PROJECT WHIRLWIND

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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)

During the last quarter of 1952 the computer was assigned to applications work for 515 hours, of which 83 percent yielded useful results.

The test equipment in the computer test control has been largely replaced by permanent WWI panels, increasing the convenience and reliability of the system.

Installation of the new input-output system has been completed, operating characteristics have been checked, and the new order code put into use. Further changes in the in-out system are being made to accommodate magnetic-drum equipment. The magnetic-tape system has given some trouble from noise in the switching circuits and from the tape drive mechanism, but these difficulties have been largely eliminated.

The addition of an ion-collector plate to the Whirlwind storage tubes has substantially increased the reliability of storage. Research continues on the maintenance of uniform spacing between the storage-tube collector screen and the storage surface proper, and on the Philips type "L" cathodes.

This report contains a summary of data on the life of vacuum tubes used in the computer since it started operation in December 1948. Failure rates for the principal types have settled down to consistent levels, so that it is possible to predict the number of failures of a given tube type in a given type of service. The very small number of heater burn-outs may be attributable to the practice of cycling the heater voltage on and off over a 5-minute period. Life tests of vacuum tubes have been started again, and a new testing device is being used for the detection of intermittents. Work on the problem of cathode interface impedance continues.

A new and more flexible system has been developed for getting programs into the computer and getting solutions out. Known as the Comprehensive System, it provides for conversion by the computer from Flexowriter-coded perforated tapes to tapes in pure binary-coded form, as well as other automatic selection and conversion schemes. Although the number of outside users of the computer has been temporarily reduced by changes in the computer and procedures, fifteen widely diverse problems on which the computer has been used are described in Section 4.2 of this report.

2. OPERATION OF WHIRLWIND I

During the period of 1 September through 1 December, a total of 515 hours of computer time was assigned to the applications groups. Operation of the computer during these 515 hours resulted in a reliability figure of 83 percent.

2.1 TEST CONTROL

The computer test control has been substantially revised during the past quarter. Most of the test equipment in test control has been replaced with permanent WWI panels which include marginal-checking facilities for maintenance of higher reliability. In addition, many of the switches used to control the course of a program have been replaced by push buttons, so that it is now impossible accidentally to leave control switches in the wrong position. A new erase system for electrostatic storage no longer depends upon test equipment for operation. Now the Whirlwind panel "ES Erase Control" uses the facilities of the new input-output system to count the delays required in erasing the surface of the storage tubes.

2.2 IN-OUT SYSTEM

Installation of the new in-out control system has been completed. All pulse amplitudes and other operating characteristics have been checked and some modifications made to increase the reliability of operation. Marginal-checking facilities and programs have been worked out so that routine maintenance of the new in-out system is integrated with automatic marginal checking. Since the new in-out system has resulted in a change of the order code of WWI, marginal-checking programs have been rewritten and the variety of programs increased.

The present in-out system includes the following facilities: three 16-inch and three 5-inch display scopes, one automatic scope camera, three output typewriters, one paper-tape punch, one mechanical paper-tape reader, one photoelectric paper-tape reader, and three magnetic-tape units. The new Flexowriter units now in operation combine, in one package, the functions of an automatic typewriter, a paper punch, and a mechanical paper-tape reader. Two more photoelectric tape readers which will operate at higher speed than the present one have been ordered; delivery of these units is expected in February or March.

2.21 Magnetic-Drum Equipment

At present, changes and additions are being made to the in-out system to accommodate the magnetic-drum equipment. Two magnetic-drum systems are being built for Whirlwind I - an auxiliary storage drum and a buffer storage drum. The manufacturer has completed the construction and preliminary tests on the auxiliary drum system; delivery was made during the second week of December.

It appears that there are several potentially troublesome features in the drum system - the switching relays have given contact troubles, and in addition there has been difficulty with cross-talk. A lengthy testing period is planned before the drum system is slated for use by the applications groups.

2.22 Display System

Some changes are expected to be made in the display system during the next period. A new deflection yoke tested on the 16-inch scopes has been found to produce much less distortion than the previous type. Noise in the deflection system has caused distortion in the plotting of very small letters and figures on the scopes. The exact source of the noise has not been determined, but it appears to be power supply and 60-cycle noise accumulated in the different components of the system. The difference in ground potential between the various points in the system probably aggravates it. The design of a better system will be investigated during this next period. The display system now has available 16 intensification lines, which enormously increase the flexibility of the display system.

2.23 Magnetic-Tape System

The new magnetic-tape system has not operated quite as well as had been expected. The difficulty stemmed from two causes - from the tape drive mechanism and from noise in the electronic switching circuits. The trouble in the drive mechanism was found to be improper tracking of the tape on the head during periods of acceleration and deceleration. The incorporation of several tape drive units into the new magnetic-tape system made the circuit adjustments much more critical than for any one of the drive units. The noise in the amplifiers has been difficult to deal with because of its occasional nature. Errorless runs of several hours are the rule rather than the exception, but occasionally an extra pulse appears. Several noise sources, such as intermittent connections and noisy tubes, have been found and eliminated. Testing continues whenever computer time is available.

The magnetic-tape installation consisting of three magnetic-tape drive units is shown in Fig. 2-3. The tape unit in the left-hand rack is connected to the computer. The contacts for the two units in the right-hand rack pass through a multi-pole double-throw switch on the upper left-hand panel so that one unit is always under control of the computer while the other is connected to the automatic print-out equipment. The preliminary model of the automatic print-out equipment is shown in the rack on the extreme right.

Fig. 2-1. Storage tube ion collector plate.

2.3 ELECTROSTATIC STORAGE

Toward the end of this quarter the reliability of electrostatic storage was increased substantially. A spare digit column was installed which can be cabled in as a replacement for any storage digit column which is not operating reliably.

2.31 Ion Deflection-Shift

An ion-collector plate has been added to the Whirlwind storage tube to eliminate the ion deflection-shift described in the last report. This shift occurs when the reading and writing beams go to different points of the storage surface because of an ion space charge which has a different density during reading and writing. The storage tube group has found that an electrode having a rather large area and operated at the potential of the holding-gun cathode is able to collect positive ions formed within the tube. This collection process proceeds rapidly enough so that an ion cloud is not allowed to build up to a sufficient density to deflect the read-write beam. Figs. 2-1 and 2-2 show two views of the ion-collector plate which is being installed in storage tubes. In Fig. 2-1, the holding-gun second anode is directly in the center of the tube; the large plate which is physically mounted on the second anode, but insulated from it, is the ion-collector plate. The ion plate is supported from the back wall of the

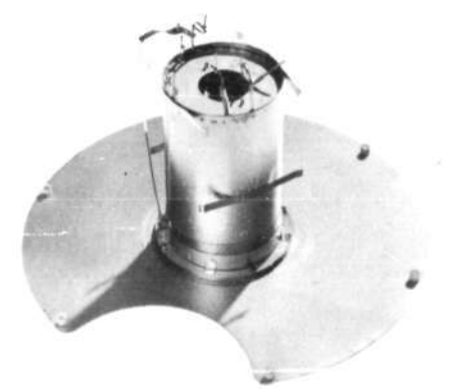

Fig. 2-2. Storage tube ion collector plate.

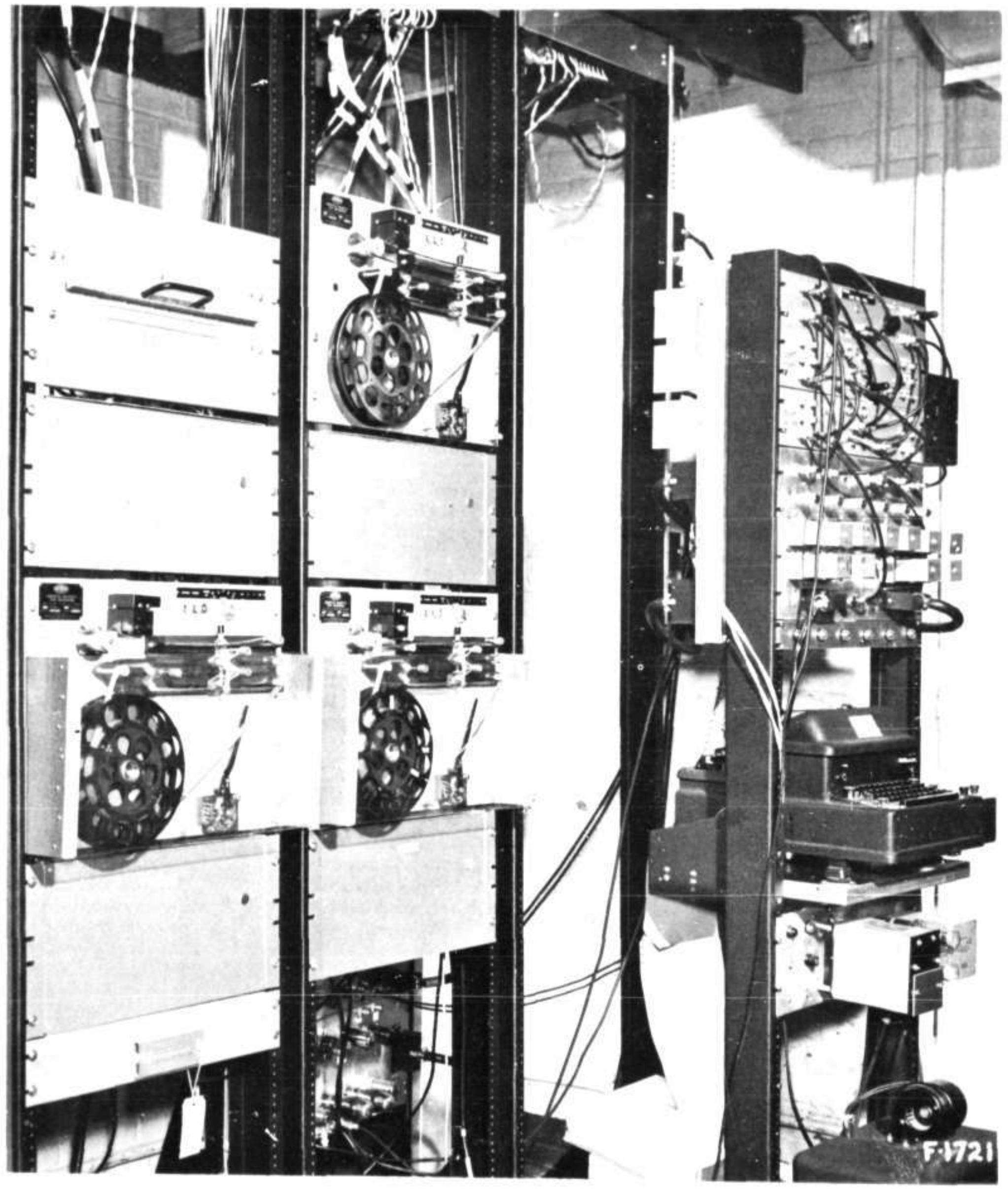

Fig. 2-3. Magnetic-tape installation.

tube by six ceramic posts. In Fig. 2-2, the holding-gun assembly has been removed from the tube, and details of the new ion plate construction are clearly visible. The installation of this ion plate posed somewhat of a problem, since it was desirable to seal the holding gun into the tube after the target had been installed and after the body seal in the middle of the tube had been completed. Consequently, the ion plate is set into the tube and held loosely with wires running in the holding-gun neck. After the body seal has been made and the read-write gun sealed into the tube, the holding gun is inserted in its neck. Then the four screws which hold the ion-collector plate to the second anode cylinder are inserted with a small screwdriver.

At the end of this quarterly period, six ion-collector tubes (700-series) were operating in the computer. The eleven 600-series tubes still in the computer will be replaced as new tubes become available. Since the introduction of the ion-collector plate constitutes a rather radical change in the design, we must gain operating experience with these tubes before we feel confident about going into exclusive production of this type. So far no consistent trouble has been apparent with the new tubes. However, two of the tubes did exhibit an unexplained shift in the holding voltage required for stable storage. Tubes operating with holding-gun currents from 5 to 10 times greater than those used in 600-series tubes have shown no traces of ion deflection-shift.

2.32 Spacing Between Collector Screen and Storage Surface

Fig. 2-4 provides data on the life of all the storage tubes that operated in WWI during the fourth quarter of 1952. The left-hand bar graph shows the hours of operation to date of the 17 tubes in the computer at the end of the quarter. The right-hand graph shows the hours of operation at the time of failure for the 17 tubes that failed during the quarter. The "failures" include tubes that still had satisfactory operating margins but that were removed to make way for the installation of new 700-series tubes.

