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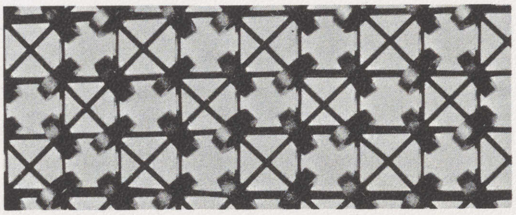
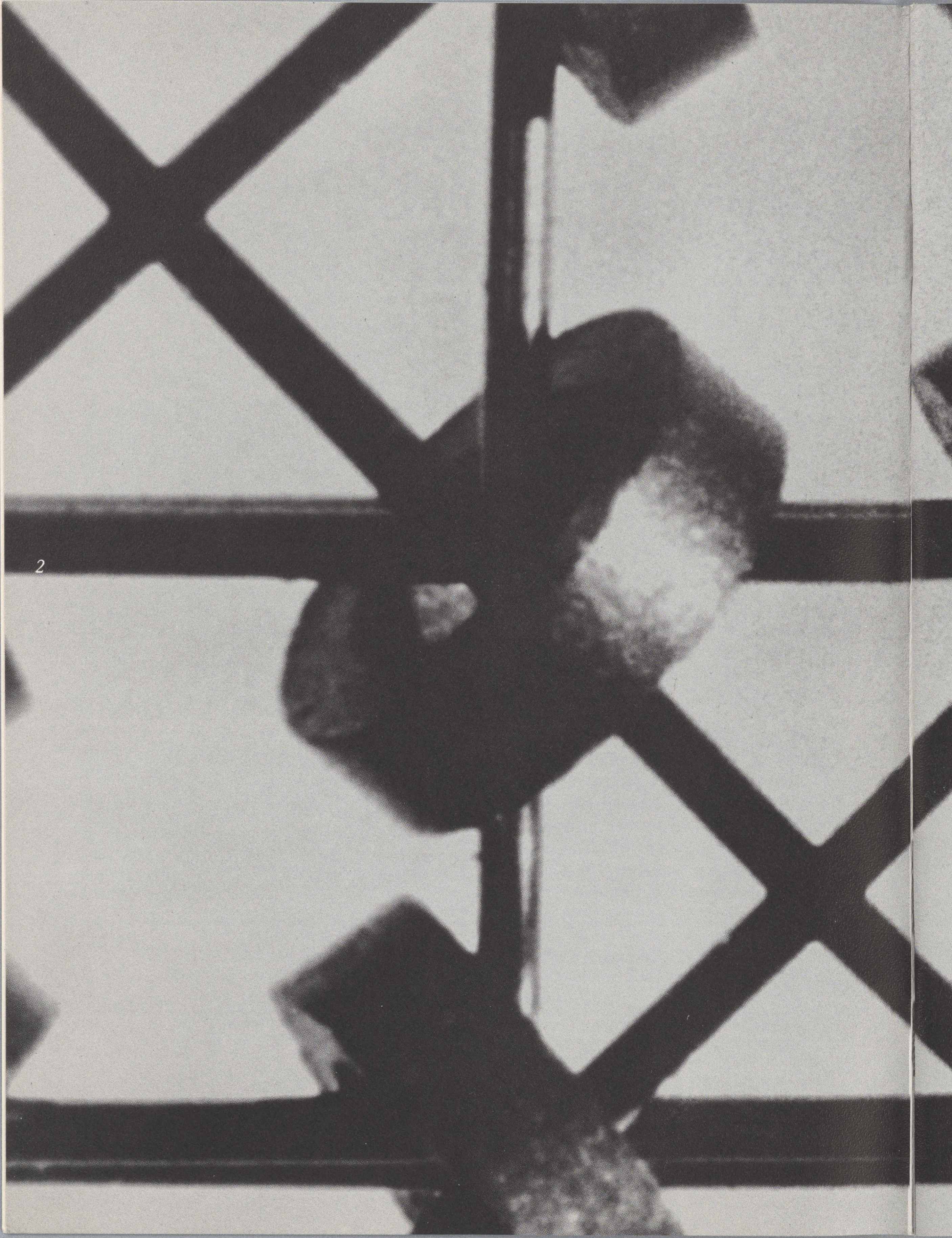
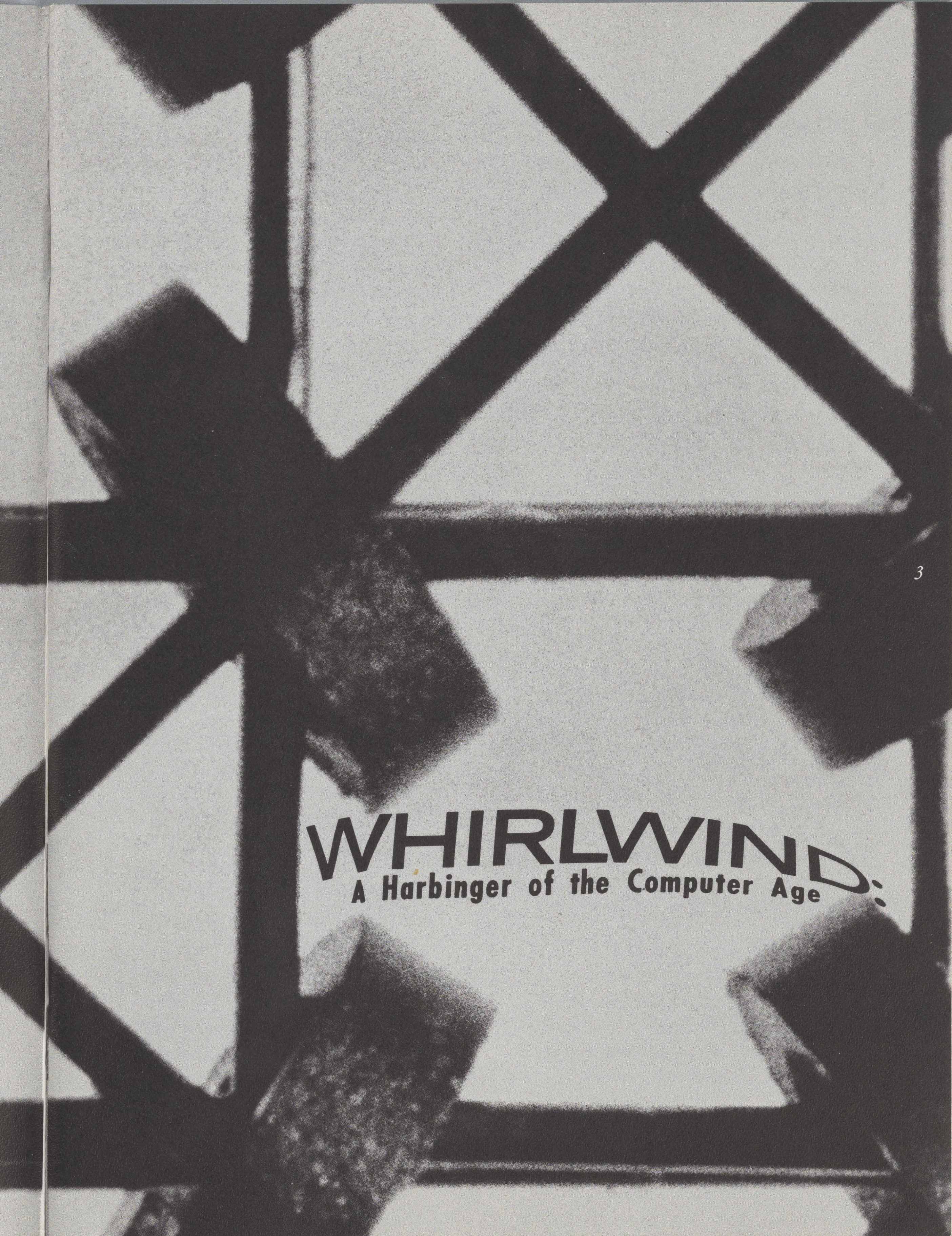
Norm McCullough 40 (right).
Ed Paradiso 8 (top), 26-27, 40 (left).

THE COVER: The Whirlwind computer will be remembered for its core memory, a data-storage system used in the majority of today's computers. The matrix of magnetic cores shown on the cover was part of Whirlwind's memory unit. This issue of MITRE MATRIX features a story about Whirlwind.







# WHIRLWIND: A Harbinger of the Computer Age

*The Smithsonian Institution recently acquired title to the Whirlwind computer, an important pioneer of American technology. Documentation has been transferred to Washington, D.C., and important subassemblies will follow. A number of MITRE people were heavily involved in the Whirlwind development.*

Whirlwind, a progenitor of today's computers, has many accomplishments to its credit.

Whirlwind provided the first large-scale, real-time control system. From early work in tracking aircraft using a digital computer, the experimental Cape Cod system was devised, with Whirlwind as the control element. The system was a network of radar sites feeding data to the computer. It detected and tracked target aircraft and transmitted vectoring instructions to fighter interceptors.



These techniques were later incorporated into air defense, including the SAGE system, for which Whirlwind and the Cape Cod system were the prototype.

Since as many as 16 manned consoles could interact simultaneously with the central computer, Whirlwind can be looked upon as a time-sharing forerunner.

In its initial version with electrostatic storage, Whirlwind could perform 20,000 operations per second. It had a word length of only 16 bits, but the arithmetic unit was implemented in such a way that, when necessary, results containing up to 32 bits could readily be handled. It also included a software package that provided for multiple precision and floating point arithmetic.

Its input/output facilities consisted of a Friden Flexowriter plus a photoelectric tape reader. Later in its development, Whirlwind's electrostatic storage was replaced through the first use of magnetic core storage (2048 words), which not only resolved problems of storage reliability then threatening the success of the whole project, but also greatly increased the computer's operating speed.

A more efficient input/output system was later installed and additional input/output devices were provided. These included an auxiliary storage and magnetic drum, with 24,576 word capacity, a buffer storage magnetic drum for handling radar input data, display oscilloscopes, and digital magnetic tape units.

### Not as a Computer

Whirlwind had its origins in an effort to build something other than a computer. In 1943 the Special Devices

Division of the U.S. Navy realized the need for an improved aircraft simulator. Flight trainers of that day had proved their worth, but they had drawbacks. They were expensive to build, especially for multi-engine aircraft, and not very versatile. Each trainer could represent just one type of aircraft – and that type only.

Captain Luis de Flores of the Special Devices Division reasoned that if a universal type of trainer could be built, it would reduce the cost of providing trainers, especially for new types of planes.

The Navy subsequently asked MIT to investigate the possibility of building a universal trainer. The Servomechanisms Laboratory at Massachusetts Institute of Technology had already developed several complex electromechanical devices for the military, and developing a universal flight trainer was one more way MIT could help the war effort.

