PROJECT WHIRLWIND

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DIGITAL COMPUTER LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Cambridge 39, Massachusetts

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FOREWORD

Project Whirlwind

Project Whirlwind at the Massachusetts Institute of Technology Digital Computer Laboratory is sponsored by the Office of Naval Research under Contract N5ori60. The objectives of the Project are the development of an electronic digital computer of large capacity and very high speed, and its application to problems in mathematics, science, engineering, simulation, and control.

The Whirlwind Computers

The Whirlwind computer is 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) may be regarded as a prototype from which other computers will be evolved. It is being used both for a study of circuit techniques and for the study of digital computer applications and problems.

Whirlwind I uses 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 permits the computation of many simulation problems. Calculations requiring greater number length are handled by the use of multiple-length numbers. Rapid-access electrostatic storage initially had a capacity of 4096 binary digits, sufficient for some actual problems and for preliminary investigations in most fields of interest. This capacity is being gradually increased toward the design figure of 32,768 digits. Present speed of the computer is 20,000 single-address operations per second, equivalent to about 6000 multiplications per second. This speed is higher than general scientific computation demands at the present state of the art, but is needed for control and simulation studies.

Reports

Quarterly reports are issued to maintain a supply of up-to-date information of 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 the publications issued during the period covered by this Summary, together with instructions for obtaining copies of them, appears in the Appendix.

1. QUARTERLY REVIEW (AND ABSTRACT)

A new input-output system was installed in the computer during the last three weeks of August. This new system permits faster operation of the computer, because it provides for partial parallel operation of the computer and its terminal equipment. Thus the computer does not have to wait for the slower terminal equipment to complete operations. The new system also provides for the use of more terminal equipment, particularly magnetic drums (to be installed in the next few months) and additional display equipment. The new input-output system has entailed the formulation of a new set of in-out orders and a new process of coding that has been designed to facilitate use of the computer.

Installation of the new input-output system required a three-week shutdown of the computer, from August 11 to the end of the month. By the end of the quarter the computer was back to normal operation, and the applications groups were able to resume their activities. Preceding the shutdown a number of the more important problems were completed. A set of rules have been established for allocating computer time to the people who want to solve problems on it, as well as a routine for use of the computer after time has been assigned.

During the period before the shutdown, the computer was reliable for 86% of the 592 hours assigned to applications. Electrostatic storage has been increasingly reliable. During the quarter 7 storage tubes failed after an average service of 2333 hours. The 17 tubes in the computer at the end of the quarter had been in operation from 26 to almost 5000 hours, for an average of 1979 hours. Storage-tube research is being directed toward a reduction in the shift of the read-write beam caused by ions in the tube. Various measures give promise of eliminating this source of trouble.

The study of vacuum-tube life continues. A new approach is the correlation of tube performance with the spacing between elements in the tube.

A special two-week course of instruction on Digital Computers and their Applications, under the supervision of Professor C.W. Adams of the Digital Computer Laboratory, was held at MIT during the summer. Ninety-five people from 61 different organizations took the course. Registration in Institute courses in Digital Computation for the fall term has been considerably higher than ever before.

2. OPERATION OF WHIRLWIND I

2.1 SHUTDOWN AND MODIFICATION OF COMPUTER

A shutdown of the WWI computer was started on August 11 and completed August 30. During this shutdown a new input-output system was installed in the computer, and all terminal equipment is now operating in this new system. During the shutdown period no application time was scheduled, but since the completion of the shutdown, new programs written by the applications groups were tried with their new orders, and the whole system checked out under varying conditions of operation. The computer is now back to normal operation.

The new input-output system has several basic advantages. The computer can now operate at a higher speed than before, because the new input-output system allows partial parallel operation of the main computer element and the terminal equipment. In the old in-out system each order for operation of a piece of terminal equipment was sent to the terminal equipment, and the computer then sat idle until a completion pulse was received indicating that the piece of terminal equipment had finished its operation. With the new in-out system the computer can order an operation of the terminal equipment and then continue calculation in its normal program. When the terminal equipment completes its operation, the new in-out system will then wait for the computer to ask for another operation. An interlock stops the computer if it asks for operation of a piece of terminal equipment before the completion of a previous in-out order. Thus in most cases a programmer can arrange to have the computer operate independently of the speed of the terminal equipment.

In addition to possessing the advantage of higher speed, the new input-output system allows more terminal equipment to be handled. In particular, the display system can be extended, and magnetic drums can be used with the new system.

The terminal equipment orders have been changed with the installation of the new in-out system. All the temporary in-out orders have been consolidated into three general-purpose orders, and these orders plus two new block orders can handle all the presently expected terminal equipment. These five orders will include two new type orders known as block transfer orders, which can specify that a block of information be transferred between electrostatic storage and the terminal equipment in either direction. This will cut down the number of in-out orders required in any program and will speed up the operation of the in-out equipment.

