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PROJECT WHIRLWIND

(Device 24-x-3)

SUMMARY REPORT NO. 14

NOVEMBER 1948

Submitted to the

OFFICE OF NAVAL RESEARCH
Under Contract N5ori60
Project NR-720-003

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 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 (WWI), 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 Office of Naval Research, Navy Department, Washington 25, D. C.; or where approval has previously been arranged, to Jay W. Forrester, Project Whirlwind, Servomechanisms Laboratory, Massachusetts Institute of Technology, Cambridge, Mass.

GENERAL STATUS

Installation of the Whirlwind I arithmetic element has been progressing rapidly. The B-register has been delivered and installed in the last month. Completion of sufficient wiring and delivery of accumulator panels in December should permit testing of the entire arithmetic element to start in January.

Five storage tubes with a beryllium mosaic on mica have been processed. Two had mechanical defects. The other three show good results, and tubes of similar construction should be satisfactory for life tests and tests for operation at high repetition rate. The equipment for the latter tests is progressing more rapidly than predicted in the last report, and should be ready for preliminary operation in December.

APPLICATIONS STUDY GROUP

The rational design of a device as complex as the Whirlwind computer demands that the men in charge of each phase of the design know (a) what the general objectives are and (b) what is being done by other departments or groups in the project. This need was emphasized at Project Whirlwind when some of the electronics engineers expressed a desire to know what the machine will actually be called upon to do - in other words, how it will be applied.

As a specific answer to this request and to promote the general effectiveness of the Project, an Applications Study Group has been formed. Key members of the Electronics Engineering, the Block Diagram, and the Mathematics groups meet for one hour each week to discuss the solution of various computer application problems. Actual solutions are worked out by the individuals as "homework" on their own time.

Problems considered will be of increasing complexity, with emphasis on control applications. Those undertaken so far include: (a) Coding for evaluation of sin x and cos x by expansion of a series and by interpolation in a table, (b) Coding for Newton's method of determining square roots, (c) The guiding of a ship through a channel.

It is hoped that this study group will lay part of the groundwork for the use of the Whirlwind computer when its construction is completed. In the meantime, the exchange of information and viewpoints among the men responsible for the various phases of its design facilitates the work of all groups.

INSTALLATION OF WHIRLWIND I

As shown in the accompanying photographs, construction and installation of the Whirlwind I computer have made concrete progress beyond the stage illustrated in the September Summary Report, No. 12.

The row of racks in Fig. 1 contains, primarily, the arithmetic element together with certain other repetitive elements of the computer. All panels shown have received extensive video tests; individually, they meet all specifications.

The two left-hand racks, together with a third not visible in the photograph, contain the parts of control peculiar to the arithmetic element. The succeeding racks to the right each contain one digit of the several registers making up the computer.

The third rack from the left contains some prototype and some production panels in their final locations. From top to bottom in this rack, the function and status of the panels are as follows: (1) Bus driver prototype; in production; delivery of 19 units in December. (2) Program register; delivery complete. (3) Program counter prototype; completion not needed before central control some months hence. (4) B-register; delivery complete. (5) Accumulator prototype; in production; delivery of 18 units in December. (6) A-register; delivery complete. (7) Check register prototype; production during the winter.

Testing of the integrated arithmetic element consisting of A-register, B-register, accumulator, and arithmetic control will begin late in December and continue into the winter while the central control is being constructed and installed.