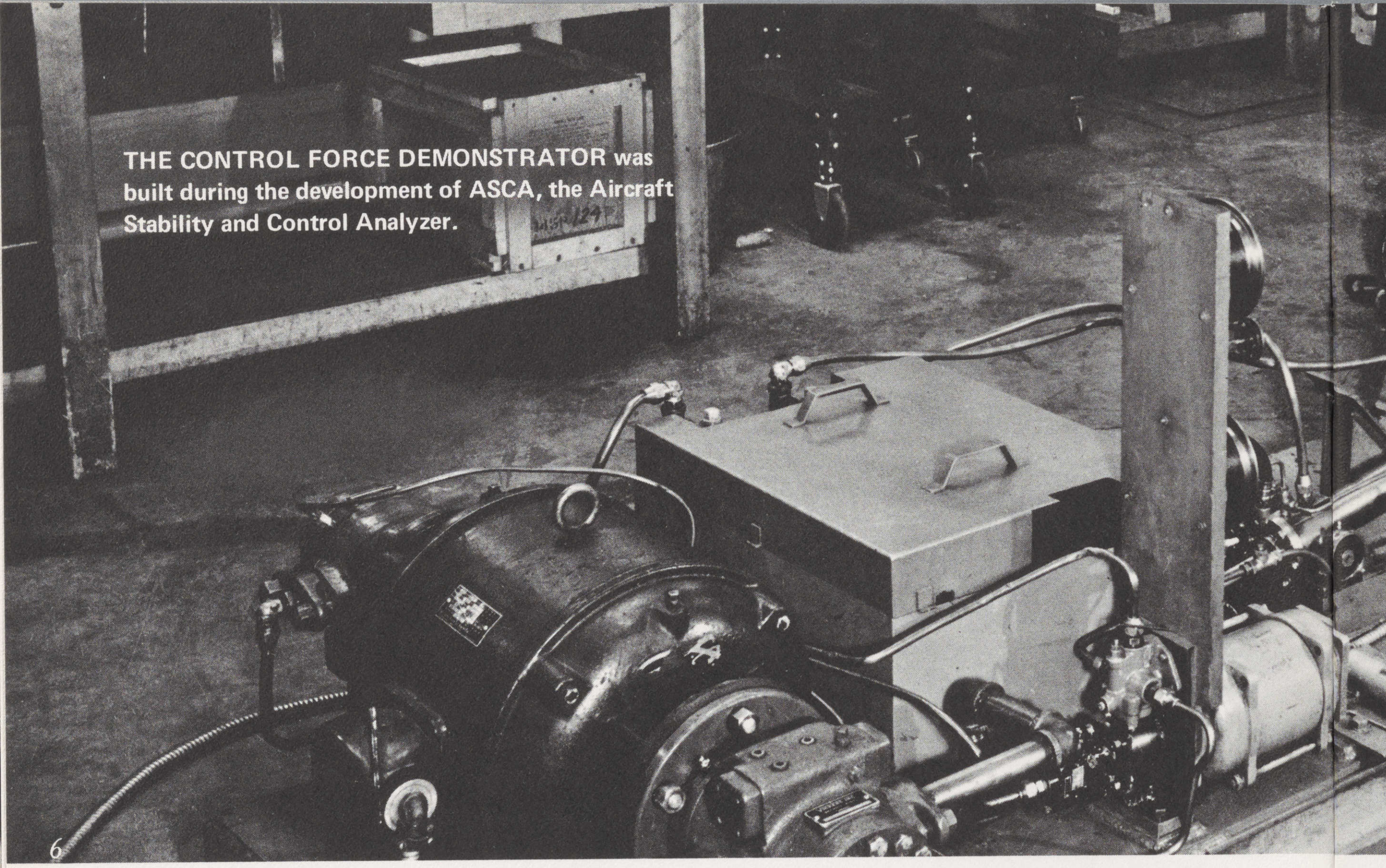
After a preliminary study, the MIT engineers concluded that the project was feasible. Encouraged by the success of the MIT Differential Analyzer, and with the thought of using this technology as a building block in a larger computing device, they went one step further. They proposed a simulator which would go beyond the functions of a flight trainer and actually evaluate the performance of airplanes still on the drawing board. Such a simulator would be invaluable for studying pilot/aircraft interaction, for example. This is a critical area because it is possible inadvertently to design an aircraft so that whatever a pilot does to correct a given situation is exactly the wrong thing to do by the time he does it. Despite its obvious complexity, the engineers gave their enthusiastic support to the project.

But as time went on, this proposed technical innovation did not receive unanimous support. Critics within the Navy said the proposed device was "essentially a physicist's dream and an engineer's nightmare" and that the claims made for it were technically unsupportable and fallacious.

Nevertheless, the Navy (looking toward the goal of a generalized flight trainer) and MIT (looking toward the further goal of a flight simulator) set out in 1944 on the mutual project of building ASCA, the Aircraft Stability and Control Analyzer.

#### Forrester and Everett Head Project

Gordon S. Brown, Director of the Servomechanisms Laboratory, appointed one of his assistants, Jay W. Forrester, to head the project.



THE CONTROL FORCE DEMONSTRATOR was built during the development of ASCA, the Aircraft Stability and Control Analyzer.



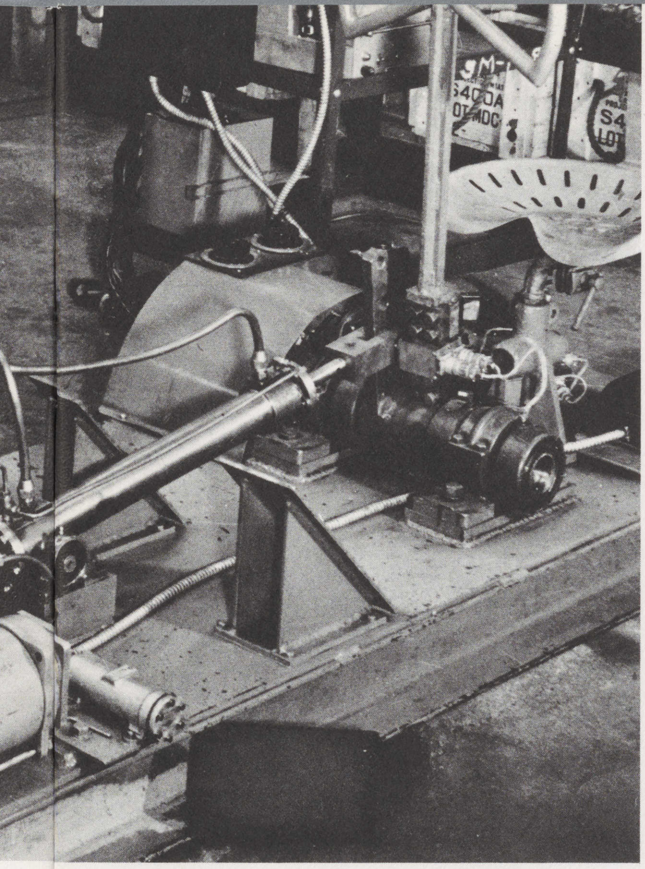
Forrester subsequently brought in Robert R. Everett.

Forrester is now Professor of Management in the Sloan School of Management at MIT, where he is working on computer applications to social problems, particularly in the analysis of social systems. Everett's affiliation with MIT ended when he helped start The MITRE Corporation, of which he is now President.

For the next decade these two men directed the project as it evolved from an aircraft simulator into a high-speed digital computer and finally into a key element of an air defense system – and from sponsorship only by the Navy to sponsorship primarily by the Air Force.

### The Analog Attempt

A preliminary survey began to bring the engineering problems into focus. It appeared that the simulator would have to accommodate 92 variables and 33 simultaneous equations just to describe aircraft response. The engine characteristics of even a single-engine aircraft would add more computations. And the Navy was asking for something that would simulate a multi-engine aircraft. The computations would have to be done at a very high speed. Since the pilot would be in the loop, the calculations had to be



done in "real time" if results were to be realistic.

As time went on, the problems of building ASCA centered around the computing machinery. Originally the ASCA engineers had explored analog computing devices, but the drawbacks to representing all the ASCA problems on an electromechanical analog machine began to seem insurmountable.

Such a device would be exceedingly large and complicated. Perhaps the greatest difficulty with a purely electrical analog was the extreme range of values which entered the problems. This factor put a practical limit on the analog approach. The further the engineers traveled down the analog path, the more it became evident it would not lead to where they wanted to go.

### The Digital Approach

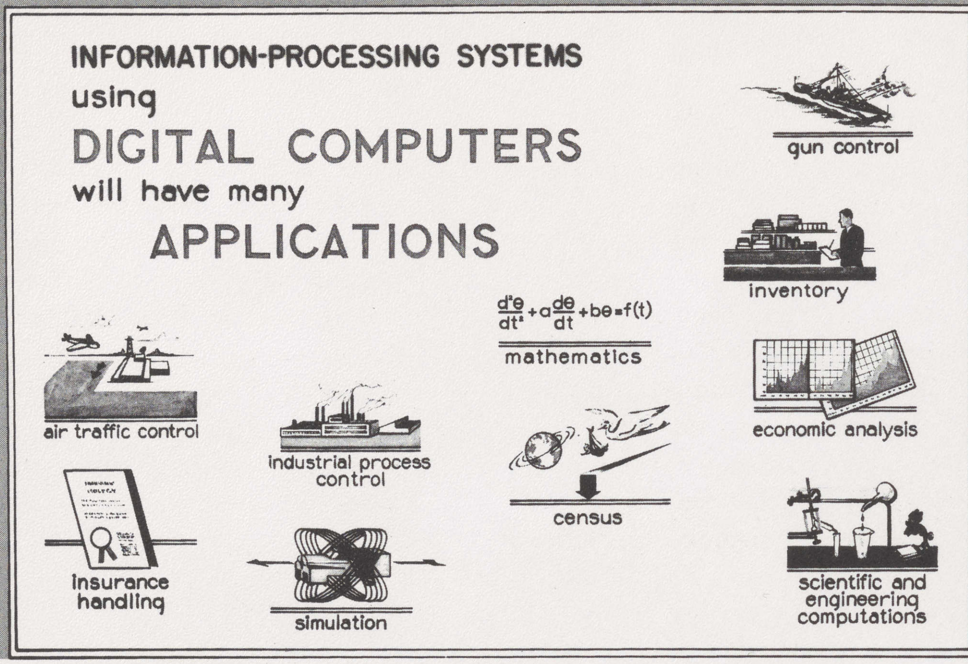
By coincidence, one of Forrester's friends, Perry O. Crawford, was deeply involved in the relatively new field of digital computers – devices which manipulated numerical values to solve problems – as opposed to the analog approach being tried in ASCA.

After some investigation of the digital approach, Forrester recommended to the Navy that numerical computation methods be used, since the rewards would be greater reliability, higher accuracy, lower cost, smaller size and more flexible operation. And it would permit the solution of many scientific and engineering problems other than those associated with aircraft flight.

In a bid for time and money to develop a "universal computer," Forrester outlined – for the first of what was to be many times – the possible applications of this powerful computation tool. For the military, it could be used in gun control, guided missile warfare and automatic radar tracking. And for general scientific

**MITRE PRESIDENT ROBERT R. EVERETT** took a final look at a Whirlwind film last October 30 (above). The film went to Washington for inclusion in the Smithsonian's Computer History Project. An earlier picture shows him seated at the control force demonstrator.

PROFESSOR JAY FORRESTER of MIT as he appeared in a recent issue of National Geographic Magazine (above) and in the Whirlwind days (R). Forrester, who pioneered the data storage system used in the majority of today's computers, has recently applied the computer to industrial and urban problems.




**"WILL HAVE MANY APPLICATIONS"** **This picture was taken in 1950.**



research, it could be applied to the fields of thermodynamics, mechanical engineering, civil engineering, and to statistical studies.

The Navy subsequently authorized the construction of a small digital computer – a project which would involve the development of electrostatic storage tubes and electronic switching, and mathematical studies of digital computation. The Navy was still expecting an aircraft analyzer based on the computer. Later, project ASCA was abandoned and the prime objective became an attempt at building a high-speed, general-purpose digital computer.

**Paying the Bills**

Not the least of Forrester's achievements was that of convincing the Navy, which was undergoing considerable post-war reorganization, that they should continue to fund the project at an accelerated rate, or even at the same rate. At one point, $1.8 million (a very large sum for those days) was requested to cover the next fifteen months. This, in addition to an unspent sum, represented a forecast requirement of over $2 million, a figure equal to the sum the Navy had allotted to the entire area of mathematical research. It was no wonder that top administration at MIT and

Naval Research found themselves in a confrontation.

Dr. James Killian, Jr.*, then Vice President of MIT, requested a detailed review of the project by an impartial panel. The panel gave him a favorable report. Everything was on schedule and the memory tubes were promising, but if they failed to meet expectations, alternative memory systems were available.

### Going Digital

There were new technical problems that the old analog approach never hinted at. Everett headed a group enmeshed in the tasks of system building and conversion of mathematical operations into information which another group could use to build electronic subassemblies. Everett's group also had the job of designing a control system which would allow these operations to be carried out.

For the sake of additional speed, Everett elected to accept the complexities accompanying parallel processing, a technique by which computations could be done in parallel rather than series.