During the period July 3 through August 11, a total of 592 hours of computer time was assigned to the applications groups. During these hours the reliability figure was 86%. Electrostatic storage has become more reliable during this quarter. This improvement has permitted us to operate programs for longer periods without encountering computer errors and also has allowed us to reduce the number of hours scheduled for maintenance of electrostatic storage. Some of the new tubes being developed by the Storage-tube group show great promise, and it is hoped that the reliability of storage can be increased substantially and the number of hours of maintenance reduced during the coming quarter so that manpower can be released to work on system testing of the new in-out system and the magnetic drums.

A magnetic drum with its associated equipment will be installed, tested, and tied in with the computer during the next few months. Preparation of the room which will contain this equipment is essentially complete, and installation of air-conditioning and racks is progressing. The auxiliary magnetic drum, designed to complement the internal high-speed electrostatic storage, will be delivered by Engineering Research Associates during November. This equipment will be immediately installed and integrated into the WWI system. Part of the associated circuitry will consist of panels containing special plug-in units. These plug-in units are, in general, packaged versions of the basic circuits used in the WWI computer. Detailed plans are being formulated for the testing of this equipment, and provisions for power for special test equipment are being made.

2.2 SYSTEMS ENGINEERING

2.21 Electrostatic Storage

Electrostatic storage continues to be the most important factor affecting reliability of the Whirlwind I system. It has operated quite well for the last quarter. During one period the computer operated for 23 hours without a parity alarm.

The principal limitation on storage reliability at the present time appears to be the compromise necessary with respect to restoring current. Too little restoring current results in failure to stabilize the negative areas, particularly in the corners. Too much causes an increase in positive-ion concentration through bombardment of the dag; this in turn causes gun failures and readout failures of positive spots because of deflection shift.

Complete records are kept of all storage failures. Occasionally a particular program will cause consistent storage failures. These cases are investigated to determine the mechanism of the failure. Information obtained from these sources is used to determine the best compromise on operating parameters for the storage tubes.

Most of the research effort of the Storage-tube group has been directed toward more refined measurements of the small shift in write-read beam position caused by ions within the body of the tube. This was a part of a larger investigation carried out as a master's thesis concerning the effects of ions upon the operation of the MIT electrostatic storage tube. An effective method of studying the ion-deflection shift, developed during the course of this research, is to use a Faraday cage with the cage current being used as an indication of the position of the write-read beam. When the holding beam is cut off, the cage current continues to change for about 20 microseconds. It is postulated that this is the time required for dispersion of a positive-ion space charge within the body of the tube. The ion shift of the write-read beam is undesirable because the write and read operations take place at different times after the holding gun is cut off.

The simplest way to insure tracking of the write and read beams would be to delay both operations until roughly 30 microseconds after holding-beam cutoff, allowing dispersion of the ion cloud, but the consequent addition to storage access time would be intolerable. Experimentally it has been found that a reduction of the holding-beam current from its previous value of 1.5-2 ma to about 0.4 ma does not unduly affect operation, and the amount of ion-deflection shift is in most cases insufficient to cause trouble. This is the course being followed at present. However, to enable a return to the higher value of holding-beam current with its somewhat higher reliability, we are continuing the development of stannic oxide coatings (which should release less gas to be ionized), and plan to add an ion collector ring within the body of the tube.

Our interest in Philips Type L planar cathodes continues high following announcement by their laboratories of the development of a new heater structure which reduces the incidence of heater burnout. A master's thesis research into the problems of processing Philips cathodes is being started.

2.22 Engineering Improvements

Modifications of the RF Pulser have improved its stability and reliability. Oscillations in the phase-reference channel were eliminated and output stability improved by changes in the control-amplifier circuit. A tendency for the gate generators of the pulser to free-run has been eliminated by replacing the gate generator circuit in the pulser with a modified register-driver gate generator on an external panel.

Marginal readouts from flip-flop storage during operation at low duty cycles were found to be caused by clamping difficulties in the selection-gate circuits of flip-flop storage. The trouble had been present since the panels were first installed but had not been recognized because it is not present during normal high-speed operation of the computer. The difficulty has been eliminated by d-c coupling all stages of the selection-gate circuits. (A -300-volt power supply was added to make this possible.) Rise and fall times of the selection gates were increased in order to provide sufficient gain for clipping in each stage. This has resulted in a gating system which is extremely tolerant of tube variations.

3. CIRCUITS AND COMPONENTS

3.1 VACUUM TUBES

3.11 Vacuum-tube Life

During the past quarter the WWI computer operated 1800 hours. Because considerable new equipment was installed during this period, much of the time was spent in checking both newly-installed and old equipment for proper operation in the augmented system. This additional checking has made itself evident in the large number of 7AD7 failures during this quarter.

The trends of the failures for the three most numerous types are shown below.

Tube Type	Failure rate, percent per 1000 hours: To August, 1951	First Quarter 1952	Second Quarter 1952	Third Quarter 1952
7AD7	3.4	1.0	1.8	2.3
7AK7	0.4	0.06	0.3	0.3
6SN7GT	0.9	2.25	0.7	0.9

It is interesting to note that 7AK7 and 6SN7GT tubes appear to have a rather stable failure rate about equal to the early failure rate as determined to August, 1951. However, the 7AD7 tubes, following the drastic drop in the first quarter of this year, have a rising rate which is approaching the early-life failure rate. As was mentioned in Summary Report 29, the drop in the failure rate was accompanied by a changed procedure in marginal checking. It remains to be seen whether the rate under the new checking procedure will rise to the old level.

