PROJECT WHIRLWIND
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FOREWORD

Project Whirlwind makes use of the facilities of the Digital Computer Laboratory. The principal objective of the Project is the application of an electronic digital computer of large capacity and very high speed (Whirlwind I) to problems in mathematics, science, engineering, simulation and control.

Whirlwind I 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 magnetic-core memory, in which binary digits are stored as one of two directions of magnetic flux within ferro-magnetic cores.

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 magnetic-core memory has a capacity of 32,768 binary digits. Present speed of the computer is 40,000 single-address operations per second, equivalent to about 20,000 multiplications per second.

1. REVIEW AND PROBLEM INDEX

This report covers the specific period of March 18, 1957 to May 26, 1957. During this time, 60 problems made use of 347.32 hours of the 404.40 hours of Whirlwind computer time allocated to the Scientific and Engineering Computations (S&EC) Group. Of the 404.40 allocated hours of computer time, 3.3% was down time because of computer malfunctions. 43.73 hours of the allocated time were used for terminal equipment testing and calibration, demonstrations and various inter-run operations not logged to specific problems.

The 60 problems run during this quarter cover some 18 fields of application. The results of 19 of the problems have been or will be included in academic theses. In these 19 problems, there are represented 12 Doctoral theses, 5 Master's, 3 Naval Engineer's and 1 Bachelor's. Nineteen of the problems have originated from research projects sponsored at MIT by the Office of Naval Research.

Two tables are provided as an index to the problems for which progress reports have been submitted. In the first table, the problems are arranged according to the field of application and the source and amount of time used on WWI are given. In Table II, the problems are listed according to the principal mathematical problem involved in each. In each table, the letter after the problem number indicates whether the problem is for academic credit and whether it is sponsored. The code is explained in section 2.1, Introduction.

Field	Description	Problem Number	Minutes of WWI Time	Supervisor or Programmer
Aeroelastic & Structures Research Laboratory	Temperature and stress response	400 C.	115.6	J.C. Loria
Aeronautical Engineering	Horizontal stabilizer analysis	257 C.	855.9	E.Criscione
	Blast response of rotor blades	364 C.	177.2	E.A. Witmer
Aerophysics Research Group	Extraction of stability derivatives from flight test data	317 C.	781.6	L.Mazzola
	An analytical study of bluff bomb trajectories	409 C.	245.6	P.G.Kase
Chemistry	Frequency spectrum of magnesium	408 C.	26.5	L.Slutsky
Civil Engineering	Response of a multi-story building under dynamic loading	203 C.	653.0	R. Gray
	Dynamic response of shear walls	360 B.	216.9	S. Ho
Electrical Engineering	Switching circuits	380 B.	104.5	C.Roth, Jr.
Geology	MIT seismic project	106 C.	140.5	S. Simpson
	Fourier synthesis for crystal structures	261 C.	71.0	M.J.Buerger
Hydrodynamics Laboratory	Stokes particle velocities	383 C.	2.3	T. Marlow
Lincoln Laboratory	Eigenvalue problem for propagation of electromagnetic waves	193 L.	1000.3	H.B.Dwight
	Tropospheric propagation	300 L.	.8	W. Mason
	Error analysis	312 L.	290.4	L.Peterson
	Prediction analysis	327 L.	700.8	L.Peterson
	Coverage analysis	377 L.	477.0	L.Peterson
	Phase error calculation	395 L.	68.6	D.MacLellan
Mathematics	Nonlinear second order differential equations in the theory of elastic shells	337 N.	81.2	H.Weinitschke
Mechanical Engineering	Laminar boundary layer of a steady, compressible flow in the entrance region of a tube	199 N.	6.8	T.Y.Toong
	Rolling bearings	293 C.	25.0	A.Shashaty
	Growth of fatigue cracks	361 B,N.	46.3	J.B.Walsh
	Supersonic flow of air in a tube	389 D.	134.0	J.Radbill
Meteorology	Statistical and dynamic methods in forecasting	341 C.	547.3	E. Kelley
Naval Supersonic Laboratory	Free convection past a vertical plate	386 C.	153.5	M. Finston
	Diffusion boundary layer	407 C.	33.6	J.R. Baron
Nuclear Engineering	Fuel composition in nuclear reactors	405 B.	158.9	M. Cohen
Physics	Theory of neutron reactions	245 N.	356.5	H. Feshbach
	APW as applied to face- and body-centered iron	253 N.	390.1	J. Wood
	Analysis of air shower data	273 N.	1235.1	F. Scherb
	Multiple scattering of waves from a spatial array of spherical scatterers	274 N.	71.3	P.M.Morse
	Energy levels of diatomic hydrides LiH	278 N.	2384.9	A. Karo
	Atomic wave functions	288 N.	1222.2	R. Watson
	Polarizability effects in atoms and molecules	290 N.	1118.1	L.C.Allen
	Pure and impure potassium chloride crystal	309 B,N.	300.7	L.P.Howland
Servomechanisms Laboratory	Data reduction	126 C.	794.2	D.T.Ross
	Temperature distribution in aircraft generators	388 D.	211.1	R.Moroney
	Automatic programming for numerically controlled machine tools	394 C.	517.7	D.T.Ross

Table I Current Problems Arranged According to Field of Application

Mathematical Problem	Procedure	Problem Number
1. Matrix algebra and equations		
Eigenvalues	Diagonalization	278 N.
Eigenvalues	Diagonalization	288 N.
Orthonormalization, eigenvalues	Schmidt process, diagonalization	290 N.
Inversion	Crout	312 L.
Linear equations	Crout	317 C.
Diagonalization, inversion	Successive approximation, Crout	341 C.
Inversion, eignevalues	Crout, iteration	364 C.
Arithmetic operations	Direct	377 L.
Boolean algebra, Boolean matrices	McCluskey-Quine reduction	380 B.
Arithmetic operations	Direct	383 C.
2. Ordinary differential equations		
System	Gill	199 N.
Wave equation	Milne predictor-corrector formula	245 N.
Different sets of differential equations	Step by step	257 C.
Two simultaneous, non-linear, second order equations	Power series	337 A,N.
Sets of simultaneous second order differential equations	Backward difference equations	360 C.
Pair of simultaneous non-linear equations	Kutta-Gill	386 C.
Non-linear differential equations	Finite difference	388 D.
Different sets of differential equations	Kutta-Gill	389 N.
3. Partial differential equations		
Second order equation	Finite difference	400 C.
4. Integration		
Integrations	Simpson's rule	278 N.
Fresnel integral	Conversion power series with a complex argument	300 L.
Integrations	Barnet and Coulson expansion	309 B.
Integrations	Gauss quadrature	312 L.
Integration	Simpson's rule	395 L.
Integration	Simpson's rule	405 B.
Integration	Kutta-Gill	407 C.
Integration	Kutta-Gill	409 C.
5. Transcendental equations		
Curve fitting	Least squares	273 N.
6. Complex algebra		
Complex roots and function evaluation	Iteration	193 L.
7. Data reduction		
Data reduction	Polynomial fitting, etc.	126 C
8. Fourier series		
Fourier synthesis	Direct evaluation	261 C.
9. Statistics		
Multiple time series	Prediction by linear operators	106 C.
10. Integral equations		
Volterra type	Trapezoidal	361 B,N.