One of the most critical aspects of our storage tube assembly is that of maintaining a uniform spacing between the collector screen and the storage surface proper. For satisfactory operation, it has been found that this spacing must be no greater than 0.005 inch. Similarly, it has been observed in several tubes that if this spacing is less than 0.004 inch, the electrostatic force of attraction which exists when the collector screen and storage surface are 100 volts apart is sufficient to cause the collector screen to be deformed so that it touches the storage surface. Contributing to this problem is a slight amount of buckling of the 0.005-inch-thick mica target which probably occurs when the tube is processed. Several research tubes have been made to investigate various methods of improving the uniformity of the spacing

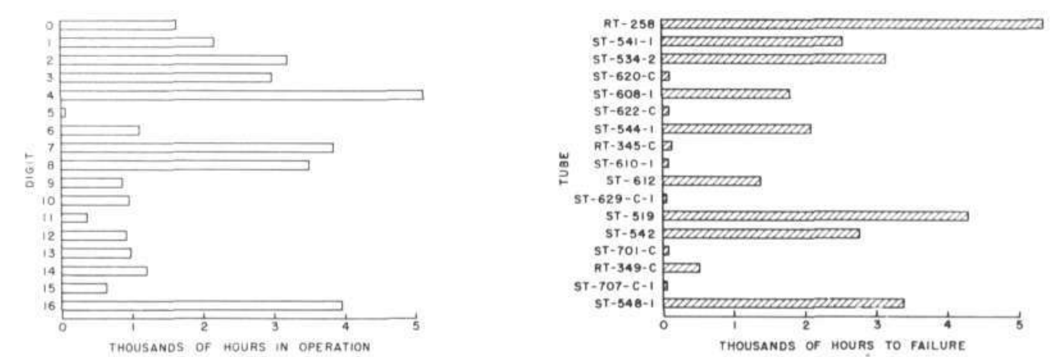

Fig. 2-4. Life of storage tubes in WWI.

without the danger of the collector screen touching the storage surface in some area normally used for storing spots.

2.33 Philips Type "L" Cathodes

The research work concerning activation and processing problems associated with Philips type "L" cathodes is progressing satisfactorily. Approximately twenty tubes have been constructed all of which activated properly, and several Philips cathodes have been installed in reprocessed storage tubes which were rejected for computer use. None of the Philips cathode tubes have yet seen service in the computer; however, one of these tubes is still operating normally after more than 500 hours of computer-type use. The problem which we are studying currently is that of reducing the transconductance of the read-write gun assembly in order to obtain a cut-off characteristic similar to that of the guns presently in use. This characteristic is largely determined by the spacing between the cathode and the grid aperture. It is much more difficult to maintain close spacings with the Philips cathode because of the higher-temperature operation and the attendant expansion of the grid-cathode assembly.

2.34 Relocation of Storage Registers

The storage tube deflection-decoder characteristics were modified in WWI to produce a higher degree of storage reliability. Prior to this change, consecutively numbered registers in storage were located adjacent to each other on the surfaces of the tubes. For normal programs, this resulted in operation at a number of registers in a small area with little holding-gun stabilization time between operations. The storage decoders were reconnected so that consecutively numbered registers are not adjacent to each other and, in fact, are located in such a way that counting through the registers in sequence results in a deflection pattern which is evenly spaced in time over the whole surface. This has appreciably lessened interaction between spots and has reduced the number of storage alarms (errors) by a factor of about 4.

3. CIRCUITS AND COMPONENTS

3.1 VACUUM TUBES

3.11 Vacuum-tube Life

As of December 31, 1952, Whirlwind I power had been on for 15,891 hours since December, 1948. Of this total time, 6390 hours were accumulated during 1952, and 1632 during this past quarter. It seems appropriate at this time to present information on all tube failures in WWI both during this past year (Fig. 3-2) and also since operation began (Fig. 3-3), in addition to the usual summary of failures for the past quarter (Fig. 3-1).

During the past several months an effort has been made to determine counts for all tube types in WWI. The "total in service" figures in the following tables are more precise than those given in previous summary reports.

It is interesting to examine the relative failure rates of the three principal tube types in WWI, as has been done in the previous summary reports for this year. This information is given below:

changed, whereas the physical totals did not change for this type.

The number of failures during the past year is great enough for many tube types to obtain some idea of the failure rates. These have been calculated for those types with sufficient data and for which the number in service did not change appreciably during the past year. In percent per 1000 hours, the failure rate for the OD3 is 6; C16J, 18; 3E29 and 829B, 2.9; 5U4G, 17; 6AG7, 2; 6AK5, 2.8; 6AL5, 0.4; 6AS7G, 1.8; 6L6G/GA, 3.8; 6Y6G, 0.75; and 715B/C, 13.

As failure rates are very much dependent upon the circuits in which tubes are used as well as the life end-points, the above figures must be considered typical only for WWI as it has been operated during 1952. They can not be applied further unless knowledge is available concerning the exact operating conditions. For example, the failure rate of 6AG7 tubes during the past year was 2 percent per 1000 hours, whereas the stable failure rate for 7AD7 tubes seems to be near 3 percent per 1000 hours. From these figures it might be inferred that the 6AG7 is superior to the 7AD7. This is not necessarily the case, since the majority of 7AD7 failures occur in flip-flops, a circuit in which the 6AG7 is not used. Qualitative observations indicate that life of 7AD7 tubes is superior to that of 6AG7 tubes used in similar circuits.

	Failure Rate, Percent per 1000 Hours				
Tube Type	To August 1951	First Quarter 1952	Second Quarter 1952	Third Quarter 1952	Fourth Quarter 1952
7AD7	3.4	1.0	1.8	2.3	2.5
7AK7	0.4	0.06	0.3	0.3	0.3
6SN7GT	0.9	2.25	0.7	0.9	0.9

Perhaps the most unusual thing about these data is the consistency of the 6SN7GT and 7AK7 rates. These tube types have 5 to 10 failures during a quarter on the average. Such events follow a Poisson distribution, which means that the expected standard deviation of the number of events is approximately the square root of the observed number of events. In general, the fluctuations seldom exceed the expected statistical variations.

Following the change in checking procedure for WWI flip-flops (described in Summary Report 29), the 7AD7 failure rate declined sharply, as indicated by the rate in the first quarter of 1952. Since then the rate has been climbing again. At the present time the rate seems to be quite stable, as the change between the third and fourth quarters can be accounted for by the change in the "totals in service" figures used to calculate the rates. As mentioned above, the figures

The rather high failure rates of C16J and 5U4G rectifiers are perhaps causes for concern. The smaller xenon-filled rectifiers and vacuum rectifiers, which are probably operated more conservatively, have somewhat lower failure rates. However, there is a bank of 8008 mercury-vapor rectifiers, six in all, which has had no failures reported in the more than 10,000 hours it has operated. It would seem that either mercury-vapor rectifiers or perhaps selenium-plate rectifiers would be more satisfactory than vacuum or xenon-filled rectifiers when high reliability and low maintenance are important, provided that suitable means for regulation are available.

Figure 3-3, the complete summary of vacuum tube failures in WWI, is presented primarily as a reference to those persons who are concerned with failure patterns of vacuum tubes in digital computers. There is a vast amount of information in this table, too much to digest easily. There are certain salient points, however, which deserve comment.

It will be observed that there are very few heater burn-out failures for any of the tube types used in WWI except the 2C51. In the case of the 2C51, some of these burn-outs may be attributed to circuit troubles, when another failure in the circuit applied excessive heater-cathode voltage. The low rate of failure from heater burn-out has been attributed to the practice of cycling the heater voltage on and off with a linear variation over a 5-minute period. Unfortunately, there is no data on a machine of similar size, with the same tube types from equivalent lots, operated with no heater cycling. In the absense of a control, conclusions are quite risky; however, it seems safe to say that cycling is definitely not injurious and may be quite beneficial. It is important to add that all heater voltages are regulated to 0.1 volt (for 6.3-volt heaters) at the socket in the computer proper. The same sort of regulation is practiced in some (but not all) power supplies.

Various tube types seem to show individual failure patterns. For example, the 7AD7 shows a peak rate of failure between 2000 and 3000 hours, with lower rates both before and afterward. Changes in characteristics, primarily low plate current and shifts in cutoff, are about twice as prevalent as mechanical causes, which include breakage as well as tap, flicker, and dead shorts. For the 7AK7 the first 1000 hours is the bugaboo, with many more failures there than in any other 1000-hour interval. Also, mechanical failures, principally various shorts, with some opens and breakage, constitute more than two-thirds the total failures of 7AK7 tubes. For the 6SN7GT the two chief causes of failure are about even.

A large number of 6AK5's failed between 10,000 and 11,000 hours. This peak is artificial, since these failures were found on routine retest when the 6AK5's were being tested prior to being replaced by 5654's. The high rate for the 6AS7GT during the first 1000 hours is attributable to one lot of these tubes which suffered very badly from flaking of the cathode coating. The large number of 715B/C tubes failing between 8000 and 9000 hours is a result of a cathode instability which develops about this time, making them unsuited for the precision d-c amplifier service which is their main use in WWI.

An additional classification of failures will be found in Fig. 3-1 for this quarter. In-

Type	Total in Service	Hours at Failure	Reason for failure; number failed: Change in Characteristics	Breakage	Shorts and Opens	Burn-out	Gassy
7AD7	2030	0-1000	3		1		
		1000-2000	2				
		2000-3000	2		1		
		3000-4000	4				
		4000-5000	1	1	1		2
		5000-6000	3	1	2		1
		6000-7000	6		1		1
		7000-8000	4		2		
		8000-9000	4				
		9000-10000	5	2	1		
		10000-11000	2				1
		11000-12000	2		1		
		12000-13000	1	1			1
		13000-14000	9	2			
		14000-15000	7		4		
7AK7	1764	3000-4000	1				
		13000-14000	2		1		
		14000-15000	1	1	1		
		15000-16000			1		
6SN7GT	422	5000-6000			1		
		13000-14000			1		
		14000-15000	1		2		
		15000-16000	1				
OA2	19	12000-13000	2				
OD3/VR150	24	5000-6000	1				
		7000-8000	1				
		12000-13000	1				
C3J	18	15000-16000	1				
C6J	4	0-1000	1				
		14000-15000	1				
C16J	12	6000-7000	2				
		9000-10000	1				
2C51 5670	58	0-1000		7			1
2D21	54	4000-5000	1				
3B24W	6	0-1000		1			
3D21A	4	10000-11000					1
3E29 829B	209	6000-7000	3		4		
		10000-11000	1				
		11000-12000	1				
		12000-13000		1	1		
		13000-14000					1
		14000-15000	1		1		
5U4G	17	5000-6000	1		2		
		6000-7000	1				1
		11000-12000					1
5Y3GT	9	6000-7000	1				
		10000-11000	1				1
6AC7	7	12000-13000					1
6AG7	126	5000-6000	1				
		10000-11000	5				
		12000-13000	1				
6AK5	204	5000-6000	4				
		6000-7000			2		
		8000-9000			1		
		10000-11000	15		10		
6AL5	249	5000-6000	1	1			
		6000-7000	1				
		9000-10000	2				
		10000-11000	6				
6AN5	20	3000-4000					1
		4000-5000	1				
6AS6	3	10000-11000	1				
6AS7G	194	0-1000			1		
		6000-7000					1
		9000-10000	3				
		11000-12000		2			
6L6G 6L6GA	77	3000-4000	1				
		4000-5000	2				
		6000-7000	1	2			
		7000-8000	1				
		9000-10000	1				
		14000-15000	8				
		15000-16000	2				
6SH7	3	4000-5000	2				
6SL7GT	12	7000-8000	1				
6V6GT	38	6000-7000	2				
6X4	10	6000-7000					1
6X5GT	7	4000-5000		1			
		11000-12000	1				
		14000-15000	2				
6Y6G	319	0-1000			1		
		2000-3000					1
		14000-15000		1			2
12AY7	39	0-1000	3				1
715B 715C	30	0-1000	1				
5651	14	14000-15000	1				
5687	85	0-1000		1			
5963	42	1000-2000			1		

Fig. 3-1. Tube failures in WWI October 1 - December 31, 1952.

