PROJECT WHIRLWIND

(Device 24-x-3)

SUMMARY REPORT NO. 4

JANUARY 1948

Submitted to the
SPECIAL DEVICES CENTER, OFFICE OF NAVAL RESEARCH
under Contract N5ori60

SERVOMECHANISMS LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Cambridge 39, Massachusetts

Project DIC 6345

TABLE OF CONTENTS

FOREWORD

Project Whirlwind

Project Whirlwind at the Massachusetts Institute of Technology Servomechanisms Laboratory is sponsored by the Special Devices Center of the Office of Naval Research under contract N5ori60. The original objective of the Project was the development of a device that would simulate airplanes in flight. An integral part of such a simulator is a digital computer of large storage capacity and very high speed, to provide continuous solutions to the equations of motion of an airplane.

As Project Whirlwind has evolved, applications to other types of simulation and to control have become important. Because the digital computer is basic to all these as well as to important applications in mathematics, science, engineering, and military problems including logistics and guided missiles, nearly all project resources are at present devoted to design of a suitable computer.

The Whirlwind Computers

The Whirlwind computers will be of the high-speed electronic digital type, in which quantities are represented as discrete numbers, and complex problems are solved by the repeated use of fundamental arithmetic and logical (i.e., control or selection) operations. Computations are executed by fractional-microsecond pulses in electronic circuits, of which the principal ones are: (1) the flip-flop, a circuit containing two vacuum tubes so connected that one tube or the other is conducting, but not both; (2) the gate or coincidence circuit; (3) the electrostatic storage tube, which uses an electron beam for storing digits as positive or negative charges on a storage surface.

Whirlwind I (WW1), now being developed, may be regarded as a prototype from which other computers will be evolved. It will be useful both for a study of circuit techniques and for the study of digital computer applications and problems.

Whirlwind I will use numbers of 16 binary digits (equivalent to about 5 decimal digits). This length was selected to limit the machine to a practical size, but it will permit the computation of many simulation problems. Calculations requiring greater number length will be handled by the use of multiple-length numbers. Five special orders expedite the subprogramming of multiple-length operations, so that coding is no more complicated than for single-length numbers, but computing time is substantially increased. Rapid-access electrostatic storage will have a capacity of 32,000 binary digits, sufficient for large classes of actual problems and for preliminary investigations in most fields of interest. The goal of 20,000 multiplications per second is higher than general scientific computation demands at the present state of the art, but is needed for control and simulation studies.

Reports

Summary Report No. 2, issued in November, 1947, was a collection of all information on the Whirlwind program up to that time. The present series of monthly reports is a continuation of the Summary Report series, designed to maintain a supply of up-to-date information on the status of the Project.

Detailed information on technical aspects of the Whirlwind program may be found in the R-, E-, and M-series reports and memorandums that are issued to cover the work as it progresses. Of these, the R-series are the most formal, the M-series the least. A list of publications issued during the period covered by this Summary appears at the end as an appendix. Authorized personnel may obtain copies of any of them by addressing a request to The Special Devices Center, Office of Naval Research, Port Washington, Long Island, New York; or where approval has previously been arranged, to Jay W. Forrester, Project Whirlwind, Servomechanisms Laboratory, Massachusetts Institute of Technology, Cambridge, Mass.

GENERAL STATUS

In January final plans for Whirlwind I construction began to take shape. Organizational procedures for dividing work between Massachusetts Institute of Technology and Sylvania were established.

Time schedules were prepared for prototype and production construction of those computer units which will be processed first.

Studies were continued on the effect of age on secondary emission in storage tubes. Procurement of materials for full-size 5-inch tubes was begun. The first tubes to test construction techniques should be assembled and processed in March.

One member was added to the administrative staff to help carry the general load and to organize scheduling of the work on Whirlwind I computer construction.

An installation group was started to prepare for the arrival of computer assemblies and equipment.

SYLVANIA SUBCONTRACT

Massachusetts Institute of Technology and Sylvania Electric Products Inc. have agreed on a number of Whirlwind I specifications, including System Standards, Layout Standards, Wiring Standards, and Markings.