Table II Current Problems Arranged According to the Mathematics Involved

2. WHIRLWIND CODING AND APPLICATIONS

2.1 Introduction

Progress reports as submitted by the various programmers are presented in numerical order in Section 2.2. Letters have been added to the problem numbers to indicate whether the problem is for academic credit and whether it is sponsored. The letters have the following significance.

A implies the problem is NOT for academic credit, is UNsponsored.

B implies the problem IS for academic credit, is UNsponsored.

C implies the problem is NOT for academic credit, IS sponsored.

D implies the problem IS for academic credit, IS sponsored.

N implies the problem is sponsored by the Office of Naval Research.

L implies the problem is sponsored by Lincoln Laboratory.

The absence of a letter indicates that the problem originated within the S&EC Group.

2.2 Progress Reports

106 C. MIT SEISMIC PROJECT

During the past quarter, we have completed the testing of the stationarity hypothesis on seismic traces and well logs, and also the construction of theoretical random media with controlled scattering properties. Beyond this, we plan to do a few miscellaneous computations which may be necessary for the Project's final report.

S. Simpson
Geology and Geophysics

126 D. DATA REDUCTION

Problem 126 is a very large data-reduction program for use in the Servomechanisms Laboratory. The overall problem is composed of many component sections which have been developed separately and are now being combined into complete prototype programs. Descriptions of the various component sections have appeared in past quarterly reports. After the development and testing of the prototype Whirlwind programs is completed, the programs will be re-coded for other, commercially available, large scale computers, (probably the ERA 1103, IBM 701 and IBM 704 computers), for use by interested agencies for actual data reduction at other locations. The programs are currently being developed by Douglas T. Ross, David F. McAvinn, Benson H. Scheff and Dorothy A. Thompson, Servomechanisms Laboratory

staff members with the assistance of John F. Walsh. This work is sponsored by the Air Force Weapons Guidance Laboratory through DSR Project 7668.

The nature of the problem requires extreme automaticity and efficiency in the actual running of the program, but also requires the presence of human operators in the computation loop for the purpose of decision making and program modification. For this reason extensive use is made of output oscilloscopes so that the computer can communicate with the human, and manual intervention registers so that the human can communicate with the computer in terms of broad ideas, while the computer is running, and have the computer program translate these ideas into the detailed steps necessary for program modification to conform to the human operator's decision. The program which does this translation and modification is called the Manual Intervention Program (MIV). The most recent version of the prototype data-reduction program is called the Basic Evaluation Program.

During the past quarter, work has continued on the development of SLURP (Servo Lab Utility Routine Program). As described in the last quarterly report, the SLURP program operates like a specially designed simulated computer with unusual control features. Work has continued on the latest version of the logging program which creates a logical record of all manual intervention actions and displays during a computer run on magnetic tape. Further additions to the Editor Generator program have also been made and these programs are now in the final testing stage. A new Input Translation Program for the SLURP computer, which incorporates increased flexibility for making changes in SLURP programs, has also been completed.

Most efforts during this quarter have gone into the preparation of programs for data reduction on the Univac Scientific 1103 computer at the Air Force Armament Center, Eglin Air Force Base. The Whirlwind I-1103 Input Translation Program developed under Problem 256 for this work has received final modifications and extensive translations have taken place during this quarter. It is expected that this work will be completed within the next month or so.

Because of the extreme dependence of the work of Problem 126 on manual intervention and oscilloscope output, it is planned that continued use of the Whirlwind computer will be made during the next year. Where appropriate, portions of the work will be transferred to the IBM 704 computer at the Computation Center. But until equivalent specialized input-output equipment is available on that computer, the basic research in computer applications will continue on the Whirlwind computer.

D. T. Ross
Servomechanisms Laboratory

193 L. EIGENVALUE PROBLEM FOR PROPAGATION OF E.M. WAVES

Calculation of eigenvalues, eigenfunctions and mode sums have continued for the bilinear model at 410 and 3000 Mc. The 410 Mc computations using the present program have been completed; the 3000 Mc computations will be extended to higher mode numbers. Similar calculations are being carried out at 50 Mc using an inverse-square model.

Programmers working on this problem are H. B. Dwight and R. M. Ring.

R. M. Ring
Lincoln Laboratory

199 N. LAMINAR BOUNDARY LAYER OF A STEADY, COMPRESSIBLE FLOW IN THE ENTRANCE REGION OF A TUBE

Solutions were obtained for the case where temperature dependence of the viscosity and thermal conductivity of air is taken into consideration. More solutions are to be obtained for different entrance Mach numbers.

T. Y. Toong
Mechanical Engineering

203 C. RESPONSE OF A MULTI-STORY FRAME BUILDING UNDER DYNAMIC LOADING

During the past quarter a five-story program was completed. The debugging of a new general program, using expanded high-speed storage, is now in process.

R. G. Gray
Civil Engineering

245 N. THEORY OF NEUTRON REACTIONS

During this quarter, test runs have been made to determine the values of ζ and c. These will probably give the best fit between the theoretical and experimental curves. The values chosen were c = 1.65, ζ = .08. Work on a complete set of cross-sections and angular distributions for these values has also been started.

Elizabeth Campbell
Laboratory for Nuclear Science

253 N. APW AS APPLIED TO FACE- AND BODY-CENTERED IRON

A plane wave test for the face-centered crystal is nearing completion and matrix elements for the face-centered phase of iron are now being computed. The computation of the matrix elements for body-centered iron and the diagonalization of the secular determinants containing these matrix elements for both the face- and body-centered phases still must be completed.

Programmers working on this problem are J. H. Wood and M. M. Saffren.

J. H. Wood
Solid State and Molecular
Theory Group

257 C. HORIZONTAL STABILIZER ANALYSIS

Additional production runs have been satisfactorily completed during the last quarter. Hopefully, all production runs will be completed by the end of the next quarter.

Programmers working on this problem are N. P. Hobbs and E. Criscione.

E. Criscione
Aeroelastic and Structures
Research Laboratory

261 C. FOURIER SYNTHESIS FOR CRYSTAL STRUCTURES

During this quarter we have completed our 3-dimensional transform computations for the crystal Rhodonite and are presently contouring the results. Unless the contoured results show behavior which makes us suspicious of the computations, our problem is completed. If there is trouble, a few computations may have to be rerun.

S. Simpson
Geology and Geophysics

273 N. ANALYSIS OF AIR SHOWER DATA

Most of the computer time used during the past quarter was devoted to the reduction of air shower data. A Monte Carlo analysis of 25 artificial showers is in progress for the purpose of determining the resolution of the experiment. As yet, we have not started working on the 704 version of the program.

A paper on the air shower experiment will be published soon in Nature. The title is "An Experiment on Air Showers Produced by High Energy Cosmic Rays".

Programmers working on this problem are G. W. Clark and F. Scherb.

F. Scherb
Physics

274 N. MULTIPLE SCATTERING OF WAVES FROM A SPATIAL ARRAY OF SPHERICAL SCATTERERS

Fitting formulae, $F(k^2, K)$ have been obtained for three additional sums: $-2\pi^2 k^2 M_1^o$ and $-2\pi^2 k^2 M_{1e}^o$ and $-2\pi^2 k^2 M_{1o}^o$. Each of these covers all seven directions of K. There now remain five more sums to fit and these are now being prepared to run on Whirlwind.

