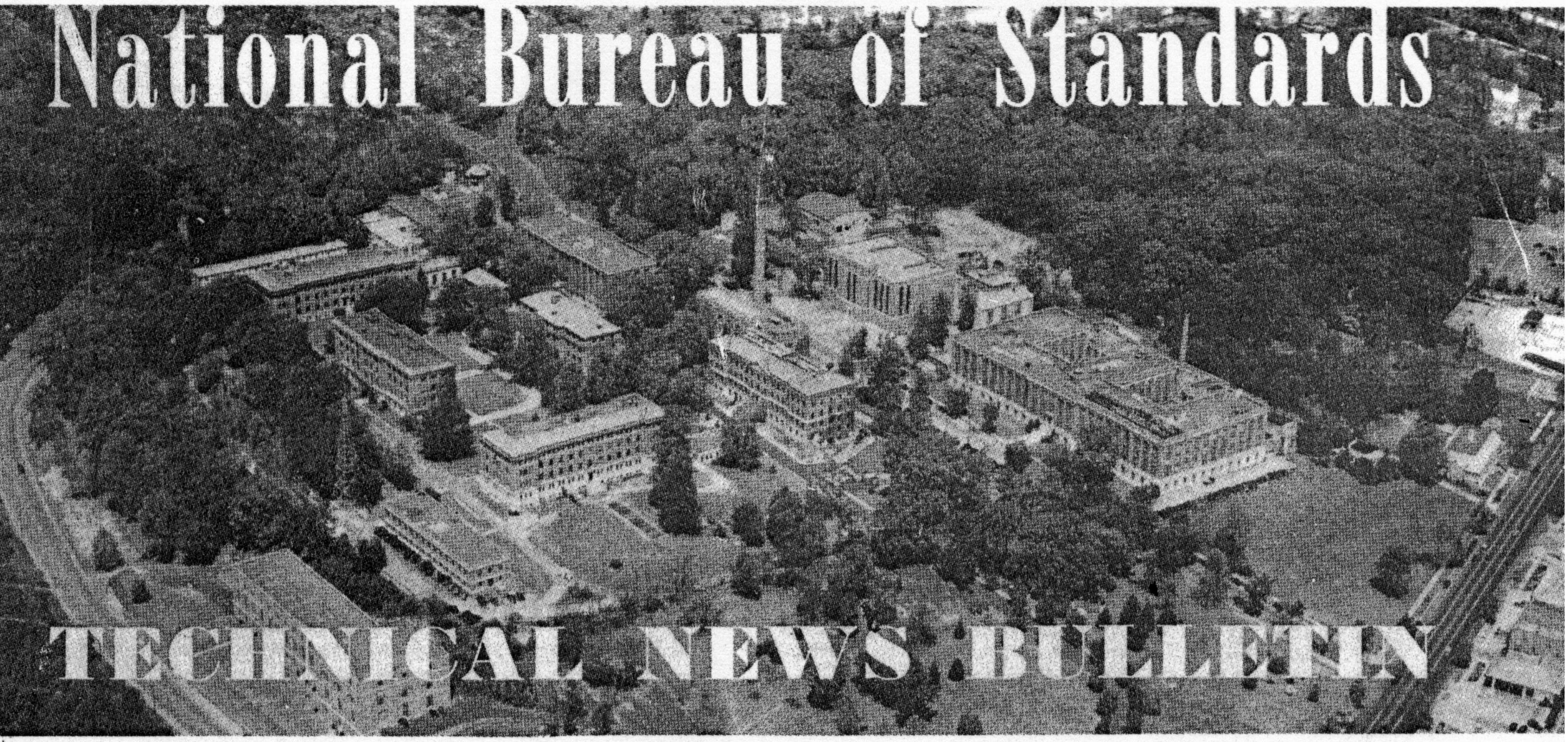

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SEAC

The National Bureau of Standards Eastern Automatic Computer

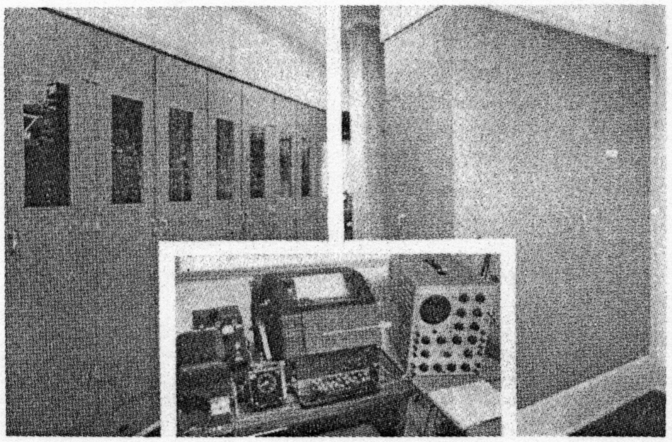
The completion and successful operation of SEAC—the National Bureau of Standards Eastern Automatic Computer—has been achieved by scientists of the National Bureau of Standards. SEAC is the fastest, general purpose, automatically sequenced electronic computer now in operation. It was developed and constructed, in a period of 20 months, by the staff of the National Bureau of Standards under the sponsorship of the Department of the Air Force to provide a high-speed computing service for Air Force Project SCOOP (Scientific Computation of Optimum Programs), a pioneering effort in the application of scientific principles to the large-scale problems of military management and administration. SEAC will also be available for solving other important problems of general scientific and engineering interest.

SEAC automatically performs all of the logical and arithmetical operations required to solve a particular problem when it is supplied with coded instructions and numerical data. Its high speed permits the use of many simple steps that can be combined into a complex and powerful sequence for the solution of difficult problems. This makes it possible to solve important mathematical, computational, and statistical problems which would otherwise be impossible of solution in any reasonable period of time, or which would be prohibitive in cost if attempted by conventional methods.

SEAC is a binary machine. That is, it uses only two digits, "0" and "1," to represent all numbers and instructions. The presence of a pulse is used to indicate "1" and the absence of a pulse indicates "0." A sequence of 45 binary digits is known as a "word" and may convey operational instructions to the machine as well as numerical data. The binary system was chosen because it is simple and rapid, and particularly suited to electronic machines. Conversion from the decimal system, in which the problems are prepared, is done automatically.