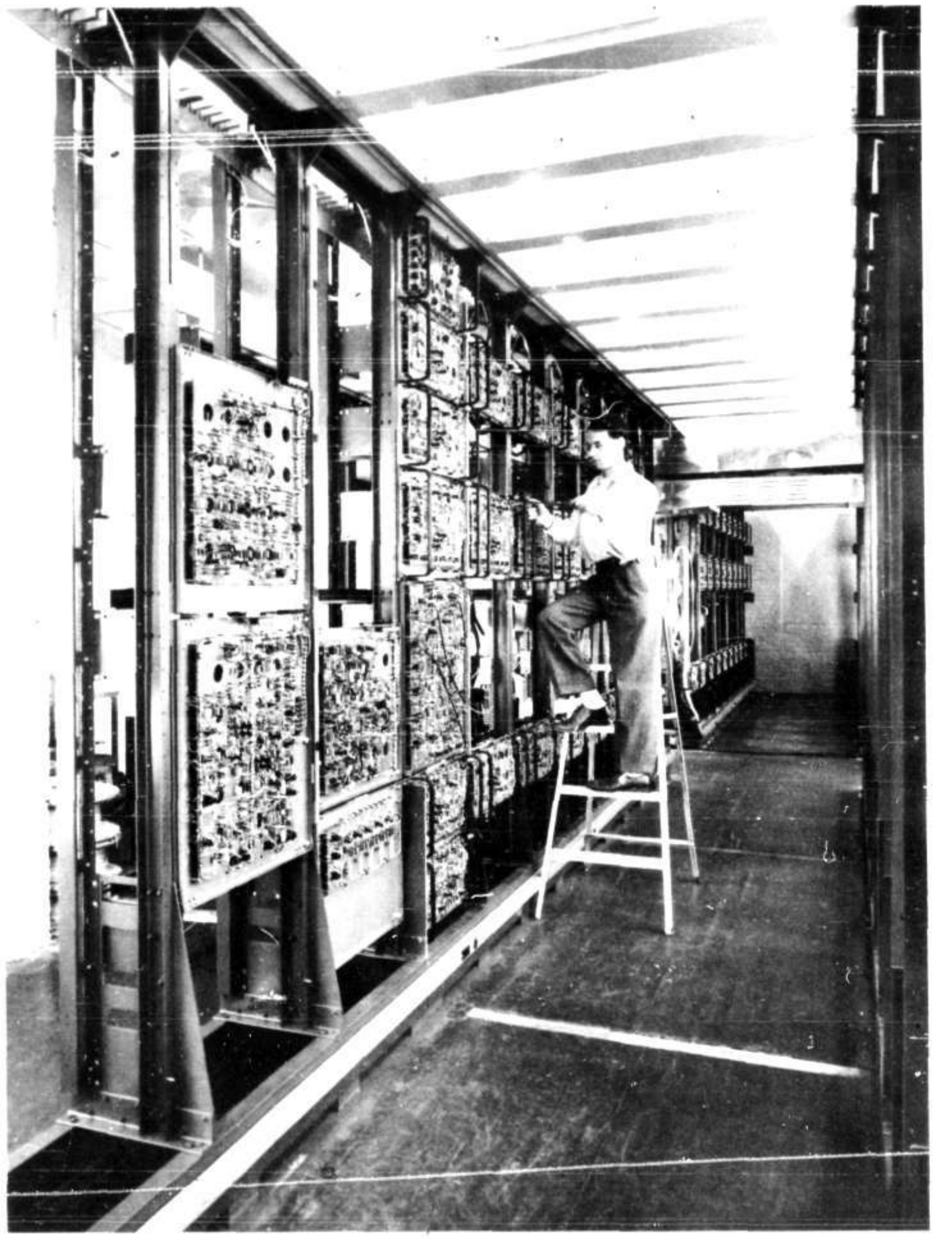
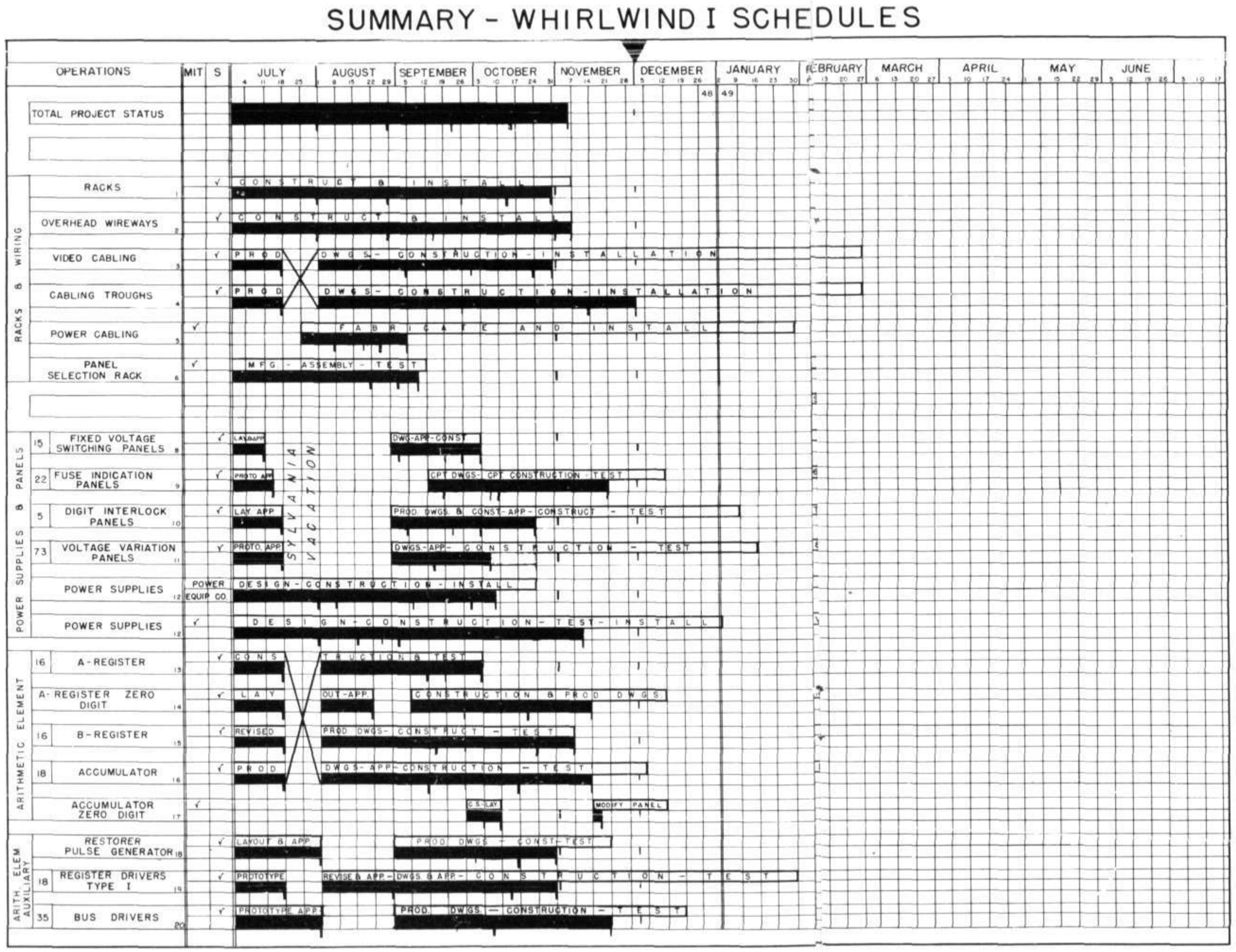