### The Storage Tubes

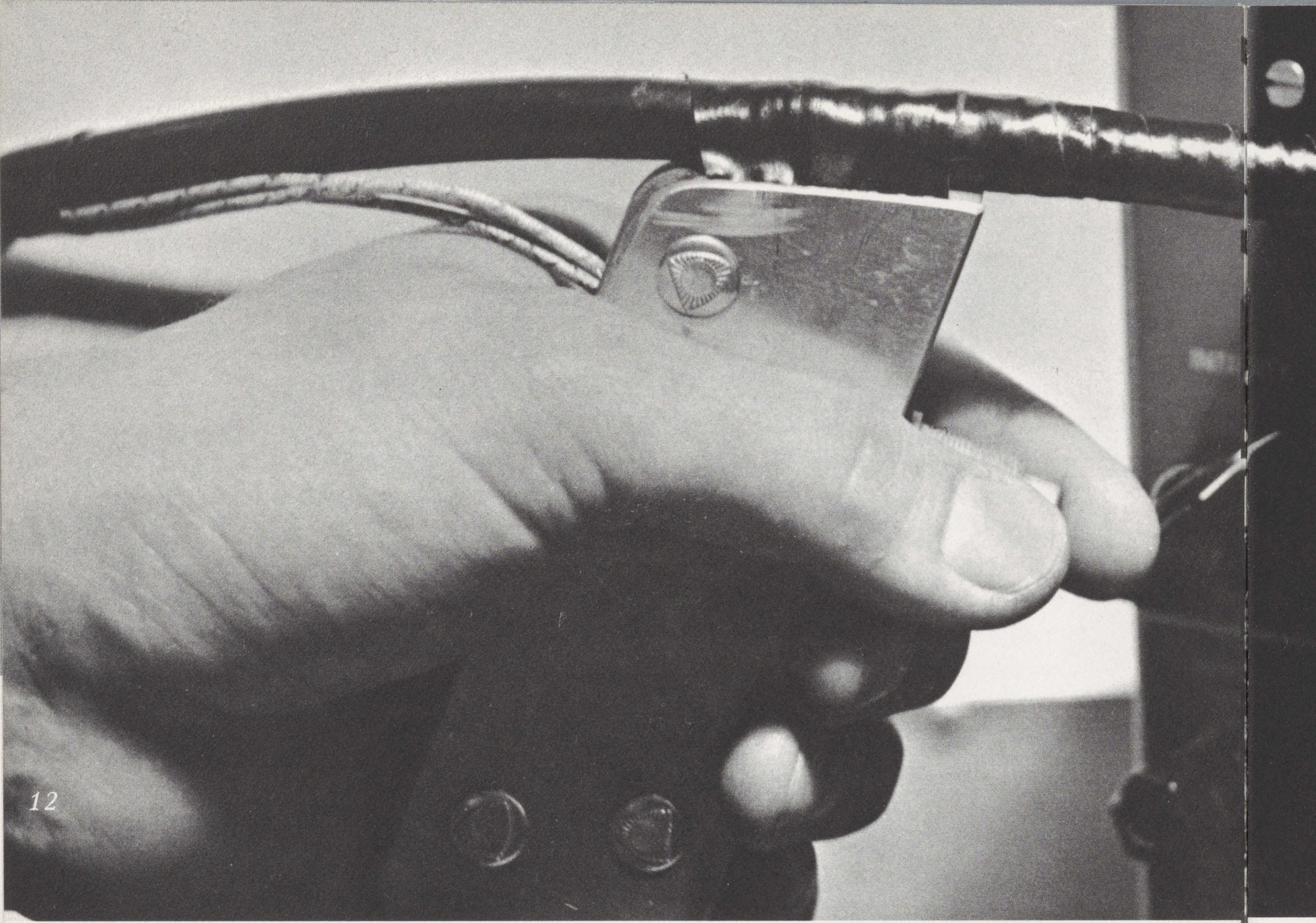
One set of technical problems never did get completely solved — those surrounding the electrostatic storage tubes used for Whirlwind's memory — the same tubes mentioned in the panel's report to Dr. Killian. No matter how carefully built, the tubes never reached the desired level of reliability at the high memory densities wanted. Hand made, and each one taking almost a week to construct, the tubes cost upwards of $1500 each.

Many of Whirlwind's contemporaries had a reliable memory device in the form of a tube-shaped tank of mercury. These acoustic delay line memories, as they were called, were too slow, as was a rotating magnetic drum then available. The storage tubes were fast, and it had seemed that the reliability problems could be solved — no doubt eventually they could have been.

In a very general way, the memory tubes worked like a television tube. An electron gun "wrote" binary information on a flat surface of the tube in the form of electrically charged spots — the same way an electron gun traces a picture onto the screen of a television tube. In the storage tube, however, the information could be "read" at a later time. A second gun in the tube was used to hold information.

At one point it became evident that the whole computer would be assembled and ready to operate —

**Dr. Killian is now Chairman of the MIT Corporation and a member of MITRE's Board of Trustees.*



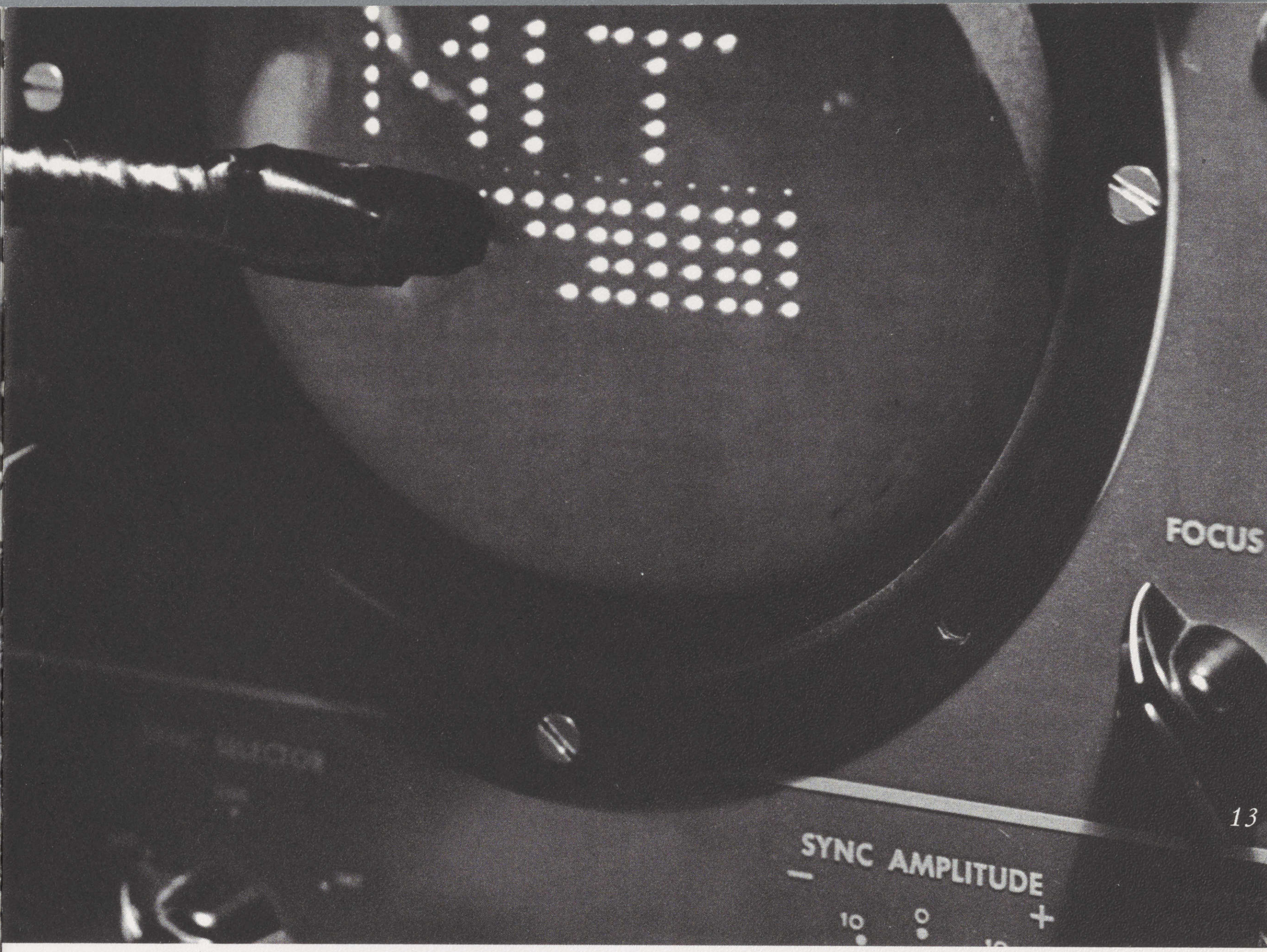


with a balky memory unit. But reliability is a relative term. What would have been ample reliability in a laboratory computer used for producing mathematical tables and the like, where frequent periods of downtime would be acceptable, was not quite good enough for Whirlwind, which was being designed for use as a reliable engineering device to operate in real time.

**Core Memory**

It was the storage tube's resistance to perfection that led to what is probably Whirlwind's most significant feature, the core memory.

Basically there were only two requirements for the memory other than capacity and accessibility: the ability of its elements to hold either



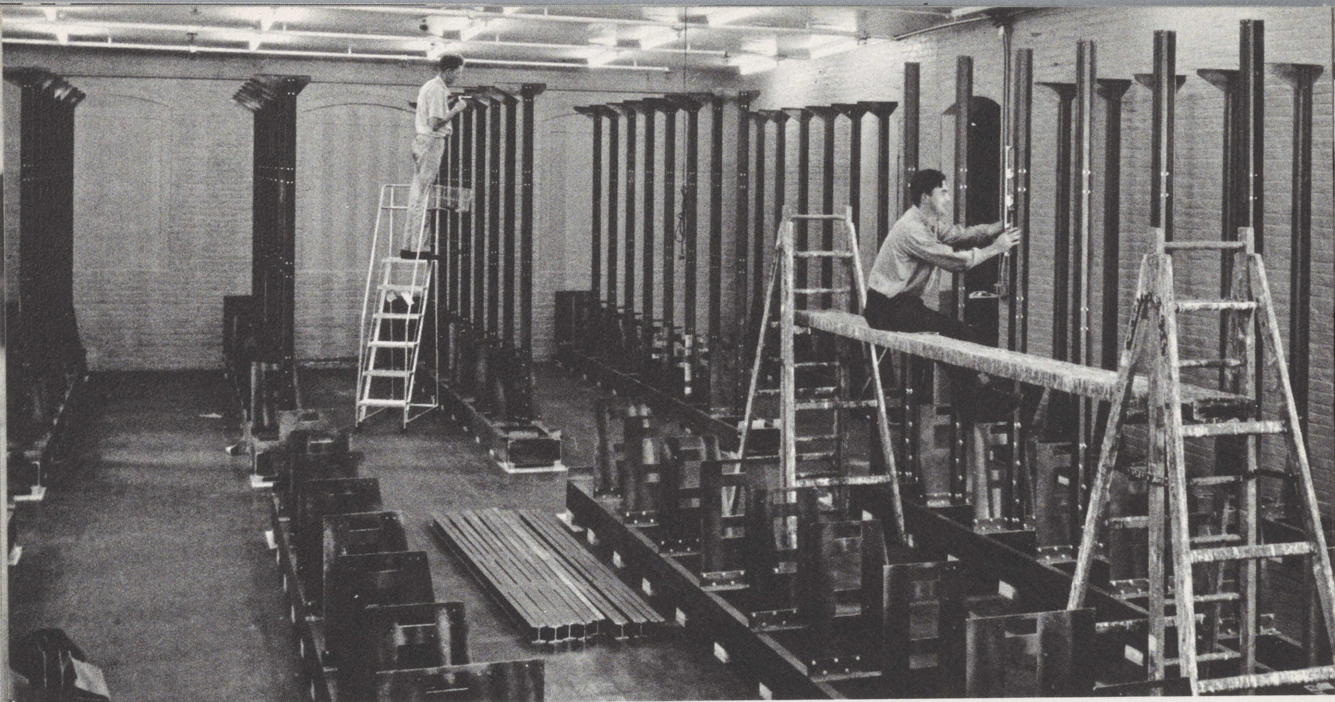



**THE LIGHT GUN** provided a new way for an operator to interact with a cathode ray tube display. This photograph of a handmade prototype was taken in 1952.

one of two stable electrical states and the ability to change these states in a matter of microseconds.

Project people recall that at one time Forrester secluded himself in a corner of the lab with a collection of doughnuts, not the kind for dunking in coffee, but doughnuts of metal and ceramic, capable of holding one of two electromagnetized states until reversed by a control signal. There was no question that they could be made into a memory device, but it remained to be seen whether such a device would be more reliable than the storage tubes, and as fast.

A graduate student, William N. Papian, began the job of testing sample cores. The cores worked, but at first they were slower than the tubes. Four years later, however, when the



**THE COMPUTER ROOM which housed Whirlwind. Whirlwind filled the room from floor to ceiling. This shot, perhaps better than any other, illustrates the size of Whirlwind.**

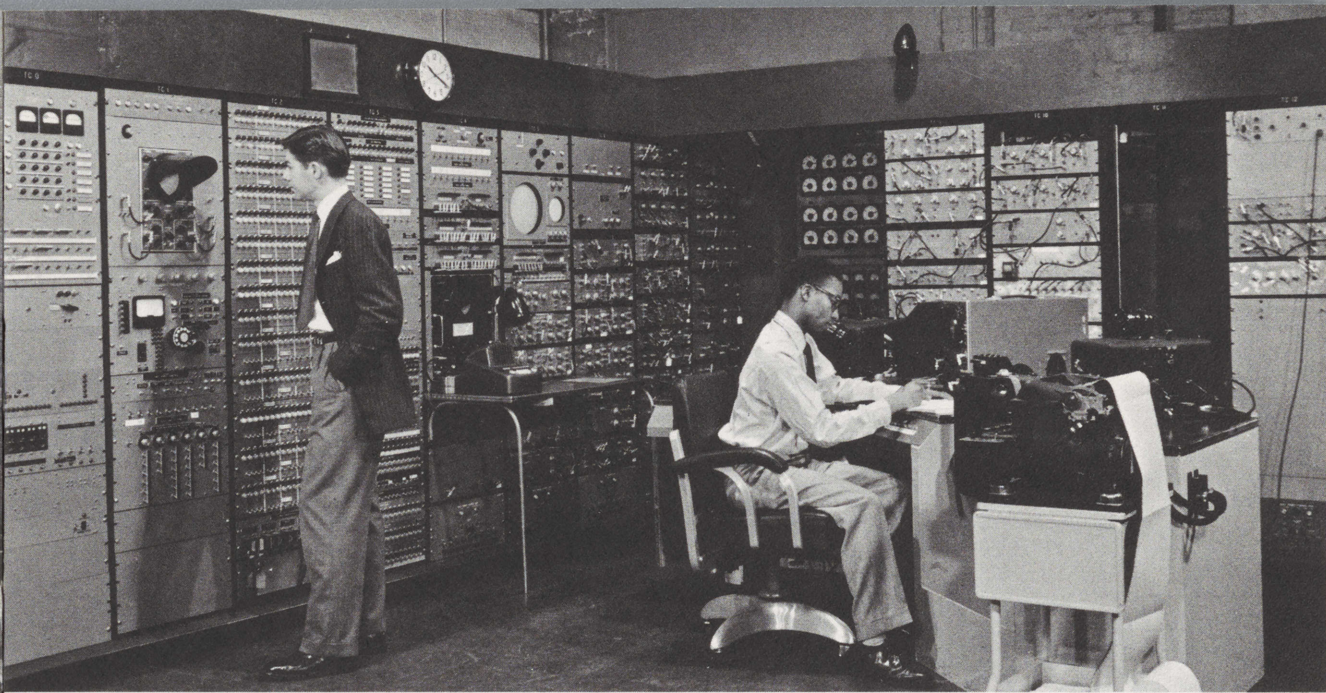


first core-storage unit was wired into the operational Whirlwind, access time had dropped from 25 microseconds for tube storage to 9 microseconds for the magnetic cores. The problem of a reliable memory had been solved.