Sample production drawings of a program register panel have been received from Sylvania. The panel itself will follow shortly. This was designed from preliminary circuit schematics to serve as a model for establishing drafting procedures, specifications, and construction methods for Whirlwind I.

Final circuit schematics of the A-register, digits 1 through 15, have been released to Sylvania for layout of the Whirlwind I prototype of this element of the computer. Production of those panels which will be required in quantity will be preceded by approval of a prototype built to the final drawings. Required connections can be made before the full quantities are started.

A considerable number of minor changes in the repetitive units have slightly delayed the release of other circuit schematics. The arithmetic element schematics will run over into February, and the control and test storage into March. These delays will not affect production schedules as set up, and Sylvania is being kept informed of changes to assist in procurement of parts. The changes consist mainly of the addition of video decoupling condensers and changes in the values of coupling condensers.

WHIRLWIND I INSTALLATION

Air Conditioning

The estimated power consumption for the computer is 50 kw, with possible additional equipment bringing the eventual load up to 60 kw. This power must be dissipated as heat. Since the top operating temperature for the equipment is set at 87 F by the allowable temperature of the germanium-crystal rectifiers, a large volume of cool air must be supplied, requiring the installation of refrigeration equipment. In addition, humidity control over reasonable limits will be provided.

Over a period of time any appreciable dust accumulation within the computer would be undesirable, and dust may affect photographic equipment, so that thorough filtering of the air is essential. Therefore, a filter system, possibly of the electrostatic type, will be provided as an integral part of the air conditioning system.

Because of space limitations in the building, air conditioning equipment will be located on the main roof, directly over the computer room. The necessary foundations for the equipment can be readily provided, and an inexpensive steel-frame sheet-steel garage-type shelter will conform to the Cambridge Building Code. A proposal for providing and installing the equipment was received from the Carrier Corporation; the specifications will be submitted to at least two other companies for competitive proposals.

Cabinets

A cabinet design proposed by Sylvania consists of a pair of vertical channels to which the equipment panels will be bolted, enclosed in a metal cabinet with full-length removable doors front and back. Cabinet dimensions are 27½ inches wide by 18 inches deep by about 9½ feet high. Eight or nine cabinets will be joined together on a base to form, in effect, one large cabinet. Cooling air will be introduced into the bottom and will discharge through the top into the room. Open ducts will be provided for electric cabling across the tops of the cabinets.

Power Supplies

Total filament power requirement for Whirlwind I is estimated to be 30 kw. About five hundred 10-ampere filament transformers of one standardized type will be used in the Whirlwind I computer; tentative specifications have been drafted.

Building Alterations

Partitions have been removed from the Whirlwind I area and the general layout of the computer equipment planned. Preliminary schematics of the cabling ducts and lighting equipment have been drawn up.

Fire Protection

Fire protection for the computer equipment seems desirable. A sprinkler system must be maintained in the computer area, as its removal would make insurance rates extremely high. Any accidental discharge of water will do a great deal of damage to the equipment, so a system that will eliminate this hazard is being investigated. An air-filled sprinkler system with safety valves will be installed. A CO_2 system to flood the whole area was considered, but seemed undesirable, as it would introduce a considerable hazard to personnel. Within the cabinets themselves, however, CO_2 is practical and is being investigated.

PROJECT STAFF

Organization

The attached chart shows the January organization of the Project Whirlwind technical staff. Assignments of staff members are shown and relationships of the different activities are indicated.

Staff members of the Project fall into several categories. Some are appointed to full-time positions by the MIT Division of Industrial Cooperation, which administers Whirlwind and similar research projects. Others are research assistants or research associates appointed by the Electrical Engineering Department of the Institute, who, in addition to their nominal full-time work on the Project, carry on graduate studies as candidates for advanced degrees. A few members of the Institute teaching staff regularly devote a portion of their time to the Project, while other faculty members are consulted on technical problems as the need arises. Occasionally graduate students who are not appointed to a staff position by the Institute use Project facilities to conduct research on thesis subjects related to Whirlwind activity.