Figure 3-1 shows a total of 20 6AK5 failures. Previously this tube has been absent from these lists or reported only occasionally. However, at the present time these tubes are being retested on a routine basis in an effort to put the 10-megacycle amplifiers into the best possible condition and to prepare for the re-installation of a second bank of storage tubes. Defective 6AK5 tubes are being replaced by 5654 tubes. The 5654 is a premium, ruggedized tube which should have much better life.

The 715C tubes used in the storage-tube deflection circuits were tested again for droop in plate current, following the same technique used earlier this year (Summary Report 29, page 10). Although the amount of droop was less than that observed in the tubes rejected at the earlier test, it was still necessary to reject some tubes because of this instability. Leakage and mechanical faults (open welds) are also troublesome with this type. An effort is being made to find a tube type more suited to this service.

The punched-card system of tube records is not yet completely ready for the determination of survival curves for important tube types. Progress has been delayed by the press of other work on the personnel preparing the cards for this system. With additional help now being used on this job, it is expected that data on some types will be available by the first of the year.

3.12 Vacuum-Tube Research

A study of the relationships between various internal dimensions and the electrical performance of vacuum tubes has been conducted during this period. Initially, grid-cathode spacings were desired as an aid in the selection of vacuum tubes for applications where shorts between these electrodes could be very troublesome. One technique used in their measurement was to fill the interstices in the tube with clear resin and then section the tube; see Fig. 3-2. Once the dimensions had been obtained, an effort was made to correlate the performance of actual tubes with the theoretical performance of tubes using the same electrode spacings and areas. The reduced data showed that performance was quite dependent upon the ratio of grid-pitch distance to grid-cathode distance. When the grid-pitch distance is large compared to the grid-cathode distance, performance is adversely affected. This study has in the main confirmed results which were common knowledge, but not readily available in detail.

Some study has been made of the duration of flicker shorts in vacuum tubes being tapped. This information is necessary for the

Type	Total in Service	Hours at Failure	Reason for failure; number failed: Change in Characteristics	Mechanical	Burn-out	Gassy
7AD7	2290	0-1000	2	3		1
		1000-2000	2			
		2000-3000	3	1		
		3000-4000	2	1		
		4000-5000	11	2		
		5000-6000	4			
		6000-7000	5	2		
		7000-8000	6			
		8000-9000	3			
		10000-11000	11	1		
		11000-12000	5			
		12000-13000	8	7		1
		13000-14000	8	4		
7AK7	1800	0-1000		3		
		7000-8000		1		
		10000-11000		2		
		12000-13000		1		
		13000-14000		2		
6SN7GT	500	5000-6000		1		
		8000-9000	1			
		11000-12000		1		
		12000-13000	1	3		
		13000-14000		1		
3E29(829B)	241	0-1000	1	1		4
		4000-5000	2			
		10000-11000	2			
		12000-13000				1
		13000-14000		1		
OD3/VR150	47	0-1000	1			
2D21	40	9000-10000	1			
3D21A	4	3000-4000		1		
5U4G	41	0-1000	2			
		7000-8000			1	
6AG7	120	0-1000	2			
		1000-2000		1		
		11000-12000	1			1
		12000-13000	1			
6AH6	15	0-1000		1		
		13000-14000		1		
6AK5	90	0-1000	1			2
		1000-2000		3		1
		4000-5000	4			
		5000-6000	5	4		
6AL5	186	1000-2000		1		
		4000-5000	2			
		8000-9000		2		
6AS7G	165	12000-13000	1			
6L6G	111	0-1000			1	
		13000-14000	4	1		
6V6GT	41	13000-14000	1			
6X4	17	0-1000	1			
6Y6G	300	0-1000		1		
		4000-5000	1			
		12000-13000	2			1
12AY7	36	0-1000	1			
C16J	12	3000-4000	1			
		4000-5000	1			
		7000-8000	1			
715B	28	0-1000		2		
		1000-2000		1		
		2000-3000	2			
		3000-4000	2			1
		8000-9000	7			
5651	34	0-1000	1			
5687	21	0-1000		1		

Fig. 3-1. Tube failures in WWI
July 1 - September 30, 1952

Fig. 3-2. Section of 6AN5 tube cast in clear resin for dimensional analysis.

intelligent design of short-checking equipment. It was found that the duration of most shorts exceeded 100 microseconds. Additional studies will be made in the future as time and equipment become available.

A new device for initial check of tubes to eliminate those with shorts and opens has been designed. This device will check for shorts in one operation, opens in another. Each operation will take about two seconds, the tube under test being tapped while rotating about the longitudinal axis. This device will provide a more complete check with less possibility of tube damage. Completion is scheduled in November.