Type	Total in Service	Hours at Failure	Reason for failure; number failed: Change in Characteristics	Mechanical	Burn-out	Gassy
7AD7	2030	0-1000	6	4		1
		1000-2000	6	2		
		2000-3000	10	5		
		3000-4000	14	6		
		4000-5000	15	6		2
		5000-6000	11	4		1
		6000-7000	16	4		1
		7000-8000	13	4		
		8000-9000	13	2		
		9000-10000	12	9		
		10000-11000	22	9		1
		11000-12000	7	3		
		12000-13000	11	8		2
		13000-14000	17	6		
		14000-15000	7	4		
7AK7	1764	0-1000		3		
		3000-4000	1			
		6000-7000	1			
		7000-8000		2		
		9000-10000	1			
		10000-11000		7		
		11000-12000		2		
		12000-13000		1		
		13000-14000	2	3		
		14000-15000	1	2		
		15000-16000		1		
6SN7GT	428	2000-3000	1			
		3000-4000	3			
		4000-5000		1		
		5000-6000	1	2		
		6000-7000	2			
		8000-9000	4			
		10000-11000		1	1	
		11000-12000	1	1	1	
		12000-13000	1	3		
		13000-14000		2		
		14000-15000	1	2		
		15000-16000	1			
OA2	19	12000-13000	2			
OD3/VR150	24	0-1000	2			
		5000-6000	2			
		6000-7000	1			
		7000-8000	2			
		12000-13000	2			
C3J	18	15000-16000	1			
C6J	4	0-1000	1			
		14000-15000	1			
C16J	12	1000-2000	2			
		2000-3000	1			
		3000-4000	2			
		4000-5000	1			
		5000-6000	1			
		6000-7000	3			
		7000-8000	3			
		9000-10000	1			
2C51 5670	39 19	0-1000		7		1
		1000-2000			1	
		2000-3000		2		
		5000-6000			2	
		8000-9000			2	
		10000-11000	2			
2D21	54	4000-5000	1			
		9000-10000	1			
		10000-11000	1			
3B24W	6	0-1000		1		
3C	2	4-5000	1			
3D21A	4	0-1000	1			
		3000-4000		1		
		10000-11000				1
3E29 829B	209	0-1000	2	1		4
		2000-3000	2			
		3000-4000	7			
		4000-5000	2			
		5000-6000	1			
		6000-7000	3	4		
		10000-11000	4			
		11000-12000	1			1
		12000-13000		2		1
		13000-14000		1		1
		14000-15000	1	1		
5U4G	17	0-1000	4			
		4000-5000	1			
		5000-6000	3	2		
		6000-7000	2	1		1
		7000-8000			3	1
		11000-12000				1

Type	Total in Service	Hours at Failure	Reason for failure; number failed: Change in Characteristics	Mechanical	Burn-out	Gassy
5Y3GT	9	6000-7000	1			
		10000-11000	1			1
6AC7	7	6000-7000				1
		10000-11000			1	
		11000-12000			1	
		12000-13000				1
6AG7	126	0-1000	2			
		1000-2000		1		
		4000-5000	1			
		5000-6000	1			
		9000-10000	1			
		10000-11000	5			
		11000-12000	1			1
		12000-13000	3			
6AK5	204	2000-3000	1	2		2
		5000-6000	4			
		6000-7000		2		
		8000-9000		1		
		10000-11000	15	10		
6AL5	249	1000-2000		1		
		2000-3000	1	1		
		4000-5000	2			
		8000-9000		*2		
6AN5	20	3000-4000				1
		4000-5000	1			
6AS6	3	10000-11000	1			
6AS7G	194	0-1000		7		
		1000-2000	1	3		
		3000-4000	1	3		
		6000-7000				1
		9000-10000	3			
		11000-12000		2		
		12000-13000	1			
6AU6	8	4000-5000	1			
6J5	5	6000-7000	1			
		11000-12000	1			
6L6G/GA	115	0-1000			2	
		3000-4000	3			
		4000-5000	2			
		6000-7000	2	2		
		7000-8000	1			
		9000-10000	1			
		13000-14000	4	1		
		14000-15000	8			
		15000-16000	2			
6SH7	3	4000-5000	2			
6SL7GT	12	7000-8000	1			
6V6GT	38	6000-7000	2			
		13000-14000	1			
6X4	10	0-1000	1			
		6000-7000				1
6X5GT	7	4000-5000		1		
		11000-12000	1			
		14000-15000	2			
6Y6G	319	0-1000		2		
		2000-3000				1
		4000-5000	1			
		10000-11000		1		
		11000-12000	2	1	1	
		12000-13000	2			1
		14000-15000		1		2
715B 715C	36	0-1000	2	2		
		1000-2000	3	1		
		2000-3000	2	1	1	
		3000-4000	2			1
		5000-6000			1	
		8000-9000	12			1
12AY7	39	0-1000	4			
5651	14	0-1000	2			
		14000-15000	1			
5687	85	0-1000		2		
5963	42	1000-2000		1		

Fig. 3-2. Tube failures in WWI January 1 - December 31, 1952.

Type	Total in Service	Hours at Failure	Reason for failure; number failed			
			Change in Characteristics	Mechanical	Burn-out	Gassy
7AD7	2030	0-1000	44	25	1	6
		1000-2000	61	25		1
		2000-3000	77	30		
		3000-4000	48	31		1
		4000-5000	63	25		6
		5000-6000	31	30		3
		6000-7000	34	18		1
		7000-8000	26	12		
		8000-9000	17	5		1
		9000-10000	13	9		
		10000-11000	22	9		1
		11000-12000	7	3		
		12000-13000	11	8		2
		13000-14000	17	6		
		14000-15000	7	4		
7AK7	1764	0-1000	5	12		
		1000-2000	2	3		
		2000-3000		3		1
		3000-4000	2	1		
		4000-5000		4		
		5000-6000	1	2		
		6000-7000	2	2	1	
		7000-8000		8		
		8000-9000	1			
		9000-10000	1			
		10000-11000		7		
		11000-12000		2		
		12000-13000		1		
		13000-14000	2	3		
		14000-15000	1	2		
		15000-16000		1		
6SN7GT	428	0-1000	3	4		
		1000-2000			1	
		2000-3000	4	3		
		3000-4000	4	2		
		4000-5000	1	2		1
		5000-6000	3	5		1
		6000-7000	7			
		7000-8000	2	5		
		8000-9000	5			
		10000-11000		1	1	
		11000-12000	1	1	1	
		12000-13000	1	3		
		13000-14000		2		
		14000-15000	1	2		
		15000-16000	1			
OA2	19	8000-9000	1			
		12000-13000	2			
OD3/VR150	24	0-1000	2			
		1000-2000	1			
		2000-3000	2			
		4000-5000	1			
		5000-6000	2			
		6000-7000	1			
		7000-8000	2			
		8000-9000		1		
		12000-13000	2			
C3J	18	6000-7000	1			
		7000-8000		1		
		15000-16000	1			
C6J	4	0-1000	1			
		14000-15000	1			
C16J	12	1000-2000	2			
		2000-3000	1			
		3000-4000	3	1		
		4000-5000	4			
		5000-6000	1			
		6000-7000	3			
		7000-8000	3	1		
		9000-10000	1			
2C51 5670	39 19	0-1000	3	8	1	1
		1000-2000			2	
		2000-3000		2		
		3000-4000			1	
		5000-6000			2	
		8000-9000	1		2	
		10000-11000	2			
2D21	54	1000-2000		1		
		2000-3000		1		
		4000-5000	1			
		9000-10000	1			
		10000-11000	1			
3B24W	6	0-1000		1		
3C	2	1000-2000	1			
		3000-4000	1			
		4000-5000	1			
3D21A	4	0-1000	1			
		3000-4000		1		
		4000-5000	1			
		10000-11000				1
3K29 829B	209	0-1000	4	4		9
		1000-2000	1			
		2000-3000	10	2		
		3000-4000	9			
		4000-5000	16	1		
		5000-6000	3			
		6000-7000	5	5		
		7000-8000	1	1		
		8000-9000	6			
		10000-11000	4			
		11000-12000	1			1
		12000-13000		2		1
		13000-14000		1		1
		14000-15000	1	1		
5U4G	17	0-1000	6			
		1000-2000	3			
		3000-4000		1		1
		4000-5000	3			
		5000-6000	5	2		
		6000-7000	2	1		1
		7000-8000			3	1
		11000-12000				1
5Y3GT	9	5000-6000		1		
		6000-7000	1			1
		10000-11000	1			1
6AC7	7	6000-7000				1
		10000-11000			1	
		11000-12000			1	
		12000-13000				1
6AG7	126	0-1000	4			
		1000-2000		1		
		2000-3000	1			
		3000-4000	4	1		
		4000-5000	6			
		5000-6000	1			
		9000-10000	1			
		10000-11000	5			
		11000-12000	1			1
		12000-13000	3			
6AH6	7	4000-5000	1			
6AK5	204	0-1000				1
		1000-2000		2		
		2000-3000	1	2		2
		4000-5000	3	2		
		5000-6000	4			
		6000-7000		2		
		8000-9000		1		
		10000-11000	15	10		
6AL5	249	1000-2000		1		
		2000-3000	2	2		
		3000-4000	2	1		
		4000-5000	4			
		8000-9000		2		
6AN5	20	3000-4000				1
		4000-5000	1			
		6000-7000	1			
		7000-8000		1		
6AS6	3	10000-11000	1			
6AS7G	194	0-1000	12	7		
		1000-2000	1	3		
		2000-3000	2			
		3000-4000	1	4		
		6000-7000				1
		7000-8000	3			
		9000-10000	3			
		11000-12000		2		
		12000-13000	1			
6AU7	8	4000-5000	1			
6J5	5	3000-4000		1		
		6000-7000	1			
		11000-12000	1			
6L6G/GA	115	0-1000	2	1	2	
		1000-2000	3			
		2000-3000	1	1	1	
		3000-4000	3			
		4000-5000	3			
		6000-7000	3	2		
		7000-8000	1			
		9000-10000	1			
		13000-14000	4	1		
		14000-15000	8			
		15000-16000	2			
6SH7	3	1000-2000		1		
		4000-5000	2			
6SL7	12	7000-8000	1			
		8000-9000	1			
6V6GT	38	2000-3000	2			
		3000-4000	2			
		6000-7000	2			
		8000-9000	1			
		13000-14000	1			
6X4	10	0-1000	2	1		
		6000-7000				1
6X5GT	7	3000-4000	1			
		4000-5000		1		
		7000-8000	2			
		11000-12000	1			
		14000-15000	2			
6Y6G	319	0-1000		4		
		1000-2000		1		1
		2000-3000	7	1		1
		3000-4000		4		
		4000-5000	6	2		
		5000-6000				1
		10000-11000		1		
		11000-12000	2	1	1	
		12000-13000	2	1		
		14000-15000		1		2
715B 715C	36	0-1000	2	3	1	
		1000-2000	3	1		
		2000-3000	2	1	1	
		3000-4000	2			1
		5000-6000	2	1	3	2
		8000-9000	12			1
12AY7	39	0-1000	4			
5651	14	0-1000	2			
		4000-5000	1			
		8000-9000	1			
		14000-15000	1			
5687	85	0-1000		2		
5963	42	1000-2000		1		

Fig. 3-3. Tube failures in WWI
December 1948 to December 31, 1952

stead of lumping breakage with shorts and opens into "mechanical," two categories are used. The object is to present more information in a usable form. Because the report for 1952 and the complete history of failures were derived from earlier summary reports, the old "mechanical" category is used in them.

The five-digit multiplier has now completed 38,000 hours and has been removed from service. Tube records were kept over its life, even though it has not been on a reliability run for the last year. Tube life information was last reported in Summary Report 27, for the third quarter of 1951. A plot of survival experience is given in Fig. 3-4. This figure was derived from data calculated as described in R-179 and SR-22. The survival curve for the 7AK7 tubes follows very closely the curves given previously; however, the curves for 7AD7 and 6AS7 tubes lie well below those given previously. Curves for both 7AD7 and 7AK7 tubes lie well below curves following the nominal failure rates for these types in WWI, shown superposed as 0.4 percent per 1000 hours (7AK7 in WWI) and 3.0 percent per 1000 hours (7AD7 in WWI).

It is interesting to note that beyond 10,000 hours the multiplier curves parallel approximately the WWI rate curves.

The sharp break in the 6AS6 curve at 10,000 hours is also somewhat inexplicable, but it is known that much of the poor experience with the 6AS6 was caused by the checking circuits which required selected high-plate tubes in order to operate at all. All in all, the nature of the curves can be explained at least partially by assuming that the overall survival is the sum of the survivals of different kinds of circuits, some intolerant of tube changes, others quite tolerant, with the additional assumption that the failures in any given circuit follow a random distribution. Since both wide-tolerance and narrow-tolerance circuits exist in the multiplier, this explanation seems quite reasonable. However, a rigorous analysis is prevented by other variables which are difficult to evaluate, namely routine tests and heater-voltage fluctuations. For details, see R-179, which describes tube life in the multiplier up to 10,000 hours. A reasonable number of all three tube types remained in service beyond 30,000 hours. How-

B-53802

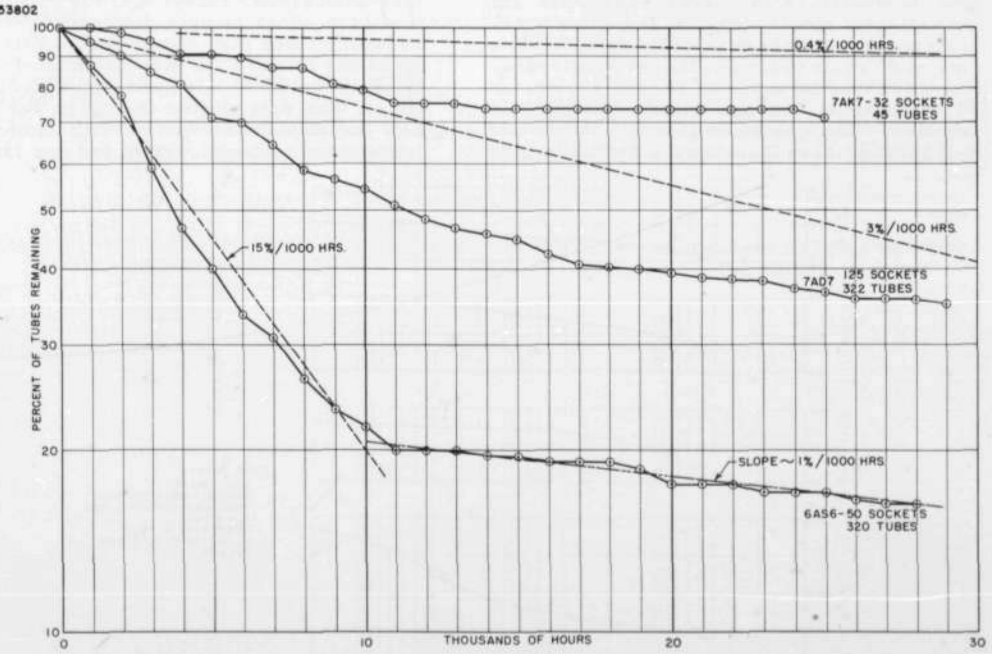

Fig. 3-4. Tube-life experience in multiplier.

ever, there were no failures of these tubes beyond the last points shown on the curves.