SEAC's high computing speed is the result of its rapid pulse rate and its large "memory." Being entirely electronic, it can operate much faster than machines which rely on the action of mechanical parts, whose response is far slower than that of electrical circuits. Numbers and instructions, in SEAC, are represented by trains of electrical pulses at the rate of one million per second. This rapid pulse rate, coupled with a memory of 512 words, makes it possible for SEAC to add or subtract pairs of 11-digit numbers 1,100 times per second, and multiply or divide them 330 times per second. These rates include the time it takes for the machine to search its memory for the numbers, operate upon them, and return the result to the memory. The actual arithmetical operation of addition or subtraction is completed in 50 millionths of a second (50 microseconds); multiplication or division, in 2,500 microseconds.

SEAC's computing functions are carried out in four main sections: An input-output unit, a memory unit, a control unit, and an arithmetic unit. The input-output unit is the link betwen the machine and its operators. Here numbers and instructions are fed in and answers are printed out. The memory unit stores numbers and



SEAC is housed in two cabinets. The acoustic memory is in one (right) 60 inches wide, 31 inches deep, and 84 inches high. The rest of the computer is in the other (left). It is 15 feet long, 5 feet deep, and 8 feet high. A manual keyboard (center) is at present employed for direct input, and punched paper tape for indirect operation.

instructions, as well as partial answers, until they are needed. The control unit constantly selects the paths along which information must travel, searching the memory for numbers to send to the arithmetic unit, returning answers to the memory, and finally directing the memory to deliver the answers to the operator via the input-output unit. The arithmetic unit carries out the actual computations which the control unit directs it to perform.

Engineering Design

In the development of SEAC, emphasis was placed on designing circuits especially for computer use rather than adopting the standard techniques of television and radar circuitry. All computing and switching are performed by interconnected germanium crystal diodes rather than by electron tubes. Tubes are employed only for power amplification. A uniform tube-and-transformer combination, consisting of a single type of electron tube coupled to the load through an appropriate transformer, is used throughout the machine to simplify both design and maintenance. The transformer method provides effective high-frequency coupling with a minimum of cross-talk between circuits. These advances in circuit design as well as several unique construction features make it relatively easy to add units to the machine, and the present version of SEAC is forming a nucleus for a larger and more versatile computer.

Because SEAC was needed for use as quickly as possible, its design was kept simple, and the equipment which had to be built initially was held to a minimum. SEAC was designed to operate as a serial machine because this mode of operation requires less equipment than the parallel method; this does not, however, mean less functional effectiveness. The list of basic operations or instructions was abridged for the same reasons, but provision was made for later expansion.

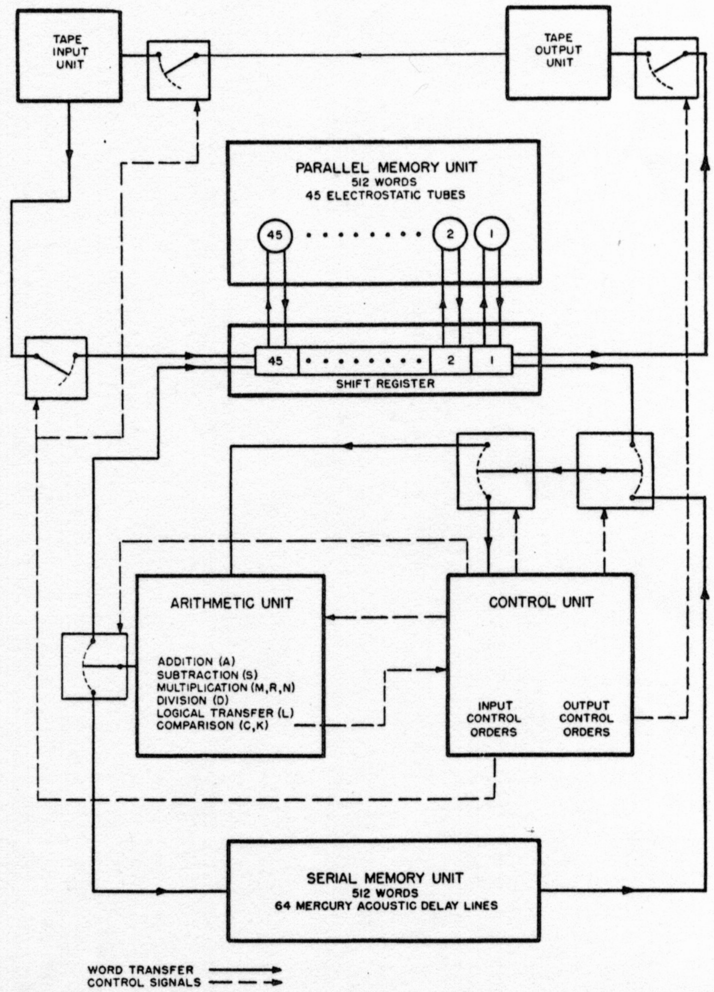
SEAC has seven basic orders, chosen after a study which established their convenience for solving the most elaborate problems the machine is expected to handle. The orders are addition, subtraction, multiplication, division, comparison, logical transfer, and input-output control. The comparison order allows two numbers to be compared to determine which is larger. This feature gives the machine a degree of choice. The result of a comparison thus dictates which of two alternative operational sequences the machine is to perform next. The logical transfer order makes it possible for the machine to alter a portion of an instruction it has previously received. Thus SEAC can modify its instructions, ascertain if it has made errors, determine when it has computed results to predetermined accuracy, and refrain from printing out incorrect answers.

SEAC's present input-output unit employs a manual keyboard for direct input and a teletype printer for direct output, using a hexadecimal notation (base 16) to represent both numbers and instructions. Indirect operation is accomplished through the use of punched paper tape. Input and output by means of paper tape proceeds at the rate of 30 words per minute. If magnetic wire or tape is substituted, the rate can be increased to 10,000 words per minute. SEAC's design allows for the later replacement of the paper tape system by an entirely automatic high speed magnetic wire system. An initial model of a magnetic wire input-output unit which provides a single information channel has already been completed and is currently being integrated into the machine. SEAC is flexible enough to accommodate a wide range of single or multiple channel input-output systems, so that future developments in magnetic tapes or drums can be directly incorporated if this is desirable.

SEAC's present memory is a serial type whose principal components are 64 acoustic delay lines and associated electronic equipment. The acoustic delay lines are glass tubes (24 inches by ¼ inch) filled with mercury which is in contact with two quartz crystals, one at each end. The electronic components reshape and amplify the pulses in the delay lines, and energize the germanium diode switches in this part of the system.