Very little work has been done on the study of the droop in cathode current within the first second after current flow is initiated. Details of this trouble are described in Summary Reports 29 and 30. Equipment is now under construction for an intensive examination of this droop, and considerable work is planned for the coming months.

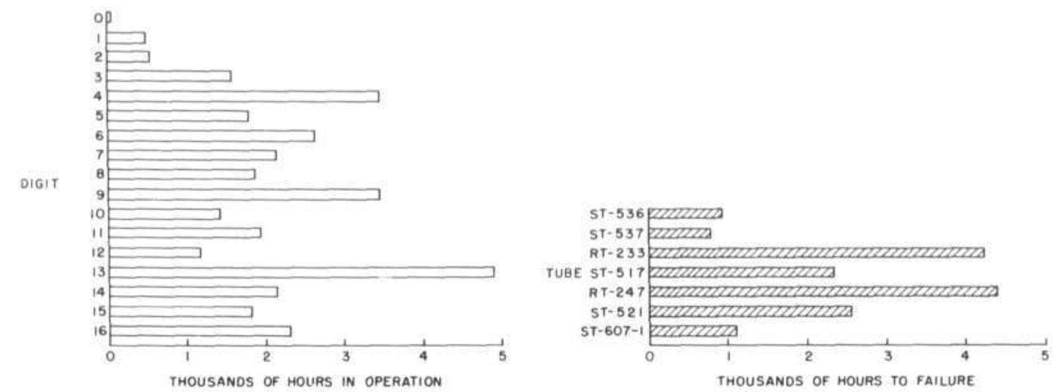
No life-test studies have been active during the period covered by this report. Additional studies are planned as soon as a new lot of 6145 tubes is received. (The 6145 is the replacement for the 7AD7.)

3.2 STORAGE-TUBE LIFE

Fig. 3-3 provides data on the life of all the storage tubes that operated in WWI during the third quarter of 1952. The upper bar graph shows the hours of operation to date of the 17 tubes in the computer at the end of the quarter. The lower graph shows the hours of operation at the time of failure for the 7 tubes that failed during the quarter.

3.3 COMPONENT REPLACEMENTS IN WWI

Fig. 3-4 lists the replacements of components other than tubes during the third quarter of 1952.



(a) Tubes in service on September 30, 1952 (b) Failures, July 1 - September 30, 1952

Fig. 3-3. Life of storage tubes in WWI.

Component	Type	Total in Service	No. of Failures	Hours of Operation	Comments
Capacitors	Mica 0.01 mfd	15072	1 1	89 5491	Shorted Mechanical
	Trimmer 4-30 mmfd	120	1	4026	Open
	Trimmer 7-45 mmfd	116	1 1	4921 6236	Open Open
Crystals	D-357 & 1N34A	7700	2 3 1 10 3 1	1000-2000 7000-8000 9000-10000 11000-12000 12000-13000 13000-14000	Low back resistance
	D-358 & 1N38A	3384			
	1N38A		1	903	Drift to low back resistance
	D-358		1 2	11000-12000 12000-13000	Low back resistance
Potentiometer	1000 ohm 2 watt	112	1	4146	Open control
	2500 ohm 2 watt	204	1	7833	Intermittent contact
Resistors	Nobleloy 5000 ohm ±1% 1 watt	160	9 3 1 1	3000-4000 4000-5000 6000-7000 7000-8000	Over tolerance
	Allen Bradley 220 ohm ±5% 1 watt	12052	1 1	89 9858	Burned out
Transformer	Pulse 5:1 6.193-8	344	1 1 2	11000-12000 12000-13000 13000-14000	Open secondary

Fig. 3-4. Component failures in WWI July 1 - September 30, 1952

4. MATHEMATICS, CODING, AND APPLICATIONS

The recent long-planned computer shut-down to provide new switching equipment for selecting input-output and secondary storage facilities (see Sec. 2. 1) has been accompanied by an equally long-planned change in procedures for using the computer. These procedures are of two sorts. The first is concerned with the techniques of writing and performing programs (Sec. 4. 1); the second with administrative details of making the computer available to the persons or groups who want to use it (Sec. 4. 2). Actual applications of the computer are treated in Sec. 4. 3.

4. 1 PROGRAMMING TECHNIQUES

In order to simplify the process of coding, a comprehensive system of service routines is being designed. The system will provide:

(1) Very elaborate facilities for conversion during input.

(2) Versatile output and secondary-storage routines automatically selected.

(3) Easy-to-use interpretive routines for performing extra-precision and/or floating-point arithmetic, automatically selected.

(4) Powerful mistake-diagnosis routines of both interpretive and post-mortem variety.

All these facilities, complicated as they are to provide, and complicated as they are to explain in detail, will greatly facilitate the use of the computer by technical personnel untrained in machine computation - those whose primary concern is the solution of a problem arising in their own field of digital computation. To these casual users, the facilities provided by the service routines will seem much the same as the facilities built into the machine itself. Thus, the casual programmer need never know the actual storage locations into which his instructions go or the actual binary form in which numbers in the computer must ultimately appear.