Working directly with the staff members on the construction of equipment are 28 technicians. In addition, the drafting, secretarial, purchasing, and building service functions employ 53 persons.

Two comparatively new phases of the work, input-output and installation, are beginning to assume considerable importance. At present input-output work consists principally of liaison with Eastman Kodak on the photographic reader-recorder, but other types of equipment will soon be undertaken. The installation of Whirlwind I presents a variety of problems, including racks and cabinets; d-c power supply and distribution, which must be coordinated with the test program; video cabling; the design and layout of the operator's console; the purchase and installation of air-conditioning equipment; and the preparation of the building.

New Staff Members

The following people joined the 6345 staff in January: H. S. Lee, working on the power supply problem for Whirlwind I. Mr. Lee took the Lowell Institute courses in Electrical Engineering and Mechanical Engineering before entering the Army, under whose sponsorship he attended the Harvard and MIT Radar Schools. He served in the Southwest Pacific on procurement and distribution of radar supplies, and as assistant director and director of Radar School, Fort Monmouth.

R. A. Osborne, with J. C. Proctor on administrative problems and time schedules. Mr. Osborne is a graduate of the University of Pennsylvania, 1944, B. S. Economics. He worked with Westinghouse and Raytheon before joining Project Whirlwind.

VISITORS

During January Captain D. P. Tucker of ONR and Captain G. M. O'Rear and Mr. H. C. Knutsen of the Special Devices Center visited the Laboratory to discuss engineering phases of Project Whirlwind. Captain Tucker devoted an additional two days to study of technical details of the computer.

Lt. Commander F. W. Kinsley, the Bureau of Ordnance Liaison Officer at MIT, discussed applications of high-speed digital computers to ordnance and fire control. He was interested in the possibilities and will invite further consideration of Project Whirlwind equipment by the Bureau of Ordnance.

Dr. E. R. Piore of ONR and Mr. R. W. Hart of the ONR Boston Branch Office visited the Laboratory. Mr. N. L. Kiser of Sylvania at Emporium, Pennsylvania, came to the Servomechanisms Laboratory for conferences on the 7AK7 gate tube and other tube problems.

Representatives of the Watson Laboratories Cambridge Field Station of the Air Materiel Command are interested in application of storage tubes to communications problems and have also exchanged information with the Project on conversion between digital and analog information.

A conference was held with Special Devices Center representatives and engineers from General Precision Laboratories to consider optical information-display devices for use with digital computers in simulation and control problems.

