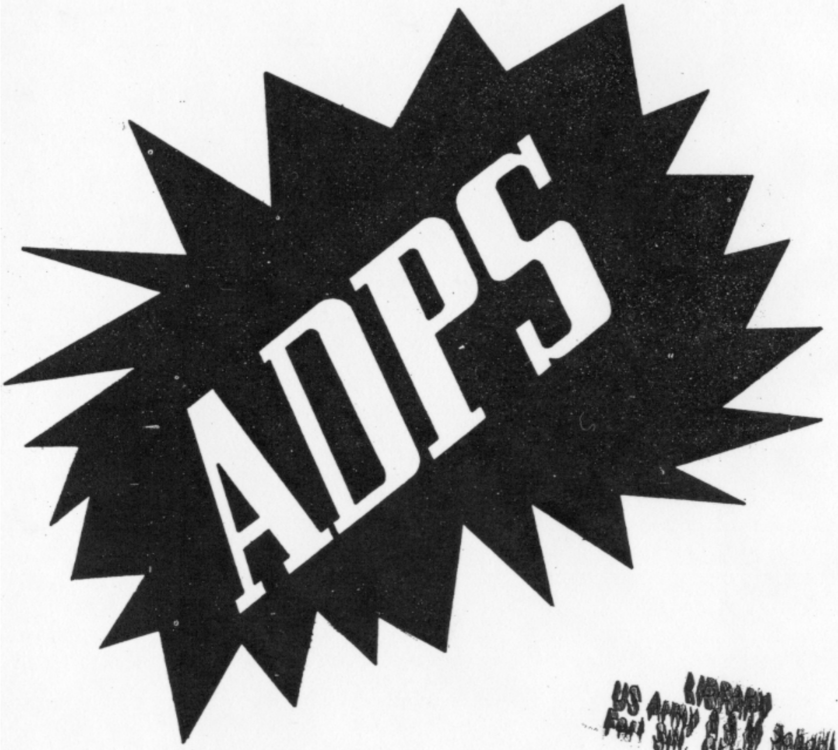
ARTILLERY
TRENDS



U S Army Artillery and Missile School

September 1960

ARTILLERY
TRENDS

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In This Issue

● ARTICLES

● COVER

ARTILLERY TRENDS latest endeavor—bringing the field artillery's effort with an automatic data processing system (ADPS) from 'darkness into light' for artillerymen worldwide.

Army Chief of Staff, General Lyman L. Lemnitzer, recently said that today's military leaders must have the vision to see the extensive new capabilities of modern equipment as it becomes available. He also added, "They must have the understanding to apply these capabilities alone and in combination, to achieve maximum effectiveness."

This issue of ARTILLERY TRENDS is devoted exclusively to automatic data processing (ADP) in the field artillery, with an account of the developmental work now being undertaken with digital computers and associated equipment. The US Army Artillery and Missile School believes that this effort will result in a significant gain for artillery. The information contained here is designed to stimulate thought among artillerymen worldwide, with the result that we will be prepared for the operational changes which will be caused by automation.

It must be kept in mind that much of the work being done is in the development stage. It must not be inferred that all items of equipment discussed are presently under construction. Many of the equipments mentioned are in prototype, however.

Material was submitted by the members of the Automatic Data Processing Committee at the Artillery and Missile School. This issue is for orientation purposes only, and does not necessarily reflect official Department of the Army or US Continental Army Command doctrine.

"Decisions in the saddle" TO ADPS

General Pope of the Army of the Potomac once made a statement that his headquarters was in the saddle. Warfare was relatively simple then, and the idea was at least feasible. Field headquarters were small, staff work was minimal, and a commander could make a decision quickly and effectively while on horseback. Today, however, the complexities of modern war have greatly increased the problems of command, requiring large headquarters and staffs to process the volumes of reports and routine matters which previously did not exist or were easily handled by the commander and his small staff.

Field artillery of the future will have an advanced weapon system capable of highly accurate and rapid fire. Better weapons, modern communications, and battlefield mobility have increased the tempo of war so that the time required for command decisions and staff reactions must be constantly reduced. There will be an increasing use of data between the elements of the weapon system. Presently, a variety of means, from message books to charts, are used to collect and process data, to disseminate it to the battlefield units, to obtain results in the form of "iron on the target" and to make reports and estimates on which command action is taken. These means serve us well today, but they will not be good enough in the future.

