previous year. These limits have been set by space and the graduate student quota. Although quality is not to be equated with size, it is becoming increasingly evident that means must be found to expand the Department. The basic reason is that the fields we represent are expanding rapidly in scope and we must keep abreast of new developments if we are to maintain our preeminent position. The most sensitive indicator of our competitive position is the number of applicants we admit who choose to go elsewhere, and this number is rising rather rapidly. A recent analysis has confirmed the visual impression that the Department is one of the most crowded in the Institute. Some slight relief will occur on completion of the building for the Center for Space Research, but additional space is the most urgent present requirement of the Department.

The research program is the fabric into which is woven the educational program and the principal activities of the faculty and staff. Thus the health and vigor of the Department is crucially dependent on the funds available for research. On a short-term basis we are faced with the same funding stringencies found in other fields of science. This has not led to serious curtailment of research activities but, in many instances, a desired expansion of effort has not been possible. Perhaps this has been somewhat of a blessing in disguise because space restrictions would not permit much expansion even if additional funding had been secured.

The longer term outlook in meteorology and oceanography seems most promising. Proposals first made by President John F. Kennedy to the United Nations for international cooperation in meteorology have been pursued aggressively by the World Meteorological Organization and the International Council of Scientific Unions working in concert. Two broad programs have been proposed called the World Weather Watch and the Global Atmospheric Research Program. The former calls for the development and operation of a system to observe the atmosphere on a truly global basis and is the particular responsibility of the World Meteorological Organization. The Global Atmospheric Research Program encompasses a broad research program in which research groups in many countries will participate. Close feedback is planned between this research program and the World Weather Watch so that appropriate observations may be taken. Preliminary studies and experi-

ments are under way, but the major programs are scheduled for the next decade. If these programs do not founder for lack of funding, they will result in an order of magnitude increase in meteorological research.

Although oceanography is also a fertile area for international collaboration, the most promising developments are occurring on the national scene. Currently the Marine Resources Council, headed by the Vice President and the Marine Sciences Commission, chaired by Dr. Julius A. Stratton, are studying the national oceanographic program and its organization. This is only some of the more visible evidence that presages a continuation of the rapid growth of oceanography in this country.

The new programs in meteorology and oceanography seem certain to include large and complex undertakings commensurate with the scale of the phenomena of the oceans and atmosphere. This will call for new mechanisms whereby universities and their students can participate without becoming overwhelmed by management responsibilities. We should strive to play a leading role in devising appropriate means to this end.

Although honors received by the faculty are listed elsewhere, it seems appropriate to note here that the World Meteorological Organization chose Professor Edward N. Lorenz to deliver the first International Meteorological Organization (predecessor to W.M.O.) lecture at its recent Congress in Geneva. Professor Lorenz's topic was the general circulations of the atmosphere, one of the central problems of meteorology and one to which he and many other members of our faculty have made notable contributions over three decades.

Members of our faculty have participated extensively in both the national and international discussions of the brave, new proposals for meteorology and oceanography referred to above. They have also served scientific societies and federal agencies in various capacities to further sound progress in meteorology and oceanography.

We were pleased to have Professor Walter H. Munk of the University of California with us for the second half of the year and Dr. Clive D. Rodgers of Oxford University for the entire year.

HENRY G. HOUGHTON

DEPARTMENT OF NUTRITION AND FOOD SCIENCE

TEACHING

DEGREE CHANGE

The programs now pursued by the Department are much wider in appeal than implied by the title S.M. or Ph.D. in nutrition. Since 1961,

the faculty has grown from ten to 28 and has enlarged in disciplinary breadth as well. Graduate students now number nearly 100, with about 25 postdoctoral fellows of various kinds. It now includes faculty members, staff, and students studying problems in clinical nutrition, nutritional pathology in animals, nutritional biochemistry, food toxicology, oral science, metabolism and endocrinology, and experimental medicine as well as the traditional areas of food science, food technology and biochemical engineering. The type of nutrition degree offered by this Department clearly requires distinction from the S.M. or Ph.D. in nutrition conferred by departments in schools of agriculture and home economics. After careful consideration, a request was made for a change in the title of the S.M. and Ph.D. degrees in nutrition to the S.M. and Ph.D. in nutritional biochemistry and metabolism. This change was approved and became effective in June, 1967.

SIGNIFICANT DEVELOPMENTS IN SUBJECTS

The undergraduate projects laboratory entitled Nutrition and Food Science Projects Laboratory (20.02) was offered for the first time during the spring term. Twelve students were registered. This laboratory subject is being presented by Associate Professor Gerald N. Wogan, and Assistant Professors Theodore P. Labuza, Vernon R. Young and Edwin D. Bransome, and is under the direction of Professor Wogan. With the changes in the nutritional biochemistry and metabolism program, the subject Basic Nutrition (20.30) has been expanded to two one-term subjects in Nutritional Biochemistry and Metabolism (20.30) and Advanced Nutritional Biochemistry and Metabolism (20.31).

A new subject in endocrinology entitled Neuroendocrine Control Mechanisms (20.80T) will be offered by Associate Professor Richard J. Wurtman. It will deal with the study of the interactions of the nervous and endocrine systems (with emphasis on the biochemistry of neurotransmitters) and of hormones of neural origin, the anatomy and physiology of the neuroendocrine transducers, the control of endocrine homeostasis and biological rhythms by the central nervous system, the effects of hormones on cerebral functions, and the mechanisms by which certain psychoactive drugs produce endocrine effects.

A new subject entitled Metabolic Aspects of Inherited Disease (20.84) will be given by Professor John B. Stanbury. It will deal with the genetic and biochemical principles underlying inherited human disease, principles of human genetics as applied to human disease, systematic survey of the biochemical lesions of inherited disease, and consideration of therapeutic resources.

The subject 20.38, Factors Influencing the Nutritional Values of Foods,

will be changed from an elective subject to one required of all students in the Department. Lectures will be provided by several members of the staff and the subject will be coordinated by Assistant Professor Steven R. Tannenbaum. It will provide an introduction to the chemical and physical basis of food preservation and the impact of processing and storage on the nutritive value of human food supplies. It will also point out the role of present and future technology in the solution of world food problems. This will then permit a reorganization of the subject 20.11, Food Science and Technology, for majors in food science and technology.

Modification and consolidation are planned for food science and technology laboratory subjects in the next academic year. This will include dropping 20.111, Food Science and Technology Laboratory, and the laboratory in Advanced Food Technology (20.52). In their places a single laboratory subject, Laboratory Projects in Food Science and Technology (20.12) will be offered. This will consist of laboratory work on a project basis designed to investigate chemical, physico-chemical, and engineering principles of importance to food processing and storage. Small groups will work on individual projects covering such topics as reaction kinetics in the frozen state, sorption phenomena, packaging kinetics, browning, lipid oxidation, dehydration mechanisms, and thermal properties of foods.

The Research Management in the Food Industries subject (20.85) was offered for the first time since the retirement of Dr. Charles N. Frey. Professor Samuel A. Goldblith was responsible for it and a number of guest lecturers from the food industry participated. In addition to covering the fields suggested by its title, this subject also dealt with problems of science and society. The subject will be offered in alternate years.

RESEARCH

NUTRITIONAL BIOCHEMISTRY AND METABOLISM

Professor Hamish N. Munro and Assistant Professor James W. Drysdale are conducting research on nutritional and hormonal factors affecting protein metabolism at the cellular level. An *in vitro* system has been developed to study the iron storage protein, ferritin. Other studies include investigation of how hormones affect genetic control of RNA synthesis and research on the metabolism of lymphocytes to determine the relationship between dietary protein and resistance to infection.

Professor Wurtman is studying the hormonal control of the metabolism and action of neurotransmitters, the biologic rhythms and their control by light, and will study each of the enzymes involved in serotonin synthesis and metabolism in an *in vitro* system based on growth of rat pineal

glands in organ culture. Research is planned to study the effects of biological rhythms on the net nutritional value of certain dietary proteins at varying times of day.

Associate Professor Sanford A. Miller and his associates continue their efforts to elucidate the nature of protein synthesis in the neonatal rat. Work has also progressed on studies of synthetic dietary energy sources, and *in vitro* studies of sulfur amino acid metabolism in the cat have been completed.

Associate Professor George Wolf continues to work on vitamin A function and on the biosynthesis and metabolism of carnitine.

FOOD PROCESSING

Professor Goldblith continues work on the dielectric properties of food-stuffs. Comparative effects of thermal energy and microwave on several species of microorganisms have been investigated. He and Professor John T. R. Nickerson, with Dr. Joseph J. Licciardello, are exploring radiation preservation of marine products and poultry, and they have completed studies on the kinetics of thermal lability of the toxin of type E. *Cl. botulinum*.

Associate Professor Marcus Karel has extended his studies on oxidative deterioration of dehydrated foods and continues to work on the mechanisms which control the desorption of organic volatiles from foods during vacuum processing, and on mass and heat transfer in freeze dehydration. Work on heat process requirements for foods packaged in flexible containers has been completed, and work continues on protective packaging of foods. He and Professor Labuza are investigating the effects of composition and moisture content on deterioration rates in model systems resembling space foods.

During the past year, Professor Tannenbaum has extended work on new sources of protein in collaboration with Associate Professor Richard I. Mateles. Professor Tannenbaum is also studying non-enzymatic browning of stored dehydrated milk, and continues his research on thiamine deficiency.

BIOCHEMICAL AND FOOD ENGINEERING

Professor Mateles is carrying on research on continuous culture, fungal toxins, and single-cell protein. He, with Professor Wogan and Professor George H. Buchi of the Department of Chemistry, is studying a toxic metabolite prepared from *Penicillium rubrum*. Professors Mateles and Tannenbaum are also studying the effect of growth conditions on amino acid composition of *Bacillus megaterium*.

Assistant Professor Daniel I. C. Wang has studied mass transfer be-

havior of fermentation vessels subjected to high agitation and high aeration. A program to examine the use of polyelectrolyte membranes for the concentration of biological substances such as enzymes, proteins, and bacteriophages is in progress.

Dr. Zeki Berk of the Department of Food Biotechnology at the Technion, Israel, has spent the year here as Visiting Associate Professor of Food Engineering and has also been conducting research on vapor-liquid equilibrium of volatile flavor substances to develop theoretical relations and experimental data necessary for predicting volatile retention in evaporation and distillation processes.

FOOD MICROBIOLOGY

Associate Professor Cecil G. Dunn is exploring the potentialities of nutrients derived from microbial sources, particularly with respect to their amino acid and fat composition and vitamin content.

Assistant Professor Gerald Silverman continues work on microbiology of freeze-dried foods, the mechanism of action of ionizing radiations on bacteria, and on the sterilization of surfaces by dry heat. He is also investigating the microbiology of the human intestinal tract.

Dr. Licciardello is following up his work on radiosensitivity of salmonellae organisms and, with Professors Nickerson and Goldblith, on the kinetics of response of *Cl. botulinum* toxin to ionizing energy and thermal energy.

FOOD AND FLAVOR CHEMISTRY

Associate Professor Emily L. Wick is extending her studies on the identity of volatile constituents in bananas responsible for the production of characteristic odor and flavor to determine their precursors and to establish the mechanisms of their formation. The flavor chemistry of fish protein concentrate is being investigated further.

Assistant Professor Phillip Issenberg continues to study wood smoke composition and absorption of volatile smoke components by foods. Retention of volatile compounds during freeze-drying of model system and food products is being studied. This is an excellent example of the interaction of basic chemistry with food processing. Professor Issenberg has established and is responsible for the operation of the Department's new Mass Spectroscopy Laboratory Facility.

FOOD TOXICOLOGY

The research program of Professor Wogan pursues various aspects of the problem of aflatoxin. The mold toxins, ochratoxin A, and *Penicillium rubrum* are also being investigated to define their target tissues and

modes of action. Carcinogenesis in rainbow trout is being studied with Dr. J. E. Halver of the Western Fish Nutrition Laboratory in Cook, Washington, and the binding characteristics of aflatoxin to DNA continues to be investigated in collaboration with Dr. M. P. Sporn of the National Cancer Institute in Bethesda, Maryland. Professor Wogan has initiated a program on mycotoxin research in Bangkok, Thailand, and Assistant Professor Ronald C. Shank is in residence there for the next two years.

Professor Leo Friedman's research program is concerned with the interaction of chemicals in living animals. New approaches such as testing the safety of foods are also being explored. He and Assistant Professor Samuel I. Shibko have developed a biochemical screening procedure to test the hepatotoxic potential of test compounds.

Assistant Professor Janis Z. Gabliks is investigating the effects of insecticides on mammalian cells, and, with Professor Friedman, is studying chemical carcinogens. Professor Gabliks is also studying the interaction of nutritional factors in viral infections.

NUTRITIONAL ANIMAL PATHOLOGY

Professor Paul M. Newberne, with Dr. Adrienne E. Rogers, has pursued studies on cirrhosis and on the etiology of liver cancer. The deranged protein metabolism of obese animals which renders them more susceptible to disease is being investigated at cellular and subcellular levels, and congenital anomalies in vitamin A-deficient rabbits are also being studied. Professor Newberne and Assistant Professor Charles E. Hunt are also studying the relationship of copper deficiency, ascorbic acid, and lipotropic imbalance to the pathogenesis of cardiovascular disease in several species of laboratory animals.

ORAL SCIENCE

Professor Robert S. Harris has been studying the effects of dietary restriction on dental caries formation in rats, and is investigating caries activities of phosphates and trace minerals. He and Associate Professor Juan M. Navia are continuing their studies on the cariostatic properties of phosphates, particularly trimetaphosphate. Professor Harris is also studying the cariogenic effect of dietary sucrose as a determinant of polysaccharide formation by bacteria.

CLINICAL NUTRITION

Professors Nevin S. Scrimshaw and Young continue to work on protein and amino acid requirements and the way in which they are influenced by genetic variation, stress, dietary factors, and the proportions of essential and non-essential amino acids. The effects of infection on protein

metabolism are being investigated further, and research cooperation with the Institute of Nutrition of Central America and Panama in Guatemala includes termination of a series of reports on field studies of the interaction of malnutrition and infection, and plans for the evaluation of the efficacy of dried skim milk extended by the addition of glycine and diammonium citrate for meeting the protein needs of young children.

Dr. John E. Gordon, Senior Lecturer in Epidemiology, continues to study the interaction of nutrition and infection among infants and pre-school children of developing countries. He is also editing and assembling for publication the proceedings of the M.I.T.-Nutrition Foundation Conference on Malnutrition, Learning, and Behavior.

Visiting Professor Seymour J. Gray has been studying amino acid accumulation in tissues of normal and obese subjects. Intestinal epithelium in obese subjects is being investigated. The effects of dietary changes on the rat intestinal mucosa are being explored to elucidate protein synthesis and amino acid transport.

EXPERIMENTAL MEDICINE

Professor Stanbury is working to identify membrane fractions from endocrine cells and has isolated and purified embryonic sea urchin nuclei to study the early labeling of RNA. Work continues on both acute and chronic effects of medicinal and natural goitrogens and on naturally occurring goitrogens in the pathogenesis of endemic goiter.

Professor Bransome is studying the hormonal stimulation of growth, with characterization of the range of response of nucleic acid and protein synthesis. The self-regulation of cell growth is also being investigated, with particular effort to characterize the protein and nucleic acid components of this regulatory system in adrenal cortical and other cells.

Associate Professor Leslie J. DeGroot is studying the formation and metabolism of thyroid hormone in patients with hereditary thyroid disease. Also, he is working to purify the thyroid enzyme which mediates the iodination of Tyrosine, and to determine the nature of the prosthetic groups of energy source for the reaction. Absence or inactivity of this enzyme, which is apparently a heme-containing peroxidase, is related to one form of human congenital thyroid disease.

SYMPOSIA AND CONFERENCES

During the past year the Department has held two well-attended conferences. The first was held in October under Industrial Liaison Office sponsorship and dealt with some practical approaches to world protein problems. The second, held in March, was an International Conference on Malnutrition, Learning, and Behavior; it was sponsored by M.I.T.

and the Nutrition Foundation and attracted more than 500 participants from 33 countries. The proceedings will be published by the M.I.T. Press. The Department, in conjunction with the Sloan School of Management, is planning an International Conference on Single-Cell Protein to be held in October. These conferences, together with the summer programs, are further important means for bringing various outside groups to the Institute, and for increasing the interrelationships among the faculty, staff, and students in fields of interest.

FACULTY CHANGES

During the past year Dr. Richard J. Wurtman and Dr. Edwin D. Bransome Jr. have joined the Department. Dr. Wurtman has come as Associate Professor of Metabolism and Endocrinology. He is a graduate of the University of Pennsylvania and Harvard Medical School and was most recently a Medical Research Officer in the Laboratory of Clinical Science at the National Institute of Mental Health. At the same time, he was a Clinical Assistant in Medicine at the Massachusetts General Hospital and is continuing this association. His research areas are in endocrinology and pharmacology.

Dr. Edwin D. Bransome Jr. is a graduate of Yale University and Columbia University College of Physicians and Surgeons. He has served a residency in internal medicine, and from 1964-66 he was an Associate in the Endocrine Division of the Scripps Clinic and Research Foundation. He joined our group in experimental medicine as Assistant Professor of Metabolism and Endocrinology on July 1, 1966.

Dr. Charles E. Hunt is a graduate of Washington State University in Veterinary Medicine and was an instructor and graduate student at Auburn University before coming to M.I.T., where he obtained his Ph.D. degree in nutrition, majoring in nutritional animal pathology under Professor Newberne. Dr. Hunt, since January 1, 1967, has been an Assistant Professor of Animal Pathology.

Dr. Tony J. Sinskey, a 1962 graduate of the University of Illinois, received his doctorate in food science and technology at M.I.T. with thesis work in the field of food microbiology. Dr. Sinskey is at Harvard University this year as a postdoctoral fellow studying virology, and he will initiate a new program in food virology in this Department this coming year. Dr. Sinskey's appointment as Assistant Professor of Food Virology should be important not only for the development of this new and important area in food science and technology but will also provide additional strength in the over-all program in food microbiology.

Dr. Ronald C. Shank is joining the Department as Assistant Professor of Food Toxicology. Dr. Shank received his S.B. and S.M. degrees at

DEPARTMENT OF PHYSICS

M.I.T. in food technology and his Ph.D. from M.I.T. in nutrition (food toxicology) in 1965. Since that time he has been on a National Cancer Institute (NIH) postdoctoral fellowship at the Toxicology Research Unit of the Medical Research Council, Carshalton, Surrey, England. He has been active in the field of aflatoxins, and during the next two years he will be in charge of the program on mycotoxins in Southeast Asia, working with Professor Wogan.

Dr. Gerald Silverman, Assistant Professor of Food Microbiology, has been promoted to Associate Professor effective July 1, 1967. Dr. Silverman received his Ph.D. in dairy chemistry and bacteriology at Cornell University in 1954, and has been a member of the Department since 1958.

FACILITIES

Two important developments have occurred which will mean much to research activities of the Department. The first was the generous gift of the Campbell Soup Company, which enabled the Department to purchase a mass spectrometer and ancillary data processing equipment. This facility will aid in the development of the departmental program in food and flavor chemistry.

Part of the gift of Mr. Stephen P. Mugar has made possible the installation of a new pilot plant in the Department. The present facility will be completely renovated and newly equipped. This will be an important asset to the teaching and research activities in food engineering, food toxicology, biochemical engineering, and in some aspects of applied nutrition.

NEVIN S. SCRIMSHAW

DEPARTMENT OF PHYSICS

In the last several years, the Department of Physics has grown to over 100 faculty plus lecturers and instructors. The areas of research of the Department have proliferated in variety as well as size, and for this reason will not be reported here but rather in a separate publication to be published concurrently with this report and entitled *Physics Research at M.I.T.*

Professor William W. Buechner, Head of the Department since 1961, asked to be relieved of his administrative responsibilities effective January 1, 1967. Professor Victor F. Weisskopf, who returned from CERN (European Organization for Nuclear Research) in January, 1966, became Head of the Department, relieving Professor Buechner. Professor

George G. Harvey continues as Executive Officer, and Daniel H. Gould has become Administrative Officer.

After consultation between Professors Buechner and Weisskopf, joined by many of the senior staff, it was decided to define three research divisions for the Department and to assign to these divisions a good deal of the administrative load. These divisions are:

1. Division of Nuclear Physics — Professor Peter T. Demos, Head. This division is, of course, closely identifiable with the physics share of the Laboratory for Nuclear Science and jointly with Harvard has the use of the Cambridge Electron Accelerator facility.

2. Division of Astrophysics and Space Physics — Professor Bruno B. Rossi, Head. This is a new physics research venture at M.I.T., but we feel that with the post-war developments of radioastronomy and of space technology, the time has come for the Department to participate in a major way in this particularly important and growing field. This group works closely with the Institute's Center for Space Research and the Research Laboratory of Electronics, and expects in time to augment its interests to include optical astronomy.

3. Division of Solid State and Atomic Physics — Professor Robert A. Smith, Head. The research of this division is supported in large part by the Research Laboratory of Electronics, the National Magnet Laboratory, and the Center for Materials Science and Engineering, plus work on quantum electronics centered in the Department under Professor Ali Javan.

In addition, a Theoretical Center is being established under Professor Herman Feshbach in newly refurbished space on the third and fourth floors of Building 6. This Theoretical Center crosses all experimental lines, and aids each of the research divisions.

In another purely staff function, Professor Felix M. H. Villars has the responsibility for insuring the quality of teaching of all our undergraduate and graduate subjects. In a sense, these two staff functions serve to insure the integrity of the departmental research and teaching activities.

The curriculum changes suggested by the Committee on Educational Policy for the Institute as a whole are now in effect and pretty well shaken down. In the freshman year, 8.01 and 8.02, which are required of all M.I.T. undergraduates, cover the fields of Newtonian mechanics, relativistic mechanics, and oscillations and wave motion. 8.03 is a departmental requirement for about three-quarters of the sophomore class and covers electricity and magnetism, as in the past. 8.04 is a departmental requirement for about half of the sophomore class and in effect is an introduction to quantum theory.

With the elimination of the required freshman and sophomore physics laboratories, the Project Laboratory, 8.14, under Professor John G. King, has proven to be a very effective means of giving real laboratory experience to freshmen and sophomores and has become very popular with the students — so popular that it is over-subscribed and is being enlarged.

The departmental requirements beyond the sophomore year include the well-established junior laboratory subjects, 8.09 and 8.10, presently under Assistant Professor William H. Moore. 8.05 serves as a phenomenological introduction to modern physics, and the theoretical sequence 8.06, 8.07 and 8.08, developed by Professor Villars, includes classical mechanics, electricity and magnetism, thermodynamics and quantum mechanics. In addition, students are offered electives in phenomenological fields such as nuclear physics, atomic physics, solid state, astrophysics, quantum electronics, and others. However, although the sequence 8.01 through 8.10 plus two electives is suggested for students expecting to attend graduate school, a good deal of flexibility is allowed in the theoretical sequence 8.06, 8.07 and 8.08 and the various possible electives.

This spring the Department made a determined effort to increase the quality of our graduate student body. The effort was aided greatly by the establishment by the Institute of the Karl Taylor Compton Fellowships for Graduate Study in Physics. This campaign to increase the quality of our entering graduate students was very successful; so successful that the quantity as well as the quality went up. Next year we will have a total of 300 graduate students in the Department of Physics. While this sum seems large, it must be remembered that our faculty, plus qualified physicists working as D.S.R. staff members, totals over 150. Even if the faculty alone were considered, the ratio of graduate students to faculty is only 2.7:1, which is substantially lower than most if not all departments similar to ours.

The Department has done a good deal of soul searching on the relationship of the faculty members to the individual students and finds that both faculty and students desire a closer and more frequent means of communication. For the graduate students we have initiated a system of faculty advisors to new graduate students; one faculty member will advise one or two new graduate students until the student is firmly established in a research program that suits his needs and interests.

Because of the numbers involved when one includes the non-department students taking physics subjects, the problem of faculty and student relationships with the undergraduates is more difficult. Nonetheless, in our departmental deliberations, conducted in good part with very vocal

representatives of the student body, we have found many ways of improving the situation. It is our earnest desire to see that each student, at least our own physics majors, gets to know several faculty members well before he finishes his bachelor's program.

PERSONNEL

During the coming academic year Professor Henry W. Kendall will be on sabbatical leave at Stanford; Professor Francis E. Low will be at the Institute for Advanced Study, Princeton, New Jersey; and Professor Clifford G. Shull will be at Brookhaven National Laboratory. During the same period Professor Sergio P. Fubini will join our Theoretical Center as Visiting Professor from the University of Torino, Italy, as will Professor Steven Weinberg of the University of California, Berkeley. Dr. F. Alistair Johnson, of the Royal Radar Establishment, Malvern, England, will join us as Visiting Professor of Physics and will be associated with the Center for Materials Science and Engineering. Professor Frederick Reif of Berkeley will come to the Institute as Visiting Professor in both biology and the Department of Physics, and Professor Michael J. Stephen of Yale will be Visiting Professor and will be associated with our Solid State Group. Dr. Joshua Zak, of Technion, Israel, will join us as Visiting Associate Professor and will divide his time between the Department and the National Magnet Laboratory. Dr. Gerd Koppelman, of the Technical University of Berlin, will be Visiting Associate Professor of Physics, as part of the exchange program sponsored by the Ford Foundation.

As of July 1, 1967, Professor Alan H. Barrett, whose interests are in radioastronomy, transfers to the Department from the Department of Electrical Engineering. Professor Irwin I. Shapiro, formerly of the Lincoln Laboratory, will hold a joint appointment in the Departments of Physics and Geology and Geophysics as Professor of Geophysics and Physics.

In addition, the following new faculty members will join our department: Assistant Professors Henry J. Lubatti, William K. Rose, Marlan O. Scully, Vytenis M. Vasyliunas, and Bradford L. Wright. Newly appointed instructors are Doctors Taber deForest, Pao-Kuang Kuo and Wallace M. Manheimer.

Two faculty members in the Department retired this year but will remain in the Department as Senior Lecturers:

Professor William P. Allis joined the Physics Department Staff in 1926, and except for an occasional leave of absence, he has been with the Department ever since. As a theoretical physicist interested in the behavior of charged particles, he has seen the field that originally was

known as the "passage of electricity through gases" change its name to the field of "gas discharges," "gaseous electronics," and finally "plasma physics." These name changes relate in part to his contributions to the field.

In the 1920's emphasis was placed on understanding the individual charged particle and on an attempt to understand the gaseous conduction phenomenon in terms of an average charged particle. Professor Allis' great contribution to the field was to pioneer the use of velocity distribution functions using an integrated average over the total charged-particle population, going more and more toward the continuum behavior of the total plasma medium as a way of understanding the detailed nature of the physical processes. This dictated to a great extent the acceptability of the various changes in the field's designation.

Professor Allis has the attribute, fairly rare among theoretical physicists, of being able to communicate clearly and succinctly with experimentalists in a day-to-day and detailed fashion. Experimentally inclined graduate students and colleagues alike have been constantly at his doorstep, and he has put his indelible mark on all facets of his chosen field.

Professor Bertram E. Warren, a recognized authority on the use of x-rays to probe the structure of matter, retires this year after 47 years at M.I.T. as student and professor. As Professor Emeritus he will continue teaching and research this summer and fall, and in January, 1968, will go to Paris under a Fulbright Grant to lecture at the College du France for six months.

While Professor Warren was a graduate student, the late M.I.T. President, Dr. Samuel W. Stratton, arranged for the British physicist, Sir Lawrence Bragg, a pioneer in x-ray diffraction studies, to deliver a series of lectures at M.I.T. Dr. Warren was assigned the task of constructing models of crystal lattices to illustrate the Bragg lectures. He has been involved in x-ray diffraction ever since. He studied at the University of Göttingen and at the Technische Hochschule in Stuttgart, Germany, in 1926-27 and returned to M.I.T., where he received his doctoral degree in 1929. He spent the year 1929-30 as Malcolm Cotton Brown Fellow, studying and working with Sir Lawrence Bragg at the University of Manchester, England. During World War II Dr. Warren worked on National Defense Research Committee projects, developing radio-controlled bombs that were successfully used in the China-Burma-India theatre. For the period of Professor Slater's absence at Bell Telephone Laboratories, Professor Warren served as Executive Officer of the Department. Following the war he returned to x-ray studies, in particular, imperfections in metal crystals. In 1957, under Fulbright sponsorship, Professor Warren lectured at the College du France on these studies. His

forthcoming lectures there will concentrate on non-crystalline materials and new techniques.

It was with a sense of personal loss that many of the department members heard of the death in January of our former colleague, Dr. Robert J. Van deGraaff. Van was a great and wonderful man whose contributions to nuclear physics are incalculable. At the time of his death, he was proposing experiments with accelerated, multicharged, heavy nuclei — experiments that will result in much fruitful physics research in the next few years. He was extraordinarily human and very modest; he could never bring himself to refer to the nuclear accelerator that bears his name as anything but an electrostatic generator.

VICTOR F. WEISSKOPF

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M.I.T. has traditionally been a school in which interdepartmental collaboration is encouraged and is relatively easy to achieve. The Institute prides itself on the low potential barriers between departments. It is this easy communication between scientists, on the one hand, and engineers and applied scientists on the other, between the School of Engineering and the School of Science, which has made M.I.T. a unique institution. It is easy and commonplace for faculty members to move back and forth between departments in the School of Engineering and in the School of Science, and, in fact, entire departments have crossed these boundaries from time to time.

It is upon this two-way communication between scientists searching for knowledge and engineers searching for solutions to practical problems that today's technological society depends, and M.I.T.'s great contribution in its early history was the development of these interrelationships. In recent years, with social and environmental problems looming so large, similar close relationships have been developing between the social and political sciences, the humanities, and the traditional engineering disciplines of M.I.T. The fostering of these relationships, too, is essential.

In the postwar period, interdepartmental collaboration among faculty members has been facilitated and stimulated by the development of a new administrative and intellectual entity — the interdepartmental laboratory, sponsored jointly by several departments and inhabited by faculty members and students of many departments and generally, although not always, reporting to the Provost. The first of these laboratories were the Research Laboratory of Electronics and the Laboratory for Nuclear Science created in 1946, followed shortly by the Center for International Studies. More recently a Materials Science Center, a Space Research

Center, and Project MAC, a computer research center, have been established. Reports from each of these laboratories are included here.

In addition to the interdepartmental facilities, M.I.T. faculty members have access to a number of inter-institutional research organizations. Two of these are sponsored jointly by Harvard University and M.I.T., while others have an even more broadly based sponsorship. The Harvard-M.I.T. facilities are the Cambridge Electron Accelerator and the Harvard-M.I.T. Joint Center for Urban Studies. M.I.T. is also a member of the Associated Universities, Inc. which operates the Brookhaven National Laboratory, a center for nuclear research in New York State, and the National Radio Astronomy Observatory in West Virginia.

M.I.T. faculty members have also been very active in the establishment of the Northeast Radio Astronomy Corporation (NEROC), a new non-profit corporation, organized for the purpose of developing and constructing a very large radio telescope, whose membership includes 13 universities in the northeast section of the United States. This organization is an outgrowth of the Cambridge Radio Astronomy Committee (CAMROC) established two years ago by Harvard University, the Smithsonian Institution, the M.I.T. Lincoln Laboratory, and the M.I.T. campus for the purpose of exploring the feasibility of establishing a New England radio astronomy facility. Scientists associated with these four organizations have made some of the most significant contributions in the field of radio and radar astronomy of the past two decades; with the proposed new facilities, their leadership would be assured for the years ahead.

The studies by the CAMROC group have resulted in a major technological breakthrough in the design of large steerable precision antennas, demonstrating the feasibility of housing a very large antenna (400 to 1,200 feet in diameter, fully steerable paraboloids) in a radome in order to separate the environmental problems and the problems of building a precision antenna. The import of this is twofold. First, the cost of very large, high precision antennas has been greatly reduced; second, it is possible to build a much more precise instrument in the protected environment than can be made if it must be exposed to the elements. The NEROC group has applied to the National Science Foundation for funds to do the engineering design of such an antenna, to build it, and to operate it somewhere in the northeastern section of the United States and is anxiously awaiting the NSF's decision.

URBAN STUDIES

M.I.T. recently received a large grant from the Ford Foundation to increase teaching and research activities related to urban affairs. In

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addition to endowed chairs in urban studies, these funds will enable the Institute to establish an interdisciplinary laboratory in which faculty members from a number of departments can do their research, some as individuals and some as members of research groups. In addition, the Ford Foundation grant will make research support available to faculty members who are not associated with this laboratory. It is expected that much of this work will be related to and coordinated with the activities of the Harvard-M.I.T. Joint Center for Urban Studies.

INTERDEPARTMENTAL BIOMEDICAL ACTIVITIES

During the past year there has been a very extensive examination of M.I.T.'s future role in the biomedical and bioengineering fields, largely as a result of the widespread interest on the part of faculty, particularly in the School of Engineering, in the possibility of greater involvement in medical and health care activities. The Committee on Engineering and Living Systems, under the leadership of Professor Murray Eden, sponsored a series of lectures by Professor David D. Rutstein of Harvard University on problems related to medical care. A joint Harvard Medical School-M.I.T. Committee to explore the possible areas of collaboration in biology, medicine, and engineering was created during the year, and the Committee on Engineering and Living Systems sponsored a ten-day summer study to explore possible future areas of research and teaching in the life sciences at M.I.T.

The Harvard Medical School-M.I.T. Committee has identified four areas for possible collaboration and these are now being investigated by subcommittees. These are cooperative educational programs, collaborative research activities by individual Harvard Medical School-M.I.T. faculty members, cooperative study and developmental activities in the delivery of health care, and large-scale collaborative research in biomedical and bioengineering activities.

The M.I.T. summer study attended by more than 50 M.I.T. faculty members and approximately 20 persons from other institutions was highly successful. It provided an extremely stimulating review of current M.I.T. biomedically oriented activities and a thoroughgoing discussion of opportunities in medicine, bioengineering and health care. The study highlighted possible areas of collaboration between engineers and life scientists, and it brought out a number of areas in which M.I.T. faculty were anxious to work. At the end of the study the group proposed a number of institutional and administrative arrangements for expanding M.I.T.'s role in the biomedical field. It is interesting to note that there was considerable overlap between the areas of interest of M.I.T. faculty and areas which seem most fruitful for collaboration between the Har-

vard Medical School and M.I.T. We now are in a position to develop the biomedical-bioengineering activities at the Institute and the coming year should witness progress in this direction.

JEROME B. WIESNER

CENTER FOR MATERIALS SCIENCE AND ENGINEERING

It is still true today that many possible advances in our technology are held up for a lack of suitable materials to implement in a practical way ideas shown to be feasible by laboratory or theoretical studies. This was fully appreciated in 1960 when a large national expansion of academic research in materials science and engineering was planned with support from Federal funds. In 1961 the Center for Materials Science and Engineering at M.I.T. was established in order to enable the Institute to participate more effectively in this national advance and to provide a focus for the large amount of research in this field already being undertaken at M.I.T. In addition it was decided to build a new laboratory with help from the Advanced Research Projects Agency (ARPA) to provide a means of centralizing some of the expensive equipment required for this kind of research and for encouraging the interdisciplinary cooperation that has already proved fruitful in this field.

The new laboratory building, named after Dr. Vannevar Bush, has now been occupied for about two years and provides gross space of about 150,000 square feet for research and teaching. It is staffed mainly by faculty from a number of academic departments together with their students aided by technicians and engineering assistants, and a small number of full-time postdoctoral research staff. The latter are employees of the Division of Sponsored Research who are located in the Materials Center.

At present, the principal academic departments represented in the laboratory are Metallurgy and Materials Science, Electrical Engineering, and Physics with smaller numbers from Chemistry and Chemical Engineering. Support for activities in some other departments on a small scale is also provided by the Center.

The laboratory is financed partly by funds made available from ARPA under Contract SD-90 and partly from a considerable number of smaller contracts and grants held by individual professors attached to the Center.

In addition to helping with the building costs and providing research funds, the ARPA contract has made it possible for us to purchase a lot of equipment far too expensive for a small research group to carry.

This equipment has enabled us to set up our central facilities for which the operating costs are also largely drawn from the ARPA contract. These facilities form a vital part of the interdisciplinary activity in the laboratory and form the cement which binds the various groups into a working unit. Apart from the beneficial results of proximity to groups from other academic disciplines but having similar interests (and these benefits are not to be minimized), without these central facilities the laboratory would do no more than provide more research space at M.I.T. It is in fact hoped that it will do much more and although it is a bit early to judge, there are encouraging signs that this interaction will produce some outstanding results.

At present the staff of the interdisciplinary laboratory consists of a total of 55 professors, including 24 full Professors, 10 Associate Professors and 21 Assistant Professors. Nineteen other academic staff members, 24 D.S.R. postdoctoral staff, and 179 graduate students are also on the staff, in all 277 persons. There are also a number of undergraduates doing senior theses in the laboratory. These together with secretaries and technicians, bring the total staff up to about 400. This does not include *all* staff closely associated with the Center; a number of other groups have some financial support and make a good deal of use of the laboratory facilities.

CENTRAL FACILITIES

The central facilities established so far are: general service facilities — Central Analytical Laboratory, Central Machine Shop, Electronics Construction and Instrument Service Facility, Central Computation Facility, Materials Center Library and Reading Room, and Central Administrative Office; specialized research facilities — Microscopy and Metallography Facility, X-ray and Electron Optics Facility, X-ray and Electron Diffraction Facility, and Gas Analyzer Mass Spectrometer Facility; materials preparation and processing facilities — Insulating and Optical Crystal Growth Facility, Semiconductor Crystal Growth Facility, Metal Crystal Growth Facility, Metal Crystal Preparation Facility, Ceramic Materials Preparation Facility, and Materials Technical Information Services. We have added to our X-ray and Electron Optics Facility a scanning electron microscope after a survey of the Institute showed a widespread need for such an instrument. We already had a homemade instrument which had given useful experience, but the commercial instrument we now have is much more flexible and gives considerably higher resolution. Use of our facilities is not restricted to those working in the laboratory, and we expect this instrument to be widely used.

Our central facilities are organized in a rather unusual way. There

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is no main central organizational unit apart from the fact that the Director of the Center takes a close personal interest in the healthy operation of all these facilities; the facilities are broken down into fairly small units, as listed above, each, with one exception, under the immediate direction of a senior professor. The one exception is the analytical chemistry facility which is under a senior D.S.R. staff member. Many doubts have been expressed about the effectiveness of this kind of arrangement and undoubtedly it has its dangers. It depends very heavily on having faculty able and keen to supervise such facilities. In this we have been most fortunate and with us the arrangement seems to work admirably. The professor in charge must naturally spend some time with the facility, keeping it up-to-date and developing new techniques. In return he will have first-class equipment for his own research program. He generally will have a D.S.R. staff member to help with the day-to-day running of the facility. Each professor in charge has his own research program and the facilities are intimately connected with these. We shall therefore postpone further discussion of them to the next section which deals with the research program of the Center.

RESEARCH ACTIVITIES

Many of the research groups working in the interdisciplinary laboratory or closely associated with it are now well established, but we are continuously setting up a small number of new groups as faculty change. One of the most important uses of the ARPA research funds is to enable such new groups to be started; hopefully they will find their own support for at least a proportion of their research later. Many of the outstanding well-established groups in the Center were started in this way. Perhaps the most important new group being helped to establish itself at present is that under Professor Robert H. Rediker of the Department of Electrical Engineering. Professor Rediker has made notable contributions to the physics of devices using solid-state techniques and particularly those using semiconductors such as photo-detectors and crystal lasers.

In the past year 46 doctoral theses and 24 Master's theses have resulted from research carried out in the Center. A large number of publications has resulted, and many lectures have been given by staff in other laboratories and institutions and papers presented at meetings of learned societies. Most of this research by the groups closely associated with the Materials Center has been reported under the various academic departments; there is no point in repeating it here. We shall simply indicate the scope and refer to one or two highlights.

The basic study of solid-state physics provides the firm background on which all materials science and engineering is founded, and we have a

small number of groups concerned with such basic studies. Professor George B. Benedek, assisted by Professors James D. Litster and Thomas J. Greytak, has an extremely active group concerned with light scattering and modern optics. This is one of the leading groups in the field, and techniques are now being developed with considerable sophistication that enable the scattering of light from gases and even from liquid helium to be observed as well as from more conventional solids and liquids. Although this work is of great intrinsic interest from a scientific point of view, it has also important repercussions on the development of extremely pure and highly perfect single crystals, in that it provides a technique for studying their deviation from perfection. A small group under Professor Robert A. Smith is concerned with semiconductors and infrared spectroscopy and also with measurements at low temperatures. Dr. Carl A. Shiffman and Dr. James E. Neighbor, who have been very active in the latter field as postdoctoral research staff members, have both received academic appointments as professors and are leaving this fall. Theoretical physics is represented by Professors George F. Koster, Peter D. DeCicco, and Marlan O. Scully of the Department of Physics and Professors George W. Pratt Jr. and Leonard W. Gruenberg from Electrical Engineering. In addition we normally have a number of visiting professors attached to the laboratory for short or longer times. The theoretical physics activity is a vitally important part of the laboratory research potential and every effort is made to facilitate the interaction of the theorists with the experimental program.

Professor Daniel Kleppner has a research program concerned with atomic and molecular beams and atom-atom spin exchange. The Department of Chemistry is represented by Professor David P. Shoemaker who is responsible for our low-energy electron diffraction facility and by Professor Carl W. Garland who is using resonance techniques originally developed for physics research in the study of phase changes and order-disorder phenomenon.

From the Department of Chemical Engineering we have a small group under Professor Michael Modell concerned with surface catalysis and, in particular, with the role of semiconductors in catalytic processes. Here we have a good example of the close interaction between chemists and semiconductor physicists that the laboratory can provide.

One very important group of materials in technology consists of the wide range of insulators, semiconductors, and magnetic materials used in electrical engineering. Studies of these materials are carried out by Professors Rediker, Richard B. Adler, David J. Epstein, Frederic R. Morgenthaler, and Alexander Smakula. Professors Adler and Rediker are responsible for one of our crystal preparation facilities while Profes-

sor Smakula is in charge of the important central facility concerned with the growth of insulating crystals. This central facility is closely linked with his active research program dealing with the study of imperfections in highly perfect crystals.

A large part of the research program is concerned with a variety of metallurgical studies covering materials ranging from semiconductors and superconductors to high tensile steels. Professor Harry C. Gatos and Professor August F. Witt are concerned with problems of crystal growth, particularly in semiconductors, as well as with the study of certain types of high-field superconductors. In their work on crystal growth they have recently developed an extremely powerful new technique for studying the microscopic growth rate of semiconductor crystals. This technique arose from a study of irregularities in the impurity distribution of added dopants. These irregularities are technologically troublesome in certain applications, and their elimination is of considerable importance. The new technique, however, which consists effectively of producing in crystals the analog of growth rings in trees by injecting low frequency sound waves into the crystal during growth, is of very far-reaching importance. The pressure waves of the sound change very slightly the rate of segregation of impurities and this in turn affects the etching rate of the crystal in certain specially developed etches. The growth rings can then be seen using advanced techniques involving phase contrast microscopy and give a direct measurement of the microscopic growth rate. While it is too soon to predict all the developments which should come from this new technique, enough has already been seen to indicate its power, and some beautiful pictures of growing crystals have been obtained which have shown up some very interesting phenomena, such as growth along a twin boundary. Professor Gatos is also in charge of the important semiconductor crystal growth central facility which serves a large number of users both in the physics and electrical engineering areas.

Professors John Wulff and Robert M. Rose are studying the effects of metallurgical treatment on the properties of superconductors, while Professor John W. Cahn is concerned with the basic theory of precipitation in metals. Professor Benjamin L. Averbach, in addition to his work on x-ray and neutron scattering, is working with Professor David J. Sellmyer to apply methods developed in solid state physics research to the study of the electron configuration of alloys. This also represents an interesting link between metallurgy and physics. Professor Averbach is also in charge of the metal crystal preparation facility. Professor Michael B. Bever and his colleagues are concerned with the thermodynamics of stable and metastable phases and with problems of radiation damage, while Professor Morris Cohen, Professor John F. Breedis and

Professor Kenneth C. Russell are concerned with kinetics of precipitation and nucleation and in studying the effects of nucleation on the mechanical properties of metals. Professor Breedis is responsible for the electron microscope central facility.

Professor W. David Kingery and Professor Robert L. Coble are concerned with the basic study of ceramic materials and are responsible for the central facility for preparation of such materials. Professor Merton C. Flemings is concerned with problems of solidification of metals, and basic research carried out in his group is having important applications in the development of castings for various special purposes concerned with aircraft and spacecraft development. Professor Flemings is responsible for our central facility for the preparation of pure metals and single crystals of metals and alloys.

Professor Robert E. Ogilvie and Professor Thomas O. Ziebold are concerned with various studies using x-ray, electron-optical, and electron microprobe techniques and in particular with radiation damage in metals caused by nuclear radiation. Professor Ogilvie is responsible for x-ray analysis and electron microprobe central facilities and will also be responsible for running our new scanning electron microscope.

Professor Nicholas J. Grant is concerned with high temperature metallurgy and with the properties of new metastable phases, while Professors Roy Kaplow and Simon C. Moss are using advanced techniques in x-ray structure analysis and Mössbauer spectroscopy for the study of ordering in alloys. High pressure studies are conducted by Professor Gatos and Professor Donald R. Uhlmann, the latter being mainly concerned with polymers.

EDUCATIONAL PROGRAM

One of the most important activities aimed at fostering interdisciplinary activity is the Materials Center Colloquium which meets regularly each Friday afternoon during the term. The colloquium provides an opportunity for faculty, staff, and students from different academic areas and also from outside M.I.T. to meet and discuss problems of current interest. Colloquium speakers are invited both from M.I.T. and its associated laboratories and also from other academic, government, and industrial laboratories. Distinguished visitors have also given lectures organized by the Center from time to time.

On the teaching front some interdisciplinary graduate courses have been given aimed at presenting basic concepts of materials science to an audience drawn from a number of academic departments. The main teaching contribution of the Center is, however, the training which both graduate and undergraduate students are receiving in its research labora-

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tories with equipment more advanced than is usually to be found in academic surroundings. Although the research output from the Center is of very great importance, even more important is the flow of trained graduates with experience in up-to-date techniques who will continue to make an even more important contribution to the development of materials science and engineering in the wider world of industrial and government research.

ROBERT A. SMITH

CENTER FOR SPACE RESEARCH

The Center for Space Research has recently completed its fourth year of operation as an interschool center and focal point for a broad program of space research. The growing interest and participation of faculty members and students provides the key to the development of a sound and viable research activity.

To the physical scientist, the Center is becoming a source of support and stimulation in making new and exciting measurements and discoveries about our planetary and galactic systems. To the social scientist, the Center and its program of space research has provided an opportunity for further study of the economic and political consequences of new technological developments. For the life scientist, the Center has provided support in the study of extraterrestrial life and in solving some of the problems of maintaining man in space, and ultimately it seeks to provide engineering support for biospace experiments of general interest. To a significant segment of the engineering faculty, the Center has provided funding and facilities support for basic studies and experiments in advanced space technology. To all faculty, the Center seeks to furnish opportunities for interdisciplinary communication and joint activity in broad work areas.

The new space science reading room; the space science seminar series (inherited from the COMPASS program), and the soon-to-be-completed Space Center Building, all represent important aids in making the Center a useful entity to the participating groups.

Over the past year the generation of technical publications and student theses has grown significantly. Under projects carried out in the Center and/or directly supported by the Center, 71 journal articles and research reports were written. Twenty-six graduate theses and five undergraduate theses were completed in the last academic year among the 62 graduate and ten undergraduate students participating in the program. Faculty supervisors directly concerned with the space research of the Center numbered 70.

At the present time, funding resources of the Center are predominantly made up of grant and contract program funds for specific space experiments. However, the basic research funds made available under the NASA Sustaining University Grant NsG-496, which the Center administers, continues to provide the most valuable asset for interdisciplinary communication and contact between the Center and the Institute faculty at large. These funds, at a current level of \$900,000 per year, are distributed to some 40 separate projects under faculty supervisors representing four schools and 16 departments of the Institute. The research so sponsored includes basic studies in the social, life, and physical sciences and engineering on topics generally related to the national space program. The distribution is made under the supervision of the Center, subject to the review of the Institute Committee for the Center for Space Research.

These basic funds have provided unique opportunities for the preliminary study and evaluation of ideas and concepts that, in a number of cases, have generated alternate funding support from other agencies. Eight projects have been specifically identified in this category. A like number are in the process of active negotiation. New contributions to the state of the art of space research have been generated and the base of funding support for space research has been broadened. Support for the research activity of new faculty, and in particular junior faculty, has been made possible with the released funds.

GENERAL RESEARCH PROGRAM

The growth in program funding available to the Center over the last year, together with the basic research funds under NASA Grant NsG-496, has permitted a deeper attack on the several research themes selected for concentrated effort by the Center. This has been possible despite the ten per cent reduction in general funds put into effect by NASA in December, 1966.

Astrophysics research has increased in activity with continuing studies under sponsorship of the general and program funds within the Center. Professors Chia Chiao Lin, Christopher Hunter, Alar Toomre, and Dr. Chi Yuan of the Department of Mathematics have found, in applying density wave theory to the study of the local structure of the galaxy, that variations in the rotation curve from radio observations correlate very well with the distribution of atomic hydrogen. Several studies are continuing related to the theory of the migration of stars and aspects of the basic mechanism for the maintenance of the spiral density waves.

Professor Icko Iben Jr., of the Department of Physics, in his studies of population II evolution has found a definite conflict between (a) stellar

evolution theory, (b) R. R. Lyrae pulsation theory, and (c) the normal interpretation of the Hubble time. A correlation exists between R. R. Lyrae luminosity and cluster age as determined by (a). The R. R. Lyrae luminosity suggested by (b) then leads to cluster ages which are significantly larger than the age suggested by (c), regardless of the assumed initial stellar helium content. Other studies are proceeding on population II stars as they reach the red-giant tip, and giant branch stars taking into account losses by postulated neutrino processes.

Professor Philip Morrison of the Department of Physics and associates have been analyzing the optical intensity course and spectrum of supernovae. Their studies indicate that all types of supernovae can be understood with the use of a single fluorescent model. Other work is being done on the operational parameterization of the region near a Schwarzschild singularity and departures from thermal equilibrium in the last stages of the big bang.

Professor David H. Frisch of the Department of Physics is designing equipment for an orbital test of general relativity, and Professors George W. Clark and Herbert Schnopper, also of Physics, are conducting design and laboratory studies of a crystal x-ray spectrometer for use in measurements of cosmic x-rays.

The x-ray astronomy research reported last year under the direction of Professors Clark and Hale V. Bradt of the Department of Physics has been actively continued using sounding rockets with a payload having an extremely large viewing area for the detection of celestial x-rays over a wide range of energies. The regions of the sky of particular interest include the Scorpio X-1 source, the Virgo cluster, and the galactic center. The payload has been prepared and was scheduled for launch in late June, 1967.

This group has received authorization to begin the design and construction of an additional rocket payload for further x-ray experiments.

Work has also been initiated on the design and construction of a complex, four-color x-ray survey experiment which will detect energy and time variations of celestial x-ray sources and is to be placed on the NASA Orbiting Solar Observatory-H.

The Sunblazer solar probe project under Professor John V. Harrington's direction has been placed in the advanced mission category by NASA with first flight scheduled for 1968-69. A series of flights is to follow thereafter running into the 1970's. This spacecraft, which has a total weight of about 25 pounds including its own power supply, stabilization system, and transmitter, is designed to be launched by a five-stage Scout rocket into solar orbit passing behind the sun as close as about 55,000,000 miles. Radio pulse transmissions are to be made through the

extended solar corona, giving a measure of the electron density in the corona. Other appropriate experiments are being considered for the Sunblazer spacecraft.

Solar astronomy research at the El Campo, Texas, phased-array radar site has continued under the direction of Professor Harrington and Dr. Jesse C. James. During the past year, the average solar radar cross section has increased but not nearly as much as was expected on the basis of the increase in average sun-spot number. Statistical studies have shown that the average solar radar cross section is larger on days with a large amount of flare activity prior to the radar experiment. Analyses of these data have supported the theory that strong shocks are generated in association with flares and that within a few hours' time these shocks propagate out to a level in the corona where they can reflect radar signals.

As can be seen by the increased activity in astrophysics reported in the foregoing section, the Center's Laboratory for Space Experiments has made rather important progress during the past year in translating several studies into specific space flight projects. Notable growth in personnel and facilities has taken place in support of these programs. The Laboratory has a current total personnel count of 64, of which 20 are full-time staff. Four faculty members are concerned with the over-all supervision of the research activities and a like number participate as principal investigators on the experimental projects. Twelve graduate students are carrying out thesis research within the Laboratory.

Under the sponsorship of the general funds administered by the Center, other physical science studies include the research by Professors William H. Pinson Jr. and Patrick M. Hurley of the Department of Geology and Geophysics and associates on meteorites, tektites, and ultrabasic rocks. Based upon rather complete comparative chemical and age analyses, they have concluded that the specific crater site rock that produced the Ivory Coast tektites is as yet unidentified. However, impact glass from the assumed crater source, although chemically unidentifiable with these tektites, shows identical fusion (K^{40}/A^{40}) dates and chemical differentiation (Rb/Sr) dates.

Among their other studies is one of Greenland icecap dust which indicates that some of this material is of cosmic origin, the remainder being terrestrial.

In the transition region between physical science and engineering research are a number of projects supported by the general funds of the Center such as the kinetic theory of plasmas studies by Professor James E. McCune, Heinrich J. Volk, and Rodney J. Mason Jr. of the Department of Aeronautics and Astronautics, and Professor Thomas H. Dupree of the Department of Nuclear Engineering. These investigations deal with

plasma waves, instabilities, and their non-linear behavior, all of current plasma physics interest. Professor Marten T. Landahl of the Department of Aeronautics and Astronautics has been working on a wave-guide model for turbulent shear flows near rigid or flexible boundaries. A number of studies related to behavior of materials in space environment are being supervised by Professors Michael B. Bever, Philip L. deBruyn, Harry C. Gatos, Robert E. Ogilvie, and August F. Witt of the Department of Metallurgy and Materials Science; Professor Leon E. Beghian of the Department of Nuclear Engineering, and Professors Charles C. Ladd and Leslie G. Bromwell of the Department of Civil Engineering.

Research in space propulsion and power received significant support from the general funds of the Center and consisted of 11 projects supervised by faculty of the School of Engineering. The scope of this research ranged from studies of the problems of chemical and nuclear rocket propulsion through those related to generation of power in space.

Social sciences research sponsored under the Center's general funds have dealt with analysis of the growth of technology-based enterprises, the impact of research and development on the economy of the United States, and the impact of the space program on international relations. Significant results have been produced in this area resulting in several important reports, two new books and a series of meetings and seminars on certain of the larger socio-economic problems facing the nation as a whole. This research has been under the supervision of Professor Eugene B. Skolnikoff of the Department of Political Science, and Professors William H. Gruber and Edward B. Roberts of the School of Management.

Finally, a series of four projects in the life sciences have dealt with the general problems of predicting potential extraterrestrial life forms and the problems of successfully maintaining man in space for extended periods.

JOHN V. HARRINGTON

LABORATORY FOR NUCLEAR SCIENCE

The Laboratory's program of high- and low-energy nuclear physics last year occupied the efforts of 61 faculty members and 112 Ph.D. graduate students, and resulted in the production of 29 Ph.D. and 56 undergraduate theses in the Department of Physics. The Laboratory's program in nuclear chemistry continues and includes studies in nuclear inorganic chemistry, chemistry of the fission elements, and researches in nuclear organic chemistry. A summary of the researches of the chemistry group is included in the report of the Department of Chemistry.

LABORATORY FOR NUCLEAR SCIENCE

Other staff, including Ph.D. research personnel, undergraduate students and technical and administrative staff, numbered 360. The year's operations, including funds used for the purchase of major experimental apparatus, were performed at an over-all cost in excess of six million dollars.

Of special note this year were: the definite initiation of construction of the Laboratory's 400-Mev Linear Electron Accelerator and the acquisition of senior management and accelerator physics staff for that program; arrangements to replace the Laboratory's IBM 7044-1401 computer system with an IBM 360/65; and the decision to propose to the AEC the acquisition of a Tandem van de Graaff generator to be installed at the Middleton, Massachusetts, site along with the linear accelerator for which that site was acquired.

Research efforts spanned theory and experiment, including the now considerable front of effort in elementary particle and nuclear structure physics being pursued in the Laboratory's theoretical center; experiments with the Laboratory's on-campus cyclotron and van de Graaff accelerators; and work at the Cambridge Electron Accelerator, the Brookhaven National Laboratory, and the high-energy Stanford Linear Electron Accelerator (SLAC), which began successful operation in early 1967.

The Laboratory's Bubble chamber, involved in the July, 1965, fire and explosion at the Cambridge Electron Accelerator, has now been repaired and located at the Argonne National Laboratory where it will be used (in high-energy experimentation) both by M.I.T. faculty and by interested physicists from the midwest.

STATUS OF NEW FACILITIES

TANDEM VAN DE GRAAFF

As the L.N.S. Visiting Committee pointed out in its 1966 report, one of the most pressing problems facing the L.N.S. is obtaining an adequate replacement for the outdated M.I.T. cyclotron and ONR generator. Stimulated by this report, the Laboratory staff and the Institute administration have reexamined our situation in experimental nuclear structure physics and possible facilities most appropriate for the Laboratory. As a result of these discussions, we have prepared and submitted to the Atomic Energy Commission a new proposal for a so-called TU Tandem van de Graaff accelerator to be installed on our Middleton site. In it we stress the increasingly important role of heavy ion bombardment in nuclear studies and we outline in some detail the experiments which the TU would enable us to carry out. We have the experimental and theoretical strengths to utilize this facility in a most effective way. At the same

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time, we recognize that it will be unique and should be made available to other users. The building we have planned will be sufficiently flexible to accommodate other research groups and can easily be expanded.

LINEAR ACCELERATOR

As of April 6, 1967, the 400-Mev linac construction program was designated by the AEC as officially begun. A formal contract is now in existence and several of the major component construction programs have been started.

In addition to the construction program itself, a major effort is underway to prepare for the research program with the machine. A scientific study arranged for the summer of 1967 had the participation of a large representation of specialists in photonuclear and electronuclear physics from several countries.

L.N.S. COMPUTER FACILITY

In October, 1964, the Laboratory acquired an IBM 7044 computer. L.N.S.'s computing needs had outgrown the capacity of the M.I.T. Computation Center and other available resources. The 7044 facility has maintained both batch-processing and open-shop services. More than 200 physicists use the computer and it now is in use for three shifts each weekday and about 30 hours each weekend. The uses include long searches of the numerical solutions of the Bethe-Salpeter equation, many short theoretical calculations, fitting of data to theoretical models, and great quantities of processing and analysis of experimental data. Because of the easy accessibility and flexibility of operation of the facility, it has been possible to run approximately 3,000 jobs per week.

It became clear more than a year ago that the computer was approaching saturation and a search was made for a faster machine. The IBM 360/65 has been selected for this and was scheduled for delivery during the summer of 1967. The IBM 360/65 is expected to provide ultimately about four times the computing capacity of the 7044. Plans for converting existing programs to run on the new computer are under way.

RESEARCH SUMMARIES

HIGH-ENERGY PHYSICS

THEORY A great deal of effort of the group in the high-energy physics area has been devoted to particle physics. In particle theory the relativistic three-body problem is of central importance in any dynamical consideration. A deeper understanding may be developed from the exact solution found in charged scalar static theory which has been developed

here. A number of papers on the consequences of unitary symmetry schemes and quark models have been prepared. Similar investigations of the current algebras are in progress. A paper on the behavior of these algebras for simple models has been submitted for publication. A great deal of phenomenological study of the experimental data for nucleon-nucleon and boson-nucleon interactions has been made with a particularly signal success for the nucleon-nucleon case. Polarization in pion-nucleon scattering has been explained in terms of Regge cuts.

Studies made during the past year have included: high-energy wide angle p-p scattering, charge exchange polarization, high-energy Compton scattering, connection between Regge behavior and current algebras, and effect of cuts on superconvergence relations.

EXPERIMENT Spark chamber work at the Brookhaven Alternating Gradient Synchrotron has produced such results as the discovery of a low-mass enhancement in the $2\pi^0$ system and the definitive determination f^0 particle spin; the establishment of an upper limit for the eta meson branching ratio into $\pi^0\gamma\gamma''$; and the observation of the decay channel $\omega^0 \rightarrow \pi^0 + \gamma''$, confirming a decay mode of importance to meson theory.

Experiments with electron and photon interactions at the CEA examined: the photoproduction of μ -pairs from carbon (photo energy 5 Bev), yielding a measurement of the branching ratio of the ρ^0 meson into a muon pair (giving information about the strength of coupling of the ρ^0 to the photon); and a test of quantum electrodynamic theory that shows μ -pair production to be incompatible with the large deviations observed in the electron pair experiment carried out at the CEA.

Another experiment examined cross sections for the elastic scattering of electrons from the deuteron, which show the existence of short-range structure in the n-p interaction and reasonable agreement with some of the modern n-p potentials. Experiments were also made to examine the possible existence of a heavy lepton, proposed by Low, which couples to a photon and an electron. Such a particle would provide a basis for possible deviations from the predictions of the theory of quantum electrodynamics. No evidence was found for its existence in the mass range up to 1300-Mev.

Work at the CEA and at Brookhaven included final analysis of (γ,p) interactions (12-inch hydrogen bubble chamber at CEA) for gamma ray energies up to 6-Bev. This study has been remarkably prolific: photoproduction of the ρ^0 and ω^0 mesons was studied in detail yielding properties of these particles that bear on nuclear structure and current symmetry schemes (SU6); the popular one-pion exchange theory was ruled out as a fundamental mechanism for these production reactions; an

examination of nuclear excited states showed that strong proton excitations occur that match the resonances observed in π -nucleon interactions. A striking new observation was that the higher mass excited nucleon states decay in cascade fashion to lower ones, by the emission of π -mesons in a manner analogous to the well-known photon decays of atoms and nuclear states. High-Z spark chamber studies (Brookhaven) of π -p reactions leading to neutral final states were studied over the resonance region 500-Mev to 4-Bev, which contains many nucleon excited states. All of the expected excited nucleon states were seen clearly in the neutral final states. The charge exchange final state (π^0 N) was studied to check the predictions of Regge pole theory, of which this case is a simple one, involving only one Regge pole exchange (the ρ trajectory). The data are consistent with the theory.

Measurements of elementary particle photoproduction cross sections from (γ ,p) processes at CEA resulted in verification of a theoretical prediction (SU_3) symmetry relating to the high-energy photoproduction cross section for K^+ and π^+ mesons; and extension of π^0 photoproduction to regions of high energy and momentum transfer (to 6-Bev γ -ray energy and 4.0-(Bev/c)^2 which allow the isolation of data in which the π^0 meson is produced well within the proton. An interesting similarity is observed between the energy and angle dependences of π^0 photoproduction and those of meson-proton scattering, implying qualitatively that the same features of the proton mass distribution are effective in the two kinds of interactions; other measurements resulted in a search for quarks. To be seen under the conditions of the experiment the required quark masses would have to lie between 100- and 300-Mev and they would have to be weakly interacting. None were observed.

Spark Chamber researches followed two main lines, one of which was weak interaction experiments in cooperation with groups at other institutions, where the main contribution of the M.I.T. group lay in the data retrieval and evaluation, centered on the Spark Chamber Automatic Scanning System (SPASS) data analysis system developed by Professor Martin Deutsch of the Department of Physics. These experiments included the study of the K^0 decay in collaboration with Maryland and Brookhaven National Laboratory (BNL) groups which is now completed and published; a study of the K decay in cooperation with a Berkeley group, still in progress, has yielded results concerning the K_{μ_3} form factor. Other Spark Chamber research concerned photon-nucleon interaction studies at CEA, where preparation for the continuation of gamma ray scattering experiments has been completed and data-taking initiated.

Technical developments of special mention during the past year were: The M.I.T.-L.N.S. 500-liter bubble chamber, repaired after the accident

at the Cambridge Electron Accelerator, is now in the process of being established at the Argonne National Laboratory jointly by L.N.S. and Argonne. When working, it will be transferred to Argonne as a facility of that laboratory, and will be used for an intensive and detailed scrutiny of π^- and K-induced reactions with protons over the energy range of the Zero Gradient Synchrotron (that is, up to 12-Bev). Experience (the L.N.S. $[\gamma, p]$ bubble chamber work at the CEA) has shown that a thorough understanding of the mechanisms of particle reactions usually emerges only from fine grained systematic measurements over large energy regions. Such a study is overdue for the π, p and K, p interactions, and the plan with the Argonne installation is to generate data for use by the midwest physics community (in addition to the M.I.T.-L.N.S. group) who have expressed their strong wish to participate in the program.

The M.I.T. Precision Encoding and Pattern Recognition (PEPR) device has been completed successfully in its prototype form. The main objectives sought with the prototype were to develop a digitally controlled cathode ray tube measuring device the accuracy of which would approach that of the mechanical equivalents in use with other systems; to develop a digitally controlled tube line pattern and to investigate the efficiency of this pattern in analyzing bubble chamber film; and to develop techniques and computer programs leading to a system capable of analyzing bubble chamber events under computer control.

The prototype developed has not only demonstrated the feasibility of the cathode ray system, but its stability and accuracy exceeds that of most of the mechanical devices in use. Its absolute precision exceeds one part in 40,000. The measuring speed is orders of magnitude greater than that achievable by mechanical stages. A cathode ray pattern has been created which has been demonstrated to be effective in distinguishing and identifying bubble chamber tracks from the usual background in bubble chamber film. In addition a prototype bubble chamber analysis system (point guidance) has been applied successfully to the measurement of more than 1,000 real events. The input to this system is a minimal number of points for each event plus the film number of the event. From this point forward, the PEPR system finds and measures fiducial points and event tracks and the ionization density of each track.

The next step in this program will be the construction of a production PEPR device. This has been ordered from a commercial supplier and suitable computer control programs are being written for its use. A small extrapolation from the work with the prototype indicates that a measurement rate capability of 1,000 events per day will be possible with the production system.

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The SPASS system, which operated most successfully during the year, was used for data processing in the two cooperative experiments. A high resolution modification of this system is scheduled for completion during this fiscal year.

The data link from the CEA to the L.N.S. 7044 computer facility in Building 24 was completed and turned out to be highly successful. It permitted on-line decisions to be made during the running of experiments at CEA.

INTERMEDIATE ENERGY PHYSICS

During the remainder of 1967 the major projected task concerns design studies for the three major experimental facilities which should be operational when the Laboratory's new 400-Mev linear accelerator is ready for experimental use toward the end of fiscal 1969. A summer study group of visiting physicists are to aid in reviewing design studies and in developing and assigning priorities for the experimental program so that detailed engineering and procurement can be accomplished during fiscal years 1968 and 1969.

Facilities considered at this time to be of greatest importance and for which conceptual designing has begun are: (1) a high-resolution electron scattering facility for studying charge and magnetic form factors for nuclear elastic and inelastic scattering; (2) a large solid-angle, modest resolution detector array for accomplishing coincidence experiments such as (e, e', π) , $(e, e' p)$, (e, e', pp) and $(e, e' \pi p)$; and (3) a pion physics facility, to allow pi mesic x-ray work, low energy pion scattering, and two-body correlation work by reactions such as (π, pp) and (π, pn) . The emphasis in the first two experiments lies in the investigation of isobaric analog states, of nuclear momentum distributions, of the structure of filled shells, and of two-body nuclear correlation functions.

LOW ENERGY PHYSICS

THEORY The L.N.S. theoretical group has been engaged in many lines of research current in nuclear physics. They include:

1. The theory of nuclear reactions with particular emphasis on doorway states and intermediate structure, analog resonances, and deuteron scattering and stripping effects of the Pauli principle.
2. Development of the nucleon-nucleon potential using the boundary condition model and soft or non-local cores.
3. Work on the use of the Hartree-Fock method for calculating the binding energy and other properties of finite nuclei. This includes some shell model calculations and some estimates of effective forces for them.
4. Intermediate energy physics such as the photoproduction and electro-

production of pions from nuclei and attempts at explaining the large cross sections for deuteron production in large momentum transfer reactions on nuclei.

As may be noted, a great deal of attention is being paid to the calculation and understanding of the structure of nuclei working directly from nuclear forces as obtained from nucleon-nucleon scattering and using the Hartree-Fock or Brueckner methods. It has been found that the soft core representation of the nucleon-nucleon potential cannot be used in the Hartree-Fock method. A modified form of the Brueckner method has been found to give encouraging results. Parity mixing has been found not to exist in nuclei. Hartree-Fock calculations for deformed nuclei lighter than Ca^{40} have been performed. Continuing interest is maintained in the field of nuclear reactions where the effects of the identity of particles have been studied as well as the development of theories for the treatment of the interaction of composite systems in the nuclei. A generalized optical model for deuteron nucleus interactions has been developed. The study of intermediate resonances has continued with considerable effort being spent on the isobar analogue states as well as new examples of intermediate states.

EXPERIMENT *Cyclotron*: Cyclotron-induced nuclear reactions have produced the following significant results from alpha-particle and proton reactions using the L.N.S. cyclotron:

1. Further experimental evidence in enriched isotopes of calcium and titanium (Apparatus has been completed and work is proceeding to extend the 3^- state excitations to higher-A nuclei. It is anticipated that the remarkable fractionation observed so far in the $f_{7/2}$ shell region may extend widely throughout the periodic table.), of strong fractionation of 3^- states in disagreement with predictions from particle-hole model description of negative-parity collective states; as is also the drop with atomic number (from A40 to A50) in strength of observed 3^- and 5^- states.
2. Observation and angular distribution measurements of a number of highly excited 4^+ levels (between 5- and 8.5-Mev). The number and the occurrence of these (and others observed elsewhere) largely in the Ca-Ni region are suggestive of a systematic mode of excitation that may be related to that of 4^+ levels seen in closed shell Ca and Pb nuclei.
3. Measurement (via $\text{Ti}^{48}(\alpha, p)\text{Sc}^{51}$) of level spins and energies in Sc^{51} , which agree well with a shell model calculation inspired by the data. (The (α, p) reaction used for this study appears to proceed by a three nucleon transfer reaction, opening an interesting study of complex nuclear configurations and hard to reach nuclei like Sc^{51} .)

4. Study (via $\text{Ca}^{40}(\alpha, \alpha'\gamma)$) of two 3^- state decay properties; and the confirmation of spin (1^-) assigned to the Ca^{40} state at 6.94 Mev in other (α, α) M.I.T. work. This last unusual and very strong 1^- state has been assumed by other workers to be 3^- .

5. Study of low-lying states in Ca^{42} via reaction $\text{Ca}^{42,44}(p, p'\gamma)$. These measurements allow comparison with theoretical predictions based on the coupling of deformed and single particle states.

Cyclotron-induced nuclear reactions have also produced significant results from (p,d) and (p,t) reactions using other cyclotrons (University of Colorado, Oak Ridge National Laboratory):

1. Location of isotopic spin $1/2$ and $3/2$, $d_{3/2}$, and $s_{1/2}$ hole-states in Ca^{41} , via the reaction $\text{Ca}^{42}(p,d)$. The information is important to nuclear structure theory and illuminates weakness in some recent calculations. This and a related $\text{Ca}^{44}(p,d)$ experiment are being prepared for publication.