M. Karakashian
Laboratory for Nuclear Science

278 N. ENERGY LEVELS OF DIATOMIC HYDRIDES LiH

Extensive use is being made of the digital computer facilities in evaluating all of the overlap, one-electron and two-electron integrals which will be required to complete the work on the problem which has been outlined in previous reports. The purpose of including π orbitals on both centers is to provide for a better degree of angular correlation in the molecular wave function than has been obtained before.

Tabulation of the integrals is proceeding for the purpose of utilizing the Whirlwind Roothaan programs written by Meckler and Nesbet to determine the molecular symmetry orbitals, found as linear combinations of the appropriate atomic functions, which will give the lowest energy for the single Slater determinant representing the ground state configuration. The SCF MO ground state calculation will be supplemented with a limited configuration interaction to give some physical reality to the molecular wave function at larger internuclear distances and, consequently, to the electronic energy and the dipole moment.

Programmers working on this problem are A. R. Olson and A. M. Karo.

A. M. Karo
Solid State and Molecular
Theory Group

288 N. ATOMIC WAVE FUNCTIONS

Atomic calculations with the Roothaan procedure were made for the following:

1) $O^{=}$ with various numbers of basis functions.
2) $(45)^2$ $(3d)^6$ configuration of Fe.
3) $45(3d)^n$ configuration of Fe.
4) $(3d)^8$ configuration of Fe.
5) $(45)^2$ $(3d)^8$ configuration of Ni.

R. Watson
Solid State and Molecular
Theory Group

290 N. POLARIZABILITY EFFECTS IN ATOMS AND MOLECULES

As noted in our last report, we are now engaged in production runs on our atomic and molecular problems. For the diatomic hydrogen fluoride molecule we are carrying out a determination of the binding energy, dipole moment and quadrupole moment as a function of internuclear separation. In addition, we are seeking a Hartree-Foch solution of this molecule (for R = Re) by successively adding basis functions of higher angular momentum and to date we have gone as far as f orbitals. Besides these calculations, we have also been attempting to determine Hartree-Foch solutions for the free fluorine atom, fluorine ion and neon atom. The Roothaan scheme has been used here (as in the molecular problem above) and an indication of the successful convergence of the method is that our most recent runs differ from each other by only .03 e.v. out of a total energy of approximately 3000 e.v.

These problems and others developed for electronic structure problems have utilized Whirlwind in an efficient and thoroughgoing way. It is also true that digital computers and Whirlwind especially have revolutionized the calculation of electronic wave functions for atoms and simple molecules. In transferring to the IBM 704 one can gain the advantage of standardization and it is hoped that it will be possible to interest people in translating and improving programs now in existence. Since this is the final Whirlwind I Progress Report and we have not yet finished all of our molecular calculations, we will continue to report on these problems in the Solid State and Molecular Theory Group Quarterly Reports.

Finally, we should mention a computation underway on Problem Number 412. No machine time has yet been used but an energy band calculation for Potassium is being actively worked on. The calculation will be carried out by the Augmented Plane Wave method and will largely use programs built up by M. M. Saffren and J. H. Wood (these have been discussed previously in Whirlwind Progress Reports). There is considerable interest in evaluating the accuracy with which this mathematical model represents the physical situation and in particular a variety of assumed one-electron potentials are to be tested.

Results of this work will also be given in the Solid State and Molecular Theory Group Progress Reports.

L. C. Allen
Solid State and Molecular
Theory Group

293 C. ROLLING BEARINGS

During the past quarter, some short runs were made using new input data. No future computations are contemplated at present.

A. Shashaty
Mechanical Engineering

300 L. TROPOSPHERIC PROPAGATION

An attempt is being made to compute some of the quantities required for a study of the bearing of properties of the geomagnetic field upon radio propagation. Programmers working on this problem are P. A. Duffy and J. N. Skenian.

P. A. Duffy
Lincoln Laboratory

309 B,N. PURE AND IMPURE POTASSIUM CHLORIDE CRYSTAL

Details of the charge density of KCI in an x,y,0 plane containing nuclei have been obtained. Now the resulting contours of the charge density have been drawn and comparisons with recent experimental data have been made. Information on a few other minor points may still be sought on Whirlwind as long as the machine is available.

L. P. Howland
Physics

312 L. ERROR ANALYSIS

This problem, with its various modifications, has been used for production runs during the past quarter. There will probably be more production runs in the future on Lincoln time. Programmers working on this problem are E. Hutcheson and L. Peterson.

L. Peterson
Lincoln Laboratory

317 C. EXTRACTION OF STABILITY DERIVATIVES FROM FLIGHT TEST DATA

In the past quarter this project has continued the investigation of the lateral-stability-derivative extraction problem, using Shinbrot's method, the derivative method and a new statistical method developed by this project. Investigations of the effect of gusts on extraction accuracy for longitudinal derivatives, and of the $C_{m_{\gamma}}$. extraction problem have also been started. It is expected that the computation phase of the problem will be finished in the next quarter by completing the investigations now in progress. Results will be published in a series of Wright Air Development Center Technical Notes.

Programmers working on this problem are M. E. Hoult, L. L. Mazzola, M. N. Springer, J. F. White and L. E. Wilkie.

M. N. Springer
Aerophysics Research Group

327 L. PREDICTION ANALYSIS

The Maximum Likelihood Method program, described in previous Quarterly Progress Reports, has been run to test various characteristics of the method as programmed. Some of these characteristics are:

1) How poor the first guess may be in order to have the system converge.
2) Whether it would be sufficient to insert a fixed first guess and what it would be.
3) How various input parameters affect the functioning of the system.

In order to investigate a few more characteristics, there will be some testing done in the future.

The power series approximation method mentioned in Progress Report No. 47 has been checked, but programming continues in order to check how the method compares with the M L method and how to extend the permissible range of input values.

The program concerned with the effects of the earth's oblateness, mentioned in Progress Report No. 47 is checked out. Runs will be made in order to tabulate the values of errors due to this factor.

A prediction method has also been programmed. It has been helpful in understanding the results of the data processing part of problem 377 (first

mentioned in Progress Report No. 46). This new program is also interesting in that it has been written to handle a much more general set of conditions than has been considered in previous programs.

Programmers working on this problem are E. Hutcheson, L. Peterson and P. Willmann.

L. Peterson
Lincoln Laboratory

337 N. NONLINEAR SECOND ORDER DIFFERENTIAL EQUATIONS IN THE THEORY OF ELASTIC SHELLS

Computations for problem 337 have been completed this term. The results have been written up for a Technical Report, submitted to the Office of Statistical Services.

H. Weinitschke
Mathematics Department

341 C. STATISTICAL AND DYNAMIC METHODS IN FORECASTING

During this past quarter, work has been completed on a project dealing with a statistical-dynamic approach to numerical weather prediction. The results were not especially encouraging; however, the changes necessary in order to make the method successful are believed to be known.

A short investigation of the possibility of forecasting mean monthly temperatures at a single station (Washington, D.C.) for a given year, from the empirical orthogonal functions of the mean monthly temperatures at the same station for the preceding year, was also conducted. Preliminary results are quite promising and may be of considerable interest to those engaged in long-range forecasting.

Programs for testing developed linear forecast methods on a set of independent data were completed and run during the last quarter. This brought to an end this particular phase of studies of sea-level pressure by empirical orthogonal functions.