Realizing the need for reduced reaction time with the increased exchange of data, the United States Army has sought the assistance of technology, and a partial solution appears to lie in the field of automatic data processing (ADP). Defined as the recording, filing, computing, and production of data by electronic circuitry, ADP is the application of electronic digital computers and associated devices to information handling and decision processes. Automatic data processing can perform computations and produce information to assist in making decisions. Automatic data processing tasks fall into two categories: First, technical computing and, second, the recording, filing, sorting, and compiling of data.

Technical computing is of extreme importance to the artillery as well as the other arms and services. For example, complex mathematics relating to ballistics must be solved by computers to increase the speed and accuracy of artillery fire. Data processing is also of great interest to all the arms and services. The problem of handling operational records, statistics, and analyses expeditiously while reducing the clerical army of manual processors and increasing the accuracy of output is Army-wide. It is difficult to draw a line between technical (mathematical) computing and data processing because many operations contain elements of both. In either application, computers will produce results not normally attainable in the manual solution of the same problem.

DIGITAL COMPUTER, "HEART" OF ADPS

The heart of an automatic data processing system (ADPS) is the digital computer. It is a machine that uses electronic circuits to perform the functions of simple arithmetic and elementary logic. Once a "program" (a set of instructions to the machine) is stored in a computer's memory, these functions are automatically performed on data communicated through the system to the computer.

At this point, however, it is important to note the last word in "automatic data processing system(s)." The system is the key to the successful application of ADP in the field army. Only when a series of computers are connected by a digital communication system is their true value to tactical operations realized. Computers at various echelons, and peripheral equipment, such as input-output devices, control panels, and display elements, at many points on the battlefield will make up the system.

The Army's approach to tactical ADPS was initiated by studies in 1955 and 1956 which pointed out the advantages of ADPS to the army in the field. Its principal advantage is that it saves reaction time by accomplishing the Army's information handling and data processing in a more efficient manner, thereby enhancing command and control capabilities.

A Department of the Army research and development project was established, consisting of two major parts: (1) A hardware development program and (2) an application study program, which was directed toward developing a capability of performing the individual functions by machine methods and to combining the functions into ADPS subsystems—each to be a part of the common field army ADP system.

In the hardware development program, a family of data processing equipment is being prepared and will consist of mobile, general purpose digital computers, associated peripheral equipment, and digital communications devices.

In the study program, organizations with doctrinal responsibility in a particular area were selected to perform studies in that area. The US Army Artillery and Missile School, Fort Sill, Oklahoma, prepared four studies on the application of ADPS in the fields of fire control, fire planning, survey, and ammunition status control. Based on studies like these, subsystems will be designed, tested, evaluated, and finally implemented.

THE ARTILLERY'S EXPERIMENT IN AUTOMATION

Currently, the Artillery and Missile School is working with the US Army Electronic Proving Ground, Fort Huachuca, Arizona, in the development of Fire Support Subsystem 1 (SS1), the artillery portion of an ADPS for the field army. It is an experiment in automation and will be the first tactical subsystem to be created. Other subsystems now being developed involve logistics, intelligence, and administration.

Areas in which ADP will perform tasks for artillery are shown in figure 1. Emphasis is being placed on subjects related to the fire control function; the other areas will be completed at a later date as experience is gained and other subsystems are developed. The goal is to create a single, integrated system which will give commanders at all echelons a responsive command tool to aid them in exercising control which is vital to battlefield success.

1. Fire control
2. Survey
3. Meteorology
4. Target acquisition
5. Fire planning
6. Fire support coordination
7. Tactical ammunition control
8. Warning
9. Artillery intelligence
10. Combat intelligence
11. Logistics
12. Personnel administration
13. Map distribution
14. Training management

Figure 1. Areas in which automatic data processing will perform tasks for artillery.

An initial demonstration is expected to be conducted this fall at the Electronic Proving Ground Laboratory. A computer will be used to compute firing data, prepare a division artillery fire plan, handle survey and meteorological data, and perform other functions. A firing demonstration to culminate this work is being planned for early 1962 at Fort Sill.