2. Data from the reaction $\text{Pb}^{208}(p,d)$ that indicate the ground state of Pb^{208} to differ from that predicted by shell model theory.

3. Data from (p,t) reactions in enriched isotopes of lead, tin, and calcium for comparison with calculations using two nucleon transfer reaction theory. Comparison is at present being made with the $\text{Ca}^{42,44}(p,t)$ data and with that of the related $\text{K}^{39}(\text{He}^3, p)\text{Ca}^{41}$ (ONR van de Graaff) experiment.

LINEAR ACCELERATOR GROUP Work continues to be centered about studies of the two-body system and nuclear structure using the electromagnetic interaction as a probe; although one of the recent efforts (described below) concerned the polarization of neutrons scattered from carbon. The group's immediate future plans are for work with the National Bureau of Standards linac at intermediate energies; long-range plans are for the development of experiments and apparatus for the new 400-Mev linac.

Efforts of this past year included:

Photoneutron polarization studies were conducted this year, including:

1. $\text{D}(\gamma, n)$ polarized photoneutron data, analyzed using recently measured detector response functions, yielded accurate photomagnetic disintegration amplitudes ($4 \leq E_\gamma \leq 30$ Mev) in agreement with predictions of most recent theories of the two-body system potential.

2. Data on polarized photoneutrons for the giant resonance region (~ 8 to 30 Mev) in O^{16} shows a large polarization value that has none of the structure observed in its cross-section behavior. The results indicate strong s-wave neutron emission, in contrast to the pure d-wave emission used previously to interpret the photoneutron angular distributions.

Measurement of photoneutron energy spectra and angular distributions revealed that:

1. Evaporation and resonance-direct photoneutron components for a number of medium and heavy nuclei show the evaporation behavior to be strongly affected by the closing of major shells. The direct component is strongly correlated to atomic number; and much larger than the predictions of simple theories.
2. Multipolarities and partial cross sections were established from Be⁹ data yielding spin and parity values. A state of importance to theories of the p-shell ($1/2^-$ at 4 Mev) is thought to have been observed.

An intermediate energy photoeffect was that photoprotons (from 100 Mev γ -rays on Li⁶) show energy and angular dependence that mainly follows predictions based on a pseudodeuteron process. Some structure that may associate with a more complex mechanism occurs at the highest proton energies.

Other experiments dealt with polarization of 14.7-Mev scattered neutrons; results of a first experiment with C¹² show the definite feasibility of the technique and apparatus for studies of nuclei having comparable excited state separations. The preliminary C¹² elastic-scattering polarization data is much larger than predicted by optical potential theories.

Instrumentation developments: The beam optics has been investigated and a design initiated for a 180° scattering system for the National Bureau of Standards (NBS) facility to be used in a program of elastic and inelastic electron-scattering investigations starting with the deuteron and other very light nuclei. The system elected is patterned after the so-called Koerts magnet, different from the usual 180° systems, which has the very useful feature that the solid angle subtended at the target by a detector outside the magnet is independent of scattering angle. The preliminary design is to accommodate 150°-180° scattering.

NUCLEAR ENERGY LEVEL STUDIES GROUP The last year involved the analysis of a wide variety of reactions including (d, α), (d,d), (s,p), (p,p' γ), and He³,d). Efforts of note were:

1. Work with the new He³⁺ beam, with which a number of interesting results were obtained, including studies of levels excited strongly in Ca⁴¹, (via K³⁹[He³,p]) and thought to have strong two-particle one-hole character.
2. Some interesting weak level angular distributions, by prolonged (d,p) exposures under very good background conditions. Classified earlier as non-stripping levels, these do not fit distorted wave born approximation or other pertinent theoretical predictions.
3. Measurements of particle-gamma coincident decay reactions to

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measure decay branching ratios of selected levels in Cu^{63} , Cu^{65} , Ni^{61} , Cr^{53} , and Zn^{67} .

In order to diversify the types of experiments that can be carried out on the generator and to speed up data acquisition time for certain reactions, the use of solid-state detectors has been employed in several experiments. A scattering chamber is being designed for further use in such reactions. Along with continued improvements to the Laboratory's large multiple-gap spectrograph, major development of scintillation detection apparatus adapted for use with that spectrograph is under way.

The final modification and testing of a new He^{3++} ion source have been a major effort during the period covered by this report. This now delivers a well-regulated beam up to $0.1\mu\text{A}$ in intensity and at energies from 10 to 15 Mev.

RADIOACTIVITY GROUP The study of the static moments of excited states and the by-product study of electric and magnetic fields acting on nuclei in solids received significant impetus during 1966 with the development of techniques to implant unstable ions. Investigations also continued using the Mössbauer effect, and angular correlation with radioactive sources. Significant results from each of these areas are:

1. The measurement of the magnetic moments of first 2^+ states in even-even nuclei of Te. The values of μ are high and in serious disagreement with predictions.
2. The first measurement of centrifugal stretching in deformed nuclei showing that, in a rotational band, the first 2^+ states have larger average radii than do the ground states.
3. The measurement of the internal magnetic field on lead nuclei in iron, showing the onset of a new region of positive internal fields.

Heavy ion research, apart from the implantation work mentioned above, continued with the measurement of charge distributions and energy losses of heavy ions of Br, I, Ta, and U traversing foils and gasses. This work extended, both in energy and mass of ion, the previously known data.

COSMIC RAY AND SPACE PHYSICS

Most of the work being carried out in this area can be broadly classified as astrophysics, nuclear physics, or some combination of these disciplines. In the area of astrophysics the most active areas of research are x-ray astronomy, the properties of the interplanetary medium (properties of the solar wind), and high-energy cosmic gamma rays. Additional problems which are currently being studied are astronomical observations in the far infrared (1 to 2.5 microns and 10 to 2,000 microns) and a

search in the Mev region for nuclear gamma rays which are produced as a result of nuclear synthesis in stars.

Activity in the field of x-ray astronomy has been increasing for the past few years. This year is no exception; extensive observations have been carried out using balloons and rockets and an experimental program using satellite-borne instrumentation has been initiated. The most noteworthy result of the x-ray program during the past year was the optical identification of ScoX-1, the great x-ray source in Scorpio. This result was obtained by a rocket experiment conducted in March, 1966, and involved a collaboration with scientists at American Science and Engineering, the Palomar Observatory, and the Tokyo Observatory. The experiment employed a multi-grid modulation collimator which is based on the same principle as the two-grid modulation collimator developed earlier at M.I.T. and used by the A.S. & E.-M.I.T. group in a previous rocket experiment that set an upper limit of seven arc minutes on the angular diameter of ScoX-1. Analysis of the data yielded two probable locations of ScoX-1, each with an uncertainty of about one arc minute.

Astronomers at the Tokyo Observatory and at Mt. Palomar were informed of these results, and both groups observed a blue stellar object of magnitude 13.0 *plus* 0.5 within one arc minute of one of the prescribed positions. This object was observed to fluctuate rapidly by as much as one-half magnitude in one day. The visible spectrum shows several identified lines with rapid variations. A complete description of the results on ScoX-1 obtained in this investigation is contained in three publications in the *Astrophysical Journal*.

The experimental program in x-ray astronomy using rocket-borne instruments is being continued. An entirely new rocket-borne experiment has been designed in collaboration with the Center for Space Research. It is scheduled for launch during July, 1967.

Activities in the area of balloon x-ray astronomy increased very substantially this year. New results on the spectra and distribution of cosmic x-ray sources were obtained. In summary, the activities and results were:

1. A sky survey between right ascensions 18^h and 6^h and declinations -10° and $+70^\circ$, and measurements of the spectra of CygXR-1 and TauXR-1 between 15 and 70 Kev were carried out with a 400 cm² NaI (T1) scintillation detector telescope.
2. Several potential x-ray sources (SN1604, Cas A) were inspected and the spectrum of TauXR-1 was measured with a 57 cm² NaI (T1) scintillation detector telescope whose orientation is controlled by telemetry from the ground.
3. Two new balloon-borne instruments have been designed to obtain

increased sensitivity and energy resolution. One of these units will be used to study the energetic x-radiation from TauXR-1; particular attention will be given to a high resolution measurement of the energy spectrum and to possible time variations of the intensity. The orientation of the second experiment can be controlled from the ground. Initially this experiment will be used to scan the Virgo cluster in an attempt to locate extra-galactic sources of hard x-rays.

As of July, 1967, the M.I.T. group has provided 13 plasma experiments for 11 NASA satellites and space probes. Of these, ten experiments are still operating although the recovery of data from some is limited because of the great distance between these particular spacecraft and the earth. During the past year the IMP-D and IMP-E satellites were launched with the intention of achieving a lunar orbit; in this way it is possible to study the conditions near the moon from the standpoint of particles and fields, and in particular it is possible to study the interaction of the solar wind with the earth and with the moon. The first flight in July, 1966 did not achieve lunar orbit but, because of excellent planning beforehand, it was possible to obtain a greatly elongated earth orbit with apogee at about 80 earth radii. IMP-D is now the most distant of earth's satellites, and it is returning excellent data of great scientific interest. The sister satellite IMP-E is to be launched in July, 1967; if a lunar orbit is achieved, this satellite should give a definitive answer to the problem of how the solar wind interacts with the moon and should yield important information about the composition and structure of the moon itself.

In addition to the experiments aboard the IMP satellites, a plasma experiment was successfully launched aboard the 1967 Mariner space probe to Venus. This experiment will reach Venus in October, 1967; the results should add considerably to our understanding of the particle environment near the planet and to our knowledge of the configuration and strength of the planetary magnetic field of Venus.

During the past year an intensive program of data analysis has been underway using results from IMP-1, IMP-2, OGO-1, OGO-3, Mariner 4, Pioneer 6, and Pioneer 7. The results are contained in a series of papers which pertain to the following subjects:

1. Properties of the plasma in the interplanetary region;
2. Correlation of plasma properties with solar and geophysical phenomena and the interpretation of the observed correlation;
3. The interaction between the plasma wind and the geomagnetic field;
4. The morphology of low-energy (about 1 Kev) electrons within the magnetosphere.

In addition to the research program outlined above, work continues

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on extensive air showers (EAS). At the BASJE site (Joint Bolivian Air Shower Experiment) located at 17,000 feet on Mt. Chacaltaya a study of the Cerenkov light associated with EAS of energy 10^{16} eV has been carried out. At Volcano Ranch (Albuquerque, New Mexico) a large array of scintillation counters is being installed to study the lateral distribution function at energies between 10^{16} and 10^{18} eV. The work on very large air showers is relevant to our understanding of nuclear interactions at very high energy, but even more important are the possible astrophysical implications. Cosmic rays of extremely high energy should interact strongly with the postulated universal three degree black body radiation so that a cut-off in the cosmic ray primary spectrum is predicted at about 10^{19} eV. Present experimental results indicate that the spectrum extends at least to $\sim 10^{21}$ eV and additional work is clearly in order.

PETER T. DEMOS

PROJECT MAC ADMINISTRATION

Project MAC is an interdepartmental research laboratory in the computer sciences. It is supported by the Advanced Research Projects Agency of the Department of Defense, under a contract with the Office of Naval Research, and it is presently housed in an office building adjacent to the M.I.T. campus.

The main objective for which Project MAC was organized in the early spring of 1963 was conducting a research and development program on machine-aided cognition and multiple-access computer systems. Since that time, the original emphasis on the development and exploitation of time-sharing systems has gradually broadened, in response to faculty and student interest, into a program of basic research in many facets of the computer sciences, as well as of computer research motivated by objectives in other fields. At the same time, research objectives and educational objectives have become increasingly intertwined, to their mutual benefit, not only in conjunction with graduate seminars and thesis research, but also in the development of undergraduate subjects of instruction in the computer sciences.

Research support is provided by Project MAC to faculty and graduate students representing 14 academic departments, in the form of access to Project MAC's computer facilities, office and laboratory space, and salary support. Data on participation in Project MAC and on the nature of support provided are given in Table I. On a full-time-equivalent basis, the research staff totals 84 people and the support staff totals 49, including 20 computer operators.

Student participation continues at an active level. During the academic year 1966-67, 15 doctoral theses were completed with Project MAC support, 3 Engineer's theses, 15 Master's theses, and 6 Bachelor's theses.

Table I Personnel Summary and Nature of Support

	Salary support	Office/Laboratory in Technology Square	Total participants
Faculty	21	25	91
Research Associates, Lecturers, Instructors	7	10	22
Research Assistants and other students	31	42	157
Research staff	62	65	101
Guests	—	12	12
Computer operators	20	20	20
Other support personnel	41	41	43
Totals	182	215	446

Professor Harry D. Huskey of the University of California at Berkeley spent the fall term of his sabbatical year at Project MAC as Visiting Professor of Electrical Engineering, and Professor Maurice V. Wilkes, Director of the Cambridge (England) University Mathematical Laboratory paid a two-week visit to Project MAC during the spring, as he has done each year since his full-time participation in the 1963 summer study. Several governmental, industrial, and university laboratories, both foreign and domestic, have expressed interest in having members of their research staff work at Project MAC for a year or more for the purpose of becoming intimately familiar with particular research and development efforts of special interest to them. Many of these requests could not be satisfied because of lack of supervisory time and of office space. Still, Project MAC was host during the past year to 11 visiting scientists and engineers selected on the basis of their ability to contribute to the research project of interest to them as well as to learn from their participation in it. These arrangements have in all cases proven to be of significant mutual benefit.

The work on time-sharing systems is attracting a growing number of foreign visitors, both official missions formally introduced by their embassies and private individuals. Because of other travel plans, these visitors often cannot attend the scheduled monthly briefings and must be given personal attention. While the interest in Project MAC on the part of both foreign and domestic visitors is gratifying indeed, the task of serving as host to them has become a major demand on the directors' time.

An Industrial Liaison Symposium on Project MAC research was held on January 11 and 12, 1967. The attendance of 415 people, representing 59 industrial liaison companies, set an all-time record, surpassing the record attendance at the symposium on Project MAC research on May 6 and 7, 1964. The symposium was chaired by Professor Robert M. Fano; papers were presented by Professors Fernando J. Corbató, Jack B. Dennis, Edward L. Glaser, Chung L. Liu, Marvin L. Minsky, Seymour A. Papert, Jerome H. Saltzer, Joseph Weizenbaum, Dr. Myer M. Kessler, William A. Martin, Joel Moses and Robert H. Stotz. Professor Saltzer gave a two-week series of lectures on time-sharing systems at the Electrotechnical Laboratory in Tokyo, Japan, during the summer of 1966. Professor Minsky and Richard G. Mills, Assistant Director of Project MAC, lectured at the 1966 summer school sponsored by NATO at the University of Edinburgh. The continuing, widespread interest in Project MAC is evidenced by the large number of invited lectures given by members of the staff in addition to the many contributed papers presented at the Fall and Spring Joint Computer Conferences and at other technical meetings. The September, 1966 issue of *Scientific American*, which focused on the theme information, included invited articles by Professors Steven A. Coons, Martin Greenberger, Corbató, Fano, and Minsky, and also an article by Christopher Strachey of Oxford University, who spent the academic year 1965-66 at Project MAC as a Visiting Lecturer in Electrical Engineering.

COMPUTER FACILITIES

The current time-sharing system at Project MAC (CTSS), which employs an IBM 7094 installation, began operation in the fall of 1963 as a duplicate of the system already in existence at the M.I.T. Computation Center. A great many improvements and additions to CTSS have been implemented since that time — both hardware and software. In particular, many user-developed programs and subsystems of general interest have been published in the form of system commands for general use. Thus, the system's capabilities have grown considerably as a direct outgrowth of its use on the part of the community. The software facilities offered by the system to the community of users amount to approximately one million words of code, roughly equivalent to a 2,000 page book. Special facilities for automating and decentralizing system management and for allocation of computer resources, have proved to be very successful, particularly because they make it possible to place the responsibility for allocating resources to individual users and for monitoring resource consumption directly in the hands of the research supervisors with personal knowledge of needs and priorities. Equally successful have been the facili-

ties for on-line administration of Project MAC, including accounting, budgeting, and personnel and space management. The ease with which a variety of data can be readily abstracted from the records stored in the computer system has greatly facilitated the administration of Project MAC and the reporting of its activities.

The only major system improvement implemented last year was the automatic monitoring and control of performance. It involves a complex of programs which monitor various overload conditions and take appropriate actions for relieving them, such as dynamically reducing the maximum number of simultaneous users. When users are automatically logged out of the system, the current state of their work is preserved so that it can be continued at some later time without any loss. These monitoring and control programs have proved to be very effective in preserving good service at all times.

A summary of the system utilization over the period from June 1, 1966 through May 31, 1967 is given in Table II. The sharp decrease of maintenance time is the result of reducing scheduled equipment maintenance from five periods (ten hours) to two periods (six hours) a week. It also reflects a very high level of equipment reliability and over-all system performance. The record of 527 hours of charged time during the month of April represents an extremely high degree of system utilization. It also indicates that the system must be badly overloaded from a user's viewpoint, in the sense that a user's chance to gain access to the system at any convenient hour of the day is bound to be rather small. Each research group has priority right for one or more of the 30 lines that are allowed to be simultaneously in use at any one time. The number of lines is clearly insufficient to meet the needs of the research groups, so that many users find it impossible to utilize the computer time which, in principle, is allocated to them. No significant increase of system capacity can be expected until the new Multics system opens for general use in early 1968.

Delivery of the General Electric 645 computer installation began in September, 1966, and by February, 1967, the installation was sufficiently complete and in good enough operating condition to permit release of the General Electric 635 installation which had been used for more than a year for the development of the Multics system. The units of the new installation which are still missing are scheduled for delivery during the current calendar year. The installation includes two central processors, two input-output controllers, four core memories of 64,000 words each, and a four-million-word magnetic drum. Other mass memories will be delivered at a later time. The installation is being used solely for the development of the Multics time-sharing system.

Table II Time Sharing System Utilization Summary (Hours [Per cent]*)											
	June 1966	July 1966	August 1966	September 1966	October 1966	November 1966					
Charged time**											
On-line time	357[49.6]	324[43.5]	397[53.4]	346[48.1]	384[51.6]	340[47.2]					
Background time	49[6.8]	42[5.7]	59[7.9]	44[6.0]	70[9.4]	70[9.8]					
Total charged time	406[56.4]	366[49.2]	456[61.3]	390[54.1]	454[61.0]	410[57.0]					
Maintenance time	100[13.9]	196[26.3]	99[13.3]	69[9.6]	80[10.8]	93[12.9]					
Other time	214[29.7]	182[24.5]	189[25.4]	261[36.3]	210[28.2]	217[30.1]					
	720[100.0]	744[100.0]	744[100.0]	720[100.0]	744[100.0]	720[100.0]					
	December 1966	January 1967	February 1967	March 1967	April 1967	May 1967					
Charged time**											
On-line time	351[47.2]	386[51.9]	348[51.8]	414[55.7]	426[59.2]	398[53.5]					
Background time	51[6.9]	63[8.5]	73[10.9]	80[10.9]	101[14.1]	94[12.7]					
Total charged time	402[54.1]	449[60.4]	421[62.7]	494[66.6]	527[73.3]	492[66.2]					
Maintenance time	139[18.6]	120[16.4]	50[7.5]	59[7.9]	52[7.2]	62[8.4]					
Other time	203[27.3]	175[23.2]	201[29.8]	191[25.5]	141[19.5]	190[25.4]					
	744[100.0]	744[100.0]	672[100.0]	744[100.0]	720[100.0]	744[100.0]					

*Base = Total number of hours in month.

**On-line time is the computer time used by people operating from remote terminals.

Background time is the computer time used by conventional batch execution of programs.

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The Digital Equipment Corporation's PDP-6 computer is developing into another major computer installation to meet the needs of the visually-controlled-manipulator project. A quarter-million words of core memory with a 2.7 microsecond cycle time was added during the past year and is now in regular operation. This memory, developed by the Fabri-Tek Company, is the first of its type to be placed in operation, and its characteristics (including a very low cost per bit) are unmatched at this time. It is meeting very well the large memory needs of the project for which it was acquired.

RESEARCH PROGRAM

Project MAC is supporting research in various M.I.T. laboratories and departments by providing access to its time-sharing computer facilities and, in some instances, by providing partial salary support. This research is reported by the individual departments and laboratories that provide the primary support. The following are examples of work supported entirely by Project MAC.

SYSTEM RESEARCH

The entire effort of the system research group, under the leadership of Professor Corbató, has been devoted for some time to the design and implementation of the Multics system, a project which is being carried out in cooperation with the Bell Telephone Laboratories and the General Electric Company. This totally new time-sharing system is being implemented on the General Electric 645 computer, but could also be made to operate on other computers with similar characteristics. Professor Corbató represents Project MAC in the technical committee supervising this joint research and development effort, and Professor Glaser is in over-all charge of the design and implementation effort.

The over-all design of the Multics system was described in a series of papers presented at the Fall Joint Computer Conference 1965. The system is described in detail in the Multics System Programming Manual which includes nearly 2,500 pages of English text. The final size of this document will probably be in the neighborhood of 3,500 pages. The system software is being programmed in a subset of the language PL/1, a fact which will greatly facilitate the system's implementation on other computers as well as its future tuning up and evolution. The first major milestone was reached in early May, 1967, with the successful integrated checkout of a major and critical part of the system representing approximately one-third of the software to be developed. The second major milestone corresponding to the integrated checkout of approximately half of the software will be reached in early August. The entire

system is expected to be available for general use at Project MAC in early 1968.

Professor Elliott I. Organick of the University of Houston, the distinguished author of a number of computer textbooks and manuals, has been preparing a *Guide to Multics for Subsystem Writers* in an effort to help members of the M.I.T. community who wish to reprogram for the Multics system special facilities developed for the current time-sharing system. Three chapters of the guide were published in preliminary form during the spring term. These chapters were used in a graduate seminar on the Multics system led by Professor Greenberger of the Sloan School of Management, Professor Roy Kaplow of the Department of Metallurgy and Materials Science, Dr. John W. Brackett of the same department, and Professor Kent F. Hansen of the Department of Nuclear Engineering. Professors Corbató and Glaser of the Department of Electrical Engineering participated in the seminar by presenting an initial outline of the design of the Multics system.

VISUALLY CONTROLLED MANIPULATOR

The use of computers as personal intellectual aids is presently limited to abstract problems and to problems already abstracted from the physical world. If computers are to aid people in exploring and modeling the physical world, they must be provided with general-purpose "eyes" and "hands" capable of observing and manipulating their physical environment. A research effort aimed at these objectives has been in progress since the summer of 1965 under the leadership of Professor Minsky of the Department of Electrical Engineering and Dr. Papert who has recently been appointed a Visiting Professor of Mathematics. The first measure of success was obtained in early fall of 1966. The system, consisting of a modified industrial manipulator, an image-dissector camera, and a Digital Equipment Corporation PDP-6 computer, was able to construct, without human intervention, a tower from cubes of different size thrown at random on a table. In order to proceed to more elaborate and difficult tasks major equipment improvements were needed, and above all a better understanding of the problems of automatic scene analysis. A quarter-million-word core memory and a more precise and accurate image-dissector camera has since been acquired, and a more highly articulated arm has been designed and built. Experimentation with various techniques for building a suitable hand is still in progress. The problems of scene analysis are being studied by a growing group of faculty and graduate students under the leadership of Professor Papert. The advances made during the past year will be embodied in a demonstration experiment tentatively scheduled for the early fall of 1967.

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OTHER RESEARCH TOPICS

The rest of the research program, corresponding to approximately half of the Project MAC salary budget, consists of many separate topics of interest to individual members of the Faculty and their students whose description is beyond the scope of this report. One topic, however, deserves special mention because of its bearing on undergraduate education. The computer linguistics group under the leadership of Professor John M. Wozencraft of the Department of Electrical Engineering has been concerned with the dual objectives of isolating various linguistic facilities underlying the specification of algorithms, and organizing the resulting body of knowledge into an introductory subject of instruction for undergraduates who anticipate a major professional interest in computer sciences. The two objectives are mutually reinforcing: without research, subject development would not be possible; and without subject development, discovering the strength and weaknesses of a proposed formulation would be far more difficult. Accordingly, this work is being supported jointly by Project MAC and the Department of Electrical Engineering. The principal accomplishments of the group to date consist of a first draft of class notes and a programming language, called PAL, especially designed for educational purposes, which has been implemented on the current time-sharing system. Both the notes and PAL were used in a trial section of 20 sophomores and juniors during the spring semester of 1967.

ROBERT M. FANO

RESEARCH LABORATORY OF ELECTRONICS

This interdepartmental laboratory provides facilities for academic research covering a large range of topics, most of which fall into one of three broad categories, designated as general physics, plasma dynamics, and communication sciences. During the past year, 118 faculty members, 287 graduate students, and 79 undergraduates from 17 academic departments participated in the program. The research support provided by the Laboratory contributed to the completion of 49 doctoral, 16 Engineer's, 53 Master's and 66 Bachelor's theses. The total number of degrees based on theses supported by the Laboratory since it was founded now stands at 2,435, of which 535 were doctoral, 97 were Engineer's, 810 were Master's, and 993 were Bachelor's.

Major support for the research is provided by the Joint Services Electronics Program of the Army, Navy, and Air Force as well as the Atomic

Energy Commission, the National Science Foundation, the National Institutes of Health, and the National Aeronautics and Space Administration.

The following sections summarize the major research accomplishments of the past year.

GENERAL PHYSICS

Research in general physics includes a variety of activities, many of which are based on atomic resonance phenomena. The experimental techniques required to observe these basic properties of matter and to exploit them in engineering applications span most of the electromagnetic spectrum from radio wavelengths to x-rays. Other experimental requirements include the use of extremely high frequency vibrational waves, the use of liquid helium temperatures, the use of megagauss magnetic fields, and rather extensive use of computers.

During the past year, Professor John G. King and others in the molecular beams group have been extending and perfecting atomic beam techniques for studying quantum fluids, namely liquid helium and superconductors. New apparatus has been constructed to repeat and extend the beam velocity distribution measurements, which have so far indicated that the atoms emitted from liquid helium are about one degree hotter than the source, and also to observe for the first time the diffraction of atoms at a slit. This experiment has a great deal of pedagogical interest and makes possible the use of interference methods with atoms.

The microwave spectroscopy group, supervised by Professors Malcolm W. P. Strandberg and Robert L. Kyhl, has conducted a theoretical study of the electromagnetic surface impedance applicable to metal single crystals at low temperatures. The study has greatly strengthened the present understanding of the size effect method for measuring the Fermi surface of metals, but also indicates how electron mean free times in metals may conveniently be studied.

Members of the radio astronomy group under the direction of Professors Alan H. Barrett and Bernard F. Burke have used the 120-foot and 85-foot parabolic antennas of the Haystack and Millstone Field Stations of Lincoln Laboratory for observations of the OH spectral lines at 18 centimeter wavelength and continuum sources at 3.6 centimeter and 2 centimeter wavelengths. During the past year considerable effort has been directed toward establishing the size of the OH emission sources by interferometric techniques. These efforts progressed through a series of increasing interferometer baselines, culminating in observations using the Haystack antenna in Westford, Massachusetts, and the 140-foot telescope of the National Radio Astronomy Observatory in Green Bank,

West Virginia, as an interferometer pair. The separation of 845 kilometers (4.7×10^6 wavelengths) required the use of atomic clocks to preserve phase coherence and accurate time information since the large separation of the observing stations precluded a direct local-oscillator link. The observations showed that the interstellar OH emission sources have apparent angular sizes less than 0.02 seconds of arc.

Professor Robert P. Rafuse, Dr. Donald H. Steinbrecher and their students have been working on computer-aided design of microwave circuits for varactor multipliers and parametric amplifiers. New theoretical analyses of punch-through varactor multipliers, microwave mixers, and high dynamic range mixers and phase detectors have been developed. Under development are a 23.5-GHz parametric amplifier, various frequency multipliers and low- and high-frequency mixers, phase detectors, and associated equipment with dynamic ranges of 120 to 140 decibels.

Professor Hermann A. Haus and his associates have continued their studies of electrical noise in optical masers and microwave parametric frequency multipliers. Studies include thermodynamic fluctuation theory as applied to non-linear devices and an attempt to extend the techniques used for noise measurement in optical masers to the detection of low-level optical signals.

During the past year, Professor Daniel Kleppner and his students constructed an atomic scattering apparatus which utilizes magnetically polarized atoms. The success of initial experiments with the apparatus indicates the feasibility of this new technique which yields detailed information on interactions between atoms.

Professor Clive H. Perry and his group have investigated a series of perovskite fluorides to obtain the lattice vibrational spectrum. The same materials show impurity-induced absorption at liquid helium temperatures in the extreme far infrared. The infrared spectra of CdS/Se mixed crystals have been measured and a consistent two phonon assignment for zone boundary modes obtained. The second order Raman spectra of KTaO_3 , SrTiO_3 , and other ferroelectrics have been investigated as a function of temperature. The reststrahlen bands of KCl-KBr mixed crystals and NH_4Br and ND_4Br have been studied down to low temperatures and the normal modes obtained. The Raman spectrum of NH_4Br has also been investigated in three of the crystal phases.

Professor Gary D. Bernard, in collaboration with Dr. William H. Miller of the Yale University School of Medicine, has been studying the optics of compound insect eyes in various moths and flies. Corneal structure is of particular interest. Use of the electron microscope has revealed that the eyes of flies such as the horsefly and the deerfly contain a specialized set of layers just beneath the front surface. These layers have differ-

ing dielectric properties and apparently function somewhat like an interference filter.

PLASMA DYNAMICS

Research in plasma dynamics includes the basic topics of gas discharges and plasmas, the generation of highly ionized plasma by electron-beam injection, studies of solid-state plasmas and a number of potential applications such as ion propulsion and controlled fusion. Microwave, infrared, and optical techniques are used extensively as diagnostic aids in studying the properties of plasmas.

During the past year, the active plasma systems group under the supervision of Professors Louis D. Smullin, Abraham Bers, and Richard J. Briggs has demonstrated the possibility of exciting ion-cyclotron waves in a beam-generated plasma. This can be done by either modulating the electron beam current at the ion-cyclotron frequency, or by feeding this power to a coil that surrounds the plasma. A good theoretical model, appropriate for plasma-waveguide propagation near the ion-cyclotron frequency, has been developed and correlated with these experiments.

The afterglow plasma in the group's largest beam-plasma-discharge system has been thoroughly diagnosed. Typically, at the time the beam is turned off the plasma consists of mostly cold electrons (density: $10^{13}/\text{cm}^3$; temperature: 50-100 electron-Volts) and a small hot-electron component (density: $10^{10}/\text{cm}^3$; temperature: 10^4 electron-Volts). The hot plasma decays stably, with time constants of the order of one second. The cold electrons scatter out faster than the hot ones, so that after 40 milliseconds the plasma essentially consists of only hot electrons (density: $10^9/\text{cm}^3$) and cold ions.

Studies of active plasma effects in solids have shown striking new effects. A bar (one centimeter by one millimeter by one millimeter) of n-type InSb, at 4.2 degrees Kelvin, with parallel applied electric and magnetic fields (3-20 Volts/centimeter, and 700-3000 Gauss), produces microwave radiation with resonant peaks that are periodic, as a function of the applied magnetic field. At 77 degrees Kelvin the microwave radiation does not exhibit the resonant peaks, and a theoretical model of electron-phonon instabilities predicts the observed minimum thresholds in applied fields for onset of the emission.

The interests of the plasma physics group under the supervision of Professors William P. Allis, Sanborn C. Brown, George Bekefi, and John C. Ingraham are oriented toward phenomena related to plasma-wave interactions, instabilities and turbulence.

Professor Allis is conducting theoretical studies on wave propagation in finite size, inhomogeneous plasmas. He and his associates have also

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investigated the generation of echoes in plasmas, similar to those found in nuclear magnetic spin systems.

Professor Bekefi and Bradford L. Wright have completed a series of experiments on the emission of microwaves from non-thermal plasmas, and from the observed spectra, they were able to deduce the distribution of particle velocities. Work is also in progress on non-linear wave-wave coupling in plasmas and on the effect of turbulence on transport properties.

Professor Brown and his graduate students are continuing work on the interactions between far infrared radiation and dense plasmas. In addition to this work they are studying the properties of plasmas generated by high-power lasers. Because of the short life of these ionized gases, new diagnostic techniques are being designed with a time resolution equal to a small fraction of a nanosecond.

Professor Ingraham is pursuing work on atomic processes in ionized gases. He is also measuring effects of low-frequency instabilities on transport properties, such as plasma diffusion.

Professors Thomas H. Dupree, Elias P. Gyftopoulos, Lawrence M. Lidsky, David J. Rose, and their colleagues have continued work in the fields of plasma kinetic theory, thermionics, and plasma phenomena related to controlled nuclear fusion. One unusually interesting development, by Dr. Kunmo Chung, is the discovery, identification, and quantitative check with the theoretical predictions of a number of important unstable waves in a highly ionized plasma column. Another, by Professor Lidsky, is the experimental modeling of interactions between plasma waves and particles by using electromagnetic field fluctuations created by fixed conductors, and electron beams. The scheme allows experimental check of and guidance for a number of new developments in plasma kinetic theory.

COMMUNICATION SCIENCES AND ENGINEERING

Research in communication sciences includes topics related to natural and man-made systems and interactions between them. A combined program of research and training in communications bioengineering was initiated during the past year. The training aspects of the program will include predoctoral training of electrical engineering graduate students and postdoctoral training for those with backgrounds in the life and health sciences. The training will be conducted with a research base provided by R.L.E. activities in communications biophysics, neurophysiology, cognitive information processing, and speech communication, plus a close relationship with the other aspects of the communication sciences research. This new program will increase the number of individuals

with the dual backgrounds needed to provide a high order of competence in applying engineering skills to the solution of problems in the life and health sciences.

The communications biophysics group, under the direction of Professors Walter A. Rosenblith and William M. Siebert, continued its studies of the physiological and behavioral implications of neuroelectric and other activity observed in various sensory systems, particularly the auditory system. Professors William T. Peake, Thomas F. Weiss, Peter R. Gray, and Dr. Nelson Y-S. Kiang, with several graduate students, have worked at the Eaton-Peabody Laboratory of the Massachusetts Eye and Ear Infirmary on systematic studies of the electrical and mechanical activity of the ear and of the behavior of single neurons in the auditory nerve, cochlear nucleus, and superior olivary complex. Other students at M.I.T. have studied isolated nerve fibers and single neurons in other systems, such as the visual system and the respiratory system. The response patterns to auditory stimuli of single cells in the cerebellum have also been explored. Professor Peter G. Katona (in association with Dr. G. Octo Barnett of the Massachusetts General Hospital) has extended his quantitative investigation of the cardiovascular control mechanisms. Much effort has gone into mathematical models of all these experimentally observed phenomena. Instruments have been developed for the real-time analysis and display of interesting aspects of non-stationary electroencephalographic data. In addition, Nathaniel I. Durlach has continued a number of psychophysical investigations, and Dr. Robert D. Hall has continued his studies of the electrophysiological correlates of conditioning.

The work of Professor Jerome Y. Lettvin and his associates in the neurophysiology group includes studies on nervous coding and the handling of such codes. Having found the multiplexing of information in single fibers of the optic nerve, Dr. Shin-Ho Chung, with Professor Lettvin, then considered the problem of an apparatus capable of handling such information. They have found that the axonal tree provides under suitable assumptions a type of filter whose action is best expressed in the time domain rather than the frequency domain. This filter is capable of resolving both different sequences and different statistics of pulse intervals in pulse trains along the single fiber. Stephen A. Raymond, working with Professor Lettvin, has addressed himself to discovering whether the assumptions used for the axonal tree are in fact physiologically proper. Finally, Dr. Dora C. Gerschenfeld has discovered in the optic brain of the frog a variety of cell that is sensitive to touch and sound as well as to visual stimuli. In this type of cell the response to any stimulus is contingent upon the nature of the stimuli in other modalities.

During the past year, Professors Murray Eden, Francis F. Lee, Donald E. Troxel, and their associates in the cognitive information processing group have made additional progress in the study of problems related to the development of a reading machine. English text in conventional spelling is converted into phonemic form through a morpheme decomposition and translation process by a computer program. The phonemic spelling of sentences is further converted into control signals for the operation of a terminal analog speech synthesizer. Sentence intonation is derived from punctuation marks imbedded in the original text as well as word stresses obtained from the phoneme conversion process. The system, capable of performing English text-to-speech conversion in real time, was demonstrated both at the M.I.T. Open House and at the R.L.E. Annual Research Review. Further work will include speech quality improvement on both the segmental and sentence level.

Professors William F. Schreiber and Thomas S. Huang, Dr. Oleh J. Tretiak, and their students have been working in the area of digital picture processing: in particular, on the problems of designing efficient picture transmission systems and the dependence of picture quality on system parameters. Dr. Tretiak and Professor William L. Black have begun adapting the image-processing techniques to biological and medical purposes. Research on chromosome karyotyping, classification of leukocytes, and neural structure mapping is currently in progress.

Research in speech communication under the supervision of Professor Kenneth N. Stevens has made increasing use of digital computers for the analysis of speech and for the simulation of various aspects of the human speech-communication process. Models of the larynx and of tongue, lip, and jaw motions during speech have been developed and the performance of these models has been studied. A scheme for the synthesis of speech by rule from phonetic segments has been implemented, and has generated speech that is reasonably intelligible although lacking somewhat in naturalness. New procedures for signal analysis utilizing homomorphic deconvolution, have been applied successfully to voiced sounds of speech. The speech communication group is also continuing its studies of the physiological aspects of speech production, and is carrying out further investigations of the manner in which children acquire the ability to generate and to perceive the sounds of speech.

Research in linguistics under the supervision of Professors Morris Halle and Noam Chomsky has been dominated this year by two topics, the relationship between semantics and syntax, and attempts to develop a theory of markedness in phonology. While it is still too early for definite results to have emerged, the explorations have been most fruitful in that they have raised questions about fundamental issues that were once

thought to have been settled. Among the more important publications of the group we may mention Thomas Bever's *Leonard Bloomfield and the Phonology of the Menomini Language*; P. Lieberman, *Intonation and Perception of Language*; P. Kiparsky, *A Phonological Rule of Greek*; M. Halle and J. Keyser, *Chaucer and the Study of Prosody*; M. Halle and N. Chomsky, *The Sound Pattern of English* (in press); N. Chomsky, *Some General Properties of Phonological Rules*; and N. Chomsky, *The Formal Nature of Language*.

Institute Professor Roman Jakobson made numerous contributions to the field of linguistics during the past year by extensive publication, participation in several international conferences, and many invited lectures.

The detection and estimation theory group under the supervision of Professor Harry L. Van Trees has done work in three major areas. In the sonar area, effective array processing techniques and channel measurement have received major emphasis. In the communication area, decision feedback systems and analog communication systems have been studied. The third area of interest is random process theory and its applications. State variable and Markov process techniques are being applied to the solution of various communication and detection problems.

HENRY J. ZIMMERMANN

SPECTROSCOPY LABORATORY

During the last year members of the Spectroscopy Laboratory staff were quite active in the use of lasers to aid in solving spectroscopic problems and in the application of spectroscopic methods to research in biophysics.

The grating ruling project of Professor George R. Harrison completed the transfer of the highly productive ten-inch ruling engine to an industrial firm. This engine, the first to use interferometric control successfully, has produced a majority of the world's largest gratings either directly or by replication. The project is now engaged in the development of two larger engines, one of 16 inches and one of 24 inches ruled width. A dozen trial gratings have been ruled to date on the 16-inch engine. Steady improvement in the quality of these gratings has taken place as the many factors that lead to difficulty in the ruling of such large gratings are brought under control. Interferometric control with laser radiation has proved highly successful in operation over the large ruled width of the 16-inch engine. The 24-inch engine was constructed during the past year and is now being equipped with auxiliary optical and mechanical devices. This engine must solve the problems associated with positioning

a 500-pound mass repetitively to within a few hundredths of a millionth of an inch. To do this many thousands of times over a distance of 24 inches during a period of two weeks requires the employment of technological developments from many fields of physics.

The group working with Professor Richard C. Lord has benefited greatly from the continued improvement in the performance of the far infrared double beam spectrometer built for the Laboratory by the Jarrell-Ash Company. A doped-germanium detector operating at four degrees Kelvin has been installed in the spectrometer by Dr. Thomas M. Hard and the improvement in the spectra recorded with the help of this detector is gratifying. At present a signal-to-noise ratio of 20 to one or larger can be achieved with a resolution of 0.2 cm^{-1} and time constants of 17 seconds, and in some regions the resolution has been pushed to 0.1 cm^{-1} or better. The instrument has been used mainly for investigation of the spectra of small molecules in the gas phase, with the help of a multi-reflection cell that permits optical absorbing paths 40 meters long.

Dr. George O. Neely has completed an extensive study of the pure rotational spectra of hydrazoic acid and related molecules. He has obtained spectra of very high quality (unprecedented for these molecules) and has found it necessary to extend the theory of centrifugally distorted molecular rotation in order to interpret these spectra in detail.

Dr. Jaan Laane has obtained remarkable far infrared spectra of a number of ring molecules, particularly silacyclobutane and cyclopentene. These molecules show a rich vibrational structure in the range of $20\text{--}250\text{ cm}^{-1}$, the interpretation of which gives quantitative information about the unusual potential-energy functions and also the structure of these molecules. Computer programs for calculation of the eigenvalues of the potential functions have been set up by Dr. Laane to enable rapid interpretation of the details of the spectra.

In collaboration with Professors Alexander Rich and Richard C. Lord, Dr. Yoshimasa Kyogoku has used infrared techniques to study the molecular interaction of a number of bases related to DNA and RNA. These studies show that in chloroform solution the hydrogen-bonded association of adenine with uracil — one of the pairs holding the double helix of RNA together — is about 20 times more effective than that of either base with itself. Similar results have been found with the guanine-cytosine pair. The effect of substituents on the association has been studied for many derivatives of the bases with a view to understanding the geometrical and electronic factors within the base molecules which give rise to the observed specificity of the interaction. Other interactions are also being studied between the bases on the one hand and certain types of

drugs on the other. It has been found, for example, that some drugs acting on the central nervous system interact strongly with adenine but not with the other bases.

With the addition of a laser to the Raman spectrometer in the Laboratory, a more powerful means of producing Raman spectra is available. The laser has not yet been in use long enough for extensive results, but it has already been found that very small quantities (a milligram) of biopolymers such as polyadenylic acid are sufficient to give usable spectra. The extensive survey work of Dr. George J. Thomas Jr. and Professor Lord on the Raman spectra of nucleic acid derivatives in aqueous solution has now been published, and their work is being extended with the help of the laser unit.

Professor Clive H. Perry and his group have continued measurements of the optical properties of solids in the far infrared. Dr. Eugene F. Young has completed a series of perovskite fluorides to obtain the lattice vibrational spectrum. Dirk J. Muehlner has studied the same materials at liquid helium temperatures and found many bands attributable to impurity-induced absorption. John F. Parrish has investigated a local mode due to a sulphur impurity in CdSe and also has obtained a consistent two-phonon assignment for zone-boundary modes in CdS/Se mixed crystals. Jeanne F. Fertel and Thomas F. McNelly have investigated the second-order Raman spectrum of KTaO_3 and SrTiO_3 as a function of temperature, and Mrs. Fertel and Elliot M. Immerman have obtained the infrared spectrum of mixed crystals of KCl-KBr . Neal E. Tornberg and Thomas G. Davis have completed a laser-Raman right-angle scattering experiment and are presently investigating some ferroelectric crystals.

Professor George Benedek and his associates have continued their studies of laser-excited Brillouin spectra with the ten-meter Czerny-Turner spectrometer in the Laboratory. This work is included in the account of Professor Benedek's work that appears under the report of the Center for Materials Science.

Visiting scientists working in the Laboratory during the past year included Dr. Hard from the University of Wisconsin, Dr. Kyogoku from the University of Tokyo, and Dr. Mireille de Yagupsky from the University of Buenos Aires.

RICHARD C. LORD

EDUCATION RESEARCH CENTER

The last year has presented a challenging opportunity for growth and reexamination of the part of the Center in M.I.T.'s extensive role in

educational research and development. Early in the fall, the President and the Chairman of the Corporation encouraged the Director to explore means of broadening the scope of operations of the Center to include all of the schools of the Institute instead of just the School of Science, with which its activities had been previously concerned. Conferences were held with deans and other representatives of each school to discuss the role the Center might play in educational experimentation and development in these areas, and an Advisory Committee was established to work with the Director on establishing a broader range of programs. The present membership of the Advisory Committee includes: P. L. Thibaut Brian, Professor of Chemical Engineering; Richard M. Douglas, Professor and Head of the Department of Humanities; Kevin A. Lynch, Professor of City Planning; Charles L. Miller, Professor and Head of the Department of Civil Engineering; Ithiel de Sola Pool, Professor and Head of the Department of Political Science; John Ross, Professor and Head of the Department of Chemistry; Ascher H. Shapiro, Professor and Head of the Department of Mechanical Engineering; Louis D. Smullin, Professor and Head of the Department of Electrical Engineering; Hans-Lukas Teuber, Professor and Head of the Department of Psychology; Felix M. H. Villars, Professor of Physics; and Zenon S. Zannetos, Professor of Management.

After some discussion it was decided to change the name of the Center from the Science Teaching Center to the Education Research Center. In addition to the broadly based Advisory Committee, a Program Committee was named and has been functioning. It consists of members of the Faculty and staff who are currently involved in programs at the Center. This Committee meets frequently to work out immediate plans and to work with the Institute administration on funding of programs. The current membership of the Program Committee includes: Norman C. Dahl, Professor of Mechanical Engineering; Anthony P. French, Professor of Physics; Malcolm M. Hubbard, Assistant to the Director of the Education Research Center; Robert I. Hulsizer, Professor of Physics; Dr. Merton J. Kahne, Medical Department; Cyrus Levinthal, Professor of Biology; Louis D. Smullin, Professor of Electrical Engineering; Dr. Benson R. Snyder, Medical Department; Edwin F. Taylor, Research Staff, Education Research Center; William D. Tobin, Assistant to the Director of the Education Research Center; George E. Valley Jr., Professor of Physics; Joseph Weizenbaum, Associate Professor of Electrical Engineering and Political Science; and Jerrold R. Zacharias, Professor of Physics.

The work of the Center continued and grew to some degree; growth was limited not by lack of ideas and faculty interest but by a shortage

of funds. This shortage reflects the current limitations in funds from the Federal government and the foundations in support of non-military research. Presently the three major areas of work at the Center are: (1) curriculum development, (2) educational technology, and (3) studies of the students' interaction with the educational environment.

In the field of curriculum development, the main effort continues to be the development of new materials for introductory physics. It was in this area that the initial program of the Center started in 1960, and it has continued to be a major activity of the Center. This year a contract has been signed with W. W. Norton, Inc. of New York to publish text materials produced in the project; two volumes of an expected 13 volumes have been sent to the publisher for preparation. Two more volumes will be completed and submitted shortly. The material assembled will cover what would represent the first year of introductory physics. The topics include a general review of the particulate nature of matter, mechanics, special relativity, and oscillations and waves. In addition to these first four volumes there is substantial progress towards the completion of a volume on introductory ideas of quantum physics, and preliminary work on a volume on electricity and magnetism.

In addition to text material, considerable work has gone into the development of simple laboratory experiments or demonstrations. The viewpoint in developing these demonstrations or simple experiments (which often can be set up in halls) originated from the decision made by the Faculty in 1965 to discontinue conventional laboratories associated with introductory courses in science and engineering. Project laboratories to replace the formal laboratory instruction previously offered are believed to be extremely valuable, but the main introductory courses still need to provide the students with a rich contact with the physical world. The demonstrations and simple laboratory experiments being developed are an attempt to fill this need. About 15 corridor experiments and demonstrations have been developed in the past year. A point of considerable interest and encouragement to the Center is the fact that undergraduate students have shown a great deal of interest in working to develop these exhibits, both through part-time employment in the winter and full-time work in the summer. This student participation in the development of the project has enabled the staff of the Center to come much closer to the conceptual needs and interests of the student body than they would have been able to if the development had to be brought to some preliminary stage before involving students.

In addition to laboratory experiments and demonstrations, work continues on the production of films demonstrating or illustrating the phenomena of physics. Several small demonstration films have been

made, and one major film, half an hour long, has been completed on the classic Stern-Gerlach effect.

Work has also been done on the development of a modern biology laboratory carried out in collaboration with the Department of Biology. This laboratory has been extremely successful, and a new version is being planned for next year.

Substantial progress has been made in Professor Levinthal's efforts to use a computer with a cathode ray display to show the structure of the complicated molecules found in biological systems. This work has received international acclaim for its success in clarifying these complicated structures.

In the field of educational technology, a major effort has been initiated in the study of the use of computers in education. The Institute is replete with examples of the use of computers by students for solving problems. The work of the Center has been concentrated not on the use of computers by students to do computations but rather on the use of computers in computer-aided tutoring or instruction, and the use of computers to produce displays for classroom use or for films that illustrate phenomena that cannot be shown easily by blackboard drawings or by still pictures. A classic example of this type of film production is a film showing the motions that bodies would experience under the influence of different types of forces. The study of the use of computers in computer-aided tutoring and learning has been concerned primarily with the basic problem of constructing a framework in which a faculty member can phrase questions to be addressed to students and analyze the answers to find the weaknesses or gaps in the student's understanding. Such gaps or weaknesses, once discovered, would lead to further questions or supplementary information to be supplied to the student. Questions would follow to test the student's success in remedying his deficiencies. The basic problem in this type of development is whether it is possible to program a computer to analyze student responses without running into serious difficulties with the complex linguistic structure of the English language. It is felt that considerable progress is being made as evidenced by the fact that 15 faculty members from institutions around the country have been sufficiently impressed to agree to come for a second summer of writing material for such computer-aided dialogues and tutoring sessions.

The third major area of work at the Center concerns the continuation of the Student Adaptation Study initiated by Dr. Snyder in 1961. The initial study of the Classes of 1963 and 1965 has been completed to the extent that a preliminary report was issued in June. On the basis of the preliminary report, further studies of those two classes are being continued and plans are being made for studies on succeeding classes. The

general result of the study is that there are distinctly separate types of students attending M.I.T. and that their responses to the environment are markedly different. An attempt to identify these different types and to learn how to cope with the differences in their reaction to the environment is part of the goal of this study.

In the last year a new study has been initiated of the educational role of the recitation section. An experienced psychologist has been sitting in on some classes to observe the type of activity that goes on in the class and then has been conducting extensive interviews of the students who attended the class to find out how much of their needs had been met by the classroom activity in an attempt to identify the needs which were left unfulfilled by the regular recitation class.

The continued funding of these various activities has presented some major problems. The National Science Foundation has a Curriculum Improvement Program which has provided support for the physics program since the beginning and has indicated that they will continue to support this work. The biology work has had initial support from the NSF and is likely to continue to receive support from them. The computer program has received some support from the IBM grant to M.I.T. but was denied support by the Office of Education and by the National Science Foundation because of shortage of funds. An approach has been made to the U.S. Air Force for financial support for this activity and also to IBM for an expanded program of support. The Student Adaptation Study was financed by the W. T. Grant Foundation from its inception and has subsequently received support from the Bing Foundation and also from the Shell, Kettering and Victoria funds that were available to the Center for its general program. These latter funds are essentially exhausted and the W. T. Grant fund has been exhausted, so that funding this program remains a major need. The Office of Education was approached on this subject but was unable to provide support because of a severe cut in its research budget.

ROBERT I. HULSIZER JR.

GRADUATE SCHOOL

In this, my last report as Dean of the Graduate School at the end of a 15-year tenure, I wish to present my ideas in three main sections in addition to the usual statistics on enrollment, graduate student support, and degrees granted.

In the first section I shall review briefly, as characterizing its operation, the principal items of business considered by the Committee on Graduate School Policy during this past year and include some discussion of the changing dimensions of the graduate student subsidy problem and the subject of graduate student numbers and quotas. In the second section I look at some of the changes that have occurred over the 15-year period in the size and scope of the program of the Graduate School. In the third section I present some of the thoughts and ideas underlying my activities as Dean of the Graduate School during the 15-year period.

HIGHLIGHTS OF 1966-67

The role of the Committee on Graduate School Policy (C.G.S.P) is seldom spectacular, but its deliberations and actions on questions brought before it have a major effect on concepts of quality and standards of our graduate work and degrees. It seems worthwhile to give briefly the highlights of C.G.S.P. activities for this past rather typical year; they appear grouped under appropriate headings.

OCEAN ENGINEERING

Professor Alfred A. H. Keil, Head of the Department of Naval Architecture and Marine Engineering, presented to the Committee on Graduate School Policy at its November meeting the proposal for various graduate

degree programs in ocean engineering in elaboration of a previously circulated memorandum on the subject. His presentation further qualified what ocean engineering is conceived to be, why he felt ocean engineering should be a part of the curriculum, and how ocean engineering should be implemented at M.I.T. The oceans are assuming a significance in human activities rapidly exceeding the bounds of surface ships. Deep ocean exploration, fixed platforms for a variety of purposes, scientific and applied, Mohole operations, hydrofoil, hover and other forms of unconventional ocean transportation, and study of the nature and characteristics of ocean phenomena as they influence engineering structures — all of these call for engineering competence reaching far beyond conventional naval architecture and marine engineering. However, naval architecture and marine engineering as a discipline undoubtedly provides the best base from which to launch this more generalized concept of ocean engineering. The discussion at this meeting was followed by further study and extended discussion at the December meeting. Then the Committee on Graduate School Policy voted approval in principle of graduate programs in ocean engineering, subject to further consideration for approval of specific subjects, degree requirements, and other program details. The degrees contemplated were Master of Science in Ocean Engineering, Ocean Engineer, and Sc.D. or Ph.D. in Ocean Engineering. With this Committee on Graduate School Policy endorsement, the Faculty voted at its meeting on February 15 to recommend to the Corporation establishment of these graduate degree programs; the Corporation acted favorably on June 9.

FOREIGN LANGUAGE REQUIREMENTS FOR THE DOCTORATE

This problem, a hardy perennial in all of the nation's graduate schools, was again raised in three facets: first, whether the requirement should be Institute-wide or departmental; second, the nature of the requirement; and third, the acceptability of so-called exotic languages. Following a subcommittee study and extended discussion of the entire subject of language requirements at three meetings, Institute requirements were approved incorporating modest changes responsive to experience. These are reading competence in two languages or intermediate competence in speaking and reading one language, including provision for so-called exotic languages when they have clear professional significance. The specification of intermediate competence tempers the existing requirement of substantial competence which was characterized by Professor William F. Bottiglia, Head of the Department of Modern Languages and Linguistics, as noble but unrealistic. Such nice distinctions might be misinterpreted as academic nitpicking; actually they express the fact that the language requirement is taken seriously both by the professional depart-

ments and by the Department of Modern Languages and Linguistics. New requirements are found in the *General Catalogue*.

CLASSIFIED THESES

During this year extended discussion of classified work was precipitated within the Faculty and the administration by a group who felt strongly that classified activity and theses were incompatible with the academic integrity of a Graduate School and the Institute. This subject has been of continuing concern to the Committee on Graduate School Policy which for many years has discouraged and stringently monitored proposals for classified theses and has required its approval for each proposed individual classified thesis. Its criteria for acceptance have been: first, that a superior educational opportunity is thus provided, and second, that a sufficient number of faculty and graduate students be involved to insure an adequate community of intellectual interaction and an adequate breadth of base for academic standards of judgment. The outcome of this total discussion is a statement on classified research and theses included in the records of the faculty meeting of November 16, 1966, which in effect endorses the policy followed by C.G.S.P. which has resulted in only some two to five graduate theses each recent year that were actually classified at the time of their submission. This discussion was very healthy, it appears to have cleared the air, and the C.G.S.P. benefited by the review and endorsement of its present policies and practice.

DOCTORATE OF MATERIALS SCIENCE IN THE DEPARTMENT OF METALLURGY AND MATERIALS SCIENCE

At its meeting on March 14, Professor Thomas B. King, Chairman of the Department of Metallurgy and Materials Science, presented to the C.G.S.P. a previously circulated proposal that his Department be authorized to add Materials Science to the fields in which it recommends award of the doctorate. The national pattern, especially among leading departments, is clearly moving in this direction, in no small measure as a result of leadership and faculty members educated in our own Department. Favorable action by the C.G.S.P. led to faculty approval on March 15 and Corporation approval on June 9.

THE EXTRAORDINARILY GIFTED STUDENT

Recognizing that it had among its graduate students one with exceptional creative ability but with a record of complete disinterest for meeting normal requirements for a degree, one of our departments was encouraged to bring this subject to the C.G.S.P. for an initial discussion. Because of the far-reaching educational significance of any decision in

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such a case, both the Head of the Department and the Provost were invited to participate in the discussion. The discussion was extensive; opinions ranged from desire to maintain the meaning of the degree as represented by the regular requirements, to the notion that for a sufficiently creative and productive person in a sufficiently persuasive case, all normal rules should be waived. The purpose of this first presentation was to initiate widespread reflection by departmental committees, graduate committees, and faculty. Thus, if and when the particular case develops, there will be an appropriate background of mature and broad-based consideration to provide a maturely considered and sound philosophical base for action. As a general observation, it may be remarked that in the past this multistage approach to a problem has often been quite successful. Ideas planted by an initial general discussion mature over an interval before the specific decision must be made and make the final definitive discussion and decision fairly clear and straightforward. This is a good example of the quite inconspicuous but significant way in which the C.G.S.P. defines the meaning of our graduate degrees.

THESIS REGISTRATION

M.I.T. tuition is high; hence graduate students, being human, and their professors rightly sympathetic, are very ingenious in seeking ways of easing the impact of tuition charges. Graduate and especially doctoral thesis is one of the most difficult areas in which to achieve mutual fairness in tuition charges to the student and to M.I.T. This area has to be re-examined cooperatively by C.G.S.P. and the administration about every two years to keep leaks in the tuition dike repaired. Such a leak which had developed as a laxity in administering registration for thesis presentation was studied and corrected. While this may appear to be a purely technical and trivial matter, experience has shown that the dike metaphor is far from inapt and that early attention to "trivial" detail in the sensitive area of tuition structure is the key to keeping it out of the category of a major problem. I wish to commend in the highest terms the intellectual honesty and fairness displayed by the members of the C.G.S.P. in handling extremely sensitive subjects when they know what it means to their individual graduate students. At the moment our graduate tuition structure, the result of continuing intensive work by the C.G.S.P. and administration, appears both to have integrity and to provide sound means for handling the occasional legitimate special case.

GRADUATE STUDENT STATUS OF NASA EMPLOYEES

One of the important considerations leading to the selection by NASA of the Cambridge site for its Electronics Research Center was the proximity

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of M.I.T., Harvard, and other educational institutions. Such a research facility is carrying out its proper mission when it seeks to maximize the attractiveness of available graduate education resources in its professional recruitment policies. Some practices growing out of earlier individual informal negotiations had reached a stage that called for over-all review to understand the Institute's standards and policies for graduate work. During the past year a degree of understanding has been achieved. Staff at NASA's Center recognize the conditions under which M.I.T. can offer Regular Graduate Student status for work toward an advanced degree without compromise of its normal standards. This is an example of understanding reached among intelligent people of good will seeking a common objective of excellence in graduate study, in an area in which subtle and somewhat complex values and procedures are deemed essential to insure the integrity of our degrees.

NAMES OF GRADUATE DEGREES IN THE DEPARTMENT OF NUTRITION AND FOOD SCIENCE

The Department presented to the C.G.S.P. the request that its Master's and doctoral degrees be redesignated from the field of Nutrition to Nutritional Biochemistry and Metabolism. To the question "what's in a name?" the Department made a good case that the answer is "a great deal," and made it sufficiently cogently that the change has been approved. Involved here are the character and standing of this program to many scattered throughout the world who may not make the intangible but highly significant distinction between a program that borders on the purely vocational and one recognized as of a high professional nature.

GRADUATE ENTRANCE STUDY

During this past year, substantial effort has been made to develop some type of criteria to predict success in our Graduate School from the material presented to Departmental Graduate Committees to make decisions on Graduate Student admission. A major statistical study has been launched on the relation between grade averages which the student brings to M.I.T. and his first year graduate performance. Populations of approximately 4,000 and 1,400 students were used in two portions of the study. No real surprises have thus far emerged, but the study is to be continued and extended. One of the more significant results so far is that the subjective estimates of a few knowledgeable faculty members concerning the interpretation of undergraduate records earned in a substantial group of nationally known undergraduate schools as related to their varying reputations, yields evaluations not significantly different from those emerging from this long statistical study. This in itself is a useful result.

STUDY OF POSTDOCTORAL EDUCATION IN THE UNITED STATES

Consideration over the past half dozen years of the rapidly increasing number of postdoctoral students at M.I.T. led to the realization that we know little about our postdoctoral population. Even the number of individuals involved is not definitely known. The Associate Dean of the Graduate School, Sanborn C. Brown, became interested in this subject and, with the encouragement and cooperation of the Academic Council, has done much to bring order out of chaos in the official status and number of our postdoctoral population. When we began to understand our own situation and shared the knowledge with other institutions through the two National Graduate Associations, it became clear that we had no monopoly on ignorance, and that in fact, institutions across the country were eager to cooperate in any endeavor to shed light on postdoctoral study. It became obvious that neither we nor our sister institutions could come to any reasonable policy decisions about our postdoctoral education program without understanding the national picture. Through a long series of negotiations, a national study of this program was organized. Headquarters and funding are centralized at the National Research Council in Washington. At the Institute a special office has been set up under contract between M.I.T. and N.R.C. in which Dean Brown, as national director for the study, is involved part-time, and Mr. Robert K. Weatherall, formerly Executive Officer of the Graduate School is a full-time Research Associate. The principal goals for this study are:

1. a demographic description of the present postdoctoral population.
2. a description of the range of administrative practices concerning postdoctoral education.
3. a measure of the cost and benefits to (a) the individual, (b) the institution, and (c) the nation.
4. promotion of informed discussion of postdoctoral education and provision of information that will provide policy guidance.

As one of the basic steps, a census is being taken of the present postdoctoral population with the national cooperation of Graduate Deans, Department Heads, Laboratory Directors, and the individual postdoctoral appointees themselves. This is a study of major magnitude on a subject about which we know very little, but about which the nationally felt need for information and understanding is great.

GRADUATE SCHOOL DEVELOPMENT 1952 TO 1967

The changes in the Graduate School during my 15-year tenure as Dean are sufficient to make a brief review of interest. They are less the result of explicit initiative within the Graduate School than of the evolving character of M.I.T. as a whole and of the national pattern of graduate study.

Developments in three areas will be considered. First, M.I.T.'s evolution into a university of limited objectives, second, growth in size and numbers, and third, the changes in the pattern of graduate student support.

EVOLUTION IN THE M.I.T. PROGRAM

In 1952 M.I.T. offered graduate degrees in science and engineering (doctoral) and in what might be called the applied fields of industrial economics and group psychology. Since then important extensions in doctoral programs have been made into the humanities and social sciences. The evolution of this development is of interest. When Dr. Karl T. Compton became President in the early thirties, one of his guiding thoughts was that if M.I.T.'s engineers (and M.I.T. was fundamentally an engineering school at that time) were to have adequate education in science they should be taught science by scientists of full professional quality and stature. This meant having departments of science that were not restricted to service functions but that had their own graduate students, research, and advanced degree programs. Only then could they attract and nurture first-rate faculty and provide the environment in which the sciences have a vitality of their own.

On his assumption of the presidency, Dr. Killian applied the same argument for the same reasons to the humanities and social sciences. This was the step that makes legitimate the use of the word university to describe M.I.T.'s character. This step makes M.I.T., in Dr. Killian's words, "a university polarized about science."

As a natural consequence, proposals for new doctoral programs have been developed in a number of fields. A complete list follows of new doctorate authorizations in all fields (a few are obviously for formal tidiness only) during the 15-year period.

- 1953 Ph.D. Biochemical Engineering (in Nutrition)
- 1955 Sc.D. Nuclear Engineering
- 1958 Ph.D. City and Regional Planning
- Ph.D. Political Science
- 1959 Sc.D. Materials Engineering
- Sc.D. Aeronautics and Astronautics (from Aeronautical Engineering)
- 1960 Ph.D. Industrial Management
- Ph.D. Oceanography
- Ph.D. Linguistics
- 1961 Ph.D. Nutrition
- Ph.D. Food Science and Technology (from Food Technology)
- 1962 Ph.D. Psychology
- 1963 Ph.D. Philosophy

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- 1965 Ph.D. Economics (from Industrial Economics)
- 1966 Ph.D. Management (from Industrial Management)
- 1967 Ph.D. Nutritional Biochemistry and Metabolism (from Nutrition)
- Ph.D. Ocean Engineering
- Ph.D. Materials Science (Department of Metallurgy and Materials Science)

Note: In each case the interchangeability of the Ph.D. and Sc.D. (requirements identical) authorized by the Faculty applies.

A word on the processes leading to official authorization of a new doctoral program may be of interest. Developing aspirations in a department result in a proposal for a doctorate from the department. Recommendation to the Corporation for authorization is dependent upon a favorable outcome of two considerations. The first consideration is examination by the administration (including the Budget Committee) for the appropriateness of the proposed program in the total context of M.I.T.'s role and resources. Is the proposed graduate program one which takes sufficiently high priority in M.I.T.'s over-all plan of development to justify allocation of the necessary resources to give it adequate support? The second consideration is examination of the quality of the faculty, the program, and the resources underlying the proposed new degree. Responsibility for such appraisal of academic resources underlying recommendation to the Faculty lies with the C.G.S.P. The Dean and the C.G.S.P., with concurrence by the administration, have felt that any such program and resources underlying it should have the benefit of examination by a group representing recognized national strength in the field. Therefore, for each such new program an ad hoc committee of a half dozen has been assembled, including members from institutions having programs of nationally recognized strength as well as members from our own Faculty. The recommendations of such an ad hoc committee are then reviewed by the C.G.S.P., and if favorably evaluated, the C.G.S.P. recommends to the Faculty that it recommend to the Corporation that it authorize the appropriate department to make recommendations for the proposed new degree. This appraisal process evolved rather informally and has standing simply as representing a consensus judgment of what constitutes an adequate basis for appraisal.

Although the extension of our doctoral programs into the fields of humanities and social sciences represents a striking aspect of our development, it should be mentioned that evolution in graduate programs is continuous in the other Schools. New doctoral programs in the Sloan School of Management and in the School of Architecture and City

Planning have responded both to the national need for such programs and to recent developments that have generated the scholarly materials for good doctoral programs.

Examples of the evolutionary process in science and engineering include the emergence of nuclear engineering, oceanography, shifting emphasis in nutrition, ocean engineering, interdepartmental work in materials, operations research, and computer science. All of these fields and others have emerged with new emphasis during the past 15 years.

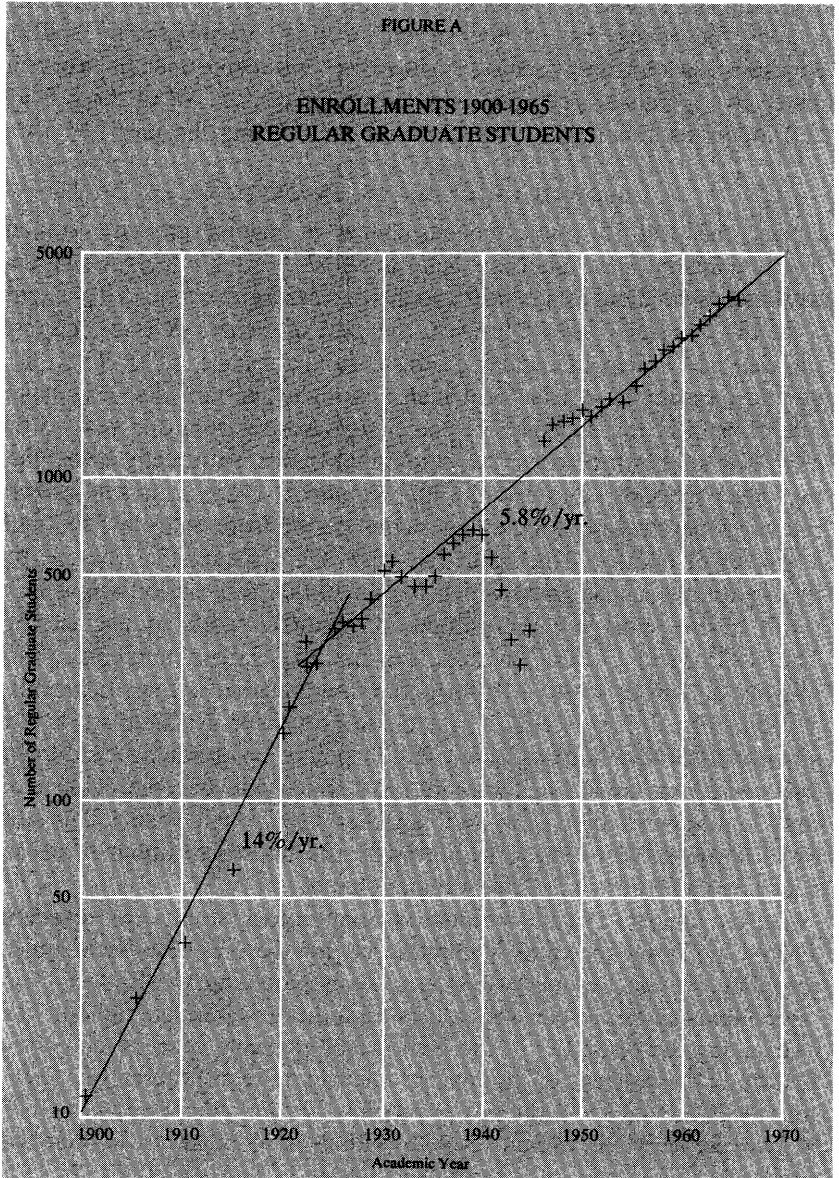
GROWTH OF GRADUATE ENROLLMENT

During the past 15 years, the enrollment of regular graduate student degree candidates has almost exactly doubled. Master's degrees awarded have increased about 80 per cent and the doctorates by about 130 per cent.

In this over-all view of growth, the plot of Figure A is of interest, showing enrollment of regular graduate students since 1900. These are plotted on a semi-log scale on which a straight line indicates a constant rate of growth, that is, constant percentage growth from one year to the next. For unknown reasons, the enrollment trends historically break into two clear periods, one from 1900 to about 1925 with the growth rate of 14 per cent per year, and a second period from 1925 to 1965 with a growth of about 5.8 per cent per year. Only speculative reasons for these patterns can be given which for the 1900-1925 period might be a result of the emerging recognition of graduate work in engineering. The 1925-1965 period involves substantially larger numbers (very roughly a tenfold increase from a few hundreds to a few thousands) and undoubtedly represents a systematic growth of graduate work plus growth in the population itself. M.I.T. policy on graduate enrollment calls for a new trend beginning in 1964 which will become evident on such a long-term plot only after another five or ten years. This new trend is presently projected as a growth rate limited to about three per cent per year as discussed below under Quota.