FIG. 1. INSTALLATION OF THE ARITHMETIC ELEMENT OF THE WWI COMPUTER IS NEARING COMPLETION

FIG. 2. POWER DISTRIBUTION HARNESSES, TERMINAL STRIPS, AND FILAMENT TRANSFORMERS ARE BEING INSTALLED IN THE COMPLETED RACKS

SUMMARY - WHIRLWIND I SCHEDULES



LEGEND

JULY

Period of one month, comprising the total number of days in the month.

PROTOTYPE

Operation to be performed, and estimated time allotted for its completion. Estimates made in July 1948.

Work done. The ratio of the length of the solid bar to the length of the open bar above it shows percentage of completion at the end of the month.

Date of latest posting.

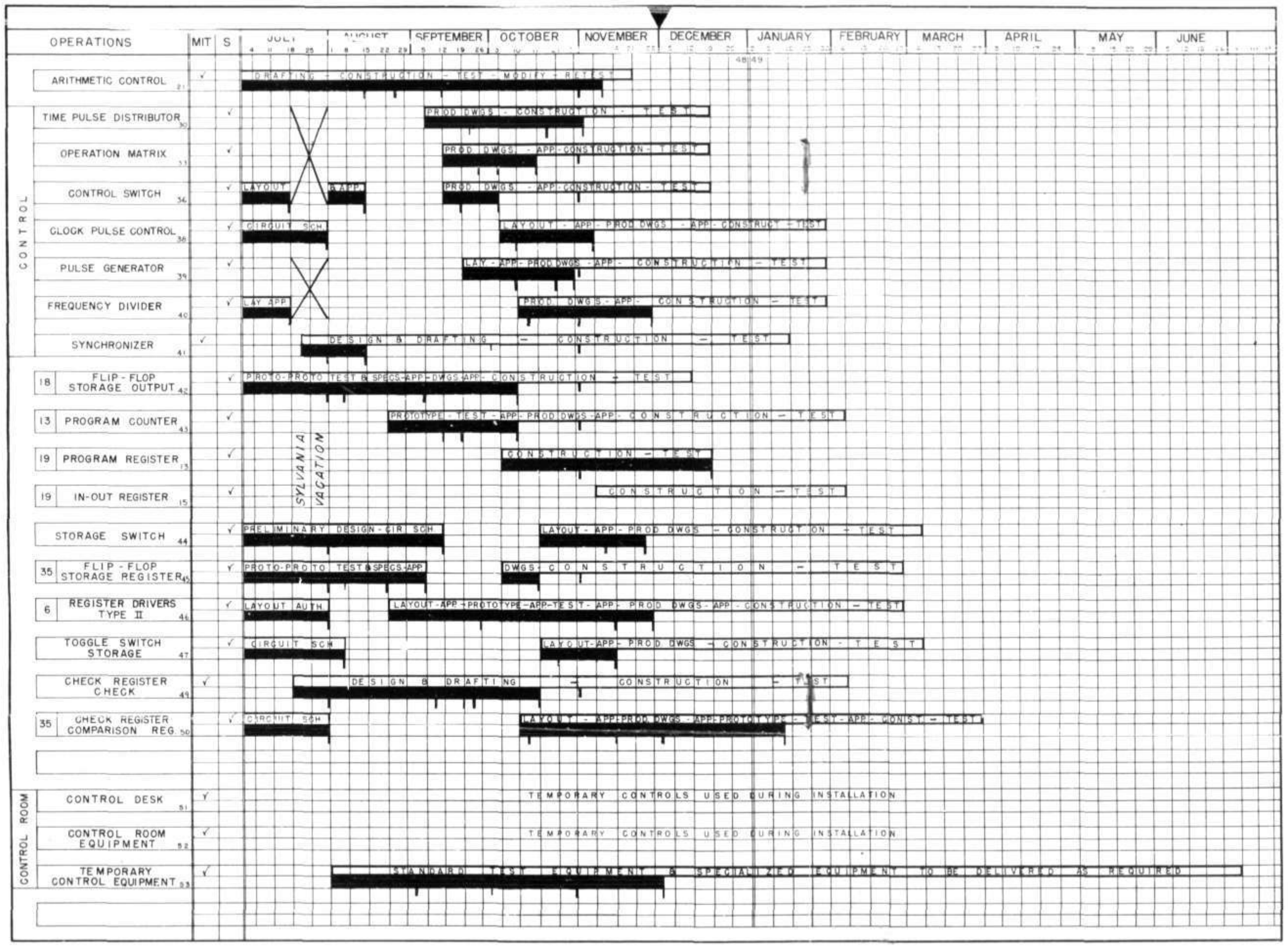
Summary line. Shows overall status of the project.