### Tubes vs. Cores

Alan Roberts, who is now Associate Technical Director of MITRE's Tactical Systems Division, and who at one time spent 20 hours a week maintaining the storage tubes, cautions against selling the tubes short – even though core storage needed only 2 hours per week of his time.

"The storage tubes were by no means a bad way to store data. In fact, they were a revelation. The tubes we built were the finest electrostatic storage tubes in the country. They did a magnificent job. In comparison with core memory they didn't stack up, but Whirlwind was the fastest computer in the world when it used electrostatic storage tubes. Core memory made that dramatic increase in speed from 25 microseconds to 9, but that was the *next* breakthrough. Whirlwind, before the core memory, was a breakthrough. At its origin it was a very powerful machine.

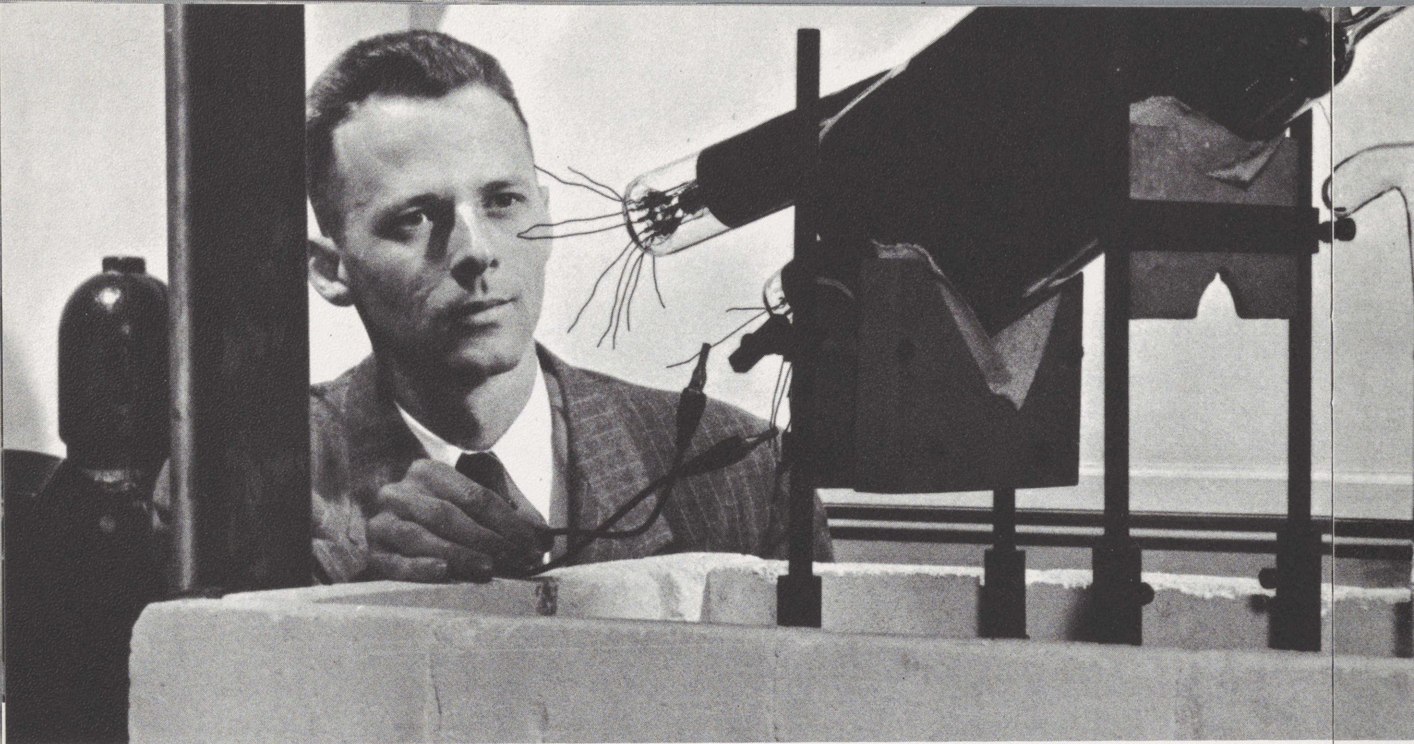


**WHIRLWIND TEST CONTROL** as it appeared in May 1952.



"The reliability problem came into focus during the process of trying to increase the memory density. The problem was quality control. For one thing, it was difficult to plate the surface well enough, although we were pushing the state of the art in plating beryllium. And as we improved one item, something else needed to be upgraded – for example, the guns. From a cost effective point of view, it was the best storage medium until the cores came along.

"I was there when we made the switchover to magnetic storage. That was a tremendously exciting evening. We had a little speaker hooked up to one of the bits in the accumulator and it would produce a particular tone depending on how you read the numbers into the accumulator. When we went from electrostatic storage to magnetic, the pitch of the thing went way up. And all of the programs we had been accustomed to sounded completely different. When we did marginal checking we used to listen for changes in the tone of the program as we put the margins on. We had to learn the sounds of the program all over again."



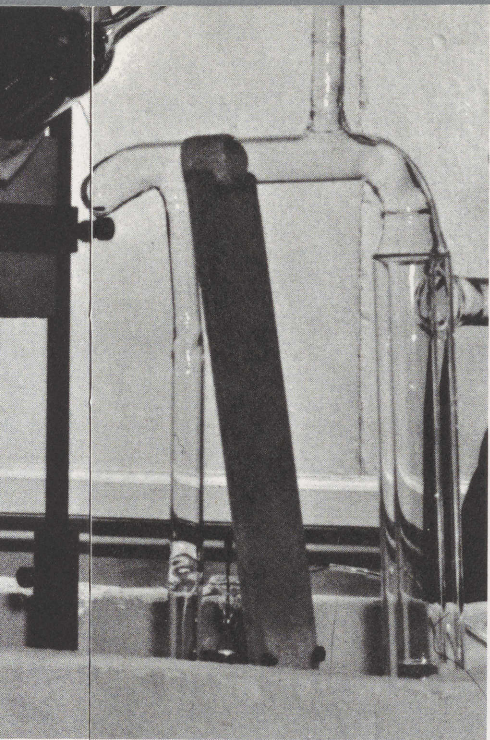


### Marginal Checking

The electrostatic storage tubes were not the only tubes whose reliability needed improvement. The everyday vacuum tubes, of which Whirlwind had more than 5000, were prone to unpredictable failure. And the failure of any one of them could stop the computer.

A long range answer to the problem was to help the manufacturer make a better tube. An order-of-magnitude improvement in the tube life eventually resulted from this effort. A more immediate approach was to replace the tubes before they had a chance to fail, but a policy of scheduled replacement did not solve the problem. New tubes would often fail soon after being put into operation and old tubes frequently continued working long after they were expected to quit. The project developed an answer to the dilemma through a technique which they called marginal checking.

In marginal checking, the tubes would be periodically operated under marginal conditions – at less than rated voltage, for example. Under these conditions a tube which was barely keeping pace under operating voltage would fail under the stress of the marginal condition. Error-locating circuits would then help technicians



**FORRESTER EXAMINES an electrostatic storage tube under construction.**



pinpoint potential trouble during a scheduled maintenance exercise, rather than during an operating period.

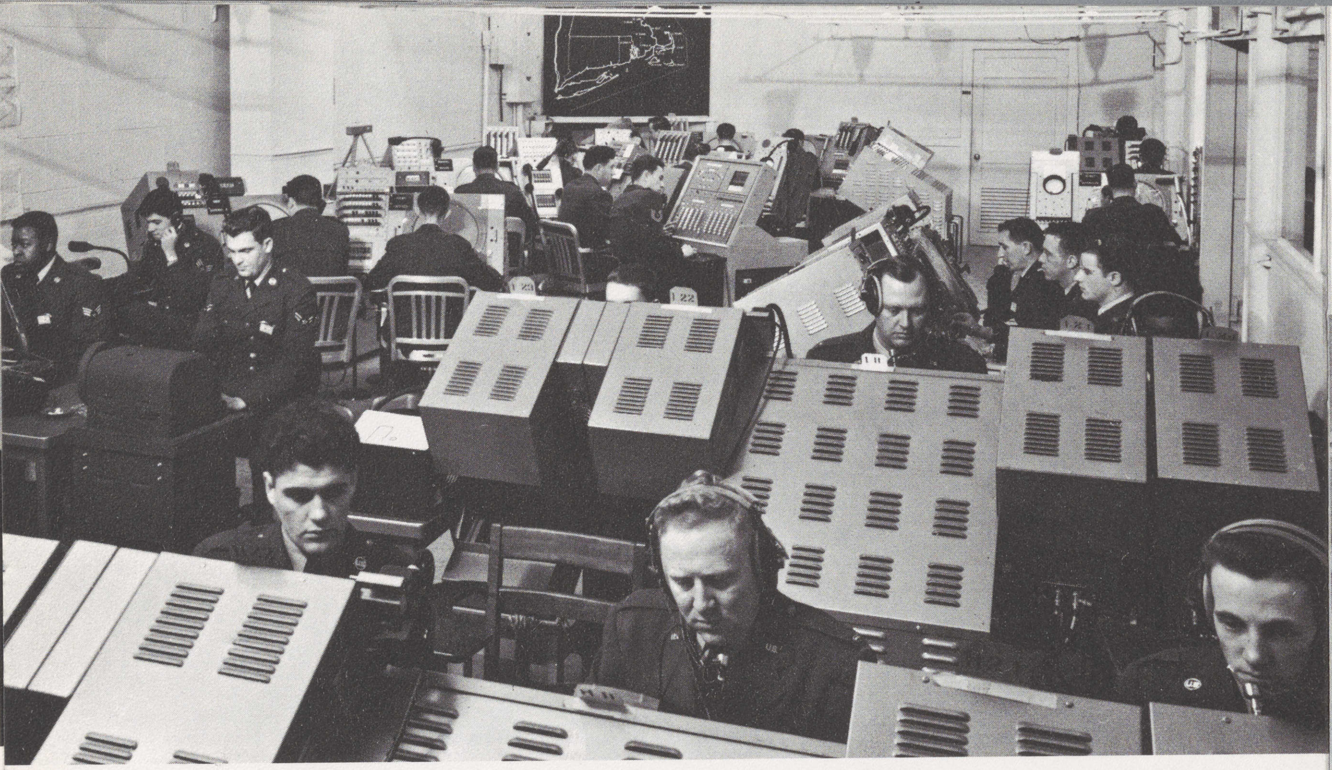
Marginal checking was only one aspect of the effort to improve reliability. Another way was the philosophy of using as few different circuits as possible – using only tried and tested basic building blocks. There had to be a very strong reason for using something different.

When a component failed, a very aggressive group investigated the reason why. An extremely rigorous analysis was made of failures in flip-flop circuits – basic building blocks for Whirlwind's logic.

### A Funding Crisis

All the technical breakthroughs aside, the Navy wanted an operating computer from their million dollar a year project. The top administration at MIT, anticipating that they might be called upon to make a strong defense of Whirlwind, requested a report on the potential uses and costs of digital computers. The project rapidly produced a voluminous response.