During the past 15 years graduate school growth, despite the long-term 1925-1965 trend shown by Figure A, has for the first time been subject to policy control. About 1958 it became apparent to the Budget Committee that the forces generating expansion in the Graduate School were outrunning the resources of the Institute in available space, faculty, and finances. The concept of graduate student enrollment quotas was therefore instituted. In 1959 the policy provided for an annual quota increase of five per cent for normal growth with a total of seven to nine per cent to include increases permitting initiation of new programs. In 1964 the Budget Committee felt that these rates should be reduced to 2.5 per cent normal and three to five per cent over-all growth, to be followed in

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1967 by a new target of three per cent annual over-all growth. Thus it appears in terms of Figure A that, beginning in 1964, the plot of growth should show a drop from the just under six per cent per year for the preceding 40 years to about three per cent annually thereafter. Further changes will no doubt be made as circumstances change.

GRADUATE STUDENT SUBSIDY

This is a very large subject, especially now when federal aid to graduate study is such a major factor in the nation and when as a consequence of political realities, the fact of a small number of recognized centers of high excellence already geographically concentrated comes into direct conflict with the concepts of geographic distribution and a center of excellence for every state or region. This was discussed in last year's report and remains a problem. Here I shall pass over this subject to look broadly at changes during the past 15 years. In this period much greater changes have occurred in graduate student financial aid than have occurred in enrollment numbers. Whereas graduate student enrollment has increased by a factor of two in that period, fellowship and scholarship aid has increased more than 12 times. The predominant effect in this increase is the large magnitude of federal support of graduate students both in the form of fellowships and traineeships (these two categories appear to be distinguished for practical political rather than functional reasons) and in the form of research assistantships funded on a very large scale through federally subsidized research activities. If we include staff salaries for both teaching and research assistants in the graduate student financial benefit total (and there is a good deal of justification for doing so because they actually function to a large degree as fellowships), the total of graduate student support is practically doubled. Assistantship salaries (which in the case of research assistants indirectly include tuition scholarships) are somewhat larger in total than the total of fellowship funds supporting graduate students. Consequently roughly 90 per cent of our graduate students are supported by funds other than individual personal funds or, in other words, the opportunity for graduate study here is not dependent upon financing by the individual student.

We have given continuing study to the many problems associated with best use and administration of these major funds for support of graduate students. However, the problem of graduate student subsidy is rapidly increasing in complexity so that a much larger scale of effort is needed to gain an understanding of the national and local effects of subsidy programs, and to learn how best to design our operation to optimize their

total contribution to graduate education. The time appears to have come for substantially more intensive work on this subject.

GUIDING THOUGHTS

As the third section of this last report as Graduate Dean, I wish to include some of the ideas that guided my administration of the Graduate School. I emphasize particularly the doctoral work because it represents a much greater step beyond undergraduate work than does Master's work. In pattern of educational activity, doctoral work differs greatly from undergraduate work. At the Master's level much of the student's effort is associated with regular class and laboratory instruction carried on, it is true, at a more advanced and demanding level, but otherwise in much the same pattern as undergraduate work. At the doctoral level, however, the most important and central process is essentially that of the master-apprentice relation, surprisingly similar in many aspects and in fact traceable to that highly developed in the craft guilds during the early Middle Ages.

To examine the essential nature of the educational process at the doctoral level, I should like to consider its nature at three successive stages graded from the explicit to the inner, deeper, and more subtle aspects. At the first stage, we note that discourse concerning education tends almost universally to equate education with acquisition of knowledge. That this is a significant element in education is scarcely open to question, yet, fundamentally, knowledge is to education as a building stone is to a great architectural structure—necessary as a building element, contributing (but in only a small way) to achievement of the grand concept of the final structure. On reflection, we all recognize that the more advanced the stage of education we consider, the more such education goes beyond mere subject matter and knowledge.

At a second stage, we generally recognize that education involves development of skill in making knowledge serve felt human needs, skill in the generation of new knowledge, new insights, and understanding, and also skill in inspiring, stimulating, and aiding others to learn. Such skills are a clearly recognized and visible evidence of education.

But third, deeper still, and especially significant at the doctoral level, education involves engendering the inner drive to achieve these skills and to put them to use. An essential element of the doctoral educational process is lighting the inner fires in an individual that make the scholarly, creative, and productive intellectual processes in him continuously self-regenerating.

For the first stage, the acquisition of knowledge, there are many aids, and these aids are being improved continually. Better access to books and

periodicals, teaching machines, better laboratories and research facilities, interdisciplinary interactions through interdepartmental laboratories and centers, and especially interdisciplinary spirit and practice, can all contribute to more rapid and more effective acquisition of knowledge. These and various forms of project work can also contribute to the second level, that is, development of skill in making knowledge serve human needs.

But at the third level, the engendering of the life-long inner drives, the best learning situation we know is that in which the student, having progressed fairly far in the first stage and having acquired some skill in making knowledge useful, becomes, figuratively speaking, an apprentice of a master who by close association, example, and subtle interaction, stimulates the arousal and activation of the self-sustaining and self-regenerating inner spirit. This process is clearly costly of our most precious educational resource, able faculty. But during nearly a millenium of western higher education no better way has been found.

I conceive that the most basic role of a Graduate School is to contribute as effectively as possible to the achievement of this inner growth process. We begin by attracting and developing the ablest faculty and students we can find, and we seek to generate and sustain the best possible facilities and environment for their work and interaction. These are the essence of a great graduate school. At M.I.T. the Graduate Dean can contribute his bit to the quality of faculty and environment through his participation as a member of the Academic Council. He can exert substantial influence on the quality of graduate students attracted and encouraged. He can encourage interaction among departments to generate, sustain, and raise the standards of expectation, working always through faculty and administration. He can work through formal organization and procedures, but he can have even greater influence in informal personal ways. A substantial contribution to over-all quality can be made by catalyzing channels of communication and interaction so that the ideas, experiments, and educational programs of one department will be sought after, studied, and used as a stimulus and guide for other departments. The Dean can encourage the attitude of experiment and flexibility in the graduate administration that looks upon rules and regulations as simply the means of doing more easily those things that have to be done repeatedly; but that readily lays aside rules when promising new opportunities for experiment or innovation are better served by direct application of fundamental educational principles. Such activities are seldom visible except to those directly concerned; they do not lend themselves to popular exposition. Yet I believe that herein is one of the major opportunities for a Dean and his colleagues to enhance the quality of the Graduate School.

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In this connection, I should like to pay tribute to the Committee on Graduate School Policy. This Committee has been characterized as an operating committee, and there is truth in this characterization. Yet in considering and making decisions in particular cases involving new educational questions or interpretations, policy is generated by a process quite analogous to that which generated common law. This process also constitutes an effective medium for making visible those departments and types of activities that best encourage and develop high quality and standards. Furthermore, there is a very strong and all-pervading sense of idealism that consistently impels those who learn of better procedures and of superior methods and standards to initiate means to enhance their own operations. I wish to attest especially to the objectivity of C.G.S.P. members who consistently place the good of M.I.T. and the Graduate School as a whole above departmental or group concerns. An individual C.G.S.P. member very properly becomes a departmental proponent as he presents a departmental proposal, but this process is clearly recognized and he clearly steps out of this departmental role to return to his Institute role as soon as his role as advocate has been completed. The Institute can take pride in the intellectual honesty and integrity and in the judicial consideration given to any subject considered by the C.G.S.P.

Finally I express my deep indebtedness to my colleagues in the Graduate Office for consistently able and dedicated involvement in the welfare of the Graduate School, the graduate students, and the activities of my office.

HAROLD L. HAZEN

GRADUATE SCHOOL

APPENDIX

Tables I-A, I-B, II, III, and IV give statistics on Graduate School registration and quotas, graduate degrees awarded, graduate student financial support, and federal support for M.I.T. graduate students 1951-68. These tables, with their notes, are intended to be self-explanatory.

Concerning enrollment by Schools it should be noted that the total of 3,710 includes 512 Special Students (most of whom are taking only one subject and very few of whom taking more than two) in courses already being given for degree candidates. Thus the total of 3,198 Regular Graduate students is a far more meaningful measure of our size than the substantially inflated figure of 3,710.

It is hoped that Table III on financial aid is a reasonable compromise between the complexity necessary for reasonable accuracy of description and the simplification essential to ready understanding.

Table I-A Graduate School Quotas and First-Term Registration, 1966-1967

	All Schools	Engineering	Science	Architecture and Planning	Humanities and Social Science	Alfred P. Sloan School of Management
Quota	3232	1605	973	107	256	291
Registration	3198	1522	979	119	275	303

Table I-B History of Quotas and Registration, All Schools, 1961-1966*

	1961	1962	1963	1964	1965	1966
Quota	2181	2288	2842	2963	3084	3232
Registration	2058	2202	2804	3087	3196	3198
Registration/quota	94.4%	96.1%	98.5%	104.2%	103.6%	98.9%
Increase in quota	5.6%	4.9%	24.2%	4.2%	4.1%	4.8%
Increase in registration	4.7%	7.0%	6.3%	10.0%	3.5%	.06%

*For the years 1961-1962, registration represents regular graduate registration in the Schools of Science and of Architecture and Planning and equivalent full-time registration in the Schools of Engineering, Humanities and Social Science, and Management. From 1963 registration is entirely by head count.

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Table II Graduate School Statistics, 1966-1967

Advanced Degrees Conferred:	M.Arch. and M.C.P.	S.M.	Engineer	Sc.D.	Ph.D.	Total
September, 1966	30	227	24	32	93	406
February, 1967	5	165	27	49	82	328
June, 1967	14	341	90	30	100	575
Total	49	733	141	111	275	1309
Graduate School Registration:			Summer 1966	Fall 1966	Spring 1967	
School of Engineering			932	1828		1659
School of Science			597	1084		993
School of Architecture and Planning			40	135		138
School of Humanities and Social Science			64	315		293
Alfred P. Sloan School of Management			83	348		307
Total			1716	3710		3390
U.S. and Canadian citizens				3087		
Other nationalities				623		
Total				3710		
Regular Students				3198		
Special Students				512		
Total				3710		

Table III Graduate Student Support Fall 1966, Spring, Summer 1967

Most of the 3,198 regular graduate students registered in September 1966 received one or more forms of financial support during the ensuing year. This table provides approximate totals (rounded to the nearest thousand) and approximate average awards (rounded to the nearest hundred). The number of awards does not necessarily reflect the number of students supported since loans, partial awards, and awards from endowed funds are frequently made to students already receiving primary support from other sources.

	Number	Dollar Total (Stipends and Institutional Allowances) (thousands)	Average Award (thousands)
Fellowships (Traineeships) Awarded by M.I.T. to Recipients			
Chosen by M.I.T.:			
National Aeronautics and Space Administration Traineeships	45	\$ 228	\$5.0
National Defense Education Act Traineeships	72	387	5.4
National Science Foundation Traineeships	132	664	5.0
National Institutes of Health Traineeships	86	539	6.3
Industrial and Foundation Fellowships (awards in excess of \$2,500)	150	653	4.3
M.I.T. Endowed Fellowships	77	225	2.9
		562	
		\$ 2,696	
Fellowships (Traineeships) Awarded to M.I.T. Students			
Chosen by Sponsors:			
Atomic Energy Commission Fellowships	30	68 ^t	2.3 and stipend
National Science Foundation Fellowships	231	1,161	5.0
National Institutes of Health Fellowships	97	509	5.2
Hertz Fellowships	12	98	8.2
Woodrow Wilson Foundation National Fellowships	11	21 ^t	1.9 and stipend
Other Industrial and Foundation Awards (awards in excess of \$2,500)	4	17	4.3
		385	
		1,874	
Teaching and Research Assistantships:			
Tuition Staff Scholarships for Teaching Assistants	1,507 ^a		916

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Salaries for Teaching and Research Assistants
September 1966 through June 1967
July-August 1967^s

	1,507	5,011 706	\$6,633	
Special, Partial, and Supplementary Awards: M.I.T. Special Awards (Departmental Adjustment)	49	37		0.8
Partial and/or Supplementary Awards by M.I.T. from Industrial and Foundation Sources (awards up to \$2,500)	162	206	243	1.3
Totals	2,665		\$11,446	
Loans by M.I.T. Student Aid:	400 ^t		487	1.2
Totals	3,065		\$11,933	

The above table does not include the following two programs: The Sloan Executive Program which provided 44 students with a total of \$151,000, resulting in approximate awards of \$3,500; and the new National Science Foundation Summer Traineeship Program for Graduate Teaching Assistants which will provide 15 students with support for 12 weeks in the summer of 1967, resulting in a total of salaries and institutional allowance of \$24,000.

In addition, many students are known to be receiving partial or full support from employers and sponsors. The following data reflect Bursar's billings for tuition to such employers and sponsors. These figures include a small amount of special graduate students.

Students Sponsored by Industry and Foundations	93
Students Sponsored by Foreign Countries and International Programs	98
Students Sponsored by Military Agencies:	
Navy	73
Air Force	14
Army	13
Coast Guard	8
Foreign	2
Total	301

^tTuition only—stipend paid directly to recipient by sponsor.

^sThe total of 1,507 represents 985 Research Assistants and 522 Teaching Assistants.

^tThe 400 loans were awarded to 375 graduate students.

^sThe total for July-August 1966 is \$613.

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Table IV Federal Support for M.I.T. Graduate Students

	Atomic Energy Commission	Housing and Urban Development	National Aeronautics and Space Administration	National Defense Education Act	National Science Foundation Fellowships	National Science Foundation Cooperative	National Science Foundation Traineeships	Total
1951-1952					48			48
1952-1953					46			46
1953-1954					51			51
1954-1955					61			61
1955-1956					64			64
1956-1957					64			64
1957-1958	26				92			127
1958-1959	35				100			186
1959-1960	43			4	102	39		195
1960-1961	39			14	152	40		258
1961-1962	39			25	165	42		272
1962-1963	34			29	178	44		272
1963-1964	35		15	32	206	53		313
1964-1965	41		30	28	207	58	79	442
1965-1966	27		45	40	231	55	114	488
1966-1967	30		45	72	231	8	132	518
1967-1968	40	3	39	124	240	—	146	592

This table does not include data on the continuing National Institute of Health fellowship and traineeship programs which had their inception in the 1940's.

VICE PRESIDENT, ACADEMIC ADMINISTRATION

Administratively, the offices of the Dean of Student Affairs, the Student Aid Center, the Admissions Office, the Registrar, the Medical Department, the Placement Bureau, the Office of Public Relations, and the Office of Institutional Studies are responsible to the Vice President, Academic Administration. The reports of these offices follow in detail and indicate clearly contributions which these service activities have made during the past year to members of the Institute community, particularly in connection with the student body. As I have written previously, "With the growing demands and rigor within the classroom, it is increasingly important that we provide outside the classroom an environment and a community spirit which in themselves are an important supplement to the over-all educational mission which we pursue."

I should like to call attention to a number of questions or problems or accomplishments which require special attention as we look ahead. They include:

1. The question of the future role of M.I.T. in the field of educational television.
2. The Faculty Committee on Undergraduate Admissions and Student Aid has undertaken a comprehensive review of our current policies in these areas. Among the issues to be considered are (a) should academic factors other than predicted ability to perform in mathematics, physics, and chemistry receive major consideration in the academic evaluation for admission and (b) how much emphasis should be placed on non-academic criteria in the admissions process? Lively discussions are certain to be had on these and other issues in these areas in the period ahead.
3. The quality and quantity of undergraduate housing continues to be,

in my judgment, one of the most pressing problems at the undergraduate level. I do not wish to belittle the headway made in recent years, but the magnitude of the need requires an even greater effort to secure new funds for this purpose. M.I.T. is almost an exception among the major institutions in that it has not provided significant new undergraduate male housing since the end of World War II. A capital fund of upwards of \$10,000,000 could be effectively used for these purposes.

4. Undergraduate housing has required and used up whatever unrestricted funds were available for capital needs outside of the academic program, and since this need has had higher priority than the need for funds for additional athletic facilities, the capital development program in the athletic area has suffered. There are major capital needs in the athletic area which are outlined elsewhere by Director of Athletics, Ross H. Smith.

5. In this past year there occurred a dramatic change in undergraduate student aid policy. Through an increase of 27 per cent in scholarship funds and an increase of 12 per cent in loan funds, for the first time all undergraduates who applied for aid and demonstrated need had that need met by our student aid program. Our current policy, which I strongly recommend be continued, makes it financially possible for any young man or woman admitted to attend M.I.T. without regard to financial need and without the requirement to work part-time. There is already strong evidence indicating that this new policy has significantly affected the quality of our entering classes.

MALCOLM G. KISPERT

DEAN OF STUDENT AFFAIRS

I would estimate that in this past academic year I have participated in approximately a dozen meetings or informal discussion groups involving members of the Faculty and administration of other colleges and universities in which the topics of conversation of greatest over-all perplexity and concern have been student unrest, activism, withdrawal, and discontent. Almost invariably participants who for one reason or another are not very familiar with M.I.T. have turned to me with comments which may be categorized under two rather extreme points of view — a few comments are “sympathetic” because “your students are so ‘apathetic and insensitive,’ typical of the ‘engineering mentalities’ you have there at the ‘factory’ ”; at the other extreme are those comments which run along the lines “I don’t care why M.I.T. students are not on the rampage; you’re lucky; I’d give anything for a more ordered campus.”

I shall not attempt to paraphrase my responses to these kinds of comments; usually I have been more than amply supported by other discussion participants who are more familiar with the M.I.T. of today.

The facts are that we at M.I.T. are indeed lucky, if you will — lucky to have a long history of student-faculty-administration relations which are open and frank, a climate in which strong views from all segments of the community may be and have been expressed freely with respect for the rights of others to speak and act in opposition. In the past year, this campus has not been isolated from the turbulence of social and political upheaval in this country and abroad. Our students have not been unconcerned about the relevance of their M.I.T. education to social and political issues, to themselves and to their own future roles in society; and certainly they have not submitted passively and without question to some of the glaring defects which still exist in the Institute's educational scheme of things. But their expressions of concern and their actions have been almost always carried out with a sense of responsibility, of civility, and most of all — with that inherent M.I.T. characteristic of participation in the solution in a constructively critical fashion. If I were to use the words engineering mentality to characterize the vast majority of M.I.T. students, I would do so in a complimentary, not a deprecating fashion. For, given the problems which face them, they typically do not choose only to find fault and place the blame; they also work hard at finding viable solutions.

I should be less than candid if I did not admit to the existence of considerable apathy or withdrawal on this campus. But, the fraction of students who fall in these categories is certainly decreasing each year. And there is some comfort in the fact that those who do withdraw, typically withdraw into their academic pursuits — not from the institution and not into the hippy culture.

Whether or not in the next several years we will be able to find the means to help our students come to grips with the problems which beset both them and us is an open question in my mind. I suspect that more than ever before, they will be groping for standards, fundamental values, and the means to participate more actively in both Institute affairs and social and political issues outside the campus. Hopefully, we on the faculty and administration will have the sensitivity and insight to meet these needs before we face a crisis in understanding. To repeat a paragraph in my report to the president for 1964-65:

The burden of my concern, then, is that we not be smugly complacent at the relative tranquility of the M.I.T. campus over this past year, and further, that we fully recognize (and, in fact, applaud) the on-campus activist stage of student involvement in social and political issues. I suspect we will need to find new means to

extend our ability to discuss, to argue, and to arrive at joint decisions with many more student groups than we presently see. In no sense do I wish to infer the establishment of an atmosphere of uniform 'togetherness.' Instead, I propose we need to find the means to expand to a broader spectrum of students the quality of relationship [the president of the Undergraduate Association] characterized. Our traditional reliance on our students' perception, responsibility and "common sense" — together with the establishment of an understanding as to where decision-making authority rests — have proved uniquely successful in the past. I would hope we can proceed in this vein — without finding it necessary either to establish a complexity of rules and regulations on the one hand or the big-brother counseling concept on the other.

UNDERGRADUATE RESIDENCE

At the undergraduate level, the Institute has become essentially a residential university. In the years immediately following World War II, approximately 1,450 undergraduates were housed in fraternities and Institute Houses. The remaining 2,000 to 2,400 commuted from their own homes or apartments in the surrounding area. The opening of Baker House in 1949 and Burton-Conner in 1950 coincided with a drop in total undergraduate enrollment from the post-war bulge so that the number of undergraduates commuting from their family homes or from apartments and rooming houses declined to about 750 in the early fifties. The total number of undergraduates in these two categories* has been in the range of 800 since that time. The number of "independents"*** would be lower each year if we could supply Institute Housing — September demand always exceeds supply. Invariably many college transfers, readmitted upperclassmen, and continuing students who wish to move into an Institute House from an off-campus location are denied accommodations since freshmen must be given first priority.

Within the total of independents plus commuters, the number of bona fide commuters has declined steadily — from about 450 in the early fifties to about 150 to 200 at the present time. All unmarried independents and commuters are by definition male undergraduate members of the Non-Resident Student Association (the N.R.S.A.) which occupies 311 Memorial Drive as a club house. Only about 100 of this group are actively involved in the N.R.S.A. and, through it, in extracurricular campus life generally.

Although there are times when a shortage of beds forces us to deny on-campus residence to freshmen from greater Boston, we are attempting to bring as many of these students on campus as we can. In many in-

*A "commuter" is an undergraduate who commutes to M.I.T. from the home of close relatives in the surrounding area.

**An "independent" is an undergraduate who is not affiliated with a fraternity or the M.I.T. Student House, who does not reside in an Institute House or the home of close relatives but who does commute from an apartment or rooming house.

stances, their backgrounds are such that they stand to gain more from the on-campus living experience than students from farther afield.

The data in Table I show in detail the recent history of population in both the undergraduate men's and undergraduate women's residential programs. The following trends are evident from the data:

1. Despite the Admissions Office ground rule to hold the male freshman input constant at about 875, there has been a slow increase in the total undergraduate men's population. This growth results from occasional over-shooting in admitting the freshman class, a slight increase in college transfer admissions, fewer withdrawals, and fewer academic disqualifications. If the freshmen admission is held at 875 and if the college transfer admission is held at about the present 60-75 level, I would guess that the total undergraduate male enrollment will level off at about 3,650.
2. Each September, we need every bed we can make available within the Institute House system for undergraduate men. Actually, the demand is always greater than we can meet so that many men who live off-campus do so not because they so desire but because we cannot provide beds for them in the Institute Houses in September. The 1962-63 Committee on Student Environment prediction of a gradual growth in the Institute House population to 2,000 — for a total undergraduate male population of about 3,600 and no change in the fraternity structure — appears to be valid. I believe the present growth results from the increase in male population as discussed in (1) above; the increased difficulty students find in locating satisfactory off-campus quarters; and our stepped-up efforts to make more attractive both the individual Institute Houses and the West Campus.
3. Fraternities have also grown so that most chapters require more beds than are available in the chapter house. In addition, the total fraternity beds available within the houses has increased because several chapters have purchased adjacent buildings to increase their in-house bed count and because all have squeezed in beds to maximum or above maximum capacity. The trend toward larger chapters results primarily from the chapters' efforts to hold per-man costs down by spreading fixed costs over the larger brotherhoods. Fraternity men would also claim there are more "fraternity types" coming to rush week, but I suspect economics are really controlling.

INSTITUTE HOUSES FOR UNDERGRADUATE MEN Although we predicted in March that we would face an overload on the Institute House system for undergraduate men for September, 1966, we were unable to identify a sufficiently large auxiliary House to accommodate this overload. We did house 35 men in a small apartment building at 27 West Street, Cam-

Table 1 Recent History of Undergraduate Residence Population

	1961	1962	1963	1964	1965	1966	1967
<i>Men</i>							
Institute Houses	1,510	1,518 + 24 ¹	1,613 ²	1,619	1,632	1,650 ³	1,714 ⁴
M.I.T. Student House	34	34	34	34	34	34	34
28 Fraternity Chapters living in chapter house(s)	908	871	948	962	1,005	~1,000	1,000
living outside house	238	227	126	180	197	~ 185	200
Total men on campus including fraternity men living in-house only	2,425	2,447	2,595	2,675	2,671	2,727	2,749
Total including all fraternity men	2,680	2,674	2,721	2,795	2,868	2,912	2,951
Total off-campus ⁽⁵⁾ men	805	781	769	720	727	761	711
Total Undergraduate Men (excluding special students)	3,485	3,455	3,490	3,515	3,595	3,673	3,660
<i>Women</i>							
On campus ⁽⁶⁾	50	39	74	106	142	161	176
Off campus ⁽⁶⁾	27	59	48	19	18	23	34
Total Undergraduate Women	77	98	122	125	160	184	210
Total Undergraduates	3,562	3,553	3,612	3,640	3,755	3,857	3,870

¹ Overload of 24 in apartment on Massachusetts Avenue.

² Addition of Bexley Hall to Institute House system.

³ Overload accommodated by doubling up 35 singles in East Campus; using two floor lounges in Baker, and renting small apartment at 27 West Street.

⁴ Estimated capacity; 27 West Street (capacity 35) discontinued; 282-290 Mass. Ave. (estimated capacity of 100) opened.

⁵ Two new chapters since World War II: TEP in 1954, ZBT in 1958.

⁶ Includes married students, a small number of whom occupy on-campus apartments at Westgate.

⁷ On-campus for undergraduate women refers to 120 Bay State Road and Bexley Hall in 1961 and 1962; McCormick Hall in 1963 and 1964; McCormick Hall and Moore House in 1965; McCormick Hall and Westgate Annex in 1966-67.

bridge. We were forced to double-up single rooms in East Campus and to convert floor lounges to student rooms in Baker House (note the column headed September, 1966, in Table 1). Almost all of the temporarily overloaded facilities in East Campus and Baker House were returned to normal use by the opening of the spring term.

At the present time, we project a need of 50 to 100 additional beds for September, 1967. Hence we have made arrangements to occupy a large rooming house at 282-290 Massachusetts Avenue beginning in September. The very successful but small group of students of the auxiliary House at 27 West Street will transfer to the Massachusetts Avenue property as a nucleus from which we hope will develop a strong new addition to the House system.

The population trends shown in Table I as evidenced by the necessity to find more and more auxiliary housing when coupled with the increasingly severe shortage of suitable student housing off campus in the Cambridge area make abundantly clear the necessity of moving ahead in our planned new House construction and old House remodeling program. This program was developed from 1961 to 1963 by the Faculty Committee on Student Environment and has been reviewed in some detail in my earlier reports to the President. It is this program upon which we are presently basing our construction and remodeling plans for the Institute Houses. We hope to be able to break ground for MacGregor before the end of this year so it will be available for occupancy in September, 1969. Whether we will then be able to proceed immediately to the massive job of remodeling Burton-Conner will depend upon our ability at that time to absorb the student capacity lost during and after this remodeling and upon our ability to finance the high remodeling costs. I suspect we will find ways of staging the remodeling program in smaller increments both in measures of lost beds and immediate capital outlay.

HOUSING FOR UNDERGRADUATE WOMEN The graduation of the Class of 1967 marks the first generation of women students to have lived in McCormick Hall. They entered M.I.T. just as this House was opened and are therefore the first class to have experienced both the benefits and frustrations of living on campus. They also are the first class which contained a large number (40) of women students. In consequence, coeds in the Class of 1967 have had much to do with the development of student government within McCormick Hall and with successful integration and participation of women students in the academic, social, cultural, and community life at M.I.T. Each year has seen increased progress toward establishment of a residential community of sufficient

size to provide diversity of background and interests and to support programs and activities that depend upon a coed population of significant size.

During 1966-67 the distribution of undergraduate women students on and off campus was:

Class	McCormick Hall	Annex in Westgate	Off-Campus	Total
1970	50	1	0	51
1969	41	2	1	44
1968	24	17	5	46
1967	14	12	17	43
	129	32	23*	184

* 15 are married students.

Use of Westgate as a temporary annex during construction of the addition to McCormick Hall has been successful. This opportunity for on-campus apartment living will be missed by some coeds living in Westgate when they return to McCormick Hall in February, 1968. At that time 110 single rooms will become available in McCormick East, and McCormick West will return to its original capacity of 116. The availability of 226 spaces on campus, and married women students and coeds in each senior class who choose to live off campus should make it possible to reach an undergraduate women's population of about 300 within the next several years.

In May, 1967, an experimental modification was made in the on-campus living requirement for single M.I.T. women undergraduates who do not live at home or with close relatives. The on-campus requirement had existed since September, 1963, when McCormick Hall was opened. The reasons for establishing this requirement were to develop a women's community of critical size, to encourage identification with and participation in the M.I.T. community, and to provide residential conditions of high quality in contrast to the deteriorating quality and safety of the neighborhoods near M.I.T. where students normally seek apartments or rooms for off-campus residence.

The on-campus living requirement has in fact accomplished the acceptance of women students as first-rate contributing members of the student body. Because of this general success, because some coeds have consistently wished for an opportunity to live off campus, and because careful consideration of all aspects of the matter indicated its reasonableness, the on-campus living requirement for single undergraduate women has been modified on a trial basis.

Beginning with the academic year 1967-68 senior women will be permitted to live off campus provided that:

1. The senior will have reached 21 years of age prior to the opening of the term in which she proposes to move off campus,

or

2. She has obtained written permission from her parents.

Since the character of the area immediately surrounding the Institute has unfortunately not improved since the on-campus living requirement was initially instituted, the Institute will not be able to take the same degree of responsibility for those girls who live off-campus. Further, we cannot assume the responsibility of identifying an approved list of apartments or rooming houses. The decision to modify the requirement was made after very careful consideration of all aspects of the matter, and we hope that experiences gained under the trial modification will be good.

SIGNIFICANT CHANGES IN RULES AND PROCEDURES Following the election of the new dormitory council in the spring of 1966, the council through its chairman, Jeffrey Wiesen '67, asked to review the parietal hours and procedures which had been in effect in the Institute Houses substantially without change for about a decade. I brought together an ad hoc student-faculty-administrative group to review the bases for all rules governing life in the Houses as well as the parietal rules. There followed during the fall term discussion meetings among the faculty in residence and their student groups within the individual Houses as well as on an all-campus basis. The outcome of all of these discussions was a general agreement that the consent of the governed existed for essentially all dormitory rules and regulations and would also report a modest extension of the open-house (parietal) hours coupled with rigidly enforced sign-in sign-out procedures — the whole being administered by responsible members of the individual house governments.

Final approval for new all-campus maximum parietal hours was given by the Academic Council in November, subject to the development of satisfactory student administrative procedures. The individual Houses then developed hours and procedures best suited to the desires and geography of the Houses and by late spring, all had submitted satisfactory proposals to me. The new parietal hours which resulted are, for the undergraduate men's Houses:

Monday through Thursday	4:00 p.m. to 12:00 inidnight
Friday	4:00 p.m. to 2:00 a.m.
Saturday	12:00 noon to 2:00 a.m.
Sunday	12:00 noon to 12:00 midnight

and for the undergraduate women's House (McCormick Hall) :

Monday through Thursday	4:00 p.m. to 10:00 p.m.
Friday	4:00 p.m. to 12:45 a.m.
Saturday	12:00 noon to 12:45 a.m.
Sunday	12:00 noon to 10:00 p.m.

In line with our efforts to decentralize authority and responsibility to the individual House level, we developed over this past year a new student room assignment system. Cooperatively among the student House governments, faculty in residence, House Manager, the Campus Housing Office and my staff, we have been able to devise a system in which the necessary centralized bookkeeping and records-processing functions will be retained but in which the individual House governments will control the assignment of individual students in rooms and roommates.

A portion of upperclass room assignment had been accomplished at the House level in the recent past; the new system extends this flexibility to almost all upperclass assignment and to the freshmen level. Beginning with the fall term, freshmen who wish accommodations in an Institute House will be asked to indicate their choice of House and type of room assignment. Priorities will be established by random-ordering of the applications and, in order of this priority, these men will be assigned by the dean's staff to the House which most nearly meets their requirements. The actual room assignment within the House and later shifts (to match personalities and for other reasons) will be done at the House level.

The new system has also been adopted by Ashdown House for graduate students, so that the Ashdown House executive committee will also control — within certain agreed-upon policy guidelines — the room assignment of both continuing and new residents in that House.

At the beginning of the spring term, the dining service began an experimental unlimited seconds program for those students taking their meals on the commons plan. As we expected, during the early days of the program food consumption skyrocketed but then gradually tapered down to a steady value somewhat higher than that experienced under the regular limited seconds program. The "steady-state" increase in cost was calculated at \$41.25 for the academic year (total \$519.75) and the dormitory council was asked to advise as to whether the unlimited seconds program should be adopted as the standard program beginning in September. Following some discussion, it was decided to adopt the new program in Baker House and Burton-Conner and for those commons meals served in Ashdown House and Walker but to retain the present limited seconds program in McCormick Hall.

FRATERNITIES The data of Table I indicate clearly that the 28 fraternity chapters form an important component of our residential program for undergraduate men.

In contrast to the relations between fraternities and the host institutions at most top-flight northeastern colleges and universities, our relations are good. The goals of the individual chapters are essentially those of the Institute, and they are generally supportive and constructive partners. This is not to say there do not remain some problems of discrimination, cruel pledge-training, hazing, and the like. The fact is, however, that we are making rapid progress across the board — with the undergraduate I.F.C. taking strong positive leadership.

The physical plant problems faced by most of our fraternities are not dissimilar from those we face in the Institute House system. Many houses are too small to house a critical number, which is estimated to be about 40 to 50. Deferred maintenance over the years now requires major expenditures to bring the physical plant up to safety and health standards. Zoning problems and neighborhood problems are also severe. Twelve chapters (with 14 buildings) are in the "H5" zone of Back Bay where fraternities are a forbidden use. Ten chapters (with 12 buildings) plus the M.I.T. Student House are in the "H4" of the Back Bay where fraternities are a conditional use. Two chapters are in Brookline, and four chapters are in Cambridge on Memorial Drive.

Difficult problems also arise from the patterns of chapter house ownership throughout our fraternity system. Each house is owned by a separate corporate alumni body whose responsible officers are usually local alumni. There is a wide disparity in the wealth of these independent owning and operating corporations.

The Alumni Interfraternity Conference was revitalized in 1963 under the chairmanship of Marshall Dalton '15. At least two alumni from each house-owning corporation are asked to be members of this group, which meets about twice a year to trade information on common problems. A Central Committee, whose membership includes members of the Institute Administration and three student members of the undergraduate I.F.C. executive committee, meets about once every six weeks during the academic year.

Efforts to date have focused on:

1. Fund raising for the Independent Residence Development Fund — which currently stands at about \$400,000;
2. Providing help, either from the Institute or by swapping information among fraternities, on fire inspections, health inspections, and remodeling advice;

3. Providing up-to-date information on zoning changes and trends;
4. Fostering better relations with social and political groups — particularly in the Back Bay;
5. Continuously searching for longer-term solutions to the housing problems.

The A.I.F.C. membership is somewhat diffuse, and many members are discouraged by what they regard as insurmountable problems, particularly in the Back Bay, and by the absence of feasible alternatives in other locations. There is no doubt that we did not forecast accurately the future of the Back Bay when, in 1961, we issued a progress report over Dr. Stratton's signature. At that time, we revised a prior recommendation to locate new houses on the west campus and recommended major remodeling of existing structures, particularly in the Back Bay. The deterioration in the Back Bay has been almost exponential since that time.

Recent efforts on the part of individual fraternity men and the I.F.C. have had a striking effect on our fraternities' relationships with many of their Back Bay neighbors, and several community, civic, and planning groups in the area. Begun earlier under the leadership of Henry Perritt '66, these constructive efforts were formalized this year under the I.F.C. Community Relations Committee chaired by Stephen B. Douglass '67. Generally, our fraternity men are not only conscious of the need to control student behavior and upgrade physical plant through the Back Bay, they are actively working to counteract the deteriorating trend.

Hopefully, the fraternities will be able to ride out the storm in the Back Bay so that the area will again become a pleasant and safe place in which to live and they will be welcome neighbors. Since this may not be possible, we have searched for suitable alternatives. We have been able to locate no areas other than the Back Bay in which a sufficient number of suitable older structures might be found for fraternity housing. The only alternative appears to be new construction; however the costs of new construction are such that many fraternities will simply have to have long-term, low-interest I.R.D.F. funding in order to undertake this approach.

At the present time, I do not see a clear-cut plan of attack for the long-range solution of our fraternities' housing problems. I suspect we must rely upon an approach which is even more opportunistic in the near term than that for the Institute House program. But in the longer pull we must find a way to meet these problems, for if the fraternities fail, we shall not only be left with an additional massive requirement for added facilities within the Institute House system but — of even greater importance — we shall have lost one of the major elements of flexibility and diversity

which we believe to be an important and desirable characteristic of our undergraduate residential program.

There is no indication of lack of enthusiasm and spirit at the undergraduate level. There is frank recognition of problems in many areas and there is an open, candid discussion and strong willingness to attack these problems constructively. The success of last Rush Week — during which a record 365 freshmen and upperclassmen pledged — is one good harbinger of the future. The new I.F.C. leadership this spring recognized outstanding contributions of retiring student leaders by awarding the Frederick Gardner Fassett Jr. Award to two men — Peter R. Denton '67 and Robert D. Howard '67.

GRADUATE AND MARRIED STUDENT RESIDENCE The pattern of on-campus graduate and married student residence over the past few years is shown in Table II. As in the case of the undergraduate men's residences, we find we are faced each September with a demand which substantially exceeds our capacity. The increased number of both single and married students admitted to the Institute together with the ever-tightening rental market result in this over-demand.

The projected opening of Eastgate in September, 1967, will practically double the number of our on-campus quarters for married students, but

Table II Graduate Student and Married Student Statistics

Year	Regular Graduate Enrollment	Married Students Under-graduates	Grad-uates	Graduate Single students on campus ¹	Married Students on campus
1960	2,353	N.A.		448	0
1961	2,449	N.A.		448	0
1962	2,637	N.A.		448	0
1963	2,804	139	1,424	448	210 ²
1964	3,087	152	1,601	435	210
1965	3,196	153	1,691	435	210
1966	3,198	161	1,685	428	190 ³
1967 (est.)	3,300	160	1,700	428	355-375 ⁴

¹ All Ashdown House.

² All Westgate, opened 1963.

³ 20 apartments in Westgate used as McCormick Annex.

⁴ Eastgate capacity of 204 roughly 25 per cent faculty; McCormick Annex in Westgate returned to married student occupancy in February.

Waiting list for Eastgate and Westgate as of June 1, 1967 after assignment of all space in both facilities: 279.

Normal September for Ashdown House: applications = 450, housed = 150, waiting list = 170.

we now find that the demand exceeds even this doubled capacity. As we face up to this demand, I suspect we will wish to integrate plans for the development of additional on-campus married student housing more closely with those for the long-proposed Graduate Center.

The Graduate Center has proved to be an elusive proposition. Over the years a number of faculty committees have called for the establishment of a facility or facilities which would not only house an appreciable fraction of the graduate student population but which would serve also as a cultural and social center for the residents, commuting graduate students, and many members of the Faculty.

The last formal report on this subject by a faculty committee was the so-called Bush-Brown report of the late 1950's. As then conceived, the Center was to house 1,200 single students with residential and commons facilities very much like those of an undergraduate House. The long range goals for graduate housing established at that time are:

	Single	Married	Total
On Campus	1,200	800	2,000
Off Campus	1,800	1,200	3,000
Total	3,000	2,000	5,000

To date, these goals have not been changed.

Although the Graduate Center was an unfilled objective of the Second Century Fund, the Building Committee in 1963 selected a site on the West Campus, just west of Kresge, for the proposed complex. The architectural firm of Harry Weese and Associates was retained for the initial planning. The program developed by the Planning Office in the Graduate Residence Report in 1964 was a charge to the architect based primarily upon the Bush-Brown studies.

As various schemes were developed by the architect and reviewed by interested student-faculty-administrative groups, two fundamental difficulties became apparent. First, the concept of a monastic or collegiate house system for a graduate student community as diverse as ours did not make sense under careful scrutiny. The original program was therefore changed markedly — through discussion and argument — to what is most simply described as modified apartment houses — in which single men, single women, and married couples are accommodated in apartments of various sizes — with a few faculty interspersed and with several commons areas and facilities provided to foster communal exchange. Common-commons facilities were programmed to bring the residents of the several apartment houses and the commuting graduate students and faculty together at meals, social affairs, seminars, and musicals.

The second difficulty became apparent as the architect struggled to accommodate the program on the site just west of Kresge. The combined

impacts of such a massive set of structures and of an added 1,200 inhabitants on the West Campus were judged to be just too great to risk without reopening the entire question of concept and location of a Graduate Center.

Therefore, approximately one year ago, our design work was halted and the Planning Office undertook an extensive re-study. This study has included a questionnaire survey and selected depth-interview studies of graduate students as well as an assessment of several possible sites. The results of the study are scheduled for initial presentation in the very near future.

Thus, if we decide to develop a future Graduate Center on the modified apartment concept, we may then wish to combine the married student housing program as an integral part of the Center concept.

Westgate has proved to be a generally satisfactory facility although the lack of commons space has posed several problems. The Technology Nursery School has served to bring together an appreciable fraction of the community and several administrative and faculty wives in a worthwhile program. More recently, the Westgate Council has been formed, and we hope cooperatively with this student group to develop further the quality of life in this area.

Ashdown House, the residence for single graduate students, now accommodates 428 students. During 1966-67 27 of the 148 women graduate students enrolled lived in Ashdown House. Women's residence in Ashdown House has been very successful as evidenced by the continued demand for rooms and the hope expressed by Ashdown House Executive Committee that more women could become residents. Under the new decentralized, student-controlled room assignment procedure described earlier, we may find a few added women in residence in a buffer zone between their present quarters and those reserved for men.

The new Housemaster of Ashdown House, Professor John W. Irvine Jr. and his wife have taken a particularly active role in promoting faculty-student interaction and student social life in Ashdown House. Generally, the quality of life in the House has continued to improve, and this year two graduate student leaders were awarded the Avery Allen Ashdown prize for their contributions to the House. They are Miss Karen A. Cohen, G, XI, who is conducting the graduate student and married student survey mentioned earlier, and Martin C. Jischke, G, XVI, president of Ashdown House for 1966-67.

The Ashdown House dining service has faced mounting economic problems over the past few years. The move of many administrative offices to Daggett, the increased use of food vending machines in the academic and research buildings, and the opening of the Student Center

have combined to reduce patronage significantly. Ashdown has operated in the red for the last three years although attempts have been made to reduce costs by closing on Saturdays and Sundays during regular terms and closing during the summer.

Since the dining room is the most important vehicle bringing the residents of the House together — both among themselves and with other non-resident students — we plan to refurbish the dining room this summer and to mount an all-out drive to increase patronage over the coming year. If this effort fails, we shall probably then be forced to institute a required commons meals contract for House residents. (This last ditch course of action has actually been suggested by House leaders as preferable to the loss of the dining room.)

STAFF

During the past academic year, the M.I.T. community suffered the loss of two of its most beloved members. In September we were grieved to learn that Mrs. Frederick G. Fassett Jr. had suddenly passed away in Damariscotta Mills, Maine. The gracious and charming wife of our former Dean of Residence, Julie had lived only a few happy months after the Fassetts left M.I.T. last June for their much-deserved terminal year leave of absence. Her loss was felt throughout every part of the community, and several students, alumni, faculty, and administrative officers formed the Julie Pattangall Fassett Foundation to perpetuate on the campus a small part of the beauty she had always provided. The purpose of the Foundation is:

“to enhance the amenity, beauty, and civility of life at M.I.T., and in so doing to perpetuate the memory of Julie Fassett, whose warm personality, gracious hospitality, and sensitive understanding enhanced the educations of generations of M.I.T. students.”

The first project of the Foundation will be to:

“establish a garden retreat on the campus — a place of natural beauty and quiet not readily found at M.I.T. Surrounded by a wall or tall hedge, it would be a haven from the austerity and intense pace of the Institute. With reasonable care, it should perpetuate itself, as did the flowers that graced the front yard of Moore House when the Fassetts were there. It should be a garden where spring comes in its own time and ways, not put there by an army of gardeners, and flowers of all seasons would unfold their colors with the advancing year. For the visitor there might be some old-fashioned wooden benches, and perhaps a sun dial and a waterfall to remind him of the things of nature.”

During the Christmas vacation, James N. Murphy, assistant superintendent of building services, and staff advisor to Alpha Phi Omega, departed with several members of APO to attend the national convention of APO in Minneapolis. The car in which Jim Murphy and four students —

David L. Wright '67, John P. Augustine '69, and John F. Keil '69 of M.I.T. and David B. Arlen of the University of Massachusetts — were driving west on the road to a fatal crash in Wisconsin early on the morning of December 27. The tragic loss of these well-liked and most promising students and of an employee who had risen over a 34-year period from the position of helper in the old shade shop to become one of our students' most valued and staunchest counselors — and friends — stunned the entire community.

The boys were remembered at a memorial service in the M.I.T. Chapel at which the eloquent words of those students who had lived and worked with them stand as evidence of lives which were short but rich in living and giving to others. James Murphy — the ubiquitous Jim, helpful to all and loved by all — will be remembered through the establishment of a new award in his honor. The James N. Murphy award will "be given from time to time to an M.I.T. employee who has contributed spiritedly to the Institute family — with special regard to contributions to the students (Mr. Murphy) loved so well."

Neither Julie nor Jim were administrative members of the dean's staff but in every other way they were part of our team — working selflessly for the enrichment of student life on campus.

Dr. John T. Norton, Professor Emeritus of Metallurgy, was appointed by Dr. Stratton as M.I.T.'s first Foreign Study Advisor in 1963. As a member of the dean's office he responded creatively to the increasing interest of undergraduate students in study abroad. Working closely with both the M.I.T. faculty and the faculties of foreign universities, Professor Norton personally advised students whose future careers would most benefit by foreign study; and his efforts in establishing policies for overseas study have resulted in adoption by the Faculty of measures to facilitate our students' study abroad. Since Dr. Norton has asked to be relieved of his post at the end of this academic year, President Johnson has appointed Dr. Harold L. Hazen to succeed him. Dr. Hazen, who will retire as Dean of the Graduate School at the close of this academic year, brings considerable first-hand experience with foreign education to his new position.

Professor Lynwood S. Bryant will leave his post as Master of McCormick Hall at the close of this year. As the first master of McCormick Hall, Professor Bryant and his charming lady have contributed greatly to the progress of community, social, and cultural life at McCormick Hall. We are indebted to the Bryants for their significant help in developing our residential program. At this writing, Professor Bryant's successor has not yet been appointed.

Mr. James Taylor '65 resigned as Assistant to the Dean of Student Af-

fairs in December, 1966, to take a new position with the Humble Oil Company.

Mr. Richard Sorenson, presently Assistant Dean of Men at the University of Oregon, will join our staff on July 1 to share with Dean Speer primary responsibility for student counseling.

Mr. Kenneth Schoman '67 will also join our staff as Assistant to the Dean of Student Affairs on July 1, to work with Dean Gray and Mr. Browning on our freshman programs.

As in the past, I have asked my associates to report on those areas for which they carry primary responsibility. Their reports follow.

KENNETH R. WADLEIGH

STUDENT ACTIVITIES

In reporting on the general condition of student activities this year, it seems especially appropriate at the outset to give a brief organizational overview of the many student-initiated activity functions.

By custom and tradition, nearly all student organizations and activity have been referred to as student activities. This general title served us well in a time when the role of each extracurricular organization was readily known to students, faculty, and alumni, and when the entire range of activity was of a size that permitted easy association with other components of student life. However, over the past two decades, there has occurred a substantial growth in the number, variety, and complexity of student extracurricular interests. Though smaller in scale, this development is not unlike the recent growth in the variety and scope of the undergraduate curriculum. In kind, these newer additions are, as were their predecessors, duplicates of the many voluntary interest groups and task organizations one finds in cities, suburbs, and villages. They serve a variety of purposes and generate a quality of freshness and vitality.

For ease of description, it is now helpful to distinguish between four existing types of student activity, namely: undergraduate activities, undergraduate government, graduate government, and community programming.

The term undergraduate activities is applied currently to those 90 student organizations which are similar to and continue the honored traditions of the early M.I.T. This is also the context for the largest number of students participating in activities. For convenience, these activities are loosely classified in the following categories: professional societies, service organizations, foreign students' clubs, student honorary societies, special interest groups, religious groups, political groups, publications, and the performing arts.

The several organizations in these categories are recognized, at the

student level, through membership in the Association of Student Activities, and are supervised by its executive arm, the Activities Executive Board. Where financing is necessary, it is accomplished through the budget process of the Undergraduate Finance Board. The Activities Development Board, composed of students, faculty, and administration is the developmental arm of this over-all effort. Most of the organizations in this grouping are aided, either formally or informally, by faculty or administrative advisors. It is members of these organizations who, each year are eligible to receive the William L. Stewart Jr. Award.

The term undergraduate government is employed to describe the operational branches of the Undergraduate Association and its legislative assembly, the Institute Committee. By means of a number of permanent subcommittees and special committees of the Institute Committee, undergraduate government expresses active student interest and involvement in a variety of phases of undergraduate life and student welfare. Containing as it does, within the governmental structure, representatives of the three upper classes and of the residential units, it is customary also to speak of class government and residential government. Responsible by tradition to the Dean of Student Affairs and through him to the President, it is this undergraduate governmental sector which has consistently initiated major innovations congenial to student welfare.

The term graduate government refers to the functions of the Graduate Student Council, which at this level combines both elements of government and activity sponsorship and coordination. Currently in a stage of transformation, the Council has expressed its general role as follows:

"Broadly, the purposes of the organization are to provide for, and to stimulate, interest in cultural, civic, social, and athletic activities within the graduate community, to provide for welcoming and counseling incoming graduate students, and to advise and cooperate with the administration on all matters pertaining to the general welfare of graduate students."

The Council is composed of one representative from each of the academic departments, one representative each from Ashdown House, the Association of Graduate Women, and Westgate, and a representative of the foreign students.

Present plans call for the establishment of a Council office and lounge in Walker Memorial during the coming year, the employment of a secretary, and the investigation and sponsorship of a series of new programs and events.

The term community programming is an attempt to describe and identify organizations and agencies within the M.I.T. family which sponsor and present all-campus functions and events although not based organizationally within the preceding three groupings. Utilizing the facilities

of Kresge Auditorium, the Student Center, and Walker Memorial, these programs usually are sponsored by social committees of residential units, student dining and service staffs, faculty-graduate groups from academic departments, and organizations such as the Technology Dames, and the Community Players. Events and programs in this category are increasing, and they provide enjoyment and additional opportunities for interaction among peers and colleagues.

Although residential activities might possibly constitute a fifth organizational grouping, because of their connection with government and community programming, nevertheless the focus of residential efforts is mainly directed to in-house needs and preferences, and consequently is more properly designated as residential. However, their increasing sponsorship of campus-wide events is heartily applauded.

By focusing briefly on some of the highlights of the past year, a partial view of the general good health of this over-all area may be attained.

The spring of 1967 marks the end of the second year that all major student activities have been located in the Student Center, and the Activities Executive Board thought it appropriate to analyze the manner in which these activities were utilizing their Student Center facilities. This analysis grew to encompass all student activities whether or not they were housed in the Center, and the final project was a comprehensive study of the current status of activities, their programs, their needs, and their goals. The study will be of tremendous help both to space planners and to financial planners of all student activities.

For the last two years, the Symphony Orchestra has made concert tours; this year it played to appreciative audiences in Baltimore and at Rutgers University. Joining the Orchestra on concert tour were the Logarithms who had their own highly successful spring vacation tour through Connecticut, Maryland, and Pennsylvania. The Logarithms, as tuneful ambassadors of M.I.T., sang to college, high school, alumni, and community groups. The Concert Jazz Band placed in the finals at both the Villanova and Notre Dame Jazz Festivals.

At home, the musical groups enjoyed an outstanding year. In its concert the Concert Band premiered a number of contemporary works among which were the Prelude, Epigram, and Elegy by Daniel Pinkham. The Symphony Orchestra performed a Beethoven Violin Concerto with guest soloist Joseph Silverstein, Concertmaster of the Boston Symphony Orchestra, for a standing-room-only audience. The Glee Club held joint concerts with the college choirs of Vassar and Smith; with Smith they sang "Les Choephores" by Darius Milhaud.

This year marked a change in the annual Tech Show. The student directors looked beyond M.I.T. for their subject matter to create a first-

rate musical comedy with general audience appeal. Dramashop upheld its excellent reputation with solid performances of G. B. Shaw's *Heart-break House* and Maxim Gorki's *The Lower Depths* while the Gilbert & Sullivan Society produced outstanding performances of *The Gondoliers* and *The Mikado*.

Political groups were increasingly active. The Committee to End the War in Vietnam held a rally on the steps of the Student Center which presented a number of anti-war speakers who were challenged from time to time by members of the assembled crowd.

The program of the Art Studio in the Student Center increased both the type and number of its non-credit art courses. In its second year, this program has doubled the number of students taking the painting, drawing, and sculpture courses and using its facilities for associated artistic efforts.

In reviewing its role and responsibility, the Activities Development Board determined that it should be increasingly active as a sounding board for major changes in emphasis and direction of both individual student activities and of the entire student activity area.

Under the leadership of Frank A. March '67, Undergraduate Association President, the Institute Committee held two all-day conferences on student concerns; one was on student stress and the other on student housing. These conferences brought knowledgeable faculty and staff members who provided background as a basis for discussion. These conferences provided the students with a body of reliable facts which they could draw upon and then could apply to problems which arise in their regular legislative meetings.

The Social Service Committee continued its vigorous interest in programs of education for Cambridge younger citizens. Over 100 students were actively engaged in the campus-based Science Camp program and the C.E.F.U.E.T.-Tutoring Plus program sponsored by the Alliance of Cambridge Settlements, Inc. This committee continues to consider imaginative and effective ways in which it may assist in community improvement.

Reflecting the community's growing awareness of changes being made in the physical environment as well as opportunities for further changes, a new student committee, the Student Committee on Environment, was formed. This committee, working in conjunction with the Faculty Committee on Environment has elicited student ideas on possible environmental changes. One of their first projects, a contest for the design of a classroom, produced many worthy new concepts and ideas.

As in the case of the environmental effort, both students and faculty are exploring new ways to work together on common concerns. In some

instances students are joining faculty members on committees; in other cases cooperation is achieved by a series of joint meetings of faculty and student committees.

As has always been the case, many student-sponsored programs are open to and benefit the entire M.I.T. community. Outstanding among such programs this year were the Lecture Series Committee's sponsored lecture by Harrison Salisbury on Vietnam, the Timothy Leary-Professor Lettvin debate on the harmful effects of LSD, and the American Society of Mechanical Engineers' symposium on Engineering Ethics with Ralph Nader as guest speaker.

Following three years of trial and uncertainty, Technology Student Enterprises, Inc. came of age during the past year. After the spring vacation it proudly opened new offices at 95 Vassar Street, immediately adjacent to the campus. That this is a T.S.E. milestone is evidenced by its ability, financially, to acquire and convert the space to use, reflecting a decreasing dependence upon the Institute for support. The Tech Travel Service, the programming agency AMREC, and Tech Hi-Fi all experienced increased sales volume and profit. Viable leadership arising from logical business decisions was provided throughout the year by Ralph G. Schmitt '66, G XVI, T.S.E. President; and assistants Gerald Tomanek '67, Nicholas Covatta '68 and Richard Mazer '68. T.S.E. is a growing corporation.

In early May the campus was treated by Senior House to a performance of *Arsenic and Old Lace*. Playing in the Student Center before packed houses, with both casting, set, and lighting design coming from its own membership, this production is typical of the new vitality found in the activities of the Institute Houses.

In late May the Awards Convocation honored outstanding endeavors of both individuals and groups. Among the many honors given were the William L. Stewart Jr. Awards for contributions to extracurricular life and the Karl T. Compton Prizes for outstanding contributions in promoting high standards of achievement and good citizenship within the M.I.T. community. The recipients of these awards and their citations are indicative of the breadth and quality of campus life at M.I.T. The recipients are as follows:

WILLIAM L. STEWART JR. AWARDS

Roy Nahum Gamse '67

For ideas and initiative reflected in this year's *Technique*, compiled under his direction as Editor-in-Chief.

Stanley Humphries Jr. '68

For major literary contributions to *Tangent*, *Technique*, and Tech Show.

DEAN OF STUDENT AFFAIRS

Karla Sue Hurst '68

For her performance as President of Alpha Chi Delta, during which time the organization has firmly established itself as an independent entity with a strong program of service within and outside the M.I.T. community.

Martin Eric Landey '67

For his work with the Gilbert and Sullivan Society. He was one of the founders and has been an officer each year since; his efforts have been a significant factor in the success of the group.

David Roy McMillan '67

For his contribution to music at M.I.T. and especially for his performance this year as General Manager of the Combined Musical Clubs and as President of the Logarhythms.

William Burton Zimmerman '68

For his contributions to stage productions at M.I.T. including Drama-shop, Gilbert and Sullivan, and Tech Show. His performance as director of this year's Tech Show helped make it the strong success it was.

Tech Show

For a show of outstanding quality and entertainment value that broke with tradition in looking beyond the M.I.T.-Cambridge scene for its subject matter.

THE KARL TAYLOR COMPTON PRIZES

Stephen Burr Douglass '67

Skillful ambassador of M.I.T. within the Boston community.

Robert Vincent Ferrara '67

Scholar, athlete, who has worked devotedly to extend the cultural horizons of our city's youth.

Charles Eugene Kolb Jr. '67

Discerning journalist, perceptive commentator, astute critic of the M.I.T. community.

Frank Adams March '67

With insight and vision he opened new avenues for student-faculty dialogues on common concerns.

Jeffrey Michael Wiesen '67

He has provided means by which Institute Houses and their councils may increasingly enrich the campus environment.

Burton House Reflector

Accepted by James Edward Rumbaugh '67, Editor. To the staff of the *Reflector* in recognition of its comprehensive service to Burton House

residents in reporting with accuracy and detail the issues and activities of House and campus.

Operating Committee, Technology Nursery School

Accepted by Mrs. Lawrence T. Papay, Committee Chairman. In recognition of the imagination and energy of the members of the Operating Committee in nourishing this bright program for our youngest scholars.

Spring Weekend 1966

Accepted by Thomas Oakley Jones '66. In recognition of the Committee's creative efforts which made Spring Weekend 1966 an event of color and style and set new standards for social occasions.

The Urban Challenge

Accepted by David Steven Mundel '66. "It is no longer enough that the engineer, the sociologist, the city planner, and a host of others be involved in the urban area. They must be involved together." To the Conference Committee which through decisive determination of the issues and concerted planning did indeed join together students and professionals from these varied disciplines for constructive interchange on the problems of urban society.

As the number of women undergraduates continues to increase, there is an even greater increase in the extent of the participation by women in student activities. A reflection of this increased participation are the women honored at the Awards Convocation.

A William L. Stewart Jr. Award went to Karla Sue Hurst '68. Cheryl Ann Klitzke '67 received a Baton Society Award for "outstanding contributions to music at M.I.T." A new award, the M.I.T. Athletic Association Pewter Bowl, for "outstanding contributions to women's athletics by a fourth-year woman student" was presented to Ruth Beckley McDowell '67. This award is symbolic of the active participation of women students in athletics. Their abilities and interest in athletics were recognized in February, 1967, when the M.I.T. Athletic Association extended full membership in the Association to the women students. Further evidence of the women's over-all participation was the election of Maria Kivisild '69 to Quadrangle Club as its first coed member.

The following comments are appended in way of summary and of a look ahead:

1. Undergraduate activities and undergraduate government are proceeding effectively upon the traditional base of student initiative. Their understanding and view of their role and function regarding contributions to student life is inspiring. In the case of certain specific activities, there are organizational problems which need attention. A particular case

in point is the Combined Musical Clubs which finds it necessary, because of program expansion, to reorganize its operational procedures. David McMillan '67, Wendell Brase '68, and Kent Stockwell '68 have launched a successful preliminary assault on this problem. Some progress also has been made during the year on a related problem — the Musical Clubs Tour Schedule. Conversations with representatives of the Admissions Office and the Alumni Association have been helpful in choosing favorable itineraries. These conversations will continue in the expectation that tour schedules may be negotiated with adequate lead time for purposes of budgeting and control of details.

2. The Graduate Student Council needs broad support and assistance in establishing its potential role and functions in the areas of graduate government, activity, and welfare. Particularly auspicious now is the necessity for active consideration of these needs at the faculty and departmental levels. Several methods will be tried next fall to develop this participation. The newly elected council, under the leadership of Dean H. Vanderbilt, G, VI, president, is off to a commendable beginning.

3. The community programming function is destined to expand. To deal more effectively with the many aspects of these potential interactions and developments, Jay C. Hammerness, Assistant Dean of Student Affairs, this summer will move his office to the Student Center, the geographical center of most of these activities and events.

4. There is a continuing need for the approximately 20 members of the staff and faculty, who are directly involved as coaches and directors of various parts of this over-all program to meet more frequently with students for purposes of planning and evaluation of the total effort. Steps will be taken to create occasions for this purpose in the coming year.

In closing it is important to consider the broad sweep of the programs and events contained in this area, the deep commitment of its countless participants, and the impact and effect this effort produces to make the M.I.T. community a richly rewarding, living experience.

ROBERT J. HOLDEN, JAY C. HAMMERNESS

THE FIRST YEAR

This academic year is the second in which undergraduates have entered the Institute under the new curricular structure introduced in 1965; half of the undergraduates now at M.I.T. have experienced the new program. For all those involved: students, teachers in the core subjects, and faculty counselors, this two-year period has been a time of learning and of challenge. While most who have participated in and observed first-year academics during this period are agreed that the flexibility and curricular latitude inherent in the revised requirements are beneficial and constitute

a step forward, no one suggests that we have evolved a fully satisfactory or stable situation. In many respects the experiences of the last two years have served to highlight the problems which remain. Most of these relate to the extraordinary breadth of the spectra of preparation and interests which the freshmen bring to the Institute and to the mechanisms by which the Institute can provide educational experiences which are, for essentially *all* who enter, intense and challenging, but not overwhelming.

This progress report on the first year has three objectives: first, the academic performance of the Class of 1970 is reviewed; second, the range of individual first-year programs is summarized and compared with that of a year ago; third, several problem areas are discussed and recommendations are made.

ACADEMIC PERFORMANCE

The experience of the Class of 1969 under the revised program was, as reported last year, characterized by a sharp decrease in the number of students who ended the year in severe academic difficulty. Specifically, the number of freshmen whom we disqualified in June because of unsatisfactory academic performance dropped from an average of 23 for the Classes of 1966, 1967, and 1968 to nine for the Class of 1969. This is the case again this year; eight members of the Class of 1970 were disqualified for academic reasons.* The classes are compared in more detail in Table I, which shows probations as well as disqualifications.

Table I Incidence of Probation and Disqualification

Class	Probation in February	Probation in June	Disqualification in June
Average of 1966-1968	51	43	23
1969	35	41	9
1970	35	52	8

These numerical differences, coupled with the observations of Freshmen Counselors and instructors in the first-year subjects suggest that the new curriculum has indeed made it possible for individual students to adjust to the pace and the intellectual demands of the Institute with fewer personal failures.

VARIANT PROGRAMS

The new curriculum reduced by a factor of two the number of science-core subjects each undergraduate is required to take. Thus, it is now

*Both last year and again this year the number of freshmen who withdrew voluntarily prior to the end of the year was approximately eight.

possible for a freshmen to adjust the timing and total load of the core subjects to achieve a better match with his own preparation and directions. As a result, the first-year programs taken by members of the Classes of 1969 and 1970 show considerable variety, at least in comparison with the essentially monolithic first-year program of prior years.

In terms of science-core subjects, these variant programs fall into three categories:

1. Programs which include mathematics, physics, and chemistry in the first term. In the comparisons which follow, programs of this type will be described as defer nothing.
2. Programs which include mathematics and physics, but no chemistry, in the first term. These are described as defer chemistry.
3. Programs which include mathematics and chemistry, but no physics, in the first term. These are described as defer physics.

Of course nearly all individual programs include in the first term a core subject in humanities as well, and most include at least one elective subject.

The distributions of these programs for the Classes of 1969 and 1970 are shown in Table II. The numbers in the table describe the situation at a point in time near the end of the first term. Thus, the numbers in the defer chemistry and defer physics columns include students who initially registered for, but later dropped, chemistry or physics as well as those who began the term without one or the other of these subjects.

Table II Distribution of Variant Programs (Class of 1969 and 1970)

Class	Defer Nothing	Defer Chemistry	Defer Physics
1969	566 (59.7%)	194 (20.6%)	185 (19.7%)
1970	620 (69.0%)	130 (14.4%)	150 (16.6%)

These data show that fewer students used the opportunity for deferment of a science-core subject during the second year under the program than in the first. Specifically, about 40 per cent of the Class of 1969 deferred a science-core subject while only about 30 per cent of the Class of 1970 did so.

This regression toward the former monolithic first-year program is curious because it occurred in the face of more complete counseling on the part of the Freshman Advisory Council, and in spite of evidence concerning the benefits which can result for deferral of a core subject for those students whose preparation warrants it.

Three factors appear to have influenced this situation. First, upper-classmen have generally advised freshmen *not* to defer a science-core subject on the grounds that the potential loss (restriction of later elective

freedom, scheduling difficulties, "second-class citizenship") is not balanced by the potential gain (improved academic performance). Second, several departments actually imposed, by means of the structure of their second- and third-year curricula, severe penalties on the student who, as a freshman, deferred a science-core subject. Third, there are too few substantive elective subjects which can be taken by first-term freshmen and which can be used to fill the time made available by deferral of a science-core subject.

We have made progress in all of these areas this year, and hope that these factors will be moderated somewhat in their influence on the choices of first-year programs made next year by the Class of 1971. In particular, we have continued to discuss with upperclass leaders and with student counselors the relationships between preparation and performance at M.I.T., and have tried to clarify the intent and consequences of variant programs in the first year. There seems to be a broader appreciation of these matters among the upperclassmen now in comparison with last year, and we are hopeful that the general tone of the counseling provided by upperclassmen to members of the Class of 1971 will be more supportive of the counseling that will come from the freshmen advisors.

Also, *all* departments have now adjusted their second- and third-year programs so that they can accommodate, without prerequisite or scheduling penalty, a student who deferred physics or chemistry as a freshman.

Although the range of elective alternatives open to freshmen has increased slightly, limitations here still restrict the flexibility of freshmen more than necessary. We are continuing to encourage developments that will relieve this pressure.

PROBLEM AREAS

There are four areas in which changes that are desirable in terms of the Institute's educational objectives appear feasible within the next year or two. These areas are:

1. Elective alternatives in the first year.
2. Science-core subject alternatives.
3. Patterns of operation of the science-core subjects.
4. Methods of evaluation and grading.

In discussing these areas and making specific recommendations that affect them, I shall speak in more personal terms.

Although there are many freshman elective subjects and undergraduate seminars that are appropriate for first-year students, very few of the science-distribution subjects and laboratory subjects can be taken by first-year students because of prerequisite or scheduling problems. The limited number of nine- or 12-unit electives open to freshmen is an

important factor in limiting the widespread use of the curricular flexibility implicit in the General Institute Requirements, as discussed in the previous section. There is a real need for new elective subjects which do not require more background than first-year calculus taken simultaneously. If possible these subjects should also be applicable to the science-distribution requirement. Such subjects might also provide a better introduction to a discipline than many of the present science-distribution subjects, and would thus be helpful to freshmen who are trying to acquire information on which a choice of course can be based. I believe that the departments should be encouraged to develop subjects which will meet these objectives.

It has become increasingly clear, particularly in the areas of mathematics and physics, that a single version of a science-core subject cannot encompass the entire range of backgrounds of the students who meet our admission standards. We must either make the General Institute Requirements more flexible or introduce several subjects in each of the science-core areas, any one of which will meet the General Institute Requirement in its area. This change is obviously expensive, not only in terms of dollars, but in terms of the first-rate intellectual effort required in the development; it is also difficult because some degree of interchangeability must be preserved, and because we must at the same time learn how to assist individual freshmen in deciding upon the subjects appropriate for them. Nevertheless, I am of the opinion that we must eventually introduce this diversity in the core subjects, and I think it would be well to begin now. The experiment which the Department of Mathematics is contemplating for next year in first-year calculus is an encouraging step in this direction.

The science-core subjects in the first year are taught on a lecture-recitation basis with uniform quizzes and examinations. Many students, as well as a significant fraction of the instructors in these subjects, question the value and effectiveness of the recitations, particularly in the spring term. Furthermore, many students are at best doubtful, and at worst bitterly cynical, about the reliability of the quizzes and examinations as the principal instruments which determine their grade in a subject. I believe that we should evolve different patterns of operation for these subjects, patterns in which small-group personal contact with teachers is considerably more important than at present both in the learning process and in the evaluation of student performance.

Finally, I believe that we must re-examine the consequences of our present methods of evaluating and reporting individual academic performance. The present grading system certainly provides relatively rapid feedback to the student concerning the quality of his work, and, also

provides a simple quantitative index by which the Institute can evaluate the quality of its students. However, the one-dimensional nature and the permanence on the record of the present system introduce, particularly in the freshman year, tensions, pressures, and patterns of study which are neither productive or desirable as personal attributes. I believe that we should immediately commence the development of a system of evaluation and grading which would recognize the several dimensions of academic performance — a system which would reduce rather than increase the distance between instructors and students, and which would minimize overt competition for grades while still providing students with reliable measures of their performance. In this regard, the particular pass-fail system which is now standard in the first two years at the California Institute of Technology may be of some use as a model.

PAUL E. GRAY

STUDENT COUNSELING

The responsibility of the Office of the Dean of Student Affairs for counseling is on occasion linked with the responsibility for discipline which it exercises in conjunction with the Faculty Committee on Discipline. In summarizing the situations of a disciplinary nature that arose during 1966-67, it is well to bear in mind that, in general, the majority of such situations are responsibly handled by the various Judicial Committees of Student Government and that as a result the dean's office is infrequently involved. Of those situations that did involve the dean's office and the Faculty Committee on Discipline, the majority concerned the use of marijuana.

It is important to separate the subject of LSD from that of marijuana. The two are frequently spoken of together because both are hallucinogenic and both are illegal. But it is reasonably clear that the majority of M.I.T. students, whatever their opinion of marijuana, have come to the conclusion that experimentation with LSD is dangerous. In 1965-66 approximately half a dozen students who used LSD required hospitalization, in some cases for extended periods of time. None of these cases was followed by disciplinary action; the severity of the psychological consequences seemed more than adequate as a deterrent, both to the individuals involved and to others. In 1966-67 there was no known case of an M.I.T. student's use of LSD that required hospitalization. Most students appear to have a healthy fear that use of LSD, even if not followed by psychotic reactions that require hospitalization, will impair their power of judgment. In the spring of 1967 the Lecture Series Committee sponsored a joint lecture on LSD by Doctor Timothy Leary

and M.I.T.'s Professor Jerome Y. Lettvin in which the latter unequivocally made this point. The number of those who have used LSD in 1966-67 without apparent ill effects is unknown, but the available evidence suggests that it is small.

Marijuana presents a different problem. The Faculty Committee on Discipline reviewed the available information on approximately two dozen students who were involved to some degree in the use or sale of marijuana. The degree of involvement ranged from those who experimented with it once or twice to a few who were selling it to other students. Two students were required to withdraw; several were placed on formal disciplinary probation; approximately a dozen were placed on "admonition" (a less stringent form of probation which does not involve a notation on the student's official transcript); the others were considered to be admonished *de facto* if not *de jure*.

Four students were arrested, one by federal and three by state authorities. The charges against one were dismissed; the charges against another were filed; one is currently on probation; and one is still awaiting a trial in federal court.