3.12 Vacuum-tube Research

During this past quarter, life-tests have been initiated again. Life tests are now in progress on types 5963, 5687, 6145, and 5899. Preliminary results on types 5963 and 5687 indicate that these tests may yield interesting and valuable information concerning proper cathode temperatures, but additional tests and analyses are needed. No results are available yet on the other tests.

During this quarter a new and unique intermittents detector has been put into service in the test shop. This device taps a tube while it is rotating in order to detect any possibility of shorts from loose particles within a tube. Any short with a resistance less than 2.5 megohms causes a neon lamp to light; the lamp stays on until manually released. Pick-up time is less than 2 microseconds for dead shorts and about 10-15 microseconds for 100,000-ohm shorts. As most shorts last for 100 microseconds or more, these times seem adequately short. All electrodes are checked simultaneously, with higher sensitivity for non-adjacent electrodes. At the same time, heater-cathode leakage is tested using 70 volts rms at 60 cycles between the two electrodes. Rejection may be made at 10, 20, 30, 40, or 50 microamps leakage either positive or negative. The combined test for shorts and H-K leakage takes 2 seconds; a switch is then thrown after which a check for intermittent opens is made in another 2 seconds. All in all, this equipment provides a more complete test than available previously in the shop, while at the same time it is much more rapid and much easier on the tube being tested.

Additional work has been done toward making detailed studies of the slow decay of cathode current which has been described previously in Summary Reports 29 and 30. At the present time a fairly precise measuring set has been constructed and checked. It is planned to use this equipment in an extensive series of tests during the next six months in conjunction with a thesis study.

Additional observations of some properties of cathode interface impedance have been made. A recent addition to the transconductance bridge used for research on the nature of cathode interface impedance allows the measurement of the interface impedance during the last two milliseconds of a pulse which may last from 5 milliseconds to 1.5 seconds. The interface impedance is determined by a null-balance method as described in R-207, "The Use of a Transconductance Bridge in the Measurement of Cathode Interface Impedance," except that the null indication is a short sample displayed every few seconds rather than continuously. This technique has allowed the measurement of variations in cathode interface impedance with time. The data plotted in Figure 3-5 shows how the impedance varies with time after initiation of cathode current for one sample.

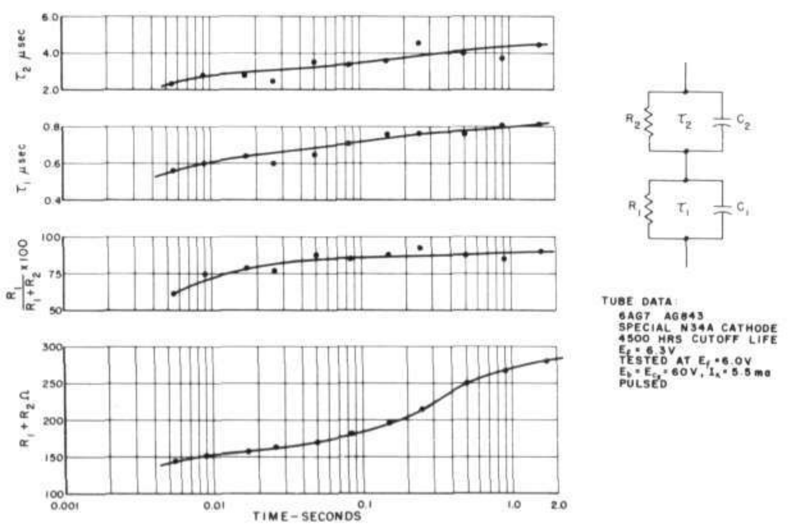

Fig. 3-5. Variation of interface impedance with time.

Additional measurements have indicated that the interface impedance may decrease as well as increase with time as cathode current flows. These changes are in general quite repeatable and have time-constants less than 1 second. They apparently are not directly related to the major changes in cathode interface impedance which occur when heavy cathode currents are drawn for minutes. (These latter changes are also reversible, but they have longer time-constants.) The cathode interface impedance may increase by a factor of 3 within a second after cathode current is initiated, or it may decrease by 20 percent or more. The direction and amount of the change in interface impedance appears to be somewhat dependent on the previous history of the tube concerned. It is planned to investigate this factor, as well as the effects of current and temperature variation, during the next several months. There seems little doubt that these variations, which can change a tube profoundly, have given computer circuits considerable trouble in the past, and may well do so in the future.

3.2 COMPONENT REPLACEMENTS IN WWI

Fig. 3-6 lists the replacements of components other than tubes during the fourth quarter of 1952.

Component	Type	Total in Service	No. of Failures	Hours of Operation	Comments
Capacitors	Ceramic Trimmer 4-30 mmfd	87	1	8000-9000	Open
	Ceramic Trimmer 7-45 mmfd	122	1	6000-7000	Open
Crystals	D-357 & 1N34A	7700			
	D-357		1	6000-7000	Drift to low R_b
			8	11000-12000	Drift to low R_b
			7	12000-13000	Drift to low R_b
			3	13000-14000	Drift to low R_b
	1N34A		1	0-1000	Low R_b
			1	3000-4000	Low R_b
			2	4000-5000	Low R_b
			1	10000-11000	Low R_b
			2	11000-12000	Low R_b
			1	13000-14000	Low R_b
	D-358 & 1N38A	3384			
	D-358		1	1000-2000	Drift to low R_b
			1	6000-7000	Drift to low R_b
			1	11000-12000	Drift to low R_b
			1	13000-14000	Drift to low R_b
	1N38A		2	0-1000	Low R_b
			4	1000-2000	Low R_b
			1	4000-5000	Low R_b
	D-359		1	13000-14000	Drift to low R_b
Potentiometers	2500 ohm 2 watt	173	1	7000-8000	Intermittent contact
	10000 ohm 2 watt A B	65	1	5000-6000	Intermittent contact
			1	8000-9000	Faulty contact
			1	9000-10000	Intermittent open
Resistors	Nobleloy 5000 ohm 1% 1 watt	360	3	3000-4000	3 above tolerance
			4	4000-5000	2 above tolerance, 2 open
			5	5000-6000	2 above tolerance, 1 open; 2 increased in value
			2	6000-7000	2 below tolerance
			1	7000-8000	1 above tolerance
	Carbon 100 ohm 5% 1 watt	734	1	11000-12000	Burn-out
	Nobleloy 125 K ohm 1% 1/2 watt	160	1	11000-12000	Over tolerance
			6	12000-13000	Over tolerance
	Nobleloy 450 K ohm 1% 1/2 watt	140	2	12000-13000	Over tolerance
	Carbon 220 ohm 5% 1 watt	10635	2	4000-5000	Overheated
			1	9000-10000	Burn-out
	Carbon 10 ohm 5% 1 watt	134	1	8000-9000	Burn-out
Transformers	5:1 Pulse	240	2	13000-14000	Open secondary
	1:1 Pulse	3605	1	0	Intermittent open
Delay Lines	0.5 μsec 1350 ohm	4	1	1000-2000	Open
	0.25 μsec 1350 ohm	50	1	1000-2000	Open
Choke	100 μh	524	1	4000-5000	Open

Fig. 3-6. Component failures in WWI October 1 - December 31, 1952

4. MATHEMATICS, CODING, AND APPLICATIONS

The new programming techniques and the procedures for assigning computer time to outside users, both of which were described in Summary Report 31, Sections 4.1 and 4.2, are now in use. Much of the time of the staff of the Scientific and Engineering Computation Group has been used in polishing the new techniques. The facilities now available are described in detail below. Much work remains to be done in integrating magnetic tape more thoroughly into the system, using the auxiliary magnetic drum effectively when it becomes available, and devising and perfecting better programmed methods for aiding programmers in the location of mistakes in their programs.

Changes in the computer and procedures during the past few months resulted in some confusion and reduced the available staff and computer time. Therefore relatively few (only the most hardy) outside users have carried out active work on the computer during the past quarter. Brief reports on fifteen of these problems are given in Section 4.2. These cover a number of types of applications, ranging from number theory applied to planetarium design (#94) through geophysical data analysis (#63) to lens design (#114). They include Fourier analysis for crystallography (#45) and frequency spectrum calculation (#87); variational problems applied to phosphate mining (#74) and to power generation in the Pacific Northwest (#54); and various combinations of integrations, quadratures, iterative processes, and Bessel function calculations needed in torpedo design (#46), aircraft design (#48) and (#115), turbine design (#95), electron scattering (#80), instrumentation (#57), oil well analyses (#84), and radar cloud-analysis (#93).

4.1 PROGRAMMING TECHNIQUES: COMPREHENSIVE SYSTEM OF SERVICE ROUTINES

The Scientific and Engineering Computations Group has devoted considerable time during the past several months to developing a more flexible and more effective system for getting programs into WWI and for getting their solutions out.

The system provides for conversion, by WWI, from Flexowriter-coded perforated tapes to tapes in pure binary coded form. In addition to straightforward conversion of function letters and decimal addresses, the Comprehensive System provides for (1) use of floating addresses for which assignment of final storage locations is made by the computer (this has the important advantage of permitting insertions and deletions of instructions without extensive renumbering in the program); (2) automatic selection of input-output and programmed-arithmetic interpretive subroutines, which eliminates to a considerable degree the time wasted and possible errors involved in handling preset parameters and subroutine tapes; (3) automatic cycle control (patterned after the Manchester B-tube) available within the PA routines which will reduce the need for using uninterpreted WWI instructions within an interpretive program and which will generally facilitate programming; and (4) the handling of generalized decimal numbers of the form $\pm z \cdot 2^{\gamma} \cdot 10^{\delta}$, which enables the programmer to express numerical data in whatever form is best suited to the particular calculation.

4.11 Input Conversion

Floating Address

The conversion of typewritten words into machine instructions is accomplished by the Comprehensive Conversion Program. This program permits conversion of floating-address Whirlwind instructions. A floating-address system enables a programmer to write his instructions so that they refer to the words of his program rather than to the location of those words in storage. The floating address is of the form α#, where α is any lower-case letter of the alphabet except o and l, and where # is any integer of the form 1, 2, 3... 255 with initial zeros suppressed. An example of a set of instructions with floating addresses and its fixed-address analogue follows:

floating address		fixed address	
f3,	cam9	32	ca41
	ad100	33	ad100
	tsm9	34	ts41
	cah5	35	ca42
	ad100	36	ad100
	tsh5	37	ts42
	cab2	38	ca43
	ad100	39	ad100
	tsb2	40	ts43
m9,	ca101	41	ca101
h5,	mr102	42	mr102
b2,	ts103	43	ts103
	cpf3	44	cp32

Interpreted Operations

A set of operations (called interpreted operations) analogous to the ordinary Whirlwind operations and used with the programmed-arithmetic subroutines have also been added to the vocabulary of operations of the Comprehensive Conversion Program. These will be described in Section 4.13 under the heading "Interpreted Operations and Their Functions."

Preset Parameters

Provision has been made to handle three classes of preset parameters. These parameters are of the form $\alpha\beta$# (α and β being lower case letters) where α is u, p, or z depending on whether the parameter is of the type universal (assigned particular meaning and never used for anything else), personal (can be used by anyone to mean anything desired), or subroutine (for parameters in library subroutines) respectively; β is any letter of the alphabet except o and l; and # is any decimal number of the form 1, 2, 3..., 40 with initial zero suppressed. A value may be assigned to a preset parameter by a word consisting of the parameter followed by an equals sign and the value to be assigned terminated by a tab or carriage return. After assignment, any number of parameters may be added to or subtracted from any word. Preset parameters may be assigned values which depend on other preset parameters. They may also be assigned values which depend on floating addresses.