A field artillery battalion and elements of a division artillery headquarters are expected to conduct an exercise using militarized computers and allied equipment.

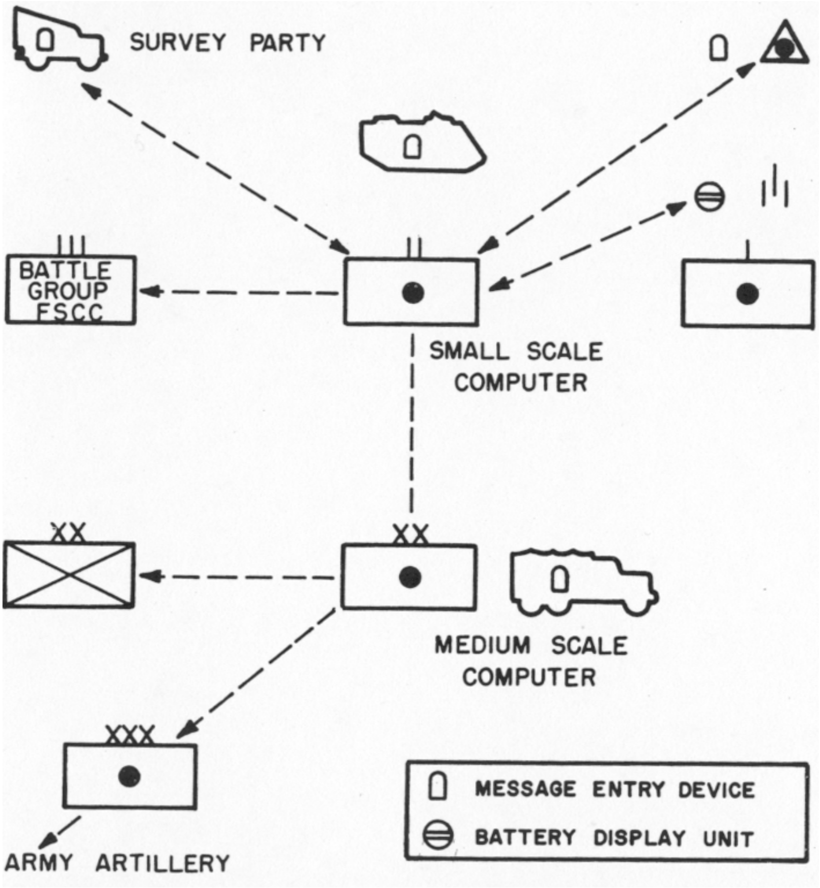

Figure 2. A possible allocation of equipment at battery, battalion, and division artillery headquarters.

The fire support subsystem must contain equipment which is rugged, simple, and easy to operate and maintain. The equipment should be designed so that the equipment configuration may be tailored to the needs of the echelon at which it is to be used. It must have characteristics which make it compatible with the other equipment in the field army system.

POSSIBLE ALLOCATION OF ADPS EQUIPMENT

The basis of issue of computers and other required equipment to units must await the results of the development and test program. However, a computer of appropriate size is visualized at each headquarters from battalion to Army artillery with simple input and output devices, such as Message Entry Devices (MED) for sending messages and Battery Display Units (BDU) to present fire commands to the batteries. In some instances, computers may be required at battery level. Figure 2 shows a possible allocation of equipment at battery, battalion, and division artillery headquarters. This equipment uses existing communication channels and must eventually have the capability of operating during movement, making it unnecessary to "close station" at a command post, thus removing a present limitation.

All subsystems developed under this program must then be integrated into one overall system for the entire army in the field. For this purpose, a study known as the ADPS Simplex Study is being conducted. This study is essentially one of system design and the application of electronic aids to provide an operational capability to the system. The study will analyze the total requirements for control of the army in the field and design a system to accommodate these requirements.

With the advent of ADP on the field of battle, artillery can expect significant gains. "First round accuracy" will give a tremendous increase in lethality when firing on targets of known location. The number of registrations and adjustments required will be reduced—thus a greater speed will be obtained and much ammunition will be saved. Many routine, lengthy computations will be eliminated. Above all, a new command tool will be gained that will enhance the position of artillery as a mighty element of combat power.