When a student is involved in court action, it is the Faculty Committee's policy in general to withhold its action until the case is disposed of in the courts. In one of the four cases referred to above, the Committee did not withhold its decision, since the evidence on which it acted was not the evidence on which the arrest was based.

Marijuana is illegal, and the Institute cannot condone its use. But it does not necessarily follow that the Institute can solve the problem of marijuana by adopting the apparently unambiguous policy of expelling automatically every student found to have used it. Students become involved in its use in varying degrees and for various reasons. Others who have no intention of using it themselves are sincerely disturbed by the social and legal prohibition of a substance which many consider to be medically not very different from alcohol. In the present state of contradictory attitudes about marijuana, it is important that the Institute's disciplinary actions be considered just and reasonable by the majority of students, for it is their common sense and responsible concern that must be actively involved if the problem is to be met with any degree of success. In only a few years it will be those who are not college students, users and non-users alike, who must share in the responsibility of determining the social and legal status of marijuana. At the Awards Convocation in May, 1967, President Howard Johnson recounted some advice he was once given, the gist of which was that a person facing a difficult problem should ask himself if he is a part of the solution or a part of the problem. All of us, in different ways, must both regard ourselves

as parts of the problem and parts of the solution of the marijuana problem.

WILLIAM SPEER

THE M.I.T. PREMEDICAL ADVISORY PROGRAM

During the summer of 1966 discussions among Dr. Jerome B. Wiesner, Dr. Albert O. Seeler, Dr. Irwin W. Sizer, and Dean Wadleigh resulted in a decision to modify the M.I.T. Premedical Advisory Program and to have it administered from the Office of the Dean of Student Affairs with policy being determined by a Premedical Advisory Committee. The increased number of students who are interested in attending medical school was a major factor in this decision. I was asked to explore the premedical advisory situation and to propose a plan and procedures for an expanded program.

Since applications for admission to medical schools in September, 1967, had to be completed and sent off by November 1 or shortly thereafter, a quick major change last fall in the advisory system would have been a disservice to the students. Dr. Harriet L. Hardy, therefore, continued to work with the seniors in the completion of their applications. I saw all the other premedical students who wished to talk about their plans. This allowed me to get a feel for the kind of counseling needed. At the same time I explored with members of the Faculty and medical staff what might be eventually the best and most practical format for a Premedical Advisory Program.

Dr. Hardy indicated that during the five years she was the Premedical Advisor, the number of applications completed with her help ranged from 18 to 30. Information received from the Association of American Medical Colleges showed that in fact a number of M.I.T. students applied independently. The available data are rather sketchy but they are given below.

Year	Total M.I.T. Applicants	Admitted	
		Number	Per cent
1962	47	39	82.9
1963	33	22	66.6
1964	44	28	63.6
1965	37	26	70.3
1966 (estimated)	39	25	64.1
1967 (estimated)	30	22	73.3

The 1967 data are based on information given by students who were known to have applied. Of the 30 applicants four were refused admission

and four did not reply to our questionnaire. The fields in which the 30 applicants majored are: 14 in biology, seven in humanities, two in economics and one each in physics, management, chemical engineering, mathematics, electrical engineering, aeronautics, and chemistry.

The purpose of the Premedical Advisory Program is to (1) provide information about medical schools and their requirements for admission, (2) offer opportunities for general counseling and discussion of possible careers in medicine and medical research, and (3) provide supplementary assistance and information to students preparing applications for admission to medical schools. The modified program was put into effect in February, 1967. An Advisory Committee was appointed by Dr. Wiesner. Its membership reflects the distribution of premedical students throughout M.I.T. departments and, in addition, possesses experience and involvement either with medical concerns or with undergraduate counseling. Members of the committee are:

Dr. Harriet L. Hardy, Medical Department
 Professor Bernard S. Gould, Department of Biology
 Professor Roy Lamson, Department of Humanities
 Professor John B. Stanbury, Department of Nutrition and Food Science, M.I.T. Clinical Center
 Dr. Philip A. Drinker, Department of Mechanical Engineering, Committee on Engineering in Living Systems
 Dr. Joseph H. Brenner, Medical Department
 Dr. Albert O. Seeler, Medical Department
 Professor Emily L. Wick, Chairman, Office of the Dean of Student Affairs, Department of Nutrition and Food Science

The Committee has met on an almost monthly basis since February. Its initial concerns ranged from discussions of the philosophy of our task to mundane mechanical details. In my opinion the Committee feels that, in general, medical schools do not know enough about the modern M.I.T. student. Many think of him as the classical "M.I.T. engineering type." One of our major responsibilities is, therefore, to inform the medical schools. The usefulness of holding a conference for representatives of medical schools at which the nature of M.I.T. and its students would be presented (somewhat analogous to the annual conference for secondary school guidance counselors) is being considered.

Another problem under discussion is the seeming incompatibility of parts of the M.I.T. curriculum with stated prerequisites for entrance to medical schools. The disappearance of Qualitative and Quantitative Chemical Analysis as formal subjects is not yet recognized by some medical schools. The proposed dropping of laboratory hours from 5.01

will also be hard for some medical schools to understand. On the other side of the ledger is the recent letter from Johns Hopkins Medical School which states that effective September, 1969, one semester of physical chemistry will be required instead of an alternative choice between quantitative analysis *or* physical chemistry. Medical school curricula are changing as are the M.I.T. curricula. All this reflects progress, but it can pose problems for the premedical student and for those who counsel him.

Since September, 1966, about 100 students have discussed with me their interest in attending medical school. Many of them may finally decide against it, but their interest in exploring the possibility is sincere. Each student is automatically listed with the undergraduate premed society and is sent announcements of its activities which included:

1. A dinner meeting at which the Deans of Admissions of Harvard, Tufts, and Boston University spoke.
2. A dinner meeting at Endicott House and discussions with present medical students, hospital residents, and several young physicians working in computer sciences.
3. A discussion meeting with Dr. Parke Gerald, Harvard Medical School and Professor Vernon M. Ingram, M.I.T. Department of Biology, on medical and academic research.
4. Opportunities to observe open heart surgery.
5. Volunteer work at the Boston City Hospital.
6. Opportunities to visit physicians in Concord, Massachusetts, and accompany them during a day's work.

The Premed Society has been very active and many of its members are very enthusiastic. Major credit for this goes to David Swedlow, '68, an Aeronautics major.

The general composition of the group of approximately 100 students who are considering medical school is shown below:

Class	Number
1970	21
1969	39
1968	35
1967	3
Graduate students	1
Total	99

DEAN OF STUDENT AFFAIRS

The fields in which they are majoring are:

Course	Name	Number
5	Chemistry	3
6	Electrical Engineering	11
7	Biology	27
8	Physics	2
16	Aeronautics and Astronautics	2
17	Political Science	3
18	Mathematics	2
21	Humanities	10

On the basis of my brief experience with the Premedical Advisory Program, I am sure that much interest exists in medicine, in biomedical research, and in engineering in living systems. Most M.I.T. students who actually apply to medical school are admitted. However, much more can be done to increase the effectiveness of premedical counseling at M.I.T.

EMILY L. WICK

RELIGIOUS ACTIVITIES

It is pleasant to report modest increases in the use of the Chapel during the past year. Scheduled religious services numbered 633, an increase from 595 reported in the previous year; weddings increased to 76; while the total of special services were doubled at 16. In addition, 27 musical events were presented, and the building was in use on 893 other occasions for religious and musical purposes.

In terms of this wider use it is especially gratifying to note the occasion on Alumni Day, 1966, of the first Memorial Services for M.I.T. Alumni. Arranged by alumni participants, the enthusiastic response to this special program of commemoration, and its continuation again this June, establishes new associations with the Chapel for many of our returning alumni. Also an innovation of pleasure and promise has been the series of special musical recitals presented in the Chapel on Thursday at noon. Arranged by John Cook, Institute Organist, this new idiom of the spirit has enjoyed increasingly appreciative audiences.

Continuing the initial impetus of a year ago, the Interface student program has taken confident steps in its attempts to open dialogue across religious traditions. Not the least of its many achievements has been the contribution of substantial man-hours of work in transforming the basement of the new location of the Religious Counselor Center, 312 Memorial Drive, into a bright and attractive meeting place. The response to its developing program of Saturday evening meetings with faculty and guests, and its special Chapel services is heartening. Far from diverting

interest from traditional religious organizations, on the contrary, this new interaction has strengthened present student groups while adding new dimensions of understanding and cooperation.

Religious Counselors report increasingly heavy demands on their time in all aspects of their work and responsibilities. Throughout the year they have met fortnightly to discuss the many facets of Institute community life with members of the Faculty and administration. Their many and varied contributions to our community cannot easily be described or conveyed. We are, however, continually grateful for their presence among us.

It is a pleasure to welcome to the campus in September two new members of the staff: The Reverend Francis Ayres, Episcopalian, and the Reverend James Sessions, Methodist.

ROBERT J. HOLDEN

FOREIGN STUDY ADVISORY PROGRAM

About four years ago the post of Foreign Study Advisor was established in response to the growing interest on the part of M.I.T. undergraduates in opportunities for including a period of overseas study as a part of their academic programs leading to the bachelor's degree. The original objective of this appointment was to examine the various aspects of an undergraduate program and to make recommendations as to what course the Institute should take in this general area. Since that time, the activities of the office have expanded to include a general advisory service for both undergraduate and graduate students wishing to spend time abroad, as well as the administration of a number of the overseas graduate fellowships.

The principal opportunity for the undergraduate student has been enrollment in existing Junior Year Abroad programs operated by other universities or private organizations which have been examined in considerable detail and have been recommended by this office. These programs include preliminary intensive language instruction and are primarily centered about the areas of liberal arts, social sciences, and the humanities. However students have been able to take some courses in mathematics and natural science. The subjects are divided between those offered by the program itself, for which teachers are engaged locally and subjects taken at the foreign university with which the program is associated. In general some sort of measure of academic performance is submitted by the program but the problem of academic credit at M.I.T. is a matter which must be negotiated between the student and his department here. Occasionally an undergraduate student has set up a program at a foreign university on his own but this situation is rare.

During 1965-66 about 100 undergraduate students were interviewed and of this number, ten were finally accepted by one of the programs and were abroad during the academic year 1966-67. Of these, six were in France, and one each in Germany, Spain, Israel, and Japan. The course distribution of these students is one in Course V, one in VI, one in VII, three in XVII, and three in XVIII.

During 1966-67, the number of undergraduates interviewed was much less, approximately 35, and it now appears that not more than four will be participating in overseas programs during the academic year 1967-68. This decrease in interest appears to be traceable to uncertainties in the Selective Service situation and the increasing political tensions existing throughout the world.

At the graduate level, interest in overseas study continues at its normal level, and there have been numerous applications for the several graduate fellowships. Although it is impossible to have a complete listing, our students have received two Fulbright awards, two D.A.A.D. German awards and one Marshall Fellowship.

For the immediate future, the most practical plan for our undergraduates appears to be a continuation of enrollment in existing programs abroad. The programs which have been successful in the past should be reviewed each year and additional programs investigated. The combined capacity of these good programs seems quite adequate for the present level of interest among our students. From the limited sample which we have had so far it is evident that those students who have participated consider the experience a most satisfactory one. While in some instances they have not fulfilled all of the objectives that they expected or hoped to accomplish, they all agree that the year overseas was not only very pleasant but a truly significant event in their over-all programs. The ten students who will return to M.I.T. this fall should be interviewed in a systematic way so that their experiences and views can serve as a guide in future programs.

At the October, 1966, Faculty meeting, approval was granted for a category of registration to be established for those undergraduate students in good standing who are participating in an approved academic year program abroad and who intend to return to M.I.T. to complete their degree requirements. An undergraduate registered in this category is designated as an Undergraduate on Foreign Study and is not liable for tuition payment. In order to be eligible, a student must have been accepted by a program or school of established academic merit, demonstrate that the objectives of his planned program of studies are consistent with his degree program, and have the academic and personal qualifications which will enable him to derive the maximum benefits from the ex-

perience. The program should involve a student work load comparable to an academic year at M.I.T. The Foreign Study Advisor and the student's Faculty Counselor act with power in these cases or on matters of policy with the Committee on Curricula.

For the long-range future of overseas study for undergraduates, the problem of setting up a formal program in cooperation with a particular foreign university should receive additional study. The particular university should be selected with the objectives of our overseas study program in mind. Unfortunately these objectives have not yet been clearly defined in the views of either students or faculty. The university selection should also be based upon the interests of the body of students who would be potential participants. It might well be that the best choice would be a general university rather than an engineering or a scientific school. A basic curriculum could be established with some range of flexibility and one in which our faculty as well as the foreign faculty would participate in planning. Academic credit could be determined for such a formalized plan, possibly by examinations given here when the students return. People from our staff would be actively involved, particularly in the planning stages but unless the numbers of students increases very significantly, a resident director probably would not be needed. One objective of the program would be the mastery of a second language which means that the chosen university should be in a French- or a German-speaking country.

Because of its formal nature and its official sponsorship by M.I.T. such a program would undoubtedly attract a larger number of undergraduates than the present program. It would however, present at least two important problems, both of which involve questions of M.I.T. policy. In the first place, the choice of a single university in a particular country would almost automatically rule out a considerable segment of the undergraduate body. Possibly the first selection might be considered as a first step, which if successful, could later be extended to one or two other countries. The second problem arises from the fact that a cooperative plan with a foreign university would certainly involve the acceptance of an equal number of foreign students at M.I.T. on what would be practically a tuition free basis. This again is a policy question which would have to be judged in the light of an over-all evaluation of the program. There are of course many minor problems associated with such a plan, some of which would involve expense but none of which appear insurmountable.

The development of a formal program is a matter which should concern the Foreign Study Advisor but also should involve a much greater participation of the faculty than has been the case in the past.

JOHN T. NORTON

ATHLETICS AND PHYSICAL EDUCATION

The most significant development in the area of athletics during the past year has centered in an administrative change of tack in plotting immediate and long range plans to upgrade and complement the Institute's facilities for sports and recreation. The details of a plan to keep pace with the expanding scope of our athletic program are set forth in a separate statement of projected requirements for athletic space and facilities through 1975, and are incorporated with Dean Wadleigh's June, 1967, Report on Long Range Planning to President Howard W. Johnson. Therefore, I will review at this time only those considerations which are fundamental to the recommendations and which require continued emphasis.

Over the years, the Institute has traditionally sponsored a program of athletics for all students as an integral part of an education at M.I.T. in the firm belief that participation in sports develops desirable qualities of character and generally promotes optimal personal growth. Also, we have recognized the need for the development of life-long recreative interest among our students as a positive influence in career success and general happiness in the years after graduation. The emphasis has been on participation by all students, rather than sports spectacles for a few gifted athletes. Since there have been no gate receipts, the program has been supported from general funds. The funding of facility expansion and special maintenance projects has been and continues to be a major problem.

The extension of this rather unique philosophy, particularly during this current period of transition to a residential campus with increased emphasis on the integration of extracurricular educational experiences with those of the formal classroom, presents a very real challenge. Although no substantive growth is planned in undergraduate enrollment in the next decade, we are committed to meeting the needs of a steadily increasing community of students who move directly into graduate school from their undergraduate work and who are thoroughly grounded in interests and participation patterns in athletics.

During the past academic year, the formal aspects of the intercollegiate and intramural programs for undergraduates completely filled to capacity the Institute's sports facilities during the period of peak use between 4:00 and 7:00 p.m. Except for limited space gained through recent renovations in the gymnasium and squash courts at Walker, there were no indoor facilities available for general recreation during the popular hours of the late afternoon. Briggs Field, the Ice Rink, the Swimming Pool, the du Pont Center, Rockwell Cage, Pierce Boathouse, 14 squash courts and 16 tennis courts were necessarily limited during this period to that segment of approximately two-thirds of the undergraduate enrollment who are regularly active in intercollegiate and intramural athletics. Only the Sail-

ing Pavilion has been open to general recreation during this period of peak interest. The evening and weekend schedules at all of the facilities have been extended; however, this frequently imposes an hour for recreation which is incompatible with the program of many of our students.

The case for expanded athletic facilities available for the casual recreation of all students and which generally will meet the needs of the M.I.T. community, cannot be overstated. An ultimate solution to the problems will combine the following planning considerations: (1) additional facilities for sports like squash and tennis must be included in the planning of future residences, such as MacGregor Hall and the proposed graduate center, (2) the final scheme for the development of the West Campus must include a second swimming pool, (3) a gymnasium-recreation center for that segment of the community not presently accommodated, (4) the acquisition of peripheral land for the facilities for the racquet sports and (5) a general upgrading of the existing Athletic Center in a master plan which will include a covered ice rink and a replacement of Rockwell Cage, both of which could be convertible to a multi-purpose indoor athletic facility-convocation center.

At this point, I return to my earlier reference to a change of tack in plotting immediate and long range plans to meet space requirements for the athletic program for the next decade. This past December, the Athletic Board, with the endorsement of the Director of Athletics and the Dean of Student Affairs, recommended to the Planning Office that immediate steps be taken to update plans to improve and expand existing athletic facilities independent of the unfulfilled Second Century Fund programming of a graduate center west of Kresge Auditorium.

The decision to free athletic planning of ties to the much discussed graduate center was of major importance at this time, particularly since the original site plan for the graduate center dictated an extremely expensive realignment of the running track, the du Pont tennis courts and the general layout of the athletic fields to make room for a final location of a covered ice rink. The cost of the realignment of existing facilities was estimated at \$1,250,000 in 1965, exclusive of the ice rink construction.

The recommendation of the Athletic Board does not preclude the future use of the site west of Kresge consistent with the best interests of the West Campus. It simply points to the urgent need for immediate planning to update the athletic facility requirements; and establishes the pattern for a more realistic scheme in terms of funding expectations and staging possibilities in a master plan to meet the requirements of the athletic program. The Planning Office and the Department of Athletics are currently working on the implementation of these recommendations.

PROGRAM HIGHLIGHTS FOR 1966-67

The many facets of the athletic program at the Institute are traditionally related to student values and educational objectives through the functions of the Athletic Board and the M.I.T. Athletic Association. The former has combined faculty, alumni, and administrative personnel with the undergraduate leadership of the Athletic Association in an advisory role which has been most helpful during the past year. I am especially grateful for the assistance of Professor James W. Mar, Board Chairman, in coordinating the long range planning recommendations of the Board, and the efforts of George D. Jones '67, Athletic Association President, in directing the attention of the Board to the programming needs of our students. I also extend special appreciation to Glenn P. Strehle '58, who is completing his term as an alumni representative to the Board.

PHYSICAL EDUCATION The general success of the Institute's athletic program is best judged by the regular habits of participation developed and continued by our students during their years of formal education. Last year more than 67 per cent of our students were active in some phase of organized or informal sports recreation. The Physical Education Program provides the basis for a broad exposure to athletic interests and offers instruction in sports selected according to the interests of individual students. Swimming is the only sport in which minimum skills are set for all male undergraduates.

Registration statistics for 1966-67 indicated a total of 4,011 registrations in 53 courses. This is a ten per cent increase in registrations over the previous year and includes a total of 744 non-credit registrations. In this latter figure, there was a 175 per cent increase in graduate student registrations for sports instruction.

Much of the popular response to the program is due to the strong emphasis placed on the carry over sports, the quality of the facilities, and the professional teaching offered by the coaching staff. Swimming, sailing, the shooting sports, the racquet sports, and golf, continue to attract the largest number of students. There has been a very marked increase of interest, however, in the activities of individual discipline, such as judo, development, and weight training.

New subjects introduced in physical education this past year included pistol and rifle, made possible by the long-awaited completion of the new shooting range in the du Pont Athletic Center. Also, the bowling alleys in the Stratton Student Center were utilized for instruction in off-peak hours.

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Physical Education Registration 1966-67

Activity	Number of Registrations	
Swimming		644
<i>Beginning</i>	362	
<i>Intermediate</i>	53	
<i>Diving</i>	69	
<i>American Red Cross Life Saving</i>	42	
<i>American Red Cross Instructors'</i>	63	
<i>Scuba</i>	55	
Development		539
Tennis		440
<i>Beginning</i>	311	
<i>Intermediate</i>	129	
Sailing		361
*Shooting Sports		308
<i>Pistol</i>	149	
<i>Rifle</i>	159	
Judo		200
Ice Skating		200
Golf		191
<i>Beginning</i>	132	
<i>Intermediate</i>	59	
Archery		178
Fencing		145
Squash		143
Volleyball		138
Skiing		101
*Bowling		73
Touch Football		69
Softball		61
Lacrosse		51
Badminton		45
Soccer		41
Wrestling		37
Gymnastics		32
Sigma Delta Psi		14
Total		4,011

*New subjects in 1966-67

Non-Credit Registration

Classification	Number of Registrations
Freshmen	28
Sophomores	190
Juniors	120
Seniors	87
Graduate Students	290
Faculty-Staff	28
Alumnus	1
Total	744*

*Includes 43 women students

INTERCOLLEGIATE ATHLETICS During the late summer of 1966, the M.I.T. basketball team competed in Europe at the invitation of the People-to-People Sports Committee as a part of the Committee's program to promote good will and better understanding among the nations of the world through mutual interest in sports competitions. A squad of 14 students assembled July 15 for a week of practice under the coaching of Professor John G. Barry. The itinerary included contests in Iceland, Luxembourg, and a tour through Central Europe for additional competitions in Yugoslavia and Greece before returning to Luxembourg and finally to Cambridge. The M.I.T. students played a total of 26 basketball games in the four countries, including two games against the Yugoslavia Nationals who won the World Championship in 1966. The record of 14 wins against 12 losses was of small consequence. The close relationships and understanding which developed among our students and the peoples of the several nationalities point to the real success of the experience.

The basketball team moved through the regular intercollegiate season of 1966-67 with a record of 19 wins and 4 losses for the best record in the history of the Institute. Seniors Alex Wilson, Bob Hardt, Roy Talus and '67-68 Captain-elect Dave Jansson distinguished themselves with individual honors in weekly Eastern College All-Star Selections.

The swimming team of the past year is considered the best in the history of aquatics at M.I.T. In the course of winning nine meets while losing only three, every varsity individual and relay record was broken during the season. Participating in the sweep were Mike Crane '67, Larry Preston '68, Lee Dilley '69, John McFarren '68, Dan Gentry '68, and two outstanding sophomores, Luis Clare and Bill Stage.

Also outstanding were the 8-2 record of the varsity wrestlers and the success of the freshmen who won nine matches and lost one enroute to the first New England freshman wrestling championship for M.I.T. in the long history of the league of 23 colleges. Varsity Captain David Schramm completed a 35-3 dual meet career record and won the New England Heavyweight Championship to qualify for the National Collegiate Championships.

It is interesting to note that a total of 492 varsity, junior varsity and freshmen contests were scheduled in the 1966-67 intercollegiate program. During this period, the records of our varsity competitions* include 116 victories, 114 defeats, and one tie, which indicates that our M.I.T. teams can and do compete favorably, without preferential treatment for athletes in our admissions and financial aid decisions.

Of further interest is the fact that approximately 900 undergraduates were active on 43 regularly coached and equipped squads in the 19 in-

*Excludes sailing regattas and ski carnivals.

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tercollegiate sports. In addition, there were ten athletic clubs which numbered in excess of 200 students, including graduate students, and competed regularly, though less formally, with their counterparts in the Boston and New England area. Clubs active in 1966-67 were:

Club	Number of Students
Bicycling	10
Cricket	15
Graduate Crew	12
Graduate Soccer	18
Gymnastics	24
Hockey — two clubs	30
Judo	20
Rugby — three squads	45
Water Polo	14
White Water	15
Total	203

INTRAMURAL ATHLETICS The intramural athletic program, developed around the dormitory and fraternity living groups, regularly attracts the largest segment of student participation in organized athletics at M.I.T. League or tournament competitions in 17 recognized sports were com-

Participation figures for 1966-67

Sport	Number of Teams	Average Number Players per Team	Participants
Badminton	Singles and Doubles Tournament		275
Basketball	72	10	720
Bowling	66	5	330
Cross Country	35	5	326
Cycling	3	12	36
Football	49	17	833
Golf	24	3	95*
Hockey	37	12	444
Rifle	44	4	176*
Sailing	No competition in 1966-67		
Softball	62	15	930
Squash	41	5	205
Swimming	39	5	218
Table Tennis	32	3	96
Tennis	35	7	232
Track	23	8	292
Volleyball	92	9	828
Water Polo	24	12	288
Wrestling	48	4	181
Total	726		6,505

*Includes individuals on incomplete teams

pletely organized and directed by the undergraduate Intramural Council during 1966-67. Water Polo competition was included for the first time and attracted 24 teams. Cycling was continued as a conditional sport.

ATHLETICS FOR WOMEN Genuine interest in recreational athletics continues to attract a sizable group of M.I.T. women. There were 43 registrations by women for sports instruction in the physical education classes. A section in modern dance was organized this past year. Although actual participation was somewhat limited, the Intramural Council seated Maria Kivisild '69 as a member of the Council and opened the door to women's entries in several of the intramural sports appropriate to competition for women.

The M.I.T. women's sailing team continued to dominate the New England Women's Intercollegiate Sailing Association competition among 14 member colleges in 1966-67, as evidenced by our invitation to represent N.E.W.I.S.A. in an Eastern Championship June 22-25, 1967. Ruth McDowell '67 and Alix Smullin '68 continue to win individual honors.

The fencing team, though less victorious, was well organized with intercollegiate competitions in a league composed of the Greater Boston women's colleges. A group of 20 coeds limited to intra-squad practice sessions, nevertheless, enthusiastically, reported to the new Pierce Boat-house for regular turn-outs in the early hours of the morning. A cheerleaders club continued to bolster the morale of the basketball crowds during the intercollegiate contests at Rockwell Cage.

GENERAL RECREATION Although casual recreation for students and the M.I.T. community is one of the prime objectives of the Institute's athletic program, the facilities for general recreation are necessarily limited to those off-peak hours when there is no conflict with priority commitments to intercollegiate and intramural athletics. This situation was thoroughly discussed earlier under long range planning; it will continue to be a major problem until additional facilities can be provided for recreational pur-

Athletic Card Sales for 1966-67

Students	4,686
Faculty	331
Staff/Employee	1,087
Alumni	171
Miscellaneous	145
Total	6,420
<hr/>	
Sailing Cards	1,346

poses during the popular late afternoon hours when the gymnasiums are committed to the formal aspects of the program for undergraduates.

The sale of athletic cards generally reflects the interest of the M.I.T. community in recreational use of the athletic facilities.

M.I.T. COMMUNITY PROGRAMS In addition to the informal use of the Institute's sports facilities, the special recreational programs popularly received by the M.I.T. community included children's instruction in swimming, sailing and ice skating; family swim on Friday evenings; male faculty noon-hour groups in volleyball and squash; with swimming, modern dance and physical conditioning groups organized among the women.

Special summer programs were offered in tennis and sailing. Noon-hour and twilight softball leagues were cosponsored by the Instrumentation League, the Summer Softball League, and the Department of Athletics.

The Summer Day Camp for M.I.T. children between the ages of six and thirteen continues to be oversubscribed during each of the four periods of two weeks each. The capacity of 150 campers per period is dictated by quality of the camping program and the limits of one swimming pool.

MAJOR ATHLETIC AWARDS FOR 1966-67

David N. Schramm '67

The Class of 1948 Award to the "Athlete-of-the-Year"

Robert M. Hardt '67

The Admiral Edward L. Cochrane Award to the senior who best combines qualities of leadership, humility, and scholarship in the intercollegiate athletic program

Michael A. Crane '67

The Eastern College Athletic Conference Merit Medal to the scholar-athlete of the year

Robert M. Hardt '67, David G. Jansson '68, Peter D. Kirkwood '66, Stephen J. Sydoriak '68

The Straight T Award, the highest award given for athletic performance at M.I.T.

Frederic W. Andree '70 and Ben T. Wilson '70

The Quadrangle Club Award to the outstanding freshman athletes of the year

Joe R. Deichman '67

The Varsity Manager of the Year

STUDENT AID CENTER

Beta Theta Pi

The Beaver Key Trophy to the living group with the highest percentage participation in intercollegiate athletics

Beta Theta Pi

The Varsity Club Award to the living group with the most varsity lettermen

ROSS H. SMITH

STUDENT AID CENTER

During the past year, financial assistance provided to undergraduates reached a new high. Scholarship and loan awards from all sources totaled \$3,967,569 — an increase of 27 per cent over the previous year — and allowed us for the first time to meet fully the demonstrated financial need of every aid applicant. This aid was distributed to 2,159 undergraduates, 190 more than in 1965-66. The above total is broken down in Table I.

The planned use of M.I.T. operating funds to augment our designated scholarship resources during the past year has helped to make possible this improved aid program. \$333,308 of these funds were used to cover awards made to 382 undergraduates. The level of scholarship aid from outside sources increased significantly both in total dollars and number of awards. This reflects the effect of two new scholarship programs, the Economic Opportunity Grant Program of the U. S. Office of Education and Pennsylvania's State Scholarship Program for residents. This increase, together with the increase in the endowment income, has allowed M.I.T. to attain a scholarship position equal to other leading institutions.

The average award for the year from scholarship and loan combined was \$1,890, which is again the highest level recorded by this office to date. The average scholarship amounted to \$1,126 and the average loan was \$875.

Use of outside loan help increased significantly last year, as 154 students borrowed \$176,267, compared to 96 students and \$97,333 in 1965-66. A further increase in assistance from this source is expected for 1967-68, due to the increasing use of the Government Insured Loan Program authorized by the Federal Education Act of 1965.

SCHOLARSHIPS

We report with great pleasure the establishment of three new endowed scholarship funds during the year; The Association of Iron and Steel Engineers Scholarship Fund established in memory of Ingvald Elias

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Table I Undergraduate Scholarships and Loans, 1966-67

	1966-67		1966-67		1965-66		1965-66		Total
	New Reporting Basis Number	Awards	Prior Reporting Basis Number	Awards	New Reporting Basis Number	Awards	Prior Reporting Basis Number	Awards	
<i>Undergraduate Scholarships</i>									
From M.I.T. endowment funds:									
Freshman scholarships	355	\$ 308,325	355	\$308,325	261	\$271,210	261	\$271,210	
Upperclass scholarships	809	658,414	809	658,414	569	572,195	569	572,195	\$ 843,405
		\$ 966,739		\$ 966,734					
From M.I.T. operating funds:									
Freshman scholarships	149	140,833	149	140,833					
Upperclass scholarships	233	192,475	233	192,475					
		333,308		333,308					
From outside sources:									
Freshman scholarships	338	339,370	338	339,370	289	253,571	289	253,571	
Upperclass scholarships	687	722,614	687	722,614	571	633,746	571	633,746	
		1,061,984		1,061,984					887,317
Total Undergraduate Scholarships	2,098*	\$2,362,031	2,098*	\$2,362,031	1,507†	\$1,730,722	1,507†	\$1,730,722	\$1,730,722
<i>Undergraduate Loans — As Awarded</i>									
From M.I.T. sources:									
Freshman loans	612	356,312			490	422,437			
Upperclass loans	1,464	1,072,959			1,202	869,569			
		1,429,271							1,292,006
From outside sources:									
Freshman loans	43	34,750			28	21,559			
Upperclass loans	141	141,517			84	75,744			
		176,267							97,333
<i>Undergraduate Loans — Sources</i>									
Technology Loan Fund			1,371	780,844			606	540,191	
National Defense Student Loans			703	647,027			1,071	738,465	
Other M.I.T. Loan Funds			2	1,400			15	13,350	
Total Undergraduate Loans	1,788*	1,605,538	1,634*	1,429,271	1,448*	1,389,339	1,348*	\$1,292,006	\$1,292,006
Total Scholarship and Loans	2,159*	\$3,967,569	2,005†	\$3,791,302	1,969*	\$3,120,061	1,869*	\$3,022,728	\$3,022,728

* Due to changes in reporting procedures, the figures in this column are not additive.

† Adjusted to show the total number of individuals receiving awards from all sources

STUDENT AID CENTER

Madsen; the Clair Morton Prince Hanks Fund established by the bequest of Mrs. Hanks; and the Hart Nichols '27 and Arthur Nichols '28 Scholarship Fund. In addition, new gift scholarships were established by the Alcoa Foundation and by Joel W. Campbell '17.

Endowment funds for undergraduate scholarships were increased by \$1,063,699.60 during the year. Total endowment now stands at \$15,528,876.26 reflecting a 7.2 per cent increase during the year.

LOAN FUNDS

During the year a total of \$2,009,191 in loans was granted to 2,150 graduate and undergraduate students (see Table II) from M.I.T. controlled loan funds. This total represents an increase of 12 per cent over the previous year's total. Funds allocated for the National Defense Loan Program for 1966-67 were cut slightly to \$676,797, however, so that a significant increase in loans made from the Technology Loan Fund was necessary.

The number of students gaining help under the Ford Foundation's special forgivable loan program for doctoral candidates declined this year from 43 to 33. The amount provided was correspondingly less. A substantial increase in use of the Installment Credit Plan again occurred as 143 students borrowed \$93,409.

We are pleased to report the establishment during the year, of the Helen and Leo Mayer Loan Fund, by a gift of the Helen and Leo Mayer Charitable Trust.

STUDENT EMPLOYMENT

Since M.I.T. no longer requires that students accept a term-time job as part of their aid package, and since the Office of Student Personnel has recently been reassigned as an agency of the Student Placement Bureau, statistics on student employment are not included in this section.

FACULTY/EMPLOYEE CHILDREN SCHOLARSHIP PLAN

M.I.T. provides scholarship assistance to children of faculty members who are attending college. In addition, children of faculty members or full-time employees who are enrolled at M.I.T. receive all or part of their tuition, depending on their status. During 1966-67, 29 M.I.T. students received tuition remission of \$36,693. Children attending other schools received scholarship aid totaling \$167,827.

I am pleased to announce the appointment on December 1, 1966, of Leonard V. Gallagher '54 as Associate Director of Student Aid.

JACK H. FRAILEY

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Table II Loans to Students from all M.I.T. Sources, 1966 and 1967

	1967		1966	
	Number of Students	Amount	Number of Students	Amount
Technology Loan Fund	1,630	\$1,070,714	806	\$ 741,462
Other M.I.T. Loan Funds	7	6,500	21	18,475
National Defense Student Loans	807	771,567	1,219	917,280
Installment Credit Plan	143	93,409	73	46,261
Ford Forgivable Loans	33	67,001	43	72,661
Total		\$2,009,191		\$1,796,139
Number of Loans	2,620		2,162	
Number of Recipients	2,150		1,790	

NB: Includes both undergraduate and graduate students.

Admissions Office Statistics, 1966-67

	1965	1966	1967
<i>Entrants from secondary schools:</i>			
Preliminary applications	6,545	6,068	6,240
Final applications	3,770	3,728	3,887
Admissions offered	1,566	1,423	1,416
Actual registrations	955	922	918
Registrations as per cent of admissions	60.9%	64.8%	64.8%
Number of secondary schools represented	766	702	713
Per cent of students from nine northeastern states	49%	47%	53%
<i>College transfers:</i>			
Total applications	419	479	497
Applications completed	213	250	217
Admissions offered	76	100	85
Actual registrations	61	75	78
Registrations as per cent of admissions	80%	75%	92%
<i>Graduate students:</i>			
Total applications	4,957	5,663	5,672
Admissions offered	2,361	2,463	2,284
Actual registrations	1,458	1,453	1,769
Registrations as per cent of admissions	62.1%	69%	77%
<i>Number of personal interviews:</i>			
At M.I.T.	1,413	1,490	1,514
In New York	140	143	187
By Educational Counselors	2,842	2,691 ¹	4,999
Total	4,395	4,324	6,700
Number of persons taking tours of M.I.T.	4,927	5,712	4,316
Number of secondary schools visited:			
By Educational Counselors (college nights)	115	117	91
By faculty and administrative staff members	478	435	239
By Admissions Office staff	280	255	309
Total	873	807	639

¹ This figure represents Educational Council interviews on **final applicants only**. Figures for all applicants for 1966 are not available. The comparable figures for 1967 final applicants only is 2,550 interviews.

ADMISSIONS OFFICE

Statistics on the Class of 1971, corrected as of September, 1967, and relevant information on operation of the Admissions Office during the year 1966-67 are presented herewith.

Advanced Placement†						
	Number of students seeking credit		Number of students receiving credit		Number of subjects credited	
	1965	1966	1965	1966	1965	1966
<i>Procedure:</i>						
College Board test program	418	467	337	367	480	536
Advanced Standing Examinations	20	21	19	20	12	21
College transcript	69	47	57	47	63	73
Total	467*	502*	374*	401*	555	630
Subjects credited			Number of semesters credited			
			1965	1966		
Chemistry			114	117		
Physics			1	10		
Mathematics			341	361		
Languages			3	4		
Other subjects			2	16		
Elective Credit (six units each)			94	122		

† 1967 figure not available until October.

* In some cases credit was sought and earned through two procedures; duplication is eliminated in the totals.

TRENDS

As the core curriculum becomes more flexible and the popularity of science, as contrasted to engineering, continues to grow, the admissions process becomes increasingly involved with students seeking a general or liberal education. The variety of student interests to which we may expect to appeal is expanding; the variety of colleges with which we are in direct competition for top-notch students seems to expand at a comparable rate. At the same time, the rapid growth in numbers, capacity, and quality of public colleges and universities — especially the large state institutions — has already brought about a highly significant tendency, in many parts of the country, for high school students to proceed almost automatically into the local public college, with minimal consideration of alternative plans.

In the face of this combination of factors, and probably thanks in significant measure to our excellent — and generous — financial aid

program, our applications were three or four per cent higher this year than last; and our yield — at a new high last year — remained practically constant. Continuation of these same trends is highly probable, and could augur some falling off in the number of applications, in the yield, or both, in future years.

The popularity of the coeducational institution and of our excellent dormitory facilities continues to be reflected by relatively rapid increases in numbers of applications from female students. This year, as last, the yield for coeds was slightly above that for male students. Also, the degree of selectivity seems to have been somewhat higher. It will not be possible to allow female and male applicants to compete for admission on an equal basis until the second unit of McCormick becomes available.

CRITERIA FOR SELECTION

Following extensive reports to the Academic Council and to the Faculty on the basic policies and processes of admission and allocation of financial aid, at the suggestion of the President, the Faculty Committee on Undergraduate Admissions and Student Aid has initiated a broad reevaluation of Institute policies in these areas. Such evaluation will constitute a major project for both the Committee and the two administrative staffs during the coming year.

Among the issues already defined in broad terms are two with which the Admissions Office has been particularly concerned for some time, and in regard to which we anticipate significant contributions from the Committee. The first of these relates to academic evaluation. Our procedures in this connection have been almost purely statistical applications of regression analysis techniques. The results have been relatively accurate predictions of ability to perform ably in the first year. But at the same time this technique has tended strongly toward selection of the same "types" which we have previously admitted; and it places undue emphasis on readiness to perform ably in the three core areas of mathematics, physics, and chemistry. The question arises as to whether other factors should be injected, perhaps arbitrarily, into the academic evaluation in order to broaden the academic base — even if it means some slight reduction in predictive accuracy.

The second issue, and in some respects a far more fundamental issue, relates to the relative amount of emphasis placed on non-academic factors in the applicant evaluations. The tendency over the past several years has been to increase the weight assigned to what the Admissions staff calls the Personal Rating, and to other non-academic criteria. The qualities which are evaluated, the sources of information on which the evaluations are based, and the measures of success which could be

employed to check such evaluations have all been subjective and difficult to define. Accordingly there seems to be good reason to question not only the efficacy of the techniques now being used, but also the objectives themselves.

Closely related to this second issue are questions about modifying the selection process to achieve special objectives: for example, to favor certain schools or departments; to attain broader socio-economic or geographic distribution; or to achieve some sort of balanced student body in respect to career objectives, current interests, or activities potential. All of these have been considered informally in the past. None has been systematically incorporated in the selection process.

PUBLIC RELATIONS

There is no doubt that a major function of the Admissions Office must continue to be the recruiting of highly qualified students. Over the years we believe our most effective specific program has been the annual Guidance Conference. The eleventh of these, held in October, saw some 117 representatives of public, independent, and church-related schools in 38 states and Canada, on campus for two days of discussions about secondary school-college transition in general, and about opportunities at M.I.T. in particular. There is much evidence that the multiplier-effect of these conferences is great: the guests report their experiences, both formally and informally, to large numbers of their colleagues; and the general tenor of these reports contributes markedly to our favorable image.

School visiting is a second and much more conventional device for keeping in touch with our secondary school public. The practice has become so widespread that it seems to be more of a nuisance than a help to many of the better known schools in major metropolitan regions. We continue our program because it seems essential as a means of two-way communication with schools. Unlike most colleges, we do not use the school visit as an opportunity to interview the individual student; we see fewer opportunities for group counseling sessions; but we look for increased opportunity for meeting with groups of guidance counselors on the occasion of these school visits. As the responsibilities of the M.I.T. Educational Council are expanded, it has become increasingly important to schedule sessions with local members of the Council as major components of school visiting trips.

Current students play important roles in our relations with the applicant group. Through the Dormitory Council and the Inter-Fraternity Conference visitors to the campus are afforded overnight hospitality in the several living groups. Experimental programs have been set up,

under the auspices of the Public Relations Committee, in which M.I.T. students communicate in person or by correspondence with individual applicants, to give them first-hand information and counseling about M.I.T. The efforts made in this direction have not yet demonstrated effectiveness in terms of freshman yield; but more can and will be done, we believe with benefit both to the applicant and M.I.T.

The Public Relations Committee has sponsored, for the second year, a series of talks at M.I.T. for nearby secondary school students: Topics in Technology. The program this year was under the leadership of Richard Lufkin '68. Dr. Ronald H. Cordover and Professor David W. Strangway presented stimulating programs to more than 600 students. Many of these followed up the talk with a tour of M.I.T. led by members of the Public Relations Committee.

When the award of scholarships was on a competitive basis there was significant honor attached to such award; and there was need for local follow-up with the more promising candidates to determine which should be so honored. Now that aid is available to virtually all, and the amount of aid is entirely determined by need, scholarship awards have much more mundane implications than formerly. In part to offset this, the offices of Student Aid and Admissions instituted this year a program of designating National Scholars. These scholars are selected for their superior qualifications, and comprise the top 10-15 per cent of the admitted group. Financial aid is in no way involved; and the award is made to admitted applicants regardless of whether they will come to M.I.T. or go elsewhere.

Typically the awards, including an engraved certificate signed by our president, are presented by the Educational Counselor at a ceremony arranged at the local school. We believe that this method of honoring outstanding student-citizens, the attendant publicity, the involvement of the Educational Counselor with the school, and the further opportunity for contact between the Counselor and the outstanding applicant will all redound to the benefit of M.I.T. There was no measurable increase in the yield from this group during this initial year of the program (half will not attend M.I.T.); but we hope that the future may bring more favorable impact from the standpoint of yield.

OPERATIONS

The Admissions Office staff members continue to assist in a variety of campus and off-campus programs. M. Bryce Leggett continues as the Executive Officer of the Committee on Academic Performance. Paul E. Johnson, Peter D. Leavitt, and Peter H. Richardson have been Freshman Advisors. Mr. Richardson has also served as advisor to the Whitewater

Club; and Eugene R. Chamberlain has been advisor to the M.I.T. Boy Scout Troop. Mrs. Juanita L. Stuller has carried on a series of special studies for the office of the Dean of the Graduate School. Mr. Johnson has assisted in arrangements for the inauguration, the Open House, and Commencement.

Mr. Chamberlain and Robert A. Schuiteman have continued to be active in affairs of the National Association for Foreign Student Affairs; and Mr. Chamberlain has also served as a member of the advisory group for BASIS, the Boston Area Seminar for International Students. Both Mr. Richardson and Mr. Leavitt have been counselors for the Boston program of COPE (Center for Opportunity for Progress in Education). Mr. Leavitt has also served on the Education Committee of the Urban League. Mr. Richardson has been on the NAACP Educational Council, and has assumed major responsibility in setting up the Upward Bound program at M.I.T. this summer. Mr. Greeley is the representative of the New England Association of Colleges and Secondary Schools to the College Entrance Examination Board.

During the past year many members of the Faculty have made substantial contributions to the admissions program. Some 58 have assisted in the tremendous, but interesting and informative, task of reviewing application folders. Many more such readers are needed, however, in order to achieve the desirable objective of having each folder read by a faculty member. Several members assisted by taking one-week trips to visit secondary schools. To the following we are especially indebted for their services in this respect: Professor Hale V. Bradt, Peter Buttner, Robert Cook, Professor Charles K. Crawford, Professor William H. Dennen, Thomas W. Harrington, Daniel T. Langdale, Professors Alan J. Lazarus, Robert E. MacMaster, John S. Maulbetsch, Jacob L. Meiry, Alan V. Oppenheim, and Igor Paul, Henry H. Perritt Jr., Richard R. Randlett, Richard L. Sampson, and Professors Joseph L. Smith Jr., Kenneth A. Smith, and Wallace E. Vander Velde.

The 850 members of the Educational Council continue to be an indispensable arm of the Admissions Office — and of the Institute as a whole. Their service as counselors, interviewers, and public relations ambassadors merits the most enthusiastic thanks of the Admissions Office.

ROLAND B. GREELEY

EDUCATIONAL COUNCIL

Membership in the Educational Council has grown six per cent during the past year, reaching a total of 884 alumni associated with 2,448 secondary

schools. Members of the Council conducted 87 per cent of all interviews with candidates for the Class of 1971. In addition, Educational Counselors were requested to represent M.I.T. at 146 college orientation programs at secondary schools. The following are salient features of the year's operations.

The economy of the Institute's school visiting program is being improved by more efficient local arrangements made by Educational Counselors. Alumni are bringing together small groups of guidance counselors from several schools for central meetings with the M.I.T. visitor, and evening meetings with groups of interested students and parents are proving successful. Emphasis on such local arrangements will increase as a necessary response to the competition we face in this popular type of school relations.

The new M.I.T. National Scholar program has promoted contact between alumni, schools, and students in a meaningful way at an important time. Much good will was generated at the schools, and this benefit alone is sufficient to warrant continuation of the program.

Two cooperative endeavors of Council groups and M.I.T. Clubs deserve special recognition. The Northwest M.I.T. Regional Conference in Seattle was attended by over 600 high school students and teachers from Washington, Oregon, and British Columbia. Some came as far as 300 miles for the full-day Saturday session of M.I.T. speakers, including Chairman James R. Killian Jr., President Howard W. Johnson, and senior members of the Faculty. The Northern New Jersey M.I.T. Club and Educational Council attracted an audience of some 170 science students and teachers to their March meeting, which featured a speaker not associated with M.I.T., who talked about lasers. Public acceptance of these programs has encouraged planning for high school audiences in future events, such as the 1968 Regional Conferences in Philadelphia and Dallas.

An innovation in the Educational Counselor's approach to the school has been remarkably successful. It involves making available to the school through the M.I.T. representative, free loan use of film editions of the M.I.T. Science Reporter television series. Program topics were selected to include some of the less well-known aspects of study at M.I.T. The response from the schools during the three months these films were available far exceeded our supply and many requests had to be refused. This device has made school visits more attractive to our Educational Counselors, and it has opened some doors in the schools which otherwise would be closed. Many teachers expressed gratitude for what they considered to be useful additions to their teaching. This activity will be expanded during the coming year.

RECRUITING AND RESPONSIBILITY

The purpose of the Educational Council may be described as the recruiting of the most highly qualified students. We have tried to avoid this particular verb, probably because it smacks of solicitation and proselytism. Even in its most positive and favorable definition, recruiting should not entirely describe the theme of operation of the M.I.T. Educational Council. We have a greater responsibility.

The activities of the Educational Council must provide a personal kind of public relations, the purpose of which is to influence the most highly qualified secondary school students to consider M.I.T. as one of the universities worthy of further investigation as they start to select the ones to which they will apply. Generally, our recruiting system permits contacts with the student only after he has decided to learn more about M.I.T. and has identified himself in a written inquiry. This is probably the best recruiting policy. However, we must make more subtle attempts to affect the basic decision to inquire. And this very early decision is greatly influenced by many, such as peers and parents, who have little or no interest in M.I.T. and equivalent accuracy in their knowledge of it. But they do exert a powerful influence in determining whether M.I.T. gets further consideration. This is only one of the effects of our public image.

Informing the public of the current nature of M.I.T. is a constant concern of the Public Relations Office and the Alumni Association, as well as the Educational Council, and it is appropriate that the Council's efforts should be concentrated upon the secondary school, although the value of contact by these well-informed alumni with other alumni and with the wider public must be considered significant.

Rather than attempting to recruit able students at, for example, the junior year level, we must increase the awareness of M.I.T. among all students, regardless of their specific interests at the moment. It is necessary to inform the peers who influence the decision, as well as those who we hope will decide to look more closely at us.

The message that does this should be intellectually exciting to the students and aimed just a little over their heads in order to influence most those who are willing to extend themselves. By letting the intellectual ability of each student serve as a filter, we might give a general message specific appeal to those we hope to attract.

Our message must be brought into the school and transmitted to the students and teachers in a way that is interesting, is helpful to their own efforts, and thus builds good will for M.I.T. The very successful use of the M.I.T. Science Reporter films in this manner is a clear and positive indication of the ready acceptance this attitude evokes and the value to be derived from it.

M.I.T. has a responsibility to secondary schools; a responsibility to provide reasonable curriculum supplements which give their students a glimpse of the challenge and excitement for which they are preparing. We could give the advanced mathematics class a glimpse of the use of mathematical models (and computers) in modern business management; we could expose the physics class to Professor Philip Morrison's delightful treatment of mirrors and apertures; we could give the Science Club an appreciation of the systems approach through an example such as the Icarus project. Happily, fulfilling this responsibility benefits both the giver and the receiver. And the Educational Council serves as a ready-made distribution organization.

Such an attitude in our school relations program will have the added result of raising the M.I.T. alumni representative from the status of another nuisance to one of an interested helper, one who can bring into the school, through a variety of media, some of the resources of a great university. More of our attention and support must be given to this responsibility so that our alumni can have the opportunity to enter the recruiting competition for all the outstanding students who ought to consider M.I.T.

WILLIAM H. MC TIGUE

FOREIGN STUDENT OFFICE

In many foreign countries the demand from students for access to higher education far exceeds the capacity of the universities and colleges to which they apply. The United States, in contrast, continues to broadcast the drive to provide educational facilities for all its eligible citizens. In the minds of many foreign students, therefore, this country holds out to them the greatest potential for academic and social advancement.

The Institute, ranking fourth among U.S. institutions in the percentage of foreign students enrolled, continues to attract a substantial number of inquiries from interested foreign citizens. In 1966 nearly 18,400 individual pieces of mail were received by the Admissions Office, either related to foreign applications under consideration, or simply inquiries about the possibility for admission.

The table below shows the trend in applications to the Institute.

	1963	1964	1965	1966
Inquiries received	5,440	6,340	6,619	8,050
Applications sent	1,667	2,052	2,581	3,117

FOREIGN STUDENT OFFICE

The difference between the inquiries received and the applications sent represents in many instances the decision of the student not to make a formal application based on the informational materials sent to him.

Foreign student enrollment at the Institute for recent years is:

	1963-64	1964-65	1965-66	1966-67
Undergraduate	222	220	207	211
Graduate	671	693	722	724
Total	893	913	929	935

During the current academic year there were 935 foreign students enrolled (or 12.36 per cent of the total student population) from 75 countries. In this group there are 28 women students. In addition to this population 229 students were accompanied by wives (or husbands in three cases).

The foreign student enrollment in graduate programs of the five schools is as follows:

Architecture	28
Engineering	391
Humanities and Social Sciences	50
Management	66
Science	199

INDIA

In 1966 there were 82 citizens of India enrolled at the Institute. They represent the second largest contingent of foreign nationals (Canadians being first) on campus. The majority are graduates enrolled in various fields of engineering.

This is the nation, aside from Canada, from which the Institute receives the largest number of letters inquiring about the possibilities for admission. Current correspondence exceeds 2,500 inquiries a year. We respond by sending a preliminary application particularly designed for this purpose, which, if returned, can then be reviewed by a staff member to determine whether or not a formal foreign student application should be sent. This screening enables us to refuse admission to otherwise potential candidates who have academic records at the second or third division levels and are clearly not eligible for admission to the Institute. It also helps deflect those students who apply for fields of study not taught at the Institute.

The graduate departments at M.I.T. received 460 applications from

Indian students for the term beginning in September, 1966. The majority (382) had been in attendance at a university or an institution of technology in India. Seventy-eight applied from institutions in the United States, Canada, or Europe. Of these, 46 were offered admission and a select few with outstanding records were also awarded assistantships. Nineteen eventually enrolled, 27 cancelled their admission largely because offers of financial assistance were not made, or they were unable to obtain the appropriate dollar exchange from the Bank of India, enabling them to come to the United States. Some undoubtedly received what were judged to be more attractive financial awards from other institutions.

This trend in inquiries from India shows no sign of diminishing. The Foreign Student Office staff will continue to explore ways of helping the Indian candidate to make a better choice among several alternatives he may have for higher education; the staff will also help the graduate departments in evaluating applications received.

THE M.I.T. HOST FAMILY PROGRAM

In September each year, about 300 new foreign students enroll at the Institute. Many have only recently arrived in the United States for the first time. Since 1961 this volunteer program, under the leadership of Mrs. Norman Padelford as Chairman, has helped to develop a bridge "across the differences of cultures" between many American host families and foreign students within the M.I.T. community. During 1966 there were 265 families involved in the program, 145 of which were M.I.T.-related. The success of this program has also been due to the devoted work of Mrs. Frederic Fairchild and Mrs. Glenn Eichen-seer. Mrs. Roy Schwitters of the Foreign Student Office staff has been of great assistance in keeping records and relaying information between families and students.

In November, 1966, the Institute through a gift from Dr. Julius A. and Mrs. Stratton hosted a dinner for the host families and their student guests.

Because of her devotion and outstanding contribution to M.I.T., Mrs. Padelford was given the Gordon Y. Billard award by Dr. Stratton in May, 1966.

THE TECHNOLOGY MATRONS

The Foreign Student Hospitality Committee, under the direction of Mrs. Stephen Crandall, sponsored a spring concert by the Chorus Pro Musica of Boston to honor Dr. and Mrs. Stratton, Professor and Mrs. Paul M. Chalmers, and M.I.T. foreign students and their wives. More recently in cooperation with a Girl Scout group in Lincoln, members of her com-

FOREIGN STUDENT OFFICE

mittee hosted many of the wives and children of M.I.T. foreign students for a day's visit to the Drumlin Farm.

DAMES

In February under the chairmanship of Mrs. Roger Humphrey, the Dames sponsored their annual International Night program in which 20 countries were represented. This colorful affair, in which the wives of foreign students participate, gives the opportunity for members to become acquainted with the many cultural customs of the countries represented on campus.

THE INTERNATIONAL STUDENT COUNCIL

The Council, in cooperation with the Institute Committee, continued to sponsor various programs throughout the year under the chairmanship of Mr. Victor Silva.

OPERATIONS

The members of the Foreign Student Office staff continue to participate in a variety of activities related to international education, both on and off campus.

Robert A. Schuiteman is currently a member of the Steering Committee of the Foreign Student Advisers Commission, of the Government Liaison Committee, Relations Abroad Committee, and U.S. Student Abroad Committee of the National Association for Foreign Student Affairs, as well as the General Committee of the World University Service. He is also a member of the Ad Hoc Committee of the College Board Scholarship Service on Foreign Students. Eugene R. Chamberlain is also a member of this Committee.

Peter D. Leavitt is the regional representative to the New England Section of the National Association for Foreign Student Affairs which is actively planning the 1967 meeting to be held in Salem, Massachusetts, in November.

Eugene Chamberlain is the Chairman of the Professional Grants and Seminar Committee, as well as Chairman of the Program Committee for the National Convention to be held in Boston in April, 1969. He is also a member of the College Board Committee on International Education.

Mrs. Robert Gladstone, administrative assistant to the Advisor, has been of immense help in handling effectively the substantial daily routine associated with this office. The Advisor is also very grateful for the willing help he has received from all members of the Foreign Student Office staff.

EUGENE R. CHAMBERLAIN

REGISTRAR

All statistics on registration and staff in the following tables are given as of the fifth week of the Fall Term, except: 1943-44 as of August 2, 1943, 1944-45 as of November 27, 1944; and 1945-46 as of July 30, 1945. For statistics not listed in the following pages, see the report of the Registrar for 1958-59.

Table I Student Registration since the Founding of the Institute*

Year	Number of students	Year	Number of students	Year	Number of students
1865-66	72	1899-00	1,178	1933-34	2,606
1866-67	137	1900-01	1,277	1934-35	2,507
1867-68	167	1901-02	1,415	1935-36	2,540
1868-69	172	1902-03	1,608	1936-37	2,793
1869-70	206	1903-04	1,528	1937-38	2,966
1870-71	224	1904-05	1,561	1938-39	3,093
1871-72	261	1905-06	1,466	1939-40	3,100
1872-73	348	1906-07	1,397	1940-41	3,138
1873-74	276	1907-08	1,415	1941-42	3,055
1874-75	248	1908-09	1,461	1942-43	3,048
1875-76	255	1909-10	1,479	1943-44	1,579
1876-77	215	1910-11	1,506	1944-45	1,198
1877-78	194	1911-12	1,559	1945-46	1,538
1878-79	188	1912-13	1,611	1946-47	5,172
1879-80	203	1913-14	1,685	1947-48	5,662
1880-81	253	1914-15	1,816	1948-49	5,433
1881-82	302	1915-16	1,900	1949-50	5,458
1882-83	368	1916-17	1,957	1950-51	5,171
1883-84	443	1917-18	1,698	1951-52	4,874
1884-85	579	1918-19	1,819	1952-53	5,074
1885-86	609	1919-20	3,078	1953-54	5,183
1886-87	637	1920-21	3,436	1954-55	5,348
1887-88	720	1921-22	3,505	1955-56	5,648
1888-89	827	1922-23	3,180	1956-57	6,000
1889-90	909	1923-24	2,949	1957-58	6,179
1890-91	937	1924-25	2,938	1958-59	6,259
1891-92	1,011	1925-26	2,813	1959-60	6,270
1892-93	1,060	1926-27	2,671	1960-61	6,289
1893-94	1,157	1927-28	2,712	1961-62	6,454
1894-95	1,183	1928-29	2,868	1962-63	6,695
1895-96	1,187	1929-30	3,066	1963-64	6,925
1896-97	1,198	1930-31	3,209	1964-65	7,151
1897-98	1,198	1931-32	3,188	1965-66	7,408
1898-99	1,171	1932-33	2,831	1966-67	7,567

* From 1943 to 1946 Army and Navy students are omitted (see Table 3-B in reports for 1943 to 1946).

REGISTRAR

Table I-A Student Registration in the Summer Session since 1948

Year	*In Regular Subjects	†In Other Subjects	Year	*In Regular Subjects	†In Other Subjects
1948	2,146	—	1958	1,650	1,752
1949	1,875	171	1959	1,635	1,510
1950	1,852	259	1960	1,600	1,696
1951	1,861	813	1961	1,668	1,412
1952	1,689	832	1962	1,748	1,763
1953	1,672	1,289	1963	1,808	1,397
1954	1,675	1,398	1964	1,882	1,492
1955	1,619	1,653	1965	2,090	1,568
1956	1,553	2,497	1966	2,054	1,787
1957	1,548	1,757			

* Students attending regular subjects from M.I.T. curricula.

† Students attending professional and technical subjects which are not part of M.I.T. curricula and in general carry no academic credit.

Table II The Academic Staff*

	Professors	Administrators also Professors	Associate Professors	Assistant Professors	Lecturers	Instructors	Technical Instructors	Research Associates	Research Assistants	Teaching Assistants	Graduate Assistants	Technical Assistants	Total	Professors Emeriti	Others
School of Architecture and Planning															
Architecture	7	1	11	4	—	3	2	3	1	3	—	2	37	2	1
City and Regional Planning	3	2	4	2	7	2	—	—	4	4	—	1	29	—	—
Total	10	3	15	6	7	5	2	3	5	7	—	3	66	2	1
School of Engineering															
Aeronautics and Astronautics	17	1	12	15	4	1	2	—	102	11	—	—	165	3	3
Chemical Engineering	12	2	1	16	—	3	2	2	51	30	—	—	119	4	—
Civil Engineering	13	1	11	22	—	12	2	5	104	8	—	—	178	2	8
Electrical Engineering	36	6	34	42	21	16	—	11	115	92	—	—	373	5	21
Mechanical Engineering	23	2	23	22	4	5	4	10	110	6	—	—	209	12	7
Metallurgy	16	2	5	11	—	4	3	11	96	7	—	1	156	2	10
Naval Architecture and Marine Engineering	4	1	5	1	1	3	—	—	11	4	—	2	32	2	—
Nuclear Engineering	6	1	5	6	2	—	—	5	22	17	—	—	64	—	2
School Professors	2	—	—	—	—	—	—	—	—	—	—	—	2	—	—
Total	129	16	96	135	32	44	13	44	611	175	—	3	1,298	30	51
School of Humanities and Social Science															
Economics	16	2	1	10	—	1	—	—	2	15	—	1	48	3	7
Humanities	17	1	15	21	10	12	—	1	1	—	—	—	78	—	—
Modern Languages and Linguistics	4	2	3	4	2	18	—	—	3	3	—	—	39	3	—
Political Science	11	1	5	8	2	4	—	—	13	3	—	—	47	—	—
Psychology	2	1	2	5	2	—	—	9	—	—	—	—	21	—	1
Total	50	7	26	48	16	35	—	10	19	21	—	1	233	6	8
Alfred P. Sloan School of Management															
Management	18	1	15	24	15	7	—	11	37	26	—	1	155	2	28

REGISTRAR

School of Science																																						
Biology	14	1	6	8	—	—	—	—	34	3	10	—	30	106	1	38																						
Chemistry	18	1	8	14	—	—	—	—	59	67	95	—	13	275	11	15																						
Geology and Geophysics	12	1	8	8	1	1	—	—	9	37	9	—	1	87	2	5																						
Mathematics	25	1	11	11	1	25	—	3	12	36	—	—	—	125	3	2																						
Meteorology	7	2	3	—	—	—	1	2	32	2	—	—	—	1	50	—	3																					
Nutrition and Food Science	8	2	10	10	12	—	—	—	25	—	—	—	34	26	—	7																						
Physics	41	2	11	31	7	9	1	1	—	—	—	—	166	2	271	1	29																					
Total	125	10	57	82	21	35	2	133	151	152	152	200	73	1,041	18	99																						
Miscellaneous																																						
Aerospace Studies	—	1	2	—	—	2	—	—	—	—	—	—	—	5	—	—																						
Athletic	—	1	2	5	—	7	—	—	—	—	—	—	—	15	—	—																						
Medical	—	1	—	—	—	—	—	—	—	—	—	—	—	1	—	—																						
Military Science	—	1	3	—	—	2	—	—	—	—	—	—	—	6	—	—																						
Naval Science	—	1	1	2	—	4	—	—	—	—	—	—	—	8	—	—																						
Institute Professors ²	16	2	—	—	1	—	—	—	—	—	—	—	—	19	1	—																						
Administration	2	—	—	—	—	—	—	—	1	—	—	—	3	6	3	1																						
Center for International Studies	—	—	—	—	—	—	—	—	1	—	—	—	—	1	—	5																						
Center for Space Research	—	—	—	—	—	—	—	—	1	—	—	—	—	1	—	1																						
Computation Center	—	—	—	—	—	—	—	—	1	—	—	—	—	1	—	2																						
Operations Research Center	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—																						
Project MAC	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—																						
Research Laboratory of Electronics	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—																						
Total	18	7	8	7	1	15	—	4	—	—	—	—	3	63	4	37																						
Grand Total	350³	44³	217³	302³	92³	141³	17³	205⁴	823	381³	381³	200⁵	84	2,856	62⁶	224⁶																						
Faculty ex-officio														20 ⁷																								
														2,876																								

* Full professors, associate professors, and assistant professors include 15 professors, 5 associate professors, and 1 assistant professor emerit part-time active. The total faculty is 934.
¹ Includes guests, visiting scientists, visiting social scientists, research affiliates, postdoctoral associates, and fellows.
² Includes Institute lecturers.
³ Total teaching staff is 1581.
⁴ One faculty and 204 non-faculty.
⁵ Estimated research: Nutrition and Food Science, 34, Physics 129. Estimated teaching: Physics 37³.
⁶ Not included in preceding total.
⁷ Includes one emeritus part-time active.

Table III Classification of Students since 1964

Course	1964-65				1965-66				1966-67				Course Number			
	2	3	4	G	Total	2	3	4	G	Total	2	3		4	G	Total
School of Architecture and Planning																
Architecture (IV-A)	20	26	24	34	104	41	23	23	40	127	25	26	26	62	139	IV-A
Fifth year	—	—	31	—	31	—	—	35	—	35	—	—	24	—	24	—
City and Regional Planning XI ²	—	—	—	58	58	—	—	—	63	63	—	—	—	73	73	XI
Total	20	26	55	92	193	41	23	58	103	225	25	26	50	135	236	Total
School of Engineering																
Aeronautics and Astronautics (XVI)	64	55	51	236	406	72	53	46	266	437	82	72	52	248	454	XVI
Aeronautics and Astronautics (XVI-B) (Cooperative)	—	5	15	—	20	—	11	11	—	22	—	10	11	—	21	XVI-B
Chemical Engineering (X, X-A, X-B)	38	43	47	166	294	35	37	47	155	274	37	33	39	144	253	X, X-A, X-B
Civil Engineering (I)	19	34	22	207	282	21	31	38	204	294	19	30	32	216	297	I
Electrical Engineering (VI-1)	137	129	162	509	1,049	139	122	143	549	1,078	154	126	136	528	1,092	VI
Electrical Science and Engineering (VI-2)	51	31	30	—	106	54	44	27	—	90	64	43	41	—	100	VI-A
Electrical Engineering (VI-A) (Cooperative)	—	32	47	27	106	—	32	35	23	90	—	44	34	22	100	VI-A
Mechanical Engineering (II)	60	42	54	265	421	47	57	44	246	394	53	46	63	233	395	II
Textile Technology	—	—	—	13	13	—	—	—	17	17	—	—	—	16	16	II-T
Mechanical Engineering (II-B) (Cooperative)	—	3	4	—	7	—	9	4	—	13	—	5	8	—	13	II-B
Metallurgy (III-A)	6	4	4	160	213	3	9	6	162	232	—	5	11	—	—	III
Materials Science (III-B)	9	15	15	—	22	7	10	12	—	23	16	11	6	141	209	III
Ceramics	—	—	—	—	22	—	—	—	23	—	—	—	—	19	—	—
Naval Architecture and Marine Engineering (XIII)	7	5	9	39	60	2	8	8	43	61	7	5	12	45	69	XIII
Naval Construction and Engineering (XIII-A)	—	—	—	74	74#	—	—	—	77	77#	—	—	—	70	70#	XIII-A
Nuclear Engineering (XXII)	—	—	—	130	130	—	—	—	131	131	—	—	—	128	128	XXII
Shipping and Shipbuilding Management (XIII-B)	—	—	1	4	5	—	—	—	4	4	—	—	—	5	5	XIII-B
Center for Advanced Engineering Study (EN)	—	—	—	10	10	—	—	—	15	15	—	—	—	13	13	EN
Total	391	398	461	1,862	3,112	380	423	421	1,915	3,139	432	430	445	1,828	3,135	Total

REGISTRAR

School of Humanities and Social Science

Economics (XIV) ¹	—	—	—	—	10	19	11	125	165	17	26	25	130	198	XIV
Economics, Politics, and Engineering (XIV-A)	6	9	12	—	—	—	—	—	—	—	—	—	—	—	XIV-A
Economics, Politics, and Science (XIV-B)	9	19	20	173	248	—	—	—	—	—	—	—	—	—	XIV-B
Humanities and Engineering (XXI-A)	2	4	12	—	—	8	5	14	—	4	11	20	—	—	XXI
Humanities and Science (XXI-B)	11	35	25	15	104	5	29	43	127	14	33	36	34	152	XXI
Modern Languages and Linguistics [XXIII]	—	—	—	—	—	—	—	—	34	—	—	—	—	45	XXIII
Political Science (XVII) ¹	—	—	—	42	42	5	25	27	68	7	19	35	80	141	XVII
Psychology (IX)	—	—	—	21	21	—	—	—	21	—	—	—	26	26	IX
Total	28	67	69	251	415	28	78	95	472	42	89	116	315	562	Total

Alfred P. Sloan School of Management

Management (XX) ³	25	38	60	293	416	19	52	59	324	454	25	43	70	348	486	XV			
School of Science																			
Biology (VII)	32	39	30	93	194	38	34	44	98	214	47	44	37	127	255	VII			
Chemistry (V)	46	38	32	249	365	37	45	41	251	374	55	32	44	261	392	V			
Geology and Geophysics (XII)	4	16	6	78	104	17	6	17	82	122	10	18	12	73	113	XII			
Geology and Geophysics (XII-A)	—	—	—	1	1	—	—	—	—	—	—	—	—	2	2	XII-A			
Mathematics (XVIII)	116	90	110	136	452	111	126	89	138	464	85	103	115	141	444	XVIII			
Meteorology (XIX)	—	—	—	70	70	—	—	—	69	69	—	—	—	68	68	XIX			
Nutrition and Food Science (XX)	—	—	—	92	92	—	—	—	99	99	—	—	—	110	110	XX			
Physics (VIII)	164	134	124	294	716	136	131	124	303	694	132	129	129	302	692	VIII			
Total	362	317	302	1,013	1,994	339	342	315	1,040	2,036	329	326	337	1,084	2,076	Total			
Undesignated	114	—	—	—	114	114	—	—	—	114	137	—	—	—	137	Undesignated			
First-year students	907	—	—	—	907	968	—	—	—	968	935	—	—	—	935	First-year			
Grand Total	907	940	846	947*	3,511	7,151	968	921	918	948*	3,653	7,408	935	990	914	1,018*	3,710	7,567	Grand total
				#First graduate year — 20															#First graduate year — 25
				Second graduate year — 26															Second graduate year — 30
				Third graduate year — 28															Third graduate year — 15

* These totals include the fifth year in Architecture.

¹ Prior to 1965-66 included in Economics, Politics, and Engineering or Science.² Prior to 1966-67 Course IV-B³ Prior to 1966-67 Industrial Management.