MIT S

Column showing whether M.I.T. or Sylvania will do major portion of the job.

For a long-range plan from 1944 to 1952 showing the relation of this detailed schedule to past and future work, see Summary Report No. 11, August 1948.

SUMMARY – WHIRLWIND I SCHEDULES CONT.



LEGEND

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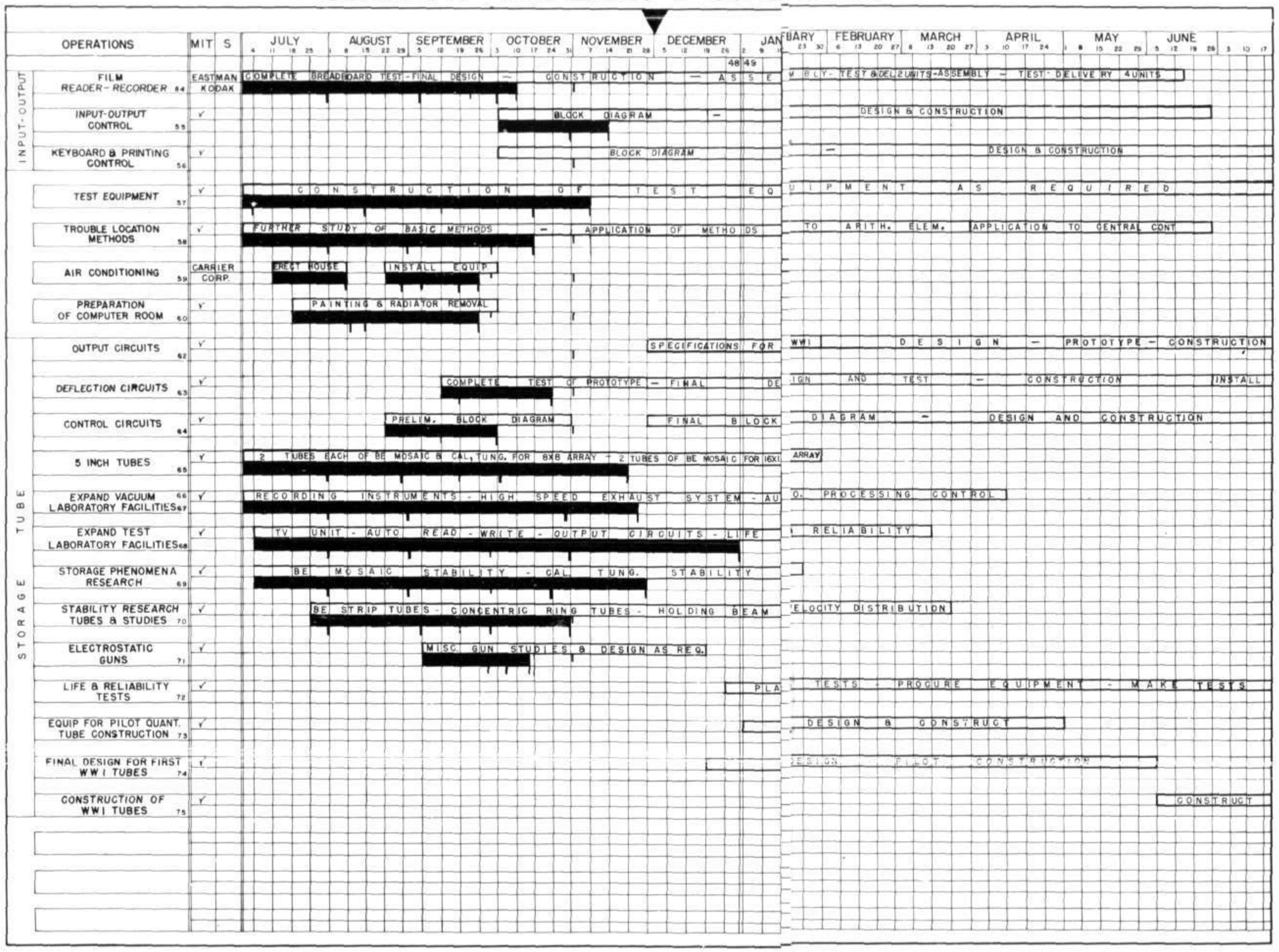
SUMMARY - WHIRLWIND I SCHE DULES -CONT.