The capacity of this memory is 512 words, that is, 8 words in each of the 64 acoustic delay lines. Each word is stored as a sequence of sound waves travelling in mercury. The waves are 8 megacycle-per-second packets that are generated by the quartz crystal at one end of the mercury-filled tube and received by the crystal at the other end. The electrical signal from this crystal goes to a special electronic amplifier that returns the pulse sequence, at its original strength, to the first crystal. In this way a word is recirculated until it is replaced by other information from the computer. Because of the serial nature of the storage, the average access time to a word in the memory is 168 microseconds. The addition of a parallel memory system of 45 electrostatic tubes storing an additional 512 or 1,024 words with an access time of only 12 microseconds is currently in progress.

SEAC is housed in two consoles; the acoustic memory is in one, the rest of the computer (including space for the parallel memory) in the other. The memory



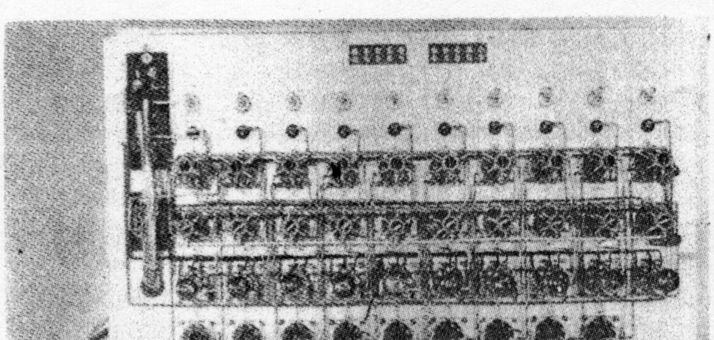
Over-all block diagram of SEAC. Switch symbols indicate electronic operations performed automatically under the direction of the machine's control unit. Switching times are about 1 microsecond.

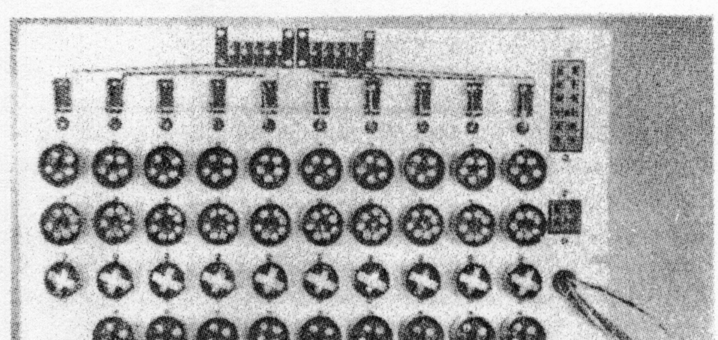
cabinet is 60 inches in width, 31 inches in depth, and 84 inches in height. The computer proper is enclosed in a cabinet 15 feet long, 5 feet in depth, and 8 feet in height. Inside this cabinet are eighteen racks, (each 19 inches in width and 72 inches in height), on which are mounted chassis bearing the individual components.

SEAC is not a "giant brain." The preparation of an instruction program to be solved on SEAC requires a great deal of skilled work by specially trained mathematicians. "Automatic" computers are so named only because they carry out their work, from problem to solution, without human intervention; but before they can attack the problem they must be given exact instructions governing every step in the solution. Thus, each machine is only as proficient as its operators. It does not replace the scientist; it merely takes the drudgery out of his work, freeing him to pursue more advanced problems. It is analogous to the assembly line which actually produces automobiles after designers have drawn the specifications both for the automobile and for the assembly line.

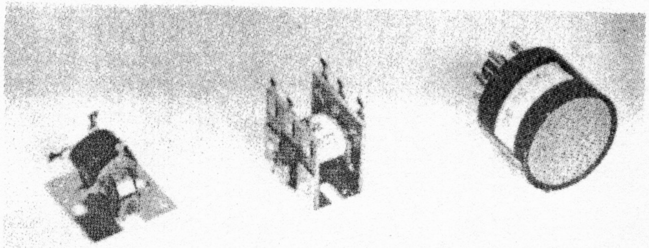
SEAC possesses a useful time-saving feature in connection with this very problem. Once the program for a particular kind of problem has been coded, it can be used over and over again with different sets of numerical data. The change-over from one type of problem to another is accomplished by sending in a new set of instructions through the input-output unit.. No rewiring or switch-setting is required. Instructions previously read into the machine may also be altered without complete erasure. This simplifies the preparation of problems since less complete instructions are needed at the outset.

SEAC has already solved important problems in optics and in thermodynamics as well as several purely mathematical problems of general interest that were solved earlier for the purpose of testing the machine. In one of the latter the machine was directed to compute the factors of any given number up to 100 billion. In a relatively short time it determined, for example, that the number 99,999,999,977 has no factors and is therefore a prime number. In order to do this, SEAC divided the number by 80,000 different trial divisors, which it systematically generated within itself. This problem, which represents 2 months' work for a man operating a desk calculator 8 hours a day, required 30 minutes for its solution on SEAC.