Computations have also been completed in an investigation of a theoretical model of the atmosphere using an expansion of the meteorological variables in a small number of spherical harmonics. In a final run the system of equations was numerically integrated by a stepwise method over the equivalent of two hundred days.

The bulk of the computations involved in the studies mentioned above have been performed on Whirlwind I. The programmers for this problem are: E. Kelley, B. Shorr, W. Sellers, K. Bryan and J. MacDonald.

E. Kelley
Meteorology Department

360 B. DYNAMIC RESPONSE OF SHEAR WALLS

During the past quarter, results were obtained on 3 x 2 grids (22" square). Efforts have been made to obtain results on 6 x 4 grids.

Shui Ho
Civil Engineering

361 B,N. GROWTH OF FATIGUE CRACKS

The integral equation was programmed to reduce the effect of round-off error, which was excessive for certain parameter values. This new program was debugged and seems to give satisfactory results.

The program for determining the elastic-plastic stress distribution in a circumferentially notched round-bar was debugged. Runs are now being made for various values of notch depth and applied degree.

J. B. Walsh
Mechanical Engineering

354 C. BLAST RESPONSE OF ROTOR BLADES

The program for computing the natural mode shapes and frequencies of the rotor has been debugged and is ready for production runs. Programs are currently being written to compute, using the natural mode shapes, certain coefficients in the expressions for the generalized airforces. Following completion of this work, a program will be written for simultaneous solution of m equations of motion of the system, utilizing the previously computed airforce coefficients. A parametric study of blast response of helicopter rotors will then be conducted.

Programmers working on this problem are E. A. Witmer and A. Holland.

E. A. Witmer
Aeroelastic and Structures
Research Laboratory

377 L. COVERAGE ANALYSIS

The problem, as described in Quarterly Progress Report No. 46, has been used in the past quarter for production runs. The resulting data has been found useful for the analysis desired. It will continue to be a production run problem for some time.

Programmers working on this problem are E. Hutcheson and L. Peterson.

L. Peterson
Lincoln Laboratory

380 B. SWITCHING CIRCUITS

A study of the use of a digital computer for the solution of several types of switching circuit problems has been completed and the results are currently being

written up in a S. M. thesis entitled, "Digital-Computer Solution of Switching-Circuit Problems". Four Whirlwind programs have been written for solution of switching problems:

1) Analysis of Single-Output Contact Networks. The transmission of any contact network with 3 to 42 nodes and 4 to 8 variables can be determined by this program. The network is specified by a Boolean matrix and the transmission is in standard sum form.

2) Analysis of Multiple-Output Contact Networks. Similar to (1) except that the transmissions between all pairs of nodes in the network are obtained simultaneously.

3) Synthesis of Non-Series-Parallel Contact Networks. This program is capable of synthesizing a contact network to realize any four-variable switching function. The desired transmission is specified in standard sum form, and the output is a Boolean matrix.

4) Determination of Prime Implicants and Minimum Sums. Given the standard sum and optional terms (maximum 512 terms) for any switching function of 14 or fewer variables, this program will determine the prime implicants and one or more minimum sums.

Using the latter program, approximately 100 problems were solved for J. P. Gouyet in connection with the development of a new character decoder for a photo-composing machine.

C. H. Roth, Jr.
Electrical Engineering

383 C. STOKES PARTICLE VELOCITIES

Problem 383 was the solution of Stokes equations for the water particle velocities in an oscillatory wave. The equations were solved for 24 values of wave phase angle and three depths for 11 waves. The wave parameters and positions were identically those used in an experimental determination of particle velocities.

The experimental and computed values were plotted to determine the range of applicability and adequacy of Stokes relations. This report served as a Master of Science thesis and D.S.R. report.

The solution of Stokes equations by Whirlwind allowed this study to be made, since manual computation would have been impossible from a time standpoint. The entire study used less than an hour of machine time with the main routine coded in the binary system.

T. Marlow
Hydrodynamics Laboratory

386 C. FREE CONVECTION

Computations were completed during the present quarter. Exact solutions were obtained for 12 representative surface temperature distributions of the form

$1 + Bx^q$ (for B = 0.1, 1.0 and 10.0 and q = -.01, -.1, -.2 and -.25). The results indicate the relative effects (on skin friction and heat transfer) of a change in q to be insensitive (on order of 0.1%) to changes in B.

J. R. Baron
Naval Supersonic Laboratory

387 C. DETERMINATION OF VELOCITY POTENTIAL

All calculations have been completed for the delta wing and work has begun on the straight wing. The program has been checked and approximately 1/3 of the calculations have been completed.

Future plans are to finish the straight wing case on Whirlwind and do the swept wing on the 704 if necessary.

Programmers working on this problem are R. Stapleford and W. Weatherhill.

R. Stapleford
Aeroelastic and Structures
Research Laboratory

388 D. TEMPERATURE DISTRIBUTION IN AIRCRAFT GENERATORS

Computed results do not agree with experimental measurements. It is hoped that certain refinements now being made will alter the situation, but in any case, this problem will terminate on August 1.

R. Moroney
Servomechanisms Laboratory

389 D. SUPERSONIC FLOW OF AIR IN A TUBE

The solutions of this fluid mechanics problem have been found to be very sensitive to the property variation assumptions. Because of this sensitivity, recalculation of the first approximation and completion of the calculations for the second approximation have been undertaken with a more exact property variation. The tapes for these calculations have been completed and checked out and will require only minor modifications.

J. R. Radbill
Mechanical Engineering

394 C. AUTOMATIC PROGRAMMING FOR NUMERICALLY CONTROLLED MACHINE TOOLS

The completion of the MIT numerically Controlled Milling Machine in 1952 introduced a new era in the automatic translation of design requirements into finished parts. The primary problem associated with this type of machine tool, the preparation of detailed instructions for making a part, has been studied using the Whirlwind Computer. Under problem 132 (Whirlwind Progress Reports 33-43) a library of subroutines was developed to assist in data preparation for the MIT NCMM. Under problem 250 (Whirlwind Progress Reports 41, 42) the feasibility of applying modern

automatic programming techniques to machine tool programming was successfully demonstrated for plane parts bounded by straight line and circular segments. Problem 394 is concerned with the extension and elaboration of these automatic programming techniques to arbitrary surfaces which can be machined by 3 and 5 axis numerically controlled milling machines. The programs are currently being developed by Douglas T. Ross, Donald F. Clements, Harry E. Pople, Jerome R. Wenker, Samuel M. Matsa, Servomechanisms Laboratory staff members. This work is sponsored by the Air Materiel Command through DSR Project 6873.

The problem may be viewed as the design of an APT System (Automatically Programmed Tool system) combining the human operator, the machine tool itself, and an APT computer, which is a combination of a general purpose computer and existing machine tool directors. The objective is a system of Whirlwind computer programs which will simulate an APT computer with a language which is convenient for human expression of machined part designs. A design expressed in this language will be automatically translated by the APT computer into machine tool instructions.

During the past quarter, a new "systematized solution" to the problem of calculating cutter motions for the APT II system, which allows programming of a part by means of arbitrary curves on the surface of the part, has been made. Output routines developed under Problem 132 have also been incorporated to provide punched paper control tape for the MIT Numerically Controlled Milling Machine at the Servomechanisms Laboratory, so that test parts can actually be machined. The new method of calculation depends only upon two programs for each type of surface. The normal vector program produces a vector perpendicular to the surface of the part at a specified point. The directed distance program calculates the distance to the surface from an arbitrary point in space looking in an arbitrary direction. Normal and directed distance programs for planes and spheres have been in use for some time. These programs are being combined into a generalized program which will calculate normal and directed distances to planes, spheres, cones, cylinders and general quadric surfaces in three dimensions. This program is now under test.