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STORAGE TUBES

As described in Summary Report 13, storage tubes with a beryllium mosaic on mica dielectric were found to be markedly superior to those with a beryllium mosaic on aluminum oxide dielectric. The fourth tube containing a storage surface of beryllium mosaic on mica overcame the difficulties encountered in the earlier tubes: storage is uniform over the surface, the signal output is high, and there is no direct pickup of electrons by the signal plate. Stable and uniform storage over the whole surface is now possible over a wide range of holding-gun beam velocities; i.e., from 50 volts to 500 volts, with optimum storage conditions at 75 volts. Output signals with a 1.5-microsecond reading pulse are of the order of 80 millivolts for negative spots and 15 millivolts for positive spots.

A reliability tester is being constructed to determine operation and life under conditions similar to those which will exist in the computer. The reliability tester is being designed to use up to five storage tubes and to read spots from one tube to a temporary storage register and then rewrite them on the next tube. Thus, a pattern may be made to cycle from one tube to the next through all five tubes and then back to the first tube, continuing in a loop over periods of hours. Any error in reading or writing will be detectable as a change in the original pattern. Changes in the type of pattern and the operating speed will permit simulation of the most severe operation to be encountered in the computer. The reliability tester consists of several parts:

1. A high-speed deflection circuit, already developed, which will deflect five of the storage tubes in parallel (see Summary Report 7).

2. Adequately regulated power supplies to run all five of these tubes and the associated circuits.

3. A cathode-ray tube accompanying each storage tube to display the signals read out from the storage tube so that an indication of the stored pattern may be obtained.

4. Input and output circuits and a temporary storage register to store information between the time of reading out and the time of reading in.

5. A control panel and numerous control circuits to channel the information and obtain different modes of operation.

Since the reliability tester must simulate computer operation, the unit must operate at high speeds and must therefore utilize a high-speed storage tube read-out system which will respond rapidly to short pulses, but which will not be overloaded by switching transients required for writing the negative spots. The r-f output system being designed operates on the basis of r-f modulation of the reading beam and an r-f tuned amplifier on the signal plate which will amplify the output signal but which will not be affected by the relatively slow rises and falls of the switching pulses. The r-f output-circuit project breaks down into four basic problems:

1. Development of a satisfactory pulsed r-f source to drive the control grid of the high-velocity gun.

2. Shielding of the signal plate and associated circuits from the r-f source and the grid of the high-velocity gun.

3. Construction of a satisfactory r-f amplifier.

4. Possible development of a gate amplifier to drive the signal plate. This may not be necessary if present equipment has satisfactory r-f characteristics.

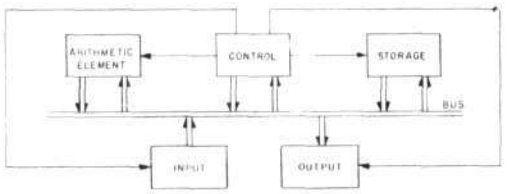
A more detailed description of this work will be given in a later Summary Report. Until the r-f output system has been fully developed, a simpler video system will be used in the reliability tester.

The filtered-air room for tube component construction and inspection has been enlarged, and these extra facilities should make it possible to fabricate more storage tubes per week. At present it is planned to continue construction of the tubes with beryllium mosaic on mica described above and to use these tubes for operation in the reliability tester and other test work.

FUNCTIONAL ARRANGEMENT, MAJOR ELEMENTS OF THE WHIRLWIND COMPUTER

Any computing machine may be broken down into five major components: Input, Output, Control, Arithmetic Element, and Storage (or Memory). If any of these components is absent, its function must be supplied by the operator. The simple desk calculator, for instance, has no input-output mechanism, and its memory and control, if any, are quite limited. It is mainly an arithmetic unit provided with control keys; the missing functions are performed by the operator.