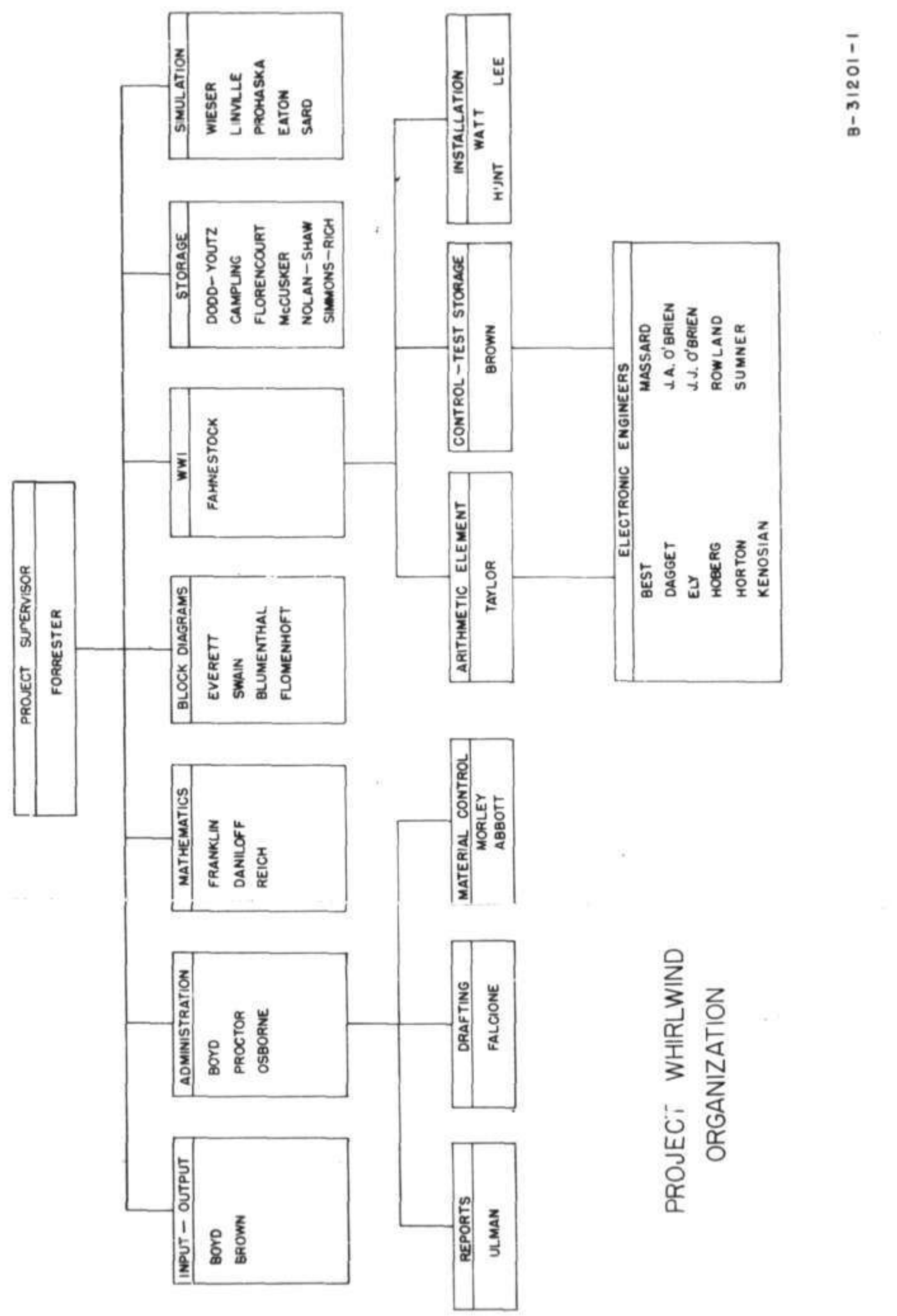
SEMINAR COURSE

The Project has undertaken an extensive series of seminars covering the nature and design of the Whirlwind computers and their use in the solution of both general and specific problems. These seminars grew out of two needs:

1. Staff education

The staff of the Project has been growing so rapidly during the past year that there has been insuffi-

APPROVED FOR PUBLIC RELEASE. CASE 06-1104.



PROJECT WHIRLWIND ORGANIZATION

ficient time for the usual informal personal instruction beyond that necessary to introduce a man to his particular job. A more general knowledge of the computer, however, is valuable both for the morale of the staff and for the efficient use of research time. Need for information exchange has been accentuated by change of emphasis, as the work has progressed, from components to systems, requiring a better general knowledge of the computer. The most efficient way to disseminate this information seemed to be an informal course.

2. Education in Computer Applications.

The need for training people in the use of computers has long been recognized as one of the more pressing problems in computer development. MIT is an excellent source of capable people with important problems suitable for high-speed calculators. It seemed logical to extend the seminar to include this group, in order to interest them in the possibilities of computers and to train them in the use of the Whirlwind machine in solving their problems. Invitations were therefore sent to the heads of departments and laboratories at the Institute and at nearby Government establishments who might be interested, inviting their attendance or the attendance of members of their staffs. The response has been excellent. A list of visitors registered is given below. Since some of the material to be covered is classified, it was necessary to obtain Navy clearance for all visitors.

A mixed group resulted from the combination of staff and visitors. Disregarding the inevitable differences in background and training, there are three main categories in the group:

1. The Whirlwind staff, largely electrical engineers with electronic training who are active in building computers.

2. Members of the Whirlwind staff who will be active in computer applications.

3. The visitors, including physicists, mechanical engineers, aeronautical engineers, mathematicians, and others who are primarily interested in using computers and only secondarily in their construction.