Examples illustrating preset parameters follow:

um3=+3	universal parameter m3	= 0 000 000 000 000 011
ca71+um3	word becomes ca74	= 1 000 000 001 001 010
pm3=0.00020	personal parameter m3	= 0 000 000 000 010 000
slr+pm3	word becomes slr16	= 1 101 100 000 010 000
zm3=rs0	subroutine parameter m3	= 0 000 100 000 000 000
zs2=pm3+um3	subroutine parameter 52	= 0 000 000 000 010 011
cs7-zm3	word becomes ca7	= 1 000 000 000 000 111
slrzs2	word becomes slr19	= 1 101 100 000 010 011

Relative Addresses and Temporary Storage

Relative address and temporary storage assignments have also been provided for.

A relative address is one used for writing instructions within a subroutine or within any block of instructions with addresses relative to the start of the block (that is, as if the block started in register zero). Such relative addresses are obtained by including a lower case "r" in the address of the instruction, e.g. ca35r (which consists of the three syllables ca+35+r).

The single lower case letter "t" indicates the zero-th register of a block of temporary storage. The value of the temporary storage parameter is assigned in the same way as for a preset parameter.

Number Systems and Generalized Decimal Numbers

(m, n) numbers shall mean numbers which are m-binary digits long with n the number of binary digits in the exponent of 2. The numbers are of the form $z = x \cdot 2^y$ where x is an m-binary-digit number and y is an n-binary-digit number.

A flexible system of number conversion has been provided which goes beyond the conversion of single-register octal and decimal numbers to include the conversion of (m, n) generalized decimal numbers of the form

$$\pm d_1 d_2 \ldots d_k . d_{k+1} \ldots d_m \cdot 2^{\gamma} \cdot 10^{\delta}$$

These numbers are processed in accordance with the last special word (m, n) which appears in the program. At the present time (m, n) may have the values (15, 0) (single-register fixed-point decimal numbers); (30, 0) (two-register fixed-point decimal numbers); and (30-j, j), j=1, 2, ..., 15 (two-register floating-point numbers with a "j" digit exponent).

4.12 Programmed Arithmetic

(m, n) interpretive subroutines shall mean a particular group of coded programs whose purpose is to facilitate computation using (m, n) numbers. These subroutines enable the programmer to write coded programs using (m, n) numbers which are in many ways analogous to ordinary WWI coded (15, 0) programs.

Entry to an interpretive subroutine is accomplished by means of the (15, 0) word IN. This word is changed into a (15,0) sp instruction by the Comprehensive System, which transfers control from the program to the proper register in the interpretive subroutine.

Exit from an interpretive subroutine is accomplished by means of an interpreted instruction sp or by means of the special word OUT. If p is the register containing the word OUT, then the special word is converted to an sp(p+1).

A multiple-register accumulator (MRA) is used in place of the accumulator in many interpreted instructions. The MRA is not special "hardware" in the sense that the accumulator is, but rather is a group of 3 ordinary storage registers contained within the interpretive subroutine.

It should be noted that ordinary calculations on WWI are in the (15, 0) number system. The Comprehensive System also provides programmed-arithmetic subroutines which perform computations on the following types of numbers:

(a) (30, 0)
(b) (15, 15)
(c) (30-j, j) j=1, 2, . . . , 14

In addition to the usual arithmetic and logical operations in these number systems (these operations comprising the first 12 operations listed under "Interpreted Operations and Their Functions") there are two optional features called (1) cycle control and (2) buffer storage.

(1) Cycle Control - this is a programmed feature, analogous to the Manchester B-tube, in which the B-tube is replaced by two storage registers called the cycle-count register pair. In addition, several instructions, which have been added to the interpreted instruction code, effectively transform each cycle-count register into a single-length accumulator. This permits modifications of instructions while they are in the interpreted mode.

The cycle-count register pair consists of an index register, whose contents is "a", and the comparison register, whose contents is "b".

If now one of the interpreted instructions ica, ics, iad, isu, imr, idv, its, iex, isp is written in the form

```
      ixy100c  } (where xy represents one
or    ixy100+c } of the letter pairs above)
```

the interpretive subroutine first forms the instruction

ixy(100+2a)

and then executes this instruction. The quantity 100+2a is formed instead of 100+a, since the interpreted instructions deal mainly with arithmetic operations numbers which occupy two consecutive registers each.

This procedure is best explained by a simple example. Suppose one wishes to transfer the (24, 6) numbers in 100, 102, 104, and 106 to registers 200, 202, 204, 206. Referring to the table of Fig. 4-1, one could write a program of instructions to be interpreted in the following way:

```
32|icr4       Set up for four cycles
33|ica100c    Pick up C(100+2a)   a = 0, 1, 2, 3
34|its200c    Store in 200+2a     a = 0, 1, 2, 3
35|ict33      Go through 4 cycles
```

Note: the (24, 6) number in "register 100" actually occupies registers 100, 101 since (30-j, j), j = 0, 1, . . . , 15, numbers are stored in two consecutive registers.

(2) The Buffer Register - Although two registers are used to store a(30-j, j)number, three registers are used for the MRA to avoid the time-consuming operation of packing the last 15-j digits of the number and the j digits of the exponent into a single register after each interpreted instruction. A further advantage is gained in that any sequence of arithmetic operations is performed using 30 digits for the number and 15 digits for the exponent. This provides in effect a (30, 15) system.

The buffer register is used for the same reasons as the MRA. It can be used in any of the instructions icab, icsb, itsb, iexb, iadb, isub, imrb. In all of these cases "b" should be considered to represent a three-register (30, 15) location. Each of the instructions is then carried out as the corresponding instruction in a (30, 15) interpretive subroutine would be carried out. The buffer can be used to store intermediate results in a cyclic program, and thus rounding off can be avoided until after the final cycle.

Automatic Assembly of Programmed Arithmetic Subroutines

Interpretive subroutines for programmed arithmetic have been incorporated into the Comprehensive System in such a way that the type of subroutine needed and the features of the subroutine desired by the programmer are selected automatically in accordance with the number system and the interpreted instructions used. For example, if the programmer uses (24, 6) numbers and operations ica, iad, etc., in his program, but does not use cycle control or the buffer register (letters c and b not used), the most efficient routine for performing (24, 6) operations, omitting the extra time and space required for the cycle control and buffer facilities, is automatically provided without any further action on the part of the programmer or the tape-preparation staff.

Interpreted Instruction	Function
ica y	Clear the MRA and add into it the (m, n) number in location y.
ics y	Clear the MRA and subtract from it the (m, n) number in location y.
iad y	Add the (m, n) number in the MRA to the (m, n) number in location y and leave the sum in the MRA.
isu y	Subtract from the (m, n) number in the MRA the (m, n) number in location y and leave the difference in the MRA.
imr y	Multiply the (m, n) number in the MRA by the (m, n) number in location y and leave the rounded (m, n) product in the MRA.
idv y	Divide the (m, n) number in the MRA by the (m, n) number in location y and leave the rounded (m, n) quotient in the MRA.
its y	Transfer the (m, n) number in the MRA to location y.
iex y	Exchange the (m, n) number in the MRA with the (m, n) number in location y.
isp y	Interpret next the instruction in register y.
icp y	If the (m, n) number in the MRA is negative, interpret next the instruction in register y; if positive, ignore this instruction.
ita y	Transfer the address p+1 into the right 11 digits of register y, leaving the left 5 digits unchanged; p being the address of the isp or icp most recently interpreted.

NOTE: the above interpreted operations are analogous to the (15, 0) WWI operations obtained by dropping the initial i from the letter triples which designate them. The binary equivalent of the interpreted operations will not, however, be equal to the binary equivalent of the corresponding (15, 0) WWI operations.

icr m	Cycle Reset - set the index register to +0 and the comparison register to +m.
ict y	Cycle Count - If $|a + 1| \neq |b|$, increase the contents of the index register "a" by one and interpret next the instruction in register y. If $|a + 1| = |b|$, replace the contents of the index register by zero and proceed to the next instruction.
ici m	Cycle Increase - increase the contents of the index register by +m.
icd m	Cycle Decrease - decrease the contents of the index register by +m.
icx y	Cycle Exchange - exchange the contents of the index register with the contents of register y and exchange the contents of the comparison register with the contents of register y +1.
iat y	Add and transfer - add the contents of the index register to the contents of register y and store the result in the index register and register y.
iti y	Transfer index digits - transfer the right 11 digits of the contents of the index register into the right 11 digits of register y.

Fig. 4-1. Interpreted operations and their functions.

4.13 Input-Output

Introduction

The output media currently available for use with the in-out routine consist of typewriters, punches, oscilloscopes and magnetic-tape units. The magnetic tapes may be used as secondary storage devices or to record data for subsequent printing on a Flexowriter independent of the computer. The oscilloscope, which is equipped with an automatic camera, may be used in any of three ways:

a) as a curve-plotting instrument

b) as a numeroscope displaying alphabetical or digital characters (i.e., "alphanumeric" characters) in any desired layout

c) to display information in binary form.

Following are the relative speeds of the several media for recording alphanumeric characters and also their characters/line limits:

When the in-out routine is required to print, display, or punch a number, the calling-in letters must be followed by a specimen number of the following general form (the numbers in parentheses refer to paragraphs below):

$$\pm\ \alpha\ \#\#\#\cdots\#\ .\ \#\#\cdots\#\ \beta_i \times 2^{\gamma} \times 10^{\delta}$$
(1)(2) (3) (4) (5) (5)

The components of the number have the following meanings: (Note that in the following description the word "print" is used to mean print, punch, or display, depending upon the medium previously selected.)

(1) Sign

+ = print the number preceded by its sign

− = print the number preceded by its sign if the number is negative, otherwise just print the number

	Characters/sec	Characters/line max.
a) Typewriter	8	160
b) Scope	130	64
c) Magnetic Tape - actual printing same as for typewriter, recording rate for later printing is:	125	90

The in-out routine is called into use by three upper case letters. The first specifies the equipment to be used, the second states whether information is to be fed into or out of the computer, and the third specifies the type of information. The letters used are the initial letters of the following words:

Drum	In	Alphanumeric
Magnetic Tape	Out	Binary
Punch		Curve
Scope		
Typewriter		
Reader		

Examples of In-Out Instruction

TOA will print alphanumeric characters on the typewriter.

SOC will display a curve on the scope.

MIB will transfer binary information into the computer from magnetic tape.

When the in-out routine is called upon, it will handle the word currently in the AC or MRA. When a number expressed in any number system other than (15,0) is to be dealt with, the calling-in letters must be preceded by the lower case letter i so that the number will be interpreted. Thus iTOA will call in the output routine to print the contents of the MRA on the typewriter.

sign omitted = print the number with no sign

(2) Zero Suppression and Normalization (α is a lower case letter)

If α is i	initial zeros are ignored in printing and the first significant digit of the number is printed on the extreme left of the column.
If α is p	initial zeros are printed as spaces
If α is omitted	initial zeros are printed.
If α is n	the number is normalized before printing, i.e., all numbers are multiplied by such a power of 10 that the first non-zero significant digit will always be in the same relative position with respect to the decimal point. This procedure cannot be used with (15,0) output.

The digits of the numerical part of the specimen number merely serve to indicate the number of digits which the programmer desires to have printed on each side of the decimal point.

Thus iTOA+p347.6210s x $2^{-3} \times 10^5$ would indicate that the programmer wanted 3 digits to the left and 4 digits to the right of the decimal point, and the numbers would be printed in the form ###.####. However, if α is n, the number would be printed in the form ###.#### x 10^u, which is the normalized case.

(3) Decimal Point

If a decimal point is indicated, it will be printed in the position indicated.

If a decimal point is omitted, none will be printed (in printing integers).

If a decimal point is replaced by r, no decimal point will be printed but the r indicates where a decimal point would have been placed had there been one.

The latter facility would be of practical use in the case of decimal fractions in which it is desired to save printing time by omitting decimal points.

(4) Terminating Character (β is a lower case letter)

The symbols(s) β_i specify the character(s) with which the printed number is to be terminated:

β_i = s	gives one space
β_i = ss	gives two spaces
β_i = sss	gives three spaces
β_i = ssss	gives four spaces
β_i = c	gives a carriage return
β_i = t	gives a tab

If β_i is omitted there is no terminating character

β_i = f	gives format, i.e., the terminating character will be determined by the layout section of the in-out routine, which is in turn controlled by the Format Specifications. (See paragraph on Format Specification.)

(5) Scale Factor

The value of $2^{\gamma} \times 10^{\delta}$ specified by the programmer is incorporated into the solution before print-out so that the programmer may have his solutions in the form desired.

a) If the number is to be printed as a decimal fraction, then γ = 0, δ = 0.

b) If the number is to be printed as a decimal integer, then γ = 15, δ = 0.

c) Whenever a factor such as 2^{γ} or 10^{δ} has a zero exponent, that factor may be omitted.

d) If any factor has an exponent of 1, the 1 may be omitted.

e) The exponents γ_i, δ_i are signed if negative, and not signed if positive.