DO FIGURES LIE?

Example 1:

(1) $a = b = 1$		
(2) $a^2 = ab$		Multply by a
(3) $(a^2 - b^2) = (ab - b^2)$		Subtract b^2
(4) $(a - b)(a + b) = b(a - b)$		Factor
(5) $a + b = b$		Divide by $(a - b)$
(6) $1 + 1 = 1$		Substitute step (1)
or $2 = 1$	QED	

Example 2:

(1) $20 = 20$		
(2) $-20 = -20$		Multiply by -1
(3) $16 - 36 = 25 - 45$		
(4) $16 - 36 + 81/4 = 25 - 45 + 81/4$		Add 81/4
(5) $(4 - 9/2)^2 = (5 - 9/2)^2$		Factor
(6) $4 - 9/2 = 5 - 9/2$		Square root
(7) $4 = 5$	QED	Add 9/2

The mathematical "proofs" in examples 1 and 2 are obviously in error. Can you find the error in each? Test yourself before turning to page 29 for the solutions.

"First Round Hits" With FADAC

The capability of guaranteed first-round hits without registration for any weapon-weather-ammunition condition would be "music to the ears" to all artillerymen. The development of longer range cannon-type weapons and missiles has added impetus to the search to improve the present gunnery solution. The search has produced improved firing tables, graphical devices, and fire direction techniques second to none, and enabled the artillery to render outstanding fire support in World War II and the Korean conflict.

About 1950 it became apparent that some type of computer solution would be necessary to achieve the goal of rapid first-round accuracy on short notice without registration. The proper solution of the artillery gunnery problem appeared to be simulation of the flight of the projectile through a known nonstandard atmosphere from the tube or launcher to impact. This is referred to as solving the differential equations of motion of the projectile. Until about 1954, the necessary equations could only be solved on large scale electronic digital computers.

The first of the M15 and M15C analog computers, the heart of the M35 Field Artillery Fire Control System, were delivered to troop units on a limited procurement contract during January and February of 1960 (fig 3). The M15 and M15C computers produce a geometric and a

ORGANIZATION	**1**	**2**	**3**	**4**
USAAMS	3	1	2	3
4th Infantry Division	5	5	5	15
101st Airborne Division	6	0	1	9
2nd Armored Division	3	0	1	4
2nd Howitzer Battalion, 2nd Artillery	3	0	1	4
2nd Howitzer Battalion, 17th Artillery	3	0	1	4
TOTALS	23	6	11	39

Key: **1** Computer gun data M15 (105-mm How) conversion unit, power M27. **2** Computer gun data M15C (155-mm How) conversion unit, power M27. **3** Gunnery officer's console. **4** Generators.

Figure 3. Issue of the M35 Fire Control System.

firing tables solution for the 105-mm and 155-mm howitzers, respectively, with a measurable increase in accuracy and speed over manual techniques. However, the analog system has several disadvantages: First, it is accurate in the solution for the shorter range weapons but, as range increases, accuracy decreases; second, the solution is built into the hardware of the machine, which means that the machine can solve a problem for just one type of weapon. A more flexible system of computing, one that would expand the computer application to all artillery weapons, was needed.

Rapid strides forward in electronic digital computers—made possible by the development of improved memories, transistors, and printed circuitry—have made it possible for Ordnance to develop the Field Artillery Data Computer (FADAC). The FADAC (fig 4) is small and is capable of meeting the accuracy, flexibility, reliability, ruggedness, operator training, and maintenance requirements imposed by the mission and the environmental conditions under which the artillery must operate. Prototype models of the FADAC reached the US Army Artillery Board, Fort Sill, Oklahoma, in March 1960, for user test.

CHARACTERISTICS OF FADAC

The FADAC is a solid-state (no vacuum tubes), general purpose electronic digital computer that uses a 4,096 word rotating disk memory. Physical and environmental characteristics of the FADAC are summarized in figure 5.