In order to meet the needs of this mixed group the problem of coverage and level was approached as follows:

1. The machine block diagrams will be covered, but somewhat sketchily.

2. Construction details will be given only where such details contribute to over-all understanding.

3. The information necessary for operating the machine will be covered in detail.

4. Those who wish a thorough and detailed knowledge of the computer must seek it by studying the available literature and by private discussion with members of the staff.

The seminars will be given by members of the Whirlwind staff who are best acquainted with the topics being discussed, the major burden falling on 5 or 6 men. It is hoped that after the elementary discussions of machine use some of the visitors will take over the seminar and discuss for the benefit of the group the application of the computer to their specific problems. The lectures are being recorded, and written notes are being prepared.

The seminars, nominally one hour long, are held two afternoons a week. Attendance is not compulsory for either staff or visitors. Homework is assigned from time to time but is not collected or examined. The duration of the seminar cannot now be stated; it will continue until the material has been covered, an estimated 4 to 6 months, and may be repeated next fall. The experience gained in giving this seminar plus the written notes should lead to a formal course in the MIT curriculum at some future date.

<u>List of Visitors Registered for Seminar Course</u>

UNITED STATES NAVY

Office of Naval Research
Hart, Dr. R. W.
Muckenhupt, Dr. C. F.

Naval Research Laboratory
Ashby, Robt. M.
Butman, R. C.
Holmes, Eugene A.

Naval Ordnance Research, Technical Liaison
Kinsley, Lt. Comdr. F. W.
Sharpe, L. W.

UNITED STATES ARMY

Signal Corps
Campbell, Capt. R. E.

AIR MATERIEL COMMAND,
WATSON LABORATORY
CAMBRIDGE FIELD STATION

Baller, M. D.

SYLVANIA ELECTRIC PRODUCTS INCORPORATED

Rochester, N.

DOUGLAS AIRCRAFT

Mengel, A. S.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Aeronautical Engineering
- Alden, H. L.
- Ashley, Holt
- Halfman, Robert
- Markham, J. R.
- Rubin, E. D.
- Zartarian, Garabed

Biology
- Loofbourow, J. R.

Civil Engineering
- Hansen, R. J.
- Paynter, H. M.

Electrical Engineering
- Edwards, C. M.
- Hazen, H. L.
- Jacchia, L. G.
- Julian, R. A.
- Kopal, Zdenek
- Lee, Yuk-Wing
- Macnee, Alan
- Taylor, Richard
- Verzuh, Frank

Instrumentation Laboratory
- Baruch, Rhoda
- Bumer, Charles T.
- Rogers, J. R.
- Wingate, Sidney

Mathematics
- Crout, P. D.
- Hildebrand, F. B.
- Lin, C. C.
- Orden, Alexander
- Reissner, E.
- Thomas, G. B.
- Wadsworth, G. P.

Mechanical Engineering
- Crandall, S. H.
- Hrones, J. A.
- Wadleigh, K. R.

Meteorology
- Malone, T. F.

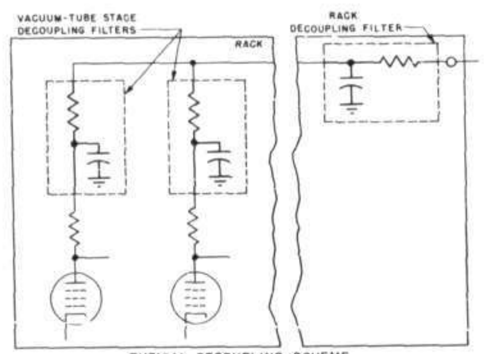
Naval Architecture and Marine Engineering
- Cochrane, E. L.

CIRCUITS

Decoupling

Current waveforms in Whirlwind I circuits consist of short-duration (0.1-microsecond) pulses. Unless care is taken, circuits connected to common power supplies tend to interact, since a pulse of current drawn by one vacuum tube causes potential differences which may affect another tube. Moreover, the very high rates of change of current during the rise and fall of a pulse may induce in the power lines voltage oscillations which sometimes behave as spurious signals.