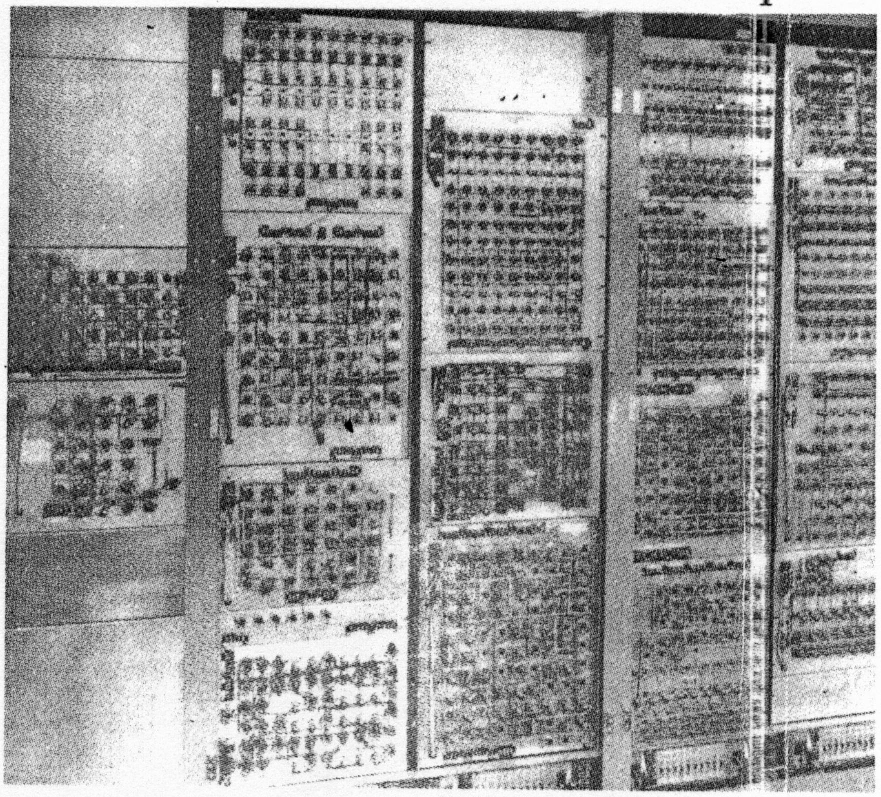


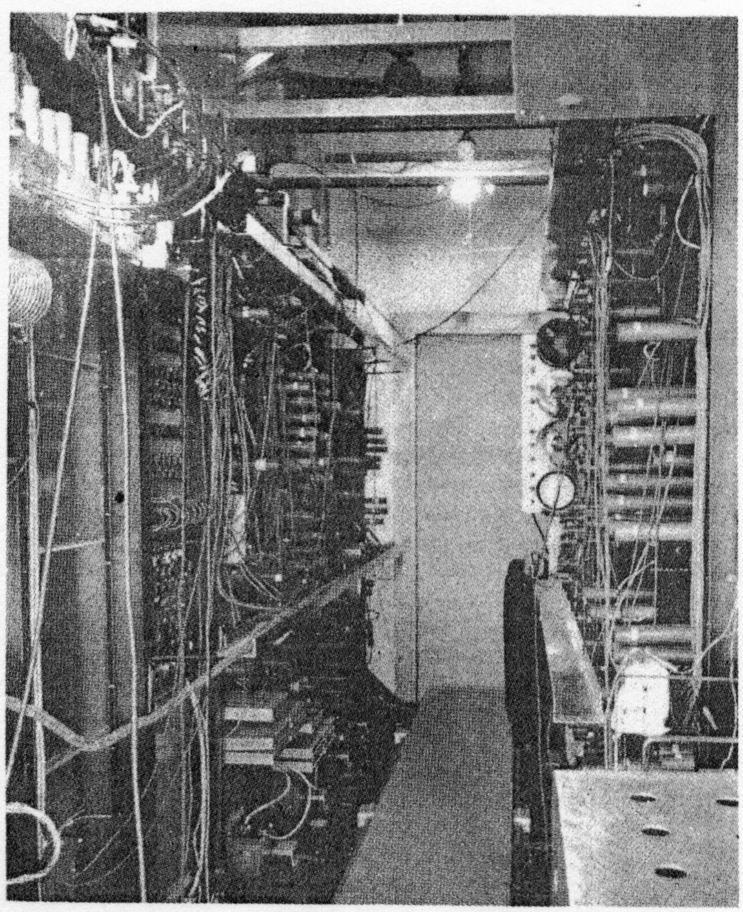
The address register (front and back) of the electrostatic memory system being installed in SEAC.

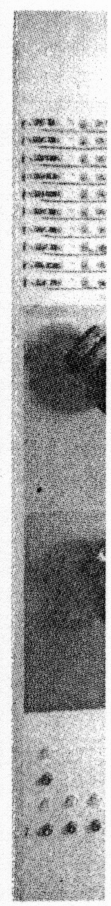


Pulse transformers provide effective high-frequency coupling with a minimum of cross-talk between circuits: Initial design (left), intermediate design (center) now being replaced by plug-in version (right). The transformers handle pulses occurring with a one-megacycle repetition rate.

The NBS Compute







The large-scale computers being developed today are electronic machines, entirely automatic and flexible, as well as fast. Under Federal Government auspices, the first bold step was taken at the University of Pennsylvania to prove the feasibility of such complex machines. The resulting machine, ENIAC, proved its value in the rapid calculation of important ballistic problems and was soon directed to the solution of pressing problems in the physical sciences. Since that time, several Government agencies, led by the Bureau of the Census and the Department of the Army (Office of the Chief of Ordnance), have requested the National Bureau of Standards to provide technical guidance and assistance in new computer programs.

Four principal phases characterize the program of the National Bureau of Standards on digital computers. These are fundamental research, engineering development, design and construction, and technical services. The program, involving work in both mathematics and electronics, has been carried out in the Bureau's Applied Mathematics Division and Electronics Division. SEAC is but one phase of this much broader program.

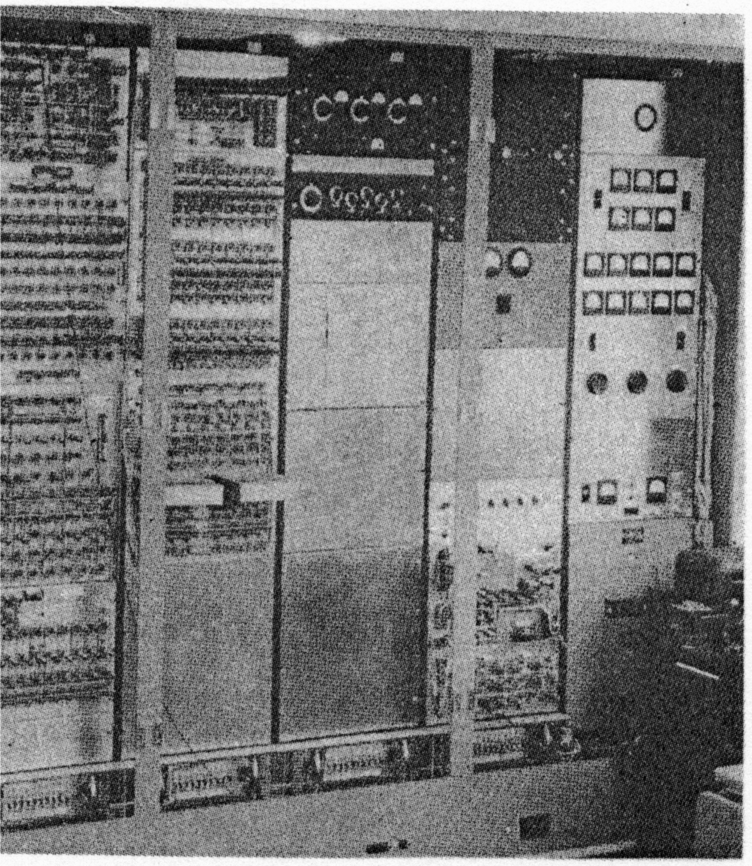
The fundamental research includes basic studies in numerical analysis, programming techniques, logical or system design, and circuit efficacy. The immediate objective is the more effective use of present machines and the long-range goal is the evolution of faster, simpler, and more versatile computers.