Table III-A Women Students Classified by Schools, Courses, and Years, 1966-67¹

Course	Year			G Total		
	2	3	4			
School of Architecture and Planning						
Architecture (IV-A)	3	2	6	6	17	
City and Regional Planning (XI)	—	—	—	18	18	
Total	3	2	6	24	35	
School of Engineering						
Aeronautics and Astronautics (XVI)	—	1	2	—	3	
Chemical Engineering (X)	2	1	—	1	4	
Civil Engineering (I)	—	1	—	4	5	
Electrical Engineering (VI)	4	—	3	4	11	
Mechanical Engineering (II)	1	1	—	—	2	
Metallurgy and Materials Science (III-A, III-B)	3	—	1	5	9	
Naval Architecture and Marine Engineering (XIII)	—	—	—	—	—	
Nuclear Engineering (XXII)	—	—	—	—	—	
Total	10	4	6	14	34	
School of Humanities and Social Science						
Economics (XIV)	2	—	1	12	15	
Humanities and Engineering or Science (XXI-A, XXI-B)	1	8	7	9	25	
Modern Languages and Linguistics (XXIII)	—	—	—	11	11	
Political Science (XVII)	2	2	1	22	27	
Psychology (IX)	—	—	—	8	8	
Total	5	10	9	62	86	
Alfred P. Sloan School of Management						
Management (XV)	—	—	1	4	5	
School of Science						
Biology (VII)	5	8	7	22	42	
Chemistry (V)	6	3	3	27	39	
Geology and Geophysics (XII)	1	1	1	2	5	
Mathematics (XVIII)	6	11	11	11	39	
Meteorology (XIX)	—	—	—	1	1	
Nutrition and Food Science (XX)	—	—	—	20	20	
Physics (VIII)	5	10	7	14	36	
Total	23	33	29	97	182	
Undesignated		8	—	—	8	
First-year students	51	—	—	—	51	
Grand Total	51	49	49	51	201	401

¹ Included also in Table 3.

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Table III-B Special Students Classified by Schools, Courses, and Years, 1966-67¹

Course	Year			G Total		
	2	3	4			
School of Architecture and Planning						
Architecture (IV-A)	—	1	3	6	10	
Fifth Year	—	—	1	—	1	
City and Regional Planning (XI)	—	—	—	10	10	
Total	—	1	4	16	21	
School of Engineering						
Aeronautics and Astronautics (XVI)	—	1	—	74	75	
Chemical Engineering (X)	—	—	—	1	1	
Civil Engineering (I)	—	—	—	28	28	
Electrical Engineering (VI)	2	1	2	144	149	
Mechanical Engineering (II)	3	1	—	27	31	
Textile Technology (IIT)	—	—	—	2	2	
Metallurgy and Materials Science (III-A, III-B)	2	1	1	7	11	
Naval Architecture and Marine Engineering (XIII)	—	—	2	4	6	
Nuclear Engineering (XXII)	—	—	—	6	6	
Center for Advanced Engineering Study (EN)	—	—	—	13	13	
Total	7	4	5	306	322	
School of Humanities and Social Science						
Economics (XIV)	1	—	—	11	12	
Humanities and Engineering or Science (XXI-A, XXI-B)	2	5	1	5	13	
Modern Languages and Linguistics (XXII)	—	—	—	11	11	
Political Science (XVII)	—	—	1	11	12	
Psychology (IX)	—	—	—	2	2	
Total	3	5	2	40	50	
Alfred P. Sloan School of Management						
Management (XV)	—	1	1	45	47	
School of Science						
Biology (VII)	1	—	—	26	27	
Chemistry (V)	1	—	1	6	8	
Geology and Geophysics (XII)	—	—	1	2	3	
Mathematics (XVIII)	2	1	3	28	34	
Meteorology (XIX)	—	—	—	2	2	
Nutrition and Food Science (XX)	—	—	—	11	11	
Physics (VIII)	2	—	—	30	32	
Total	6	1	5	105	117	
Undesignated	3	—	—	—	3	
First-year students	5	—	—	—	5	
Grand Total	5	19	12	17	512	565

¹ Included also in Table 3.

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Table IV Continued, Former, and New Students

	1962-63	1963-64	1964-65	1965-66	1966-67
Continued Students					
Undergraduate and graduate students registered at the end of the last academic year (including Special Students)	4,499	4,612	4,871	5,041	5,201
Noncontinued Students					
Former undergraduate and graduate students who previously attended the Institute but were not registered at the end of the last academic year (including Special Students)	321	365	320	333	264
Undergraduate students who enrolled for the first time since secondary school (excluding Special Students)	883	897	887	953	922
Undergraduate students who enrolled for the first time at the Institute and who transferred from another collegiate institution (excluding Special Students)	72	90	67	54	71
Graduate students who enrolled for the first time at the Institute (excluding Special Students)	721	722	817	820	840
Special Undergraduate and Graduate Students with no previous Institute registration	199	239	189	207	269
Total	6,695	6,925	7,151	7,408	7,567

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Table V Regular Students from Other Colleges and Graduates of M.I.T. Classified by Schools and Courses, 1966-67

	Entered with no previous degree	Entered with Bachelors degree from other colleges	Entered Graduate School with Bachelors degree from M.I.T.	
School of Architecture and Planning		U	G	
Architecture (IV-A)	16	21	50	6
City and Regional Planning (XI)	—	—	56	7
Total	16	21	106	13
School of Engineering				
Aeronautics and Astronautics (XVI)	10	1	111	63
Chemical Engineering (X)	11	1	101	42
Civil Engineering (I)	10	1	148	40
Electrical Engineering (VI-1, VI-2, VI-A)	36	3	215	191
Mechanical Engineering (II)	10	1	153	53
Textile Technology	—	—	11	3
Metallurgy (III, III-A, III-B, Ceramics)	—	—	107	46
Naval Architecture and Marine Engineering (XIII)	5	2	34	7
Naval Construction and Engineering (XIII-A)	—	—	69	1
Nuclear Engineering (XXII)	—	—	113	9
Shipping and Shipbuilding Management (XIII-B)	—	—	5	—
Total	82	9	1067	455
School of Humanities and Social Science				
Economics (XIV)	3	1	112	7
Humanities and Engineering or Science (XXI-A, XXI-B)	5	1	22	7
Modern Languages and Linguistics (XXIII)	—	—	31	3
Political Science (XVII)	1	—	60	9
Psychology (IX)	—	—	21	3
Total	9	2	246	29
Alfred P. Sloan School of Management				
Management (XV)	9	—	221	82
School of Science				
Biology (VII)	8	—	93	8
Chemistry (V)	8	2	253	2
Geology and Geophysics (XII, XII-A)	3	—	52	21
Mathematics (XVIII)	14	2	88	25
Meteorology (XIX)	—	—	57	9
Nutrition and Food Science (XX)	—	—	88	11
Physics (VIII)	24	1	187	85
Total	57	5	818	161
Undesignated	4	—	—	—
Grand Total	177	37	2458	740

Table VI List of Colleges and Universities with Number of Graduates Entering the Institute as Regular Graduate Students, 1966-1967¹

United States			
Adelphi University	1	Hawaii, University of	1
Abilene Christian College	1	Holy Cross, College of the	1
Amherst College	5	Houston, University of	1
Andrews University	1	Idaho, The College of	1
Antioch College	1	Illinois Institute of Technology	2
Aquinas Institute	1	Illinois, University of	7
Arizona State University	1	Indiana University	4
Arkansas College	1	Iowa, State University of	3
Arlington State College	1	John Carroll University	1
Auburn University	2	Johns Hopkins University	6
Augsburg College	1	Juniata College	2
Boston College	3	Kansas State College	1
Bowdoin College	1	Kansas State University	1
Brandeis University	4	Kansas, University of	3
Brooklyn College	1	Kent State University	1
Brown University	3	Kentucky, University of	2
Bryn Mawr College	2	Lake Forest College	1
Bucknell University	3	Lawrence Institute of Technology	1
California Institute of Technology	9	Lehigh University	6
California State Polytechnic College	2	Louisiana State University	1
California, University of, At Berkeley	13	Louisiana Polytechnic Institute	1
California, University of, At Davis	1	Long Island University	1
California, University of, At Los Angeles	8	Lowell Technological Institute	1
California, University of, At Riverside	1	Macalester College	1
Carleton College	1	Maine, University of	1
Carnegie Institute of Technology	2	Marquette University	1
Case Institute of Technology	9	Maryland, University of	7
Chicago, University of	1	Massachusetts Institute of Technology	247
Cincinnati, University of	3	Massachusetts, University of	3
City College, The	10	Merrimack College	1
Clarkson College of Technology	3	Miami, University of	2
Clemson University	1	Michigan State University	5
Colgate University	2	Michigan, University of	14
Colorado School of Mines	1	Minnesota, University of	12
Colorado College	2	Mississippi State University	2
Colorado State University	1	Missouri, University of	3
Colorado, University of	2	Mount Holyoke College	3
Columbia University	10	Mount Vernon College	1
Connecticut, University of	1	Nebraska, University of	1
Cooper Union, The	6	New Hampshire, University of	4
Cornell University	19	Newark College of Engineering	3
Dartmouth College	3	New Mexico, University of	1
Davidson College	2	North Carolina, University of	1
Delaware, University of	1	Northeastern University	7
Drexel Institute of Technology	6	Northwestern University	10
Duke University	2	Notre Dame, University of	13
Eastern New Mexico University	1	Oberlin College	2
Emmanuel College	1	Ohio State University, The	4
Florida State University	2	Ohio University	1
Fairleigh Dickinson University	2	Ohio Wesleyan University	1
Fordham University	1	Oklahoma State University	2
Franklin and Marshall College	1	Oregon State University	2
General Motors Institute	1	Oregon, University of	2
Georgetown University	1	Pennsylvania State University	7
George Washington University	3	Pennsylvania, University of	11
Georgia Institute of Technology	8	Pittsburgh, University of	4
Gettysburg College	2	Polytechnic Institute of Brooklyn	10
Grinnell College	1	Pomona College	3
Harvard University	26	Pratt Institute	2
Harvey Mudd College	3	Princeton University	16
		Providence College	3
		Puerto Rico, University of	2
		Purdue University	12

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Queens College	2	Foreign	
Radcliffe College	2	Aarhus Universitet (Denmark)	1
Reed College	2	Adelaide, University of (Australia)	2
Rensselaer Polytechnic Institute	14	American University of Beirut (Lebanon)	2
Rhode Island, University of	2	Andes, Universidad De Los (Colombia)	1
Rhode Island School of Design	1	Ateneo De Manila University (Philippines)	1
Rice University	2		
Rochester Institute of Technology	1	Baghdad, University of (Iraq)	1
Rochester, University of	2	Birla Institute of Technology (India)	1
Rollins College	1	Birmingham University (England)	1
Roosevelt University	1	Bombay, University of (India)	2
Rutgers University	3	British Columbia, University of (Canada)	3
		Buenos Aires, Universidad De (Argentina)	5
St. Francis College	2	Calcutta University (India)	1
St. Procopius College	1	Cambridge University (England)	3
Seattle University	1	Carleton University (Canada)	1
South Carolina, University of	1	Chiao Tung University (China)	1
Southern California, University of	3	Chile, Universidad De (Chile)	5
Southern Methodist University	3	Chulalongkorn University (Thailand)	3
Spring Hill College	1	College Des Sciences Economiques Et Sociales (France)	1
Stanford University	8		
State University of New York At Buffalo	3	Danmarks Tekniske Hojskole (Denmark)	1
Stevens Institute of Technology	3	Delhi, University of (India)	3
Swarthmore College	7	Durham, University of (England)	1
Syracuse University	4	Ecole Centrale Des Arts et Manufactures (France)	6
		Ecole Des Mines (Luxembourg)	2
Tennessee, University of	2	Ecole Nationale Des Arts et Metiers (Cambodia)	1
Tennessee Technological University	1	Ecole Nationale Des Industries Agricoles et Alimentaries (France)	2
Texas Agricultural and Mechanical University	1	Ecole Nationale Des Ponts et Chaussees (France)	2
Texas Technical College	2	Ecole Nationale Superieure De L'Aeronautique (France)	1
Texas, University of	6	Ecole Polytechnique (Canada)	2
Trinity College (Connecticut)	1	Ecole Polytechnique (France)	1
Tufts University	7	Ecole Special Des Travaux Aeronautiques (France)	1
		Ecole Special Des Travaux Publics, Du Batiment et De L'Industrie (France)	1
Union College and University	3	Ecole Speciale D'Architecture (France)	1
Ursinus College	1	Edinburgh University (England)	3
United States Air Force Academy	4	Ethnikon Metsovion Polytechnion (Greece)	1
United States Coast Guard Academy	2		
United States Military Academy	7	Glasgow University (Scotland)	1
United States Naval Academy	26	Goteborgs University (Sweden)	1
Utah, University of	1	Guayaquil, Universidad De (Ecuador)	1
Vanderbilt University	2	Hebrew University (Israel)	2
Vassar College	1	Hogere Technische Brouwerijschool Sint Lieven (Belgium)	1
Vermont, University of	1	Hong Kong, University of	1
Villanova University	3		
Virginia Military Institute, The	1	Imperial College of Science and Technology (England)	2
Virginia Polytechnic Institute	7	Indian Institute of Science (India)	1
Virginia, University of	2	Indian Institute of Technology (Bombay, India)	3
Washington and Lee University	1		
Washington State University	2		
Washington, University of	5		
Washington University (Missouri)	2		
Webb Institute of Naval Architecture	8		
Wellesley College	3		
Wesleyan University	1		
Western Michigan University	1		
Western Reserve University	1		
West Virginia University	1		
William and Mary, College of	1		
Williams College	4		
Wisconsin, University of	7		
Worcester Polytechnic Institute	7		
Yale University	14		
Yeshiva University	1		
Total	894		

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Indian Institute of Technology (Kanpur, India)	2	Sao Paulo, Universidade De (Brazil)	1
Institut Polytechnique (France)	1	Saskatchewan, University of (Canada)	1
Instituto Tecnologico Y De Estudios Superiores De Monterrey (Mexico)	1	Seoul National University (Korea)	3
Kungliga Tekniska Hogskolan I Stockholm (Sweden)	1	Sir George Williams University (Canada)	2
Kyoto Daigaku (Japan)	2	St. Marylebone Polytechnic, The (England)	1
Lausanne, Universite De (Switzerland)	1	Staatliche Ingenieur Schule Fur Maschinwesen (Germany)	1
Universite Laval (Canada)	2	Strathclyde, University of (Scotland)	1
Liege, Universite De l'Etata (Belgium)	1	Sydney, University of (Australia)	2
Liverpool, University of (England)	1	Technion (Israel)	2
Ljubljana, Univerza V (Yugoslavia)	1	Technische Hogeschool Te Delft (Netherlands)	1
London, University of (England)	4	Technische Universitat Berlin (Germany)	1
Loyola College (India)	1	Teheran, University of (Iran)	1
Maharaja Sayajirao University of Baroda (India)	1	Teknillinen Korkeakoulu (Finland)	1
Manitoba, University of (Canada)	2	Tokyo, University of (Japan)	5
McGill University (Canada)	6	Toronto, University of (Canada)	8
Montreal, Universite de (Canada)	1	Universidad Autonoma Del Estado De Mexico (Mexico)	1
Mount Allison University (Canada)	1	Universidad Catolica Andres Bello (Venezuela)	1
National Central University (China)	1	Universidad Catolica Centro Americana (Nicaragua)	1
National Taiwan University (Taiwan)	10	Universidad Central De Venezuela (Venezuela)	3
Naval Academy of Greece (Greece)	1	Universidad De La Republica (Uruguay)	1
Newcastle University College (Australia)	1	Universidad Nacional Del Zulia (Venezuela)	1
Nigeria, University of (Nigeria)	1	Universita Delgi Studi Di Napoli (Italy)	1
Norges Handelshoyskole (Norway)	1	Universita Delgi Studi Di Pisa (Italy)	1
Norges Tekniske Hogskole (Norway)	1	University College of Sussex (England)	1
Northern Polytechnic (England)	1	University College of the West Indies (Jamaica)	1
Nuevo Leon, Universidad De (Mexico)	1	Warsaw Agricultural University (Poland)	1
Osaka University (Japan)	1	Waterloo Lutheran University (Canada)	1
Oxford University (England)	6	Witwatersrand, University of the (South Africa)	1
Paris, Universite De (France)	1	Zagreb, Sveuciliste U (Yugoslavia)	1
Poitiers, Universite De (France)	3		
Politecnico Di Torino (Italy)	1	Total	193
Queen's University (Canada)	3		
Rijksuniversiteit Te Gent (Belgium)	3		
Royal Military College of Canada (Canada)	3		
Royal Naval College (England)	1		

¹ Graduates of 184 Colleges and Universities in the United States and 107 Foreign Colleges entered the Institute.

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Table VII Geographic Distribution of Students, 1966-67

	Under-grad	Grad.		Under-grad	Grad.		Under-grad	Grad.
United States:			U.S. Territories and Dependences:			Jamaica	0	3
Alabama	15	16	Canal Zone	0	1	Japan	4	34
Alaska	4	1	Puerto Rico	10	5	Jordan	1	1
Arizona	18	10	U.S. Citizen Foreign Address	44	64	Korea	3	10
Arkansas	12	0	Total U.S.	3,645	2,984	Kuwait	0	1
California	163	131				Lebanon	3	4
Colorado	35	15	Foreign Countries:†			Luxembourg	0	1
Connecticut	139	70	Argentina	2	14	Malaysia	3	3
Delaware	13	7	Australia	0	9	Mexico	5	11
District of Columbia	24	20	Austria	0	2	Netherlands	4	7
Florida	94	40	Bahamas	0	1	New Zealand	0	8
Georgia	29	14	Belgium	1	11	Nicaragua	1	1
Hawaii	19	3	Brazil	1	8	Nigeria	5	12
Idaho	8	3	Canada	34	103	Norway	4	8
Illinois	185	107	Chile	1	10	Pakistan	4	5
Indiana	53	34	Colombia	5	8	Peru	2	4
Iowa	14	10	Costa Rica	1	0	Philippines	1	13
Kansas	20	17	Cuba	1	8	Poland	0	3
Kentucky	12	5	Cyprus	1	0	Portugal	0	1
Louisiana	19	15	Czechoslovakia	0	1	Rhodesia	1	2
Maine	21	11	Denmark	2	4	Salvador	0	1
Maryland	100	59	Dominican Republic	1	1	Saudi Arabia	2	0
Massachusetts	474	1130	Ecuador	2	2	Scotland	0	3
Michigan	77	52	Eire (Ireland)	0	4	Sierra Leone	0	2
Minnesota	41	38	England	11	50	Singapore	2	2
Mississippi	5	5	Ethiopia	0	2	South Africa Republic of	0	6
Missouri	59	28	Finland	0	2	Spain	1	2
Montana	4	8	Formosa	16	63	Sweden	1	3
Nebraska	14	6	France	2	28	Switzerland	0	9
Nevada	2	2	Germany	3	16	Thailand	4	6
New Hampshire	27	24	Ghana	1	2	Trinidad	1	2
New Jersey	255	136	Greece	7	24	Tonga	0	1
New Mexico	14	4	Guatemala	1	1	Turkey	7	7
New York	725	381	Hong Kong	23	19	Uganda	1	0
North Carolina	26	15	Iceland	0	2	United Arab Republic (Egypt)	1	7
North Dakota	8	4	India	10	72	Uruguay	0	1
Ohio	182	83	Indonesia	0	5	Venezuela	5	14
Oklahoma	34	17	Iran	12	15	Wales	0	3
Oregon	26	10	Iraq	3	3	Yugoslavia	0	6
Pennsylvania	232	165	Israel	1	15	Stateless	2	0
Rhode Island	26	25	Italy	2	14	Total Foreign	212	726
South Carolina	19	10				Grand Total	3,857	3,710
South Dakota	7	3						
Tennessee	26	14						
Texas	90	55						
Utah	10	7						
Vermont	12	8						
Virginia	96	42						
Washington	35	22						
West Virginia	15	7						
Wisconsin	52	23						
Wyoming	1	2						

† Country of Citizenship

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Table VIII Number of Degrees Awarded in September, 1966, February, 1967, and June, 1967

	S.B.			B. Arch.			S.M.			M. Arch., M. C. P.			Engineer			Ph.D.			Sc.D.			Total	
	Sept.	June	Feb.	Sept.	June	Feb.	Sept.	June	Feb.	Sept.	June	Feb.	Sept.	June	Feb.	Sept.	June	Feb.	Sept.	June	Feb.		
School of Architecture and Planning																							
Architecture	--	--	--	--	14	--	--	--	24	1	2	--	--	--	--	--	--	--	24	2	16		
City and Regional Planning	--	--	--	--	--	--	--	--	6	4	12	--	--	--	--	--	--	--	6	4	14		
Art and Design	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	
Total	--	1	--	14	--	--	--	30	5	14	--	--	--	30	6	31							
School of Engineering																							
Aeronautics and Astronautics	1	7	53	--	--	26	10	44	--	--	--	--	4	1	4	1	2	2	2	8	5	34	28
Ceramics	--	--	--	--	--	2	--	--	--	--	--	--	--	--	--	--	--	--	3	3	1	5	3
Chemical Engineering	3	2	31	--	--	1	19	11	--	--	--	--	1	4	--	4	--	3	3	6	1	12	31
Chemical Engineering Practice	--	--	--	--	--	--	4	9	--	--	--	--	--	--	--	--	--	--	--	--	--	--	4
Civil Engineering	--	7	25	--	--	27	14	21	--	--	--	--	1	4	7	2	2	1	3	2	1	33	29
Electrical Engineering	17	18	158	--	--	69	44	66	--	--	--	--	9	12	41	11	9	12	4	1	2	110	84
Materials Engineering	--	--	--	--	--	--	--	--	--	--	--	--	--	2	--	--	--	--	--	--	--	--	2
Mechanical Engineering	7	4	48	--	--	26	13	26	--	--	--	--	6	5	7	8	3	4	14	9	43	44	
Metallurgy	--	1	15	--	--	9	6	3	--	--	--	--	2	3	1	4	6	9	7	18	17	31	
Naval Arch. and Marine Eng.	1	2	7	--	--	3	6	14	--	--	--	--	1	19	--	--	--	1	--	--	--	6	8
Nuclear Engineering	--	--	--	--	--	10	8	10	--	--	--	--	2	1	8	5	3	5	3	3	3	20	15
Shipping and Shipbldg. Mgmt.	--	--	--	--	--	--	--	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2
Textile Technology	--	--	--	--	--	3	2	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	3
Total	29	41	337	--	--	173	127	208	--	--	24	27	90	26	25	30	29	46	29	281	266	694	
School of Humanities and Social Science																							
Economics	1	--	12	--	--	1	1	--	--	--	--	--	--	--	--	8	7	10	--	--	--	10	8
Humanities and Engineering	--	1	8	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1
Humanities and Science	2	2	24	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2	2
Linguistics	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	1	--	--	--	--	--	--	2
Philosophy	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Political Science	2	1	18	--	--	2	1	1	--	--	--	--	--	--	2	5	2	--	--	--	--	6	7
Psychology	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	1
Total	5	4	62	--	--	3	2	2	--	--	24	27	90	10	12	14	29	46	29	281	266	694	

REGISTRAR

Alfred P. Sloan School of Management												
Industrial Management*												
	7	6				15	12			27	20	152
Management	45						101					
School of Science												
Biochemical Engineering							3					4
Biochemistry												
Biology											4	5
Biophysics												6
Chemistry	4	2	35			3	7	1			23	27
Earth Sciences		4	7								6	42
Food Science and Technology												7
Geology and Geophysics						3	3	3		1	2	1
Life Sciences						3	2	2			2	3
Mathematics	1	6	103									4
Meteorology						3		4			10	8
Nutrition**						6	3	2			2	1
Nutritional Biochemistry & Metabolism						1	2				1	2
Oceanography								2			4	6
Physics	8	5	112			3	1				2	2
						3	2	7			16	16
											18	1
											28	23
												137
Total	13	21	287			25	20	24			52	42
Without Course Specification											48	3
Grand Total	54	72	732			14	227	165	341	30	5	14
											32	49
											30	460
											400	1,321

* Changed to Management February 1967.

** Changed to Nutritional Biochemistry and Metabolism June 1967.

Table IX Number of Degrees of Bachelor of Science Awarded

All statistics on degrees are arranged by school as of the current year. During the years 1868-1949 the general divisions were Architecture, Engineering, and Science. In 1950 the School of Humanities and Social Studies was established and in 1951 the School of Industrial Management (after 1963, the Alfred P. Sloan School of Management) was added.

	Total by Decades										Calendar year since 1962 (included in decade total)	
	1868-70	1871-80	1881-90	1891-1900	1901-10	1911-20	1921-30	1931-40	1941-50	1951-60		1961-	Grand Total
School of Architecture and Planning¹												
Architecture	—	12	24	162	188	233	223	23	—	—	—	865
Architectural Engineering ²	—	—	—	—	—	—	108	64	—	—	—	172
Art and Design	—	—	—	—	—	—	—	—	—	—	1	1
Total	—	12	24	162	188	233	331	87	—	—	1	1,038
School of Engineering												
Aeronautical Engineering	—	—	—	—	—	—	68	287	526	340	—	1,221
Aeronautics and Astronautics	—	—	—	—	—	—	—	99	114	55	358	476
Building Engineering and Construction	—	—	—	—	—	—	32	434	726	131	—	376
Chemical Engineering	—	—	—	91	123	372	571	434	740	726	349	3,406
Chemical Engineering Practice	—	—	—	—	—	—	—	99	95	108	—	393
Civil Engineering	12	84	86	256	407	504	653	284	272	457	187	3,202
Electrical Engineering (including VI-A)	—	—	72	335	349	468	1,000	719	1,218	1,518	1,386	7,065
Electrochemical Engineering ³	—	—	—	—	28	84	133	56	—	—	—	301
General Engineering	—	—	—	—	6	226	222	230	230	133	—	817
Mechanical Engineering (including II-A)	5	40	147	329	502	623	797	602	1,164	1,049	430	5,688
Metalurgy ⁴	—	—	—	—	—	—	—	—	194	311	144	701
Military Engineering	—	—	—	—	—	—	1	4	—	—	—	5
Mining Engineering and Metallurgy	8	44	64	74	250	129	174	137	—	—	—	880
Naval Architecture and Marine Engineering	—	—	—	—	43	133	69†	100	234	139	52	943
Sanitary Engineering	—	—	—	29	54	123	34	20	4	—	—	264
Total	25	168	369	1,157	1,846	2,378	3,888	3,179	4,791	4,967	2,907	25,675
												434
												422
												406
												434
												398
												378
School of Humanities and Social Science												
Economics ⁵	—	—	—	—	—	—	—	—	—	—	27	27
Economics, Politics, and Engineering or Science	—	—	—	—	—	—	—	61	152	100	313	8
Humanities and Engineering or Science ⁶	—	—	—	—	—	—	—	—	49	244	293	37
Political Science ⁶	—	—	—	—	—	—	—	—	—	35	35	—
Total	—	—	—	—	—	—	—	61	201	406	668	45
												64
												57
												74
												66

Alfred P. Sloan School of Management ¹												
Business and Engineering Administration Management ²												
Total	—	—	—	—	—	142	872	641	909	732	3,296	
	—	—	—	—	—	—	—	—	—	172	552	
	—	—	—	—	—	142	872	641	909	904	3,848	
Total	—	—	—	—	—	142	872	641	909	904	3,848	
School of Science												
Biology or Natural History (including VII-A) ³	—	3	11	25	27	49	57	129	74	116	16	507
Chemistry	2	27	80	154	151	111	141	166	232	207	210	1,481
Earth Sciences ⁴	—	—	—	—	—	—	—	—	—	—	69	69
Food Technology and Biochemical Engineering	—	—	—	—	—	—	—	—	35	62	11	108
General Science or General Course	2	11	17	49	20	26	17	73	58	62	—	335
Geology and Geophysics ⁵	—	—	—	8	6	3	36	22	32	141	—	248
Life Sciences ⁶	—	—	—	—	—	—	—	—	—	—	—	156
Mathematics	—	—	—	—	—	—	—	19	48	72	220	578
Meteorology	—	—	—	—	—	—	—	—	56	38	—	94
Physics	—	5	6	24	19	21	49	170	306	617	793	2,010
Total	4	46	114	260	223	210	319	608	865	1,463	1,833	5,945
Grand Total	29	226	507	1,579	2,257	2,963	5,410	4,515	6,626	7,535	5,527	37,174
												214
												273
												259
												263
												274
												308
												762
												810
												771
												805
												794
												804

* Includes only February and June degrees.

† Two received the degree in Naval Architecture, Course 13B, in 1916 and three in 1917.

¹ See also Table 11.

² Prior to 1923 degrees were awarded in Architecture.

³ Prior to 1909 this course was designated as Option 3 (Electrochemistry) of Physics.

⁴ Prior to 1938 these degrees were included in Mining Engineering and Metallurgy.

⁵ Prior to 1958 these degrees were included in General Engineering and General Science or General Course.

⁶ Changed to Alfred P. Sloan School of Management in 1964.

⁷ Changed to Life Sciences beginning in January 1962.

⁸ Considered Geology and Geophysics until February 1961.

⁹ Prior to September 1965 these degrees were included in Economics, Politics and Engineering or Science.

¹⁰ Prior to February 1967 Industrial Management.

Table X Number of Degrees of Master of Science Awarded

	Total by Decades										Total	Calendar year since 1962 (included in decade total)					
	1886-90	1891-1900	1901-10	1911-20	1921-30	1931-40	1941-50	1951-60	1961-	1966		1967*	1962	1963	1964	1965	1966	1967*
School of Architecture and Planning¹																	
Architecture		8	45	31													
Architectural Engineering ²					9	10											
Total		8	45	31	9	10											
School of Engineering																	
Aeronautical Engineering				17	59	76	307	312									
Aeronautics and Astronautics							21	66	63								
Building Engineering and Construction							3	13	13								
Ceramics						3	275	467	288								
Chemical Engineering		3	2	18	69	152	241	256	288								
Chemical Engineering Practice					245	284	194	350	71								
Civil Engineering		1	4	27	53	179	546	1,164	1,038								
Electrical Engineering (including VI-A)			7	43	462	474	546	1,164	1,038								
Electrochemical Engineering				4	16	8											
Fuel and Gas Engineering				4	16	8											
Mechanical Engineering			8	22	100	176	388	559	466								
Metalurgy		1	8	22	100	176	388	559	466								
Mining Engineering					8	36	92	230	172								
Naval Architecture and Marine Engineering				9	8	16											
Naval Construction			2	1	5	20	60	169	198								
Naval Construction and Engineering				5													
Nuclear Engineering ³			39	43	101	89	206	67									
Petroleum Engineering						5											
Railroad Operation						14											
Sanitary Engineering			2	8	3	10	53	99	16								
Total		5	64	197	1,144	1,553	2,386	3,815	3,291	12,455	496	418	462	544	546	335	
School of Humanities and Social Science																	
Economics ⁸									4								
Economics, Politics, and Engineering or Science						12	16	19	10								
Linguistics									1								
Psychology ⁴									5								
Political Science ⁸									5								
Total						12	16	19	25	72	2	3	10	6	4		

Alfred P. Sloan School of Management ¹						4	60	122	581	837	1,604	113	122	121	140	129	113
Management ²																	
School of Science																	
Biology and Public Health (including VII-A)		1	1	10	1	19	25	34	11	102	1	1	1	2	3	2	—
Chemistry	2	3	7	22	32	51	53	46	65	281	5	6	11	14	14	8	—
Food Technology and Biochemical Engineering ³		1	—	—	—	—	12	51	4	67	—	—	—	—	—	—	—
General Science		—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—
Geology and Geophysics		—	—	5	21	15	17	48	—	154	5	5	7	4	12	4	—
Mathematics		—	—	2	9	25	45	96	41	218	4	10	7	2	5	4	—
Meteorology ⁷		—	—	—	—	35	99	118	—	317	7	3	10	16	10	5	—
Nutritional Biochemistry and Metabolism		—	—	—	—	—	—	—	—	64	3	8	10	15	20	8	—
Nutrition and Food Science ¹⁰		—	—	—	—	—	—	—	—	5	5	—	—	—	—	5	—
Oceanography		3	2	2	16	40	50	121	90	324	9	2	2	3	3	6	1
Total		2	8	12	41	79	301	514	409	1,551	36	47	65	73	83	44	
Without Course specification		—	—	5	308	263	123	357	170	1,226	15	23	31	31	35	36	10
Grand Total		2	21	121	274	1,544	2,083	2,948	5,286	4,732	17,011	660	612	682	802	800	506

* Includes only February and June degrees.
¹ See also Table 11.
² Prior to 1923 degrees were awarded in Architecture.
³ Included in Chemical Engineering before 1959.
⁴ Included in Economics, Politics and Engineering or Science before September 1964.
⁵ Considered Engineering until 1950.
⁶ Changed to Nutrition and Food Science in 1962.
⁷ Considered Engineering until 1956.
⁸ Prior to September 1965 these degrees were included in Economics, Politics, and Engineering or Science.
⁹ Changed to Management February 1967.
¹⁰ Changed to Nutritional Biochemistry and Metabolism June 1967.
¹¹ Includes 6 degrees in Political Science awarded in 1965.

Table XI Number of Degrees Awarded in Architecture and City Planning†

	Total by decades										Grand Total	Calendar year since 1962 (included in decade total)				
	1921-30	1931-40	1941-50	1951-60	1961-	Total	1962	1963	1964	1965		1966	1967*			
Bachelor in Architecture	—	146	126	257	148	677	14	32	19	19	22	14				
Bachelor in City Planning**	—	14	13	4	—	31	—	—	—	—	—	—				
Master in Architecture	63	81	78	191	134	547	25	17	16	23	24	3				
Master in City Planning	—	18	82	114	96	310	9	8	20	12	15	16				
Grand Total	63	259	299	566	378	1,565	48	57	55	54	61	33				

* Includes only February and June degrees.

** From 1935 to 1944, Bachelor of Architecture in City Planning.

† See Table 13 for Doctor of Philosophy degrees.

Table XII Number of Degrees of Engineer Awarded

	Total by decades					Calendar year since 1962 (included in decade total)				
	1949-60	1961-	Grand Total	1962	1963	1964	1965	1966	1967*	
Aeronautical Engineer ¹	35	42	77	9	6	7	4	6	5	
Building Engineer	5	2	7	1	—	1	—	—	—	
Chemical Engineer	17	22	39	2	2	1	3	3	4	
Civil Engineer	21	49	70	5	8	5	4	13	11	
Electrical Engineer	132	258	390	24	37	33	37	49	53	
Marine Mechanical Engineer	7	2	9	—	—	—	1	—	—	
Materials Engineer	—	7	7	1	—	—	2	1	2	
Mechanical Engineer	102	118	220	14	15	16	15	24	12	
Metallurgical Engineer	24	14	38	2	3	1	2	—	2	
Meteorologist ²	2	—	2	—	—	—	—	—	—	
Naval Architect	11	11	22	2	—	1	4	1	3	
Naval Engineer	334	165	499	21	19	26	31	26	16	
Nuclear Engineer	—	21	21	1	1	1	3	5	9	
Sanitary Engineer	9	3	12	2	1	—	—	—	—	
Grand Total	699	714	1,413	84	92	92	106	128	117	

* Includes only February and June degrees.

¹ Engineer in Aeronautics and Astronautics beginning in 1960.² Degree discontinued after July, 1955.

Table XIII Number of Degrees of Doctor of Philosophy Awarded

	Calendar year since 1962 (included in decade total)												
	1967*	1966	1965	1964	1963	1962	Grand Total	1961-	Total by decades				
								1951-60	1941-50	1931-40	1921-30	1911-20	1907-10
School of Architecture and Planning													
Architecture	1	1	—	—	—	—	1	—	—	—	—	—	—
City and Regional Planning	2	1	4	1	—	—	9	—	—	—	—	—	—
Total	3	1	4	1	—	—	10	—	—	—	—	—	—
School of Engineering													
Aeronautical Engineering**	4	8	6	4	1	3	28	6	—	—	—	—	—
Ceramics	—	1	—	—	—	—	2	1	—	—	—	—	—
Chemical Engineering	3	8	5	3	—	—	20	—	—	—	—	—	—
Civil Engineering	3	6	4	2	3	—	19	1	—	—	—	—	—
Electrical Engineering	21	33	20	18	19	12	129	9	1	—	—	—	—
Mechanical Engineering	11	13	6	8	2	8	53	4	—	—	—	—	—
Metallurgy	5	9	9	8	7	2	41	5	—	—	—	—	—
Naval Architecture and Marine Engineering	—	1	1	1	—	1	5	—	—	—	—	—	—
Nuclear Engineering	—	2	2	8	8	11	56	5	—	—	—	—	—
Sanitary Engineering	—	—	—	—	—	1	3	2	—	—	—	—	—
Total	55	91	53	52	40	38	356	33	1	—	—	—	—
School of Humanities and Social Science													
Economics	—	18	—	—	—	—	35	—	—	—	—	—	—
Group Psychology	—	—	—	—	—	—	9	1	8	—	—	—	—
Industrial Economics ¹	—	—	18	19	17	11	79	96	19	—	—	—	—
Linguistics	1	1	12	1	—	—	15	—	—	—	—	—	—
Philosophy	—	1	—	—	—	—	1	—	—	—	—	—	—

REGISTRAR

Political Science	—	—	—	—	—	—	33	33	2	2	3	8	9	7	
Psychology	—	—	—	—	—	3†	7	10	—	—	—	4	2	1	
Total	—	—	—	—	—	27	100	170	297	13	19	23	42	31	26
Alfred P. Sloan School of Management															
Management	—	—	—	—	—	—	—	35	35	1	3	6	6	11	8
School of Science															
Biology	—	1	10	17	21	38	59	146	9	7	12	11	5	11	
Chemistry	7	19	59	146	180	342	260	1,013	38	39	32	44	48	24	
Geology and Geophysics	1	7	10	22	20	71	55	186	7	13	4	8	8	5	
Mathematics	—	—	6	25	35	70	135	271	15	19	21	27	27	8	
Meteorology	—	—	—	—	—	14	20	34	1	5	3	3	7	—	
Nutrition and Food Science	—	—	—	—	4	28	28	60	2	4	4	10	3	1	
Nutritional Biochemistry and Metabolism ²	—	—	—	—	—	—	5	5	—	—	—	—	—	5	
Oceanography	—	—	—	—	—	—	11	11	1	—	1	2	5	2	
Physics	—	2	6	48	159	283	246	744	31	44	36	34	44	34	
Total	8	29	91	258	419	846	819	2,470	104	131	113	139	147	90	
Grand Total	8	29	91	258	447	979	1,390	3,202	157	193	195	244	281	182	

* Includes only February and June degrees.

** Doctor of Philosophy in Aeronautics and Astronautics beginning in 1960.

† Previously included in Industrial Economics.

¹ Changed to Economics in 1966.

² Changed to Management February 1967.

³ Changed to Nutrition.

Table XIV Number of Degrees of Doctor of Science Awarded

	Total by decades										Grand Total	Calendar year since 1962 (included in decade total)								
	1911-20	1921-30	1931-40	1941-50	1951-60	1961-	1962	1963	1964	1965		1966	1967*							
School of Engineering																				
Aeronautical Engineering**	2	4	5	18	31	50	110	5	7	9	4	5	13							
Ceramics	—	—	7	16	25	30	78	4	2	6	3	8	4							
Chemical Engineering	—	23	78	114	117	111	443	16	15	25	12	18	7							
Civil Engineering	—	2	12	23	46	57	140	9	13	7	9	8	3							
Electrical Engineering	3	12	30	34	141	101	321	20	11	16	22	12	3							
Electrochemical Engineering	—	1	1	—	—	—	2	—	—	—	—	—	—							
Materials Engineering	—	—	—	—	—	4	4	2	1	1	—	—	—							
Mechanical Engineering	—	4	13	35	125	105	282	16	10	17	16	16	23							
Metallurgy	—	14	25	70	169	131	409	12	24	14	26	21	16							
Mineral Engineering	1	—	4	—	—	—	5	—	—	—	—	—	—							
Naval Architecture and Marine Engineering	—	1	—	—	2	5	8	—	—	—	1	3	—							
Nuclear Engineering	—	—	—	—	9	36	45	3	3	8	7	9	6							
Petroleum Engineering	—	—	1	—	—	—	1	—	—	—	—	—	—							
Sanitary Engineering	—	—	2	3	18	2	25	1	1	—	—	—	—							
Total	6	61	178	313	683	632	1,873	88	87	103	100	100	75							
School of Science																				
Chemistry	—	2	5	4	3	—	14	—	—	—	—	—	—							
Geology and Geophysics	1	2	4	5	2	1	15	—	—	—	1	—	—							
Mathematics	—	2	3	—	1	1	7	—	1	—	—	—	—							
Meteorology	—	—	6	25	17	2	50	—	1	—	—	—	1							
Nutrition and Food Science	—	—	—	3	10	10	23	—	—	2	2	3	3							
Nutritional Biochemistry and Metabolism ¹	—	—	—	—	—	—	—	—	—	—	—	—	—							
Oceanography	—	—	—	—	—	1	1	—	—	—	—	—	1							
Physics	—	5	18	14	7	5	49	—	—	1	2	2	—							
Total	1	11	36	51	40	20	159	—	2	3	5	6	4							
Grand Total	7	72	214	364	723	652	2,032	88	89	106	105	106	79							

* Includes only February and June degrees.
¹ Changed to Nutritional Biochemistry and Metabolism.
**** Doctor of Science in Aeronautics and Astronautics beginning in 1960.**

MEDICAL DEPARTMENT

Table XV Summary of Degrees Awarded (1868-1967)

Bachelor of Science	37,174
Bachelor in Architecture	677
Bachelor in City Planning (discontinued after 1954)*	31
Master of Science	17,011
Master in Architecture	547
Master in City Planning	310
Master in Public Health (discontinued after 1944)*	104
Advanced Engineering	1,413
Doctor of Philosophy	3,202
Doctor of Science	2,032
Doctor of Public Health (discontinued after 1944)*	9
Doctor of Engineering (discontinued after 1918)*	4
Grand Total	62,514

* See the 1959 Report of the Registrar for details.

WARREN D. WELLS

MEDICAL DEPARTMENT

For the first time since 1960 the number of clinic visits remained unchanged from the previous year. There was a dramatic reduction in respiratory illness, not only in our community but throughout the country. If the incidence of respiratory infections had been at the usual level, the number of clinic visits would probably have increased about 15 per cent, comparable to the increase noted in previous years. Unfortunately no explanation is available for the reduction in respiratory illness, and we can only hope that this phenomenon continues. Elective visits to the Medical Department for complete diagnostic evaluation increased by about 25 per cent. Since such medical service is much more time-consuming than regular clinic visits, this striking increase kept us very busy.

During this year we have enjoyed the use of attractive new facilities obtained by remodeling the basement of Building 11, formerly occupied by the Personnel Department. Since we gave up space in Building 3, the net space gain was small, but the availability of a second x-ray machine, enlarged laboratory facilities, and a two-bed emergency ward has increased our efficiency.

The transfer of our medical records from cumbersome file drawer storage to a power filing system has not only greatly increased the speed of the record library operation, but has decreased the turnover of record room personnel as the work is now much less tiring physically. Since the law requires us to keep medical records for many years, we have begun to microfilm inactive records to facilitate long-term storage.

As mentioned in last year's report, we applied for approval by Medicare as not only do we serve many employees, staff, and faculty who are over 65 years old, but some of our students may be eligible for Medicaid. Medicare approval was given us with the understanding that we would make changes in our medical organization to conform with the regulations of the Department of Health, Education, and Welfare. New Medical Staff Bylaws have been drawn with the assistance of the Institute lawyers and have been approved by the Executive Committee of the Corporation. In addition, our accounting procedures had to be revised to conform with standard Medicare procedures. This has been accomplished with the generous help of the Institute Audit Division.

Space continues to be a critical problem for us. A new medical building is in the early planning stage, but it will be several years before it can be funded and built. Since we are now using all the space in Building 11, we have no reserve left for additional personnel to cope with the steadily increasing demand for medical service. It is our hope that our inpatient facility can be transferred to the building now occupied by the Sancta Maria Hospital that will be vacated next year. The space in Building 11 thus made available would permit the necessary expansion of our ambulatory facilities. Such separation of facilities is not desirable as it decreases efficiency and certainly will increase costs, but until we have a new building there seems to be no other solution to our space problem.

It has been our good fortune to have two additions to our full-time staff: Dr. Melvin H. Chalfen as a Physician and Dr. James A. Haycox as a Psychiatrist. Other appointments during the year were: Dr. Carl J. Canzanelli, Assistant Surgeon; Dr. Morris Dratch, Assistant Physician; Dr. Garabed H. Garabedian, Assistant Physician; Dr. George E. Ghareeb, Assistant Ophthalmologist; Dr. Harvey J. Lewis, Assistant Ophthalmologist; Dr. Dudley Merrill, Assistant Physician; Dr. Hugh Miller, Assistant Physician; Dr. Lawrence M. Miller, Assistant Physician; Dr. Earl David Nordberg, Assistant Radiologist; Dr. James J. Sidd, Assistant Physician; Dr. Elizabeth C. Spivack, Assistant Dermatologist; and Dr. Leo L. Stolbach, Assistant Physician.

Resignations from the staff were submitted by: Dr. Biagio A. Conte, Assistant Surgeon; Dr. Barry L. Fanburg, Assistant Physician; Dr. Edward F. Goodman, Assistant Ophthalmologist; Dr. Bernard Levey, Psychiatrist; Dr. Richard H. Litner, Assistant Surgeon; Dr. William Bradford Patterson, Assistant Surgeon; Dr. William J. Porell, Assistant Surgeon; Dr. Howard E. Rotner, Assistant Physician; Dr. John R. Seeley, Consultant in Sociology; Dr. Duncan P. Thomas, Assistant Physician; and Dr. Aram Tomasian, Assistant Physician.

MEDICAL DEPARTMENT

MEDICAL CLINIC

The patient load was just about the same as last year. As has been mentioned, there was a striking decrease in the incidence of respiratory infections ranging from the common cold to pneumonia. For example, there were only 26 cases of pneumonia during the year, whereas the year before there were 40 cases. There was even a modest decrease in the number of cases of infectious mononucleosis (a disease which is presumably infectious, although its etiology is still unknown).

We continue to see patients by appointment except in emergency situations. Patients are encouraged to establish relations with a single physician to obtain continuity in care. About 60 per cent of Medical Clinic care is supplied by part-time internists and the rest by our full-time internists. The trend in internal medicine is towards full-time group practice, so the relative percentage of care given by our full-time staff is bound to increase as the availability of qualified internists practicing individually decreases.

The prenatal and obstetrical program for student wives at the Boston Lying-In Hospital continues. One hundred twelve student wives are currently enrolled in this program which supplies excellent obstetrical care at a minimum cost.

Except for including a family option in our Student Health Insurance which provides coverage for pediatric hospital care, we make no provision for the children of students. We believe that some of them are not getting good medical care, and we are exploring the possibility of resuming pediatric care ourselves or, preferably, developing a program in cooperation with the pediatric service of one of the Harvard-affiliated hospitals.

SURGICAL CLINIC

The total number of patient visits to the general Surgical Clinic was 11,161 and represents no change from the previous year. There were 423 operating room procedures, 19 per cent fewer than last year, but about the same number as the year before. One hundred eighteen tissue specimens were submitted for pathological evaluation. Five of these were basal cell carcinomas; fortunately no other malignancies were found this year.

The total number of athletic injuries was 226, a slight increase over last year. (See Table I.) Fortunately none were very serious. There were eight fractures, including four of the nose and one each of the fibula, wrist, clavicle, and hand. There were thirteen dislocations, of which nine involved the shoulder. Touch football, as usual, caused more injuries than any other sport.

VICE PRESIDENT, ACADEMIC ADMINISTRATION

Table I Tabulation of Athletic Injuries and Sports in Which They Were Incurred, 1966-1967

	Football	Basketball	Hockey	Baseball	Softball	Lacrosse	Soccer	Wrestling	Swimming	Rugby	Squash	Skating	Skiing	Track	Miscellaneous*	Total
Sprains and strains	20	10	4		1		3	4		3	2		4		14	65
Contusions and abrasions	13	7	10	1	2	2	3	4		7	2	1	2	2	6	62
Lacerations	16	8	21	4	1		1	1		2	4	2	2	2	2	66
Fractures	3			1			1	1		1					1	8
Dislocations	5	2			1			2	1	1					1	13
Concussions	1									1						2
†Other	5	3							1		1					10
Total	63	30	35	6	5	2	8	12	2	15	9	3	8	4	24	226

*Miscellaneous: tennis, crew, judo, volleyball, fencing, skate board, field day, handball, water polo, and surfing.

†Other: blisters, fracture of tooth, avulsion tendon, foreign body in eye, internal derangement of knee, and hyperventilation tetany.

Dr. Conte, who has represented us in the Athletic Department, resigned because of the demands of his surgical practice. We were not able to find a qualified replacement for him. After consultation with the Director of Athletics, it was decided to have a trainer well versed in first aid in attendance at contact sport events. If necessary, the trainer will arrange for the removal of the injured athlete to the Infirmary to be treated by the surgeon on call. We do not feel that this change places the athlete in jeopardy as the role of the surgeon on the scene was only to give first aid; definitive treatment must be performed either in the Infirmary or at a hospital.

Scooters and motorcycles continue to be a major hazard for our students. There were 35 injured, two more than last year. Fortunately, there was only one serious injury, a severe concussion with a fracture of the maxilla. The fact that this student was wearing a helmet undoubtedly saved his life.

DENTAL CLINIC

This clinic continues to limit its activity to dental diagnosis and prophylaxis. A dentist visits for an hour each day. There are two dental hygienists, one full-time and the other half-time. There were 3,833 visits to the Dental Clinic, a slight increase over the previous year. About two-thirds of the visits were by students or student wives. If dental therapy is necessary, the patients are referred to qualified dentists in the community.

HEALTH SURVEYS

There was about a 20 per cent increase in the number of Faculty Health Survey examinations and a 35 per cent increase in the number of D.S.R.

MEDICAL DEPARTMENT

Health Survey examinations. These examinations are complete, including a medical interview, physical examination, chest x-ray, routine hematology, urinalysis, pulmonary function tests, electrocardiogram, and special laboratory work as necessary. This year 650 faculty members and 245 D.S.R. members were examined. The results are confidential and released only with the written permission of the patient.

STAFF AND EMPLOYEE HEALTH PROGRAM

In this area, not dependent on the prevalence of disease in the general population, there has been a striking increase in the activity of the Department. Pre-employment examinations and those requested by the patients on their own initiative make up most of the increase.

	1966-67	1965-1966
Pre-employment	1,405	1,191
Women under 30 years old	767	616
Retirement	82	86
Hazardous Occupation	79	119
Employee Health Survey	206	48
Baseline	95	68
Others	682	451
Total	3,316	2,579

PRE-EMPLOYMENT

The number of examinations in this category once more increased. It is reasonable to anticipate that this will continue as more of the new facilities at the Institute are staffed. Women under 30 years old, who are not examined except by a few screening laboratory tests, also increased in number.

The rate of medical disqualifications continues about the same. This year 14 applicants were found to have health problems sufficiently grave to disqualify them for the particular work they sought (0.67 per cent). This is a bit below previous levels.

Heart disease (five cases) was again the commonest cause of rejection, and included congenital, hypertensive, and coronary types. Other conditions discovered were severe anemia, color blindness, diabetes, hernias, liver disease, psychosis, active tuberculosis, and unstable knee.

Lest it appear that our criteria for employment are unrealistically strict, it should be noted that the nature of the work is most often the determining factor in the medical decision. This is illustrated by the fact that close to 300 people were seen after their pre-employment examinations because of findings which needed further evaluation. Of these, 72 were found to have important health problems, but the physical

requirements of the job permitted their employment without undue risk to the employee or the people around him.

The health problems encountered in this group of 72 included the following:

Hypertension	13	
Diabetes	12	
Heart Disease	8	(Three rheumatic)
Chronic Renal Disease	6	(One on dialysis)
Poor Vision	5	
Abnormal x-ray	4	(Benign on further investigation)
Obesity	4	
Hernia	3	
Renal Glycosuria	2	
Seizure Disorders	2	
Emotional Illness	2	(One psychosis)

Also encountered were anemia, asthma, arthritis, chronic bronchitis, endometriosis, hyperthyroidism, history of cancer, congenital methemoglobinemia, Peutz-Jeghers syndrome, poor hearing, orthostatic proteinuria, regional enteritis, ulcerative proctitis, and loss of hand.

HAZARDOUS OCCUPATION

The smaller number this year reflects the policy of examining younger employees only every other year. The committee of three physicians which reviews these examinations found it necessary to advise against continuing one employee in his hazardous job because of poor health. He subsequently decided to retire.

EMPLOYEE HEALTH SURVEY

This program continues to gain in popularity. This year, 448 invitations were sent to employees who reached age 45, 50, 55, 60, and 63. Two hundred and six accepted the invitation (almost 46 per cent) to have a health survey examination; this is the largest response yet encountered. The results of these examinations are considered confidential and are disclosed only to the patient and, if he wishes, to his personal physician.

BASELINE

Those women under 30 years old who have completed one year of employment at the Institute are offered a health survey examination to establish a baseline medical record. This year, 307 invitations were sent, again illustrating the 50 per cent turnover rate in this group, since 616 young women were hired during the preceding year. Ninety-five replies were received (31 per cent) — about the same number as last year. No important abnormalities were discovered.

MEDICAL DEPARTMENT

OTHERS

More than 500 of the 682 examinations in this category were done at the patient's own request for health survey purposes. The others were requested by other educational institutions, employers, and insurance companies.

DEATHS

The deaths of 32 members of the Institute were recorded this past year. Heart disease and cancer once again were the leading causes.

Causes of Death According to Death Certificates

Heart Disease	17
Cancer (lung-4)	10
Stroke	2
Accident	1
Chronic Lung Disease	1
Leukemia	1

PSYCHIATRIC SERVICE

There was a 5.4 per cent increase over the previous year in the total number of individuals seen in the Psychiatric Service during the academic year ending June, 1967. (See Table II.) This increase was associated with a small decrease (3.7 per cent) in the total number of visits. Since the Service was already operating at nearly full use of available time, the ready availability of consultation without extended delay was achieved by some reduction in the average number of visits per individual.

The highest incidence of consultation with the Psychiatric Service occurred in November. The sustained rise in prevalence for undergraduates began in March, continued through April, and reached its maximum in May. This pattern was most apparent in freshman and sophomore years; less evident in the senior year. Consultation with graduate students, faculty, and staff did not show this pattern but was relatively constant throughout the year. This finding suggests that for the undergraduate, the academic load may be related to the time of consultation.

There was a slight decrease in the number of members of the M.I.T. community referred for further clinic or private psychiatric treatment, while the total number of patients hospitalized remained the same as last year. There was an increase in the use of the Psychiatric Service by faculty and their families with acute emotional problems.

The Student Adaptation Study on the Class of 1965, supported in large measure by the Grant Foundation and supplemented by funds from the Education Research Center, was completed in June of this

Table II Psychiatric Service July 1, 1966-June 30, 1967

Total individuals seen:	901
Total number of visits:	2,884
Analysis of caseload:	

	Number of patients seen	Size of class	Percentage of class
Total undergraduates	391	3857	10.1%
Freshman	82	935	8.8%
Sophomore	116	990	11.7%
Junior	91	914	9.9%
Senior	102	1018	10.0%
Uncertain status	25		
Graduates	167	3710	4.5%
Faculty, staff, employees	189		
Other	91		

	Number of new patients	Total number of patients	Percentage seen for first time this year
Undergraduates	280	391	71.6%
Graduates	124	167	74.9%
Faculty, staff, employees	142	189	75.1%
Other	75	91	83.5%

	Number of patients hospitalized	
Total number	16	(this includes 1 readmission)
Undergraduates	5	
Graduates	2	
Faculty, staff, employees	6	
Other	2	

	Number of patients referred on
Total number	114
To clinic	40
To private doctor	74

year. One phase of this work involved an examination of the use of the Psychiatric Service by members of the Class of 1965 from their freshman through senior years. The following findings are quoted from this section of the report of the study.

“The nature, intensity, and location of educational and other stresses at M.I.T. significantly affect the time at which students make use of the Psychiatric Service. These same stresses also affect the student’s movement along his academic path, his survival in a given course. The courses have different rates for psychiatric consultation. The peak in both incidence and prevalence of consultation occurs

in different semesters in a number of the courses. In several courses psychiatric consultation appeared to be correlated with a drop in grades while in other courses such a correlation did not obtain. The incidence of psychiatric consultation varied considerably in the various living groups.

"Our data suggests that it would be wise to undertake a careful investigation of the stresses in the seventh semester. At present, the findings are consistent with an adaptive crisis in the students rather than with the sudden emergence of neurosis. Many patients with serious neurotic difficulties, especially where their neurosis limited their ability to learn, left by the end of their sophomore year. A new group appeared to be making use of the Psychiatric Service in the last two years. There are a number of indications that these students were responding as much if not more to dissonance and stress within their environment than to intrapsychic conflict.

"In summary — the Psychiatric Service appeared to be perceived and thus used as something more than simply a facility for the treatment of mental illness. The Service does not function as an administrative device for 'cooling out' failing students or other Institutional rejects. Rather, the Psychiatric Service functions more like a clearing house where individuals with initially vaguely defined, often contradictory, social perceptions can find an informed neutral arena where time is made available for examination and clarification of issues. The usual formal psychiatric configurations do not distinguish most of the patients from non-patients. Patients acknowledged anxiety more readily on a psychological test than non-patients. No other consistent clinical distinction could be drawn. Approximately 80 per cent of the students consulting the Psychiatric Service were in the previous category. Approximately 20 per cent had serious emotional difficulties. One per cent of the total required hospitalization and approximately ten per cent of the total number of patients seen required relatively long-term psychiatric treatment."

A student who has come a certain academic distance may find himself at a crossroad and wish to discuss where he has been and where he might proceed. He may find he has strong feelings that influence his judgment and his ability to perform. This need not represent illness nor need he think so. To consider his position aloud, with someone with thorough knowledge of the Institute but with no formal academic tasks nor obligations to reveal the student's thought process, can be very useful to the student. The psychiatrist, at such a time, assists and fosters normal growth more than treats an illness.

The activity of the full-time staff in various faculty committee work can be viewed from this same perspective. The aim of the Committee on Academic Performance, for example, is not simply to compute numerical standards of performance for the disqualification of students, but to understand how and why they perform as they do. Understandably, their difficulties in academic performance occupy much of the Committee's attention. In general, the Committee assumes that factors other than native intelligence are responsible for academic failure. The special task of this Committee is to become acquainted with the specific problems of a student and recommend a course of action that benefits both institution and student. The psychiatrist, as an ex-officio member of the Committee, advises on human issues when he can, without any

obligation to reveal confidential information about a particular student or even the fact that the student has consulted the Service. Most important, the psychiatrist, by virtue of his position in the institution, can and does raise relevant questions about the psychological cost of academic success or failure. The thoughtful work of the Committee is representative of a humanistic and conscientious attitude at M.I.T. which seeks the optimal educational experience for each student. In such areas, the Service, drawing on both clinical and research experience, joins with the faculty in furthering an examination of the process of education at M.I.T.

It is our continuing concern that any member of the M.I.T. community who might urgently need consultation should be able to turn to the Service, either directly or by referral from members of the community who recognize distress signals. Inevitably there are individuals who believe that consulting a psychiatrist is an admission of weakness or fear, and that the fact of their consultation will leave an indelible mark on their record, thus compromising their future careers. A small number of individuals are so depressed and isolated that they feel themselves to be beyond help.

To counter this problem the psychiatric staff is continually working out new ways to increase the sensitivity and breadth of our contact with the community at every level. During the past year, for example, there has been a significant increase in the number of calls from freshman advisors, faculty counselors, and others requesting advice on how they might best help troubled students. In several instances these calls have led to critical interventions with gratifying results. Particular emphasis is put on the availability, accessibility, and complete confidentiality of the Psychiatric Service.

SOCIAL WORK

The number of visits to Mrs. Jacqueline A. Buck increased 32 per cent over last year. The Service is used by all members of the Institute community: students, faculty members, staff members and employees. A little more than one-half of the clients were students and their wives. About one-half of all the clients were self-referrals. It is of interest that 32 foreign students were seen, many referred by the Foreign Student Office.

A relatively large number of graduate students and their wives came for help. The pace of the academic program coupled with the needs of the family, financial problems, inaccessibility of family support, and the incessant demands of small children create a stressful situation for many students. The foreign student families have the added problem of settling in a strange country.

MEDICAL DEPARTMENT

There is a continual search for concrete resources in the outside community to provide the solution to any given situation, for example, the child guidance center, the hospital, and the nursing home for the aged parents. At least 50 clients were referred to community agencies for continued service. Liaison is maintained with the agency offering service whenever it seems appropriate. Insofar as is possible, home and hospital visiting are done at crucial times.

The Social Worker represented M.I.T. as a member of the Social Agency Executives Group sponsored by the Cambridge Community Services. She was also a member of the Board of Trustees of the Technology Nursery School and served as a casework consultant to the teacher and the operating board in problem situations.

INFIRMARY

There were 625 admissions to the Infirmary during the year, a drop of 12 per cent. This reduction was almost entirely in medical admissions for respiratory infections, as the number of orthopedic, psychiatric, and surgical admissions was about the same as the previous year.

The emergency service offered at the Infirmary after clinic hours and on weekends and holidays had 3,475 visits, a reduction of eight per cent. This drop was entirely in the medical visit category and presumably was due to the general decrease in incidence of respiratory infections.

STUDENT HEALTH INSURANCE

This program continues to be voluntary with about 61 per cent of the students subscribing. As usual, some uninsured students incurred major medical expenses. The Medical Department continues to recommend that Student Health Insurance be made compulsory.

SANITATION

Routine sanitary bacteriological monitoring of the swimming pool and M.I.T. food services is performed by the Massachusetts Dairy Laboratories. Fred E. Smith, our Consulting Sanitary Engineer, reviews the bacteriology reports and inspects the facilities at least once a month. While there were sporadic cases of salmonella infection among our students, there was no evidence that our food facilities were the source.

ELECTROCARDIOGRAPHIC LABORATORY

The number of electrocardiograms taken was 1,350, an increase of 13 per cent from last year. The Laboratory is in new quarters adjacent to the X-ray Department and this has proved very satisfactory as many patients require procedures in both areas.

X-RAY DEPARTMENT

The efficiency of this Department has been improved strikingly by the new facilities. There are now two x-ray machines with an automatic developer which processes films in three minutes. In all, 11,000 x-ray procedures were performed, an increase of 12 per cent over the previous year.

CLINICAL LABORATORY

The total number of laboratory procedures was 23,506, an increase of six per cent. However, laboratory tests other than those considered routine increased 27 per cent.

OCCUPATIONAL MEDICAL SERVICE

There were no staff changes during the year. Additional staff will be required in the near future in order to accept the responsibility for the Laboratory for Nuclear Science Accelerator now in the planning stage.

INDUSTRIAL HYGIENE OFFICE

Routine operations included advice on the toxicity of materials, evaluation of potential exposures, regular hood survey program, supervision of filter changes, supervision of respiratory program, and beryllium monitoring at the Instrumentation Laboratory. The Chemical Laboratory continued to analyze biological samples for beryllium in association with the Atomic Energy Commission supported Beryllium Case Registry. The Laboratory also performed many analyses of blood and urine samples for lead in connection with Dr. Harriet L. Hardy's study of environmental lead poisoning in children.

Considerable time was devoted to the design and development of a special laboratory hood for the new chemistry building. As a result of this work, performance specifications were written and made part of the building contract.

The airflow calibration unit was redesigned making possible the evaluation of constant volume devices. As an outgrowth of this work, a special damper has been selected for use in the new chemistry building.

The Chemistry Laboratory devoted considerable time to the application of their new atomic absorption unit to the analysis of air and urine samples. To date, procedures for the analysis of lead, cadmium, calcium, and copper have been developed.

RADIATION PROTECTION OFFICE

Services increased during the year due to relocation of radioisotope laboratories into new buildings, renovations in existing buildings and the initiation of new projects.

MEDICAL DEPARTMENT

The approximate number of radioisotope laboratories and radiation producing installations that received Office services during the year is:

Radioisotope laboratories	230
Particle accelerators	13
X-ray machines	100
Lasers	150
Microwave generators	30

As of June, 1967, there were about 1,200 persons working with radiation sources. Of these, 940 were engaged in work involving sources of ionizing radiation.

Use of the Central Radioisotope Laboratory and Storage Facility has continued to increase. During 1966-67, research personnel from eight departments used the Facility for a total of 653 man-hours, compared to 588 man-hours for 1965-66. The increased work-load is also reflected in the amount of liquid radioactive waste processed at the Facility. In 1966-67, 439 gallons were processed compared to 250 gallons for the previous year.

The walk-in freezer for the storage of animal carcasses (containing radioactive material) was installed in Building 20 early in the fiscal year. Subsequently, a program was established whereby animal carcasses are collected weekly from research laboratories, stored in the freezer, and then transported on a monthly basis to the Harvard power plant incinerator. Carcasses that contain isotopes in amounts that preclude incineration are stored in the freezer and eventually disposed by shipment to an Atomic Energy Commission licensed burial site, along with the solid radioactive waste collected from radioisotope laboratories. There were three shipments of solid radioactive waste made during the year, totaling approximately 1,800 cubic feet of material.

The principal items at Lincoln Laboratory that required special attention during the year were as follows:

1. The revaluation of potential hazards at the Haystack Hill Radar installation due to an increase in beam power from an average of 180 kilowatts.
2. The review of contractor acceptance-criteria for radio frequency and x-ray hazard-control for the new Altair Antenna facility to be constructed at Kwajalein.
3. The design and use of a ten curie Strontium-90 beta ray irradiator unit.

SPECIAL PROJECTS The Reactor Radiation Protection Program involved two unusual problems during 1966-67. During November and

December a total of 56 spent-fuel elements were shipped from the M.I.T. Reactor to a fuel processing plant in Georgia. Radiation Protection Office personnel provided monitoring and radiation protection supervision during the operations involved up to the point where the shielded transportation flask left M.I.T. property.

The second unusual event at the Reactor began in February, 1967, when one of two heat exchangers began to leak and resulted in radioactive contamination (principally tritium) of the cooling tower water. The Radiation Protection Office provided extensive monitoring services during the initial evaluation of the extent of the radioactive material escape to the environs, and the subsequent operations relating to locating the leak and repair of the heat exchanger. Fortunately, the concentrations released to the neighborhood were within permissible limits.

The Nutrition Department's Cobalt-60 irradiation facility source was replaced during the year. The new source, 40,000 curies of Co-60, was installed without incident and the old source, which had decayed to approximately 15,000 curies was shipped to Oak Ridge, Tennessee. Office personnel provided monitoring services and radiation protection supervision during the operations.

The use of radioisotopes in clinical research at M.I.T. necessitated the organization of an Advisory Committee on Medical Use of Radioisotopes. Assistance was given the Clinical Research group in the calibration of its radioactivity-analysis counting equipment. This resulted in a significant improvement in counting efficiency.

RESEARCH AND TEACHING ACTIVITIES Investigation into the use of activation analysis for the determination of beryllium in biological samples has been continued. It was demonstrated that 0.004 micrograms of beryllium (foil) can be detected by $\text{Be}^9 (\alpha, 2n) \text{C}^{11}$ activation. Several runs were made using lung tissue containing known amounts of beryllium ($<1\mu\text{gm}$). The results were considerably higher than the values determined by standard chemical method. The high results were attributed to contaminants in the sample, and further work is in progress to remove the interfering elements. The objective is to be able to determine quantitatively less than microgram amounts of beryllium in lung tissue and urine.

A course on radiation protection was presented to graduate students of the Department of Nuclear Engineering twice during the year. Informal teaching activities (mainly instruction interviews) continue to occupy a significant fraction of R.P.O. staff members' time.

ALBERT O. SEELER

PLACEMENT BUREAU

Last year saw certainly the most active search for college graduates of the past decade. This activity was reflected at M.I.T. as across the nation. An ever increasing number of employers visited the Institute seeking our graduates. The number of companies that sought to interview at M.I.T. was more than 575 — by far the highest total in our history. The number of individuals taking interviews dropped somewhat from the previous high of 1965-1966, but the total number of students seeking assistance from the Placement Bureau regarding summer employment, opportunities abroad, graduate study plans, and career counseling increased.

As has been the custom, Table I indicates the breakdown by field of the various degree recipients in the June class. Since our statistics will not be final until September, some discretion must be used in interpretation of this tabulation. From our past experience, however, the percentages indicated should not vary markedly from the final numbers.

SUMMER EMPLOYMENT

Late in the fall, initial industrial contacts were made to more than 600 companies, and resulted in a noticeable increase in the summer job listings at the Placement Bureau. Jobs were located throughout the U.S. and ranged from camp counseling, to research, to construction. The emphasis, however, was primarily technical. In addition, many students were interviewed by companies willing to discuss summer positions. Industry has been enthusiastic about hiring students for the summer, not only because it gives a student valuable experience, but also because it increases the company's chances of hiring that same student as a permanent employee after graduation.

FOREIGN OPPORTUNITIES

This year sees A.I.E.S.E.C. (Association Internationale des Etudiants en Sciences Economiques et Commerciales) with a new constitution (revised by the President of the organization, Kenneth P. Morse) and with a National Committee Membership. For the first time, A.I.E.S.E.C. also has membership in the Activities Council.

The organization's goals are recruiting high quality members in economics and management to have a close working relationship with the I.A.S. (International Association of Students), and to acquire an educational experience resulting in a contribution to the future of international business. Working closely with the Placement Bureau, the fledgling organization has made material progress. This year ten students are going abroad under A.I.E.S.E.C.'s exchange program to South Africa,

Table I Placement By Field

	Doctor's		Professional		Master's		Bachelor's		Total	
	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent
Academic research										
M.I.T.	9	14	2	4	9	6	5	1	25	4
Other	5	8	0	0	2	1	3	1	10	2
Teaching										
M.I.T.	2	3	0	0	0	0	0	0	2	0
Other	12	19	4	7	1	1	1	0	18	3
Further study										
M.I.T.	0	0	20	38	36	24	115	28	171	25
Other	0	0	7	13	17	11	220	53	224	36
Industry	29	45	13	25	61	40	53	13	146	22
Government	4	6	0	0	11	8	8	2	23	3
Foreign students to native country	1	2	1	2	6	4	1	0	9	1
Armed services	2	3	6	11	8	5	8	2	24	4
Subtotal	64	100	53	100	151	100	414	100	671	100
Miscellaneous, undecided, unknown	60		44		166		314		524	
Total	124		97		317		728		1266	

PLACEMENT BUREAU

Nigeria, Japan, Italy, Switzerland, and Finland. Russia may soon join A.I.E.S.E.C. and hopefully students will be traveling there next year.

In addition to its exchange program, A.I.E.S.E.C.'s first-year activities culminated in a conference this July on Housing and Urban Redevelopment in the United States. As a result of this conference, the public's interest was stimulated, international relations were promoted, and the presence of A.I.E.S.E.C. at M.I.T. was further recognized.

Another group with an international orientation is I.A.E.S.T.E. (International Association for the Exchange of Students for Technical Experience). I.A.E.S.T.E. is a national organization, based in New York City at United Nations Plaza. It is an exchange program to provide experience for technical students, and this year 12 M.I.T. students are going abroad to such countries as Germany, Ireland, the Netherlands, Sweden, Switzerland and the United Kingdom.

FOREIGN STUDENTS

The Placement Bureau continues to devote more time to the complex employment problems of M.I.T.'s foreign students. Approximately one-third of the graduating foreign students return directly home, while the remaining two-thirds pursue further study or obtain jobs in the U.S. or with foreign companies and universities. This year has seen an increase of students from other countries using our office to seek both practical training positions and summer jobs. Usually employment is found with those firms which have international interests, and which see the foreign student as a potential long-term employee in his home country.