The programming for the APT III system, which allows programming a part by means of entire regions of the surface of the part, is also under test. The analysis used in this program also represents a systematized solution to the problem and depends only upon normal vector and directed distance programs. A number of successful tests have been completed and the program is undergoing further refinement. It is planned that, with very slight modification, the programming for the APT III system. The oscilloscope output routine which draws near perspective views of the part being made has been used with all programs.

The work on Problem 394 will transfer to the IBM 704 Computer at the Computation Center in the very near future. During the week of May 20 a meeting was held at M.I.T. to coordinate the efforts of a number of aircraft plants in a joint programming effort to develop an APT II system for two dimensional parts, along the lines set forth in these reports. The Servomechanisms Laboratory, M.I.T., is to act as coordinator in this joint effort, and it is hoped that a preliminary system for the IBM 704 can be completed by October 1957. Concurrent efforts, closely coordinated, will develop a similar system for the IBM 650.

D. T. Ross
Servomechanisms Laboratory

395 L PHASE ERROR CALCULATIONS

During this past quarter, it has been found that the problem, in its present mathematical form, will demand an exorbitant amount of WWI time. Therefore, it has been decided that the problem should be recast.

D. MacLellan
Lincoln Laboratory

400 C. TEMPERATURE AND STRESS RESPONSE

During the past quarter, an additional blade was programmed and the run performed successfully. Currently, three other blades are being programmed.

J. C. Loria
Aeroelastic and Structures
Research Laboratory

405 B. FUEL COMPOSITION IN NUCLEAR REACTORS

The interaction rate between neutrons and nuclei can be described by the following equation:

$$\frac{dN}{dt} = -\bar{\sigma}_{rh}\,\Phi\,N \qquad (1)$$

In practical cases the flux is a function of the neutron energy, as is the cross section. Hence it is necessary to define the effective cross section and flux in eq. (1) such that:

$$\Phi = \int_0^\infty \phi(E)\,dE \qquad (2)$$

$$\bar{\sigma}_{rh}\,\Phi = \int_0^\infty \sigma(E)\,\phi(E)\,dE \qquad (3)$$

If the flux is assumed to follow a Maxwell-Boltzmann distribution, and the cross section is assumed to vary inversely with neutron velocity (both reasonable assumptions under certain conditions) then eq. (2) and (3) can be evaluated exactly.

In the nuclear reactor neither assumption is strictly valid. The flux distribution is altered by the effects of neutron absorbtion, and the slowing down of neutrons from fission energy. The cross sections of a number of nuclides found in reactors do not follow the 1/v law.

The purpose of the proposed calculations is to solve eq. (2) and (3) by numerical methods.

The distribution of fission neutrons has its peak at about 2 Mev. Between 6 ev. and the upper limit of neutron energies, effects of all nuclides except U-238 may be neglected. Existing theory can be used to predict effects above 6 ev., so that 6 ev. can be used as the upper limit for this problem. The flux in the thermal range is assumed to follow a Maxwell-Boltzmann distribution, but the effective temperature is raised to account for the change from the distribution to be expected

if the neutrons were in true thermal equilibrium with the surroundings. Neutron slowing down theory will be used in the range from 6 ev. down to predict the flux.

From E_1 (the upper limit; 6 ev.) down to E_2(5kT, where kT is the peak of the thermal Maxwell-Boltzmann distribution) the epithermal flux calculated from slowing down theory will be simply added to the thermal flux distribution to give the resultant flux.

The epithermal flux calculated from slowing down theory approaches infinity as the energy approaches zero and at energies of the order of kT is obviously inapplicable. Therefore below E_2(5kT) the epithermal flux calculated from slowing down theory is multiplied by a function Q (see eq. 6e) which reduces the epithermal flux to zero below kT, and provides a smooth transition to the Maxwell-Boltzmann distribution in the range from 5kT to kT. Below E_2 the total flux is assumed to be the sum of the Maxwell-Boltzmann flux plus this corrected epithermal flux.

With the flux so defined, as the sum of a Maxwell-Boltzmann and a slowing down contribution, eq. 3 may be written as:

$$\bar{\sigma} = \int_0^{E_1} \sigma(E)\,\frac{\phi_{MB}(E)}{\Phi_{MB}}\,dE + \int_{KT}^{E_1} \sigma(E)\,\frac{\phi(E)}{\Phi_{MB}}\,dE \qquad (4)$$

The first term is the contribution from the Maxwell-Boltzmann flux, the second the contribution from the epithermal flux. From the first term, as compared to the values calculated, assuming 1/v cross sections and a Maxwell-Boltzmann flux, the effect of neglecting the non 1/v cross section characteristic may be determined. From the second term may be determined the effect of neglecting the epithermal flux. Both of these compoenets of the effective cross sections are numerically evaluated using known values of neutron cross sections as a function of energy and the Maxwell-Boltzmann and epithermal flux distributions which are calculated for the particular reactor conditions under consideration. The flux distributions must be calculated using the following equations. It is a function of the fuel composition and thus will change during reactor operation. The primary object of the calculations is to determine the relative magnitude of the contribution to the effective cross section due to the epithermal flux, and its variation with fuel compisition.

Calculation of Epithermal Flux

$$\frac{\phi(E)}{\Phi} = F(E) + \frac{f_1(E)}{\xi}\,C_1 \qquad (5)$$

where the various terms are defined by:

$$F(E) \equiv \frac{p(E)}{\xi(\Sigma_s+\Sigma_c)E}\sum_f \nu_f N_f \bar{\sigma}_{th}^{f} \qquad f_1(E) \equiv \frac{p(E)}{(\Sigma_s+\Sigma_c)E} \qquad (6a,b)$$

$$C_1 \equiv \frac{\sum_f \nu_f N_f \bar{\sigma}_{th}^{f}}{\xi - \alpha}\,\alpha \qquad \alpha \equiv \int_{kT}^{E_1}\Big[\sum_f \nu_f N_f \sigma_f(E)\Big]Q f_1(E)\,dE \qquad (6c,d)$$

$$Q = \begin{cases} 1 & 5kT \leq E \\ \frac{E}{5kT}\left[-0.1\left(\frac{E}{kT}\right)^2 + 0.85\frac{E}{kT} - 0.75\right] & kT < E < 5kT \\ 0 & E \leq kT \end{cases}$$

$$p(E) = p(E_1) \exp\left[-\frac{1}{\xi}\int_E^{E_1} \frac{\Sigma_a}{(\Sigma_s + \Sigma_a)E'}\, dE'\right] \qquad (6f)$$

The computations involved are as follows. The resonance escape probability, p(E), must be evaluated as a function of energy. Then the parameter alpha must be evaluated. The constant C_1 can then be determined. The epithermal flux as a function of energy can then be obtained from eq. (5). This is then used to evaluate the second term in eq. (4), which then gives the required result, for one nuclide.

It is estimated that 140 to 150 steps will be needed in the numerical integrations. About nine nuclides will probably be considered, and since both absorption and fission cross sections are needed in some cases, on the order of 13 x 140 or 1820 cross section values will be used.