4. 11 Input Conversion

The principal new features of the input conversion program proper will be the provision for:

(1) Floating as well as relative or absolute addresses.

(2) Conversion to desired fixed- or floating-point numbers written decimally with any number of digits, with the point anywhere within the number, and with any power of two and/or ten included explicitly if desired.

(3) Instructions written mnemonically in either the Whirlwind code or the code for interpretive programmed arithmetic.

4. 12 Programmed Arithmetic

The interpretive routines incorporate, in addition to all the features required for extra-precision and floating-point arithmetic, facilities for a special adaptation of the Manchester B-box principle called cycle-control. The desired number system, whether fixed or floating, and the desired extra facilities such as division, cycle-control, etc. are automatically incorporated, during input, into the interpretive routine to make it as short as possible consistent with the facilities required.

4. 13 Output

The output routine provides for conversion to decimal from either fixed or floating binary. It provides for direct typing, paper-tape punching, magnetic-tape recording for later typographical output, or graphical or numeroscopic output plotted under program control on standard Whirlwind oscilloscopic display equipment. The desired output form is designated by simply writing an example of the pattern desired. Naturally, more than one form of output may be called for in a given program. The proper output facilities are selected automatically by the conversion program without any wasted storage space in the same way that the interpretive routines are specialized to any given kind of floating-point and/or extra-precision arithmetic.

4. 14 Location of Mistakes

In the past, the equipment for locating programming mistakes by means of data recorded by special diagnosis routines (used either before or after the failure of the program in question) has been hampered by the lack of sufficiently powerful routines. Improvements are continually being made in this direction; new techniques already available should greatly facilitate the problem of locating mistakes. Among the facilities soon to be available are a post mortem which prints out, after a program has failed, the contents of every register which differs from its initial value, and prints it in the same form (instruction, number, etc.) in which it was originally typed.

4. 2 USE OF THE COMPUTER

About 20 hours a week of Whirlwind time is available to be assigned to outside users for problems of their own which are also of general interest to others. The person proposing the problem is expected to carry through for himself the necessary programming of the problem for solution on the computer. It is for this reason that the elaborate service routines described above are being provided for the Whirlwind computer.

4. 21 Preliminary Procedure

Once the applicant has described his problem concisely, a meeting will be arranged for him with one of the members of the staff of the Digital Computer Laboratory to discuss the details of his problem as it might be put on the Whirlwind computer. During this discussion the applicant and the staff member will attempt to ascertain the feasibility of applying the computer to the problem and will estimate the amount of computer time that would be required to carry out the problem. The applicant will at this time complete a specific written description of his problem in light of the possible use of the computer for solution.

4. 22 Assignment of Time

The description of the problem will be submitted, with a request for assignment of time on Whirlwind, to a time-allocation panel made up of mathematicians and programmers from the Digital Computer Laboratory staff. This panel will meet every two weeks and will assign time to various problems in terms of hours per biweekly period, for periods of no more than ten weeks in advance.

The time required for each run on the computer will be charged against the assignment made to the individual user by the allocation panel. The user will be assured of at least the amount of time assigned to him by the panel during the given biweekly period. Any request for computer time that exceeds the total assigned to him for a given biweekly period will be held in abeyance pending the availability of time assigned to others but not used. It is hoped that a reasonable amount of extra time will be available to most users if they need it. Generally, however, the assignments of time to each problem will be made with the intent that sufficient time be provided for the solution of the problem at hand. If not enough time can be assigned to a problem, that problem, of course, will not be undertaken at all.

In order to assure a fair chance of using the machine to thesis students and others whose work is important but who lack money and priorities, the types of users will be divided into categories (e.g., thesis students, faculty and DIC research, government and industrial research, etc.). Each category will have a portion of the total assignable time set aside for it. Thus, each potential user will be competing only with others in the same category for time assignments.

In the event of disagreement between the applicant and the allocation panel, the MIT Committee on Machine Methods of Computation will be asked to arbitrate and make a recommendation as to whether the problem is suitable for solution on Whirlwind.

There will be relatively little time available for production work involving considerable computation on any one particular problem. The time assigned to any one problem will probably average about one hour per week over a period of no more than ten weeks. A very few problems will be assigned time of the order of a few minutes up to an hour a week for a year in advance where important long-range research depends on the use of the Whirlwind computer. Generally, however, all problems must be reconsidered before they can be allowed to run more than ten weeks.

4. 23 Performance of Programs

Once a program for the solution of a problem has been prepared by the originator, it will be punched on paper tape by the clerical staff associated with the tape-preparation room at the Digital Computer Laboratory. Specially trained computer operators will then supervise the performance of the program on the Whirlwind computer. The programmer himself may or may not be present in the computer room at the time the program is run, but he will not be allowed to operate the computer himself.