In the fire control role the computer, under present concepts, will provide firing data for one battery of cannons or rockets. However, one computer is capable of storing data for three batteries and can provide firing data for any of the three batteries by simple operator selection of the battery solution desired. Without reprograming, computations can be made for three batteries of any two calibers of the cannon artillery family. For example, the computer can have the ballistic solution for 105-mm and 155-mm howitzers stored in its memory at one time. By using the memory loading unit and changing the small input face plate (see page 13), field personnel can make program changes to permit solution of other cannon, rocket, or missile problems; or other artillery problems such as survey, counterbattery, fire planning, flash and sound ranging, reduction of meteorological (met) data, and master control and programing for automatic checkout of missiles.

A problem in the use of digital computers in civilian industry today is the extensive operator training necessary to effectively use the machines. The FADAC will not require intense operator training. The method by which operation has been made simple is explained by reference to the FADAC control panel, which encompasses the entire front shown in figure 4.

By pressing the POWER ON pushbutton, power is applied to the computer, memory, and control section. The magnetic disk begins to

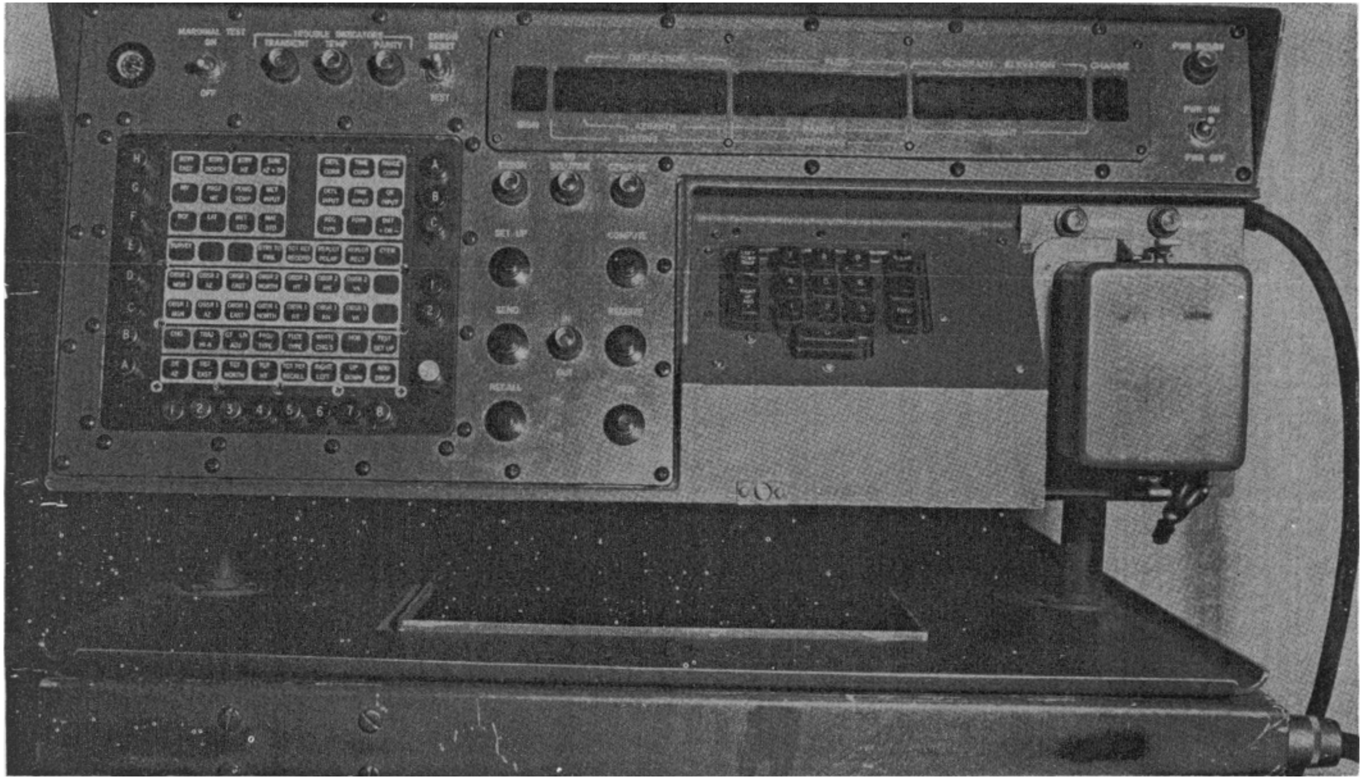

Figure 4.The Field Artillery Data Computer.