The contribution to the total effective cross section from the epithermal flux may run around fifty percent in some cases, due to large resonances in the epithermal energy range.

During the past quarter, the effective absorption cross sections of U-235, U-236, U-238, Np-237, Pu-239, Pu-240, Pu-241, Xe-135, and Carbon, as well as the effective fission cross sections for U-235, Pu-239, and Pu-241 were calculated in eight different cases. A sodium-graphite reactor was used as the basis for calculation, and effects of varying fuel composition, temperature, and macroscopic scattering cross section of the system were considered.

It was found that neglecting the epithermal flux led to estimates of the cross section that were lower than the true effective cross section, in some cases the effective cross section being eight times as large (for Pu-240).

It was found that the effective cross section was significantly affected by variations of all three parameters mentioned above. Therefore in any calculation of fuel composition over extended irradiation times it will be necessary to recalculate effective cross sections at suitable time intervals, on the basis of the current fuel composition. This type of calculation, using the methods developed for the present problem for calculating the effective cross sections, is being considered for future work, using the IBM-704.

M. Cohen
Nuclear Engineering

407 C. DIFFUSION BOUNDARY LAYER

Mass transfer into a high speed boundary layer results in the simultaneous action of momentum, energy, and mass transports and produces considerable changes in the thermal behavior of the layer. Previous computations (Problem 297) indicated the effects for free flight conditions. Presently the effects to be

encountered under wind tunnel conditions are to be evaluated in conjunction with an experimental program into the phenomena.

The descriptive system of simultaneous equations is of the form

(momentum)	$(\lambda f'')' + ff'' = 0$
(mass)	$c_1'' + ac_1' = 0$
(energy)	$T'' + b_1 T' + b_2 = 0$

in which a, b_1, and b_2 are functions of the indicated dependent variables. The end point boundary conditions involve coupling between c_1 and f and otherwise constant specifications for either the dependent variable or its derivative.

The Gill-Kutta routine will be employed for integrations and repeated integration continued until proper end point conditions are attained. Successive estimates of boundary conditions will be made on the basis of an influence coefficient routine supplied to the computer.

Integration will be over the range $0 \leq \eta \leq 6.0$ in increments of $\Delta\eta = 0.1$. Output will be taken on magnetic tape and consists of f, f', f'', c_1, c_1' T, T' all as functions of η.

During the past quarter preliminary computations were made to check out the program and to evaluate the need for special integration intervals in regions of rapid variations of the parameters. During the next quarter the computations will be devoted to obtaining solutions corresponding to wind tunnel test conditions.

J. R. Baron
Naval Supersonic Laboratory

408 C. FREQUENCY SPECTRUM OF MAGNESIUM

The development of digital computers capable of making the requisite numerical calculations has led to a revival of interest in the Born-von Karman theory of lattice dynamics. The vibrational frequency distribution function and the bulk thermodynamic properties of several metals crystallizing in the face centered cubic system have been computed using interatomic force constants derived from the adiabatic elastic constants of a metal single crystal or from the temperature diffuse scattering of X-rays. Since the most sensitive comparison with experiment is provided by the lattice heat capacity at low temperatures, calculations using the force constants at liquid helium temperatures are of the greatest interest.

Recent low temperature measurements of the elastic constants of magnesium have been interpreted in terms of a central force model considering interactions between first, second, and third nearest neighbors. It is proposed to solve the secular determinant derived from this model at 793 points in the reduced Brillouin zone. Since magnesium is a hexagonal close packed metal with two atoms per unit cell, the secular determinant is of order 6 and 4758 distinct roots will be obtained. It is expected that this root sampling, when combined with the group theoretical and topological considerations regarding the existence of singular points in the frequency distribution spectrum discussed by Phillips, will provide a good picture of the density of vibrational energy levels in magnesium.

The computational problem involves the generation of the elements of the secular determinant at each point in reciprocal space where solutions are desired and the determination of the characteristic values and vectors making use of the program developed by F. J. Corbató.

During the past quarter a satisfactory program was arrived at. The computations are in progress. A trial spectrum calculated from the roots of the secular determinant at 143 points in the first Brillouin zone have heat capacities in good agreement with the experimental data. Programmers working on this problem are E. Mack, L. Slutsky and C. W. Garland.

L. Slutsky
Chemistry Department

409 C. AN ANALYTICAL STUDY OF BLUFF BOMB TRAJECTORIES

A machine solution is to be obtained for a set of 3 differential equations describing the rigid body longitudinal dynamic motion of a bluff-bomb configuration from the instant of release at an initially prescribed altitude, attitude, and speed until it contacts the ground. Non-linearities of aerodynamic coefficients with speed, altitude, and angle of attack will be represented analytically from point to point of the trajectory and the solution will be integrated as a function of time with respect to a Euler reference axis system. Approximately 300 Kutta-Gill solutions of the set below will be required:

$$\dot{u} = -w\,\dot{\theta} + C_x\,(u,w)\,\frac{gS}{W}\,Q - g\sin\Theta$$

$$\dot{W} = u\,\dot{\theta} + C_z\,(u,w)\,\frac{gS}{W}\,Q + g\cos\Theta$$

$$\ddot{\theta} = C_{m\dot{\theta}}\,(u,w)\,\frac{S\,d^2}{2I_y}\,\frac{Q}{u}\,\dot{\theta} + C_{m\dot{\alpha}}\,(u,w)\,\frac{S\,d^2}{2I_y}\,\frac{Q}{u^2}\,\dot{w} + C_m\,(u,w)\,\frac{Sd}{I_y}\,Q$$

The Greek notation consisting of:

α	Alpha, lower case angle of attack
θ	Theta, lower case pitch angle
Θ	Theta, Capital path angle

The Roman notation being:

u	Velocity along X-axis
W	Velocity along Z-axis
C_x	X-Force aerodynamic coefficient
C_z	Z-Force aerodynamic coefficient
C_m	Moment coefficient in pitch

$C_{m\dot{\theta}}$	Aerodynamic Stability Derivative wtih respect to pitching velocity.
$C_{m\dot{\alpha}}$	Aerodynamic Stability Derivative wtih respect to rate of change of angle of attack.
g	Acceleration of gravity.
S	Reference area.
d	Roference diameter.
W	Weight.
I_y	Pitching Moment of Inertia.
Q	Dynamic pressure.

During the past quarter, the present phase of the problem was completed. Future plans will depend upon the analysis of the present results.

Programmers working on this problem are P. G. Kase and T. Carney.

P. G. Kase
Aerophysics Research Group

3. ACADEMIC

3.1 Introduction

There are a number of graduate subjects in automatic computation, numerical analysis, electronic data processing and automatic control currently offered at M.I.T. The present list of subjects directly related to machine computation offered during the Academic year of 1957 includes the following:

Subject	Description	Units	Year	Instructor
6.25	Machine Aided Analysis	3.6	4	Arden
6.535	Digital Computer Coding	3.6	G	Arden
6.538	Electronic Computational Laboratory	3-1-5	G	Verzuh
6.54	Pulse Data Systems	3.6	G	Woodrow
6.567	Switching Circuits	3-1-6	G	Caldwell
6.568	Switching Circuits	3-1-6	G	Caldwell
2.215	Methods of Engineering Analysis	3-9	G	Crandall
15.542	Management Information Systems	3-6	G	Gregory
M39	Methods of Applied Mathematics	3-9	G	Hildebrand
M411	Numerical Analysis	3-2-7	G	Hildebrand
M412	Numerical Analysis			
		3-2-7	G	Hildebrand

It is apparent from the above list that these subjects are predominantly Graduate A subjects. However, a number of undergraduate students may and do take these subjects on an elective basis.