SELECTIVE SERVICE

The Selective Service Office at M.I.T. has under its care at this time about 200 faculty and staff registrants under the age of 35 whose deferments are renewed annually. There are also 3,000 graduate students under its auspices. The Selective Service System has arranged for the administration of four College Qualification Tests during the months of May and June, as well as an additional examination in November. Most of our students took advantage of this opportunity, and obtained scores ranging from 98 to 76 — the largest percentage of scores in the high 80's. Seniors are always of great concern to this Office, as many of them are leaving M.I.T. and have no idea of how to obtain deferment for graduate school or a critical job, nor do they know the opportunities available in the various branches of the Armed Services. Therefore, it is our policy to provide them with detailed information in order to help them with their plans for the future.

ALUMNI

In alumni placement the demand for scientists and engineers reached epidemic proportions, but the demand for supervisory personnel dropped during the winter by almost 45 per cent. For the first time in several years a considerable number of people who wanted to change positions were over-qualified by education or experience, or both, for the openings about which we were informed. The number of men who registered increased by ten per cent over 1966.

It is pleasant to be able to report that in May and June employers again began to look for executive talent, so that we are starting our new fiscal year with a reasonably well-balanced Job Book, and some excellent job candidates.

SUMMARY

As indicated, the year has been one of feverish activity. The scope of the Placement Bureau continues to widen as we are increasingly called upon by our students at all degree levels for career assistance. It has been with great pleasure that we have welcomed the addition of Edward J. Carey Jr., as Assistant Director of Placement. Among his many duties, Mr. Carey will be responsible for student employment. That function was formerly the responsibility of William H. Carlisle Jr. With Mr. Carey's assistance, it will be possible for a student to seek part-time employment integrated with his over-all career plans.

THOMAS W. HARRINGTON JR.

OFFICE OF PUBLIC RELATIONS

Responsibilities of the Office of Public Relations include internal communications. In new quarters, convenient of access, the staff has intensified its efforts to keep the growing community informed. Two of the most important information channels are provided by *Tech Talk* and *The Institute Calendar*.

Tech Talk has followed a policy of remaining informal and unpretentious, we believe, and has resisted the tendency of all house organs to become overblown and boring. Under the editorship of Miss Joanne Miller, who has developed special knowledge of non-academic personnel, it celebrated its tenth anniversary with a new format.

The Calendar, upon the recommendation of the Advisory Committee on Publications, was also redesigned to permit greater scope in its coverage of events. Miss Judith Werner is the new editor.

Redesigning of these publications was accomplished by the Office of

Publications, which itself underwent some reorganization under the leadership of the new director, William T. Struble. As the group prepared to move into new offices, he was appointed to succeed John I. Mattill, who over a period of 15 years had become identified as the outstanding figure in university publications. The group continued to receive recognition. In the 1966-1967 competition of the American College Public Relations Association, a collection of M.I.T. publications received a Certificate of Exceptional Achievement, with a \$500 incentive grant. In the annual American Alumni Council competition, M.I.T. publications won four first prizes and one second prize. M.I.T. publications were also accepted for display by the Type Directors Club of New York.

FRANCIS E. WYLIE

OFFICE OF INSTITUTIONAL STUDIES

BASIC PATTERN OF OPERATION

Although the Office of Institutional Studies was established in 1964, no report of its activities has appeared in the President's Report and perhaps some note of its general purpose is appropriate.

The Office was established in recognition of the need to make advanced data processing capabilities available to the administrative offices of the Institute. The staff nucleus transferred from the Registrar's Office, where it had been developing computer programs to assist in the subject scheduling, registration, grade reporting, and permanent record processes; this work on behalf of the Registrar was the first, and is a continuing responsibility of the new office.

O.I.S., as it came to be known, was committed early to the concept of central files along functional information lines, wherein several offices might use the same information for different administrative purposes without the need for maintaining separate files. At the present time, there are two substantial central files: one in the area of student records, serving the Registrar, Admissions Office, Student Aid Center, and the Dean of Student Affairs; the second serves the Alumni Association. Several smaller files are also maintained for the use of one or another of the 15 client offices served.

O.I.S. is a service organization and supports rather than supplants the administrative responsibility of its client offices. It endeavors to design information systems according to the operating requirements of the concerned client office and to program and operate these systems so long as the need for such information is apparent. The information

VICE PRESIDENT, ACADEMIC ADMINISTRATION

in the computer files is considered to be owned by the client office; access is controlled by the client office, much as they control access to information stored in traditional forms. After a system has been developed, the O.I.S. agrees to provide, on a scheduled basis, computer outputs according to the operating requirements of the client office and to conduct special studies using the information in these files on special request. For the last fiscal year, 15 client offices were served to the following extent:

Classification of work	Computer outputs
Scheduled	2,471
Unscheduled	1,291
Total	3,762

The Office has been fortunate in that the first large files were established with the concept that by programming a generalized pattern of operation, future central files along similar lines but with different subject matter could be implemented in an efficient manner. This has proven to be the case and has materially assisted in broadening the services of the office to new administrative areas. The Office also realized quite early that not all requirements for manipulation of the data in the central files could be foreseen at the time of the systems design. Consequently, a general utility program was developed which allows information to be selectively retrieved from a computer file without special programming. Substantially all of the 1,291 unscheduled computer outputs for the current year noted above have been produced in this fashion. This continues to be a most useful and unique feature of the central file system of the Office of Institutional Studies.

CONCENTRATION OF EFFORT

In the first three years, most of the work of the O.I.S. constituted systems developed on behalf of the offices reporting to the Vice President of Academic Administration and for the Alumni Association. While the nature of the work involves a continuing relationship with such client offices to maintain and update these systems, the opportunity to use the programming talent assembled in other administrative areas has gradually become apparent during this year.

This broadening of effort to assist administrative departments will perhaps prove to be the most noteworthy event of the year. Although most of these projects are in the stage of initial review, it is anticipated that a growing percentage of the total development work load of the Office in years to come will be in offices other than the Vice President

of Academic Administration. Topics under current review include areas reporting to the Vice President of Operations and Personnel and the Vice President and Secretary of the Institute.

NOTEWORTHY DEVELOPMENTS

The Office has been supported since its inception by internal M.I.T. funds in the normal budgetary manner, but the decision has been made to provide services at the start of the coming fiscal year on a charge basis — more properly reflecting the service nature of operations. It is anticipated that this approach will better reflect the cost of providing advanced data processing services in the M.I.T. administrative community and that better control of this cost element will result.

During the summer of 1966, the IBM model 1401 computer maintained by the office was replaced by an IBM model 360-30 computer, substantially expanding the capacity of the Office to meet its commitments. In recent months, the memory core of the 360-30 was enlarged after a careful review indicated substantial service and cost efficiencies could result from this increase in our computer resource.

A continuing concern of the Office has been that the detailed systems evolved for individual offices by whatever agency would mesh within the larger framework of a large-scale, integrated information system for M.I.T. as a whole. Consequently, an initial effort in defining the dimensions of such a system was conducted and presented to the M.I.T. administration for consideration. Such a system represents a very substantial commitment on M.I.T.'s part and although this matter is still under close review, the O.I.S. is endeavoring to serve as a clearing house for new systems development to facilitate the implementation of a large-scale system at some point in the future.

Since its establishment, the O.I.S. has been charged with the responsibility of conducting special studies in support of the Academic Council and the M.I.T. Faculty, and although the concentration of its effort and resources has been in the systems area, several studies are conducted each year on special operating and policy problems. With the increasing complexity of the academic world as a whole and M.I.T.'s operation in particular, it is anticipated that this Office will be called upon for such assistance more frequently in the future.

I regret to announce the resignation of Robert E. Holz '58, as Associate Director. Since returning to M.I.T. in 1959 to initiate the electronic data processing effort in the Registrar's Office, Mr. Holz has ably directed the systems development effort of that office and subsequently of the Office of Institutional Studies. His presence will be sorely missed.

DEAN L. JACOBY

VICE PRESIDENT, RESEARCH ADMINISTRATION

The administrative units of the Institute which report to the President through the Vice President, Research Administration, include the Division of Sponsored Research, the Libraries, the Summer Session, the Operations Research Center, the M.I.T. Press, the National Magnet Laboratory, the Cambridge Electron Accelerator, and the Joint Center for Urban Studies of the Massachusetts Institute of Technology and Harvard University. A report from the Director of each of these units follows.

The total dollar volume of sponsored research in the academic departments and interdepartmental laboratories continues to increase in spite of the fact that more than 90 per cent of our funds come from the Federal government where funds for research have become increasingly tight. The increase in 1966-67 was approximately ten per cent, which follows the pattern of recent years. This increase can be accounted for largely by the interest of our faculty in areas that are of increasing concern to both government and the public such as health-related fields, transportation, pollution, and urban affairs. Space research and astronomy have also added to the total. This means that an increasing amount of our support is coming from the Departments of Health, Education and Welfare, Commerce, and the National Aeronautics and Space Administration. It is also true that in general other government agencies which have given us major support for many years, such as those in the Department of Defense, the Atomic Energy Commission, and the National Science Foundation, have not decreased their dollar volume, although the total effort has had to be decreased because they have not been able to keep up with inflationary factors or to provide some highly

desirable research tools. This means that many of our research units either have had to seek funds from other sources or they are not being funded in such a way as to realize fully their potential. For example, the National Magnet Laboratory, an expensive research facility funded by the Air Force Office of Scientific Research, cannot undertake the broader programs of which it is capable, due to budgetary restrictions. The Research Laboratory of Electronics, which has always received major support from the Army, Navy, and Air Force in the form of a single, broadly written contract, has had to supplement its funding by seeking other grants and contracts for more specific programs, although to some extent this also represents a broadening of the Laboratory's interests into areas more appropriately supported by other sponsors.

In addition to the inability of some agencies to increase funds, the government economy drive has also decreased long-term funding. A highly desirable trend in past years was toward advance commitments for several years, but this trend is now less clear and periods of uncertainty of future funding are more common. This situation is particularly bad for graduate students to whom commitments for more than one year must be made. The faculty time which must be devoted to writing frequent renewal proposals is also a demoralizing factor.

Another policy which has affected the availability of funds for research in many major universities is the attempt to build up new centers of excellence on a geographical basis. Unfortunately this is being done at a time when the war in Vietnam has forced severe budget restrictions. The need for the policy is certainly great and geographic considerations should receive attention in the award of grants and contracts from Federal funds. However, the major contribution of the older centers of excellence to this program will be the training of scholars to man the new centers, and this effort should continue to receive adequate support. Research should also be carried out by those best qualified to produce results and the over-all objectives should not suffer by pressures to make funds available on a geographical basis. The only reasonable solution to this problem is provision of additional funds to stimulate the growth of the new centers.

A problem which is increasing in proportion every year is the requirement imposed by Congress that universities contribute more than a token amount to the cost of any program of research funded by a grant from a government agency. This problem is not serious when the volume of grant supported research is small compared to the total academic budget. However, at M.I.T. it has become a major problem because grants now represent more than one-third of our research budget and the total amount of cost-sharing that we are asked to contribute is in excess of

one million dollars annually. This must come largely from tuition and endowment funds or gifts for operating expenses, and therefore it represents a major drain on funds that would otherwise be available for educational purposes.

The sponsored research program now represents about 55 per cent of the total academic budget, and 90 per cent of this comes from the Federal government, five per cent from foundations, and five per cent from industry. We are frequently asked if such major government support does not result in a decrease in quality and in our independence to pursue research programs of our own choice. Does the high proportion of project-oriented research as opposed to broad institutional support result in undue government restrictions on the conduct of research programs or on the Institute's ability to control the over-all direction of its research effort? The answer to these questions, except in rare instances, is no. Federal support, which is far greater than the Institute could afford from its own resources, has certainly increased our quality in both teaching and research and has greatly expanded the opportunity of both staff and students to pursue research programs that would otherwise be unavailable to them. These increased opportunities far outweigh any restrictions that may be imposed by a government agency, including those that are project-oriented. Furthermore, in many instances, particularly in the School of Engineering, project-oriented research fits in very well with both teaching and research.

Another question frequently asked relates to the effect of a drastic cutback in Federal funds for research. Obviously M.I.T. as well as many other major universities would have to make severe readjustments downward under such conditions, and they would be painful. About 30 per cent of our total faculty salary budget is charged to grants and contracts as well as a large share of our operating expenses. Graduate student support is also predominantly from this source. To a considerable extent, we are gambling that, short of an economic disaster, any readjustment downward would not be so sudden as to cause serious problems. Federal support of university research has become a way of life which is very important to both elements of the partnership and therefore it is very unlikely that drastic revisions of the support policy will be made.

During the year our policy on classified research, which has been in effect for many years, was set forth in a written document and approved by a vote of the Faculty. The policy is:

"This statement is written to clarify M.I.T. policy and practices regarding governmentally classified research activities, including classified theses.

"M.I.T. affirms that the encouragement of research and inquiry into intellectual areas of great promise is one of the most basic obligations

to its faculty, to its students, and to society at large. It affirms the profound merits of a policy of open research and free interchange of information among scholars, as essential to this responsibility.

“In the vast majority of research projects, the encouragement of inquiry wherever the research might lead is not in conflict with the principle of freedom of inquiry and open exchange of knowledge. However, M.I.T. is an institution that plays a unique role in important areas of science and technology that are of great concern to the nation. It recognizes that in a very few cases the pursuit of knowledge may require access to data or literature of a classified nature, or yields results whose immediate distribution would not be in the best interests of society. It affirms, therefore, that such activities are undertaken only when, after weighing the advantages and disadvantages for the academic program and for the nation, they are judged to be highly constructive. Since the implementation of classified research has some aspects which are detrimental to the academic environment of the Institute, it is essential that each project be reviewed and acted upon in the light of its impact on the Institute as a whole.

“It is the policy of the Institute, therefore, that every research project within the academic structure of M.I.T. (excluding Lincoln Laboratory and the Instrumentation Laboratory) which requires a classification on the research process or on the publication of results receive the prior approval of the President or Provost, who shall seek the advice of the Committee on Educational Policy in cases that involve modification of the existing policy and will inform the Committee of all approvals.

“Individual classified theses to be undertaken by undergraduate or graduate students must be approved by the Committee on Graduate School Policy before the work involved is begun.”

In the coming year the sponsored research program is expected to continue at about the same level, although the availability of new buildings, such as the Center for Space Research, the Center for Advanced Engineering Study, and the Computation Center may result in a modest increase.

The principal problems facing the libraries result from the greatly increased volume of publications, particularly in science and engineering. These problems can only be solved by a more selective choice of books and periodicals, the discarding or storage of old material, the construction of new facilities, or a major breakthrough in information transfer. The Institute faces some difficult decisions in these areas in the near future.

We have already embarked on an extensive program of information transfer experiments (Project INTREX) directed toward the functional design of new library services under Professor Carl F. J. Overhage in

the School of Engineering (see the report of the Dean of Engineering for details). The project has been established with the twofold objective of finding long-term solutions for the operational problems of large libraries and of developing competence in the emerging field of information transfer engineering. Two specific experiments have been funded and work has begun. Under a two-year contract (\$627,641) from the National Science Foundation, Project INTREX is creating an unconventional library catalogue to be machine-stored for remote access on special consoles to ascertain — in the area of materials science and engineering — the users' preferences for various types and formats of catalogue information. By late June, 1967, the information gathering problems and the input software problems had been solved; activity was centered on enlarging the data base, preparing machine-stored files for remote searching, and designing the logic for the console. Tests of the system with real users are scheduled for the spring of 1968. The other experimental work — in the area of text access — is supported by a grant (\$250,000) from the Council on Library Resources. During the first months of investigation, efforts have been directed to the problem of transmission of a microfiche image from a library to a remote user at a console. Page images have been transmitted with reasonable clarity over a coaxial cable in one-half second, and studies are under way to store the transmitted image and thereby enable the experimental system users to time-share a coaxial network. Funds remaining from an initial Carnegie Corporation grant (\$250,000) enable the continued exploration of the other project goals, but active experimentation awaits larger funding. Faculty and staff members of the Electronic Systems Laboratories, directed by Professor J. Francis Reintjes, are carrying on the experimental work of Project INTREX. The arena for experiments in the user community will initially be the Engineering Library, which is to undergo extensive rehabilitation for this purpose during the coming year. The construction is to be supported partially by the Office of Education under a Title II Grant (\$1,044,999).

CARL F. FLOE

CAMBRIDGE ELECTRON ACCELERATOR

The Cambridge Electron Accelerator is a research facility for high-energy physics sponsored jointly by M.I.T. and Harvard University, located at Harvard and supported by the U.S. Atomic Energy Commission. It provides beams of electrons and photons at energies up to six billion electron volts (GeV). Staff members and graduate students of the De-

partments of Physics at M.I.T., Harvard, and several other universities in New England share the use of the facility.

During the last year the performance of the accelerator was steadily improved. Average monthly utilization was 660 user-hours, far greater than in any previous year.

A new world's record for long-term storage of very-high-energy particles was achieved at the CEA in September, 1966, when electrons of three billion electron volts were maintained in orbit for 30 minutes. In this time interval the electrons traveled a distance approximately equal to two round trips to the sun. Such storage trials pave the way for eventual use of the CEA as a colliding beam machine, in which stored electrons traveling in counter-clockwise orbits will collide with stored positrons traveling clockwise. In such collisions of unprecedented violence, a wealth of new and revealing behaviors of subatomic particles are expected to be demonstrated.

A far more powerful linac accelerator for injecting electrons into the synchrotron was purchased and installed. It is expected to improve the accelerator performance in several respects, notably higher intensity and greater reliability.

M. STANLEY LIVINGSTON

DIVISION OF SPONSORED RESEARCH

The most significant factors affecting the operations and organization of the Division during fiscal 1967 were the increased volume and broader base of sponsored research; the growth of support in such areas as institutional development, student financial assistance and training, academic facilities, and community service; and the administrative problems resulting from this diversity of sponsors and programs. As a result, the Division has modified its organization in order to provide increased specialization by sponsoring agency and category of program, and is accelerating its use of electronic data processing for project administration and for generating management information for use by M.I.T.

SPONSORED RESEARCH

In fiscal 1967 the volume of sponsored research administered by the Division increased by approximately nine per cent over the 1966 figure of \$45,000,000.

With few exceptions, the percentage increase was fairly evenly distributed throughout the departments and laboratories and represented a one-third increase in industrial, foundation, and other private support

DIVISION OF SPONSORED RESEARCH

as compared with a seven per cent increase in Federal sponsorship. In the Federal sector, comprising approximately 90 per cent of fiscal 1967 sponsored research volume, support by the Department of Defense, 34 per cent of total volume, changed only slightly. Support from the AEC, NASA, and NSF increased moderately, while that from the Public Health Service, 12 per cent of the total, increased by 25 per cent. Research volume sponsored by other Federal agencies was down slightly.

EDUCATION AND TRAINING PROGRAM

Federal fellowship and traineeship support increased in 1967, although not as dramatically as in 1966, and amounted to more than three million dollars for 700 graduate students.

Of this amount, the National Science Foundation provided roughly \$1.9 million under five programs, most of it for the support of 360 graduate fellows and trainees. The National Institutes of Health provided over \$575,000 for the support of 105 predoctoral and postdoctoral fellowships, while 45 graduate trainees and several international fellows were supported by NASA, 72 NDEA fellows by the Office of Education, and 31 special fellows by the AEC.

In addition, the D.S.R. assumed joint responsibility, with the Graduate School and academic departments, for a number of non-government predoctoral and postdoctoral fellowship programs providing more than \$210,000 for 42 individuals.

The Division continued to participate in the administration of four international education programs designed to assist in the development of foreign universities. Three of them are sponsored by the Ford Foundation — the Birla Institute of Technology and Science in Pilani, India; the Technical University of Berlin, Germany; and the Indian Institute of Management in Calcutta, India. The fourth — the Indian Institute of Technology at Kanpur, India — is sponsored by the State Department's Agency for International Development, and M.I.T. is one of several universities participating under agreement with the Education Development Center, Inc. From a total of \$326,000 in 1966, total expenditures for these programs increased in 1967 to more than \$900,000, primarily due to activity in the Birla program as it progressed from the planning to the operating stage.

FACILITIES PROGRAMS

Federal support for construction of facilities increased in 1967, with the most significant developments as follows: The Institute received a grant of \$2.9 million from the National Science Foundation for partial funding

of the construction of the Camille Dreyfus Building for graduate research in chemistry, and ground was broken in Eastman Court this spring.

The contract for design of the building which will house the 400-mev linear accelerator in Middleton, Massachusetts, was awarded by the AEC; construction is scheduled to commence in the fall of 1967. Procurement of major accelerator subsystems has begun, based on specifications developed by the Laboratory for Nuclear Science.

Work continued on two other facilities scheduled for occupancy in the fall of 1967 — the Center for Space Research, which receives three-quarters of its support from NASA, and the Center for Advanced Engineering Study, which receives one-third of its funds from the Office of Education under Title II of the Higher Education Facilities Act. Final design for remodeling of the Engineering Library, also funded in part under Title II, neared completion. Actual renovation will begin in the fall of 1967.

ADMINISTRATION

Specific problems involved in administering sponsored programs in fiscal 1967 were not significantly different from those of recent years. The most burdensome problem administratively, as well as financially, was again cost-sharing, since the 1967 appropriations for the major Federal agencies sponsoring research stipulated, as in 1965 and 1966, that each recipient of a research grant must share the cost of the grant from non-Federal funds in more than a token amount. Some improvement has resulted from negotiation with the Public Health Service of an institutional cost-sharing agreement which minimizes some of the administrative problems inherent in determining cost-sharing on a project by project basis. In 1967 cost-sharing approximated \$1.1 million, and for most agencies represented five per cent of grant awards. The National Science Foundation, however, continued with an approach which resulted in cost-sharing of roughly 15 per cent.

The over-all character and direction of program administration continued to change in response to a number of trends in Federal support, one of which is the broader range of programs being supported. Some of these programs represent the extension of research support into new areas of concern such as transportation, air pollution, water resources, and ocean engineering. Other programs involving institutional development, student financial assistance and training, academic facilities, and community service have been expanded or created by recent legislation. These present an entirely new set of administrative problems and regulations, complicated by the trend to decentralized administration through state agencies and regional offices and the fact that in a number of cases

the programs are administered by agencies which have themselves only recently been established.

It should be noted that during fiscal 1967 the Division administered programs sponsored by 46 Federal contracting agencies, including 12 within the Department of Health, Education, and Welfare and 22 within the Department of Defense. Within just one sponsor, the National Science Foundation, the Institute received support from five research divisions and 11 other program areas. Private sponsors included 84 industrial organizations and 101 foundations and other non-profit organizations.

This trend to diversity in programs, sponsorship, and administrative requirements has required modifications to the Division's organization. Traditionally each program administrator in the Division has been assigned a number of departments and laboratories and for all sponsored projects conducted within them has acted as principal administrative liaison with the Federal agencies or other sponsors supporting those projects. It has now become necessary to assign certain program areas to specialists on an Institute-wide basis without regard to the department or laboratory involved. This approach has thus far been adopted for the administration of fellowship and traineeship programs, the international education programs, facilities and construction grants, and institutional programs such as the NSF Institutional grant, the NIH Biomedical Sciences Support Grant, and the Ford Foundation grant for international studies.

Turning to another aspect of Federal support, there have been some notable attempts by individual agencies to maintain flexibility and simplicity in administrative regulations and requirements and to grant greater authority to the grantee institutions, as under the NIH pilot study, but unfortunately the over-all trend is in the other direction. Paradoxically, increasing intra- and interagency coordination may have aggravated the problem. While such coordination has eliminated some unnecessary variations in policy and practice, there are indications that it may also reduce flexibility in accommodating to the particular needs of individual grantees or programs. It may also facilitate the spread of the most, rather than the least, restrictive requirements, and move substantial leeway for making decisions and the exercise of judgment out of the hands of accessible personnel in the sponsoring agencies, and into the hands of inaccessible committees and coordinating groups. For these reasons, it has been necessary to deal with Federal agencies on a broader basis by assigning to specific individuals within the Division the responsibility for becoming familiar with the regulations and administrative policy

apparatus of the major agencies, and for negotiating with agency representatives on contract problems and administrative regulations.

Paralleling the increase in coordination among Federal agencies and related to it is the growing interest of the Federal government in more comprehensive statistics and information on the character of its support to colleges and universities. This has led to requirements for more information on administrative reports to sponsoring agencies as well as an increase in detailed statistical surveys covering a broad range of educational and research activities at grantee institutions. This, in turn, has created some doubts within the university community as to whether the usefulness of the data generated warrants the administrative burden of preparing it.

In any event, this trend, in combination with the need within M.I.T. for better management information, has led the Division to place more emphasis on the use of electronic data processing systems not only for project administration but for retrieving information on sponsored programs. Much of the information to be retrieved is derived from data already present in the accounting computer system. Current efforts to improve data processing capacity center on refining those inputs and developing programs for easy retrieval on a demand basis using utility programs developed by the Institute's Office of Institutional Studies. Since this flexible system may be useful in other administrative areas or may itself profit from the experience of others, close contact is being maintained with other Institute activities interested in the development of information systems.

F. LEROY FOSTER

JOINT CENTER FOR URBAN STUDIES

The last academic year was marked by two developments of considerable consequence to the Joint Center.

First, the five-year-long involvement of the Center with the development of the Guayana region of Venezuela came to an end: on schedule, and with signs of achievement everywhere to be seen, not least being the genuine regret of all those involved that the time had come for parting. Professor Lloyd Rodwin and others now turn to the ambitious series of publications (of which several have already appeared) which will seek to relate and refine the experience for the world of scholarship and of affairs that was so uniquely and happily blended in the course of this singular enterprise.

The second development, if less tangible, has even greater relevance for the future work of the Center. During this year the social condition of American cities became a matter of conscious national concern. The term crisis came to be routinely, if not always accurately, used to describe that condition. In a now familiar pattern, government turned to the academy for information and occasionally for advice. A steady stream of task forces, committees, elected and appointed officials, experts and amateurs, and plain busybodies made their way to the Center, while in turn the Director and others found themselves in Washington more perhaps than was good for anyone involved. It became a curious function of the Center to insist more and more on what is not known, and not understood, in a nation clamoring for solutions to problems that have barely been formulated, much less resolved.

In this atmosphere it becomes more than normally important for the Center to be vigilant in the protection and encouragement of fundamental and slowly maturing research: to plant olive trees where others sow radishes. This has been our object, although none will know for decades whether it has been the result. Funds were extremely limited, and with the phasing out of the Guayana project, overhead unusually high. This required a certain amount of near-commercial activity in order to pay the rent, while leaving "free" money to be used for research. Because of the amounts available, the strategy continued of giving small sums to as large a number of individuals as possible, in as wide a range of studies as could be managed. This worked well enough.

BASIC RESEARCH

As in past years, the approximately 60 studies pursued at the Joint Center during 1966-67 covered a broad spectrum. Some were theoretical analyses; others were descriptive. Many were individual researches conducted by a single faculty member or doctoral fellow; others involved a team of students under the direction of one or more faculty members. About a third of the Joint Center's research during 1966-67 had to do with one or another aspect of urban social processes — a somewhat higher proportion than in previous years. A listing of these studies may serve to illustrate the scope of interest of Joint Center members in this general area. Studies were made on: participation of low-income people in planning, redistricting as a means of alleviating racial imbalance in Boston schools, computer models of internal migration in the United States, computer models of segregation processes, the politics of welfare, politics and planning in London, health services planning in relation to urban planning, factors in unemployment among Negroes, multiple use school-community centers, suburban delinquency, people and social plan-

ning, social psychological models of the desegregation process, social change in Bavaria in the nineteenth century, Christian values and the urban ethos, the changing social and economic position of working class Boston residents from 1890 to 1930, social change and political upheaval in France between 1830 and 1960, and education policy and politics in three Massachusetts towns. Studies of urban government, urban economics and transportation, and of housing and land use continued to constitute a large part of the Joint Center's activities. Fewer studies were undertaken in urban design than in previous years, however, and Joint Center studies in urban problems in other countries was limited to writing up phases of field work previously conducted. Several manuscripts were completed concerning aspects of the Venezuelan project; others, reporting the results of work in a number of other developing countries and in Europe are in progress.

A few synopses of research currently under way shows the variety of subject matter and of methodology characteristic of research at the Joint Center. For example, in a study for the Boston Housing Authority, Professor Charles Tilly undertook to evaluate the effects of rent supplementation in Boston by studying matched samples of 200 low-income families before and after their removal to various types of different housing situations. The test group was 40 large low-income families displaced by urban renewal action that moved to apartments in each of three new garden-type private housing developments financed under the FHA moderate-income mortgage insurance program, with their rents partially subsidized under the Boston Housing Authority program. This group was compared with 40 families moving to similar housing, but not receiving rent supplementation, with 40 families moving to public housing, and with 40 families moving to private housing. Before and after interviews determined the characteristics of the families, the nature of present and past housing experience in the housing market, and social participation. This study involved a good number of student interviewers, coders and programmers, and extensive statistical analysis.

Another study, being conducted by Walter B. Miller, seeks to measure the nature and extent of juvenile delinquency in the suburbs. Besides demographic analysis and study of police records, the research employs techniques of monitoring police broadcasts in selected suburbs of known characteristics, using tape recordings of conversations between police cars and headquarters. Field work also includes observation at various natural gathering places of teenagers such as corner drug stores.

In contrast to these descriptive studies, Professor Jerome Rothenberg is attempting to set up an explicit formal model of the interaction between economic outcomes and political decisions in a representative

political system. His study focuses on the transmission of economic events to political relevance for constituencies, their political action, the consequent effect on legislator commitments, and resulting legislative decision making. It is hoped that the model will enable one to predict economic-political patterns in metropolitan areas.

Still another research tool, computer mapping, was employed and developed in a doctoral thesis by Carl F. Steinitz on the congruence of urban form and activity. The study included field surveys of urban form and social activity in central Boston, evaluating their congruence through the use of the SYMAP computer mapping program for analysis and graphics. It investigates how the physical environment of city neighborhoods acts as a field of communication.

PUBLICATIONS

The Joint Center during 1966-67 added four books to the growing list of publications resulting from the research of its members. They were: Ira M. Lapidus, *Muslim Cities in the Later Middle Ages*. (Published jointly with the Harvard Center for Middle Eastern Studies.) A study of the social structure and political processes of some Muslim cities in the period of the Mamluk Empire. Major attention is given to Damascus and Aleppo, with Cairo, Alexandria, Beirut, Tripoli, and other smaller towns also examined.

Martin Meyerson and Edward C. Banfield, *Boston: The Job Ahead*. A discussion of a variety of problems facing Boston, such as housing, schools, police, and taxes.

Richard M. Soberman, *Transport Technology for Developing Regions: A Study of Road Transportation in Venezuela*. A case study of planning transportation facilities for the Guayana region of Venezuela, intended primarily to illustrate the application of various economic concepts to engineering design.

James Q. Wilson, editor, *Urban Renewal: The Record and the Controversy*. A collection of articles about the background, workings, and problems of the federal urban renewal program, discussing the major economic, legal, social, political, planning, and design issues surrounding the program.

In addition, two works were published under the auspices of other organizations which sponsored research and writing carried out under the direction of the Joint Center:

Planning Metropolitan Boston, published by the Metropolitan Area Planning Council of the Commonwealth of Massachusetts. A comprehensive statement of the Council's program of activities in metropolitan Boston over the next few years, resulting from a research program and series of

conferences conducted by the Joint Center for the Council in 1965 and 1966.

The Metropolitan Enigma: Inquiries into the Nature and Dimensions of America's "Urban Crisis," published by the United States Chamber of Commerce. A collection of 11 papers, written by urban scholars and edited by James Q. Wilson, analyzing current problems in America's cities. The papers were commissioned from the Joint Center by the Chamber of Commerce as resource material for its Task Force on Economic Growth and Opportunity.

ACTIVITIES ON THE NATIONAL SCENE

The Joint Center continues to enjoy the distinction of having two of its former members, Professors Robert C. Wood and Charles Haar, serving respectively as Under Secretary and Assistant Secretary of the U.S. Department of Housing and Urban Development. Professor Frieden and a number of others associated with the Center have been active consultants with the new Department.

In a novel undertaking that promises to have significant long range results, the Joint Center, with the cooperation of the Bureau of the Census and the National Center for Health Statistics, sponsored a Conference on Social Statistics and the City in Washington from June 22 to 23, 1967. This meeting, the first of its kind, brought together the government officials responsible for the gathering of social statistics and representatives of the various scholarly disciplines that use them. Papers presented to the conference established that in the past, Negro and other minority groups have been seriously undercounted in official data. A series of resolutions concerning measures to resolve this problem, and to improve national social statistics generally, was adopted by the conference and has received widespread attention.

ACTIVITIES FOR THE BOSTON AREA

Several new avenues for contributions by scholars to public programs in the Boston area were opened up through the efforts of the Joint Center in 1966-67. These efforts received the continued support of the Permanent Charity Fund of Boston, in the second year of its two-year grant of \$50,000 to the Metropolitan Boston Studies Program.

A study of the arts in Boston and their sources of support, leading to a conference and a report early in 1968, was begun in February by Bernard Taper of New York City. Officially, the study is being carried out under the auspices of the Cultural Foundation of Boston, with a grant from the Permanent Charity Fund. However, the Joint Center has performed the work of organizing the study, and will conduct some of the surveys required, as well as the 1968 conference.

Proposals drafted by the Joint Center, in conjunction with the Boston Redevelopment Authority, have resulted in a grant of \$368,000 to the Authority by the Urban Beautification Demonstration Program of the U.S. Department of Housing and Urban Development. The concept of a study to develop a comprehensive policy for outdoor signs and lighting for the City of Boston, including experimental demonstrations, has evolved in discussions with the Authority that were begun by the Joint Center in the fall of 1965. This is one of the two major current projects of the national urban beautification demonstration program. It will be headed by Stephen M. Carr, Assistant Professor of Urban Design at M.I.T., under the auspices of the architectural consulting firm of Ashley, Myer and Associates of Cambridge.

A member of the Joint Center's professional staff continues as a member of the Massachusetts Commissioner's Task Force on Racial Imbalance in the Public Schools, following the completion of a study of redistricting prepared for the Task Force during 1966. Major contributions to the Task Force this year have involved advice on locations and attendance areas for proposed new school buildings to alleviate racial imbalance, and expert testimony in the court review of the State's actions on the Boston plans for racial imbalance.

The cooperation of university scholars and city officials has led to the submission of a unique and highly promising application by the City of Cambridge for its participation in the Model Cities program created by the 89th Congress. Through the coordination of the Joint Center, 21 faculty members from M.I.T., Harvard University, Tufts University, and Brandeis University drafted various key sections of the program, anticipating a continuing role in carrying them out, should Cambridge be designated as the site of one of the model cities. This has been only one part of the active assistance of the Joint Center to the new community development program in Cambridge, which has also included aid in continuing and expanding on-going programs.

The two-year collaboration between the Joint Center and the Metropolitan Area Planning Council led to the publication in April of a 212-page comprehensive report entitled *Planning Metropolitan Boston*. It combines an objective review of the state of the region and its planning with a specific action program for the Council. Membership of the Council includes delegates from the governing bodies of 87 cities and towns in an area extending to roughly a 30-mile radius around the center of Boston, from Ipswich on the north to Marlborough on the west to Duxbury on the south. State agencies that play key roles in the development of the Boston area are also represented. The program drafted by the Joint Center was officially adopted by the Council in April, 1966.

The Joint Center staff has continued and expanded its liaison with many city and state agencies, and handled innumerable requests for advice and assistance from a variety of people that ranges from high school students to Federal, state and local officials, and to candidates for political office. A case in point is the role of Joint Center staff and faculty members in the new Citizens Housing and Planning Association of Metropolitan Boston, organized in the fall of 1966. Four of the members of the Executive Board of C.H.P.A., as well as some of the most active members of its working committees, are members of the Joint Center. Another case in point is the forthcoming critique of the public housing program in Boston, sponsored by an ad hoc advisory committee which has received a great deal of time and effort of members of the Joint Center.

MEETINGS

One of the most important functions the Joint Center serves is to bring together people from a variety of academic backgrounds and experience to consider the special problems of the city. While a good deal of inter-university and interdepartmental activity of this sort is carried on through our research activities, a great deal more is generated through the various meetings held during the course of the year at the Joint Center. It is of particular note that at most of our functions, graduate students from a variety of departments, our Fellows, and our research assistants, have regular opportunities to exchange views with professors and with our visiting associates from other countries.

Among the 25 speakers at our Tuesday lunches last year we had the privilege of hearing from activists as well as theorists. Mayors Lindsay and Cavenagh, Robert C. Wood and Robert Moses, for example, brought us accounts of their own front-line operations. A number of Joint Center members, including Stephan Thernstrom, Martha Derthick, and John F. C. Turner, shared their thinking on their own research endeavors.

It was a special pleasure for the Center to have as a springtime luncheon speaker the Honorable Paul Ylvisaker, the newly appointed Commissioner of Community Affairs in the State of New Jersey. As Director of Community Affairs for the Ford Foundation, Dr. Ylvisaker was in a sense one of the founders of the Joint Center, a move he continues to defend with enthusiasm and skill.

The Joint Center was the host of two term seminars: one on the relation of health planning to city planning, conducted by Professor Bernard Frieden of M.I.T. and Professor Robert Morris of Brandeis; one on the economics of transportation planning conducted by Professor John Kain of Harvard. Among the single session seminars given at the

Joint Center, one by Erving Goffman and another by Danilo Dolci were of note.

DANIEL P. MOYNIHAN

LIBRARIES

Last year's annual report was devoted largely to the state of the M.I.T. Libraries system. This year the emphasis will be on planning for the future. Like all libraries which attempt to maintain a historical record as well as to keep abreast of current publications, we are growing at an ever increasing rate. In such a situation new space must be acquired periodically. Predictions of space needs for coming years constitute the first part of this report. Following that is a section on the application of computer techniques to library operations, and finally a section on the current year's activities.

GROWTH AND SPACE NEEDS

Conservative projections for the growth of the M.I.T. Libraries to 1980 (Table I) show the number of years before the various Libraries will be filled to capacity. Long before that, however, trouble begins in the form of local crowding. New books arrive but there is no room on the shelf where they belong, so shelves of books may have to be moved to make space. This is the situation now in both Science and Humanities. The other Libraries, Engineering excepted, are either new or have been remodeled within the last six years. Engineering will be renovated, and its collections are being weeded and sorted so older materials can be moved to storage. The same procedures will be applied next year to the Hayden Building where the Science and Humanities Libraries are beginning to crowd each other in the basement stacks.

The Hayden Building will be too full for efficient use in four years and solid full in five. The Rotch Library of Architecture and City Planning is full now. Though expanded two years ago, it is again approaching the situation where to add a book you have to take one out. The Music Library is in a similar condition. Archives has been desperately short of space, but plans have been made to improve the situation by early next year. The Technical Services Departments also expect relief through expanded quarters.

The library space problem is only part of a total space squeeze in which the Schools of Architecture and City Planning and of Humanities find themselves. Both are planning new buildings and libraries. This relief cannot come too soon. The Rotch Library is an active collec-

Table I Projected Growth in Square Footage of M.I.T. Libraries (excluding Engineering Libraries) 1966-1980

	Years									
	1966	1968	1970	1972	1974	1976	1978	1980	1966 capacity	1980 capacity
Dewey	19,266	28,865	32,954	37,190	41,457	45,916	50,431	54,315	2*	2*
Humanities (including Music)	30,660	41,186	45,817	50,040	53,961	57,623	60,663	62,823	4**	4**
Rotch	7,980	12,325	14,352	16,158	17,565	19,188	20,636	21,909	0	0
Archives	2,880	5,845	7,774	9,569	10,960	12,009	12,751	13,500	0	0
Central Services	10,690	16,650	18,700	21,150	23,600	26,100	28,400	30,100	0	0
Subtotal***	71,476	104,871	119,597	134,107	147,543	160,836	172,881	182,647		
Science (including Lindgren)	28,230	41,670	46,241	50,894	55,389	59,642	64,665	68,670	4	4
Student Center	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000		
Total	124,706	171,541	190,838	210,001	227,932	245,478	262,546	276,317		

*five if we move into the second half of the second floor.

**square footage includes Music which is now full.

***approximately five per cent less if combined in one building.

tion rapidly growing in the new areas of the history of art and of architecture. Removal to storage of substantial numbers of volumes would fragment the collection in a most undesirable manner. Nor would it be desirable to store any of the Humanities collections; the need for more retrospective materials at hand was emphasized in last year's report of the SCEP (Student Committee on Educational Policy) Subcommittee on the Libraries. Either the Humanities Library or the Science Library will have to be moved out of the Hayden Building in the near future to make room for a healthy growth of the one which remains. The proximity of the Science departments in Eastman, Dorrance, Whittaker, and the new Chemistry building make it more logical for the Science Library to remain in Hayden.

Our figures show that the Science Library alone will fill the Hayden Building in 15 years. This prediction may seem surprising but it is firmly based on statistics such as the fact that the literature of physics is doubling every eight years. Our inadequate humanities collections will also have to double every eight years to provide for advanced undergraduate and graduate study in the present and contemplated fields of activity of the School.

The quarters of the Dewey Library are only two years old, but the unexpected addition of political science materials and a growth rate more rapid than had been anticipated because of purchases from a grant of the Ford Foundation International Program now allow only two years of continued growth before Dewey is full, five years if the second half of the second floor is incorporated. Weeding does not offer much possibility for relief because the collections are relatively new. Dewey had approximately 61,000 items when it was moved to the Sloan Building in 1952; now it has 223,000.

There are good reasons for combining the libraries of the Schools of Architecture, Humanities, and Management. The interdisciplinary needs are increasingly evident. For example, books on employment, data processing, statistics, and water resources are needed by planners located in Building 7 as well as economists in the Sloan Building; historians in Hayden have need of political science material now in the Dewey Library; and political scientists are interested in the art and literature of emerging countries, often the only printed clue to social characteristics, and those books are in Humanities or Rotch. To satisfy such needs each divisional library is now buying some material, but no collection in depth is available in one place. Pulling these together in one location would greatly strengthen our research resources for all. A combined library for these three schools would bring about considerable savings in staff, particularly for circulation, bookchecking and photocopying activities

and would allow the professional librarians to spend more time in collection development and reference service for their own faculties. It will also require about five per cent less area and an estimated saving of 15 per cent.

I recommend that we now start thinking about a new building, with 160,000 square feet to be available by 1976, to house Rotch, Humanities, and Dewey plus a number of activities for which present locations are inadequate such as Archives and Rare Books, the Music Library, the Technical Services Departments, and the Library Administration. To provide for continuing growth there will have to be 183,000 square feet by 1980. This space would not be needed all at once but could be designed, as the Hayden Building was not, to provide for expansion as the need arises. If the new homes for the School of Architecture and City Planning and the School of Humanities could be located in the Ames, Amherst, Main Street triangle, a library building in the same area would be convenient also to the School of Management. This would release the Hayden Building for the Science Library and its future growth.

In my opinion, books, journals, and technical reports will continue to be the primary means of storing knowledge and transmitting information for the next ten or 15 years at least. The world publication rate is increasing at about ten per cent a year. It is not to be expected that book publication will suddenly stop and that microfilm or some other microform will take its place. For the foreseeable future we shall have to plan libraries for books and film as well as for card catalogs and computers. That is the usual way of technological change; the old and the new continue to exist side by side for a long time.

RESEARCH AND AUTOMATION

For a number of years we have had an active program of research in information retrieval under the leadership of Dr. Myer M. Kessler, Associate Director of Libraries. In my previous reports this Technical Information Program has been covered only briefly. It has now reached a stage to warrant a more complete treatment.

Project TIP started officially in April, 1962, with a grant from the NSF “. . . to *design* a pilot communication system for the technical community. . . .” This evolved through a two-year grant (1963-1965) “. . . to *construct and operate* an experimental model of a technical information system . . .” to the present two-year grant (1966-68) “. . . to *operate* an experimental model. . . .” Thus, the project developed from design, through construction, to its present status as a prototype operation.

In each of our proposals the opening sentence quoted above was

followed by the statement. "It shall serve as a test bed for ideas and components. . . . It shall provide systems experience for operation and evaluation." The intent was to exploit modern computer technology in the cause of scientific communication and to set up a working model of a system that will demonstrate the potential promise of the engineering contribution to this field.

This has been a mission-oriented project. But, as often happens in such cases, extension of techniques and generalization of concepts lead to a beneficial fall-out beyond the intended mission. We have learned a lot about such matters as file organization, the handling and manipulating of structured lists, the organization of large data banks, and the design of interactive languages. The present generalized TIP package, which we call NEWTIP, is a very flexible tool that can handle structured data in general, not only scientific information. As such, it is applicable to library catalogs, personnel files, and financial and managerial information. These extensions are now being explored.

Our goal throughout this period has been to engage in many functions rather than to offer a massive service in any one area. The following type functions have been developed and tested:

1. The basic TIP library of about 100,000 articles from physics journals is in machine-usable form. Of these, 30,000 are on line, the rest on magnetic tape. This library grows at the rate of some 1,200 articles per month.
2. The TIP search package allows a variety of console operations to be performed on the above library for purposes of search and retrieval.
3. Several review articles and a book have been written on the basis of TIP literature search.
4. TIP is in constant use from about 20 consoles each week.
5. A console has been installed in a room used by physics graduate students who are now writing theses. The use of this facility is being monitored.
6. We have instituted a weekly notification of M.I.T. physicists when one of their papers is cited.
7. Social scientists and historians have used TIP to study the flow and dynamics of scientific literature.
8. Several students are using the facilities of TIP for research papers and theses.
9. The TIP package is being tried by several administrative offices at the Institute as an aid to their managerial functions.
10. The TIP package is being used to collect, process, and prepare for

publication a catalog and inventory of M.I.T. journal and periodical holdings.

11. A catalog of books and materials in the Student Center Library was prepared and printed with TIP facilities.

The list above indicates that our original goal of prototype design and operation is now more or less accomplished. For the next two or three years we have in mind the following course of action:

1. We should continue our present research and development program, including the transition of NEWTIP into the new computer environment.
2. Responsible administrative structures must be evolved to assure eventual and orderly transfer of functions when they reach the service level.
3. We must train people who can exploit the operational capabilities that we have already achieved.
4. We have to extend our investigations into areas where legal, social, and human problems predominate.
5. We should integrate our work with other research and teaching activities on the campus.

In order to support a reasonable effort along these lines, certain facilities will be required. Space is not a major problem, and funds, we have reason to expect, can be arranged one way or another. Several outside sources have expressed interest. The critical items are personnel and computer access. We need six or eight people of the postgraduate, research associate variety. In order to attract such people, we must offer them a meaningful experience at M.I.T. for a year or so. This would ordinarily involve an attractive mixture of research and education. In both areas we are leading the pack, so to speak, and should have no trouble, given reasonable compensation, in attracting a constant flow of gifted postgraduates. We hope to get outside support for this program.

The matter of computer access is more difficult. In order to continue our present research and training and provide a minimum capability for the orderly transfer of TIP functions to interested agencies inside and outside the Institute, we need the equivalent of a present-day memory unit (40,000 to 80,000 tracks), some 20 output consoles, and the equivalent of 40 to 50 hours of processing time per month. Needless to say, this aims at the new computer era which may be two years away. During the transition from the present to the new computer era we shall have to accommodate to our present facilities.

TIP as a project was not planned to be directly concerned with general library automation, and has not been funded to improve and modernize the M.I.T. Libraries. There has, nevertheless, been a steady fallout from TIP activities of use to the Libraries. The 12,000 odd serials and journals that we receive are well on the way to being under computer control.

We have also given serious thought to such things as book catalogs and circulation control.

What we usually call library automation concerns the internal management and inventory control of the growing bulk of material and number of transactions in large libraries. The problems are not much different from those encountered in other services that dispense to the public such as large banks, insurance, and mail order companies, to say nothing of the Internal Revenue Service, social security, and the Army Quartermaster Corps. This work cannot depend entirely on TIP fallout, and if we are to proceed seriously along these lines, we must find independent financing for it. An effort is now in progress to raise funds for this purpose. If we want library automation now, we can have it, but the price tag is too high. It is only now beginning to approach feasibility.

The improvement of the management function in the library, important as it is, does not, however, represent the main thrust and promise of computer technology in the field of information handling. The revolutionary dream is that the computer, as a logical machine, has application not only as a bookkeeper but also as a correlator of recorded knowledge and a discoverer of relations between isolated bits of information whose record, although available, is so dispersed that the integrated pattern does not emerge. Knowledge, like energy, in order to be useful must be gathered into a concentrated package. It must be brought into a focus in space and time. Only then can human imagination play on it and acquire insight. A computer can gather dispersed knowledge as a parabolic mirror gathers dispersed sunlight. This is a gleam and a conjecture, but the record of our experimental system makes us think that it is a direction that we should speculate on.

It is no exaggeration to say that the average engineer or scientist acquires information from an intelligent use of recorded knowledge as much as from direct experimentation. From the very beginning of its history, M.I.T. has recognized the importance of laboratory work and instruction in experimental techniques. I suggest that the opportunity is now here to do equally pioneering work in exploring new approaches to the vast record of existing knowledge. The techniques of knowledge extraction from the record should be introduced into our scientific and engineering curriculum, even as the experimental techniques are now being taught.

If we accept this challenge and consider the library to be the proper locus for such activity, then we will, indeed, have set ourselves a goal beyond the standard application of computers to library automation. This would be consistent with M.I.T. policy that, rather than mere efficiency of operation, excellence and distinction are to be sought.

THE LAST YEAR

A principal project of the last year has been an effort to bring books and journals to the shelves more speedily after the initial selection has been made. Miss Frances R. Lubovitz, Acting Head of Technical Services and Head Cataloger, and Robert L. Hadlock, Head of Acquisitions, have scrutinized each procedure, written new manuals of instruction, and revised many forms. To aid in this effort, Fred Wood of the management consulting firm of Wood and Tower was asked to survey the situation and make recommendations, especially concerning the processing of rush and reserve books. We hope that the new procedures we have adopted and others Mr. Wood will recommend in his final report will significantly improve the situation next year.

Any delay in getting reserve books on the shelf is critical. Two factors have made this more difficult in the past few years. First is the large increase in the number of titles requested by faculty for reserve and recommended reading. The Dewey Librarian, for instance, reports that 10,781 items were requested this year, 5,880 in 1965-66; the Rotch Library experienced a 43 per cent increase in reserve requests this year over last. The other factor which the library cannot control is the lateness with which faculty members send in lists. A form sent out early in the term in conjunction with the Coop has helped considerably, but the increased length and number of reading lists partially offsets progress that had been made as a result of this joint effort.

Everyone can rejoice over the decrease in time that journals are now at the bindery, three weeks instead of six to ten. The new contractor calls for and delivers weekly.

Experience with Project INTREX indicates that additional money can speed up processing substantially. Three people have given special handling to items designated rush by the Engineering Libraries. Methods such as telephoning orders, having books sent by air mail, and personal pick-ups at local bookstores are effective. They are, nevertheless, too costly for general application within our present budget.

Catalog cards received under Title II C of the Higher Education Act of 1965 are of great assistance in cataloging our foreign material. The Library of Congress is obtaining catalog copy by setting up its own offices in many foreign countries. In this way, cards are printed by the time the books arrive here. M.I.T. is one of the cooperating libraries receiving a complete set of cards. We match our receipts against the file and, since we use the Library of Congress system, can thus catalog them immediately. We receive Library of Congress copy for about 70 per cent of current acquisitions. In spite of the improvements discussed above there are still backlogs and delays to which the shortage of pro-

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fessional personnel and the high turnover of clerical help are major contributors.

Table II shows how the acquisitions in our Divisional Libraries have increased in the last two years:

Table II Volumes Added

	1965-66	1966-67
Dewey	19,576	28,267
Engineering	12,557	14,344
Humanities	9,617	13,754
Rotch (excluding slides)	4,819	4,983
Science	9,953	11,804
Total	56,522	73,152

This increase is particularly startling in the case of the Dewey Library where serial literature and government documents play a serious role. This literature is difficult to handle because of its form and complicated bibliographical nature. A document center within the library system would be desirable.

As our library expands, the basic policies of book selection become more important than the techniques of handling. We must spend our funds as wisely as possible to ensure quality. This topic has been of deep concern to all our librarians for several years and the subject of numerous staff meetings. Do we collect only in present fields of research interest? If so, in what depth? How much should we rely on the resources of other large libraries? Do we completely ignore fields in which interest has slackened but may pick up again? By then the journals are out of print and costly. Many examples of the problem could be given. One brought up this year by Miss Margaret Otto, the Lindgren Librarian, may illustrate. In the past few years she has noted a shift in emphasis from traditional geology toward geophysics. Do we continue to add to our present superior geology collection, or do we drop it as a major element in our collection profile? As a further complication, geophysicists probe into astronomy and astrophysics, where the journals are being collected elsewhere in the system.

During the past year book selection policy has been discussed in the Academic Council and a call for assistance was issued to some faculty members in a letter from the Director. There was response in certain areas. We need more. If it proves impossible to get the necessary guidance from our faculty, we may want to consider faculty appointments where part time is specifically designated for library development. Another alternative is to appoint subject specialists to the library staff, a method

widely adopted by large academic libraries. These specialists would work with the faculty and on their own.

The past year has been our first with an Archivist on the staff. Professor E. Neal Hartley reports "very encouraging progress in the translation of a collection of Institute memorabilia and files of published materials into working Archives. Central in the process has been the gradual development and partial implementation of policies for the flow of M.I.T. original record materials from active to inactive to archival." Just at the year's end, space has been found for sorting and arranging the significant collections now ready for transfer from offices, departments, and laboratories as established by a survey during the year. A modest program of microfilming valuable and heavily used materials is being launched.

The enthusiasm with which the Student Center Library has been received on the campus is heartwarming. In fact, word of it has gone forth to all the campuses in the Boston area, causing an influx of outsiders. M.I.T. students through SCEP and Student Center Committees have been most cooperative in deciding to exclude their own guests during reading and examination periods. They also prepared signs for the study carrels asking people not to monopolize them by leaving books or papers while they go out for lunch or class or sleep.

The popularity of this study-hall/reserve book library necessitated two decisions made during the year — it will remain open 24 hours per day all year including summer and vacation periods, and all persons entering are asked to show M.I.T. identification. The total attendance was 397,000 for the first whole year of operation compared to 178,000 for the first seven months of operation last year. The heaviest single week was that of January 9, 1967, when 14,000 persons entered; last year's heaviest was the last week in May with 10,000. Requests for facts about this library and words of approbation on its operating philosophy are coming from librarians all over the country. M.I.T. appears to be pioneering in a new kind of library — a convenient, attractive, comfortable room open 24 hours a day containing the basic books needed for current graduate and undergraduate subjects.

Though Archives and the Student Center Library have been specifically mentioned above, other libraries and units in the system have also been active.

Dewey's fast growth, its difficulties in receiving material promptly from the central Technical Services, and looming space problem have already been touched upon. It experienced a 20 per cent increase in circulation. Rotch Library, too, has experienced a dramatic increase in circulation, largely of reserve books; the number of reserve books

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doubled over that of last year. The Engineering Library also had a 20 per cent circulation increase, reflecting increased emphasis on purchasing adequate numbers of copies in anticipation of demand, and better guides and assistance to readers. Plans for renovation of its quarters are in the final stages and will combine traditional and experimental facilities for the operating environment of Project INTREX.

A first step has been made in implementing the DeGennaro report on the Science Library, mentioned in my report last year. In late June a handsome new carpet was laid over the entire reading room floor. This one stroke has taken away the airport waiting-room effect and brought about a quiet, more attractive atmosphere. It is also an experimental carpet. The manufacturer has woven in fibers of stainless steel to offset the electrostatic effect which is so troublesome in times of low humidity. The Science Library staff is giving much thought to the arrangement of collections on the first floor and in the basement in order to give maximum access to the most used books. Intense use of Science Library materials, as always, is made by industry, mostly through copying of journal articles via the Microreproduction Laboratory. With the NASA Electronics Research Center beginning to function nearby, government use is increasing too. NASA maintains a full-time person in the libraries to gather and arrange for photocopy processing.

The Microreproduction Laboratory reports a 17 per cent increase in its over-all activities. In December, 1966, it was agreed that its Head, Peter Scott, would spend a substantial portion of his time with Project INTREX. To handle the day-to-day administrative functions of the Laboratory, John E. Soares was appointed Administrative Assistant.

The Humanities Library has experienced an active year in collection development with the welcome assistance of some faculty members. Because of its physical proximity to the Union Catalog and the national bibliographies it acts as a distribution center for answers to bibliographic questions forwarded from many departments of the Institute. It also handles the interlibrary loan and interlibrary borrowing, giving it an over-all view of the lacunae in our collections. The calls by our faculty and graduate students for titles not owned by the library were mostly in the fields of biology, medicine, and humanities, an indication of need to strengthen these areas.

GIFTS

We are deeply grateful for the many gifts received through the year from alumni, faculty, and friends of the Institute.

STAFF ACTIVITIES

Only a few library staff members have been mentioned individually in this report, but the active cooperation of all is deeply appreciated. Divi-

sional Librarians and Department Heads particularly bear considerable burdens and it is due to their creative response to problems that the library progresses.

The M.I.T. Libraries were well represented at many professional meetings held during the year. These include the Association of Research Libraries, the American Library Association, Special Libraries Association, Music Library Association, New England College Library Association, New England Regional Medical Library Association, and New England Technical Services Librarians, as well as the American Documentation Institute and the International Federation of Documentation. The activities mentioned below are only a few in which our industrious staff are involved.

Eileen E. Borland, Music Library, aided in the arrangements for and was hostess at the Music Library Association regional meeting held at M.I.T.

Joseph M. Dagnese, Assistant Director of Libraries, went to Pilani, India, for a year's leave of absence at the Birla Institute of Technology and Science where he is acting Director of Libraries and advising the administration in their efforts to strengthen the Birla Institute Library.

Mrs. Irma Y. Johnson, Science Library, was appointed a member of two Committees of the Special Libraries Association (Boston Chapter), the Liaison Committee with Commonwealth Technical Resources Service and the Consultation Committee.

Dr. Myer M. Kessler, Associate Director of Libraries, spoke at the annual meeting of the American Documentation Institute held at Santa Monica, California, and participated in the Ciba Foundation Symposium in London and the Conference on Computers in Humanistic Research at Texas A & M University. His committee memberships include the Advisory Committee on Documentation of the American Institute of Physics and the Advisory Committee on System Development of the National Library of Medicine.

Eileen R. Kibrick, Catalog Department, at the beginning of this year completed a three-month period on loan to the National Agricultural Library in Washington, D.C., helping them with their work on the *Agricultural/Biological Subject Category List*.

William N. Locke, Director of Libraries, was elected a Councilor of the American Documentation Institute and Vice President and President-elect of the National Federation of Modern Language Teachers Associations. He has been appointed Chairman of a new International Federation of Documentation Committee, Linguistics in Documentation (FID/LD), and attended the International Congress of FID as Alternate U.S. Delegate in The Hague, Netherlands. In the spring Professor Locke

went to Berlin under the exchange program with the Technical University of Berlin Library to study German university library procedures.

Frances R. Lubovitz, Catalog Department, was a Lecturer at Simmons College School of Library Science in the field of Cataloging and Classification. She also retained her memberships on two American Library Association Committees, the Subcommittee on Filing and the Descriptive Cataloging Committee.

James M. Matarazzo, Science Library, served as a member of the Membership Committee of the Special Libraries Association (Boston Chapter).

Peter R. Scott, Microreproduction Laboratory, was Chairman of the Library Standards for Microfilm Committee of the American Library Association. Mr. Scott's other committee responsibilities are as follows: Chairman, U.S.A. Standards Institute Committee on Microfiche and Micro-opaques; Vice Chairman, U.S.A. Standards Institute Committee on Photographic Reproduction of Documents; and member of the editorial boards of *American Documentation* and *National Micro News*.

Patricia M. Sheehan, Technical Information Program, addressed the Committee on Library Automation of the American Library Association at the Pre-conference Institute on Library Automation in San Francisco, California, and a meeting of the Science-Technology Group of the Special Libraries Association. She also lectured at Simmons College School of Library Science.

Mrs. Virginia E. Smith, Circulation Department, and William H. Scholz, Acquisitions Department, were members of the Hospitality Committee of the Special Libraries Association (Boston Chapter) during this past year.

WILLIAM N. LOCKE

THE M.I.T. PRESS

For four years, I have made the following points in my annual reports:

1. The M.I.T. Press has become as capable of first-class publishing service to its authors, to the Institute, and to the world of research scholarship as any university press or professional publisher anywhere.
2. In this endeavor the essential resources that have been made available to the Press by the Institute are (a) working capital to provide our development and growth, (b) editorial advice and judgment from the M.I.T. faculty and The M.I.T. Press Board, (c) contributions from M.I.T. authors which now account for 40 per cent of the books we publish.

3. M.I.T. measures the achievement of its Press by the number of good books it publishes.

The present mission of The M.I.T. Press continues as before — to publish as many good books as it can afford. Of the 96 books published last year, 20 were paperback reprints, 15 were imported books in whose creation we shared with overseas publishers. The other 61 were works of *original* American scholarship ranging widely in subject and audience. The previous year we published 85 books in accordance with our plan to issue no more than 100 books a year through fiscal 1967-68. Total M.I.T. Press book publications are now over 500, about 80 per cent of which have been published in the last five years.

The selection of manuscripts deemed worthy of publication is the responsibility of the Director of The M.I.T. Press. The certification of the manuscripts deserving of the imprint of The M.I.T. Press is the responsibility of the faculty Board of the Press. The Board is assisted in its evaluations by the best critical reviewers that the Press can find. The quality of a work is the governing consideration for publication. Questions of potential sale are not critical in the Board's appraisal since the absolute value and utility of a given publication is not a function of the size of its potential market.

Table I on the next page shows the distribution by subject of books published by the Press over the last five years and indicates the source of the manuscript as from within or outside M.I.T. (For this summary doctoral dissertations have been regarded as from within M.I.T. though the authors may have completed the manuscript elsewhere.)

A few comments on the summary are in order.

The larger number of titles published in the humanities and social sciences is a product of (1) professional forces within these disciplines which, unlike science and engineering, favor book over journal publication, and (2) a deliberate editorial policy of the Press to supplement (as well as follow) curricular patterns of M.I.T., most notably in our paperback reprint series, and there principally in the subjects of history of science and technology, social science and politics, education, and science and public policy.

A reflection on the character of our list is a recurring emphasis upon contemporary social, political, and technological problems. This is better seen from The M.I.T. Press catalogue than from the numbers above. Our list reflects an M.I.T. preoccupation, that of addressing real concerns in our time in order to seek solutions for our time.

For five years we have sought to publish books for scholars' reference, for students' instruction, and for the non-specialized enlightenment of the specialized world. We have been most successful in the first quest,

Table I Distribution of M.I.T. Press Books by Subject Matter 1962-1967

	1962-63		1963-64		1964-65		1965-66		1966-67	
	*	†	*	†	*	†	*	†	*	†
<i>Engineering</i>										
Aeronautics			1	1						
Chemical engineering			1		1					1
Civil engineering				1	2		1		3	
Electrical engineering	6		5	2	2	1	6	4	3	1
Mechanical engineering	1	1	1		1				4	1
Metallurgy	1				2	1	2			
Naval architecture										
Nuclear engineering				1	2					3
<i>Science</i>										
Biology					1		6			
Chemistry										
Geology and geography					1	1				
Mathematics			3	1	2	2	1	1	2	7
Meteorology										
Nutrition			1		2				1	
Physics	1		4	1	2		3	1	2	6
<i>Management</i>	1		6	2	1	1	6		2	
<i>Social Science</i>										
Center for International Studies	2		2	2	5	2	2	2	4	3
Economics	2		1	3	1	2	6	4	1	4
Linguistics, History of Science and Technology, Library Science										
Political Science	1			2	3	7	1	5	2	9
Psychology						4		1		
<i>Humanities</i>		2	3	7	3	15	5	15	3	20
<i>Architecture and Planning</i>		3	4	3	4	5	1	9	2	10

*Source of the manuscript within M.I.T.

†Source of the manuscript outside M.I.T.

least successful in the second, and are frustrated rather than satisfied by our partial success in the third.

Our internal or mechanical growth in strength and dimension is not always linear, as is evident from the following chart. We have grown substantially in scale, much faster than any other American university press. A few scars of rapid growth are with us still, but they are counterbalanced by continuing imaginative pursuit and energetic execution. Our growth in numbers of titles published and sales is the joint product of those qualities, of a substantial M.I.T. investment (currently just under one million dollars rendered as a non-retiring loan on which the Press pays interest monthly at the portfolio income rate), and of an unrelenting investment of taste and energy in the selection and exploitation of titles published. Five-year performance figures by publishing function are listed in Table II.

VICE PRESIDENT, RESEARCH ADMINISTRATION

Table II Five-Year Performance Figures (by year)

	1962-1963	1963-1964	1964-1965	1965-1966	1966-1967
<i>Editorial</i>					
Total expenditure	\$ 23,332	\$ 36,765	\$ 43,790	\$ 65,084	\$ 66,024
Pages edited	5,036	12,220	16,068	19,292	19,540
Cost per page edited	\$ 4.64	\$ 3.00	\$ 2.77	\$ 3.38	\$ 3.38
<i>Production</i>					
Total expenditure	\$ 18,521	\$ 23,063	\$ 37,275	\$ 56,793	\$ 55,185
Total pages produced (thousands)	29,404	67,607	137,858	153,876	200,098
New pages	12,834	56,415	85,390	98,498	110,619
Reprint pages	16,573	11,192	52,468	55,378	89,479
Cost per thousand pages produced	\$ 6.30	\$ 3.42	\$ 2.70	\$ 3.70	\$ 2.67
<i>Sales and Promotion</i>					
Total expenditure	\$ 58,352	\$ 123,663	\$ 206,110	\$ 276,062	\$ 341,733
Sales volume achieved	301,621	487,503	1,027,581	1,210,126	1,633,312
Volume per Sales and Promotion dollar spent	\$ 5.20	\$ 3.96	\$ 4.99	\$ 4.38	\$ 4.74
<i>Business and Warehousing</i>					
Total expenditure	\$ 51,558	\$ 101,523	\$ 188,846	\$ 257,447	\$ 331,251
Total sales volume	301,621	487,503	1,027,581	1,210,126	1,633,312
Cost per dollar of volume	\$.170	\$.204	\$.184	\$.211	\$.204
Invoices processed	7,581*	19,349	56,650	71,777	85,201

*We assumed business and warehousing responsibilities for our booklist from John Wiley & Sons on January 1, 1963.

The level of generality of these summary figures also requires explanation.

EDITORIAL We use our permanent staff to meet our minimum needs and employ experienced free-lance editors for exceptional or seasonally heavy manuscript editing requirements.

In all summaries of pages edited it is to be understood that there is no such thing as an average unit of work. One book may take months of editorial time, whereas another may take two weeks or even a few days.

PRODUCTION The major performance measures do not account for the difficulty of the task set. The complexity of the process, the stringency of the specifications set by design, the constraints of cost are all part of the achievement of production proficiency and, like editing, are subject to qualitative measure as well as to quantitative measure.

SALES AND PROMOTION Here straight quantitative measures are useful. The money we spend on promotion all contribute, to a measurable result. Effective marketing to our known and specifiable markets utilizing imaginative as well as routine methods is as calculable as running against a clock.

BUSINESS AND WAREHOUSING The same statement applies here. Increased effectiveness means lower cost, and the converse is only too visible when true.

GENERAL COMMENT Some over-all measures of comparative performance are perhaps indicative. One such, belying the notion of an easy life for university press employees, is the volume of sales per employee, Table III.

Table III Sales per Employee during 1966

For printing and publishing as a group (Fortune 500)	\$26,678
McGraw-Hill	26,846
Crowell, Collier, and Macmillan	29,780
John Wiley & Sons	33,800
The M.I.T. Press	32,666
Average of 25 American university presses	19,563

Any annual report ought to end with a forecast of things to come. Otherwise, the outcome of the game holds no tension. Next year the Press projects sales of \$1,800,000. We plan for a break-even operation, following the policy held during the past six years of operation. There will be no budgeted increase in the number of new titles published.

Believing that journal publication will continue to be the prime mode of scholarly publication for many disciplines, the Press plans to explore the publication of scholarly journals on a substantial scale during the forthcoming year.

In addition, the Press feels obliged to explore the requisite steps to a full program of microform (microfilm and microfiche) publication. We foresee a substantially enhanced role for this mode of publication in future information technology.

Last, the Press, having failed to publish most locally developed printed curricular materials, will commence a study of the uses and effectiveness of sight and sound instructional materials publishing.

Internally the Press in the coming year will:

1. Try to develop better performance indices for all Press departments.
2. Integrate manuscript editing with the production processes of estimate, design, composition, and printing of our books.
3. Introduce changes in the responsibility for list development with individual acquisition editors assigned to specific subject areas.
4. Obtain greater office space close to the Institute to meet the space needs arising from our growth.

To these few goals we address ourselves this year ahead.

CARROLL G. BOWEN

NATIONAL MAGNET LABORATORY

Research activity by Laboratory staff, M.I.T. faculty, graduate students, and visiting scientists continued at a high level. Significant progress in high magnetic field research and development and in high magnetic field physics including quantum magneto-optics, magnetism, superconductivity, ultrasonic studies of metals, and low temperature physics has been achieved.

Six magnets providing fields above 150 kilogauss and twenty magnets with lower fields were in constant use. Studies of possible expansion of the power plant and cooling system have led to a feasible plan for adding 20 megawatts of direct current capacity at a reasonable cost and without undue disruption of the research effort. The design of a 30 megawatt magnet to give fields above 300 kilogauss is nearly complete. The design of a hybrid superconducting and water-cooled magnet to give 200 kilogauss with five megawatts input is also well advanced.

Several new modulation techniques have vastly improved the sensitivity of magneto-absorption and magneto-reflectance measurements in semiconductors. In one experiment in which the reflectance is modulated by acoustic waves, the spin orbit splitting and the split-off hole effective mass in indium antimonide have been measured for the first time. In another experiment an electric field modulation technique has been used to gain new information on the energy bands of germanium, indium antimonide and indium arsenide in energy regions far removed from the Fermi level. The use of laser sources for magneto-absorption and magneto-reflection experiments has been expanded during the year. Resonance multiphoton absorption was observed in lead telluride, indium antimonide, indium arsenide, and tellurium using 10.6 micron radiation from a carbon dioxide laser. Other non-linear and multiphoton processes were explored theoretically and appropriate experiments to test the theories are in progress. A theoretical study of the effect of magnetic fields on the laser threshold current in solid state diode lasers was completed.

A number of new magnetic susceptibility measurements on single crystals of the rare-earths, dysprosium, erbium, holmium, and terbium have provided new information on the complex spin systems of these elements. In dysprosium a permanent deformation was observed when an intense magnetic field was applied along a hard axis indicating an enormous magnetic anisotropy. The high-field magnetic properties of palladium-iron alloys and $ZrZn_2$ were also studied. In all of these studies, low field measurements are not adequate to reveal the details of the magnetic structure. The first direct experimental verification of the Fermi-Dirac distribution was obtained by studying the giant quantum os-

cillation at 138 kilogauss in the ultrasonic attenuation in gallium. Mössbauer effect measurements gave new information on the hyperfine interaction in Fe_2O_3 and palladium, and in iron ions in MgO and CaO . A most exciting result has been the confirmation of the Kondo bound state in FeCu alloys using the Mössbauer effect at high fields. The effective exchange field of the Kondo state was determined.