1. Overall size	14 inches high, 24 inches wide, 34 inches deep
2. Weight	Approximately 165 pounds
3. Power	Three-phase, four-wire, 400 cycles per second system; 120/208 volt (60 cycles per second will also be evaluated)
4. Operating temperatures	External temperature at sea level; —25 to 125 degrees Fahrenheit; —40 degrees Fahrenheit with kit
5. Environmental control	Inner chamber sealed during operation by combination case and heat exchanger. Internal air is recirculated through heat exchanger inner section for cooling
6. Field operation	a. Operable in dusty or humid environments b. Operation at elevations up to 10,000 feet above sea level and at any orientation up to 20 degrees from normal operating orientation c. Continuous operation for one year, alternating 16 hours on and 4 hours off, with normal maintenance

Figure 5. Physical and environmental characteristics of the Field Artillery Data Computer.

rotate and as soon as it reaches operating speed (6,000 revolutions per minute) the POWER READY lamp lights.

COMPUTER CHECKED FOR CORRECT OPERATION

Next, the computer is checked for correct operation by pressing the TEST button. This causes the computer to perform test functions to determine if it is in working order. The results are checked against answers stored in the computer circuitry. If there is an incorrect comparison, the ERROR light flashes and the operator knows he must go through simplified maintenance procedures using the FADAC Automatic Logic Tester (FALT) (fig 6). The procedure is entirely automatic and standardized due to a prepared test tape. Checkout operations can be performed by relatively nonskilled personnel. If there is no error, the COMPUTE lamp lights when the TEST button is pressed and remains lighted until test routines have been solved. When this light goes off, the operator can proceed to the next step.

Selection of input data is made by using an input function, for example, Battery Easting or Muzzle Velocity, on the input selection panel (fig 7). The eight buttons at the left side and the eight buttons at the bottom of the input selection panel are pushbuttons. The larger rectangular