An anxious moment came when an ad hoc panel was set up to examine



**THE CAPE COD SYSTEM** was an evolutionary step between the Whirlwind computer and the SAGE Air Defense System.



digital computer projects throughout the Department of Defense. The panel commended the Whirlwind project for its excellent job of training graduate students, and the excellence of its staff and their work, but concluded that the effort should be terminated if no suitable end use could be found.

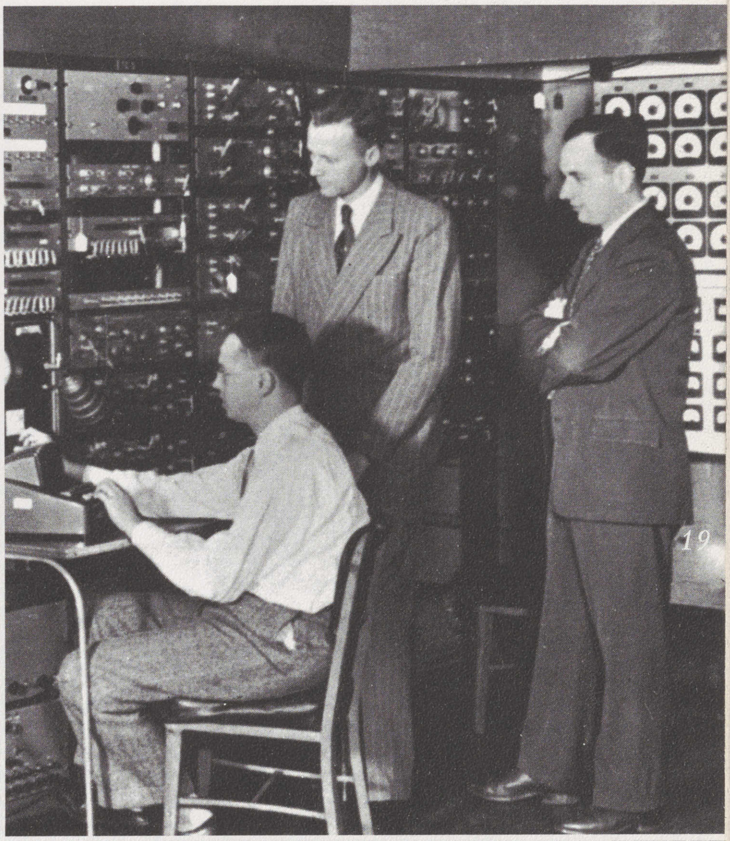
Seen from the panel's point of view, the total development cost of Whirlwind's contemporaries (UNIVAC, ENIAC, EDVAC, etc.) averaged between $1/2 and $3/4 million each, and it looked as if Whirlwind was going to cost upwards of $4 million. But no one at the time knew that Whirlwind's core memory alone would be worth many times that amount. So it was no wonder that the panel wanted some solid justification for the expense.

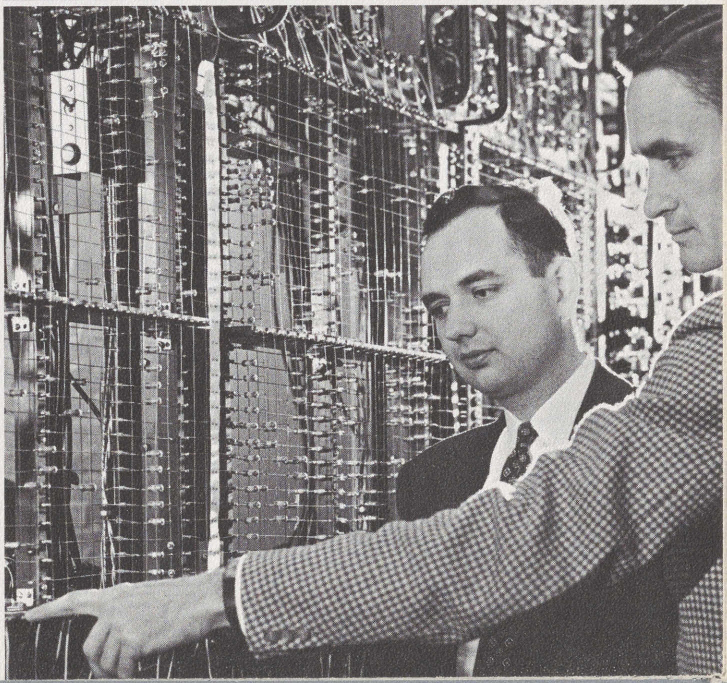
### A Need Arises

The world situation in 1950 created the "end use" to justify Whirlwind's expense account. The invasion of South Korea was heating up the cold war. Russia had exploded her first atomic device, and intelligence reports hinted at the possibility of bomber attack via the North Pole.

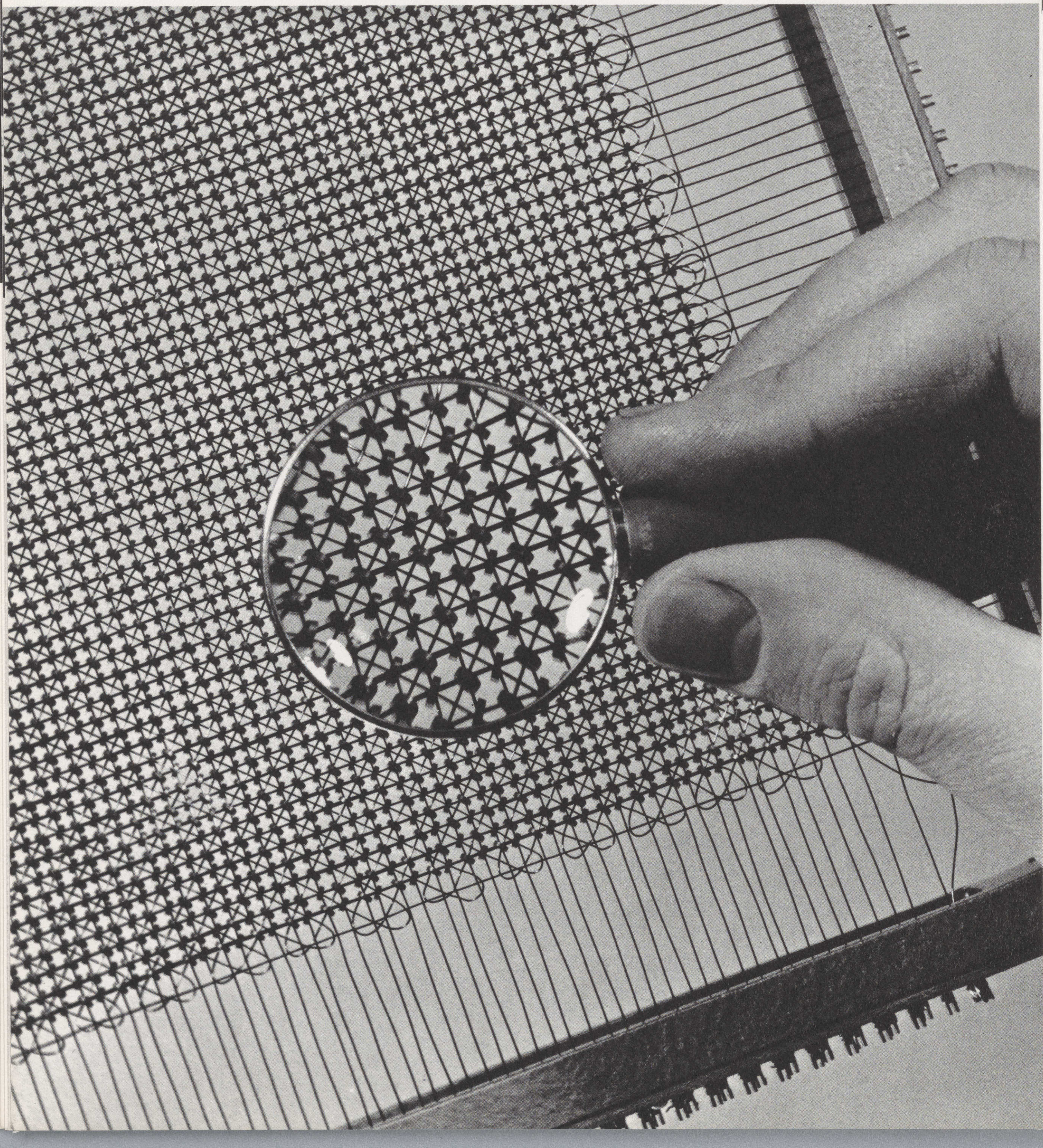
At a time when volunteer civilian observers were watching the skies with binoculars and relaying their reports by telephone, air defense became an urgent national priority. A board set up to evaluate the air defense problem said in one report that the current operation was like "an animal that

Jay Forrester and Pat Youtz check the operation of an electrostatic storage tube (L). Steve Dodd, Forrester and Bob Everett at the test console (above right). Everett and Gus O'Brien (lower right).





**THE MAGNETIC CORE MEMORY** was the breakthrough which gave Whirlwind additional speed and improved reliability.



was at once lame, purblind, and idiot-like, and of these comparatives, idiotic is the strongest."

What was needed was a system that could gather and organize great quantities of diverse information with great rapidity.

Whirlwind was the only existing "brain" large enough and fast enough to do the job. From this point on, Whirlwind had a practical purpose of national urgency. With the Air Force ensuring financial support, and the Navy also contributing, the effort finally blossomed into something other than headaches. Out of this situation, Whirlwind's practical task evolved from a successful ground-controlled intercept, to a prototype air-defense system (the Cape Cod System), and ultimately to a real-time communication and management system for the air defense of the entire North American continent (the SAGE system).

Associated with this evolution, MIT's Project Lincoln evolved to Lincoln Laboratory. And when the job of technological support to the military establishment for air defense grew more extensive than MIT cared to handle, The MITRE Corporation was formed to carry on the work. It was, to a great extent, weapons integration into SAGE (including non-Air Force weapons) which precipitated the events leading to the formation of MITRE.

The completion of the first sectors of the SAGE system, plus growing requirements placed on the country's air traffic control system, focused attention on the problems of coordinating and possibly integrating the two systems. The CHARM system, an exploratory effort in this direction, was MITRE's debut into the area of air traffic control. In the CHARM system Whirlwind was used to correlate flight plan data with radar data.

In the spring of 1959, MIT decided Whirlwind had outlived its usefulness. The Wolf Research and Development Corporation of Bedford, Mass., later indicated an interest in the computer and leased the entire installation from the Navy.

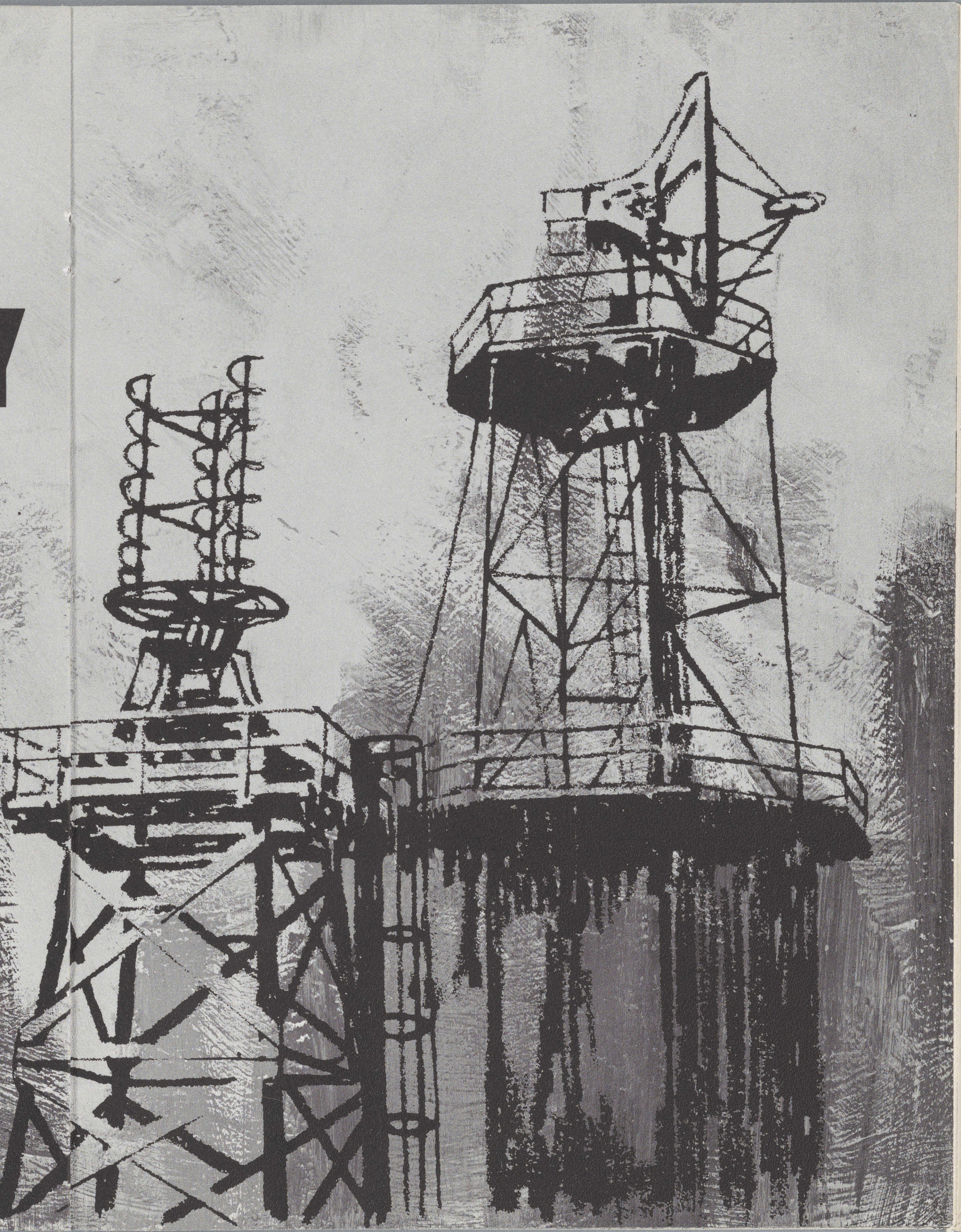
**Whirlwind in Perspective**

From an aircraft simulator to an air defense system, Forrester, Everett and their associates had succeeded with the "physicist's dream and engineer's nightmare." As their notebooks show, they had the vision to foresee much of the impact that high-speed digital data processing would have. They helped kick off an information revolution whose social impact rivals that of the industrial revolution.