4. 24 Location of Mistakes

The location of programming mistakes will be with the aid of the special mistake-diagnosis routines mentioned above. The programmer will be responsible for locating mistakes in his own program, again with the aid if necessary of consultation with members of the Laboratory staff. Each time a mistake is detected and corrected, the program tape will be modified and the modified tape will be rerun on the computer. The calendar time involved in locating mistakes by programmed methods is frequently greater than the time that would be involved in trouble-shooting directly in front of the machine, because of unavoidable delays in getting back on the machine when the trouble has been located. Nonetheless, the total amount of actual computer time and of actual programmer time and skill is usually greatly reduced by programmed mistake-location. The new methods of distributing computer time being put into effect will also greatly speed up the process by eliminating unnecessarily long delays between one attempt of a program and the next. As long as his time assignment has not been exceeded, the programmer will be able to get on the machine with his problem at least as often as once a day.

4.3 PROBLEMS BEING SOLVED

The third quarter of 1952 was broken in the middle by the computer shutdown on August 11. Since that time practically no outside problems have been undertaken. Because of the sweeping changes in procedures, which require considerable computer and staff time, return to normal operation is not expected before November, although the computer returned to almost normal operation in September.

During the first half of the third quarter, the computer operated on a 168-hour-a-week basis for the first time. The time was spent in permitting a number of important problems to be completed before the shutdown. Some of these problems are described briefly in the following paragraphs. Most of them have been described more fully in previous quarterly reports.

Problem #48. Gust Loads on Rigid Airplanes in Two Degress of Freedom

This problem, performed by C.W. Brenner of the MIT Aeroelastic and Structures Research Laboratory as part of a Bureau of Aeronautics contract, has been completed. The gust load equations have been solved for both sharp-edge and graded gusts for approximately 200 values of the parameters. The majority of these gave only the peak values of the airplane acceleration ratio, the wing-load ratio, and tail-load ratio. Fifteen of the more important cases were made to print out complete time histories of these three quantities.

Problem #50. Lattice Analogy Applied to Shear Walls

This problem was first successfully performed on WWI by Mr. G.D. Galletly to verify analytically the static load-deflection curves obtained from laboratory tests on reinforced concrete shear walls. The lattice analogy as used by Galletly is at present the only satisfactory analytical method of handling the shear-wall problem. This method is very tedious for hand computation, and it was found desirable to obtain a large number of solutions with the aid of the Whirlwind computer.

The Structural Dynamics Division of the MIT Department of Civil and Sanitary Engineering now desires to obtain stress-strain curves for a range of representative shear walls in connection with present work on a Blast Resistant Design Manual. A new program has been prepared by Professor Archer using a previous program prepared by Galletly as a guide. Certain features of the old program were revised, such as elimination of hand manipulation of the readout, elimination of certain complex symmetry correction, and provision of greater flexibility with more storage capacity. This program was prepared for the computer before it was shut down on August 11. Professor Archer is now engaged in making the minor program revisions necessitated by the engineering changes in the Whirlwind terminal equipment. Since more time has in the past been spent in printing out the solutions than in solving the problem, other methods of recording the solutions are being considered. No final decision has been reached on the class of readout equipment to be incorporated in the revised program.

Problem #71. Optimum Operation of a Chemical Reactor

During the past quarter, a solution of a chemical reactor problem involving a set of simultaneous non-linear partial differential equations was completed by members of the Polychemicals Division of E. I. duPont de Neymours, Inc. The equations describe a homogeneous chemical reaction carried out under non-isothermal non-adiabatic conditions. Computations were made for approximately 50 sets of parameters representing various reaction conditions. The successful solution of the problem indicates that the method is generally applicable to homogeneous chemical reactions. Ways of obtaining increased rate of production from a chemical plant reactor were indicated.

Problem #79. Tracing Rays Through a Spherical Microwave Lens

Work at the Laboratory for Electronics required optimization of the design of a symmetrical microwave lens to satisfy two requirements. Considering a central section (the intersection by a plane which contains the optical axis), the rays (i.e., normals to the spherical wave fronts) in this plane emanating from a source position exterior to the lens must (1) have approximately the same "path length" and (2) be such that the incidence angles of the final refracted rays on a specified plane are all approximately 90 degrees.

The program used a compact vectorial method (due to Silberstein) of tracing rays through an optical system. A family of pairs of spheres were taken as the spherical interfaces which defined the lens. In this way specifications for the most suitable "spherical" lenses, and for the associated source position, were obtained.

Problem #85. Meteor Computation V

The solution of a set of 15 simultaneous first order non-linear ordinary differential equations was programmed by T.C. Duke of MIT Project Meteor. Four different forms of the equations were considered. In three of the forms considered, three of the dependent variables were determined by use of three bivariate tabular functions. Solutions were obtained in all four cases, but only the one which did not use the bivariate function tables proved to be satisfactory. It is believed that the difficulties in the other three arise from programming mistakes in the part of the program which deals with the external magnetic-tape unit on which the bivariate tables were stored. Unfortunately, the inaccuracies in the solution were not detected until after the computer shutdown in August. During the shutdown these cases were programmed for the IBM equipment at the MIT Office of Statistical Services, but no solution has yet been obtained.