"Decoupling" of such circuits, i.e., prevention of interaction between them, is of great importance in the design of computer systems. In the method most commonly employed on the Project, a low resistance is placed between the circuit terminal and its power supply lead. A mica capacitor is connected between the circuit terminal and ground. The natural time constant of this two-component filter network should be large relative to the time between pulses, so that the potential of the circuit terminal cannot change appreciably during operation. From another viewpoint,



TYPICAL DECOUPLING SCHEME

the decoupling network must store enough energy between pulses to supply the tube current during the pulse. The power lines need not transmit rapid surges of current, but need only replenish the charge on the shunt capacitor at a comparatively slow rate. Oscillations are then less likely to occur, but if present they are damped by the series resistance and shunted to ground by the capacitor, so that they have little effect upon tube and circuit. Thus a "decoupled" circuit is less sensitive to unwanted voltage changes, and has less tendency to produce undesirable effects in adjacent circuits.

For some Whirlwind applications two separate stages of decoupling will be used. In addition to the

decoupling filters installed near each vacuum tube, a larger filter will be placed in the power-supply lines feeding a number of similar vacuum-tube circuits on the same equipment rack.

Sometimes an inductor, rather than a resistor, is used as the series element in the decoupling filter. For good results, the natural period of oscillation of the series inductance and shunt capacitance must then be of the order of 100 times the interval between pulses.

Successful decoupling is sometimes difficult to achieve when high-current pulses occur at irregular intervals, as in many Whirlwind circuits. However, experiments indicate that with proper engineering precautions interaction between circuits can be reduced to a safe level.

STORAGE

Gas Storage

A master's degree thesis research on gas-discharge data storage has been completed. A low-pressure gas-filled gap has two stable states at a properly selected voltage, one conducting and the other not conducting. Higher and lower voltages can be imposed to select a gap and to switch it from one state to the other. In principle, a matrix of parallel wires passing through a series of plates can form glow discharge cells at the plate-wire intersections for the storage of binary digits.

An attempt was made to evaluate breakdown and glow discharge characteristics for application to gas storage and cell-selection switching as described in M-70, Data Storage in Three Dimensions. The research has been theoretical, with experimental verification, and was largely of an exploratory nature. Gap dimensions and their effect on breakdown and extinction voltages were studied. No work was done on the very serious problem of obtaining uniformity in gas discharge gaps. Research in this field has been terminated until additional staff time is available.

MATHEMATICS

Changes in Orders (Scale Factor)

Once the basic and more or less self-evident operations have been incorporated in a computer, the designer is faced with unlimited opportunity for special operations intended to speed up or simplify the special problems in which he is interested. For a true "general-purpose" machine there may be no justification for operations beyond the basic ones. For a machine with definite leanings toward a specific class of problems, and particularly for a machine with certain peculiarities, many refinements may be justified. In any event the temptation to add operations is great, and since the cost of each is small there is considerable possibility of unwittingly adding an appreciable amount of equipment to an already complicated machine. The difficulty is increased because the special controls needed, while simple, are one-of-a-kind units requiring disproportionate design time.

All proposed additional orders must therefore be carefully studied before inclusion in the machine control. An important duty of the Whirlwind mathematics and applications groups is to make these studies and to recommend changes and additions to control.

The Mathematics group has recently proposed the addition of a special order to Whirlwind control. Whirlwind I is a prototype having a register length of 16 binary digits and a binary point (analogous to the decimal point in decimal-system arithmetic) fixed with respect to the register. This combination of short register length and fixed point sometimes results in a delicate situation requiring great care in setting up a problem and considerable critical readjustment by the machine while the computation is proceeding: scale factor must be continually adjusted to keep numbers within the registers. This critical readjustment or the alternative, computation with multiple-length numbers, appreciably slows up the machine, particularly if accomplished by subprograms using standard orders. Many manipulations are saved by an operation having the following characteristics:

1. The number in the accumulator is shifted left until its first non-zero digit is in the digit place just to the right of the binary point. The number is thus made to lie between 1/2 and 1, and completely fills the machine register. As many places are retained as is possible in one register length.
2. The number of places shifted is counted and retained.