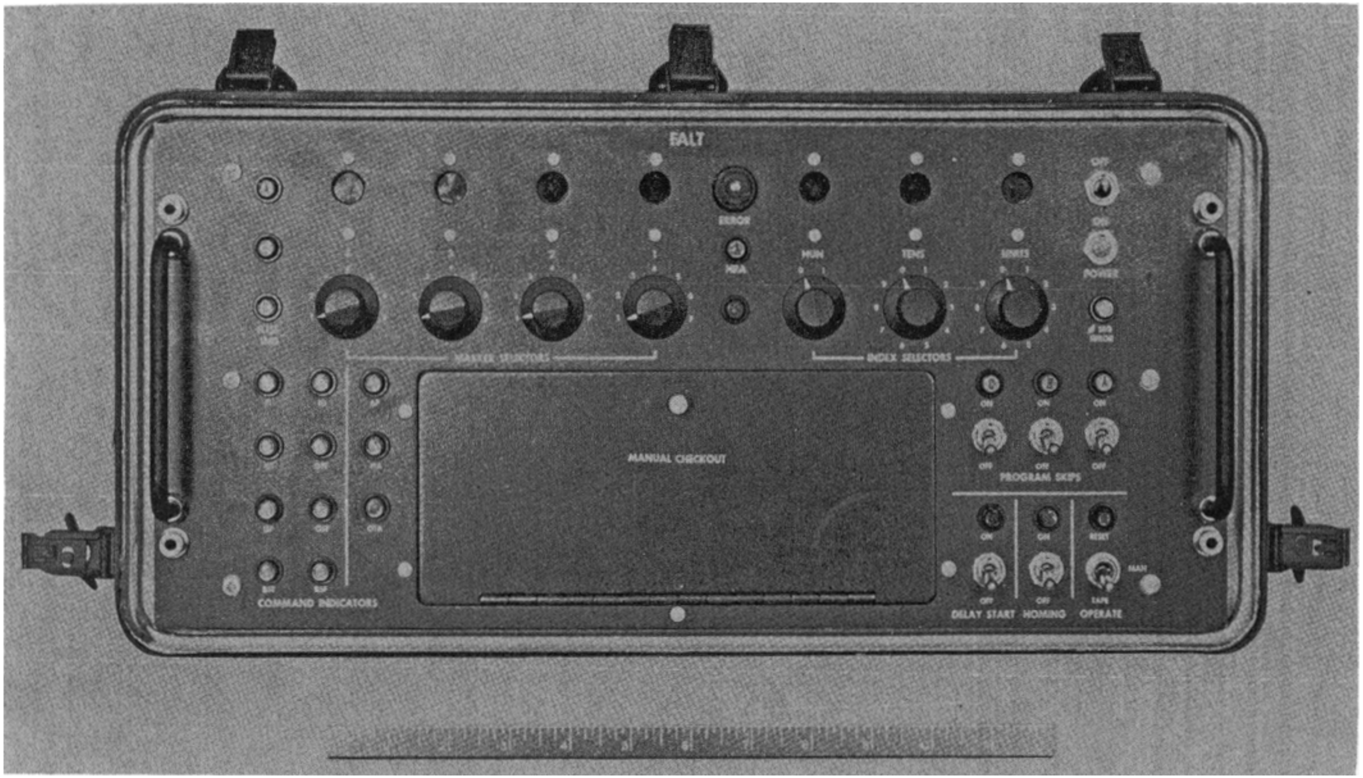

Figure 6.The Field Artillery Data Computer Automatic Logic Tester.

openings are rear lighted windows with the input data functions engraved on their faces, and are arranged for selection convenience. This provides 64 possible button combinations for entering specific problem input data. The 64 rear lighted windows permit the display of information in terminology familiar to fire direction center and battery personnel, thus reducing special operator training. Operators familiar with current graphical means of solution can be trained to operate FADAC in a short time. To enter input data, the operator locates the function name on one of the windows and presses a button directly below and another at the left of that window. The following events then occur:

(1) The selected input window lights up and enables a visual check on the proper input function selection.

(2) The computer program (a set of stored instructions) samples the position of these buttons so that the input data, when entered from the keyboard (fig 8), is stored in a predetermined memory location. Activation of these buttons will not affect the memory during computation.

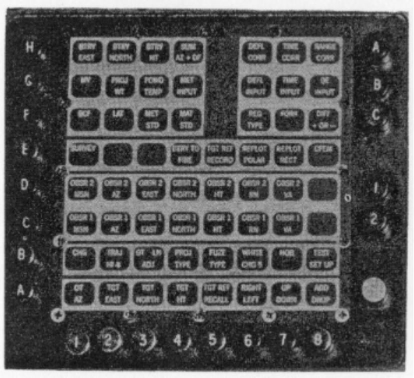

Figure 7. The input selection panel.

(3) The keyboard lamp flashes to indicate that a keyboard entry is necessary and power reaches the keyboard so that input can be entered.

The proper keys enter the sign and numerical data for an input function. As input data are entered from the keyboard, they are displayed in neon decimal indicators (Nixie tubes) for verification before entry into the computer memory. Actuating the CLEAR button clears the Nixie display and erases an erroneous entry before it goes into the working memory. After each entry, a new input function is selected, and the process continues until all entries have been made.

Once an entry has been made the data will stay in effect until replaced by a new entry into the proper memory location. This means that after the setup data, such as battery coordinates and powder temperature have been fed to the computer, succeeding fire missions will require only a new target location.

BUTTONS A, B, AND C

On the right side of the input selection panel there are three buttons labeled A, B, and C (fig 7). These buttons provide input and solutions for three batteries. For example, the upper left selection window is labeled BTRY EAST; by depressing the A, B, and C buttons in turn, it is possible for the operator to input the battery easting coordinate of the three batteries. By using the A, B, or C buttons in conjunction with the COMPUTE button, a solution can be obtained for any of three batteries.

There are also two buttons labeled 1 and 2 (fig 7) on the right side of the input selection panel. These buttons provide the operator a solution for two types of cannon, depending on which program is in the machine. For example, if button 1 was depressed, this could mean a 105-mm howitzer solution; if button 2 was depressed, this could mean a 155-mm howitzer solution.