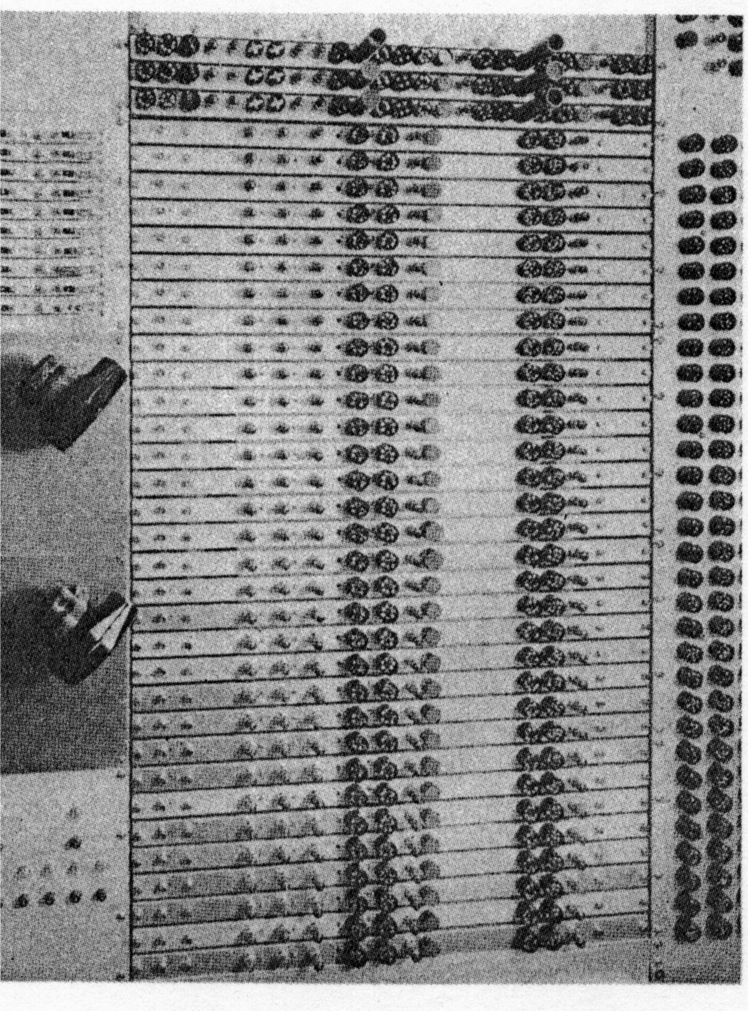
The mathematical aspects of the fundamental research phase are carried on in the Bureau's National Applied Mathematics Laboratories. This is a central computing laboratory and mathematical service facility for Government agencies, established at the suggestion of the Office of Naval Research. SEAC is one of three automatic computers to be installed in this division. From the start the division has followed a pattern laid down in many other parts of the Bureau, complementing the various lines of service work with vigorous research in pertinent fields of theory.

In particular, mathematical studies of the theory of numerical analysis have always played a particularly important role in NBS mathematical activities. These

Front of SEAC (top), with doors removed: (l. to r.) Control unit (racks 1, 2, and 3); arithmetic unit (4 and lower 5); time pulse generator (upper 5 and 6); clock pulse generator (7); controls and power supplies, and circuitry for punched-tape input-output (8 and 9).

ter Program





studies are carried on chiefly at the Los Angeles unit of the Bureau, called the Institute for Numerical Analysis. The research work there is largely supported by the Office of Naval Research.

The engineering aspects of the fundamental research phase are carried out in the Bureau's Electronic Computers laboratory. This is a section of the Electronics Division devoted to research, design, construction and consulting service on problems associated with computer equipment. Here the mathematical requirements serve as a guide for the lay-out of proposed computer systems. Mathematical and electronic research brings out the detailed nature of the equipment requirements. Thus, the relative advantages and limitations of different kinds of electrical and mechanical computer components can be judged, and engineering development is undertaken on components that need improvement. Recent work has been concentrated on certain critical computer needs: efficient memory systems, high-speed switching, and increased reliability of electronic components.

The design and construction phase represents the application of the knowledge derived from NBS research and development work and from current advances in the computer field. The basic design problem is the conceiving and devising of a specific and complete system in terms of operational requirements. The computer design and construction projects have already provided valuable engineering training and experience and will permit extensive programming and operating practice.

In addition to SEAC, a second machine, the National Bureau of Standards' Western Automatic Computer (SWAC), has now been completed in the NBS Los Angeles Laboratories.[1] SWAC was built under the sponsorship of the Office of Air Research, Department of the Air Force.

The final phase of the NBS computer program is in providing technical services for other Government agencies. This involves, in addition to mathematical and electronic consulting services and the construction and operation of SEAC and SWAC, technical coordination of contracts placed with industry for five other large-scale computers: One for the Bureau of the Census to tabulate and compute statistical information, one for the Air Force Comptroller for further work on program planning problems, one for the Army Map Service for calculations arising in map adjustment, all under construction by the Eckert-Mauchly Computer Corporation; one for the Office of Air Research to handle engineering computations, to be constructed by the General Electric Company; and one for the Office of Naval Research (to be operated by the NBS Computation Laboratory), under construction by the Raytheon Manufacturing Company.

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[1] A full description of SWAC will be published in an early issue of the Technical News Bulletin.

Lower left: Interior of SEAC's main cabinet. Right: The serial memory includes a bank of 32 recirculation amplifiers and 3 selection generators (top). The generators select the proper acoustic channel and send signals to the access circuits (right).