The adiabatic demagnetization cryostat has been completed. Absolute temperature measurements using the anisotropy of gamma ray emission from Cs^{137} indicate that temperatures of three millidegrees are reached. Studies of high-field superconductors including magnetization, dc resistance, rf loss, and peak effect measurements and theoretical investigations have increased our understanding of these technically important materials. Measurements on the properties of He^3 near the critical point have been completed and have resulted in a new expression for the equation of state. A theoretical study of magnon side bands in the optical spectra of antiferromagnetic crystals is being conducted. Previous theoretical work on dilute alloys has been extended to describe the magnetic behavior of 5d and 6s conduction electrons in rare-earth metals. Theoretical studies of local moment-conduction electron exchange coupling and direct and superexchange interactions in antiferromagnets have been completed. An explanation of the anomalous specific heat of dilute magnetic alloys has been derived from a consideration of the ferromagnetic exchange interaction between conduction electrons in the presence of magnetic impurities.

The Laboratory continues to be the world center of high magnetic field research. Visitors use about half of the total magnet operating time. Many of the visitors are engaged in basic solid state physics studies; others need high magnetic fields for plasma experiments, magnetohydrodynamics, and magnetobiology.

Twelve graduate students were directly associated with the Laboratory and four doctoral theses were completed during the year. A number of other graduate students from M.I.T. and several other universities carried on part of their research at the Laboratory as visiting scientists.

BENJAMIN LAX

OPERATIONS RESEARCH CENTER

The objectives of the Operations Research Center are (1) to provide for communication and common action by faculty members in different departments who are interested in the field, (2) to display to students the variety of opportunities in the profession and to coordinate their

educational programs, and (3) to support research by faculty and students.

Research conducted last year has continued a recent trend toward the area of public systems. Professors Philip M. Morse and John D. C. Little have supervised several projects related to the flow and control of vehicular traffic. Professor Morse has continued his research work on the operational aspects of libraries; a monograph resulting from this work will be published soon. Professors E. Farnsworth Bisbee and Alvin W. Drake have directed research on the scheduling of high-speed ground transport systems. Professor Drake has also supervised graduate theses dealing with regional blood banking systems and urban police force operations.

This Center now offers a special annual summer program, "Operations Research for Public Systems." The lectures presented at the 1966 program, edited by Professor Morse and Laura W. Bacon, will be published in the summer of 1967.

Professor Leon S. White is working on mathematical models of certain complex practical operations, such as the allocation of inspection effort for multistage production processes and quality control based on noisy measurements. Professors White and Drake have conducted research in Markovian decision processes. Professor Drake has also supervised thesis research in multiple queue systems with crossover times.

In matters related to the Center's educational programs, Professor George P. Wadsworth has prepared an undergraduate subject in probability and random variables, emphasizing the operations research approach, which will be offered for the first time during the 1967-68 academic year. Professor Drake's text, *Fundamentals of Applied Probability Theory*, representing his undergraduate subject in the area of probabilistic systems, was published in February, 1967.

This year the Center was fortunate to be host to two more foreign visitors, Yoshihiro Saito from the Technical Research Laboratories of the Japan Broadcasting Corporation and Dr. Carl A. Zehnder from the Federal Institute of Technology in Zurich. These gentlemen contributed to the research work of the Center and enriched the educational programs of our students.

Also this year, Professor Morse served as honorary host to the Fourth Triennial Conference of the International Federation of Operational Research Societies at M.I.T. Professor Drake was appointed Associate Director of this Center and assisted in the preparation of the Cambridge Model Cities proposal. Richard Larson served on the Science and Technology Task Force of the President's Commission on Law Enforcement and Administration of Justice. Professor Gordon M. Kaufman spent

SUMMER SESSION

the second semester as a visiting associate professor at the Catholic University of Louvain, Belgium.

The initial Annual Report of this Center was issued in January. This and subsequent reports will summarize all activities, publications, and research efforts of the Operations Research Center.

PHILIP M. MORSE, ALVIN W. DRAKE

SUMMER SESSION

In the last report, reference was made to the success of the Summer Session as viewed from the scope of activities and the widespread response from the outside. From the latter standpoint, the 1966 Summer Session was even more successful than the 1965 Session.

SPECIAL PROGRAMS

The one- and two-week Special Summer Programs are designed to give outside professionals opportunities to keep pace with advances and trends in their fields. The total registration in the 30 programs was 1,787 as compared with a registration of 1,569 for 27 programs in 1965. The average registration of 59 per program is almost as high as the 60 per program in 1962 when two unusually large lecture programs were presented. From 1959 to 1965, the total number of programs ranged from 25 to 29 so that 1966 represented a small increase in total activity over that of the past seven years.

Registration limits are imposed on many programs, particularly those which involve laboratory demonstrations or discussion groups. As a consequence, many desirable applicants had to be refused admission and program quotas were often filled well in advance of the starting date. The demand for the programs in the School of Management was unusually high. For the four programs offered by Professors Arnold E. Amstutz, Martin Greenberger, Edward B. Roberts, and Zenon S. Zannetos, we received applications from twice as many people as could be admitted.

Again this year there was outside financial support for faculty from other institutions.

1. Ford Fellowship Program. Through part of the Ford Foundation grant, we made 126 awards to engineering faculty. The recipients represented 69 different colleges or universities and there were fellowship holders in 26 of the 30 programs.

2. Kellogg Foundation. For the second time, the one-week program in "Recent Advances in the Biosciences and Applied Sciences Pertinent to

Operative Dentistry" was financed in part by the Kellogg Foundation. Ninety-three of the 96 attendees were members of dental faculties.

3. The Society of the Plastics Industry. Again this year, the Society provided support for 18 members of architectural faculties to attend the program in "Plastics in Architecture."

Primarily, as a consequence of these sources of aid, 17 per cent of the registrants came from other educational institutions. The participation of these faculty members is welcomed and it is hoped that we can retain and, if possible, extend this aspect of the Summer Session.

CONFERENCES

A conference entitled Perspectives on College and University Education, sponsored by the Church Society for College Work under the direction of the Reverend R. C. Holtzapple, was attended by 25 university teachers, administrators, and chaplains. The conference was conducted from June 19 to June 29.

During the week of July 25 through July 29, 109 people attended a civil engineering computer systems conference co-sponsored by the Center for Advanced Engineering Study and the Civil Engineering Systems Laboratory. Professor J. Melvin Biggs of the Department of Civil Engineering was the conference director.

Professor Douglas P. Adams of the Department of Mechanical Engineering held a conference on recent developments in kinematics. Forty-six people from academic institutions and industry attended this conference from July 11 to July 22. It was sponsored by the National Science Foundation.

Twelve participants representing special education teachers in public and residential schools for the blind, and faculty members from the Teachers College at Columbia University attended a conference from August 15 through August 19 on the subject of sensory aids. John K. Dupress of the Sensory Aids Center was in charge.

M.I.T. was host to approximately 330 members of the International Federation of Operational Research Societies, who met on campus from August 29 to September 2.

The Center for Advanced Engineering Study had 19 people enrolled in their Experimental Solid-State Physics course which ran from June 20 to July 22.

For the eighth consecutive year, M.I.T. students conducted a Summer Study Program for talented high school students. A total of about 1,000 students were enrolled in the subjects which were offered from 7:00 to 10:00 p.m. on Mondays and Thursdays. The 21 instructors were M.I.T. undergraduate and graduate students who contributed their services

SUMMER SESSION

without any compensation. M.I.T. can well be proud of this student activity.

REGULAR SUBJECTS

The number of subjects has remained substantially constant during the past five years. Registration figures follow: 1962 — 1,748; 1963 — 1,808; 1964 — 1,882; 1965 — 2,090; 1966 — 2,067.

Increased enrollment since 1961 can be attributed to the expanding size of the Graduate School. Graduate students (1,659) represent 80 per cent of the student body during the summer term.

SERIES IN THE ARTS

During the summer four functions of an entertainment nature were held in Kresge Auditorium or Little Theater. On July 12 — William Mooney presented a program of frontier humor, "Half-Horse, Half-Alligator." During the weekend of August 2-4 the M.I.T. Community Players performed "The Death and Life of Sneaky Fitch." On August 16 Professor Klaus Liepmann conducted a summer concert by the M.I.T. Choral Society and the Cambridge Festival Orchestra. The M.I.T. Classical Musical Society gave performances of "Kiss Me Kate" on August 19-20 and 23-27.

All of these functions were attended by large and enthusiastic audiences.

JAMES M. AUSTIN

VICE PRESIDENT, SPECIAL LABORATORIES

The Lincoln Laboratory and the Instrumentation Laboratory are the two largest laboratories at M.I.T. and are totally supported by federal contracts. This year, as in the past, the Laboratories made major technological contributions to important national programs. The Laboratories also played a significant role in the academic and educational pursuits of the Institute.

Both Laboratories exist to meet urgent national needs, a purpose for which they are well qualified because of the Institute's academic resources and its attractiveness to scientists and engineers of the highest caliber. The Laboratories not only have responded to government needs, but also have helped identify new directions for government effort. New technological developments, changing national priorities, and the changing roles of private and government institutions require that we continually examine the Laboratories' programs and role. These considerations involve the faculty and administration of M.I.T., with their primary concern for education, and the Laboratories' management and professional staff, with their commitment to advancing technology and responding to national needs. The Laboratories are important national resources with clearly demonstrated histories of accomplishment. They have the dynamism which makes it possible for them to change course as needs demand.

The Laboratories' facilities enrich M.I.T.'s educational efforts in advancing science and technology. The Laboratories, too, benefit from the stimulating effects of student and faculty involvement in their programs. There are problems in a completely open door policy because much of the Laboratories' work is classified. However, we are trying to find ways

to increase the interaction between the Laboratories, their programs, and the Institute's faculty and student body. We believe the Laboratories can be staffed primarily by a full-time professional staff working on major national programs and yet interact strongly with the academic programs of the Institute.

As mentioned above, both Laboratories are supported by government contracts. Lincoln Laboratory's support comes from the Department of Defense and the Instrumentation Laboratory's support comes from the Department of Defense and the National Aeronautics and Space Administration. Occasionally there are contracts from other government agencies. The federal government, of course, supports a great deal of faculty and graduate student research on campus as well. Of some concern to us is the way various reports have in recent years presented the dollar volume of federal support of research at universities. Such reports often combine support for the research at the Laboratories organized outside the academic structure with the support for the educationally oriented research performed by faculty and students. The result, which places M.I.T. at or near the top of universities receiving federal support, is a distortion of the true picture of direct federal support for education and research at the Institute. We are trying to correct this so that future reports will separate the support for the Instrumentation and Lincoln Laboratories which, while playing a significant role in education, are not in direct support of faculty and student research.

A second concern which recent events have brought into sharper focus arises from the characterization of the Lincoln Laboratory by the Department of Defense as a Federal Contract Research Center. This term is a government designation for the not-for-profit organizations for which it provides nearly all the support. Many of these organizations are independent corporations without university affiliation. The RAND Corporation and the Institute for Defense Analyses typify the "think tank" organization in this category while the MITRE and Aerospace Corporations are representative of the Systems Management type of organization. This listing makes no distinction between the organizations cited above and a university-managed laboratory like Lincoln Laboratory.

This designation has not been applied to the Instrumentation Laboratory although some of its funds have been reported by the government as being "in support of a Federal Contract Research Center." This is because different agencies of the government supporting the efforts at Instrumentation Laboratory report their activities differently.

In recent years Congress has been limiting appropriations to the Federal Contract Research Centers and has expressed concern about their role as government advisors and about their growth patterns. How

this designation will affect Lincoln Laboratory remains to be seen. We think that by its Institute affiliation and by the nature of its programs and responsibilities, Lincoln Laboratory is an institutional creature different from the Federal Contract Research Centers that have concerned the Congress and that Congress needs to recognize this in its rightful scrutiny of federal expenditures.

There will continue to be problems regarding the relationship between the M.I.T. campus, the Laboratories, and the government. There will be differences of opinion within M.I.T. about the relationship between the needs and goals of the special laboratories and the academic laboratories and departments. These issues are important and complicated, both in their political and administrative aspects and in their articulation of educational philosophy. They deserve argument. Despite the problems, the following reports demonstrate clearly that the technical programs at the Laboratories go on with vigor and intelligence.

The Lincoln report was prepared by the Laboratory's new Director, Dr. Milton U. Clauser, who has also been appointed a Professor of Aeronautics and Astronautics. C. Robert Wieser has been appointed Deputy Director of the Laboratory. Dr. Clauser and Mr. Wieser are forceful additions to the Laboratory top management.

Dr. C. Stark Draper prepared the Instrumentation Laboratory report. In the past year he retired as Institute Professor and Professor of Aeronautics and Astronautics, but he continues as the very creative and involved Director of the Instrumentation Laboratory.

J. P. RUINA

INSTRUMENTATION LABORATORY

Instrumentation Laboratory activities increased last year with expenditures rising from 40 million dollars per year to about 47 million dollars per year, due chiefly to an increase in subcontracting on the Poseidon and Apollo programs. The National Aeronautics and Space Administration contributed approximately 35 per cent of the Laboratory's support for the year, the U.S. Navy approximately 34 per cent, the U.S. Air Force 28 per cent, and the U.S. Army and the Federal Aviation Authority most of the remainder.

Total personnel remains at about 1,900. During last year about 400 students were associated in some way with the Laboratory. Facilities and leadership for 13 Ph.D. theses and 31 Master's theses were provided. About 60 per cent of the 302 graduate students in the Department of Aeronautics and Astronautics took courses or carried out research work

under the supervision of faculty and staff member colleagues of Professor Walter Wrigley, the Educational Director for Instrumentation. Of these graduate students two per cent were military, a change from 1962 when 22 per cent were drawn from the military services.

Many Department faculty members have served on the Laboratory staff or have collaborated in teaching and research projects. Professor C. Stark Draper continues to serve as Laboratory Director, with Professor Walter Wrigley as Educational Director, and a faculty group including Professors Rene H. Miller, Morton Finston, Henry P. Whitaker, Yao T. Li, Wallace E. Vander Velde and Winston R. Markey; Associate Professors Walter McKay and Robert K. Mueller, and Assistant Professors James E. Potter and Jacob L. Meiry. Staff members of the Laboratory who have taken part as lecturers for courses of the Department are Doctors Richard H. Battin, Ramon L. Alonso and Elmer J. Frey. Roger B. Woodbury, Forrest E. Houston and Ralph R. Ragan have served as Deputy Directors of the Laboratory. Joshua B. Feldman holds the position of Executive Officer.

Laboratory projects sponsored by the U.S. Navy, the U.S. Air Force, the U.S. Army, the National Aeronautics and Space Administration and the Federal Aviation Authority have been concerned primarily with pioneering in the technology of sensing, transmission, processing, and application of information for stabilization, control, navigation, and guidance in flight systems ranging from submersibles and aircraft to missiles and vehicles of space. The Laboratory has for about 30 years successfully advanced the frontiers of these fields. Individuals experienced in these technologies, publications, and operating systems and components have brought widespread recognition for the Laboratory. This recognition has been an essential factor in bringing to the Laboratory opportunities for exploratory and production technology that are represented by the major projects for which it is now receiving active support. The following sections describe the larger activities now under way in the Laboratory.

APOLLO GUIDANCE

APOLLO Guidance has been conceived, designed, model tested, documented, and production supervised by the Laboratory. At the present time the A-C Electronics Division of General Motors has carried all the control and guidance hardware, either through acceptance testing or into late states of manufacture, for both the **BLOCK I** and the **BLOCK II** Systems. The Instrumentation Laboratory has largely fulfilled its commitments to **NASA**, except for efforts that must be continued in the generation of computer programs for the software necessary to future **APOLLO** flights.

Guidance equipment designed by the Laboratory performed satisfactorily as a self-contained system on the suborbital flight of an unmanned APOLLO Command Module on August 25, 1966. Errors due to guidance alone were within about one mile in eighteen thousand, a result well within the goal set for the system. It is expected that guidance will meet all the specifications of performance and reliability on the second unmanned APOLLO flight that will occur late in 1967, and that effective systems will be ready when manned flights to the moon are started.

PACE

PACE, a high performance system for stabilization, control, navigation, and guidance for aircraft has been designed, built, laboratory tested, and is now at Holloman Air Force Base for flight trials to be started in the near future. This system embodies combinations of sensors, inertial reference members, and computer programs that will open new possibilities in accuracy and long periods of self-contained operation. Results of the Holloman trials can be expected to have important influences on the design of future guidance systems.

SEAL

SEAL is a project under Federal Aviation Authority sponsorship. Its purpose is to design and build an inertial reference research system to speed up the plotting of accurate field intensity maps of radio and radar beams for aircraft navigation. The system is currently in hardware with laboratory testing well along before the start of field operations. The performance of this system makes it possible to map positions of measured field strengths within a few tens of feet for navigation, and within a few feet for landing purposes. Accuracies within these tolerances offer hope for greatly improved over-all traffic control operations and prove the feasibility of safer air transportation by substantially eliminating interference from bad visibility weather.

SABRE

SABRE is a system incorporating many advances in the technology of guidance for intercontinental missiles. It includes the ability to continue high performance operation during the severe acceleration and temperature environments of reentry and maneuvering terminal guidance. This capability is achieved by means of a hydraulic-servo-positioned reference member floated without gimbals inside a spherical housing. This mechanical design, combined with revolutionary electronics will give Sabre-type guidance equipment a place of great importance for long range missiles of the future. Several systems have been built by the Instru-

mentation Laboratory and two industrial contractors. Static testing is substantially complete, and high acceleration trials on the Laboratory's 40-foot-arm centrifuge are to start soon.

POSEIDON

POSEIDON guidance is directed toward advanced fleet ballistic missiles that will replace current Polaris weapons within the next few years. The new equipment now being developed has higher accuracy, greater reliability, and capabilities for handling more complex reentry vehicles. Designs and engineering tests are well along, with industrial arrangements made to supply equipment in production quantities when this is required.

DEEP SUBMERGENCE

Deep Submergence stabilization, display, and control systems belong to the pioneering regions of exploratory technology for the ocean depths. Laboratory efforts are directed toward design, engineering, construction, and realization for U.S. Navy submarine rescue craft capable of taking their crews great distances below the surface and taking on board men from disabled submarines. The problems of control and navigation are not only delicate but must have almost perfect reliability under difficult circumstances. This situation is certainly challenging today, but must be regarded as only the prelude to many requirements of tomorrow's subsurface technology.

The system being developed in the Laboratory is now well along in conceptual design and engineering, and hardware procurement has been started substantially on schedule. Oceanography is receiving rapidly increasing attention today, and it is expected that the current deep submergence project will be only the opening of a stimulating and long term area of progressive technology.

TACTICAL GUIDANCE

Primary effort in this area is sponsored by the U.S. Army and is directed toward increasing the operational effectiveness of helicopters and tactical aircraft by providing all-weather capabilities. The program will resolve the twofold problem of providing stable control and accurate navigation without outside aid under conditions of zero visibility. The design of the control system has involved the introduction of entirely new concepts that have been demonstrated by experimental equipment installed in an Army helicopter. A prototype version of this system will be combined with precision inertial navigation equipment to provide a core system for operational helicopters and VTOL aircraft.

SKIPPER

SKIPPER is a program sponsored by the U.S. Air Force and has the primary task of introducing Instrumentation Laboratory-designed specific-force sensors into the guidance systems of operational Minute Man Intercontinental Ballistic Missiles. Primarily the task involved is providing industrial suppliers of instruments with documented information from which they can effectively produce devices that meet stringent specifications of performance, reliability, and long life.

ORBITING ASTRONOMICAL OBSERVATORY

This program is sponsored by NASA. It is designed to make use of the latest gyro technology to provide the orbiting observatory with a precise orientational control system which will allow the required complicated maneuvers to be performed accurately and with a minimum dependence on star trackers.

THIRD-GENERATION INERTIAL SENSOR DEVELOPMENT

Information, sensed, transmitted, processed, compared with desired situations, and applied to the control of operating systems, is the region of primary interest for the Laboratory. The phases of greatest concern are those associated with technology, the activity devoted to the realization of effective working systems. This viewpoint requires that all of the theoretical and engineering factors which limit over-all performance must be identified and attacked by all available means. At the present time, considerations of theory are generally so well in hand that performance levels are determined by mechanization rather than through program imperfections. Under circumstances of this kind, the Laboratory has in the past made many significant contributions in the field of sensing devices and the subsystems in which they are applied. In particular, gyro units have been carried through two generations, each about two orders of magnitude better in performance than the instruments then in current use. The same progress has accompanied developments of specific force receivers, devices that are commonly called accelerometers.

At the present time, progress in systems for applying information in flight vehicle systems is limited by the performance of instruments for sensing angular motions and specific force. Projects, generally on the basis of relatively low level-of-effort support have been in progress for some time to improve gyro units and accelerometers. Some progress has been made, but necessary results have not been reached.

Recognition of this state of affairs by NASA and by the U.S. Air Force is now affording the Laboratory one of the most exciting opportunities in its 30-year history. Support is being provided for the development over

a three-year period of a third-generation gyro and a third generation accelerometer. Two years are allowed for design and engineering tests, with a third year devoted to production design and the documentation of manufacturing information.

This project, with associated efforts in the design of aeronautical and astronautical systems, will occupy a considerable part of the Laboratory's capabilities for some time into the future.

SCIENTIFIC TECHNOLOGY DIVISION

There has developed over the years within the Instrumentation Laboratory a unique assembly of knowledge, talent, and facilities in many diversified fields. While this capability is a result of our efforts in guidance and control technology, it has also proven to be applicable to projects and specific interests of the scientific community at M.I.T. and elsewhere. Specific examples of efforts undertaken by the Laboratory will bring into focus existing opportunities and challenges. Sometime ago the Electromagnetic Group (EES) joined with the Department of Chemical Engineering to develop a new type of viscometer that has a threshold level never before obtained. The Laboratory currently is supporting Woods Hole Oceanographic Institution by determining the dynamic environment of deep-ocean moored instruments.

To use our talents effectively in meeting the needs of scientific groups and to emphasize its support of this concept, the Laboratory has established a new organization which has the responsibility for determining, defining, and implementing areas of joint cooperation between the Laboratory and the scientific community. This organization has been designated as the Scientific Technology Division to denote a broader charter than that implied for any group or project. This charter will encompass the spectrum of interests that are important for the scientific community.

C. STARK DRAPER

LINCOLN LABORATORY

The Laboratory's major efforts were centered in the areas of re-entry technology and space communications, with a smaller program in seismic detection. An additional program of general research supported this work and provided an opportunity to explore new ideas and techniques that have less immediate application to national defense needs.

SPACE COMMUNICATIONS

The Air Force-sponsored space communications program is currently directed toward the development of military tactical communications

among many small mobile stations. The experimental test beds are the Lincoln Experimental Satellites (LES) and the Lincoln Experimental Terminals (LET).

LES-1 and LES-2, launched two years ago, and LES-4, launched last year, were directed toward long-range strategic communications. They established the value of the basic system concepts; demonstrated in space the first all-solid-state microwave transponder and other new equipment and techniques, such as a high-gain electronically switchable antenna and change in the satellite spin axis by interaction with the earth's magnetic field; and yielded data needed for further development of space communications systems. LES-3, launched in 1965, served as a vehicle for ultrahigh frequency propagation measurements contributory to the design of LES-5.

LES-5, launched July 1, 1967, is the first satellite specifically designed for communication experiments, over long or short distances, among compact surface terminals with antennas small enough to be mounted conveniently on individual vehicles, including trucks, ships, and aircraft.

Within its first few days in orbit, LES-5 provided a dramatic demonstration of the capability for direct, dependable communication between small, mobile terminals, a capability that could provide an unprecedented degree of coordination and control of United States operations and activities in many parts of the world.

The Lincoln Experimental Terminals are transportable or mobile ground transmitting and receiving terminals embodying unique systems, components, and techniques that provide digital voice and teletype communications via active and passive satellites and the moon. LET-4, nearing completion and housed in a standard camping vehicle, was designed for ultrahigh frequency satellite communications experiments.

A modulation-demodulation scheme called TATS (Tactical Transmission System) was developed at the Laboratory and is now under procurement by the U.S. Air Force. The system, operating at 75 bits per second for teletype and 2,400 bits per second for vocoded voice provides multiple access and protection against noise and multipath, as well as man-made interference.

RE-ENTRY TECHNOLOGY

Re-entry technology, the Laboratory's largest program, consists of three mutually related parts: Pacific Range Electromagnetic Signature Studies (PRESS) and Radar Discrimination Technology (RDT), both sponsored by the Advanced Research Projects Agency (ARPA), and Ballistic Missile Re-entry Systems (BMRS), sponsored by the Air Force.

PRESS, a program of research in re-entry physics, is aimed at achieving

better understanding of the phenomena associated with ballistic missile re-entry into the earth's atmosphere. Investigation of these phenomena contributes to improved techniques both for defense against ballistic missiles and for penetration of defense systems by ballistic missiles. Investigations include theoretical studies, experiments on small pellets fired from light-gas guns in the Laboratory's re-entry simulating range, and field measurements on full-scale ballistic missile re-entries at Kwajalein in the South Pacific, using specially developed large radar and optical sensors. Analysis of PRESS field data yielded increased knowledge and understanding of the discriminants available for identifying lethal re-entry vehicles.

During the past year, several new sensor measurement systems were built or brought close to completion. ALTAIR (ARPA Long-Range Tracking and Instrumentation Radar) will soon provide PRESS with enhanced capability in the very high and ultrahigh frequencies. It is expected that ALCOR (ARPA-Lincoln C-band Observables Radar), giving PRESS a new capability, will be installed by the middle of next year. An Airborne Infrared Telescope (AIRT) has been designed and built for mounting in the KC-135 aircraft. The telescope, which is pointed by PRESS ground facilities, will give excellent spatial and spectral resolution of the radiation from re-entry vehicle wakes.

The Radar Discrimination Technology program is directed toward the development of improved capability for target designation and discrimination through the most effective use of phenomena observable by radar. Extensive analysis and engagement exercises have been used to study the strengths and weaknesses of modeled radar responses to advanced penetration systems consisting of re-entry vehicles, decoys, chaff, jamming, and nuclear precursors. One aspect of this research involved the development of models of array radars and exploration of their utilization in the defense of urban areas against ballistic missile threats in the 1975-80 period.

The Ballistic Missile Re-entry Systems program supports the Air Force BMRS program to develop new and improved ballistic missile re-entry vehicles and penetration aids. The Laboratory has continued to provide assistance to the Air Force in the planning of re-entry tests that make use of PRESS radar and optical instrumentation. An important element in test planning is to secure a match between the measurements requirements and the capabilities of the instrumentation. The Laboratory assists in identifying instrumentation requirements and in the procurement of instrumentation.

Re-entry tests involve the gathering of very large quantities of data that must be reduced, analyzed, and reported on a timely basis. A system

has been developed and established for quick data reduction and reporting within a few days following a test.

An exploratory electronic countermeasure effort has been conducted. This work is closely coordinated with related Air Force programs.

VELA UNIFORM

The seismic detection program, Vela Uniform, sponsored by the Advanced Research Projects Agency, is aimed at developing improved techniques for the detection, location, and identification of underground nuclear explosions. Having played a major role in the design of the Large Aperture Seismic Array (LASA) in eastern Montana, Lincoln Laboratory is now responsible for assessing its capability. LASA has the largest aperture of any seismic array in the world and consists of 525 buried seismometers, grouped into 21 subarrays, within a circular area 200 kilometers in diameter. Individual seismometer outputs are transmitted to a data processing center in Billings, Montana.

Measurements of energy ratios at two different frequencies, of spectral complexity, of surface and body wave magnitudes, and other characteristics of earthquakes and nuclear explosions have yielded promising techniques for distinguishing between them. A daily bulletin from the Montana LASA site, listing all seismic events observed, has been initiated.

GENERAL RESEARCH

SOLID STATE

The objective of the Solid State research program is to investigate fundamental phenomena in solids and exploit their potential for advanced electronics applications. Approximately one-half of the work is fundamental in nature and is intended primarily to provide sufficient breadth to serve as a basis for the balance of the work that consists of pioneering applications of new technical developments.

Lasers constituted a major area of research in this program. Laser emission was achieved in wavelengths from the ultraviolet to the infrared in new semiconductor materials with optical and electron beam pumping. Applications included photovoltaic detectors, Gunn effect oscillators, and low-noise receivers. Investigations of carbon dioxide lasers have contributed to improved components and techniques for laser radar systems. Operation of a small-scale doppler laser radar, using an optical heterodyne receiver, has been demonstrated on nearby targets. The system has operated in the auto-track mode and has provided radial velocity information on slowly moving objects.

The fundamental work included physical investigations of semicon-

ductors, metals, and magnetic and optical materials, as well as closely integrated theoretical studies. The measurements employ microwave, millimeter, infrared, optical, ultraviolet, x-ray, ultrasonic, and direct current electric and magnetic techniques, combined with low temperatures, high magnetic fields and high pressures. Several new detection methods involving sample modulation by electric fields (electroreflectance), strain (magneto-piezorefectance), or temperature (thermal modulation) have been developed. These methods, coupled with the use of lasers as spectroscopic sources, allow energy levels to be investigated with much higher resolution than has been possible.

Two areas in quantum electronics have been investigated: laser scattering from collective excitation, such as phonons, polarons, plasmons, and magnons; and non-linear optics, which is concerned with the behavior of matter subject to intense optical fields such as are produced by high-power lasers. An application of the study of quantum electronic processes to other fields was the detailed development, in collaboration with Lincoln radio astronomers, of a maser amplifier model to account for the anomalous 18 centimeter interstellar OH emission.

DATA SYSTEMS

The Data Systems program is concerned with the development of computer components and techniques for improved utilization of computers.

Thin magnetic films were studied in terms of potential usefulness in advanced computer components. By using a rotating magnetic field, a new method of measuring the uniaxial anisotropy spectrum of such films was developed. New techniques for improving the detection of magnetic-film memory bits by means of magneto-optical effects were investigated.

The time-sharing system developed for TX-2, the Laboratory's experimental computer, has been revised to permit graphical inputs, to allow other computers to be joined to TX-2 in a network, and to improve the algorithm for allotting time and core storage to users. TX-2 has also been used for further research on graphical input-output techniques aimed at easier access to computers and thus providing more effective on-line computer applications.

The Lincoln Computer Center was converted from an IBM 7094 to an IBM 360/67 computer system, the first installation of this new system. This is a multi-programmed, multi-processor system based on Lincoln specifications that will make time-shared, on-line computational facilities available throughout the Laboratory. On-line time-sharing was initiated with the installation of ten consoles. This number is scheduled to increase substantially during the next year.

RADIO PHYSICS

The Radio Physics and Astronomy program included planetary studies, studies of interstellar space, and investigations of the properties of the atmosphere. Radar observations of Mercury, Mars, and Venus permitted further improvement in the planetary ephemerides, as well as more accurate information concerning the shapes of these planets. Studies of the Orion nebula, through observations of hydrogen and helium lines, included mean temperature, turbulence, and departures from local thermodynamic equilibrium. The galactic center was mapped at 16 GHz with a resolution of two arc minutes, yielding the highest resolution radio map currently available.

The high-power planetary radar system at the Haystack Research Facility was completed. Using this Haystack system, delay-doppler measurements on Mercury and Venus yielded data for a fourth test of Einstein's theory of general relativity as proposed by a Lincoln Laboratory staff member.

As a participant in the CAMROC (Cambridge Radio Observatory Committee) program, together with Harvard University, M.I.T., and the Smithsonian Astrophysical Observatory, the Laboratory has carried the major burden for the design and evaluation of various antenna configurations for a large radio-radar telescope.

The relatively small program of lunar radar studies, sponsored in part by the National Aeronautics and Space Administration, was concerned with providing data on the surface characteristics of the proposed lunar landing sites. The radar reflectivity at 35 GHz of the eight prime Apollo landing sites was mapped with a radar range resolution of about five microseconds.

ACADEMIC INVOLVEMENT

In addition to the formal and informal administrative relationships, interactions between the Laboratory and the academic departments continue to cover a broad range of educational and research activities. These activities center in those departments with disciplines pertinent to Lincoln's professional interests; primarily the physical sciences and engineering. Lincoln's staff members participate in teaching, serve as thesis advisors for graduate students, engage in joint research projects, take part in seminars and symposia, and are members of standing and ad hoc M.I.T. committees. Members of the Lincoln Staff Associates program are enrolled as graduate students during the academic year.

Members of the M.I.T. faculty and staff hold consulting and summer appointments at the Laboratory and give lectures to the Laboratory staff. Research Assistants and graduate students from the Departments of

VICE PRESIDENT, SPECIAL LABORATORIES

Electrical Engineering, Physics, Metallurgy and Materials Science, and Geology and Geophysics conduct research at the Laboratory.

PERSONNEL

Following the transfer to the MITRE Corporation in 1958 of a large proportion of the personnel working on the SAGE air defense system and the ensuing rebuilding during the next three years, the Laboratory population has remained stable with approximately 600 staff members and 1,200 supporting personnel. Laboratory personnel includes 178 holding doctoral degrees, 219 Master's, and 258 Bachelor's. Academic disciplines are represented as follows: electrical engineering — 248, physics — 149, mathematics — 74, mechanical engineering — 28, chemistry — 27, and all other — 129.

FUNDING

The basic Laboratory funding has increased during recent years. A significant proportion of this increase has been required for the operation of large field facilities such as the PRESS site on Roi-Namur island and the LASA site in Montana. The impact of this additional funding is reflected in the increase in outside procurements and subcontracts from \$24.0 million in fiscal year 1962 to \$41.0 million in this current year. The Laboratory's over-all budget increased from \$50.1 million to \$71.4 million during the same period. During this year 52.7 per cent of the total funding was supplied by the Advanced Research Projects Agency, 46.6 per cent by the U.S. Air Force and 0.7 per cent by the National Aeronautics and Space Administration.

MILTON CLAUSER

VICE PRESIDENT AND TREASURER¹

Total operations of the Institute exceeded \$200,000,000 in 1966-67, which compare with operations of \$178,000,000 in 1965-66. The Sources of Revenues and Funds used to meet Expenses of Current Operations during the year on page 624 is a summary of the educational and general and sponsored research operations for 1966-67. The Balance Sheet at June 30, 1966-67, on pages 622 and 623 shows assets of nearly \$379,000,000 in contrast to the assets on June 30, 1966 of \$356,000,000. In 1966-67 the total funds of the Institute increased from \$229,000,000 to \$240,000,000 with the significant changes in the Invested and Current Funds set out on pages 626 and 627 of this report.

OPERATIONS

The three main streams of activity of the Institute in 1966-67 are compared with 1965-66 in the following table:

	1966-67	1965-66
Educational and general expenses	\$ 48,758,000	\$41,666,000
Direct expenses of general departmental and interdepartmental sponsored research	41,621,000	37,382,000
Direct expenses of major laboratories and special departmental research	103,793,000	93,972,000

¹ The complete report of the Vice President and Treasurer, including schedules supporting those printed on the following pages; the list of gifts, grants, and bequests received during the year 1966-67; and reports of the Trustees of the M.I.T. Pension Association, Supplementary Retirement Plans and the Retirement Plan for Employees. is published separately and may be obtained on request from the Office of the Treasurer.

VICE PRESIDENT AND TREASURER

The substantial increase in educational and general expenses was due in part to an expansion in the special programs under the supervision of the academic administration, including, as examples, support for basic research, international programs, the curriculum development program, and extended computation and library services. Plant operations continue to reflect the additions to the educational plant of the Institute and the renovation of buildings. The further increase in general and administrative expenses provided the appropriate services to academic and other programs.

Educational and general expenses advanced seventeen per cent over the expenses of 1965-66, while departmental sponsored research increased eleven per cent, and the major sponsored research laboratories rose ten per cent. The greater part of the change in the activities in the major laboratories was in the operations of the Instrumentation Laboratory, and in that laboratory the main development was a substantial increase in materials and service procurement and subcontracts to other organizations.

GIFTS

The gifts for 1966-67 and 1965-66 were:

	1966-67	1965-66
Gifts for endowment	\$ 3,990,000	\$ 6,010,000
Gifts for buildings	4,095,000	3,243,000
Gifts for current use — invested	3,975,000	25,172,000
Industrial Liaison Program	1,400,000	1,415,000
Other funds for current use	2,559,000	3,347,000
Total gifts to funds	\$16,019,000	\$39,187,000
Grants-in-aid	1,843,000	1,553,000
Total	\$17,862,000	\$40,740,000

During 1965-66 the bequest to the Institute by Alfred P. Sloan Jr., a large foundation grant, and the further receipts for the Second Century Fund combined to bring total new resources for the year to a peak level. Consequently, the gifts received in cash, securities, or other property in 1966-67 were lower at \$17,862,000 as compared with \$40,740,000 in the previous year.

The contributions received for the year 1966-67 of \$17,862,000 may be compared with total fully documented commitments for new resources accumulated in 1966-67 of \$20,278,000. The difference between receipts and commitments in 1966-67 was accounted for largely by the foundation commitments to finance the new chemistry building and its maintenance to be received over a period of years.

VICE PRESIDENT AND TREASURER

The unrestricted direct gifts to the Alumni Fund are included in the total of \$2,536,000 credited by the Alumni Fund in 1966-67.

FUNDS

The change in endowment and other funds during 1966-67 is illustrated herewith:

	1966-67	1965-66
Endowment for general purposes	\$ 61,436,000	\$ 60,607,000
Endowment for designated purposes	59,441,000	49,468,000
Total endowment funds	\$120,877,000	\$110,075,000
Building and expendable funds	72,842,000	78,228,000
Other funds	46,183,000	40,815,000
Total funds	\$239,902,000	\$229,118,000

The main source of the increase in endowment for designated purposes was the transfer, by action of the Executive Committee, of over \$6,000,000 of expendable and building maintenance funds to endowment for maintenance of the buildings of the Institute. Of the additional increase of endowment of nearly \$4,000,000, the largest increment, an increase of capital funds for the support of academic departmental programs and research was derived from gifts and bequests and an increase in the book value of this endowment, resulting from the exchange of a common stock for a collateral note. The additional endowment included over \$1,000,000 for long-term support of undergraduate scholarships.

The investment income for distribution to funds was \$9,500,000. The unallocated investment income was \$5,686,000 on June 30, 1967. The general investments gain and loss account on the same date was \$7,546,000, increased from \$5,853,000 on June 30, 1966. Including the retirement funds, the total book value of the funds on June 30, 1967 was \$310,316,000.

PLANT FACILITIES

The additional construction during 1966-67 brought the book value of the plant facilities on June 30, 1967 to \$107,871,000, increased from \$96,182,000 on June 30, 1966, and \$87,524,000 on June 30, 1965. Major additions to buildings in process of construction included the Eastgate facilities for married students and faculty, the Center for Space Research, the Center for Advanced Engineering Study, McCormick Hall East, the central refrigeration plant, the computation center, the fourth parking garage, and the initial expenditures for the chemistry building. In addition to contributions and other resources of M.I.T.

applied to the financing of new plant, construction was financed during the year by issuing \$4,000,000, 3¾ per cent mortgage bonds of 1965 due 1968 — 2,015 to the Federal Housing and Home Finance Agency and through grants from the Federal Government for plant facilities. The advance from general cash resources of the Institute on a temporary basis for construction in progress was \$2,652,000.

INVESTMENTS

The investments of the Institute on June 30, 1967, and June 30, 1966, are presented in the following table, which is exclusive of the investments of the M.I.T. Pension Association, the Supplementary Retirement Plans, and the Retirement Plan for Employees.

	June 30, 1967		June 30, 1966	
	Book Value	Market Value	Book Value	Market Value
General investments:				
Bonds	\$116,090,000	\$109,645,000	\$108,046,000	\$103,080,000
Stocks	50,906,000	148,569,000	44,765,000	137,514,000
Real Estate	18,126,000	18,126,000	17,070,000	17,070,000
Commercial paper	2,946,000	2,946,000	2,922,000	2,922,000
Certificates of deposit	2,000,000	2,000,000	7,942,000	7,942,000
Total	\$190,068,000	\$281,286,000	\$180,745,000	\$268,528,000
Special investments	33,832,000	42,788,000	31,325,000	42,048,000
Students' notes receivable	8,251,000	8,251,000	6,968,000	6,968,000
Total	\$232,151,000	\$332,325,000	\$219,038,000	\$317,544,000

As in former years, the general and special investment portfolios of the Institute provide for the temporary investment of substantial funds held for future expenditure.

Funds sharing in the income from the general investments earned 6.71 per cent. Five per cent was allocated to the endowment funds plus an extra distribution of one per cent as in the previous year. The income distribution to other funds was at the same rates and on the same basis as in 1965-66. Of the total investment income for the year, \$4,859,000 was used directly for current expenses; \$2,965,000 was added to balances of expendable funds, which in turn were used for current operating expenses to the extent of \$2,857,000; and \$1,583,000 was added to funds for scholarships, loans, and buildings.

The investments of the M.I.T. Pension Association, the Supplementary Retirement Plans, and the Retirement Plan for Employees on June 30, 1967, and June 30, 1966, are presented below:

VICE PRESIDENT AND TREASURER

	June 30, 1967		June 30, 1966	
	Book Value	Market Value	Book Value	Market Value
Pension Association	\$31,840,000	\$37,886,000	\$26,848,000	\$33,119,000
Supplementary Retirement Plan — Fixed Benefit	17,195,000	17,679,000	14,445,000	15,107,000
Supplementary Retirement Plan — Variable Benefit	6,340,000	7,100,000	4,607,000	4,956,000
Retirement Plan for Employees	14,230,000	13,582,000	11,361,000	11,112,000
Total	\$69,605,000	\$76,247,000	\$57,261,000	\$64,294,000

GENERAL

During the past two years the investments in the General portfolio in short-term fixed income securities have been reduced and the proceeds reinvested in corporate bonds. The General portfolio represents not only endowment funds, but also the principal and income of term funds available for current expenditure. While more than half of the General Investments at market values were in common stocks on June 30, 1967, over two thirds of the investments of the endowment funds were in common stocks at the end of the fiscal year.

The substantial growth in educational and general expenses of \$7,000,000 from \$41,666,000 in 1965-66 to \$48,758,000 in 1966-67, was financed by additional tuition revenues of over \$2,000,000 provided largely by the change in tuition to \$1,900 effective in the fall of 1966, by further contract allowances for the reimbursement of general, administrative, and plant expenses in excess of \$2,000,000, and by an expanded use of gifts, investment income, and grants of more than \$1,700,000, with the remainder of \$1,300,000 derived from greater revenues related to auxiliary activities and endowment. The direct expenses of departmental sponsored research and of the major laboratories are met by the corresponding reimbursement for these expenses by the sponsoring agencies. The greater proportion of the accelerated increase in educational and general expenses during the past two years was financed by revenues from private sources. In recent but earlier years, the growth in the Institute was made possible by a parallel increase in private resources and resources provided by the Government. This change in the sources of support of the Institute is of major significance in the continuing strong and constructive program of developing new resources for the future.

JOSEPH J. SNYDER

VICE PRESIDENT AND TREASURER

Schedule A: **BALANCE SHEET, JUNE 30, 1967**

CURRENT AND DEFERRED ASSETS

Cash:

General purposes	\$ 2,222,050	
Restricted	867,330	\$ 3,089,380

Accounts receivable:

U. S. Government	(A-14) \$ 3,746,310	
Other	(A-14) 2,329,429	6,075,739

Contracts in progress, principally U.S. Government (A-15)	19,521,339	
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Inventories, deferred charges and other assets(A-16)	6,970,466	
		\$ 35,656,924

INVESTMENTS

General investments:

U. S. Government and Agency bonds	\$ 44,222,720	
Other bonds	71,867,566	
Preferred stocks	536,733	
Common stocks	50,369,035	
Real estate (including \$4,670,654 devoted to Institute use) and mortgages	18,125,572	
Commercial paper	2,946,133	
Certificates of deposit	2,000,000	
		(A-1) \$190,067,759

Investments of funds separately invested	(A-2) 33,831,533	
Students' notes receivable	(A-13) 8,251,474	

Total investments	\$232,150,766*	
Cash held for investment	812,482	
		\$232,963,248

* Total market, including real estate investments at cost, \$332,325,000

EDUCATIONAL PLANT

Land, buildings, and equipment	(A-20) \$107,870,613	
Construction in progress	1,177,706	
Temporary Investment and cash	1,276,086	
		\$110,324,405
		\$378,944,577

VICE PRESIDENT AND TREASURER

Schedule A: **BALANCE SHEET, JUNE 30, 1967**

CURRENT LIABILITIES AND FUNDS

Accounts payable	\$	7,258,470
Accrued wages and vacation allowances		3,166,003
Withholdings, deposits, and other credits .....(A-17)		1,608,071
Students' advance tuition, fees and deposits .....(A-18)		1,567,770
Advances by the U. S. Government for certain research contracts and grants		14,966,031
Unexpended grants for sponsored research from private sources		2,804,311
Gifts and other receipts available for current expenses	(A-19)	6,938,757
Less funds advanced for educational plant		(2,652,489)
		\$ 35,656,924

INVESTED FUNDS

Endowment funds:

Income for general purposes ....(A-3)	\$61,436,567	
Income for designated purposes (A-4)	59,440,700	\$120,877,267
Student loan funds	(A-5)	9,505,973
Building funds	(A-6)	7,891,222
Other expendable funds:		
General purposes	(A-7)	\$ 3,880,676
Designated purposes	(A-8)	61,070,157
Unexpended endowment income for designated purposes	(A-4)	3,681,709
Agency funds	(A-9)	614,774
Funds subject to life interests in income	(A-10)	2,710,033
General investments — gain and loss account ....(A-11)		7,545,908
Investment income for distribution to funds ....(A-12)		9,500,000
Unallocated investment income	(A-12)	5,685,529
		\$232,963,248

EDUCATIONAL PLANT LIABILITIES AND FUNDS

Note payable to bank	\$	320,697
Mortgage notes payable, 5¼ % due 1967-1978		1,040,693
Dining facilities bonds, 3⅛ % due 1967-1999		370,000
Married student housing mortgage bonds, 1961, 3½ % due 1967-2001		2,835,000
Student Center mortgage bonds, 1963, 3½ % due 1967-2003		2,960,000
Mortgage notes payable, 5¼ % due 1967-1981		1,053,733
Married students and married faculty housing mortgage bonds, 1965, 3¾ % due 1968-2015		4,000,000
Advanced from current funds		2,652,489
Endowment for educational plant	(A-21)	95,091,793
		\$110,324,405
		\$378,944,577

VICE PRESIDENT AND TREASURER

**Schedule B: SOURCES OF REVENUES AND FUNDS
USED TO MEET EXPENSES OF CURRENT OPERATION**

for the year ended June 30, 1967

EDUCATIONAL AND GENERAL

Expenses of current operation

Academic departments	(B-4)	\$ 21,763,570
General and administration	(B-5)	11,162,601
Student activities general and plant expenses and major dormitory repairs	(B-6)	1,595,627
Plant operation	(B-7)	9,154,880
Auxiliary activities	(B-8)	5,081,429
		<u>\$ 48,758,107</u>

Less contract allowances for general and administration, and plant operation expenses (see below)	(B-3)	13,780,766
		<u>\$ 34,977,341</u>

Sources of revenues and funds used

Revenues

Tuition and other income	(B-1)	\$ 15,067,617
Auxiliary activities	(B-8)	5,081,429
		<u>20,149,046</u>

Funds used

Endowment investment income	(B-2)	4,858,793
Gifts, investment income, and other receipts	(B-2)	9,969,502
		<u>14,828,295</u>
		<u>\$ 34,977,341</u>

SPONSORED RESEARCH

Expenses

Salaries and wages	(B-3)	\$ 58,972,545
Pension and other employee benefit costs	(B-3)	7,256,931
Materials and services	(B-3)	51,805,913
Subcontracts	(B-3)	24,709,006
Travel	(B-3)	2,669,856
Research general and administration expenses	(B-3)	3,987,476
Allowances for general and administration and plant operation expenses	(B-3)	13,780,766
Allowance for use of facilities and other reserves	(B-3)	1,949,535
		<u>\$165,132,028</u>

Revenues

General departmental and interdepartmental research		\$ 50,306,396
Major laboratories and special departmental research:		
Lincoln Laboratory		66,613,993
Instrumentation Laboratory		48,211,639
	(B-3)	<u>\$165,132,028</u>

Total operations		<u>\$200,109,369</u>
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AUDITOR'S CERTIFICATE

**TO THE AUDITING COMMITTEE OF THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY:**

We have examined the financial statements of Massachusetts Institute of Technology:

Schedule A — Balance Sheet as at June 30, 1967.

Schedule B — Sources of Revenues and Funds Used to Meet Expenses of Current Operation for the Year Ended June 30, 1967.

Schedule C — Statement of Funds for the Year Ended June 30, 1967.

Our examination was made in accordance with generally accepted auditing standards and accordingly included such tests of the accounting records and such other auditing procedures as we considered necessary in the circumstances. We used auditing procedures other than direct confirmation to establish the validity of certain U. S. Government receivables.

In our opinion, said statements present fairly the financial position of Massachusetts Institute of Technology at June 30, 1967, and the results of its operations for the year then ended, in accordance with generally accepted accounting principles applied on a basis consistent with that of the preceding year.

LYBRAND, ROSS BROS. & MONTGOMERY

Boston, Massachusetts, September 6, 1967

REPORT OF THE AUDITING COMMITTEE

**TO THE CORPORATION OF THE MASSACHUSETTS INSTITUTE OF
TECHNOLOGY:**

The Auditing Committee reports that Lybrand, Ross Bros. & Montgomery were engaged to make an audit of the books and accounts of the Institute for the fiscal year ended June 30, 1967, and their certificate is submitted herewith.

Respectfully,

GILBERT M. RODDY

DAVID A. SHEPARD

CHARLES A. THOMAS, *Chairman*

VICE PRESIDENT AND TREASURER

Schedule C: STATEMENT OF FUNDS

for the year ended June 30, 1967

	Balance June 30, 1966
Endowment funds:	
Income for general purposes (A-3)	\$ 60,606,75
Income for designated purposes (A-4)	49,468,49
Student loan funds (A-5)	8,587,00
Buildings funds (A-6)	8,544,54
Other expendable funds:	
General purposes (A-7)	4,226,15
Designated purposes (A-8)	65,457,53
Unexpended endowment income for designated purposes (A-4)	3,131,13
Agency funds (A-9)	630,61
Funds subject to life interests in income (A-10)	2,361,45
General investments — gain and loss account (A-11)	5,853,15
Investment income for distribution to funds (A-12)	8,340,00
Unallocated investment income (A-12)	4,847,77
Total invested funds	<u>\$222,054,61</u>
Gifts and other receipts available for current expenses (A-19)	<u>7,063,75</u>
	<u>\$229,118,36</u>
Gifts received during the year added to funds	\$16,019,05
Royalties received net of related costs	709,33
Receipts from foundations and agencies for student aid	4,881,23
Net gain on sales or exchange of investments	3,007,86
Appropriations from research contract allowances	1,920,57
Government construction grants	1,792,58
Fees, services, and other receipts	1,952,74
	<u>\$30,283,38</u>
Endowment investment income used to meet expenses of current operations	
Gifts, investment income, and other receipts used to meet expenses of current operations	
Scholarship and fellowship awards for tuition and stipends	
Expenditures for buildings added to educational plant	
Expenditures of service activities and other charges to funds not representing operating e	

*Investment income on endowment funds for designated purposes is included under the

VICE PRESIDENT AND TREASURER

Gifts and Other Receipts	Investment Income	Transfers In-(Out)	Expenses	Other Charges	Balance June 30, 1967
\$ 807,619	\$ 3,660,486	\$ (351,194)	\$ 3,287,097	.....	\$ 61,436,567
4,206,115	*	5,766,094	.....	.....	59,440,700
1,102,853	79,037	(212,135)	50,788	.....	9,505,973
5,887,415	354,383	(113,286)	84,776	\$ 6,697,061	7,891,222
1,076,368	184,974	(1,009,449)	361,286	236,081	3,880,676
5,488,442	2,780,108	(6,036,164)	2,495,676	4,124,085	61,070,157
.....	3,585,244	(174,913)	1,571,696	1,288,062	3,681,709
22,853	30,267	(44,445)	.....	24,512	614,774
291,677	115,916	45,105	.....	104,118	2,710,033
1,692,754	.....	.....	.....	.....	7,545,908
.....	(9,053,388)	10,213,388	.....	.....	9,500,000
.....	11,051,138	(10,213,388)	.....	.....	5,685,529
\$20,576,096	\$12,788,165	\$(2,130,387)	\$7,851,319	\$12,473,919	\$232,963,248
<u>9,707,291</u>	.....	<u>2,130,387</u>	<u>6,976,976</u>	<u>4,985,700</u>	<u>6,938,757</u>
\$30,283,387	\$12,788,165	.....	\$14,828,295	\$17,459,619	\$239,902,005

..... \$ 4,858,793
 9,969,502
\$14,828,295

..... \$ 6,879,261
 8,508,879
 nses. 2,071,479
\$17,459,619

tion "Unexpended endowment income for designated purposes."

VICE PRESIDENT, OPERATIONS AND PERSONNEL

In the spectrum of activities described in the reports of the offices that follow, there are several matters which bear emphasis. This is so not necessarily because they are the most important, but rather because they indicate new or modified emphases and events which have characterized the last year's operations.

Problems and opportunities in the area of employment have moved to the forefront in the concerns of our personnel relations endeavors this last year. In a time of relatively high employment and a time of increased Institute needs for a wide variety of skills, the competition for manpower in the market has tightened noticeably. We are undertaking new approaches and expanding old ones in the attempt to acquaint prospective employees with the many advantages we believe the Institute offers as an employer. Concurrently, we have been addressing ourselves to the problems of unemployment among disadvantaged groups. As outlined in the report of the Director of the Office of Personnel Relations, a number of programs are involved, one of the most successful being the Summer Youth Employment Program. Additional efforts will be made in this general area and the understanding and cooperation evidenced by all elements of our community will continue to be important to its success.

Construction and planning continue for new physical facilities and for the rearrangement of existing spaces. This is an effort of considerable magnitude and is described in the reports of the Planning Office and the

Director of Physical Plant. Two items in these reports bear mentioning here. These are our telecommunications facilities and our basic utility systems. With the considerable growth in the size and complexity of M.I.T. during the last few years, the problems of voice communications have intensified and the advent of communications needs in connection with computation facilities has added a significant new dimension. As a result, studies are underway to determine and plan the course ahead. This is being done in conjunction with the New England Telephone and Telegraph Company and will call for major operational decisions in the near future.

As indicated in the reports that follow, the burgeoning of our utility requirements far exceeds any straight-line measure of growth in our physical plant. Planning to meet our requirements is under constant and intensive study. Utility expansion and renewal represent capital expenditures of a high order — not seen on the skyline but vital to our future operation. In all our physical planning, we are attempting to develop new techniques and systems for gathering and analyzing the rapidly proliferating data we feel to be essential to our task.

In the areas of safety and loss prevention, the expanding community increases our exposure to accidents of all kinds, but we believe that recent augmentation of our Safety Office staff and a consequent widening of surveillance and educational activities can meet this challenge. As the Safety Officer points out in his report, fire safety in our Institute Houses and housing projects continues to receive constant attention. A program instituted several years ago to upgrade and refine student protection is continuing and will have to do so for several years.

The importance of additional student housing becomes more urgent with each passing term. This need has been amply described by the Dean of Student Affairs. It is encouraging to record that final plans for a new undergraduate house are nearing completion. Although occupancy of this one facility in about two years will have a major impact on our residence program, it will need to be supplemented by additional accommodations if we are to care adequately for our student population.

Operations and Personnel lost through death three devoted, able, and long-term members of its management group in this last year: William H. Carlisle Jr., Manager of Student Personnel, James N. Murphy, Assistant Superintendent of Building Services, and Charles A. Kalalian, Manager of the Graphic Arts Service. Their contributions to the Institute and particularly to the students, will be remembered by generations of M.I.T. men and women as well as by their working associates.

PHILIP A. STODDARD

OFFICE OF PERSONNEL RELATIONS

The Office of Personnel Relations administers the personnel policies approved for all Institute personnel except members of the Faculty and teaching staff, certain others holding academic staff appointments, and M.I.T. student employees. The statistics and other material contained in this report, therefore, do not apply to personnel in these categories.

EMPLOYMENT AND TURNOVER

The shortage of skilled manpower, which was acute in the Greater Boston area, created severe problems for the Institute in recruiting and retaining personnel to meet its expanding needs. Termination rates in all categories rose to unprecedented levels, as did the list of unfilled positions. Notwithstanding these difficulties, the Institute's staff continued to grow, increasing 5.7 per cent to 7,570 by the end of the fiscal year. The largest increase again was on the campus (7.9 per cent), followed closely by the Instrumentation Laboratory (6.8 per cent). As has been the case for a number of years, there was no increase in the staff of the Lincoln Laboratory. In terms of employment categories, the largest increase was in the office-clerical category — an increase of 11.1 per cent.

EQUAL EMPLOYMENT ACTIVITIES

Because of nationwide concern about high rates of unemployment among certain minority groups, particularly Negroes, the Institute has been making efforts to encourage employment applications from members of these disadvantaged groups. The efforts include special advertising and recruiting, liaison with 14 local agencies which specialize in preparing and placing the disadvantaged, helping to find volunteers and equipment for such agencies, and joining in organized programs such as the Summer Youth Employment Program. Such efforts are not only urged by voluntary employee associations like Plans for Progress, of which the Institute is a member, but required by the federal government of its defense contractors. Regular statistical employment reports are submitted as a means of measuring progress.

Thanks to the understanding and support of administrators and supervisors throughout the Institute, a beginning has been made to increase the number of minority group members working at the Institute. This trend will undoubtedly be reinforced by the impressive educational programs for disadvantaged young people being conducted on and near the campus by student and faculty groups.

UNION RELATIONS

Agreements with three unions representing approximately 2,300 main-

tenance and laboratory service employees in four separate bargaining units expired June 30, 1966. Negotiations continued through the summer and were concluded without incident in September. The principal terms of settlement were:

1. Two-year agreements providing for general increases of 4 per cent on July 1, 1966 and 3½ per cent on July 1, 1967.
2. Inequity adjustments of varying amounts for certain skilled classifications.
3. A substantial improvement in pension benefits financed by increased contributions from both the Institute and the employees.
4. Continuation of the present hospitalization and medical insurance coverage without increase in the cost to the employees.

An agreement with a fourth union representing security guards at the Lincoln Laboratory expired June 30, 1967. Negotiations for a new agreement were concluded in June and the settlement ratified by the membership before the expiration date. Terms of the agreement were essentially the same as those outlined above.

One of the most time-consuming responsibilities of the office continues to be the handling of grievances and arbitration cases. In recent years the employees represented by the Research Development and Technical Employees' Union alone have submitted about 60 grievances each year, of which about 15 per cent have gone on to arbitration. This union represents, among other skilled personnel at M.I.T., more than 1,000 laboratory technicians with a great diversity of skills employed in a wide variety of research activities. A high percentage of these grievances have related to questions of classification and promotion, particularly the requirements for advancement and the rate of progress through classification levels. To help resolve these problems, a special procedure was negotiated several years ago that provides for an additional step in the grievance procedure to give special consideration to classification cases. It also provides for arbitration of these cases in an informal atmosphere by a permanent panel of two arbitrators who are empowered to report their general conclusions and recommendations to the parties from time to time. This procedure has increased the percentage of cases settled in the grievances procedure without arbitration, and greatly expedited the arbitration process itself. More importantly, it has contributed to improved relations between the Institute and the union by bringing about a more consistent interpretation and application of classification standards, and by demonstrating the progress which can be made through joint efforts to resolve problems which are mutually recognized and understood.

OFFICE OF PERSONNEL RELATIONS

PERSONNEL POLICY COMMITTEE

The Personnel Policy Committee is chaired by the Vice President for Operations and Personnel and includes representation from the Faculty, the administration, and the major research laboratories. Its function is to provide continuous review of the Institute's personnel policies and practices and to recommend to the President changes designed to maintain a framework of wages, salaries, benefits, and other employment conditions adequate to the Institute's needs and appropriate to its status as a non-profit educational institution also engaged in extensive research and development activities. The Committee met nine times during the fiscal year ending June 30, 1967. Among the matters considered and acted upon were the adjustment of wage and salary structures, vacation policy for research staff, compensation for field site personnel, compliance with the Fair Labor Standards Act, pay rates for student personnel, holiday closings, union negotiations, and overtime policies.

WAGE AND SALARY ADMINISTRATION

Salary structures applying to about 2,000 members of the research and administrative staffs, 2,200 office personnel, and 650 supervisory and other exempt personnel were revised during the year to maintain Institute salary levels in appropriate relationship to applicable local or national salary patterns. The performance and duties of each employee in these categories were reviewed under the terms of the Institute's merit program, and promotions and increases were made effective as warranted. In addition, the performance and duties of some 1,450 hourly-paid laboratory service personnel and 170 draftsmen were reviewed and appropriate adjustments made.

TUITION ASSISTANCE FOR STAFF MEMBERS

The Institute has had in effect since 1960 a tuition assistance plan for hourly-paid and office personnel, but a formal plan for staff members was not adopted until 1965. This plan supports members of the research, administrative, and academic staffs in work-related studies. Under the terms of the plan, eligible individuals may be reimbursed for 75 per cent of the allowable costs of approved courses of study, both at the Institute and at other recognized schools.

During the past year 411 members of the staff participated in this program, of whom 270 took courses as special students at M.I.T. The remainder were scattered among a dozen different schools, most of them in the Greater Boston area.

SUPERVISORY TRAINING

Last year, 13 supervisors and administrators of office and laboratory personnel, most of them new to their present jobs, completed a series of seminars reviewing the principles of good supervisory management. Some 300 supervisors from all parts of the Institute have completed a similar basic program, and more than a third of them have gone on to participate in additional programs to develop their knowledge and skills in such fields as interviewing, human relations, psychology, problem solving, and communication. Some have also attended courses given by the American Association of Industrial Management.

CAMPUS PATROL

The responsibilities of the Campus Patrol continue to increase as the Institute continues to expand its activities, staff, and physical plant. The Patrol now consists of 28 Patrolmen, four Sergeants, one Lieutenant, and a Captain, whose general mission is to help to protect property, maintain order, and attend to the safety and welfare of students, staff, and visitors seven days a week and 24 hours a day. The Patrol is expected to accomplish this mission with a minimum of emphasis on what might be regarded as police functions and authorities, and a maximum of emphasis upon cooperation with other Institute agencies in providing a variety of services to the community.

The Patrol provides a complete emergency service, including the operation of a well-equipped ambulance in which it responded to 292 emergency calls during the year. It directs traffic on campus and enforces parking regulations in the Institute's 35 scattered parking lots and garages. Because the Institute is an open, quasi-public institution in an urban location, there is a considerable incidence of theft and other crimes. The Patrol investigated 632 written complaints during the year covering a wide variety of offenses, and recovered a large quantity of stolen property. Members of the Patrol are trained to exercise judgment and restraint in their relations with students and as a consequence have earned the respect and confidence of the student body.

ROBERT J. DAVIS

PLANNING OFFICE

The Institute Planning Office has as its central concern the proper development and utilization of M.I.T.'s physical environment.

The Long Range Planning section maintains a continuing 15-year perspective with comprehensive reviews and plan extensions every five years.

PLANNING OFFICE

The building programs required to fulfill the long range plan are prepared by the Planning Office staff, in close cooperation with the faculty who will use the buildings.

With more than four million square feet of assignable space at M.I.T., planning for assignments, improvements, and other changes in our buildings is a formidable task. The Planning Office coordinates this effort to ensure that the Institute community enjoys the maximum use of existing space resources.

The increasing complexity of the community's planning needs and the proliferation of information demands have led us to seek ways of using existing and developing systems techniques to expand and improve our planning capabilities. In our Special Projects section we are continuing to discover ways of organizing physical and population information through the evolution of flexible computer programs. This is being done in cooperation with the Department of Civil Engineering — the research capability of which is unique in this area. We are, furthermore, applying existing programs to many of our current information problems.

The Institute's community relations continue to occupy a major part of our staff resources. This year we have been deeply involved in measuring the impact of alternate Inner Belt Highway routes, but we have also made substantial contributions to the preparation of Cambridge's Model Cities application. We have, as well, continued to cooperate with public and private agencies of the City in a continuing effort that seeks, as its primary objective, a healthy partnership with Cambridge.

LONG RANGE PLANNING

This year our major concerns have centered on the preparation of basic planning data for the quinquennial review of the Institute's Long Range Plan for Development.

Because of the size and complexity of the Institute community, it required a major effort to identify and quantify the various components of our expanding population. This deceptively seemed to be a simple task, and was finally handled by a system of discrete population information systems, each serving a special purpose. Since this data is the foundation upon which we must build the whole of our future planning, a major effort was undertaken to correlate various population data sources and explore new ways of providing accurate and comprehensive data in the future.

Concurrently, we have undertaken a careful inventory and analysis of our existing physical resources including land, buildings, density, utility systems, circulation, parking, and site development characteristics that will influence future development.

As we labored to identify and clarify the elements of planning, we have prepared the groundwork for an over-all assessment of the Institute's future objectives. In January of 1967, each of the Institute's Schools, departments, and laboratories was asked to forecast its needs to 1975. These forecasts are now being reviewed and will reveal the scope of M.I.T.'s long range academic and physical aspirations. As priorities for development are established, M.I.T.'s long range plan for 1975-80 will take shape.

PROGRAMMING

One of the most exciting developments in the evolution of the planning process at M.I.T. has been in the area of facilities programming. Recognition that the academic and research facilities at the Institute must respond to ever changing demands has led to the development of building programs that try to reflect our needs for essential flexibility. In special cases, such as housing, the organization of the living environment is the key to the achievement of M.I.T.'s social and educational goals. Several years of faculty/student study have gone into the preparation of a program for MacGregor House and those which will follow.

In the academic facilities area we have for some years felt the need to study more closely the evolving environmental needs stimulated by major changes in curriculum and teaching methods. Since little if any research meaningful to M.I.T. is available, we have begun a small-scale research effort that would, through the involvement of faculty, members of the Building Research Center, and the Planning Office, develop prototype teaching laboratories which, after an appropriate testing and evaluation period, would be integrated into new building programs.

With six major academic buildings and one research project under construction, there are, under various stages of programming, some 13 academic building projects, 19 landscape projects, and six residential projects.

Harry P. Portnoy, Senior Architect in the Planning Office, has joined the staff this year to undertake the responsibilities of this section.

SPACE COORDINATION

More than 200 space assignments were made by the Planning Office during fiscal year 1967. Many of the changes required extensive investigation and negotiation as competition for space is invariably keen. Frequent reference was made to the Committee for Research and Space Planning in the case of major space changes which involved unresolved differences of opinion between Schools of the Institute.

PLANNING OFFICE

Generally associated with changes in occupancy of space were major and minor renovations of rooms throughout the Institute. Sixty such projects were in progress during the year with costs ranging from \$200 to \$600,000 for individual projects and totaling more than \$3,000,000. Full accounting for each project is required. The budget for space changes is prepared during February preceding the fiscal year and decided upon by the Provost and Committee for Research and Space Planning after considerable deliberation and reductions since requirements for space changes are invariably in excess of available funds.

A program is prepared in advance of the fiscal year containing scope, descriptions, estimates, and timing for all space changes anticipated. In addition, a work schedule is prepared by the Planning Office and Physical Plant Design section. This information is constantly changing and publications of the program and schedule are periodically updated.

Records of spaces at the Institute are maintained by the Planning Office and are machine recorded. Basis statistics regarding more than 12,508 individual rooms and 4,500,000 square feet of space are recorded in the system. The accurate and timely nature of the data has been improved considerably during the past year.

SPECIAL PROJECTS ACTIVITIES

SPACE: INVENTORY AND UTILIZATION

A total information system for M.I.T. building space presently consists of two parallel efforts. The first is a pilot study (presently under way in the Department of Civil Engineering) to determine the general requirements and format of a longer-range research project that will provide a total system to handle both a space inventory and a means by which space utilization indices may be derived.

The other effort consists of an experimental space inventory that now exists to fill the gap between present need and future requirements. Nearly 90 per cent complete, this inventory file consists of the basic space data: building and room number, room type, user, and area. Present output capabilities consist of printed lists of Institute space by user, by building, or by any conceivable combination of the existing data, and summaries of space areas by the same breakdowns as above.

Future plans for the expansion of this inventory file include the addition of other space data such as services available within the spaces and the general condition of the spaces. In support of these plans, a prototype expanded file is presently being designed to store the detailed classroom data recently collected for a classroom utilization study.

STATISTICAL PROGRAM

A statistical computer program to analyze large arrays of data has recently been tested and proven worthy of further use. The data used to test the program capabilities was that received from 1,874 responses to a graduate student housing questionnaire presented by a Master's degree candidate and sponsored by the Planning Office. A first run of frequency computations is now available and cross tabulations are under way. This particular effort will provide a contemporary basis for planning future graduate student residential and community facilities.

COMMUNITY RELATIONS

The following summarizes the major components of M.I.T.'s community relations activities during the past year:

1. Inner Belt — This has involved both the detailed reviews of the proposed Portland/Albany route and the development of the M.I.T. plan for dealing with relocation housing problems. Related to this effort, contacts have been maintained with the people and agencies involved with the problem — the City of Cambridge, the Massachusetts Department of Public Works and its consultants, the Massachusetts Relocation Bureau, and others.
2. Liaison with the city in the development of the Community Development Program and the Model Cities Program applications, including participation on the City Manager's Technical Advisory Panel, created last fall to advise the City on the development of such programs. This has involved both discussion and substantive contributions to the two applications.
3. Updating of the Section 112 File, for purposes of certifying the M.I.T. expenditures eligible for credit in conjunction with the Kendall Square Urban Renewal Project.
4. Service on the M.I.T. Committee on Community Service.
5. Part-time participation in the M.I.T. Science Day Camp during the summer of 1966.

O. ROBERT SIMHA

PHYSICAL PLANT

The last year was a time of consolidation for the operating sections of the Physical Plant Department. New construction proceeded at essentially the same rate as in the last several years, but no major new projects were completed and occupied during the year. Physical Plant personnel strength rose to a high of 624 people, partially in anticipation of new

PHYSICAL PLANT

buildings to be occupied next year, and partially because of the inclusion in the Physical Plant operating group of the telecommunications office. This office encompasses not only conventional telephone service but also computer communication. The new office has initiated a joint study with the New England Telephone and Telegraph Company for the purpose of determining future requirements for expanded voice and data communication — both low and high speed.

During the temporary respite from new building occupancy problems, a review was made of the organizational structure of the department and adjustments made in an effort to accommodate changing conditions. The use of computer techniques in connection with preventive maintenance scheduling was extended to new areas of operation. With more than 10,000 pieces of heating, ventilating, and air conditioning equipment to maintain, this development has proved most beneficial and it is planned to extend this management tool in future years.

During the year, work continued on three major projects initiated earlier: the Center for Space Research, the Center for Advanced Engineering Study, and the Eastgate Residence Tower. All three are scheduled for occupancy in the fall of 1967.

Construction was started on an additional \$15,500,000 of new construction during the fiscal year with an aggregate floor area in excess of 300,000 square feet.