# RANGE TELEMETRY

## undergoes a conversion

ANTENNAS were a major part of the range telemetry conversion. Because the conversion involved a move to higher frequencies, parabolic dish antennas replaced existing helical antennas. This illustration shows the old and new.



*MITRE recently finished a four-year project of helping the Air Force update telemetry equipment at three test ranges. The effort, which was called CORTS (Conversion of Range Telemetry Systems), will be remembered for the variety of problems presented and solved, from surveying sites in the Rocky Mountains to protecting the CORTS hardware from high-power radars located nearby.*

Telemetry is the process of measuring a quantity or reporting an event and transmitting that information (usually by radio) to a distant station where the information is displayed or recorded. We are all familiar with the importance of telemetry systems in the Apollo program. The Air Force makes similar use of telemetry in the testing and evaluation of experimental aircraft, rockets, parachutes and weapon payloads.

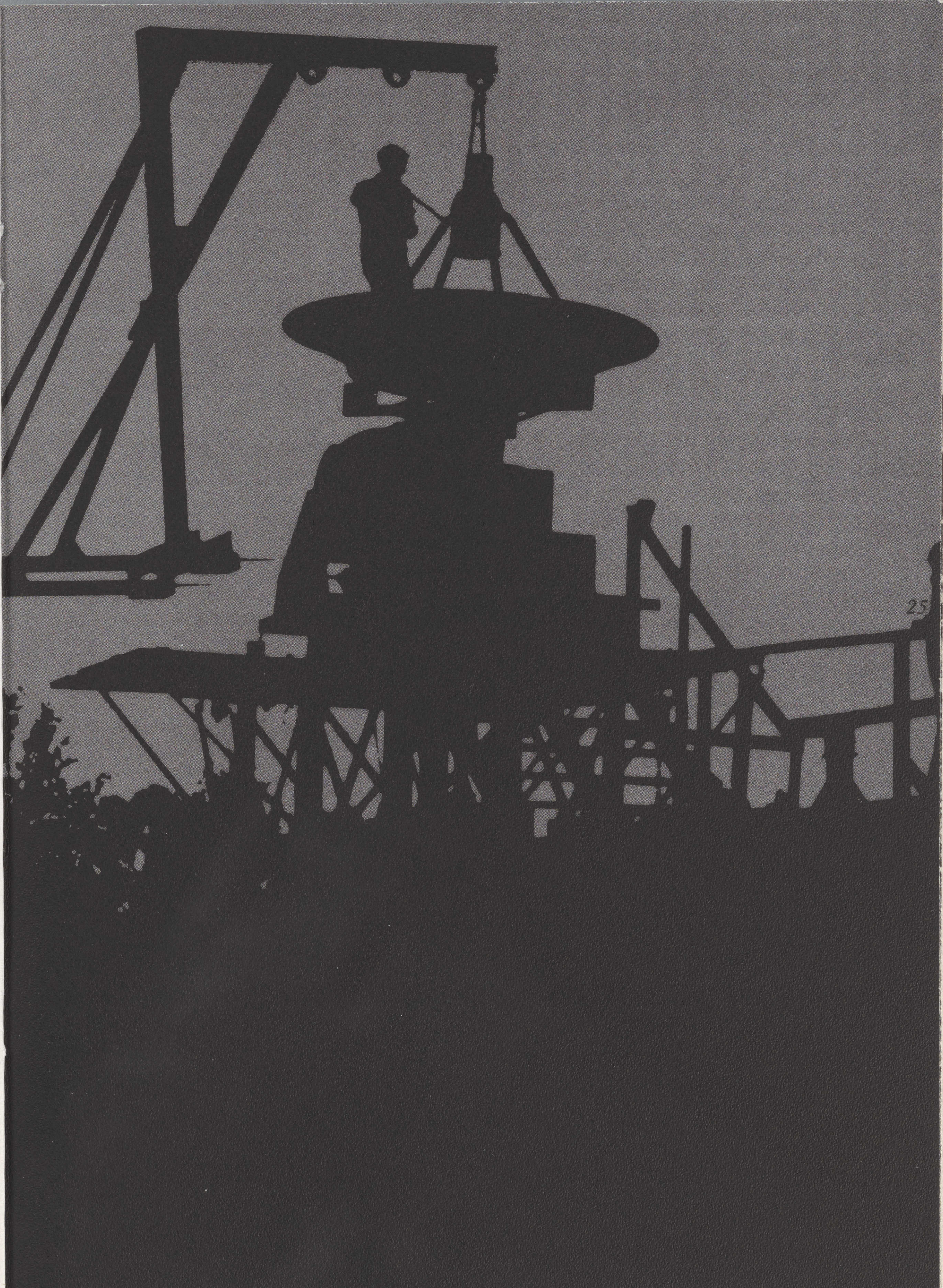
### A Move to New Bands

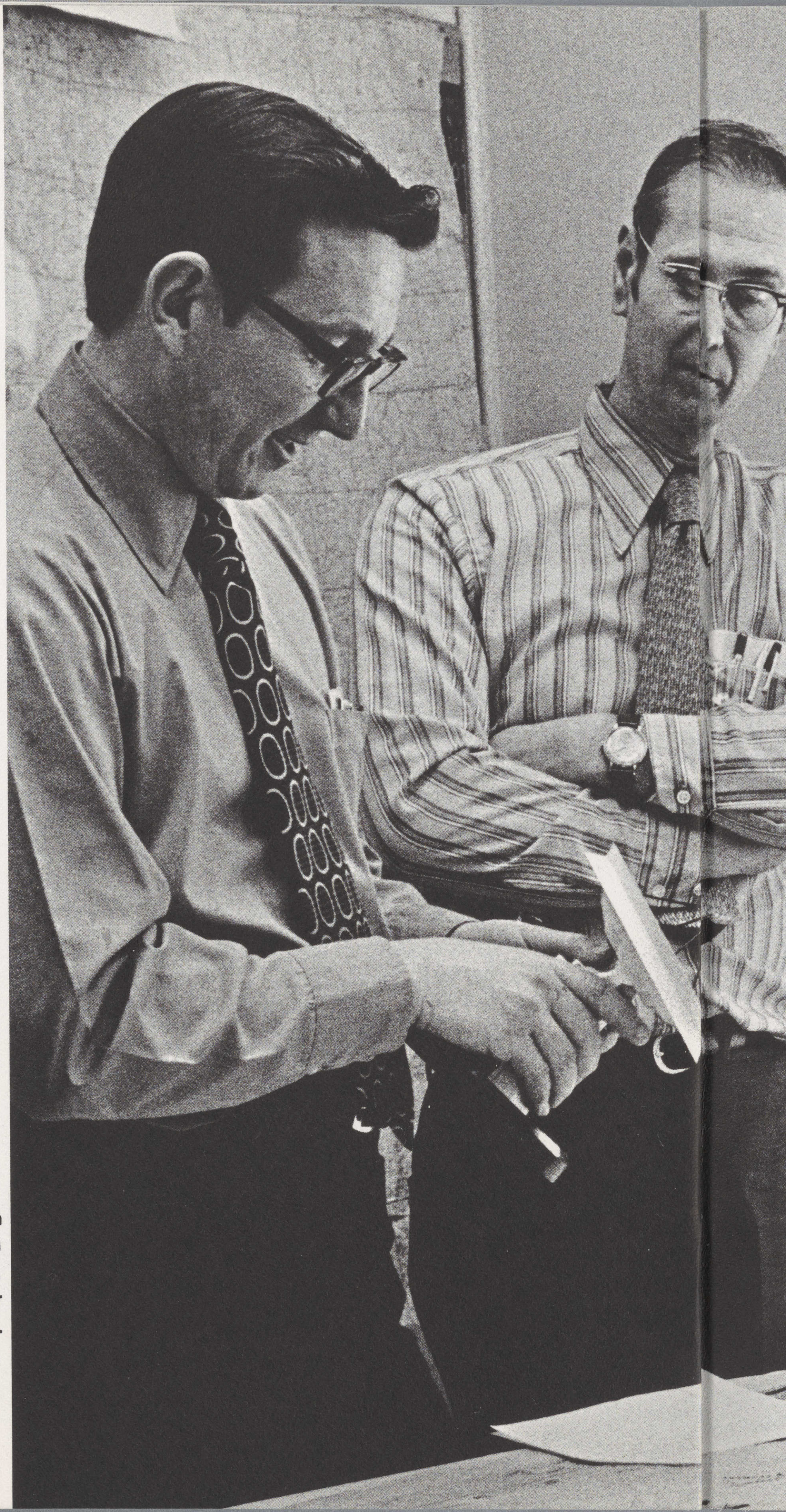
In 1965 the Department of Defense issued a directive which required that the frequencies for military telemetry operations be moved from P band (225-260 MHz) to the L and S microwave bands (1453-1940 and 2200-2300 MHz), falling within the ultra high frequency (UHF) band, by January 1970. The purpose of the move was to provide a larger number of channels and greater channel bandwidth, two items in increasing demand. The move would also free the very high frequency (VHF) band for other applications.

The Department of Defense directive came as no surprise, since it had been evident as far back as 1957 that such a move would eventually be necessary. Even before the directive came out, the Electronic Systems Division (ESD) of the Air Force and MITRE had been doing some preparatory work – reviewing current UHF technology, making preliminary site surveys and reviewing the conversion plans for all DoD ranges which used telemetry.