SEAC'S Solution of a Heat-Flow Problem

An important problem in the flow of heat through a chemically reactive material is represented by the partial differential equation

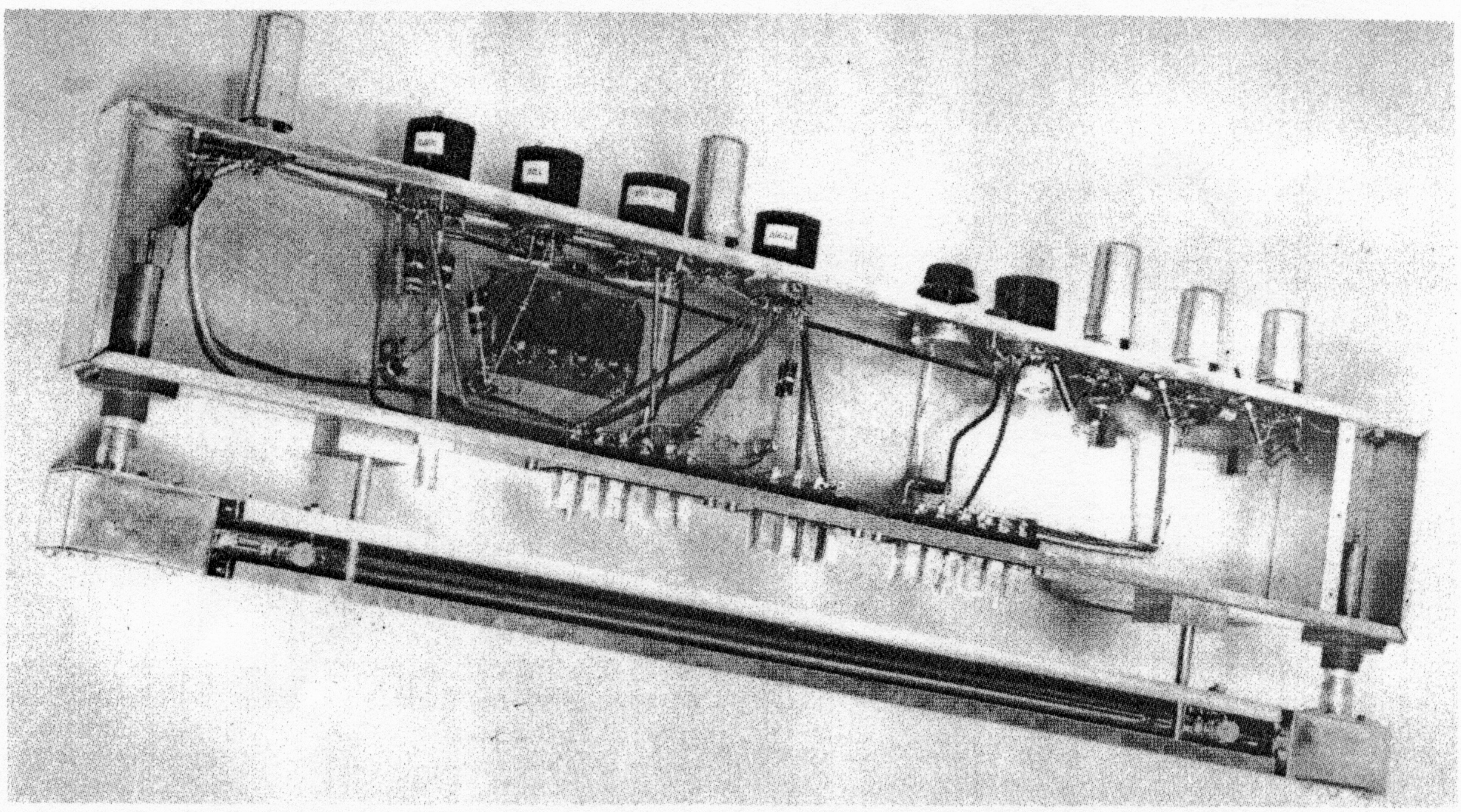
$$\theta_t = \theta_{xx} + e^{-1/\theta}.$$

The NBS Computation Laboratory has for several years been interested in solving this equation for 9 sets of initial conditions, defined by the expressions $\theta(x,0) = \theta_0$ and $\theta(0,t) \parallel \theta_1$. Because the problem is so complex, the solutions for only 4 sets of initial conditions were worked out by use of punched-card calculating equipment. As each solution is progressively more difficult, it did not seem practicable to continue with the remaining five sets of conditions. The simplest of the four solutions required nineteen days, and this time would have been more than doubled if several simplifications had not been applied.

A recomputation of the first solution was one of SEAC's earliest significant problems. The computation was completed in 46 minutes, including 16 minutes to type the results. All of the simplifications that had been applied in the earlier solution were omitted when the problem was coded for SEAC.

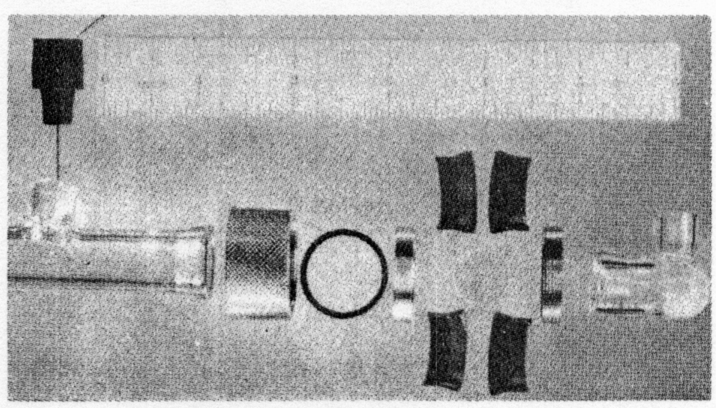
In the half-hour of actual computing, SEAC carried out the following operations: Starting with the temperature values given by the initial conditions, it derived by repetitive application of a computational formula the temperature values at successive intervals of time and distance. Each time the formula was applied, the intermediate set of temperature values was stored in the machine's memory. These were subsequently checked by another formula when the end of the time interval had been reached. The check served to monitor the accuracy of the computation.