Examples of the use of output instructions in the (30-n, n) system follow:

ex 1: Let the MRA contain the octal number 0.6277574516 with an exponent of 15 (octal).
Thus the number = 0.6277574516 x 2^{15} (octal)
This is equivalent to +0.796812369 x 2^{13} and to +0.652748693 x 10^4 (decimal).
Let the output order be iTOA + nl.234 5678c
Then the typewriter would print out +6.5274869/+03 followed by a carriage return. This number represents +6.5274869 x 10^3.

ex 2: Let the MRA contain the octal number 1.1500203261 with an exponent of 15 (octal).
Thus the number = 1.1500203261 x 2^{15} (octal)
This is equivalent to -0.796812369 x 2^{13} and to -0.652748693 x 10^4 (decimal).
Let the output order be iSOA - 12.3456s x 10^{-5}
Then the 'scope would display -00.0652 followed by a space. At present no provision is made for rounding off to -00.0653.

In-Out Order Repeated

A specimen number need not be designated each time the in-out routine is called in. If the calling-in letters are not followed by anything, the in-out routine will provide exactly the same setup as it furnished for the last in-out specification.

Format Specification

The in-out routine contains a layout section which may be set by the special word:

FOR $\alpha \times \beta \times \gamma$

a) α represents the number of words/line (maximum, 15).

b) β = 1, 2, ..., 6 represents the number of spaces between words; β = 7 indicates a tab between words.

c) γ represents the number of words per

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block (typewriter); γ represents the number of words per frame ('scope).

ex. Let us suppose that the programmer wishes to type 2500 words in blocks of 400. If he specifies that γ = 400, he will automatically get 6 blocks of 400 words each and a seventh block of 100 words. The blocks will be separated by 2 carriage returns.

Special Characters

a) One may obtain a -, +, ., s (space), t (tab), c (carriage return) at any time by merely using the call-in letters followed by any one of the above six.

exs. TOA + gives a + on the typewriter
SOA c gives a carriage return on the 'scope

b) The order COL continues the 'scope display in the next column, at the top of the frame.

The order FRA takes a picture, and sets the camera up for the next frame.

Conclusion

At present the Comprehensive System is utilizing both perforated tape and magnetic tape for the necessary secondary storage of conversion, interpretive and in-out routines and of intermediate logical and final binary values of the prescribed program being converted. It is expected that the Comprehensive System will be stored permanently in the magnetic drum as soon as the drum is available. Post-mortems and mistake-diagnosis routines will be incorporated into the system in the near future. As soon as new in-out routines are prepared, they will be incorporated into the system.

Details are extensively treated in Engineering Note E-516.

4.2 PROBLEMS BEING SOLVED

Problem #45. Crystal Structure

This project originated with the MIT Electrical Engineering Department Insulation Research Group and the Chemistry Department. One of the principal branches of x-ray crystallography is the elucidation of the crystal structure of materials, i.e., the determination of the spatial configuration of all atoms in the crystal. The chief difficulty in this field, apart from those of an experimental nature, is the assignment of the phase angles of the several diffracted x-ray beams (these may be many thousand in number). If both the intensity of these beams and their phases are known, it is straightforward to deduce the atomic positions by means of the relationship:

$$p(xyz) = \frac{1}{V} \sum_h \sum_k \sum_e |F_{hke}| \exp - 2\pi i \left(hx+ky+lz+ \frac{\alpha_{hke}}{2\pi}\right) \qquad (1)$$

where p(xyz) is the electron density of the point xyz, and $F_{hke} \propto I^{\frac{1}{2}}_{hke}$, I_{hke} being the intensity of the beam diffracted by the plane (hkl). Experimentally, α_{hke} is not measurable and must be determined by indirect means. If a trial model structure is postulated, for which the calculated values of F_{hke} are not too different from the observed values, the experimental F_{hke}'s may be associated with the α_{hke}'s derived from the model, in a Fourier series. The new set of xyz's thus obtained will correspond to a new set of α_{hke}'s, and the calculated F_{hke}'s will agree more nearly with those measured. In this way the values of xyz are made to approach ever nearer the true set, as the iterative process is continued. This process will continue until no further change in the α_{hke}'s is noted when two successive models are compared.

A simplification is obtained if only 2 dimensions are used, and if central symmetry is possessed by the crystal, in which case the Fourier series becomes

$$p(xy) = \frac{1}{A} \sum_h \sum_k F_{hko} \cos 2\pi(hx+ky) \qquad (2)$$

where α of equation 1 is now 0 or π. A program was set up to sum series such as this, and it was successfully used for eighteen computations. This program has now been modified to accommodate the changes in the in-out order schedule, and it will be very frequently used in iterative procedures of the type outlined.

An alternative method of refining a structure model is to minimize the difference between the observed and calculated values of each F_{hke} by least squares. This method has been found very successful, and is particularly suited for calculation with a digital computer. A program for using this method on Whirlwind I is now under way.

Problem #46. Torpedo Depth Response

This problem, which originated with Robert Kramer of the Servomechanisms Laboratory at MIT, may be expressed in the following way: having measured the input to and the output of a physical system, to solve the convolution integral equation for the system impulse response. A program for Whirlwind has been written to carry out the convolution integral for an input function of 600 samples and an impulse response of 300 samples. The integration formula used is essentially Simpson's rule.

The approach of the past period has been to start with the theoretical system response, convolve this with the measured input function, and on the basis of the difference between the calculated and measured output functions guess at an appropriate correction to the original impulse response. The new impulse response is convolved with the input function, and the cycle is repeated. In this initial period, the convolution program was written and checked, and in addition four impulse responses were tried. These trials yielded a measure of progress and experience.

In the future, this informal procedure will be continued, and an investigation of more formal methods of obtaining the solution to this equation - such as through the LaPlace transform or methods of steepest descents - will be made.

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

A comprehensive study of loads on airplanes struck by gusts of various shapes has been performed by Mr. C. W. Brenner of the MIT Aero-Elastic and Structures Research Laboratory in fulfillment of Bureau of Aeronautics Contract No. NOas 51-183-c. Obtaining the numerical results required solution of a pair of simultaneous integro-differential equations of motion in the dependent variables of vertical acceleration of the airplane c.g., and airplane pitch angle.

Early investigations into the solution of the equations indicated that numerical procedures were necessary, as certain terms could not be treated by standard transformations to yield an analytical solution. A finite-difference solution was prepared for manual computation, and this was adapted directly to Whirlwind programming when automatic computation was decided upon. The development of this finite-difference solution is given in an AESRL Report titled "A Further Study of Gust Loads on Rigid and Elastic Airplanes," by Gabriel Isakson, Claude W. Brenner, and Timothy F. O'Brien.

An initial program was written to yield the airplane response to a sharp-edged gust, and this response was in turn to be used to yield the response to two graded gusts by application of Duhamel's integral. Internal storage proved insufficient for performing all this in one pass, so the sharp-edged-gust response was stored externally and then reintroduced with the program for calculating the graded-gust responses. In addition a short initial program was necessary to evaluate and store tabularly a double Duhamel integral occurring in each of the equations of motion. This double integral describes the time history of the induced downwash velocity at the airplane tail. Thus the problem was broken down into three stages - evaluation of double Duhamel integral, calculation of sharp-edged-gust response, and calculation of graded-gust responses.

Originally the output program involved printing the four quantities - pitch angle, airplane acceleration ratio (i.e. dimensionless vertical acceleration), wingload ratio, and tail-load ratio (note that wing-load ratio plus tail-load ratio equals acceleration ratio) - over a given time interval for each of the three gust shapes. Print-out time alone, however, was estimated at thirty minutes per run; and for the 200-odd cases to be studied this was prohibitive. Since the information of most importance was the peak value of each of the load factors; and since, moreover, the reduction and analysis of data would have proved most tedious if complete time histories were to be yielded, it was decided to modify the programs so that only the required peaks would be yielded for each of the three gust shapes. Fifteen representative cases, however, were still to be printed out in their entirety for comparative purposes.

A final difficulty was encountered in the matter of the external storage for the sharp-edged-gust response. Magnetic tape would have proved most efficient with regard to output time; but when this problem was initiated, techniques for utilizing the existing magnetic-tape unit had not been perfected, and its reliability had not been established. For the sake of expediency the output resorted to was punched paper tape, which is considerably slower than the magnetic tape. Each run took approximately 12 minutes, and 214 cases were solved yielding peak airplane acceleration ratio, wing-load ratio and tail-load ratio for a sharp-edged gust, and two graded gusts. During solution of the 15 cases for which the entire time histories were to be printed, the magnetic-tape unit was utilized at a considerable saving in time.

The entire problem and results are presented in an AESRL Report titled "A Parametric Investigation of Gust Loads on Rigid Airplanes in Two Degrees of Freedom," by Claude W. Brenner and Gabriel Isakson.

Problem #54. Optimizing the Use of Water Storage in a Combined Hydro-Thermal Electric System

This project has as its goal the development of procedures on WWI to improve the long-range mode of water utilization so as to reduce operating costs of a pilot three-plant system. A complete description of the methods developed and the results obtained thus far appears in an Sc.D. thesis by R. J. Cypser of the MIT Electrical Engineering Department entitled "Optimum Use of Water Storage in Hydro Thermal Electric Systems."

Of particular interest is the manner in which the computer smooths the cost of operation by successively lowering the heights and eating into the sides of cost peaks in each iteration. Indications are that in the test problem being computed a point of diminishing returns has not been approached yet, and that further iterations will yield even more substantial savings and will also shed light on the manner of convergence and on the elimination of violations of operating limitations.

The revised programs will fully utilize the newly installed magnetic-tape equipment. The time required for initial data layout on magnetic tapes and for data handling in each step of the computations has been substantially reduced.

Problem #57. Runge-Kutta Differential Equation

A test program has been written for the solution by a fourth order Runge-Kutta technique of a set of 10 simultaneous first order non-linear differential equations. This program is still being tested, but several auxiliary problems have been partially or wholly solved.

1) A high-speed pseudo-random number generator was programmed and its output subjected to five tests for randomness. The results indicated that the generator would serve as a satisfactory noisemaker for certain applications.

2) A program was written to find the first and second Fourier sine and cosine coefficients of a tabulated function in which three harmonics were strongly present. This program is now in operation and is being incorporated in a Fourier analysis - autocorrelation procedure for such data with superimposed noise.

3) An interpretive program has been written to read in and solve sets of algebraic equations of a certain class, each problem being presented to the machine as a flexo-tape in essentially ordinary mathematical notation. This program has at present partial provision for the handling of more elaborate problems; e.g., iterations and the computing of special functions.

4) A program has been written to assist in the evaluation of an antiaircraft fire control system. Target path equations and computer equations have been programmed in order to compare predicted and true future target positions. As yet the program has not run successfully in its entirety.

This work is being carried out by members of the Instrumentation Laboratory at MIT.

Problem #63. MIT Seismic Project

The Geophysical Analysis Research Group of the MIT Department of Geology and Geophysics continued its research activities in the application of statistical methods to seismology. Research along these lines has now been carried on for the past three years. In particular, statistical methods utilizing so-called linear operators have proved to be a powerful tool in the analysis of seismic records.

By computing these linear operators over different sections of the seismogram it was found that the dynamic characteristic remained fairly consistent in the sense that one operator would apply to several sections except during intervals corresponding to reflected energy. Since the ability of a linear operator to detect disturbances in the dynamics of the seismogram depends directly upon the accuracy of the operator in reconstructing the trace under ordinary conditions, a multiple prediction operator has been utilized which incorporates the traces from several geophone positions.

Predictions by means of such multiple-correlation prediction operators were computed on four seismograms by Whirlwind I. Results to date have indicated that this method of analysis will greatly exaggerate the returning reflected impulses and may even differentiate zones of greater scattering which have no major reflecting surface.

Problem #74. Optimization of Strip Mining Techniques

This is the concluding report on this problem. The most important phase of the investigation is to determine how the mining rate (ratio of volume of matrix removed to the amount of necessary time required for its removal) varies with the topographical and operational factors affecting this rate.

Essentially, a mathematical model was established analytically using 11 parameters to represent the operating variables which determine the performance of the system. These parameters are: (1) distance of pivot movement or length of walls; (2) distance of machine pivot from left-hand bank of cut; (3) distance of machine pivot from right-hand bank of cut; (4) thickness of overburden layer; (5) thickness of matrix layer; (6) angle subtended by path of machine movement and radial line to furthermost left point of earth removal; (7) angle subtended by path of machine movement and radial line to further-most right point of earth removal; (8) distance of spoil bank or dam from the line of machine movement; (9) number of stands for large angle (exceeding 90° from path of machine movement) swings to well; (10) minimum radial distance to which the machine digs in any particular digging pattern; and (11) the sum of the time preparatory to walking plus the time preparatory to resuming digging.

In addition, the following constants were needed: (1) capacity of bucket in cubic feet; (2) sum of time necessary to drag bucket to fill plus time necessary to dump bucket for the matrix and also for the overburden; (3) effective or true distance walked each step; (4) time required to complete each step cycle; (5) radial width of matrix shelf left unmined to prevent dilution of overburden; (6) empirically determined constants derived from operational time data where time is a function of swing angle and radial distance; (7) length of well; and (8) distance between machine pivot and plumb point below boom sheaves for machine in question. These were all needed in the basic equation, which consisted of a relation between these values and three triple integrals.