Problem #86. Unsteady Gas Flow Through Porous Media

This problem was carried out in cooperation with the Magnolia Petroleum Company. Solutions were obtained for the non-linear system of equations representing transient gas flow through porous media. These solutions should be of considerable value to the oil industry as an aid in understanding and predicting the behavior of natural gas reservoirs.

The study of this problem resolves itself into the study of non-linear partial differential equations of the parabolic type. The non-linearity enters the problem because the gas viscosity and compressibility are assumed to be functions of the pressure in order to represent properly the conditions that occur in natural gas reservoirs. A four point difference method was used and a suitable time step was chosen to insure numerical stability.

The hypothetical reservoir studied was a flat disc of porous material charged with an initial pressure P_m. The top, bottom, and side boundaries were assumed to be sealed and therefore impervious to gas flow. It was assumed that the well pressure was suddenly lowered to a new value P_o and then held constant at that value. The desired solution of the problem is a description of the pressure distribution throughout the reservoir as a function of time. Families of solutions were obtained by varying the ratio $\frac{P_o}{P_m}$ and the coefficients of viscosity and compressibility of the gas. The concept of a steady-state core surrounding the well bore was introduced to premit the use of a larger effective time step.

Problem #87. Autocorrelation

The need was felt at the MIT Servomechanisms Laboratory for a method for obtaining a frequency spectrum for recorded data to a high degree of resolution and for a wide range of frequencies. This may be accomplished by performing an autocorrelation of the recorded data and taking the Fourier cosine transform of the autocorrelation function thus obtained. The transformed function is the desired frequency spectrum, which gives the relative amplitudes of the component frequencies in the data.

A program has been written which calculates the values of the autocorrelation function of any function represented by a sequence of any given number of values recorded at consecutive, equally spaced time intervals. The autocorrelation function is obtained at 101 equally spaced points corresponding to shifts of 0, 1, . . . , 100 of the chosen time intervals. The ability of the program to handle unlimited data arises from the fact that the computations required to obtain all 101 final values are carried on simultaneously. Data is read in groups of 50 numbers recorded in blocks on standard Flexowriter tape, with blank tape between blocks. After computations are carried out on these 50 numbers, they are discarded and the next block is read in automatically. The final values are accumulated gradually as the process continues. In order to obtain a larger range of the shift variable in the autocorrelation function, the data may be processed three times with the chosen shifts being respectively 1, 3, and 5 times the sampling rate of the original data. The result is then an autocorrelation function defined for the range from 0 to 500 time intervals, defined to a high degree of resolution on the high-frequency end and a lesser degree of resolution for low frequencies. The values of this function are printed and/or punched on tape by the computer. The resulting curve is extremely satisfactory and much above the standards for such curves ordinarily obtained by other methods.

A program for obtaining the Fourier cosine transform has been written which takes the output tape from the autocorrelation program directly and computes the desired frequency spectrum at 101 equally spaced points within any specified range of frequencies. If this range is taken large, the spectrum curve is roughly outlined, and regions of interest may be located. Then, using a small range about the region of frequencies which are of interest, optimum resolution of the spectrum function may be obtained. Results here, too, are far above those obtained by other methods.

The time required for autocorrelation of 4500 data points is about 12 minutes. Including the other two autocorrelation runs and two or three runs of the transform program, a complete frequency spectrum may be obtained in less than one hour, once the data tape has been prepared.

Both programs may be used separately, and the transform program may be easily converted to give the Fourier sine transform.

5. ACADEMIC PROGRAM IN AUTOMATIC COMPUTATION AND NUMERICAL ANALYSIS

5.1 SUMMER SESSION, 1952

A special two-week course of instruction on Digital Computers and Their Applications (Subject 6.539) was held at Massachusetts Institute of Technology from July 21 to August 2, 1952. Applications for this course were considerably heavier than were anticipated, and even though 95 persons were accepted, a number of qualified applicants had to be refused admission. The 95 who attended represented 61 different governmental and industrial organizations. Particularly well represented were aircraft industries, insurance companies, and companies involved in the production and use of digital computing equipment.

The program for the summer session involved two 1-hour lectures each morning of the ten days during which classes met The topics of these lectures are given below:

Introduction to Digital Computers	C. W. Adams
Programming	C. W. Adams
Historical Development of Digital Computers	J. W. Forrester
Number System in Computers	C. W. Adams
Programming	C. W. Adams
Subroutines	D. J. Wheeler
Storage Systems	R. R. Everett
Location of Programming Mistakes	C. W. Adams
Logical Operations	C. W. Adams
Elementary Function Evaluation	F. C. Helwig
Problems of Numerical Analysis	J. D. Porter
Conversion	J. M. Frankovich
Interpretive Mistake-diagnosis Subroutine	D. Combelic
Secondary Storage and Terminal Equipment	C. W. Adams
Matrix Operations	D. G. Aronson
Real-time Applications	C. R. Wieser, D. R. Israel
Other Computers and Systems of Design	C. W. Adams
New Engineering Developments and Trends	N. H. Taylor
Concluding Remarks	C. W. Adams, J. W. Forrester

In the afternoon the class was separated into nine approximately equal sections, with some attempt to put people of similar interests and background together. Ten members of the Digital Computer Laboratory Staff were assigned temporarily as full-time instructors in this course. These instructors met with their respective sections each afternoon for group discussion and individual instruction. Each section was further divided into two groups. Each group, aided when necessary by the instructors, wrote the necessary programs, punched tapes, and performed on the Whirlwind computer three typical (but of course fairly simple) problems which had been assigned. By the third day of the course most of the groups of the class had successfully prepared and operated their first program on the Whirlwind computer.