To determine the significance of the results the process was repeated computing the temperatures for x-values (distance intervals) much closer together and with smaller time intervals. SEAC compared the temperatures for common points and, if agreement was satisfactory, continued the computation for a second time interval. When forty such time-sets were com-



(Above)

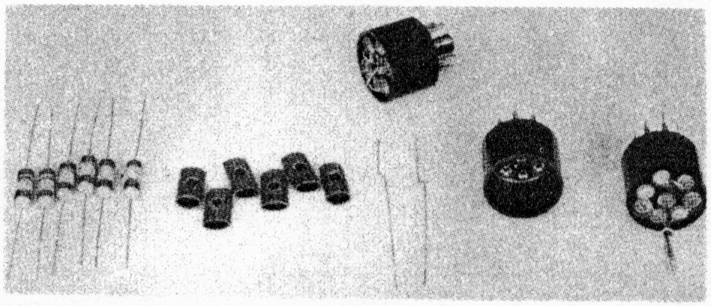
SEAC's serial memory unit consists of 64 acoustic delay lines and associated electronic equipment. The acoustic delay lines are 24-inch glass tubes filled with mercury (lower part of photo) and containing two quartz crystals, one at each end. A word is stored as a sequence of sound waves traveling in the mercury. Total storage capacity of the memory is 512 words, 8 in each of the delay lines.

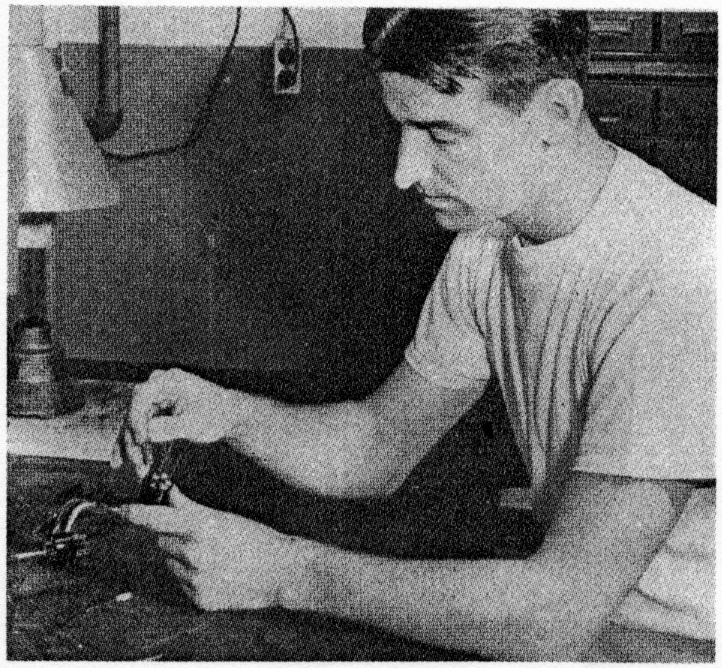


(Right)

End assembly of the mercury delay line.

All computing and switching in SEAC is done by germanium crystal diodes (left) rather than by electron tubes. The diode assemblies (right) were fabricated in the Bureau's electronic computers laboratory. In the development of SEAC, emphasis was placed on designing circuits especially for computer use rather than adopting the techniques of television and radar circuitry.

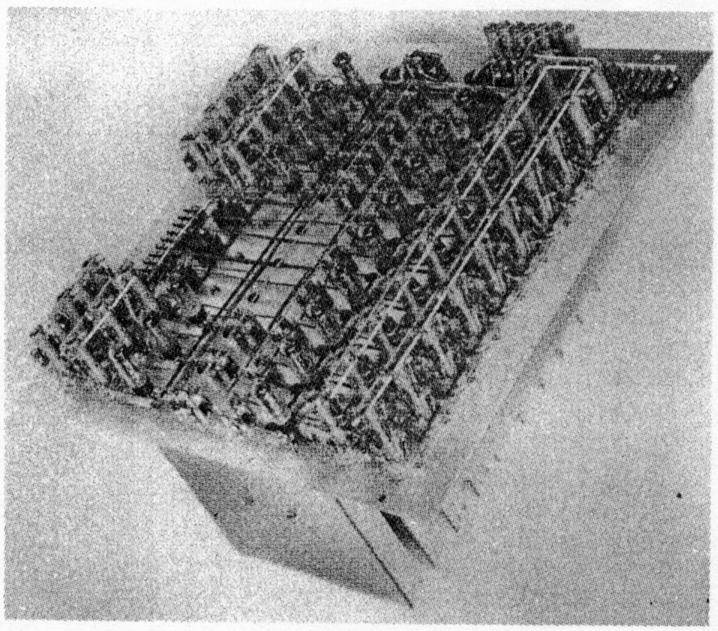




pleted and checked, the binary results for the fortieth set were converted into decimal equivalents and printed out, along with a count of the number of sets.

The 40-set cycle was repeated until the initially specified temperature was reached. At the end of that computation cycle, the machine stopped, ready to accept the next problem.

600 sets were computed in all, comprising over 30,000 points. At each point the machine evaluated the function $e^{-1/\theta}$ by a series expansion into Chebyshev polynomials. Each temperature value was examined to determine whether or not the time limit had yet been reached. As the computations progressed, SEAC had to keep a running check on the availability of storage space in the memory for the ever-increasing list of temperature values corresponding to the flow of heat in the x-direction.



The instruction register of the control unit holds an instruction word, consisting of 45 binary digits, in continuous circulation through a 48-microsecond electrical delay line. This line is coiled into 10 aluminum shields mounted on the rear of the chassis.

Operating specifications for SEAC

Characteristic	Specification
Basic repetition rate	1 megacycle per second.
Type of number representation	Binary system; serial.
Word length	Number words and instruction words consist of 45 binary digits (44 numerical digits and algebraic sign), equivalent in precision to approximately 13 decimal digits.
Instruction systems. Two modes of operation are available: [a]	
(a) 4-address system	Typical instruction word specifies 10-digit addresses of: (1) first operand, (2) second operand, (3) result of operation, and (4) next instruction.
(b) 3-address system	Typical instruction word specifies 12-digit addresses of: (1) first operand, (2) second operand, and (3) result of operation. Instructions are normally arranged in consecutively numbered memory locations.
Types of internal memory: [b]	
(a) Serial [b]	512 words stored in 64 mercury acoustic delay lines containing 8 words each. Access times: maximum, 336 microseconds; average, 168 microseconds.
(b) Parallel [b]	512 words stored in 45 electrostatic (Williams) tubes holding 512 binary digits each. Access time: average for typical operation, 12 microseconds.
(c) Serioparallel [b] (experimental).	32 words stored in 3 electrostatic (Williams) tubes holding 512 binary digits each. Access time: average, 1,728 microseconds.