The integrations were very satisfactory as long as the interval was not allowed to get too large. With an enlarged interval an overflow of the arithmetic element would occur. When the test programs showed an acceptable interval that would allow a complete integration without exceeding the machine limits, we were ready to use the delayed printer (magnetic-tape typewriter). In addition, routines were written to obtain square roots, fourth roots, and arcsines.

The complete program was assembled and it performed satisfactorily. Mining rates were obtained for all the successful parameter combinations, and code numbers were recorded whenever impractical combinations appeared. By recording all the data on magnetic tape we were able to operate to the end of the program in 35 minutes of computer time. The program was stopped at the eighteen-minute mark, and a new reel was inserted in the magnetic-tape unit. Approximately 1-3/4 reels of tape were required for the flexo characters of the entire data. The print-out time required to typewrite the results from the flexo characters by delayed printer was 2-1/2 hours.

The rates showed an improvement 60 percent above the present mining techniques for the first set of parameter combinations, according to Mr. Herbert Jacobs of Dunlap and Associates, who submitted the problem and contributed the basic formulation of the mathematical model. The results for the second series were even better.

A copy of the complete results was forwarded to the International Minerals & Chemical Corporation. They will report to us whenever the results of their field testing of the investigation is completed.

Problem #80. Scattering of Electrons

Mr. J. L. Uretsky of the MIT Physics Department is attempting to obtain an accurate description of the distribution-in-angle of low-speed electrons elastically scattered from certain gases. If it is assumed that only elastic collisions occur, then the wave-function of the system can be written as

$$\Psi = \phi(1)\, x(2) \pm x(1)\, \phi(2)$$

where ϕ is the wave function of the unperturbed atomic electron. Insertion of Ψ into Schroedinger's variational equation leads to a second order integro-differential equation for R of the form

$$LR = f(R, r, c)$$

where c is a definite integral involving R, r, and ϕ; L is a differential operator plus an effective potential.

In order to solve this equation a value of c is assumed and the process is integrated until a new value of c has converged. The method used was Heun's third order modification of the Runge-Kutta method. Solutions were compared with some previously done on a differential analyser. The agreement appeared to be excellent.

The original program is now being reassembled in the new Whirlwind code. When this has been completed it will be used as a basis for further investigation.

Problem #84. Departure Curves for Various Types of Resistivity Logs in Oil Wells

Electrical surveys in drill holes measure potentials induced by a system of current electrodes at certain specified distances from these current electrodes. These potentials are converted to the so-called "apparent resistivities" of the medium surrounding the electrode system. The apparent resistivities are recorded as a continuous function of depth in the drill hole as the logging sonde is moved up from the bottom of the hole to the surface. The recorded curves are known as resistivity logs.

Apart from their great value for subsurface geological correlations, the resistivity curves are being used more and more to furnish information on the exact location of porous and oil-bearing strata and to obtain approximations to the actual porosity and oil saturation of these strata.

The first major step in the analysis of resistivity logs for quantitative evaluation of porosities and oil saturations is to interpret the apparent resistivities in terms of the actual in-place resistivities of the formations. This is done with the aid of so-called "resistivity departure curves," which depict the theoretical relations between the apparent resistivities and the actual distribution of in-place formation resistivities.

Porous formations are usually invaded by drilling fluid to a given extent beyond the bore face. This creates an invaded zone of a different resistivity than the undisturbed true formation resistivity. The apparent resistivities measured on the logs are influenced by the invaded zone resistivity and extent of invasion as well as by the true formation resistivity beyond the invaded zone.

A limited number of resistivity departure curves has been published by Schlumberger Well Surveying Corporation. Recent advances in the instrumentation of resistivity surveys warrant the use of a complete set of departure curves that will give direct solutions for the in-place resistivities.

The analytical expression from which the departure curves are calculated is a solution of Laplace's equation in cylindrical coordinates, obeying the boundary conditions of continuity of potential and of the normal component of current density at each boundary. The computations require integration of the product of a combination of modified Bessel functions and a cosine.

Computations have been carried through for five sets of departure curves corresponding to five values of the invaded zone diameter Each set consists of 80 departure curves corresponding to selected pairs of values of true formation and invaded zone resistivities normalized with respect to the resistivity of the drilling mud. Each curve consists of 22 points corresponding to 22 different spacings between the single point current electrode and the point potential pick-up electrode.

The results of these computations are now being processed by Dr. L. deWitte of the Continental Oil Company. The curves, when completed, will be made generally available to the oil industry.

Problem #87. Autocorrelation

This problem is being carried out in cooperation with the MIT Servomechanisms Laboratory. The problem concerns the calculation of the frequency spectrum of a given function by calculation on WWI of the autocorrelation function of the given function followed by the Fourier transform of this autocorrelation function. During the present quarter, existing programs (see Summary Report 31) for these operations were rewritten incorporating the latest changes in the WWI coding procedure. Also, the method of calculation has been altered in the Fourier transform program to incorporate the use of Simpson's Rule in the evaluation of the integral in order to achieve higher accuracy. This program still requires a final check, although most difficulties have been eliminated. The rewritten autocorrelation program is now completely checked. A major modification of the autocorrelation program incorporating Simpson's Rule has also been written, but requires checking.

In contrast to the other two programs, due to the large number of registers required in this modification, the autocorrelation-Simpson program is not self-resetting; that is, the program must be read into WWI before every calculation of an autocorrelation function. Although the Fourier transform program is designed to operate with the specialized output (on punched tape) of either of the autocorrelation programs, it may very easily be altered for use with any function, and can be made to take either the cosine or sine transform.

Problem #93. The Transmission Cross Section of Absorbing Spheres Using the Mie Solutions

The problem involving the computation of the transmission cross-section of absorbing spheres arose as the result of a contract between the Cambridge Research Center of the USAF and the Meteorology Department of MIT for an instrument to measure drop size distributions in clouds in the atmosphere. The contract was initiated 2 years ago, November 1950.

As a solution of the problem it was proposed that an analysis of the intensity of infrared light at selected wavelengths transmitted through the cloud would yield a drop size distribution. As a test of the theory, a series of analyses were made of the spectral distribution of light in the visible and photographic infrared when transmitted through sulphur hydrosols. The results were encouraging. As sulphur hydrosols have an index of refraction (hydrosol to water) of about 1.5 and are non-absorbing, no difficulty was encountered in finding tabular values of the scattering cross-section from the literature.

Experiments in the Meteorology Laboratory and on Mt. Washington on sprays and natural fog have shown the expected variation of transmission with wavelength in the infrared. However, as water absorbs infrared energy, the transmission cross-section must take account of absorption as well as scattering.

Since May of 1952, James R. Terrell and Professor John C. Johnson have carried out computations of the transmission cross-section using a Monroe desk calculator and Tables of Spherical Bessel Functions. (One man has been occupied about three-quarters time.) The first five months were spent in systematizing the computational procedures, determining limits, and computing a series of curves for index of refraction of 1.29, with absorption indices ranging from 0 to 2.2. It was felt that this was the most efficient utilization of time, because after the first three months it was estimated that the points we propose to have computed by Whirlwind would take 1.5 to 2 man-years of work with a desk computer.

A program for Whirlwind I has been written to compute the transmission cross-section of absorbing spheres. This consists, essentially, of computing the values of spherical Bessel functions needed for the solution of the Mie equations. The (24, 6, 0) number system is being used, since the required numbers are floating-point.

Problem #94. Factorization of Integers

In connection with the design of gear trains to simulate planetary motion in the star and planet projector for the new planetarium which is being built for the Boston Museum of Science, it was necessary to produce the prime factors of eight integers varying in length from ten to thirteen decimal digits. A straightforward multiple-precision program was successfully run on the computer, but the factors obtained were too large for gear-design purposes.

A new program was then written in which each of the eight numbers, all of which had proved to have one or more prime factors greater than 1000, were successively altered and retested automatically within the computer by adding +1, -1, +2, -2, etc., to the original numbers until nearby numbers were found in which the prime factors were all less than 1000. The program was then modified (by changing one constant) to find numbers with all the prime factors less than 600, and then, for some of the numbers, less than 212 and, for other numbers, less than 98.

The following results were obtained:

Integers Tested	Results Obtained
I = 3,662,563,604,800	$I - 126 = 2\cdot 13\cdot 17^{2}\cdot 31\cdot 113\cdot 347\cdot 401$
Representing: Earth	$I - 794 = 2\cdot 19\cdot 67\cdot 151\cdot 163\cdot 211\cdot 277$
Max. deviation tested: ±2800	$I + 2080 = 2^{5}\cdot 5\cdot 41^{2}\cdot 227\cdot 239\cdot 251$
Max. factor accepted: 599	

Integers Tested	Results Obtained
I = 162, 552, 320, 471	$I - 471 = 2^{12} \cdot 5^4 \cdot 7 \cdot 47 \cdot 193$
Representing: Venus	$I - 541 = 2 \cdot 5 \cdot 7 \cdot 11 \cdot 13 \cdot 41 \cdot 43 \cdot 61 \cdot 151$
Max. deviation tested: ±6000	$I + 1459 = 2 \cdot 3 \cdot 5 \cdot 17 \cdot 83 \cdot 101 \cdot 193 \cdot 197$
Max. factor accepted: 211	$I - 2193 = 2 \cdot 7 \cdot 73 \cdot 79 \cdot 83 \cdot 127 \cdot 191$
	$I - 2263 = 2^8 \cdot 7 \cdot 23 \cdot 29 \cdot 31 \cdot 41 \cdot 107$
	$I - 2774 = 3^5 \cdot 7 \cdot 11 \cdot 17 \cdot 47 \cdot 83 \cdot 131$
	$I + 4030 = 3^8 \cdot 7 \cdot 29 \cdot 31^2 \cdot 127$
I = 415, 209, 106, 528	$I - 5728 = 2^9 \cdot 3 \cdot 5^2 \cdot 13 \cdot 23 \cdot 29^2 \cdot 43$
Representing: Mercury	$I - 5880 = 2^3 \cdot 17 \cdot 47^2 \cdot 61 \cdot 139 \cdot 163$
Max. deviation tested: ±6000	
Max. factor accepted: 211	
I = 8, 430, 442, 950	$I + 348 = 2 \cdot 3^2 \cdot 19 \cdot 47 \cdot 71 \cdot 83 \cdot 89$
Representing: Jupiter	$I - 1238 = 2^4 \cdot 7 \cdot 11^2 \cdot 17 \cdot 23 \cdot 37 \cdot 43$
Max. deviation tested: ±2800	$I - 2190 = 2^3 \cdot 3^2 \cdot 5 \cdot 7 \cdot 17 \cdot 47 \cdot 53 \cdot 79$
Max. factor accepted: 97	
I = 53, 168, 435, 578	$I - 378 = 2^{12} \cdot 5^2 \cdot 71^2 \cdot 103$
Representing: Mars	$I - 544 = 2 \cdot 3 \cdot 11^2 \cdot 13 \cdot 17 \cdot 19 \cdot 107 \cdot 163$
Max. deviation tested: ±1342 (stopped manually)	$I + 1282 = 2^2 \cdot 5 \cdot 7^3 \cdot 11 \cdot 37 \cdot 137 \cdot 139$
	$I - 1342 = 2^2 \cdot 3^3 \cdot 19 \cdot 29 \cdot 61 \cdot 97 \cdot 151$
Max. factor accepted: 211	
I = 3, 394, 827, 907	$I + 383 = 2 \cdot 3 \cdot 5 \cdot 7^2 \cdot 23 \cdot 31 \cdot 41 \cdot 79$
Representing: Saturn	$I + 893 = 2^9 \cdot 3^3 \cdot 5^2 \cdot 11 \cdot 19 \cdot 47$
Max. deviation tested: ±1537 (stopped manually)	$I - 1052 = 5 \cdot 7 \cdot 29^3 \cdot 41 \cdot 97$
	$I - 1537 = 2 \cdot 3^3 \cdot 5 \cdot 13^3 \cdot 59 \cdot 97$
Max. factor accepted: 97	
I = 1, 190, 305, 649	$I - 533 = 2^2 \cdot 3^2 \cdot 7 \cdot 11 \cdot 13 \cdot 17 \cdot 29 \cdot 67$
Representing: Uranus	$I - 1404 = 5 \cdot 13 \cdot 37 \cdot 67 \cdot 83 \cdot 89$
Max. deviation tested: ±2009 (stopped manually)	$I - 1439 = 2 \cdot 3 \cdot 5 \cdot 19 \cdot 31^2 \cdot 41 \cdot 53$
	$I - 2009 = 2^3 \cdot 3^3 \cdot 5 \cdot 19^2 \cdot 43 \cdot 71$
Max. factor accepted: 97	

The computing time for factoring an integer whose limits on the alteration and factors are $\mathcal{E}_{max} = \pm 2800$, $d_{max} = 97$ respectively, is about 6 minutes.