The Whirlwind computer will contain all five components and will operate at high speed; yet its basic principle may be likened to that of the desk calculator.

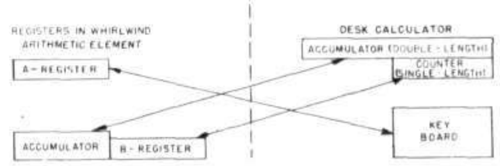


MAIN COMPONENTS

Arithmetic Element

In WWI the arithmetic element contains three registers, the A-register, the accumulator, and the B-register, as well as a number of special control units. The three registers correspond respectively to the keyboard, the double-length register on the carriage (accumulator), and the single-length register on the carriage (counter) of a desk calculator. In both machines only the accumulator is capable of addition. In the desk machine addition is performed by the rotation of a decimal counter in each digit, with the carries performed by the mechanical action of cams. In the Whirlwind computer addition is executed by electric pulsing of a binary flip-flop for each digit, and the carries are stored (remembered) by an additional set of flip-flops until a carry pulse consolidates the result. In the desk calculator the addend is brought to the keyboard manually, while in the Whirlwind computer the addend is inserted into the A-register from storage automatically.

In the WWI arithmetic element the accumulator is only a single-length register. In operations with single-length numbers, the need for a double-length register arises only for the holding of the product of two single-length numbers. In the desk calculator the multiplicand is put on the keyboard, while the carriage registers display the product (double-length) and the multiplier (single-length). In WWI the multiplicand is similarly in the A-register, the multiplier is initially inserted in the B-register, while the double-length product eventually appears in the combination of the accumulator and B-register. During the process of multiplication, each digit of the multiplier is discarded as soon as the information contained in it is used, providing room to shift the partial product to the right one step at a time until the product occupies both the accumulator and the B-register. This efficient use of the B-register results in a considerable saving in equipment and rack space.



CORRESPONDENCE BETWEEN THE DESK CALCULATOR AND THE ARITHMETIC ELEMENT OF WHIRLWIND

Control

The control of WWI is fundamentally more elaborate than that of a desk calculator. Corresponding to the control keys of the desk calculator (marked, for instance, CLEAR or ADD), WWI has control pulses to perform similar functions. However, in WWI these commands are grouped into operations, each of which consists of a specific combination of commands in a specific sequence. For instance, the operation <u>ca</u> (clear and add) clears the accumulator, inserts (adds) a number into it, and performs a carry, also taking care of a number of transfers between different units and of automatic checks. Furthermore, an automatic digital computer can perform a number of these operations in any predetermined sequence.

Storage

The automatic operation of a computer is made possible by its memory. Orders for the required operations and the sequence of their execution, as well as the numbers which are to be operated on, must be stored by the machine. WWI will have 2048 electrostatic storage registers. Control circuits will permit automatic reading and writing. In addition, 5 flip-flop storage registers and 32 toggle-switch storage registers will be available for use during testing.

Input and Output

The input-output equipment to be used will depend on the application of the computer: for simulation problems analog-digital conversion units will be needed; for numerical problems film reader-recorders will provide the link between the computer and the outside world. For other kinds of problems requiring an erasable external storage, magnetic recording can be added.

Installation and Testing

The installation of the different components of WWI will proceed according to a logical plan for testing. The arithmetic element is being installed first, for the testing of the system could hardly be meaningful without it. The installation of temporary storage and controls needed for the testing of the arithmetic element was described in detail in Summary Report No. 13. The use of temporary rather than final units will not only expedite the testing of the arithmetic element, but it will also simplify the system testing of the different final control units by providing foreknowledge of the correct operation of the rest of the system.

ARITHMETIC CONTROL

Automatic control of computing operations in Whirlwind I is accomplished on two levels. Central control (or main control) handles the overall program of operations to be carried out, but execution of a number of the more involved individual commands within these operations is delegated to one or more of a group of auxiliary control units closely associated with the arithmetic element.

The units of this "arithmetic control" are listed below together with names of the operations during which they are called upon by central control and the particular functions which they perform.

Arithmetic-control unit	Operations when used	Function of Unit
Multiply control	multiply	Carries out entire operation of multiplication by providing pulses at proper places and times.
Shift control	*shift right, shift left*	*Shifts numbers in arithmetic element* to right or left by providing necessary pulses.
Divide control	divide	Carries out entire operation of division by providing necessary pulses.
Divide-error control	divide	Sounds alarm if overflow of register occurs.
Sign control	multiply, divide, shift, etc.	Remembers signs of operands, puts operands in positive form for performance of operation, then corrects sign of result if necessary.
AC0 Carry	add, subtract	Sounds alarm if overflow of register occurs; provides "end-around carry" necessary in binary subtraction.
Special-add memory	special add	Remembers whether a carry-over occurred from the addition of the least significant halves of two double-length numbers.
Point-off control	scale factor	Shifts number to left until first significant digit is adjacent to sign digit.
Step counter	multiply, divide, shift, scale factor	Counts individual steps and provides pulse to indicate that operation is completed; remembers number of shifts made during scale factor operation.