[a] Before starting computation, the computer is set for operation in the particular system desired.

[b] The serial memory can be used in conjunction with either of the other 2 types. The experimental serioparallel type will be replaced by the 45-tube fully parallel system as soon as construction of the latter is completed. Pending this, the 3-tube system will be used for evaluating comparative performance under practical operating conditions of various types of memory tubes; e. g., Williams, Selectron. Provision is made for possible increase of the combined memory capacity up to 4,096 words.

Solution of Skew-Ray Problem

SEAC's first application in the physical sciences was the solution of a practical problem in optical design, the skew-ray problem, which involves tracing the paths of light rays through a system of lens surfaces.

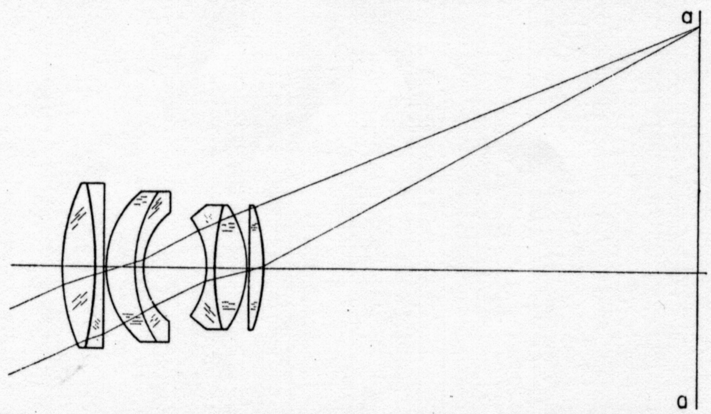
Modern photography, microscopy and astronomy are demanding optical instruments of greater precision and complexity. Progress in optical theory has kept pace with the demand, but the mathematical computations are, in many cases, so involved that ordinary methods employing desk calculators become too lengthy and expensive.

An optical system can be analyzed on paper if the designer knows the shapes and locations of all the surfaces and the speed of light through each type of glass used in the lenses. The designer then may select a few typical rays from a point on the object and compute their paths through the optical system. Having traced a sufficient number of rays, he can determine whether or not they are brought to a focus at the proper point of the image. If the rays do not focus properly, he must change the system and retrace the rays.

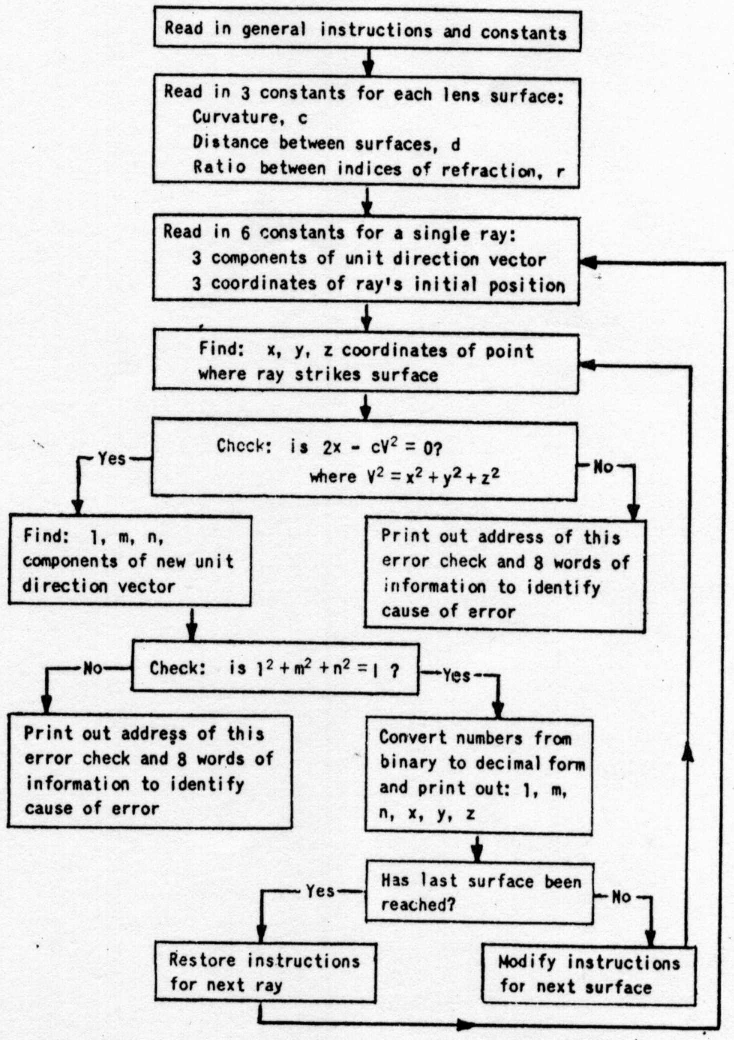
This process of designing an optical system may become so complicated as to require the services of two or three persons, using desk calculators, over a period of a year or more. Actually, after a certain amount of analysis has been done, it is often less expensive to build the system and test it experimentally than to carry the numerical calculations to completion. The time element thus puts a definite restriction on the progress of optical science, despite the improvements in glass making and lens construction which have occurred in recent decades.

SEAC has demonstrated that it can remove this restriction. The lens designer can now call on the new machine to carry out a more detailed analysis to a high degree of correction before building the lens. SEAC in solving the skew-ray problem, traced a total of 32 light rays through 11 optical surfaces. About 10 seconds were required for each ray. In a similar manner, the machine can compute an unlimited number of light-ray paths through as many as 100 or more lens surfaces. This means that for the more complicated systems SEAC can solve as many problems in 1 hour as an experienced operator can solve in 15 weeks, using the best desk calculator, or in about 6 years without mechanical aids.

The completion of SEAC at this Bureau has opened up entirely new possibilities in the numerical analysis of optical problems. It has simplified present methods of optical design and should encourage lens makers to modify some of their methods in order to adapt them to SEAC.



In a practical design problem for the Bureau's optical instruments laboratory, SEAC traced the paths of 32 rays through a system of lenses containing 11 surfaces. The position and direction of each ray was calculated at each optical surface and at the focal plane, *aa'*.



The sequence of operations followed by SEAC in computing the path of a light ray can be used for an unlimited number of rays through lens systems having as many as a hundred or more surfaces.

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