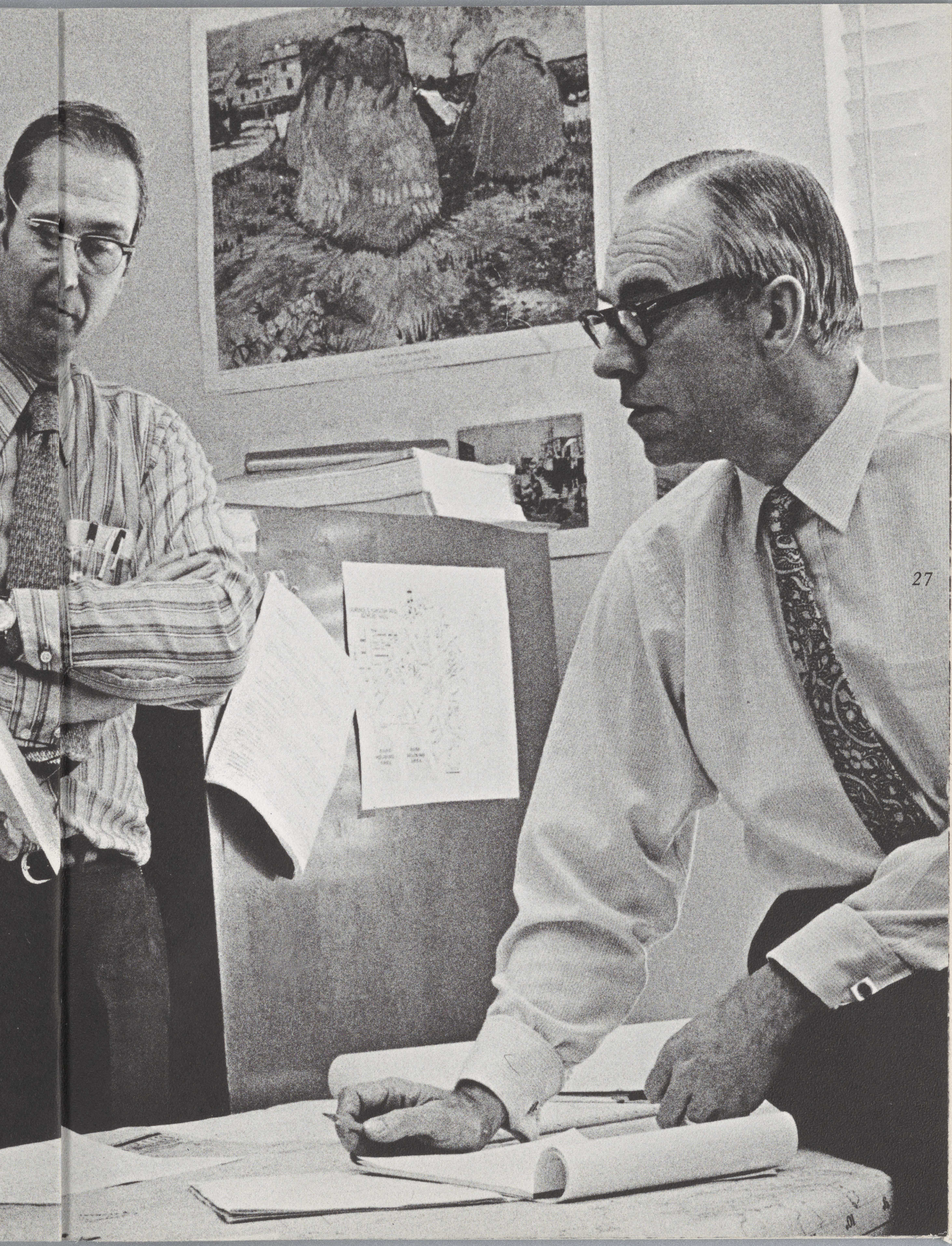
Only a month after the directive came out, MITRE and ESD were able to offer technical support to three ranges: the Air Force Flight Test Center at Edwards Air Force Base, California; the Joint Parachute Test Facility at El Centro Naval Air Facility, which is near Edwards AFB; and the Armament Development and Test Center at Eglin Air Force Base in Florida. Other Air Force ranges such as the Eastern and Western missile test ranges had already begun conversion.

During the conceptual and definition phases of the program, MITRE's role was that of systems engineer, doing site surveys, technology reviews and providing manage-





For the past two years these three men have done most of the MITRE work on the CORTS project: (L to R) Thomas O. Stiling, Paul Krenitsky and Project Leader Jan C. Havinga.



ment support. During the acquisition phase, MITRE's role was that of technical advisor, assisting in testing and getting the equipment operational.

In describing MITRE's effort, Project Leader Jan Havinga of the Strategic Offense Systems Department says, "Our work involved the ground equipment for the UHF telemetry links – the antennas, receivers and interconnecting equipment used to receive the telemetry signals. The CORTS program did not involve any data processing equipment. Nor did it include the telemetry transmitters in the various test vehicles."



### The CORTS Equipment

Modification of existing equipment was not feasible. The move from VHF to UHF required new receiving equipment of completely different characteristics and greatly improved performance. The most striking difference between the old and new equipment was in the antennas. In the old system, helical and omnidirectional antennas satisfied most mission requirements. Because of higher losses at UHF, the new bands required higher-gain parabolic dish antennas for all but a few close-in missions. The basic CORTS equipment includes two types of dish antennas: a high-gain antenna 16 feet in diameter and a medium-gain antenna 8 feet in diameter. Over the UHF band, the high-gain antenna has a gain of 35 to 38 dB (decibels), and the medium-gain antenna 29 to 32 dB. Both sizes have a feature called autotrack, the ability to follow the target without operator guidance.

The CORTS antenna complement also includes omnidirectional antennas which provide 360-degree azimuth coverage with approximately 5 dB gain.

Each autotrack antenna uses two receivers in a polarization diversity mode which improves the continuity of track and data reception. Several data receivers may be multicoupled to a single antenna to support multiple link missions.

The CORTS receivers feature a highly flexible, state-of-the-art design. Plug-in units adapt them to either L or S band and various formats of telemetry modulation. Their high (105 MHz) first intermediate frequency (IF) stage places the first local oscillator and image out-of-band throughout the entire tuning range. Other features of the receivers include highly phase-linear second IF filters, extremely stable oscillator circuits, a high resistance to interfering signals and the ability to resist overload from high-level signals. All circuits are solid-state. A special remote-control tuning unit was developed for an unmanned site.

THE ROCKY ROAD TO SHOSHONE: **Proposed sites had to be accessible by truck.**

## Edwards Test Range

The Edwards ranges are used primarily for monitoring the test flights of manned aircraft. Test flights involving takeoffs, landings and local flight need only the telemetry equipment located at Edwards (see map). Other tests, such as those for the C-5 cargo airplane and other long-range aircraft, are conducted over a course called the Edwards High Range or over the Edwards Pacific Test Range. The Pacific Test Range extends west from Edwards to Vandenberg Air Force Base and out over the ocean. The High Range extends northeast over four states into Idaho.



The Edwards High Range has three permanent CORTS sites: at Edwards AFB; Shoshone, Nevada; and Ely, Nevada. All three are connected by a wideband real-time data link. A similar data link connects Edwards and Vandenberg. Vandenberg is the key station in a different range, the Air Force Western Test Range (for testing missiles), but the data link permits that range to extend the capability of Edwards out over the ocean.

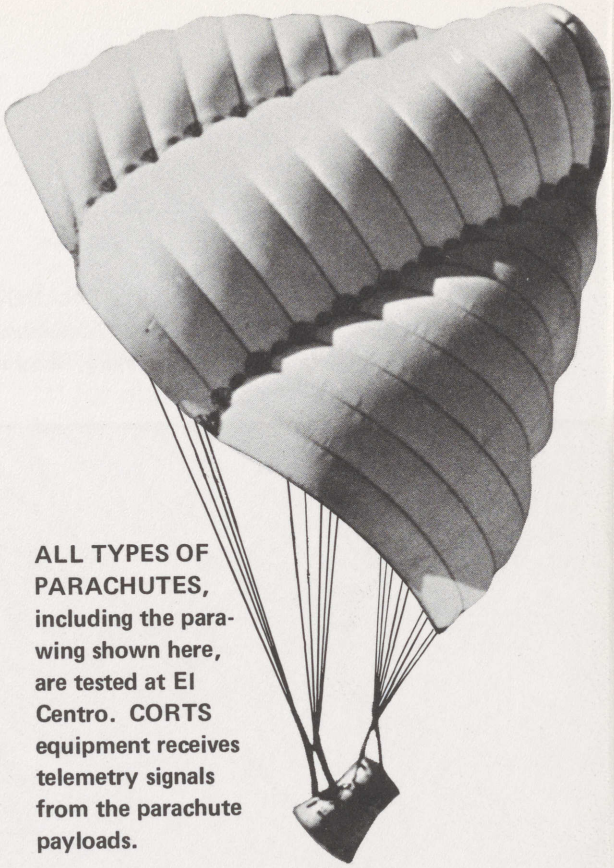
It was originally planned to stretch the Edwards High Range up to the Canadian border by adding new CORTS sites, but military funding cutbacks made Ely the northernmost permanent site.

The final destination of all telemetry data for the Edwards range is a data center building near the Edwards runway. The building itself has an omnidirectional antenna which is useful for obtaining preflight, takeoff and landing data. Inflight data is gathered by three autotrack antennas on a nearby hill.

Telemetry signals from downrange (Vandenberg) and from uprange (Shoshone and Ely) and from the hill site are sent to the data center building through microwave and land-line communication systems. The telemetry capability at Edwards includes six trucks which can be sent out for tests requiring special coverage. The trucks are outfitted with omnidirectional antennas and abbreviated receiving systems.

The Ely site, situated atop a 9,600-foot mountain, is collocated with a NASA site whose personnel take care of the CORTS equipment. The site at Shoshone is also on a high mountain top, but is unmanned. The main purpose of the Shoshone site is to cover any unscheduled landings at several dry lakes which act as emergency fields. Under normal conditions the Shoshone site is not used because the Ely and Edwards stations have a generous amount of overlap.

**EDWARDS AND EL CENTRO TEST RANGES:** The CORTS site at Ely extends Edward's coverage into Idaho, and the facilities at Vandenberg extend coverage out over the ocean. Real-time data links connect Edwards to Vandenberg, Shoshone and Ely. The El Centro facility is independent of Edwards.



**ALL TYPES OF PARACHUTES,** including the parawing shown here, are tested at El Centro. CORTS equipment receives telemetry signals from the parachute payloads.

### El Centro

The Parachute Test Facility at El Centro is a joint military facility where all types of parachutes are tested, from highly maneuverable personnel chutes to glider-wing and spacecraft-reentry types. The test facility itself is about ten miles from the El Centro Naval Air Station. There is a permanent autotrack antenna at the facility and a mobile unit for supplementary coverage.

### Eglin

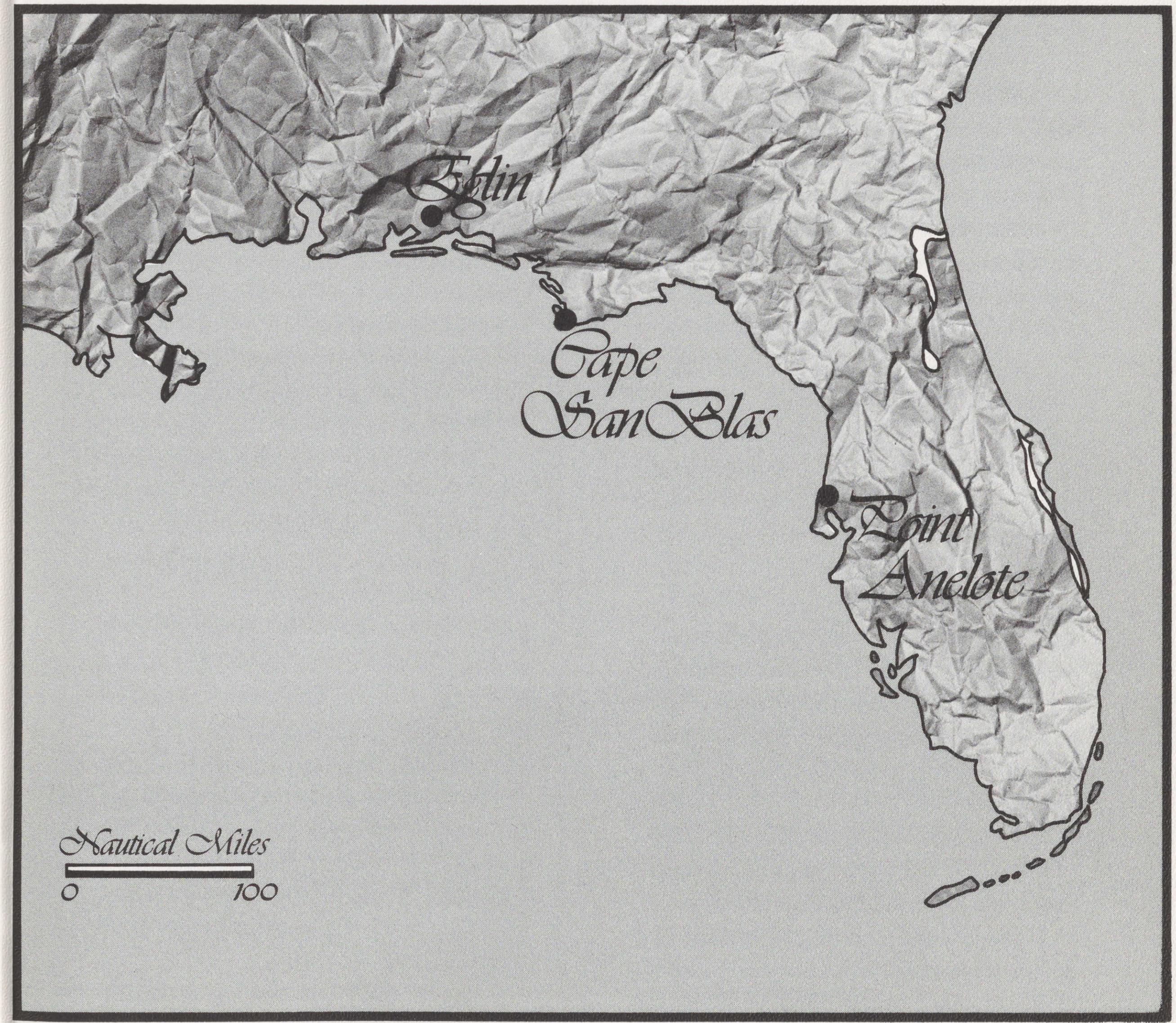
The telemetry at Eglin covers the ground test range at Eglin proper and a large area over the Gulf of Mexico (see map). The ground test range is mainly for collecting telemetry data on tests of weapons and armament. There are three fixed sites at Eglin. One of them, with three autotrack antennas, is used to track sounding rockets fired out into the Gulf. Remote autotrack stations at Cape San Blas (near Tyndall Air Force Base) and Point Anclote (near MacDill Air Force Base) plus two mobile autotrack systems complete the roster of CORTS equipment at Eglin.