To facilitate the process of teaching the elements of coding to such a varied group of students, a simplified version of the Whirlwind I instruction code was employed throughout the course. Specially designed modifications of the standard service routines then available were used to permit introduction of decimal and alphabetical information into the Whirlwind computer and to facilitate the location of programming mistakes in the programs which the students had prepared.

The first problem which the students solved was the generation of values of a seventh degree polynomial for successive values of x. The results were displayed in graphical form on the oscilloscope equipment associated with the Whirlwind computer. The second problem involved the solution by elementary numerical means of the differential equations of motion of a ball bouncing on a horizontal surface. The third problem, which was intended to exemplify the application of digital computers to business problems, was a fairly complete but simplified payroll problem.

All of the necessary payroll information was processed automatically starting with a hypothetical time clock which perforated its own paper tape. This tape could then be read directly into the computer.

While the diversity of background of the many students in the course made it difficult to provide instruction that was of uniform interest to all, this same diversity added to the success of the course by providing a stimulating interchange of ideas among students and instructors alike, with many various phases of computer applications and developmental work being well represented among the students and instructors.

5.2 FALL TERM, 1952

The academic program offered at MIT in Digital Computation and related fields includes a number of graduate subjects offered in the regular fall and spring terms. Among the fall term subjects is an Introduction to Digital Computer Coding and Logic (Subject 6.535) now being taught by Professor Charles W. Adams of the Digital Computer Laboratory, who supervised the summer session described above. Registration of 32 students and several listeners for this subject is considerably higher than it has been in the past. The subject matter in the course has changed continuously from year to year since its inception five years ago. It is being taught this year from lectures and printed notes with somewhat more continuity than those which have been provided in the past.

Another course being offered at MIT, entitled Switching Circuits (Subject 6.567) involves Boolean algebra applied to logical circuit synthesis. This is being taught by Professor Samuel H. Caldwell, using notes of his own in conjunction with the Bell Telephone Laboratories and the Harvard Computation Laboratory texts on the subject. Thirty-three students have registered for this subject, a great increase over last year's registration.

Numerical Analysis (Subject M411) is being offered for the first time by the Department of Mathematics under Professor Francis B. Hildebrand. While a similar program was formerly offered under the Department of Electrical Engineering (Subject 6.531) this represents the first course in numerical analysis to be offered by the MIT Mathematics Department. Thirteen students have registered for this new course.

6. APPENDIX

6.1 REPORTS AND PUBLICATIONS

Project Whirlwind technical reports and memorandums are routinely distributed to only a restricted group who are known to have a particular interest in the Project. Other people who need information on specific phases of the work may obtain copies of individual reports by making requests to John C. Proctor, Digital Computer Laboratory, 211 Massachusetts Avenue, Cambridge 39, Massachusetts.

The following reports and memorandums were among those issued during the third quarter of 1952.

No.	Title	No. of Pages	Date	Author
SR-30	Summary Report No. 30, Second Quarter 1952	24		
E-466	Operation of the In-Out Element	34	7-15-52	E.S. Rich
E-469	Visual Display Facilities in the Final WWI Input-Output System	13	8-5-52	J. Forgie
E-472	The Mirror: A Proposed Simplified Symbol for Magnetic Circuits	3	8-13-52	R.P. Mayer
E-473	Input Program, September, 1952	4	8-21-52	C.W. Adams
E-479	Basic Conversion Program, Sept., 1952	4	9-4-52	M. Rotenberg
E-481	Toggle Switch Inputs and Indicator Light Outputs as External Units	8	9-17-52	G.A. Young
E-482	Operation of Magnetic Tape Units	7	9-11-52	B.E. Morriss
M-1548	Use of Whirlwind I by Industrial Organizations	4	7-7-52	C.W. Adams
M-1551	Initial Operation of WWI Terminal Equipment with the New In-Out System	11	7-17-52	F.E. Heart
M-1555	A Three-Megacycle Transistor Flip-Flop	2	7-9-52	A.W. Heineck
M-1624	Short Guide to Coding and Whirlwind I Operation Code	13	9-2-52	P. Bagley
M-1649	Proposed New Order so, Subtract One	2	9-24-52	J.H. Hughes

6.2 PROFESSIONAL SOCIETY PAPERS

R. R. Everett's paper "The Digital Computer," which was delivered at the joint AIEE-IRE Computer Conference, Philadelphia, December 1951, was published in the August 1952 Electrical Engineering.