Although it is usual Whirlwind practice to place each functional unit of the computer on a separate panel, for engineering convenience some exceptions to this rule were made during the design of arithmetic control. For instance, the multiply and shift controls have been built on the same panel, while the step counter occupies two separate panels.

Construction of all units of arithmetic control has been completed by Project technicians. With the exception of the step counter, all have been carefully tested, through the use of standard test equipment, for correct logical performance and satisfactory electronic performance. Where original tests have given questionable results, circuits have been redesigned to assure adequate margins of safety throughout.

Upon completion of tests on the step counter next month, all units of arithmetic control will be ready for interconnection with the three arithmetic-element registers (see Installation of WWI above) and the temporary control and console (i.e., temporary central control; see Summary Report 13, October).

WWI POWER SUPPLY CONTROL

The principal purpose of the WWI power supply control is to provide the automatic features necessary for operation of the power supplies from a remote push-button station in the computer control room. In addition, a means of local (power-supply room) manual control of individual voltages must be provided to facilitate maintenance and tests.

The control-room panel consists of a push-button station having a key-locked "On-Off" button, a "Stand-by" button, and an "On" button. The lock-ing button is used to shut off the computer and to prevent accidental starting; when turned on it merely makes the "Stand-by" and "On" buttons operative.

The "Stand-by" button initiates the application of filament voltage to the computer. First the main filament contactor is closed, and a signal is sent to the filament voltage control, which automatically raises the filament voltage gradually over a period of about five minutes. Also, the filaments of the plate-supply rectifiers are energized and heated. The computer is then ready to be turned on.

The "On" button energizes the plate sequence timers. These timers energize the d-c power-supply rectifier anodes in the proper sequence: first relay power, then bias power, and, last, plate power. If the "On" button is pushed before the "Stand-by" button, the sequence of events is the same, except that the plate sequence timers are automatically started upon completion of the cycle of the filament voltage control.

When the computer is turned off, all power except filament power is immediately turned off. The filament voltage is decreased gradually by the filament voltage control, and after an interval long enough to insure completion of this process a timer deenergizes the filament voltage control and opens the main filament power contactor.

Special switches for emergency power shut-down are located in the control room, computer room, and power-supply room. Emergency shut-down differs from normal shut-down by deenergizing the computer filaments immediately rather than allowing the five-minute gradual decrease in voltage. The computer is automatically shut down in this way by overcurrent or overvoltage at the terminals of the filament alternator.

The power-control station in the power-supply room includes a three-position switch for "Automatic", "Off", and "Maintenance". On "Automatic", power-supply operation is controlled from the control room as described above. The "Off" position makes these controls inoperative, thus providing safe conditions for work on the supplies. The "Maintenance" position allows the d-c power supplies to be turned on by local switches as desired for test or adjustment.

In addition to the controls, both the computer room and power supply room will have the pilot lights and meters necessary to indicate operating conditions within the power system. Time totalizing meters for filament and plate power are included. It is planned to add a monitoring system which will automatically detect d-c power-supply transients greater than predetermined limits and provide an alarm signal.

VISITORS

During November the Laboratory had among its visitors the following:

Captain D. P. Tucker, Office of Naval Research, Washington.

Dean T. K. Sherwood, Professor H. L. Hazen, Professor S. H. Caldwell, and Professor J. B. Wiesner of Massachusetts Institute of Technology to discuss computer applications.

Dr. I. J. Gabelman of Watson Laboratories, Dr. R. F. Nicholson of the Electronic Research Laboratory, and Mr. B. F. Greene of the Electronic Research Laboratory to discuss air traffic control.

Mr. Wilson F. Harwood and Mr. Franklin J. Collender of the Office of Naval Research, with representatives of the Boston Branch, Office of Naval Research.

Mr. M. J. Minneman of the Glenn L. Martin Company, who was interested in airborne applications of digital computers.

Mr. L. P. Tabor, Mr. W. H. Deily, Mr. D. B. Houghton, Mr. R. O. Yavne, Mr. B. T. Svihel, Mr. W. W. Felton, Mr. E. A. Mechler, Mr. A. D. Hestenes, Mr. S. Charp, and Mr. B. B. Young of the Franklin Institute.