Problem #95. Thermodynamic and Dynamic Effects of Water Injection into Gas Streams of High Temperature and High Velocity

This problem is connected with the development of a potential gas turbine component called the "Aerothermopressor." Essentially, this device consists of a pipe (which may or may not be of constant cross-sectional area) into which flow the exhaust gases from the gas turbine. These hot gases are expanded to high velocities at the aerothermopressor inlet, where special nozzles inject water into this hot, but now high-velocity, gas stream. The complicated thermodynamic and dynamic effects of the water injection that occur during the passage of the stream through the aerothermopressor are brought about by the simultaneous action of (1) the evaporation of the liquid water, (2) the momentum interaction between the injected liquid and the gas stream, (3) wall friction, and (4) changes in cross-sectional area of the duct. In the optimum case, these effects will give rise to conditions in which the stagnation pressure at the outlet of the aerothermopressor is higher than that at the inlet. The net effect is that the stream passing through the device has been cooled with an attendant rise in total pressure. If the pressure ratio across the aerothermopressor is sufficiently large, the entrance pressure may be maintained at a pressure below atmospheric, thereby providing a larger expansion ratio for the turbine. The overall function of the aerothermopressor as a gas turbine component is, then, to increase the efficiency of the plant by allowing the turbine to deliver more work due to the phenomena described above.

It is the purpose of the development program being carried out at MIT under Office of Naval Research sponsorship and under the guidance of Professor Ascher H. Shapiro, to study, both analytically and experimentally, all the facets that enter into the successful operation of the aerothermopressor. Bruce D. Gavril of the MIT Department of Mechanical Engineering is in charge of this calculation program.

The first program is a survey of the over-all performance of the aerothermopressor under various operating conditions. This introductory analysis surveys the over-all change in state for various amounts of friction, evaporation, and area change at various entrance conditions without, however, considering the details of the evaporation processes. This analysis may be termed a "process analysis" and is analogous to performance cycles in the gas turbine field.

Numerical solutions have been obtained for one selection of the initial values on a Friden calculating machine. These calculations have kept one person occupied for about two months; however, it is believed that with the experience obtained the same person could carry out the solution for a single set of initial values and a single set of independent parameters in about four hours, or 240 man-minutes, allowing about three hours set-up time for each set of initial values. For the calculations desired, one man would require 3(24) + 384 + 3(72) + 216 or about 888 hours. This is equivalent to 53, 280 man-minutes or 23 working weeks. It is estimated that Whirlwind I can deliver the solution to this program in typewritten form in less than two hours.

Problem #114. Design of Optical Instruments

The ultimate goal of this problem is to utilize the Whirlwind I computer to carry out as completely as possible the mathematical design of optical systems to meet certain specifications. The problem will comprise two distinct phases. During the first phase, evaluation of the various trial systems as calculated on WWI will be made by an experienced designer of optical systems; during the second phase this evaluation will be done by the machine. The evaluation of the first phase and the mathematical formulation of the second phase are being carried out by Dr. F. Wachendorf of the Retina Foundation at the Massachusetts Eye and Ear Infirmary.

The basic calculation consists of tracing rays through an optical system; the program for doing this is straightforward and essentially duplicates a well-known ray-tracing method using vectors. The design procedure using this program as a nucleus will be as follows. An experienced designer of optical systems will design an approximate system to meet certain specifications. The data of this system are then used by the computer as a starting point. Certain rays are traced through the system, and their coordinates and direction upon passing through the last surface of the system are printed, along with other pertinent data. Then some of the parameters (e.g., lens thickness, lens separation, etc.) are varied by the program, and the process is repeated. The resultant data will then be evaluated by the designer.

The second phase of the problem will consist of expanding the above program so that the evaluation will be carried out as completely as possible by the machine. This more difficult problem will require extensive use of auxiliary storage to handle, among other things, the relatively large matrices involved. Toward this end, very general and flexible subroutines have been developed for using magnetic tape, the only relatively fast auxiliary storage now available. Certain matrix subroutines have also been written, although the main problem of inverting a partitional matrix has not yet been started. It is expected that several months experience with the first phase of the problem will be necessary before the second phase can be attempted in its complete form.

The optical instruments to be designed are quite specialized, but the procedures to be developed should be of general applicability to other similar optimization problems involving many parameters.

Problem #115. Transient Aerodynamic Heating of a Flat Plate: Linear Partial Differential Equation

This problem is concerned with transient temperature variation in a flat plate subjected to an environment at elevated temperature on one side and insulated on the other. It is related to the more general problem of thermal stresses in aircraft structures due to transient aerodynamic heating in very high-speed flight. The problem is a relatively new one in that aircraft are only now reaching speeds at which this effect becomes important.

The governing differential equation in non-dimensional form is:

$$\frac{\partial \phi}{\partial \tau} = \frac{\partial^2 \phi}{\partial \mathcal{E}^2}$$

and the boundary conditions are:

(1) $\mathcal{E} = 0 \quad \frac{\partial \phi}{\partial \mathcal{E}} = \beta(\phi - \phi_e)$

(2) $\mathcal{E} = 1, \quad \frac{\partial \phi}{\partial \mathcal{E}} = 0$

(3) $\tau = 0, \quad \phi = 1$

where

$$\phi = \frac{T_{e_r} - T}{T_{e_r} - T_i} \qquad \phi_e = \frac{T_{e_r} - T_e}{T_{e_r} - T_i}$$

$$\tau = \frac{\partial t}{s^2} \qquad \mathcal{E} = \frac{x}{s} \qquad \beta = \frac{hs}{k}$$

and

T_i = initial temperature of the plate

T_{e_r} = environment reference temperature

t = dimensional time

s = thickness of the plate

x = distance from the heated surface

k = conductivity of the plate

h = the heat transfer coefficient at the surface of the plate

Solutions are already available for various values of β with constant T_e. During this quarter, a program has been written to provide information for the case where T_e increases linearly from T_i to a final constant value T_{e_r}. This is intended to account for the time required for the aircraft to accelerate to high speed.

The numerical solutions are obtained by solving the difference equation

$$\phi_{n,\tau+\Delta\tau} = \frac{1}{M}\phi_{n-1,\tau} + \frac{1}{M}(M-2)\phi_{n,\tau} + \frac{1}{M}\phi_{n+1,\tau}$$

where

$$M = \frac{(\Delta\mathcal{E})^2}{\Delta\tau}$$

$\phi_{o,\tau}$ at the heated surface is obtained from boundary condition (1) and is given by

$$\phi_{o,\tau} = \frac{2}{\beta\Delta\mathcal{E} + 1.5} \cdot \phi_{1,\tau} - \frac{0.5}{\beta\Delta\mathcal{E} + 1.5}$$

The computation proceeds until the difference in the temperature at the two faces reaches a maximum, at which point the temperature distribution is recorded.

Several solutions have been obtained during the previous quarter using this program. More will be obtained during the next quarter.

The problem is being programmed by Messrs. Gabriel Isakson and Claude W. Brenner of the MIT Aero-Elastic and Structures Research Laboratory.

5. ACADEMIC PROGRAM IN AUTOMATIC COMPUTATION AND NUMERICAL ANALYSIS

The seminars on Computing Machine Methods are arranged jointly by representatives of the MIT Committee on Machine Methods of Computation and the MIT Digital Computer Laboratory. Various speakers from other MIT activities and elsewhere, as well as members of the two sponsoring groups, participate in these weekly seminars, which are held in a lecture room at the Institute. The program during the past quarter was as follows.

Date	Title	Speaker
September 30	Graphical and Numerical Methods of Superposition	Professor H. M. Paynter, Dept. of Civil Engineering, MIT
October 7	Programming a Digital Computer to Learn	Mr. Tony Oettinger, Harvard Computation Laboratory
October 14	On the Stability of Smoothing Formulae with Applications to Linear Difference Equations	Mr. D. G. Aronson
October 21	New Procedures for Using Whirlwind I (Preliminary discussion) (An outline of the tentative plans for assigning computer time to various users, for administering the time assigned, for providing necessary training to new users, and for keeping old users posted on new developments. Changes in computer logic and programming procedures were very briefly summarized, with emphasis on the purpose and expected effect of these changes.)	Professor C. W. Adams, MIT, Digital Computer Laboratory
October 28	Computations for the Numerically Controlled Milling Machine	Mr. John H. Runyon, MIT, Servomechanisms Laboratory
November 4	Machine Solutions of the Problems of Classical Physics	Professor S. H. Crandall, MIT, Dept. of Mechanical Engineering
November 18	The Role of the MIT Flight Simulator in the Field of Analogue Computation (A brief survey of the history of analogue computation and the computing facilities now available. The computing facility at the Dynamic Analysis and Control Laboratory was described and indications presented of the role such a facility plays in the field of analogue computation.)	Dr. William W. Seifert, MIT, Dynamic Analysis and Control Laboratory
November 25	Some Contributions of Analogue Computation to Control System Analysis (Some of the extensions to control-system analysis techniques made possible by the use of analogue-computer equipment at the Dynamic Analysis and Control Laboratory were described. Emphasis on experimental studies of nonlinear control systems with random inputs.	Dr. Richard S. Booton, Jr., MIT, Dynamic Analysis and Control Laboratory

Date	Title	Speaker
	The manner in which these computer studies have suggested and verified theoretical methods was described.)	
December 2	Power System Economy as a Problem in the Calculus of Variations on Whirlwind I (The efficient conversion of water resources into electrical energy on a large scale is under study at MIT, oriented towards computer-control of the industry. Progress in the mathematical formulation of the problem and its solution on WWI was discussed.)	Professor R. J. Cypser, MIT, Dept. of Electrical Engineering
December 9	Programs for Audio Output from WWI (The discussion included methods of programming WWI to produce music and speech. Experimental recordings were played.)	Mr. R. P. Mayer, MIT, Digital Computer Laboratory
December 16	Application of the IBM Card-Programmed Electronic Calculator in the Field of Statistical Computation (A brief survey of the historical development of the various IBM calculators - type 602, 602A, 604, and the card-programmed calculators (CPC) models I and II. The available general-purpose control panels for the model II CPC were described. The relative advantages of fixed-decimal and floating-decimal boards were illustrated by particular examples. A description was given of the available operational code and the manner in which a problem may be programmed for CPC solution.)	Dr. Frank M. Verzuh, MIT, Office of Statistical Services
January 6	Some Problems of Learning by Computers (The use of learning processes in computers is a controversial issue. This is in part because direct transfer of concepts from related fields causes confusion and in part because the balance-sheet of potential merits and obstacles still remains largely empty. Some introductory considerations, rather than an organized learning schema, were discussed.)	Mr. Frederick A. Webster, MIT, Digital Computer Laboratory
January 13	The Solution of Secular Equations in Molecular Problems (A configuration interaction treatment of the oxygen molecule led to high order secular equations. Numerical diagonalizations, i.e., the computation of the eigenvectors and eigenvalues of a matrix, was done by Whirlwind with high speed and great accuracy. The general program of configuration interaction and the method of matrix diagonalization necessary to the success of the program was presented.)	Dr. Alvin Meckler, Solid State Group, MIT

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 Robert R. Rathbone, Digital Computer Laboratory, 68 Albany Street, Cambridge 39, Massachusetts

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

No.	Title	No. of Pages	Date	Author
SR-31	Summary Report No. 31, Third Quarter 1952	19		
R-215	Standard Test Equipment	69	9-1-52	R. Best W. Drogue R. Rathbone L. Sutro
E-484	Policy on Outisde Users of WWI	8	9-29-52	C. W. Adams
E-490	An Octal-Decimal Slide Rule	2	10-14-52	R. Mayer
E-494	Modification of the Dumont 304-H Oscilloscope to Reduce Drift Encountered in WWI Display	7	10-29-52	D. J. Neville
E-497	External Control Box for WWI Display Oscilloscopes	3	11-5-52	D. J. Neville
E-498	An Electronic Holding Circuit	3	11-12-52	J. A. O'Brien
E-499	Operation of the Block Transfer Orders	15	11-13-52	B. E. Morriss
E-502	Computer Program Synthesis Based on Statistical Communication Theory (Abstract of R-210)	1	11-20-52	A. Katz
E-506	Effects of Ions in the MIT Electrostatic Storage Tube (Abstract of M.S. Thesis)	1	11-24-52	H. Jacobowitz
E-514	Electronic Selection and Control of Read-Record Heads of Magnetic-Tape Units (Abstract of R-219)	2	12-15-52	J. A. O'Brien
E-516	Comprehensive System of Service Routines	26	12-17-52	H. Uchiyamada
M-1768	Rudiments of Good Circuit Design	3	12-22-52	N. Taylor

6.2 PROFESSIONAL SOCIETY PAPERS

Two members of the Project Staff delivered papers before the National Academy of Sciences - National Research Council Conference on Electrical Insulation held in Lenox, Massachusetts, in September. D. A. Buck spoke on "Magnetic and Dielectric Amplifiers, "while W. N. Papian's subject was "Ferromagnetic and Ferroelectric Memory Devices." Portions of these papers were printed in an article called "Research Progress in Dielectrics - 1952" in the December issue of Electrical Manufacturing.

At the AIEE-IRE-ACM Computer Conference held in New York December 10, N. H. Taylor delivered the Keynote Address.