3.2 Electronic Computational Laboratory -- 6.538

The subject matter offered in 6.538 during the Spring term of 1957 provided the student with an opportunity to obtain a first hand knowledge of the operation of the Type 650 Magnetic Drum Calculator. Each student spent at least 14 hours in the laboratory operating and using the 650 Calculator.

The students were taught to program the 650 by first becoming familiar with the basic 650 language. After the basic language was understood, they were taught to use the M.I.T. Selective System and Bell Fixed and Floating Point Interpretive Numeric Coding System. On occasion certain students found it helpful to use one of the less common interpretive systems in their work. For example the MITILAC Decimal Interpretive Mneumonic Coding System and the FLIMSY, Floating Interpretive Matrix System were used on a very limited scale.

3.3 6.538 Term Papers Performed During the Spring Term 1957

For a number of years it has been common practice to assign a term paper as one of the major undertakings in this subject. Unfortunately, the enrollment in the course has doubled each year. Specifically, in 1955 there were 13 students enrolled in this course; in 1956 there were 26 students; in 1957 there were 52 students. As a result the amount of laboratory instruction required appears to be increasing on

the linear scale. The following term paper assignments were performed as indicated below:

The Feasibility of Monte Carlo Matrix Inversion Using Digital Computers.
Modified Aitken Method of Matrix Inversion.
Power Limit Transmission with Static Load.
Sorting on the Datamatic Computer.
A Study of Brokerage Accounting.
MITSS Subroutines.
An Attempt at Finding the Characteristic Equation of a Complex Matrix.
Data Processing in the Brokerage Field.
Floating-Point Arcsin Subroutine Trace Subroutine.
Complex Arithmetic Subroutines for Use with MITSS Floating Decimal Point System on the IBM 650 Computer.
An Integrated Program for the IBM 650 Magnetic Drum Data-Processing Machine to Calculate Certain Statistical Quantities from a Group of Data.
Subroutines for 18 Digit, Floating Decimal System.
Motion of a Body in the Earth-Moon System.
A Digital Computer Solution of Langhar's Velocity Distribution Equation.
A Subroutine for the Calculation of Statistical Variations.
Feasibility Studies of Automatic Data Processing Equipment in Business
A Study in Market Research.
An Exploration of a Logical Model to Obtain an Initial Distribution in a Stepping Stone Linear Program.
A Study of Payroll Calculation on a Computer.
Factorization of a Polynomial (Hitchcock's Method)
Double Register, 18-Digit, Floating Point Arithmetic Routines for the IBM Type 650 Magnetic Drum Data Processing Machine.
Preliminary Report on Function Display Program for the 704.
Digital Differential Analyzer Solution of Several Differential Equations.
Market Analysis of Electronic Data Processing Machines.
Solution of Bessel's Equation by Predictor Corrector Type Formulae on the IBM Type 650 Computer.
The Solution of Simultaneous Linear Equations on the IBM 704 Electronic Data Processing Machine by Use of Aitken's Elimination Method.
Routine for the Solution of Any Second Order Differential Equation.
Calculation of the Eigenvalues of a Matrix in Jacobi Form on the IBM 650 Calculator.
Error of Runge-Kutta Fourth-Order Formula Applied to a Bessel Equation.
Programming of Statistical Quantities for Computation on the 650 Magnetic Drum Calculator.
650 Program for Solution of Bessel Equation.
VADFAN. A Program to Perform Variable Degree Factorial Analysis.
A System of Matrix Arithmetic Subroutines for the IBM 650 Data-Processing Machine.

Design a System for Use with the 650 Which Will Provide Fast, Economical Input to the Machine or Payroll Information from Departments Operation on a Piece-Work Basis.
Solution of the Heat Flow Equation.
Calculation of Life Insurance Premiums Using the IBM 650 with MITSS and SOAP.
Data Processing Analysis of Annual Rate Method for Computing Group Property Depreciation.
Basic Ship Calculations on the IBM Type 650 Digital Computer.
Computation of Mean Values and Variances.
Simulation of Consumer Goods Distribution.
Solution of Differential Equation with a Maximum Error Criterion.
Sorting and Merging on Univac I and II.
An Interpretive System for Double Precision Arithmetic.

3.4 The MIT Computation Center

In the Spring Term of 1957 witness the completion of the new Karl T. Compton Laboratory and the accompanied installation of the large-scale Type 704 Computer in the new building.

The MIT Computaton Center, which was established in July 1956, is an interdepartmental activity located in the new Karl T. Compton Laboratory. The principal objective of the Center is to increase the number of students, staff and scientists qualified to use modern computing machines to further their research efforts.

The Computation Center is an activity which has many assets: qualified staff, modern computing equipment and a brand new physical plant. The participating personnel in the Center program are located at MIT or at one of the participating New England Colleges or Universities, or at the IBM Corporation. Specifically, the Computation Center represents a cooperative activity involving MIT, the IBM Corporation and, at present, 25 New England Colleges and Universities.

The following New England Colleges and Universities -- in addition to MIT -- are currently participating in this program:

Amherst College
Bates College
Bennington College
Boston College
Boston University
Bowdoin College
Brandeis University
Brown University
Connecticut, University of
Dartmouth College
Harvard University
Maine, University of
Massachusetts, University of
Middlebury College
Mount Holyoke College
New Hampshire, University of
Northeastern University

Rhode Island, University of
Tufts University
Vermont, Universtiy of
Wellesley College
Wesleyan College
Williams College

An active participation by the staffs of the New England Colleges in the Computation Center program was initiated by the appointment of 24 Research Assistants and Associates at these institutions during the academic year 1956 - 1957. These appointees provide active liaison between the staff at the Center and the students and staff at their individual institutions. Appointments of this type will be made each year -- to insure a widespread and dynamic participating program.

The physical plant of the MIT Computation Center consists of 18,000 square feet located in the recently-erected Karl T. Compton Laboratory. Specifically, the Center occupies part of the basement, the entire first floor, and part of the second floor of the Compton Laboratory. In addition, a two-story annex is used to house the IBM Type 704 Electronic Data Processing Machine (EDPM) and the associated Electric Accounting Machine (EAM) equipment.

The first floor contains adequate space for the headquarters staff, the operations staff (analysts, programmers, machine operators, etc.), IBM Institutional Representatives, New England University Research Assistants and Associates, MIT Research Assistants and Associates, classroom and seminar room, as well as the 704 computer. The basement provides space for the EAM machines, the systems research laboratory, dark room facilities, the electrical power plant, and the air conditioning equipment. The second floor provides space for the programming research staff, the visiting professors, and the library and document room.

All this area has been furnished in a first-class manner to facilitate the progress of research at the Center.