APPENDIX

REPORTS AND PUBLICATIONS

The following reports and memorandums on Project Whirlwind work were among those issued during November:

No.	Title	No. of Pages	No. of Drwgs.	Date	Author
SR-11	Summary Report No. 11	19	-	8-48	
SR-12	Summary Report No. 12	15	-	9-48	
R-152	Binary Counter Application of the Whirlwind Flip-Flop (Abstract in E-158)	8	9	10-20-48	H. Kenosian
E-143	Numerical Solution of Linear Integral Equations	48	-	9-16-48	A. J. Perlis
E-155	Trigger-Tube Circuits	3	4	10-21-48	A. K. Susskind
E-159	Block Diagram Revision - Nomenclature	6	-	10-28-48	J. M. Salzer
E-162	Extension of Runge Kutta Method to Differential Equations of Order n, where n is Greater than 4	10	-	11-15-48	P. Rabinowitz
E-163	Aged 7AD7 Tubes	6	2	11-12-48	J. J. O'Brien
E-164	Natural Frequencies of Vibration of the Circular Grid with Central Support of E. S. Storage Tube	4	-	11-18-48	M. Daniloff
M-658	Storage Holding Stability Tests on RT36	5	15	9-29-48	N. S. Zimbel
M-659	The Problem of Scale Factor as Applied to Non-simulator Problems	12	-	10-20-48	J. W. Carr, III
M-665	Standard Switch Settings for WWI	4	-	11- 8-48	C. W. Adams R. P. Mayer
M-667	Summary of Storage Tube Testing, May 1 - Oct. 26, 1948	2	2	10-28-48	C. L. Corderman J. S. Rochefort R. L. Sisson
M-672	Priority for Tube Construction	2	-	11- 2-48	P. Youtz
M-683	Bi-Weekly Report, Part I, 11-12-48	11	-	11-12-48	
M-684	Bi-Weekly Report, Part II, 11-12-48	18	-	11-12-48	
M-688	Priorities for Tube Construction	3	-	11-16-48	P. Youtz
M-689	The Effect of Non-uniform Holding Beam Velocity on Signal Stability	8	8	11- 5-48	W. J. Nolan
M-691	Master's Thesis Proposal: A Dual-Triode Capacitively-Coupled Flip-Flop	7	5	11-15-48	M. H. Hayes
M-692	Research Tube 41	2	1	11-17-48	W. J. Nolan M. I. Florencourt
M-695	Storage Tube 48 Construction and Processing	2	-	11-17-48	M. I. Florencourt
M-698	Proposal for New Orders	5	2	11-22-48	R. P. Mayer J. M. Salzer
M-699	Conference on Operator's Console	1	-	11-23-48	C. W. Watt
M-700	Vacuum-Tube Studies and Flip-Flop Circuits	6	-	11-23-48	J. J. O'Brien

No.	Title	No. of Pages	No. of Drwgs.	Date	Author
M-701	Storage Tube 41: Objective, Construction and Processing	3	1	11-23-48	M. I. Florencourt
M-702	Measurement of Velocity and Intensity Distribution of Electrons in the High Velocity and Holding Beam of the Storage Tube	2	2	11-22-48	H. Klemperer
M-706	Bi-Weekly Report, Part I, 11-26-48	13	-	11-26-48	
M-707	Bi-Weekly Report, Part II, 11-26-48	19	-	11-26-48	
A-74	Terminology	1	-	11- 9-48	R. R. Everett
C-62	Applications Study Group	2	-	11- 1-48	J. W. Forrester
C-63	Applications Study Group	2	-	11- 9-48	J. W. Forrester
C-64	Coding the Evaluation of Sin X (Problem Assigned in C-62)	5	-	11-10-48	J. W. Forrester
C-65	Hints for Problem, November 9 to 16	5	-	11-12-48	J. M. Salzer R. P. Mayer
C-66	Standardization of Coding Abbreviations	3	1	11-12-48	R. P. Mayer J. M. Salzer
C-67	A Solution of Problem, November 9 to 16	11	-	11-15-48	J. M. Salzer R. P. Mayer C. W. Adams
C-68	Problem for November 16 to 23	2	-	11-16-48	T. W. Hildebrandt P. Rabinowitz
C-69	Interpolation, A Solution to the Problem in C-63	3	1	11-17-48	J. W. Forrester
C-70	Codes for the Sine and Cosine	5	-	11-22-48	P. Franklin
C-71	Hints for Problem, November 16 to 23	1	-	11-19-48	T. W. Hildebrandt P. Rabinowitz
C-72	Solutions of Problems in C-68	7	-	11-22-48	T. W. Hildebrandt P. Rabinowitz
C-73	Problem for November 23 to 30	1	-	11-23-48	P. Rabinowitz
Translation					
E-160	Report No. 164-RÖ/E, "The Influence of the Resistance of the Oxide Layer upon the Damping of the Vacuum Tube LG11"	4	4	11- 1-48	M. Daniloff