### An Unusual Effort

"Although there were many technical problems, it was the management problems that made this particular job unusual," says Tom Stiling, a member of MITRE's Technical Staff who has been on the project from the beginning. "You might say that it was a management nightmare, primarily because of all the different agencies and companies that were involved. It was particularly difficult when the use of a commercial common carrier (telephone company) was being considered to provide the Edwards real-time data links.

"Another aspect of the management difficulties was the AFSCM-375 management system under which the Air Force System Program Office (SPO) was directed to operate. We had

**THE EGLIN TEST RANGE** includes Eglin proper and remote stations at Cape San Blas and Point Anclote.



to use procedures which were designed primarily for procurement of a large system like Minuteman, although CORTS was a much smaller job. The SPO did a great job of making it work."

**The MITRE Role**

MITRE "provided assistance to ESD," but specifically, the assistance covered everything from initial planning to eliminating bugs from the operational equipment. The table on the opposite column offers some perspective as to the size of each task.



Site Surveys: One of the first things to be done in the CORTS project was to conduct surveys of the ranges. In the case of the Edwards test range, the purpose of the survey was twofold: to check the coverage provided by existing sites, and to locate new sites for extending coverage to the Canadian border. As mentioned earlier, the goal of extended coverage was dropped later in the program, but only after considerable work had gone into the effort.

Proposed new manned sites had to provide good coverage, be relatively accessible by truck, and have commercial power available – requirements which were more or less incompatible in the rugged mountains of Nevada and Idaho. Mountains high enough to

*MAJOR EVENTS IN CORTS PROGRAM*

| | |
|---|---|
| *Site Surveys* | *1 year* |
| *Requirements Analysis* | *1 year* |
| *Preparation of Request for Proposal* | *6 months* |
| *Bidder's Briefing* | *1 week* |
| *Proposal Evaluation* | *2-3 months* |
| *Contract Negotiations* | *2-3 months* |
| *Design Specifications:* | *2 years* |

- *Review of preliminary design specs.*
- *Review of final design specs.*
- *Review of test procedure documents (Cat. I)*
- *Monitoring of performance tests in contractor plants*
- *Review of field test procedure documents (Cat. II)*
- *Monitoring of tests at the various sites*
- *Review of test results*
- *Review of system analysis documents*
- *Recommendations for meaningful tests, e.g., solar calibration of antennas, overload tests and dynamic range tests on receivers, etc.*

provide good telemetry coverage tended to be accessible only by mule or helicopter.

Requirements Analysis: Another early task was to find out exactly what the range users needed and then to develop a system concept to fulfill those needs. The system concept which finally emerged, and was defined in the bid package, answered those requirements in terms of antenna type and size, reliability and maintainability of equipment, and receiver performance – all of these factors being met with adequate margin.

Preparation of RFP: The RFP (Request for Proposal) sent to prospective contractors was based on the results of the requirements analysis. The RFP for CORTS was released in December of 1967.

Bidders' Briefing: The joint MITRE/ESD bidders' briefing gave a detailed description of the proposed CORTS system and described the AFSCM-375 management system and its documentation requirements.

Proposal Evaluation: Of the 30 contractors who attended the bidders' briefing, six submitted proposals. In general, their proposals specified new generation telemetry equipment. Several of them specified the same subcontractors, a circumstance which made the proposals quite similar and the job of separating the advantages of one proposal over the other more difficult than usual. But the price, plus the service offered, made the difference, with the contract going to the lowest bidder, LTV Service Technology Corporation.

The period of proposal evaluation called for considerable dialogue between the Air Force and the individual contractors, with questions and answers being exchanged on both sides. MITRE answered the technical questions and ESD fielded the questions on cost and documentation.



**After Contract Signing**

During the last two years MITRE's role was that of technical adviser. Most of the work was done by three members of the Technical Staff: Jan Havinga (the Project Leader), Tom Stiling and Paul Krenitsky. They received part time help from other staff members. This was a period of innumerable meetings and trips which involved MITRE, the SPO, the contractor, various subcontractors, site personnel at the three ranges, GEEIA (Ground Electronic Equipment Installation Agency) and other agencies of the government.

Paul Krenitsky offers a rundown of what happened: "The original preliminary Equipment Design Specifications were derived from the RFP and the contractor's proposal. Once the construction of prototypes had begun, there were conferences on the prototype design. We negotiated requests for changes and compromises.

"We reviewed Category I Test Procedures (for tests to be conducted at the contractor's plant) ahead of schedule so that acceptable test procedures would be available when the first article came off the production line.

"Scientific Atlanta was the major subcontractor – furnishing the receivers, antennas and the consoles. We spent a great deal of time in Georgia.



"After acceptance in the plant, the equipment was shipped out to the site. In the field, a higher level test (designated Category II) was run on the system. This culminated in a test in which an aircraft flew a prescribed course and test data were taken on the performance of the system. We participated in these field tests and then reviewed the test results.

"Between field trips and conferences there were always documents or procedures to review and changes to be made. A review of the 'system analysis' document (describing how the technical specifications would be met) was a lengthy procedure, as there were three or four versions of it as the program developed.

"Specified system noise temperatures were a major requirement of this program. A relatively new concept for measuring a system's vulnerability to overload and interference was imposed on the contractor. This concept was called Input Intercept Point (IIP) and the contractor had to exert extra effort in order to achieve the design goals.

"In the review and monitoring of Category I and II tests, we were responsible for assuring ESD that the tests were meaningful, adequate and relevant to the specifications under scrutiny. We had to use an extra amount of diplomacy in dealing with the contractor when it came to relatively new tests such as the measurement of system noise temperature by solar calibration. Other tests, such as dynamic range tests of receivers, were modified. Some tests, the IIP test for example, were developed in a MITRE laboratory during the course of the program. An innovation in this program was notch noise testing of telemetry receivers, a test common in the microwave carrier equipment field, but new in telemetry."

Special Problems: MITRE helped to iron out two problem areas which appeared when the equipment was going operational – the problem of radio frequency interference and that of lightning damage.

Says Krenitsky: "At Ely, Nevada, the CORTS equipment is collocated with a C-band radar in the megawatt peak power range. It was possible for both the radar antenna and the CORTS antenna to look at each other 'eyeball-to-eyeball' at a distance of only 200 feet. As a result, peak powers of 500 watts could be measured at the CORTS antenna terminals. This interference problem was solved by attaching mechanical stops on the radar to prevent it from 'looking' at the CORTS antenna and damaging the sensitive parts of its antenna feed.

"A more serious interference problem appeared at Eglin, where three CORTS antennas were higher in elevation than the site radars, located a quarter mile away. Because the CORTS antennas were in the far field of the radars, the RF peak powers measured were 'shockingly high' for a system designed to operate in the -80dBm (decibel referred to 1 milliwatt) range – 8,000 watts being measured in one series of tests. We recommended that filters be installed in the feed assembly as a solution to this problem.

"Another problem at Eglin was that of lightning damage. During the summer of 1970 a CORTS site at Eglin was damaged a number of times by lightning from the severe electrical storms which occur in that area. We found that part of the problem was due to heavy-gauge ground cables loosely clamped together – instead of being solidly connected to the site ground. Our recommendations included a better grounding system for the antenna towers, installation of filters on the ac power lines and a number of special solutions for vulnerable components, for example, the noise diodes in the antenna feed packages."



**Sharing the Knowledge**

MITRE's CORTS experience led to a more general contribution to the field of telemetry. The Telemetry Working Group of IRIG (Inter-Range Instrumentation Group), a professional organization of people involved in the operation of ranges, invited Paul Krenitsky to join a committee set up to standardize telemetry receiver test procedures. With the experience gained from the CORTS receivers, and with the results of MITRE tests on several models of telemetry receivers, the committee prepared a set of standard tests for telemetry receivers which are expected to receive wide acceptance in the telemetry community.

Dr. David V. Ragone
elected to
Board of Trustees

*Dr. David V. Ragone, Dean of the Thayer School of Engineering, Dartmouth College, has been elected to MITRE's Board of Trustees.*

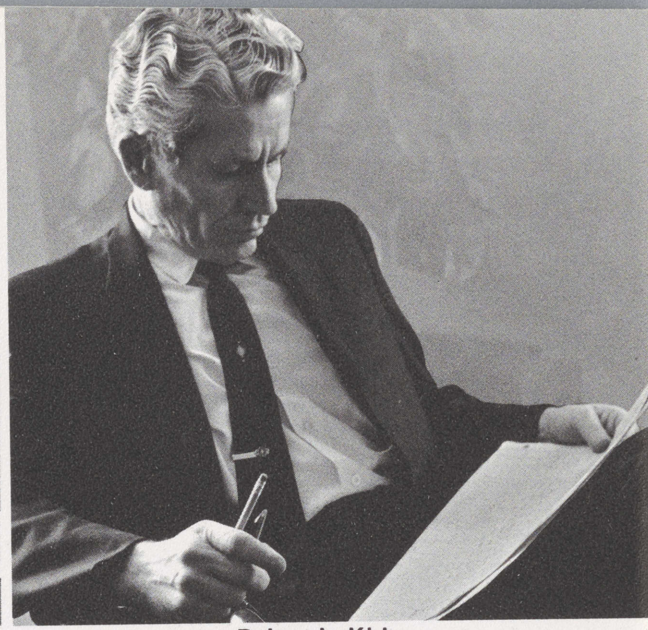
Dr. Ragone's academic background includes the positions of Associate Dean, School of Urban and Public Affairs, and Professor of Engineering (Carnegie Institute of Technology) at Carnegie-Mellon University. He held a professorship in the Department of Chemical and Metallurgical Engineering at the University of Michigan, where he was a member of the faculty for nine years. He also was affiliated with Imperial College, University of London. Dr. Ragone received his S.B., S.M. and Sc.D., all in Metallurgical Engineering, from Massachusetts Institute of Technology in 1951, 1952 and 1953.

His experience in industry includes the Chairmanship of the Metallurgy Department, General Atomic Division of General Dynamics. While at General Dynamics he also held the position of Assistant Director, John J. Hopkins Laboratory for Pure and Applied Science. He currently holds directorships in the Steam Engine Systems Company of Boston and the Zito Company, Inc., of Derry, N.H. He has served as a consultant for the Crucible Steel Company; the Ford Motor Company; Dow Chemical Company; General Atomic, San Diego; and Conduction Corporation, Ann Arbor.

Dr. Ragone is actively involved in efforts toward finding solutions to domestic problems, particularly those in ground transportation. He has served as Chairman of the Ad Hoc Panel on Unconventional Engines – Office of Science and Technology, Executive Office of the President, and a member of the Advisory Committee on Advanced Automotive Power Systems of the Council on Environmental Quality. A member of the U.S. Department of Commerce Technical Board since 1967, he is currently Chairman of the Automotive Fuels Panel and was formerly a member of the Panel on Automotive Air Pollution. He is a member of the American Society for Metals, the American Institute of Mechanical Engineers, and the Society of Automotive Engineers, of which he is a member of the Electric Car Committee. He is a member of the American Chemical Society, the American Association for the Advancement of Science and the British Institute for Metals.

Dr. Ragone has received a number of honors and awards, and has over thirty publications to his credit in thermodynamics, metallurgy, nuclear reactor materials, and power systems for electric vehicles. He is co-editor of the book *Chemical and Mechanical Behavior of Inorganic Materials*, published last year, and shares credit for a patent on a "High Temperature Thermionic Generator."


Kenneth E. McVicar


Robert L. Kirby

# New Corporate Officers: Kenneth E. McVicar and Robert L. Kirby



*Kenneth E. McVicar has been named Assistant Vice President – Bedford Operations and Robert L. Kirby has been named Assistant Vice President – Washington Operations.*

Mr. McVicar has been a Technical Director at MITRE since 1963 and an Associate Technical Director for two years prior to that.

Coming from MIT's Lincoln Laboratory, he joined MITRE as a Department Head when the company was founded in 1959.

He received a Bachelor of Science degree with distinction from Antioch College in 1944 and a Master of Science degree in Electrical Engineering from MIT in 1950. He also attended Harvard Law School 1950-1951.

Mr. Kirby, formerly Technical Director of the Systems Development Division, was a Special Assistant to the Vice President of Washington Operations before assuming his Director's post in 1967. From 1966 to 1967, he was Vice President-General Manager of the Information Services Division of URS Corporation. He originally joined MITRE in 1962 as an Associate Department Head after 22 years of service in the Air Force. He was made a Department Head in 1964 and an Associate Technical Director in 1966.

He received a Bachelor of Science degree in Mathematics from the University of Illinois in 1950 and a Master of Science degree in Engineering Science from Harvard University in 1951.

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