NEW CONSTRUCTION PROJECTS

COMPUTATION CENTER

Construction on this six-story, reinforced concrete structure was initiated in the summer of 1966. Located on Vassar Street, adjacent to the new Space Research Center and on the north-south axis of the Institute dome, it will provide 78,000 gross square feet of floor area to house new computation facilities.

The building has two passageways at ground level which provide for vehicular traffic to the inner campus. Architectural treatment of the exterior is similar in character to the Space Research Center.

MC CORMICK HALL EAST

McCormick Hall East is a second women's dormitory facility being constructed contiguous to McCormick Hall. It was undertaken in August, 1966, and is scheduled for occupancy in early 1968. It will provide living accommodations for 111 women students. Dining and kitchen facilities in the original McCormick Hall will be used for both buildings. With seven stories and a penthouse, it will be similar in general appearance to the first tower.

VISUAL STUDIES

The old Technology Store building is being renovated and altered to provide 14,000 gross square feet of floor space for creative work in the fields of visual arts, including sculpture, painting, and photography.

CENTRAL REFRIGERATION PLANT

Phase I of the Central Refrigeration Plant was started in July, 1966, on a site next to the Institute power and steam plant off Vassar Street. Initially, chilled water for air conditioning will be piped to the Center for Advanced Engineering Study, Space Research Building, Chemistry Graduate Research Building, Computation Center, and Center for Theoretical Physics, via a distribution piping system also being constructed under the project. Total machine capacity of Phase I is 3,000 tons of refrigeration.

CHEMISTRY GRADUATE RESEARCH BUILDING

With the start of construction of the new Chemistry Graduate Research Building in April, 1967, the last building planned for the Eastman Court area is under way. The new building will have five stories above ground and a double basement below; gross floor area is approximately 135,000 square feet. A tunnel and three-level bridge to the Whitaker Building as well as tunnels to the Hayden Library and the Green Building will help to integrate the new facility into the main complex of buildings.

All exposed exterior surfaces and certain interior surfaces of the cast-in-place, reinforced concrete structural system will be treated as architectural concrete. One of the functional features of the building is the unusually large amount of ventilation capability necessary for the laboratory fume hoods.

MAJOR ALTERATIONS, REMODELING AND UTILITIES EXPANSION PROJECTS

Major space renovations and alterations and utility expansion projects having an aggregate value in excess of \$2,100,000 were completed during the fiscal year. Two of the larger projects under construction are a Center for Theoretical Physics located in the Eastman Building, and the relocation of metallurgy facilities from the Sloan Metals Processing Laboratory to Buildings 4 and 8. The Electronic Systems Laboratory previously in Building 32 will move into the vacated space. Another substantial project was the construction of a mass spectrometry laboratory in the first basement of the Whitaker Building. A major utilities expansion was the construction of underground electrical and telephone duct lines to serve some of the facilities north of the railroad right-of-way.

Design work continued during the year on MacGregor House (under-

SAFETY OFFICE

graduate men's dormitory), the Engineering Library rehabilitation and renovation (incorporating INTREX, an experimental information transfer project) and the Linear Accelerator (off campus in Middleton, Massachusetts). It is anticipated that these projects will be put out for bids shortly. Several other projects in earlier stages of design are the Hydrodynamics Building Addition, an auditorium adjacent to Eastgate, and a new electrical engineering facility.

A statistic that dramatically demonstrates the impact of the new construction and new technology at the Institute is our consumption of electrical energy. In 1938 the Institute used about 3,250,000 kilowatt-hours of electricity during the entire year. In just the single month of May, 1967, more than 6,000,000 kilowatt-hours were consumed. A continuing effort is necessary to forecast, plan, and construct adequate utility services to meet this kind of growth.

During the year the Department and the Institute suffered a great loss with the tragic accidental death of James N. Murphy who had been in charge of Kresge Auditorium and the Chapel since their opening. Last year he also had assumed responsibility for the new Stratton Building. Mr. Murphy had been employed in the Department for 38 years.

CARL M. F. PETERSON

SAFETY OFFICE

Emphasis continues to be placed on fire prevention and protection in Institute housing. Automatic extinguishment for Ashdown House entered the first phase of a five-year program which, upon completion, will provide automatic sprinkler protection throughout the building.

All on-campus housing was again surveyed and evaluated, paying particular attention to those areas where the greatest good can be accomplished. As in previous years, consultation and safety advice was available to off-campus, independent housing units wishing to take advantage of this service.

To facilitate movement through and around the buildings with a greater degree of safety and convenience, further steps have been taken to remove architectural barriers to the physically handicapped, among which was the completion by Physical Plant of three washroom facilities in the main group. Further increase in the number of facilities during the coming year is planned. Progress in this direction must, of necessity, often appear to be painstakingly slow, since earlier campus buildings do not lend themselves easily to change. It is anticipated that providing more convenient access to and around the Institute buildings will permit

broader educational and employment opportunities for the physically handicapped.

The accident frequency rate continues its downward trend; however, the accident severity has remained essentially the same as last year. It is expected that the severity will soon follow the downward course of the frequency rate.

The second revision of the Accident Prevention Guide has been completed and is now being distributed.

MARK J. DONDERO

HOUSING AND DINING SERVICES

HOUSING

During the past year the undergraduate housing shortage necessitated the acquisition of approximately 80 temporary beds to accommodate freshmen and upperclass dormitory residents. Thirty-eight single rooms in East Campus were converted to doubles; eight beds were placed in Baker House floor lounges; and a Cambridge apartment building was leased to accommodate 35 students and a tutor. Yet the demand for beds continues unabated; as this report is written, a rooming house near the Institute is being remodeled for temporary use to accommodate 95 students next fall. We anticipate this shortage will continue through the opening of our new undergraduate house in the fall of 1969. This house, containing more than 300 undergraduate men, was brought into final planning stages during the year and construction is scheduled to begin late in 1967.

In this period we also began designing a second new undergraduate house and undertook planning studies for the complete remodeling of Burton House.

Construction continued on the 111-bed addition to Stanley McCormick Hall; completion is anticipated in February of 1968.

During the year a number of remodeling programs occurred through the continued generosity of the Alumni Fund. New or improved lounge facilities were created in East Campus, Baker House, Ashdown House, and Senior House, and improvements were made to student living areas in Burton House and Ashdown House. Though major renovations are scheduled for the near future, these modest improvements are vitally important to the student communities currently living in the Institute houses.

To continue involving students in decisions about their housing wher-

ever feasible, the Housing Office reviewed room assignment procedures in cooperation with the Office of the Dean of Student Affairs. The result of this study is a decentralization of the responsibility for room assignments to each undergraduate house government, with the Campus Housing Office staff playing a supporting role. Though the system will not be tested fully until this fall, preliminary results have been very encouraging.

The critical housing problem faced by our married students will be somewhat alleviated by the completion of the Eastgate married students and faculty housing project this summer. The building will contain 148 apartments for married students, 49 faculty apartments, and six apartments for guests of the Institute. The demand for this housing is so great that the student apartments were rented within a three-week period. We anticipate the development of a vigorous community in the same manner as our Westgate community, assisted by a number of community lounges and other facilities in the project.

DINING

Some innovations occurred this year in the dining services offered to resident students. On a trial basis, an unlimited seconds program was offered during the spring semester and the students were given the opportunity to recommend whether they wished to pay more for the increased food consumed. The Dormitory Council recommended acceptance of the new program, and it will be instituted this fall with an increase in the board rate.

Special parties were given on frequent occasions during the year, ranging from a clambake in the fall to a roast beef picnic in the spring. In an effort to improve communications with students, frequent meetings were sought with the various commons committees to plan these events and to monitor customer reaction to the quality of food and service offered. Further plans to improve communications are currently being drafted.

To offset increased expenses in the a la carte dining services, an increase in a la carte prices was effected this June.

The vending program will be transferred to the dining service effective July, 1967. We believe that the community will benefit from increased attention to this form of food service.

Last fall, the Corporation Visiting Committee on Student Affairs reviewed the food service program with us. We were grateful for their attention and recommendations, and hope to use many of our joint conclusions as a basis for adding new dimensions to our food service program.

LAURENCE H. BISHOFF

GRAPHIC ARTS SERVICE

The Graphic Arts Service as a whole has continued to grow at the rate of approximately seven per cent, as was the case last year.

In order to improve the efficiency of our branch services, we have added new high-volume Xerox machines as well as improved multilith printing, collating, and binding equipment. To indicate their usefulness to the Institute community, one branch, for example, has shown an increased volume during the past year of about 50 per cent.

The Bulk Mail Division is also continuing to grow at an accelerated rate of around 25 per cent.

The Audio Visual Service has had to expand considerably to cope with the demands placed upon it. Additional space has been provided in the basement of Building 4, and it is hoped that this will be ready for occupancy by September of this year.

FRANK H. CONANT

VICE PRESIDENT AND SECRETARY OF THE INSTITUTE

The Institute Secretaries, Industrial Liaison Office, M.I.T. Associates Office, Development Office, and Registry of Guests now report to the President through the Vice President and Secretary of the Institute; the latter office also administers the Corporation Visiting Committees and the Standing Committees on Membership and Development as part of its staff responsibility to the Officers of the Corporation.

CORPORATION

At the year's end there were a record 80 Members of the Corporation, 67 active Members and 13 Life Members Emeriti. The active membership represented the maximum number allowable under the Bylaws of the Corporation. During the year Luis A. Ferré '24, Partner, Ferré Industries; Semon E. Knudsen '36, Executive Vice President, General Motors Corporation; and Robert B. Semple '32, President, Wyandotte Chemicals Corporation, were elected Life Members. Albert H. Bowker '41, Chancellor, City University of New York; George P. Edmonds '26, Honorary Chairman of the Board, Wilmington Trust Company; Ralph F. Gow '25, Vice Chairman of the Board, Norton Company; Donald A. Holden '31, President and Chairman of the Board, Newport News Shipbuilding and Dry Dock Company; and H. I. Romnes, Chairman of the Board, American Telephone and Telegraph Company, were elected Term Members of the Corporation. Gregory Smith '30, President and General Manager, Eastman Gelatine Corporation, became an ex officio Member by virtue of his election as the 1967-68 President of the Alumni Association, effective July 1, 1967.

The Corporation lost through death its Life Member, Thomas D'Arcy Brophy '16 on July 29, 1967. For nearly 20 years Mr. Brophy served as a Member of the Corporation, contributing generously and imaginatively to its work. One of the most respected executives in American advertising, he served the Institute with special distinction for many years as an advisor on public relations. In his passing M.I.T. lost a distinguished alumnus and devoted member of its governing body; the nation lost one of its prominent leaders in philanthropic, medical, and civic causes.

Expiration of Term Membership has cost the Corporation the formal associations of Theodore A. Mangelsdorf '26, former Executive Vice President of Texaco, Inc.; Frank R. Milliken '34, President, Kennecott Copper Corporation; Edward M. Purcell, Gerhard Gade University Professor, Harvard University; D. Reid Weedon Jr. '41, Senior Vice President, Arthur D. Little, Inc.

As a matter of record, the Corporation met formally in four regular quarterly sessions and again on October 7, 1966, for the inauguration of Howard Wesley Johnson as the twelfth President of the Institute. The inauguration in Rockwell Cage was attended by delegates from 267 United States and foreign institutions.

Dr. James R. Killian, Jr., Chairman of the Corporation, presided at the Inauguration Exercises. His Excellency, Governor John A. Volpe brought greetings to M.I.T.'s new President from the Commonwealth of Massachusetts. Greetings from American universities were brought by President Nathan M. Pusey of Harvard University; from foreign universities by Dr. Pierre R. R. Aigrain, Director of Higher Education of the National Ministry of Education of France; from alumni by President Theodore A. Mangelsdorf '26 of the Alumni Association; from M.I.T. students by Frank A. March, President of the Undergraduate Association; and from the Faculty by Professor Elting E. Morison. President Johnson's excellent inaugural address, "The University of the Future," was heard by some 4,000 guests including an overflow audience in Kresge Auditorium who watched the investiture via closed circuit television.

Altogether it was an auspicious and memorable beginning for the new administration at M.I.T. Special thanks are due the Inauguration Committee under the chairmanship of Professor Carroll L. Wilson for its unflagging effort which made the Inauguration — an extraordinary event in the life of this institution — all the more meaningful to the M.I.T. family.

In noteworthy actions the Corporation approved the awarding of a joint doctoral degree in oceanography with the Woods Hole Oceano-

graphic Institution. In petitioning the Commonwealth of Massachusetts for legal authority to grant this new joint degree, the Institute has been granted permission to join any other institution in Massachusetts in awarding joint doctoral degrees in any field which satisfies M.I.T.'s requirements for such degrees. The Corporation also approved a new doctoral degree in the field of ocean engineering in the Department of Naval Architecture and Marine Engineering, a change in the doctoral degree in Nutrition to Nutritional Biochemistry and Metabolism, a change in the name of the Department of Metallurgy to Metallurgy and Materials Science, and corresponding changes in degree titles awarded to students in Metallurgy.

CORPORATION VISITING COMMITTEES

The Visiting Committees of the Corporation, operating as advisory groups to the Corporation, continued to bring invaluable information and stimulus to the educational and research programs of the Institute. This vital communication system comprises over 200 members organized into 26 committees. During the year the committees for the departments of Architecture and for City Planning were merged under one Visiting Committee for the School of Architecture and Planning. Nine of the Visiting Committees held meetings at M.I.T. with the following departments:

Sponsored Research	December 2 and 3, 1966
Metallurgy and Materials Science	December 9, 1966
Student Affairs	January 19 and 20, 1967
Chemistry	March 2, 1967
Political Science	March 16, 1967
Naval Architecture and Marine Engineering	April 10, 1967
Humanities	May 3 and 4, 1967
Sloan School	May 10, 1967
Nutrition and Food Science	May 24, 1967
Joint Center for Urban Studies	May 19, 1967

This level of activity represented a significant decrease from the 24 meetings held in 1966-67 and 20 meetings in the previous year. In part it reflects the completion of a two-year period of intense Visiting Committee activity and in part a desire on the part of some departments and Committee chairmen to meet at other than an annual interval. Some Committees continue to meet annually; since 1960 the average number of Committee meetings has been 18 meetings per year. During the year the Academic Council and the Corporation devoted special attention to the role of the Visiting Committees in an effort to reexamine their value and effectiveness. As a result of these helpful discussions, a number of considerations were brought out which are worth recording here.

1. The Visiting Committees are Committees of the Corporation. They serve to keep the Corporation informed about the progress and plans of the departments.
2. The periodic meetings of the Committees unquestionably help the departments to take stock of their position and quality. The participation of the deans and senior officers of the Institute is essential to this aspect of the Visiting Committee procedure.
3. The active work of the Committees is an important assurance to the departments that the Corporation is interested in their specialized fields.
4. The Visiting Committees make timely, positive recommendations which clearly have a stimulating effect. To the extent that the Committees can act as advisors to the departments, there are additional values in their operation, but they are not intended primarily for this purpose, even though their specific recommendations are often implemented. It is asking a great deal, as do many institutions who employ departmental advisory committees, in contrast to visiting committees as we know them, to expect an annual or biannual committee meeting to serve a departmental advisory function as its principal objective. The advisory aspect of the Corporation Visiting Committees is best seen as a continuing process in which departmental plans and programs are clarified through the exercise of their being presented to a group of informed, interested friends and colleagues. This informal process, rather than the specifics of reports and recommendations, is the medium through which the Committees operate most effectively.
5. University trustees have an obligation to be deeply concerned about educational matters. In carrying out this responsibility, it is not reasonable to expect enlightened trusteeship in the absence of a personal involvement with the academic programs in some depth.
6. We have a uniquely valuable system of Visiting Committees at the Institute. It profoundly helps the Corporation and the Institute by enlisting leading alumni and professional leaders from all over the country (around 150, in addition to Corporation Members, at any one time) and involving them in the work of the officers of the Institute.

Walter L. Koltun continued the work begun in 1963 by the Office of the Vice President and Secretary to strengthen the Visiting Committees through improved scheduling and information services to Committee members and to the department heads. I join Dr. Koltun in expressing grateful appreciation to the department chairmen for their thorough preparation for Committee meetings and to Dr. Jerome B. Wiesner, Provost, for his wise counsel in the selection of new Committee members for the coming year.

RELATIONS WITH INDUSTRY

The Industrial Liaison Program and Associates Program continued to emphasize the interests and activities of individual faculty members as the basis for their operation. Reports of the directors of these two programs follow in a later section.

At year's end Thomas Yonker resigned as Director of the Associates Office to accept a position in industry. David H. Robbins, formerly a staff member in the Industrial Liaison Office, succeeded Mr. Yonker in this position.

During the year, largely because of the growth of Federal support for higher education, considerable national attention was focused on the extent to which certain universities derive support for their over-all operation from Federal sources. Because of their longstanding participation in Federally sponsored university research programs, a number of private universities, M.I.T. among them, were singled out among the leaders in securing Federal funds. The unfortunate inference given to the business community was that these institutions were relatively well supported and had less need for private funds than they were claiming, or that they were overly dependent upon Federal funds, or that they were receiving more than their fair share of Federal support, or some combination of these. In M.I.T.'s case, the comparison with other universities in the matter of private versus Federal support was distorted by the frequent inclusion of Lincoln Laboratory and Instrumentation Laboratory in the academic operations of the Institute. In almost every case, the failure to distinguish between operating funds and capital formation has led to widespread misunderstanding about the critical dependence of the major private universities on private capital, especially those private institutions engaged heavily in Federally sponsored research.

Senior officers of the Institute have devoted considerable time and energy to this problem during the year, and there is hopeful evidence that the financial aspects are now beginning to emerge in their proper perspective. There still exists a surprising lack of clarity about the core needs of the private institutions and their virtual dependence upon the private sector to provide this essential funding.

DEVELOPMENT

This year's report of development activity looks back briefly in order to provide a better understanding of the Institute's current objectives and the steps being taken to organize for them.

A decade ago, President Killian wrote in his 1957 report to the Corporation an analysis of the Second Report of President Eisenhower's Committee on Education Beyond the High School. It was three years

before the Institute's announcement of the opening of the Second Century Fund when Dr. Killian wrote in part:

"Needless to say, we also concur fully in the recommendation that institutions seek greatly increased income from gifts, particularly from their own alumni and from the industries which employ their graduates and which profit from their research. Our Alumni Fund is growing, partly in response to intensive regional solicitation conducted by local alumni. Our Industrial Liaison Program is a highly successful plan for maintaining a large volume of annual corporate grants; and our well-staffed Development Office, operating under policies of our Corporation Development Committee is steadily enlarging our effort. The problem has been to raise our sights and to convince our constituency that M.I.T.'s needs of today are of an entirely different order of magnitude from those of a decade ago. In the light of the continuing decrease in the value of the dollar, we would like to hope that our annual gift total (\$8 to 10 million) be doubled."

Dr. Killian's projection was shortly to become prophetic. When the Institute announced the Second Century Fund in May, 1960, the total sought was \$66 million — roughly half of the total need identified by the faculty in a comprehensive survey of M.I.T.'s capital needs in 1958 and 1959. In the hard decisions involved in setting priorities for M.I.T.'s great capital campaign, well over \$60 million of capital items were eliminated or deferred in order to reduce the campaign objectives to a manageable total.

As every private institution knows, during a major capital drive the final outcome is modified substantially by the confrontation of campaign goals and donors' wishes. So it was that M.I.T.'s Second Century Fund experience resulted in new goals introduced by major donors, an under-subscription of some of the originally announced goals and an over-subscription in other categories announced in 1960. The \$77 million total announced in May, 1963, was a mixture of these effects, along with an additional \$21 million which had been contributed for related objectives during the three-year campaign, largely as a result of the campaign effort.

By every measure M.I.T.'s Second Century Fund was a glorious success. It brought the Institute to a wholly new level of operation and effectiveness. Moreover, this remarkable chapter in M.I.T.'s financial development demonstrated that a private university need not be timid in stating its needs and that, given an opportunity to respond, alumni and friends, corporations and foundations placed a high premium on the Institute's having the resources needed to carry out its responsibilities.

Yet, as we review the chronology of events in the past decade, it is important to note that in May, 1963, on the completion of the S.C.F. campaign, the Institute had fully \$75 million other accumulated capital requirements not yet funded, the bulk of which were identified as early as five years before. Add to this the steadily rising cost of education in

the 1960's and the three to five years needed for the payment of Second Century Fund pledges and the picture of a successful but needy institution emerges in clear perspective. M.I.T. came out of the Second Century campaign with capital needs fully as large as those which had been pledged.

In 1965, the Corporation moved to enlarge its Development Committee by the addition of 100 leading alumni to assist the Institute in the planning and acquisition of major resources for the future. At that time the Committee addressed itself to the problem of securing over \$100 million in new capital needs over a ten-year period, including some \$40 million in immediate capital requirements. The Committee concluded that in order to assure these objectives and to allow for gifts designated for operating purposes, the Institute would need to expect private gifts, grants, and bequests totaling more than \$20 million annually — over and above the redemption of Second Century Fund pledges.

It is against this background of old needs and new opportunities that M.I.T.'s continuing development program is oriented to:

1. Projects to which the Institute is already committed such as the computer building, engineering library renovation, and student housing.
2. Support for faculty and students (professorships and student aid).
3. Academic needs which arise out of the adaptation which the Institute must constantly make to advances and changes in science, engineering, management, and in other fields represented in the School of Architecture and Planning and in the School of Humanities and Social Sciences.

The hard fact is beginning to emerge that an annual gift total *greatly* in excess of \$20 million is needed to provide adequately for the core needs of M.I.T. A \$20 million level of private contributions, when measured against a growing accumulation of capital requirements and an annual operating expenditure of \$100 million for teaching and academic research, is uncomfortably small.

An institute of technology holding a position of world leadership can never stand still. To maintain its leadership, it must be highly responsive to change and avoid obsolescence in its teaching and research, and it must be ready to embrace new fields as they unfold. It must also encourage bold new ideas and imaginative pace-setting programs to discharge its mission as a leader in education.

If M.I.T. is to be first-rate, the Institute must give primary attention to holding and attracting faculty members of great distinction. There is intense competition today among the leading institutions for talented faculty, especially in science and engineering. While M.I.T.'s salary scale has been vastly improved, the salary scales of numerous other institutions have kept pace with our increases. In recent years the great

publicly supported state universities have intensified the competition for outstanding individuals. While our present over-all salary scale puts M.I.T. in the top group of universities, in regard to faculty salaries, we have not yet matched several institutions at the top. Funds are needed to strengthen M.I.T.'s competitive position in holding and attracting able staff.

We should also have funds readily available to increase the number of really distinguished faculty members. In a faculty of more than 900 professors, the Institute has fewer than 35 fully endowed chairs. This volume of faculty endowment is grossly out of line with the quality of faculty we have and the leadership responsibility they carry nationally.

The Institute has unfinished business in providing housing for its students and in augmenting its student aid. During the period when the Institute has been achieving a new order of excellence and enlarged scope, its facilities for students have not kept pace. These needs now warrant a higher priority. Private funds are needed for part of the capital cost to keep the Institute's dormitory rent structure manageable and competitive with comparable accommodations elsewhere. Better than \$20 million is needed for new undergraduate and graduate dormitory construction and for renovation of present housing. A doubling of our undergraduate scholarship endowment from \$15 to \$30 million is needed to place the present volume of student aid on a permanent footing, not to mention future increases in student aid that will be needed as we go along.

The demand for data processing in computer-aided instruction and laboratory research constitutes a first-order financial problem at the Institute. In the aggregate, computer usage has been growing at the rate of 15 per cent per year, and it now represents an annual outlay of \$5 million on the campus, exclusive of the Instrumentation and Lincoln laboratories. While research projects and programs can be expected to pay their own way, to the extent that they utilize computer services, there remains a gaping disparity between expenses and sources of funds to support the computer in the classroom and in educational experiments. The phenomenal growth of computer systems in the learning process, spearheaded in a large part by fast running developments in computer technology at M.I.T., is well out in front of the resources needed to exploit these powerful, new methods in education. No university in the nation has a greater stake in the resolution of this pressing problem than does M.I.T.

The age of many of the Institute's buildings as well as changes in their use, call for extensive plant modernization. We need to make better provision for some of our services, such as the Medical Department, classrooms, and the libraries. As an urban institution, M.I.T. is faced

with special problems in Cambridge as it seeks to provide for environmental improvement and for faculty housing.

Beyond these general needs, there is an imposing inventory of special academic needs that relate to the departments and schools at the Institute. First on this list is the overdue construction and modernization of facilities for the Department of Electrical Engineering and the Research Laboratory of Electronics. The School of Architecture and Planning and the School of Humanities and Social Sciences need major resources and facilities to meet their enormously expanded responsibilities. In the School of Science the Department of Physics must have a wholly new capital base for its further development. The Alfred P. Sloan School of Management has yet to resolve the problem of finding adequate permanent financing for its core needs. These departmental facilities and programs constitute the bulk of the development objectives which were either deferred in the Second Century campaign planning or bypassed by donors to the Fund. Many are now ten years old.

It should be noted also that the unrestricted funds available to the Institute are altogether too small. The Corporation and Administration can be aided in the wise deployment of Institute resources if they have the flexibility to draw on unrestricted funds. M.I.T.'s operating budget and its capital account represent a sensitive balance between ends and means in any given year. The quality of education hangs in this balance. At the fulcrum stands an astonishingly small volume of unrestricted funds.

Without question, private resources to meet M.I.T.'s core needs are accessible to the Institute. Hopeful evidence appears everywhere in the response of alumni, friends, industry, and private foundations throughout the nation. Considering the continued thrust of science and technology as the dominant forces shaping our society, and a growing economy, M.I.T. can expect to reach a wider constituency in consonance with its own growth. The principal handicap we face is an inevitable time lag between rapid changes occurring here and our ability to communicate these changes to a wider public.

The Institute can be aided profoundly in this task by the continuing advice and assistance of the Corporation Development Committee. This nationally constituted group of 115 Corporation Members and alumni has already proved its strategic importance in the planning and acquisition of major resources for M.I.T.

During the year, further gains were made in organizing the Deferred Gifts Program under the leadership of D. Hugh Darden, Institute Estate Secretary. At year's end the number of known expectancies, representing documented intentions of alumni and friends to make bequests to M.I.T., reached a total of 566. This compares with 452 and 223 reported at the

conclusion of two earlier years. I join Mr. Darden in expressing special appreciation to the Treasurer's Office and to the Alumni Association for their unflagging assistance in fostering the growth of deferred giving to M.I.T.

At midyear the Institute authorized the establishment of two new positions on the development staff: Institute Secretary for Charitable Trusts and the office of Institute Secretary. The former recognizes a long felt requirement at M.I.T. for a focal point for improved communication with charitable trusts and smaller personal foundations. These institutions have organizational needs and interests that differ significantly from the large general purpose foundations, and they represent in the aggregate a potentially important source of gifts and grants for special purposes at the Institute.

David J. Tobin was appointed to this new post, which is organized within the office of the Vice President and Secretary. Walter L. Koltun was appointed to succeed him in the parallel post of Institute Secretary for Foundations. Together, these officers greatly strengthen the Institute's ability to communicate systematically with foundations and charitable trusts broadly. Their work in support of the senior officers of the Institute and the faculty can be expected to play a major role in broadening M.I.T.'s sources of foundation funds. During the year, for example, a record number of 18 new foundations and charitable trusts made gifts and grants to M.I.T. for the first time.

At year's end, John H. Carter was appointed Institute Secretary. In this new position he assumes a responsibility parallel to that of Mr. Darden, in organizing more effective communication with leadership individuals on behalf of current gifts. He brings to this post a broad background of experience in industry and government which augurs well for M.I.T.'s relationships with national leaders in private philanthropy.

During the year more than 400 American corporations and their foundations made gifts and grants to M.I.T., not including alumni matching gifts. Corporate support continues to represent between 20 and 25 per cent of M.I.T.'s total private contributions. The national average is just under 15 per cent for the country's colleges and universities; the Institute's special dependence on corporate gifts and grants can be seen in this comparison. Most significantly, corporations and their foundations continue to emphasize unrestricted giving in their support of M.I.T., which lends an importance to such funds out of proportion to their absolute size.

C. Warren Smalzel continued as Institute Secretary for Corporations during the year, carrying a heavy responsibility for communication with this large group of donors. Noteworthy developments in corporate giv-

ing to M.I.T. included an extraordinary response to the special drive for funds to strengthen the Department of Chemistry and the establishment of a ten-year term professorship in energy processing by a group of electrical utility companies.

In conclusion, M.I.T.'s on-going development program is based on the principle that the planning and acquisition of major funds is an integral part of the Institute's day-to-day operation. It must be a continuous process no less than other aspects of the Institute's operation. It is too important to wait until capital requirements pose an absolute threat to quality or leadership before taking action in periodic, highly publicized capital campaigns. The magnitude of M.I.T.'s need for private funds is large and growing. It is larger today than ever before in the Institute's history because M.I.T. is larger and yet no less committed to be responsive to the changing needs of our time.

As this report is being written there is growing concern nationally over the future of the privately controlled colleges and universities. There are some who doubt that private philanthropy can keep pace with the increasing cost of financing the private institutions. There are others who forecast gloomily that the day of reckoning for the leading private universities is not far off. They point to inadequate endowments, prohibitively high tuitions, the leveling off of corporate contributions, the disappearance of great personal fortunes, and cutbacks in risk-taking on the part of some of the major foundations.

Private philanthropy is large and growing. It has never been stronger nor more committed to the field of education, and this commitment is growing. With only about 15 per cent of the nation's \$13.6 billion in total philanthropy annually going to support higher education, I think it fair to say that the colleges and universities have yet to test the limits of this support for their needs.

It is unthinkable that the private sector will stand for apathy while our leadership institutions fall back or while their quality is diluted by forces which move the system always towards a uniform rate of return on the educational dollar. Blue chip investments in education are rare, but they are not priceless. They are entirely within the reach of private philanthropy today. If first-rate education is expensive, the only thing more expensive in the future will be the lack of it — for the nation, for industry, and for the country's best students.

VINCENT A. FULMER

INDUSTRIAL LIAISON OFFICE

This year, the Industrial Liaison Office completed its 19th year of operation. During the year, several significant new levels of activity were at-

tained in providing services to the companies participating in the Industrial Liaison Program. With respect to symposia presentations, more meetings were offered than in any previous year; more meetings were held off campus; a record was established for total attendance at a single meeting; and this year there was a substantial increase in the number of M.I.T. faculty and staff attending Industrial Liaison symposia. In another very important area, the number of visits to member companies by M.I.T. faculty under the auspices of the Industrial Liaison Program almost doubled over the previous year, setting another new record for the Program. Increasing interest in Industrial Liaison Office publications was also quite evident, as the total number of individual publications available and the total number of publications inquiries processed both reached new record levels. These accomplishments reflect the continuing effort on the part of the Industrial Liaison Office to provide to member companies complete and convenient access to research and educational programs at the Institute. The value to the participating companies is clearly demonstrated in the constructive manner in which they are using the Program services to complement their own research programs.

At the end of the fiscal year, there were 103 companies participating in the Liaison Program. The distribution of these companies among the major industrial groups was as follows:

Aerospace	21%	Manufacturing	16%
Automotive	3	Metals	7
Chemical	18	Paper	1
Electronics	16	Petroleum	9
Food	3	Others	4
Insurance	2		

Industrial Liaison symposia continue to provide one of the most efficient and effective means of fostering interaction between company representatives and M.I.T. faculty. These symposia are informal progress reports by staff members on research currently under way at the Institute that can be of immediate or long range industrial significance. During these meetings the faculty discuss recent unpublished information and solicit questions and comments from the industrial guests. To promote the informality of the programs, no papers as such are presented, and no effort is made to record the proceedings. The success of this type of symposia arrangement is readily apparent not only from the number of industrial representatives who attend these meetings, but also from the number who have attended them in the past and who return to subsequent meetings held in their areas of interest.

Severe adverse weather conditions at several of the meetings closed Logan airport and prevented many of the company representatives who had preregistered from attending the meetings. Still, the total attendance at Industrial Liaison symposia during the 1966-67 series was 1,970, which is very close to last year's record high total. Significantly, 370 of those in attendance were from M.I.T., demonstrating the great interest shown in these programs by faculty members seeking either to remain abreast of new developments in fields related to their own specializations or simply to be informed about general areas in which they are curious. During coffee breaks, luncheons, and after the meetings, company representatives often take advantage of the opportunity to interact with the faculty members attending these symposia, as well as those participating in the programs.

During 1966-67, 17 different symposia were offered and two were repeated at different locations during the course of the year. The total of 19 meetings sets a new record for an Industrial Liaison Program series. Subjects of the meetings were: Practical Approaches to World Protein Problems; Solidification; Market Oriented Management Systems (held twice); Oceanography; Exploration of Interplanetary Space; Research in High Magnetic Fields; Innovation and Experiments in University Education; Computer Science Research at Project MAC; Microwave Magnetics; Electron Microanalysis (held twice); Seismic Discrimination; The Integrated Civil Engineering Systems; The Expanding Scope of Naval Architecture and Marine Engineering; Chemistry of Organometallic Compounds; Catalysis and Applied Kinetics; Application of Modern Control Theory; and Composite Materials. The symposium on Computer Science Research at Project MAC established a new record attendance of 405 for a single symposium. This particular program was a two-day meeting and represented the third in a series of progress reports held on the work of Project MAC on time-shared multiple access computers.

Whenever possible and appropriate, the Industrial Liaison Office holds several of its symposia off campus. Meetings outside the Boston area are usually scheduled on the basis of a strong geographic orientation towards a particular meeting. However, sometimes it is desirable to repeat a meeting previously held on campus because a significantly large number of company representatives have indicated they were unable to attend due to conflicts with other matters or because of bad weather. These repetitions are then held off campus. Last year, four meetings were presented away from M.I.T. They included: Electron Microanalysis (separately held at both Houston and Los Angeles); Seismic Discrimination (Houston); and Market Oriented Management Systems (Los Angeles — pre-

viously held at M.I.T. earlier in the series). The Electron Microanalysis program was the first attempt by the Liaison Office to hold a single meeting at two different away locations. This program was well attended and well received in both cities. More off-campus meetings were held in the 1966-67 series than in any previous year because the Industrial Liaison Office continues to receive many comments from company representatives attending these meetings citing their value and convenience.

Increased emphasis is being placed on visits to the campus by company representatives to discuss with faculty members subjects of mutual interest. These private conferences are arranged through the Industrial Liaison Office to discuss either specific details of research programs under way at the Institute or the general "state of the art" in some particular field of research. Companies often have requested the assistance of faculty members in solving certain proprietary problems. The Liaison Office has suggested faculty members to contact in these instances, and in certain circumstances has arranged for preliminary meetings between company representatives and faculty to permit a proper assessment of qualifications and interest prior to undertaking any consulting commitment. Such meetings have proved to be of substantial mutual benefit. During 1966-67, the number of visits arranged on campus through the Liaison Office was 327, which is just slightly below last year's record level. A total of 369 faculty and staff participated in 657 separate discussions with 582 key representatives from 90 different member companies.

To supplement campus visits by company representatives, faculty members this year made a total of 101 visits to the research laboratories of member companies under the auspices of the Industrial Liaison Office, an increase of 77 per cent over the number of such visits made last year and an establishment of a new record for this program activity. Faculty members appreciate the opportunity to visit companies and become better acquainted with new industrial developments, and also to obtain a better understanding of industrial requirements and needs from an educational standpoint. The companies participating in the Program have enthusiastically supported these visits and strongly encouraged that this activity be expanded even further.

The *Directory of Current Research* is a publication prepared annually by the staff of the Industrial Liaison Office and is a complete listing of the research currently in progress at the Institute. The 1967 edition of the *Directory* contains a record listing of 1,459 projects, almost ten per cent more than the previous year's listing. This comprehensive compilation of research projects finds widespread use by the member companies as well as by the Institute staff. This year more than 2,500 copies

of the *Directory* were distributed directly to participating companies, 666 copies were requested by and distributed to faculty and staff, and an additional 686 copies were personally distributed to company representatives by members of the Industrial Liaison Office. This year the *Directory* was reorganized to facilitate its use by breaking down the departmental and laboratory research projects into specific subdivisions. In addition, index entries were placed in a computerized system in order to provide a more complete cross-referenced index section.

The volume of M.I.T. reports and other publications systematically distributed to member companies through the Industrial Liaison Office expanded considerably this year. A total of 346 separate preprints and laboratory reports were selectively distributed to 453 different company locations. Almost 160,000 publications were distributed to companies in this manner. In addition 445 other reports were made available upon request. Many of these publications were sent personally by members of the Industrial Liaison Office staff to individuals in companies who expressed interest in specific research areas. In responding to requests from companies for publications and reference lists, a total of 3,902 separate publications inquiries were processed, representing a 32 per cent increase over last year's record. A number of companies send manuscript copies of their own publications to the Industrial Liaison Office for selective distribution to faculty. This year 781 reports were received from member companies participating in this reciprocal publications program.

Library Privilege Cards, which entitle the holders to borrow books and to use the reading rooms and reference materials in accordance with usual library regulations, are made available to employees of companies participating in the Industrial Liaison Program. At the close of this year 680 cards were held by representatives of member companies, compared with 504 one year ago.

In reviewing last year's activity in the Industrial Liaison Program, it is quite evident that the Program could not operate without the wholehearted support and cooperation of Institute faculty and the interest and enthusiasm of the representatives from participating companies. The Industrial Liaison Office staff is very grateful for the assistance provided and deeply appreciates all of the courtesy and consideration extended to them both on campus and during their visits to company locations. It is only in this type of collaborative environment that an effective interchange can take place and true and lasting benefits be derived for all concerned. The Industrial Liaison Office is especially grateful for the advice and support received from the Faculty Committee on Industrial Liaison, under the chairmanship of Professor Charles N. Satterfield. Pro-

fessor Satterfield also organized and chaired the Industrial Liaison Symposium on Catalysis and Applied Kinetics, and he has served as an excellent example of faculty cooperation and participation in Program activities.

Through the year, Richard G. Brown, Jack W. Christensen, Arthur J. Collias, Peter B. Franz, Karl B. Kehler, David H. Robbins, and Ronald S. Stone served as Industrial Liaison Officers. In August, Jack V. Drake completed his appointment and accepted a position in industry. In June, George W. Ullrich was appointed to the staff to replace Mr. Robbins who was selected to assume new responsibilities in another administrative activity. Many of the achievements reported above are directly the product of the energy, initiative, and responsibility with which these Industrial Liaison Officers have discharged the Institute's commitment to the participating companies.

FRANK T. BAUCHSPIES

M.I.T. ASSOCIATES PROGRAM

It is a pleasure to report that during the last year corporate membership in the M.I.T. Associates Program increased by 40 per cent. This Program growth attests to the value business and industry places on maintaining an ongoing knowledge of M.I.T.'s educational and research activities. It also gives us confidence in the direction of our continuing efforts in the development of the service aspects of Program membership. The new corporate members are: Harvey Hubbell, Miniature Precision Bearings, Inc., Nashua Corporation, New Britain Machine Company, Rogers Corporation, National Polychemicals, Inc., and Taft Peirce Manufacturing Co. All are representative of New England's dynamic industrial base and all have a strong reliance on science and technology.

The principal aim of the Associates Program is twofold: (1) to keep the membership informed of M.I.T.'s educational and research activities with special emphasis on those programs related to a particular company's interests and (2) to provide an effective and proper means by which a company can draw on the resources of the M.I.T. community for specific information and assistance when the need arises. The selective distribution of M.I.T. publications constitutes the principal means of accomplishing this first objective. The distribution of the Agenda of Selected Activities and numerous other announcements and newsletters also aids this reportorial function. However, the principal benefit of Program membership continues to derive from the second objective; the personalized attention this office can bring to bear on specific requests by the member companies. Through the Associates Program, the member-

DEVELOPMENT OFFICE

ship also gains full access to the M.I.T. Library system. For companies located near M.I.T. this is an especially valuable service.

At this year's Special Conference for New England Executives, faculty from the Department of Economics and the Alfred P. Sloan School of Management addressed their attention to "the International Corporation." With more than 100 New England business executives, they explored the world-wide economic, social, and political forces which strongly effect the way a firm must operate internationally.

In closing, I want to thank the M.I.T. faculty and research staff for their generous support of all our efforts, on behalf of the membership of the Associates Program. I acknowledge this debt not only on behalf of the Associates Program but personally as well, since this June marks the end of a most pleasant six-year association with the Institute. I can only wish for my successor as Director of the Associates Program, David H. Robbins, the same cooperation and goodwill that it has been my good fortune to receive.

THOMAS YONKER

DEVELOPMENT OFFICE

The cash flow of private gifts, grants, and bequests to M.I.T. for fiscal 1966-67 totaled \$17,861,579.36, including \$1,546,196.22 in payments on Second Century Fund pledges.

Some of the major purposes for which gifts were designated by the donors included the following:

Unrestricted	\$4,238,375.45
Departmental	4,368,033.32
Faculty salaries	1,346,031.80
Graduate scholarships and fellowships	1,171,557.13
Undergraduate scholarships and awards	720,756.56
Student loan funds	786,723.38
Building construction funds	4,471,941.37
Other funds	758,160.35

In addition to noting the cash flow of gifts for the fiscal year, it is important to record some of the major activities in which the development staff was engaged that will affect the gift flow in subsequent years. A primary project in this regard was the effort to secure private matching funds to complete the requirements of the National Science Foundation grant for the new chemistry building and to obtain additional private monies to fund the broader program to strengthen all aspects of chemistry at M.I.T. This program was completed successfully with more than \$9 million for construction of the facility, providing it with a ten-year

maintenance fund and allocating additional monies for renovation of existing chemistry facilities and for faculty development. The new building, which will be named in honor of the late Dr. Camille Dreyfus, the Swiss-born chemist who pioneered in polymer research, is currently under construction in the Eastman Court. Gifts and pledges totaling \$3,000,000 have been committed to the chemistry program by the Camille and Henry Dreyfus Foundation. In addition, generous support from the corporate community combined with gifts from alumni and foundations provided the balance of the funding for this project. Other areas in which staff were deeply involved during the course of the year included the funding for the Computation Center facility, the library program, the Education Research Center, the faculty development fund, the establishment of funded professorships, and the continuing effort to strengthen the student aid program. In most instances, the achievements of the staff during the last year are not reflected in the previously reported gift totals since payments on these new pledges will be received in the coming years.

JOSEPH J. LAMBERT

REGISTRY OF GUESTS

Programs for more than 1,400 foreign visitors from 88 countries were scheduled through the Registry of Guests during the year.

The greatest proportion of visitors was from Canada (153), and there was a continued accent on group visits. The largest number of individual visitors came from England (46), and the most interest was centered in the Departments of Mechanical Engineering, Political Science, and Management.

The Registry recorded a total commitment of 441 foreign staff and faculty members as of December 8, 1966, and a considerable portion of office time during the year was devoted to visa matters in behalf of these visitors. The greatest numbers of long-term foreign visitors came from England (59), Germany (36), Italy (32), Israel (28), and India (28); 50 countries were represented.

The following table contrasts the long-term visitors of the past two years with those tallied in 1959-60:

	1959-60	1965-66	1966-67
Guests	28	20	15
Administration	—	—	4
Teaching	24	134	125
Research	131	256	297
Total	183	410	441

REGISTRY OF GUESTS

As usual, the Registry worked closely with the Committee on Commencement on a variety of matters for graduation on June 9.

In addition, the Registry this year commissioned new formal Institute Greetings to be sent to commemorate important events at sister institutions throughout the world and secured delegates to represent M.I.T. at many academic functions.

CAROLYN B. COX

OTHER OFFICES

DEPARTMENT OF AIR SCIENCE

At the beginning of the academic year there were 65 cadets enrolled in the Air Force R.O.T.C. program. Of these, 41 were in the General Military Course (Basic Course), and 25 in the Professional Officer Course (Advanced Course).

The annual gaming exercise, POLMILEX IV, was held on March 18, 1967, for members of the General Military Course. Interest and enthusiasm ran as high as in previous years. The game this year was built around a situation in Southeast Asia.

During the academic year, five seniors and seven juniors were on financial assistance grants authorized by the R.O.T.C. Vitalization Act of 1964.

PERSONNEL

Major Richard E. Brubaker was appointed as Associate Professor of Aerospace Studies, and is responsible for directing the academic portion of the General Military Course. In addition, he serves as Administrative Officer for the Department. The appointment of Major Joseph A. Hart was terminated in June, 1966. He was reassigned by the Air Force to serve in Thailand. During his appointment at M.I.T. he had worked successfully in developing the curriculum for the General Military Course, and in setting the pattern for the POLMILEX Exercise.

CADET ACTIVITIES

The Department sponsored two base familiarization visits during the year. Between the second and fourth of February, 17 cadets received

OTHER OFFICES

orientation briefings and visited the facilities at Eglin A.F.B. and the Pensacola Naval Air Station. On April 19, 1967, 25 cadets visited the Air Force Cambridge Research Laboratories at L. G. Hanscom Field, and toured the Radio Astronomy Observatory at Sagamore Hill, Hamilton, Massachusetts.

The cadets directed the annual Dining-In held on September 27, 1966. The guest speaker for the occasion was Major General Harry J. Sands Jr., Commandant of the Air Command and Staff College of Air University. He spoke on his recently completed tour of duty as senior United Nations representative of the Armistice Commission at Panmunjom, Korea.

The annual Military Day and Review ceremony was directed by the Air Force R.O.T.C. detachment. The Reviewing Official was President Howard W. Johnson, and Commander of the Troops was Cadet Lt. Colonel Herbert R. Schulze, A.F.R.O.T.C. Thirteen Air Force cadets received recognition for their achievements in the Cadet Corps.

The Angel Flight, which is the coed affiliate of the Arnold Air Society, began the year with six members and five pledges. Their main objective is to provide social services for the community such as reading books onto tape for blind students.

M.I.T. A.F.R.O.T.C. GRADUATES

During the academic year 13 cadets received commissions in the Air Force. Of these, two went to flying school upon graduation; one went to active duty as a Weather Officer trainee; and ten were granted delays to complete studies for advanced degrees. The Air Force maintains the policy of assigning graduates to fields requiring the specialties developed in their academic training and of granting educational delays to those individuals who desire to go directly to graduate school.

GEORGE P. GAMACHE

DEPARTMENT OF MILITARY SCIENCE

Enrollment in Army R.O.T.C. continued to improve but is still below the desirable Department of the Army standards. The continued increase was due to several factors, mainly revitalization of the program and an expansion of the Army R.O.T.C. Scholarship Program. We had 63 students at the end of the year compared with 52 at the close of 1966.

Two seniors and one graduate student were commissioned in June and two additional men will be commissioned at the completion of the 1967 R.O.T.C. Summer Camp in late July. One completed the Military

DEPARTMENT OF NAVAL SCIENCE

Science requirements but commissioning will be deferred until completion of the first term, school year 1967-68. This man will be awarded a Regular Army commission. Eight of our new freshmen were the winners of the four-year Army R.O.T.C. Scholarship and three sophomores were awarded the two-year Army R.O.T.C. Scholarship. The total of 27 Army R.O.T.C. Scholarships over-all represents one of the highest total numbers of any institution with the Army R.O.T.C. Program in the country.

Captain John D. Blankenship was transferred at graduation and was succeeded by Captain David B. Smith who joined the staff in June. Replacements arrived early in the fall of 1966. Major John T. Myers, and Major James K. Pangman filled existing vacancies at this time. Staff Sergeant Robert S. Simpson will be discharged this summer and will return to civilian life. His replacement should arrive early in the fall of 1967.

JACK R. SHIELDS

DEPARTMENT OF NAVAL SCIENCE

There were six seniors in the graduating class this year, four of whom received commissions in the U.S. Naval Reserve in Commissioning Exercises on June 9, 1967. One will receive his commission upon the completion of the summer cruise in August, 1967, and one will receive his commission upon graduation from M.I.T. in February, 1968. Two of the newly commissioned Ensigns from the Naval R.O.T.C. program were granted deferments from active duty to complete postgraduate education.

The freshman class had an enrollment of six Naval R.O.T.C. students. There were three sophomores, one of whom has been disenrolled for personal preference. There were three juniors, making a total of seventeen students in the Naval R.O.T.C. Unit at the end of the school year. This unit also administered 101 postgraduate officers of the U.S. Navy, U.S. Coast Guard, and the navies of four foreign countries, plus nine Naval Enlisted Scientific Education Program students.

Engineman Second Class Terrill D. Williams, U.S. Navy, was graduated with a Bachelor's degree in Metallurgy, and Hospital Corpsman Second Class George A. Sanders, U.S. Navy was graduated with a Bachelor's degree in Physics.

Lieutenant Robert M. Clifford was detached in July and Chief Storekeeper Normand O. Hamel will retire from the Navy on August 14. Chief Storekeeper Charles V. Weaver will be the replacement for Chief Hamel. A suitable replacement for Lieutenant Clifford will maintain the present staff level of nine.

ROBERT E. STARK

ALUMNI ASSOCIATION

This year we were fortunate to add to our staff G. Peter Grant '35 as Director for Clubs, Mrs. Jacquelyn M. Findlay '44 as Assistant to the Director of the Alumni Fund, and John I. Mattill and Peter Gwynne as Editor and Acting Managing Editor, respectively, of *Technology Review*. Richard F. Wright's position as Advertising Manager of the *Review* was changed to a full-time assignment. Meanwhile, William T. Struble resigned as Acting Editor to assume Mr. Mattill's former responsibilities as Director of Publications for the Institute.

In Mr. Brock's first year as Director, the 1967 Alumni Fund reached a new high for the fourth consecutive year, and for the first time the M.I.T. Alumni Fund was awarded first place by the American Alumni Council for the best solicitor training handbook. Just as gratifying as the Fund's achievement of \$2,536,039 was the number of donors — 17,545 an increase of 1,273 over the previous year's record. Special mention should be made of the two-year term of Philip H. Peters '37 as Chairman of the Alumni Fund Board under whose leadership the Fund increased 59 per cent in dollars and 15 per cent in donors.

For the third consecutive year *Technology Review* has printed a record number of pages — 15 per cent more than a year ago. More important are the increasing editorial content, improved design, and the addition of new monthly columns: "Review on Science" by Robert C. Cowen '49, "Review on Education" by Corbin Gwaltney, "Review on Books" by Joseph Mindel, and "Puzzle Corner" by Allan J. Gottlieb '67.

At the 1967 Annual Publications Competition of the American Alumni Council *Technology Review* was honored as one of the top ten alumni publications of the country, receiving also the General Award for distinguished achievement in continuing education, a special award for the Puzzle Corner, and citation for appearance. At the same competition the *Review* received a *Newsweek* Award for content relating to the Institute and public affairs for its June, 1966, issue on the urban challenge, edited by Mr. Struble.

The Association's 1966-67 season was formally opened in September by the Seventh Alumni Officers' Conference and the Fourth Alumni Seminar.

The Alumni Officers' Conference under the chairmanship of Gregory Smith '30 was attended by 360 Alumni Officers on September 9 and 10. At the Conference the Harold Whitworth Pierce Boathouse was dedicated. Much of this Conference was devoted to the deliberations of the Long Range Planning Committee of the Alumni Association and to examples of new activities in research and teaching at M.I.T. In the meantime, the Association is already adopting several of the proposals

suggested in the final report of the Long Range Planning Committee which is scheduled for publication in September, 1967.

The Alumni Seminar, led by Professor Walter A. Rosenblith, was conducted on September 10 through 12, on "The Learning Process and Innovation in Education." For three days 299 alumni and their wives lived on campus and attended lectures and seminars.

On October 5, the M.I.T. Alumni Center of New York held a joint concert with the Harvard Club of New York in Philharmonic Hall at Lincoln Center in honor of President designate Howard W. Johnson. There were 1,189 M.I.T. alumni and wives in the capacity audience.

On October 7th, the delegation of alumni for President Johnson's Inauguration was led by Gregory Smith '30. Among the greetings brought to M.I.T.'s new President were those on behalf of the alumni given by Theodore A. Mangelsdorf '26, President of the Association.

The present total of 97 M.I.T. Clubs carried on the Association's roster is divided geographically into: 72 within the continental United States, 13 elsewhere in the Americas, and 12 overseas in the other hemisphere.

This year, 86 members of the Institute's staff and the Alumni Council recorded a total of 220 M.I.T. Club visits. This represented 142 meetings of 63 different M.I.T. Clubs. Chief among these was the Sixteenth Regional Conference in Seattle which was attended by 1,050 alumni, wives, guests, high school teachers, and high school students. In addition to the New York Alumni Center Concert, the Inauguration, and the Regional Conference, President Johnson addressed another 1,500 alumni and guests at M.I.T. Club meetings in Boston, Los Angeles, Montreal, New York, Philadelphia, San Francisco, and Schenectady.

Attractive Club directories were published by the Chicago, Los Angeles, and Philadelphia Clubs and the New York Alumni Center. The New York Center increased membership and interest and established a new record of 1,786 members.

At the Center's final social meeting, their Silver Stein Award was presented to M.I.T.'s former President, Julius A. Stratton '23.

The year's activities for the Association were culminated by the Annual Alumni Weekend June 10-12. Four M.I.T. classes held campus reunions. A total of 1,362 attended Alumni Day. The Institute may be justifiably proud of the M.I.T. Dining Service which, for the first time handled all catering arrangements during Alumni Weekend including Alumni Day.

The major portion of editorial work for the 1967 Alumni Register is completed, and the book is scheduled for publication in October, 1967. Advanced subscriptions totaled 6,300 by the end of June. It will

OTHER OFFICES

contain in alphabetical and geographical order the names of all 55,892 living alumni together with the 1,428 members of the Class of 1967 — accounting for the total of 57,320 alumni on the rolls as of June 30. In addition the book will list 17,855 deceased alumni and 18,607 present and former members of the Institute's faculty and academic staff as well as the customary statistical summaries.

DONALD P. SEVERANCE

PRINCIPAL PROFESSIONAL HONORS AND ACTIVITIES OF THE STAFF

INSTITUTE PROFESSORS

CHARLES S. DRAPER

Honorary degree of Doctor of Science, Eidgenossische Technische Hochschule, Switzerland.

Guggenheim Award, American Institute of Aeronautics and Astronautics.

ROMAN JACOBSON

Honorary degree of Doctor of Science, University of New Mexico.

Honorary degree of Doctor, University of Grenoble.

Honorary degree of Doctor, University of Nice.

Honorary degree of Doctor of Humane Letters, University of Rome.

Honorary degree of Doctor of Humane Letters, Yale University.

Honorary Member, Czechoslovak Society of Arts and Sciences in America.

Vice President, International Committee of Slavists, Oxford University.

Member, Presidence Scientifique d'honneur, II Congressus Historae Slavicae Salisburgensis.

EDWIN H. LAND

Popular Science Award.

Albert A. Michelson Award.

Diesel Medal in Gold.

William James Lecturer on Psychology, Harvard University.

Honorary degree of Doctor of Laws, University of Massachusetts.

Honorary degree of Doctor of Science, Columbia University.

JOHN C. SLATER

Irving Langmuir Award, American Physical Society.

CHARLES H. TOWNES

President, American Physical Society.

Alumni Distinguished Service Award, California Institute of Technology.

Medal of Honor, Institute of Electrical and Electronics Engineers.

Honorary degree of Doctor of Laws, University of Alberta.

Honorary degree of Doctor of Science, Yeshiva University.

Honorary degree of Doctor of Science, New York University.

Vice Chairman, President's Science Advisory Committee.

PROFESSIONAL HONORS AND ACTIVITIES

JERROLD R. ZACHARIAS

Honorary degree of Doctor of Science, Western Reserve University.

SCHOOL OF ARCHITECTURE AND PLANNING

LAWRENCE B. ANDERSON

Architectural Consultant, Electronics Research Center, NASA, Cambridge.
Chairman, Jury for Gateway Mall Competition, St. Louis.

PIETRO BELLUSCHI

Honorary degree of Doctor of Fine Arts, University of Massachusetts.

DEPARTMENT OF ARCHITECTURE

STANFORD ANDERSON

ROBERT GOODMAN

HENRY A. MILLON

Exhibition in "The New City: Architecture and Urban Renewal," Museum of Modern Art, New York.

HENRY A. MILLON

Vice President, Society of Architectural Historians.

ROBERT B. NEWMAN

Frank P. Brown Medal, Franklin Institute for contributions to the building industry, received on behalf of Bolt Beranek & Newman Inc.

DEPARTMENT OF CITY AND REGIONAL PLANNING

BERNARD J. FRIEDEN

Secretary, Association of Collegiate Schools of Planning.

SCHOOL OF ENGINEERING

DEPARTMENT OF AERONAUTICS AND ASTRONAUTICS

RAYMOND L. BISPLINGHOFF

Member, National Academy of Sciences.

President, American Institute of Aeronautics and Astronautics.

Member, International Academy of Astronautics.

Director, Engineers Joint Council

Vice Chairman, Aeronautics and Space Engineering Board, National Academy of Engineering.

SECOR D. BROWNE

Director, Aero Club of New England.

LEON TRILLING

Co-Chairman, Organizing Committee, Sixth International Symposium on Rarefied Gas Dynamics.

LAWRENCE R. YOUNG

Member, National Administrative Committee, Biomedical Engineering Group, Institute of Electrical and Electronic Engineers.

Member, Editorial Board, *Transactions on Human Factors in Electronics*, Institute of Electrical and Electronic Engineers.

Member, Administrative Committee, Group on Human Factors in Electronics, Institute of Electrical and Electronic Engineers.

Member, Executive Committee, Annual Conference on Engineering in Medicine and Biology.

Chairman, M.I.T.-NASA Manual Control Conference.

HONORS AND AWARDS

DEPARTMENT OF CHEMICAL ENGINEERING

LAWRENCE B. EVANS

United Engineers and Constructors Preceptorship.

HOYT C. HOTTEL

Testimonial of Appreciation, Division of Engineering, National Research Council—
National Academy of Sciences.

EDWARD W. MERRILL

Member, Editorial Board, *The Journal of Biomedical Materials Research*.

CHARLES N. SATTERFIELD

Member, Editorial Advisory Board, *Industrial and Engineering Chemistry*.

WOLF R. VIETH

Participant, Summer Faculty Program, Cherron Research Corporation.

DEPARTMENT OF CIVIL ENGINEERING

JOHN M. BIGGS

Construction's Man of the Year Award, *Engineering News-Record*.

ROBERT J. HANSEN

Transportation Section Award, Boston Society of Civil Engineers for paper on High
Speed Ground Transportation.

DONALD R. F. HARLEMAN

Desmond FitzGerald Medal, Boston Society of Civil Engineers.

ARTHUR T. IPPEN

Member, National Academy of Engineering.

Honorary degree of Doctor of Engineering, Technical University, Karlsruhe,
Germany.

Honorary Member, Venezuelan Society of Hydraulic Engineers.

RUSSEL C. JONES

Collingwood Prize, American Society of Civil Engineers.

Member, Executive Council, Division of Materials Sciences, American Society for
Testing and Materials.

Member, Executive Committee, Massachusetts Section, American Society of Civil
Engineers.

CHARLES C. LADD

Chairman, Structural Section, Boston Society of Civil Engineers.

Chairman, Committee on Properties of Soils and Soil Deposits, Soil Mechanics and
Foundations Division, American Society of Civil Engineers.

MARVIN L. MANHEIM

Medal of Commendation for Meritorious Service, U.S. Army.

FREDERICK J. MCGARRY

Citation for service to the construction industry, *Engineering News-Record*.

CHARLES L. MILLER

George Westinghouse Award, American Society for Engineering Education.

DEPARTMENT OF ELECTRICAL ENGINEERING

ROGER W. BROCKETT

Donald P. Eckman Award, Joint Automatic Control Conference.

Best Paper Award, Joint Automatic Control Conference.

JOHN N. CHURCHILL

Ford Foundation Postdoctoral Fellowship.

National Science Foundation Research Initiation Award.

PROFESSIONAL HONORS AND ACTIVITIES

WILBUR B. DAVENPORT JR.

Member, Board of Directors, Institute of Electrical and Electronic Engineers — Northeast Electronics Research and Engineering Meeting.

MICHAEL L. DERTOUZOS

Chairman, Session on Computer-Aided Circuit Design, Northeast Electronics Research and Engineering Meeting.

JEROME Y. LETTVIN

Professional Member, Eta Kappa Nu.

PAUL PENFIELD JR.

National Science Foundation Senior Postdoctoral Fellowship.

ROBERT P. RAFUSE

International Solid-State Circuits Conference Award for outstanding paper.

WALTER A. ROSENBLITH

Chairman, National Academy of Sciences — National Research Council Brain Sciences Committee.

Chairman, Organizing Committee, Third International Congress of Biophysics.

Member, National Committee on Pure and Applied Biophysics.

CLAUDE E. SHANNON

National Medal of Science Award.

JOHN G. SIAMBIS

Ford Foundation Postdoctoral Engineering Fellowship.

ALEXANDER SMAKULA

Culture Prize of the German Photographic Society.

KENNETH N. STEVENS

Member, Executive Council, National Academy of Sciences Committee on Hearing, Bioacoustics, and Biomechanics.

JOHN G. TRUMP

New England Award, from area engineering societies to an outstanding engineer.

JOHN E. WARD

Member, Subcommittee on Automation, National Academy of Sciences.

JOSEPH WEIZENBAUM

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DEPARTMENT OF MECHANICAL ENGINEERING

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JAMES A. FAY

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Member, Executive Committee, Fluid Dynamics Division, American Physical Society.

Member, NASA Research Advisory Committee on Fluid Dynamics.

AUGUST L. HESSELSCHWERDT JR.

Fellow, American Society of Heating, Refrigerating and Air Conditioning Engineers.

HONORS AND AWARDS

ROBERT W. MANN

Member, Committee on Prosthetics Research and Development, National Academy of Sciences — National Research Council.

RONALD F. PROBSTEN

Member, International Astronomical Union.

ASCHER H. SHAPIRO

Member, National Academy of Sciences.

Councilor, American Academy of Arts and Sciences.

Fellow, American Society of Mechanical Engineers.

Member, Editorial Committee for *Annual Review of Fluid Mechanics*.

Fellow, American Institute of Aeronautics and Astronautics.

THOMAS B. SHERIDAN

Editor, Institute of Electrical and Electronic Engineers *Transactions on Human Factors in Electronics*.

PRESCOTT A. SMITH

Fellow, American Society of Mechanical Engineers.

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Co-Chairman, Physical Electronics Conference.

TAU-YI TOONG

Member, Propellants and Combustion Committee, American Institute of Aeronautics and Astronautics.

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Chairman, Process Industries Division, American Society of Mechanical Engineers.
Program Chairman, Annual Conference of Gas Turbine Division, American Society of Mechanical Engineers.

Chairman, Volunteers for Technical Assistance, Boston Chapter.

Member, International Board of Directors, Volunteers for Technical Assistance.

Member, Comité Scientifique et Technique, Entropie, Paris.

American Correspondent, Institution of Mechanical Engineers, United Kingdom.

DEPARTMENT OF METALLURGY AND MATERIALS SCIENCE

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Chairman, Long Range Planning Committee, American Society for Metals.

Member, Advisory Panel, Center for Advanced Studies, University of Virginia.

Chairman, Board of Governors, Acta Metallurgica.

HARRY C. GATOS

President, Electrochemical Society, Inc.

DEPARTMENT OF NAVAL ARCHITECTURE AND MARINE ENGINEERING

MARTIN A. ABKOWITZ

Member, Seakeeping Committee, International Towing Tank Conference.

WILLIAM K. BLAKE

Fellowship of the Society of Naval Architects and Marine Engineers.

J. HARVEY EVANS

Member of Council, Society of Naval Architects and Marine Engineers.

PROFESSIONAL HONORS AND ACTIVITIES

ERNST G. FRANKEL

Chairman, Advanced Marine Machinery Panel, Society of Naval Architects and Marine Engineers.

Member, Ships Machinery Committee, Society of Naval Architects and Marine Engineers.

Member, Transportation Science Section Council, Operations Research Society of America.

Member, National Academy of Sciences Advisory Board on Hardened Electric Power Systems.

ALFRED H. KEIL

Chairman, Transportation Subcommittee of Program Committee, National Academy of Engineering.

Gibbs Brothers Gold Medal Award of the National Academy of Sciences.

ROBERT E. STARK

Chairman, New England Section, Society of Naval Architects and Marine Engineers.

DEPARTMENT OF NUCLEAR ENGINEERING

MANSON BENEDICT

Founders Award, American Institute of Chemical Engineers.

Member, National Academy of Engineering.

KENT F. HANSEN

Vice Chairman, Mathematics and Computation Division, American Nuclear Society.

SCHOOL OF HUMANITIES AND SOCIAL SCIENCES

DEPARTMENT OF ECONOMICS

EVERETT E. HAGEN

President, Association for Comparative Economics.

St. Olaf College Distinguished Alumnus Award.

CHARLES P. KINDLEBERGER

Honorary degree of Doctor, University of Paris.

Vice President, American Economic Association.

MAX F. MILLIKAN

President, World Peace Foundation.

FRANCO MODIGLIANI

Member, Executive Committee, American Economic Association.

PAUL A. SAMUELSON

President, International Economic Association.

KARL SHELL

Ford Faculty Research Fellowship.

ROBERT M. SOLOW

Member, Executive Committee, American Economic Association.

Honorary degree of Doctor of Laws, University of Chicago.

DEPARTMENT OF HUMANITIES

DAVID M. EPSTEIN

Guest Conductor, Berlin Radio Symphony Orchestra, Czechoslovak Radio Orchestra.

Composition Selected for Baltimore Symphony — Rockefeller Foundation Symposium on Contemporary Music.

HONORS AND AWARDS

ALBERT R. GURNEY JR.
Everett Moore Baker Award.

ROBERT E. HERZSTEIN
Founder's Day Award for Outstanding Scholarship, New York University.

ARTHUR D. KALEDIN
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Chief Consultant, Special House of Representatives Committee on Elections, U.S. Congress.

BRUCE MAZLISH
Fellow, American Academy of Arts and Sciences.
Social Science Research Council Faculty Fellowship.

IRVING SINGER
Fellow, Villa I Tatti, Florence.
Fellowship, Bollingen Foundation.

NATHAN SVIN
National Science Foundation Research Fellowship.

CYRIL S. SMITH
Leonardo da Vinci Medal, Society for the History of Technology.

HUSTON C. SMITH
Honorary degree of Doctor of Laws, MacMurray College.

WILLIAM I. THOMPSON
Old Dominion Fellowship.
Associate Editor, American Committee for Irish Studies.

DEPARTMENT OF MODERN LANGUAGES AND LINGUISTICS

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Officier, Ordre des Palmes Académiques, Government of France.
Chairman, Advisory and Nominating Committee of the Eighteenth-Century French Literature Group, Modern Language Association.
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Honorary degree of Doctor of Humane Letters, University of Chicago.

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Speaker, Annual Joint Meeting of New England Chapters of the American Association of Teachers of German.

DEPARTMENT OF POLITICAL SCIENCE

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PROFESSIONAL HONORS AND ACTIVITIES

FRED C. IKLÉ

Member, Board of Review and Development, American Society of International Law.

Chairman, Working Party for the Commission on the Year 2000, American Academy of Arts and Sciences.

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Distinguished Public Service Medal, Department of Defense.

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Member, Editorial Board, *The American Political Science Review*.

Member, Board of Directors, Association of Asian Studies.

Chairman, Advisory Council on Research and Development, Association of Asian Studies.

Editor, Rand McNally series on Political Change.

Member, Social Science Research Council Committee on Comparative Politics.

DEPARTMENT OF PSYCHOLOGY

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Co-Editor, *Psychologische Forschung*.

Member, International Brain Research Organization.

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DONALD E. FARRAR

Ford Foundation Faculty Research Fellowship.

Associate Editor, *National Tax Journal*.

GEORGE F. FARRIS

Marquis Award, University of Michigan.

JAY W. FORRESTER

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Member, National Inventors Council.

JAY R. GALBRAITH

McKinsey Foundation Postdoctoral Fellowship.

MARTIN GREENBERGER

National Lecturer, Association for Computing Machinery.

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Vice Chairman, Marketing College, Institute of Management Sciences.

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American Cancer Society Faculty Research Associate Award.

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Society for Biological Psychiatry Prize Award.

Consultant, National Institutes of Health, Small Grants Study Section.

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Honorary degree of Doctor of Natural Sciences, University of Hamburg.

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Honorary degree of Doctor of Science, Tufts University.

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Honorary degree of Doctor of Science, Lowell Technological Institute.

Honorary degree of Doctor of Science in Business Administration, Bryant College.

General Muir S. Fairchild Trophy, Arnold Air Society.

JAMES R. KILLIAN, JR.

Member, National Academy of Engineering.

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Honorary degree of Doctor of Science, University of Leeds, England.

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MEDICAL

HARRIET L. HARDY

Council Member, Massachusetts Thoracic Society.

Member, Permanent Commission, International Association on Occupational Health.

Member, Industrial Medical Association Committee on Toxicology.

JUNE W. PRYOR

Medical Director, University of Massachusetts at Boston.

PROFESSIONAL HONORS AND ACTIVITIES

ROBERT F. TILLEY
Secretary, Norfolk District Medical Society.
Councilor, Northeast Dermatological Society.

OTHER DEPARTMENTS AND LABORATORIES

RICHARD H. BAKER
General Chairman, International Solid-State Circuits Conference.

MACDONALD BARR
Chairman, Legislation Committee, Boston Section, New England Chapter, American Institute of Planners.

KENNETH J. BUTTON
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CHARLES E. CHASE
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CHARLES H. STEVENS
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Member, Board of Directors, Special Libraries Association.

ROBERT H. STOTZ
Secretary, New England Chapter, Society for Information Display.

INSTRUMENTATION LABORATORY

WESLEY H. MCPHEE
Member, Board of Directors, National Conference of Standards Laboratories.
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JOHN E. MILLER
Associate Editor, *Journal of Spacecraft and Rockets*, American Institute of Aeronautics and Astronautics.

LINCOLN LABORATORY

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ROBERT R. BILLUPS
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CARL BLAKE
Chairman, Boston Chapter, Group on Microwave Theory and Techniques, Institute of Electrical and Electronics Engineers.

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HONORS AND AWARDS

MILTON U. CLAUSER

Honorary degree of Doctor of Engineering, Purdue University.
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ROBERT V. DODD

Chairman, Nominating Committee, Boston Chapter, National Association of Accountants.

GENE F. DRESSELHAUS

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PAUL R. DROUILHET JR.

Chairman, Boston Chapter, Group on Communication Technology, Institute of Electrical and Electronics Engineers.

IRVING GOLDBERG

National Vice President, Property Administration Association.

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Member, Executive Committee, Solid-State Physics Division, American Physical Society.

Member, Program Committee, International Congress on Magnetism, International Union of Pure and Applied Physics.

Member, Steering Committee, Conference on Magnetism and Magnetic Materials.
Associate Editor, *Materials Research Bulletin*.

ELIS A. GUDITZ

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Reviewer, *Zentralblatt Fur Mathematik*, Berlin.

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JOHN E. MCNAMARA

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THOMAS B. REED

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PROFESSIONAL HONORS AND ACTIVITIES

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President, Western Middlesex Chapter, Massachusetts Society of Professional Engineers.

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EDWARD P. WAREKOIS

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Director of Membership, National Association of Accountants.

JOEL M. WINETT

Chairman, Hardware Configuration and Performance Committee, Time-Sharing Project, Share Organization.