Such an order, tentatively called sf, for scale factor, has been added to Whirlwind I control design. The number of places shifted is counted by the arithmetic element step counter and is put in storage in the register whose number is given by the address section of the order. Very little change is required in the arithmetic element or control.

STANDARDS BOOK

A standards book has been maintained by the Material Control group for the past two years. The purpose of the book is to list and describe components and materials which the Standards Committee have selected as being necessary and suitable for use by Project Whirlwind. Minimum stock quantities of the indicated items are maintained in an open stock room, more than a million units of several thousand different types being carried for both experimental work and computer construction. The standards book has proved indispensable in ordering and stockkeeping, and as a basis for engineering design and layout.

In addition to standard items, the book lists all available non-standard items. Many of these remain from completed research programs, and their use often saves the several days of procurement time and the additional cost of obtaining new material.

The standards book is under continuous revision to meet the changing needs of the program. At the weekly meeting of the Standards Committee, decisions are reached to add new products, drop old ones, or modify stock quantities.

Materials and components which are to be used in the Whirlwind computers receive an additional examination, more critical than the one for laboratory stock. Tolerances are usually closer and incoming inspections more exacting.

APPENDIX

REPORTS AND PUBLICATIONS

The following reports and memorandums on Project Whirlwind work were issued during January.

No.	Title	No. of Pages	Date	Author
R-120	Deflection Circuits of Electrostatic Storage Tubes (Abstract in E-89)	31	11-7-47	J. O. Ely
R-133	Timing of WWI (Abstract in E-93)	5	12-15-47	G. Hoberg E. Blumenthal
E- 87	5-Digit Multiplier - Present Status and Future Plans	3	12-22-47	N. H. Taylor
E- 88	The Function of AC0 Carry Register	7	1-2-48	G. Sumner
E- 91	Standard Bus System	3	1-6-48	C. A. Rowland
E- 92	Reduction of PRF Sensitivity	1	1-15-48	G. Hoberg
E- 94	Storage Tube Holding Beam Current Density	4	1-22-48	S. H. Dodd
M-132	Vacuum Tube Estimate for WWI	2	11-7-47	N. H. Taylor
M-135	Block Diagrams - Electrostatic Storage	7	11-10-47	R. R. Everett
M-158	" " Input and Output	8	11-10-47	R. R. Everett
M-176	Methods of Numerical Integration of Ordinary Differential Equations most suitable for use by Whirlwind I and Whirlwind II	22	12-9-47	M. Daniloff
M-197	Space and Power for WWI Electrostatic Storage	1	12-26-47	J. O. Ely
M-198	Input - Output Register Panel Space	2	12-29-47	D. R. Brown
M-199	Cabinets for WWI	4	12-29-47	D. R. Brown
M-200	Circuits for Marginal Checking	1	12-31-47	J. W. Forrester
M-201	Whirlwind I Installation Conference	1	12-31-47	H. Fahnestock
M-204	Decoupling	1	1-5-48	H. Fahnestock
M-205	Meeting of Electronics Group Dec. 31	1	1-6-48	J. J. O Brien
M-207	Meeting of Electronics Group Jan. 7	3	1-9-48	H. Kenosian
M-209	Bi-Weekly Report Part I - Jan. 9	11	1-12-48	
M-210	" " " II " "	14	1-12-48	
M-212	Project WW Seminar Schedule Jan. 12 - Feb. 18	1	1-14-48	R. R. Everett
M-214	Meeting of Electronics Group	1	1-19-48	J. J. O'Brien
M-216	Electrostatic Forces and Deflection of Storage Meshes	3	1-21-48	P. Franklin
M-220	Bi-Weekly Report Part I - Jan. 23	12		
M-221	" " " II " "	13		

<u>Translations and Transcriptions</u>

No.	Title	No. of Pages	Date	Author
M-174	On the Dielectric Constant of an Oxide Hydroxide and Oxyhydrate: Oscar Glemser, ZEITSCHRIFT FUR ELEKTROCHEMIE, V45, 1939	8	12-4-47	M. I. Florencourt