The computational facilities in the Center are supported in large measure by the IBM Corporation. Specifically, IBM is providing the 704 computer, the associated EAM equipment, and the associated maintenance personnel on a gratis basis. The following machine complement is available in the Center:

Quantity	Type	Description
1	704	Analytical Control Unit
1	711	Punched Card Reader
1	716	Alphabetic Printer
1	721	Punched Card Recorder
1	733	Magnetic Drum Unit (8192 words)
1	736	Power Frame #1
2	737	Magnetic Core Storage (8192 words)
1	740	CRT Output Recorder
1	741	Power Frame #2
1	746	Power Distribution Unit
1	753	Magnetic Tape Control Unit
10	727	Magnetic Tape Units
1	780	CRT Display Unit

Off-Line Equipment

Quantity	Type	Description
1	714	Card Reader
1	717	Alphabetic Printer
1	722	Card Punch
2	727	Magnetic Tape Units
1	757	Printer Control Unit
1	758	Punch Control Unit
1	759	Card Reader Control Unit

Auxiliary Machines

1	024	Key Punch
5	026	Key Punches
3	056	Verifiers
1	066	Printing Card Unit)Data Tran.
1	068	Telephone Signal Unit) & Rec.
1	077	Collator
1	082	Sorter
1	407	Accounting Machine
1	519	Reproducer
1	552	Interpreter

During the Spring Term of 1957 the 704 Computer and the physical plant were not sufficiently well along to permit actual use of the machine. As a result the students of 6.538 were given guided tours through the Center and had an opportunity to view the physical machine components. Unfortunately, however, they were not able to use the computer for their term papers.

3.5 Summary of Student Enrollment Statistics

An indication of interest in machine computation may be obtained by considering the enrollment in each of the subjects which have been offered during the academic year, 1956-1957.

Subject	Title	No. of Students Fall	Spring	Total
2.215	Methods of Engineering Analysis	17	0	17
6.25	Machine Aided Analysis	132	0	132
6.535	Digital Computer Coding	0	112	112
6.538	Electronic Computational Laboratory	0	52	52
6.567	Switching Circuits	52	0	52
6.568	Switching Circuits	0	48	48
15.542	Management Information Systems	30	0	30
M371	Operations Research	33	0	33
M39	Methods of Applied Mathematics	152	187	339
M411	Numerical Analysis	37	0	37
M412	Numerical Analysis	0	18	18
	TOTALS	453	417	870

It is apparent from the above list that the total attendance in these 11 subjects was 870 students. This does not mean however, that there were 870 individuals involved, since a number of students took many of the above subjects. Thus the actual number of individuals exposed to machine computation is somewhat less.

F. M. Verzuh
Assistant Director
MIT Computation Center

APPENDIX

1. SYSTEMS ENGINEERING

WWI RELIABILITY (18 March - 26 May 1957)

The following is the WWI Computer Reliability for the above-mentioned period:

Total Computer Operating Time in Hours	1687.3
Total Time Lost in Hours	40.9
Percentage Operating Time Usable	97.6
Average Uninterrupted Operating Time Between Failure Incidents in Hours	28.0
Total Number of Failure Incidents	73
Failure incidents per 24 Hour Day	1.03
Average Lost Time per Incident in Minutes	33.6
Average Preventive Maintenance Time Per Day in Hours	2.3

ANELEX LINE PRINTER

The Lincoln Laboratory use of WWI requires that a great deal of data be processed and the results printed out for visual inspection. In order to keep the computer time for this data processing to a minimum, the delayed printout system is used. However, after the information is recorded on the magnetic tape, a period of from three to four days is required before the information is all available. Because of the delay, further tests were delayed until the data was available.

Group 22 asked that the Whirlwind I people investigate high speed line printers with the objective of connecting one to Whirlwind I to print out this large quantity of data. The Whirlwind I people suggested the Anelex Synchro-printer and it was purchased from Anelex Corporation by Division II of Lincoln Laboratory.

This particular Anelex Printer has available 56 different characters, 120 characters per line, and will print up to 600 lines per minute. Due to equipment considerations, the printer is operated at only 133 lines per minute on Whirlwind I if all 120 columns per line are used. If less information is printed per line, then the speed can increase up to a maximum of 600 lines per minute with 15 columns per line.

With the use of the Anelex Printer the information that previously took several days to obtain, is now ready in less time than was required to record on magnetic tape for delayed printout. This results in a saving of computer time as well as enabling users to have the data available several days sooner.

2. VISITORS

Tours of the Whirlwind I installation include a showing of the film, "Making Electrons Count", a computer demonstration, and an informal discussion of the major computer components. During the past quarter the following 8 groups totalling 130 people visited the computer installation.

April 30	Cambridge School of Weston	8
May 1	Everett Vocational High School	17
May 8	Northeastern University Course G3-215, "Computer and Control Components"	25
May 13	MIT Course 16.21, "Aircraft Structures"	9
May 14	Brown University	13
May 16	MIT Course 6.25, "Machine-Aided Analysis"	35
May 22	Wellesley College	11
May 24	Representatives of AMEC/Numerical Control Subcommittee of the Aircraft Industries Association	12

The procedure of holding Open House at the Laboratory on the first Tuesday of each month has continued. A total of 33 people attended the 3 Open House tours during the quarter, representing members and friends of the MIT community, Western Electric Co., Convair, Northrop Aircraft, Hyde Park High School and Boston Trade School.

During the past quarter, there were also 42 individuals who made brief tours of the computer installation at different times. Represented by these individuals were MIT, University of Pittsburgh, Elliott Brothers, American Gas and Electric Co., United Aircraft Corp., Harvard University, Michael Baker, Jr., Inc., and Remington Rand Corporation.

3. PUBLICATIONS

Project Whirlwind technical reports and memoranda are routinely distributed to only a restricted group known to have a particular interest in the Project, and to ASTIA (Armed Services Technical Information Agency) Document Service Center, Knott Building, Dayton, Ohio. Requests for copies of individual reports should be made to ASTIA.

The following is a list of memoranda published by the Scientific and Engineering Computations Group during the past quarter.

DCL-161	Generalization of Conjugate Gradient Methods	D. N. Arden	1/22/57

DCL-165	SHARE Assembler Operator's Notes for Initial Use at the MIT Computation Center	S. F. Best	2/18/57
DCL-171	The Direction Cards Used by the Proposed Operator Program	F. C. Helwig	4/18/57
DCL-171-1	A Proposed Operator Program for the 704 (Revision of DCL-171)	F. C. Helwig	5/1/57
DCL-175	Summary of PKDS2, an Octal Memory Printout Program	S. F. Best	6/4/57

PERSONNEL ON THE PROJECT

COMMITTEE ON MACHINE METHODS OF COMPUTATION AND NUMERICAL ANALYSIS

Faculty Supervisors:

Philip M. Morse, Chairman	Physics
Samuel H. Caldwell	Electrical Engineering
Stephen H. Crandall	Mechanical Engineering
David Durand	Industrial Management
Herman Feshbach	Physics
Jay W. Forrester	Industrial Management
Francis B. Hildebrand	Mathematics
Chia-Chiao Lin	Mathematics
J. Francis Reintjes	Electrical Engineering

Ex-Officio

Dean N. Arden	Electrical Engineering
Fernando J. Corbató	Computation Center
Frank M. Verzuh	Computation Center

PROJECT WHIRLWIND

Frank M. Verzuh, Head
Dean N. Arden
Sheldon F. Best
Marion Callaghan
Frank C. Helwig
Jack Roseman
Arnold Siegel
Murray Watkins
Monroe R. Weinstein

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