When all input data have been entered the COMPUTE button is actuated and the computer starts solving the gunnery problem for the battery and caliber designated. When a solution has been obtained, the gun data are displayed in the Nixie readout tubes under deflection, fuze, quadrant elevation, and charge. Solution time will be from 10 to 30 seconds with computational accuracy unheard of in present day artillery.

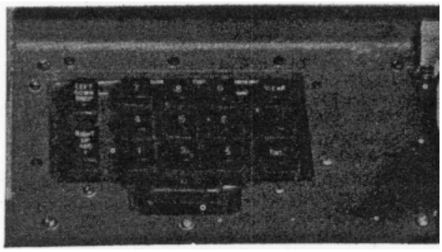

Figure 8. The Field Artillery Data Computer keyboard.

Upon successful completion of the fire mission, replot data may be obtained and displayed in the appropriate readout windows by selection of these functions on the input selection panel.

METEOROLOGICAL DATA MUST BE UNWEIGHTED

The mathematical solution used in FADAC requires the use of unweighted meteorological data. The FADAC senses the weather conditions at each of many levels through which the projectile passes and corrects for this weather at each level, thereby producing a true trajectory solution. This procedure was impossible by hand solution because of the cumbersomeness of a multiline met computation. A met message form has been approved with the heading "Computer Met Message" which transmits in 5-level teletype code the 26-line representation of the meteorological conditions prevalent at the time. To permit rapid and reliable entry of this large met data group, a simple mechanical tape reader is included on the right side of the control panel. If the punched paper tape met message is not available, or if some malfunction of the tape reader occurs, the met data can be entered by use of the keyboard.

By removing the small set screws around the perimeter of the input selection windows the complete face plate can be removed and a new plate with different window labels can be substituted to perform functions other than fire control. A new program, for example, fire planning, or possibly survey, can be loaded into the memory of the machine. Operator simplicity is maintained while giving the computer extreme flexibility in range of computational applications possible.

To be acceptable for artillery application, a digital computer must be accurate, fast, rugged, small, and easy to operate and maintain. With FADAC now on the scene, the artillery is near its goal of computational accuracy for cannons, rockets, and missiles.

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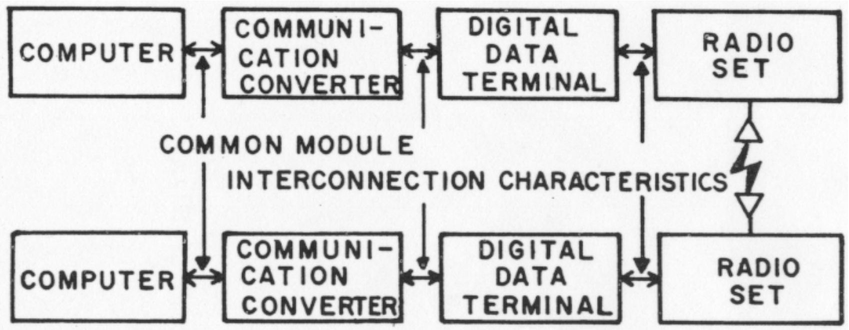
"REAL-TIME" COMMUNICATION CAPABILITY FOR ADP

The importance of a "real-time" communication capability in applying general-purpose digital computers to varied military tasks cannot be overemphasized. Among the features or characteristics that must be provided as a basis for the development and application of the family of equipment are—

(1) A communication buffer or converter with each computer.
(2) Digital data transmission equipment.
(3) A common language or code for information interchange.
(4) A common set of electrical and functional interconnection standards or characteristics for the various pieces of equipment.



The basic elements of a "real-time" communication system between two computers are shown in the above diagram.

Many tactical applications require the computer to receive data from several sources and to transmit data to several data storage or display locations. It is, therefore, usually desirable that the Communication Converter be designed for multiple input and output channels. It is probable that more than one type of Communication Converter will be required for varied tactical applications.

Road To Good Decision

Through Computers

How does an electronic digital computer work? How can it compute complex problems at such fantastic speeds and apply logical rules which have been given it to reach apparent "decisions?" This article gives an introductory view of the automatic digital computer and will help answer the preceding questions for you.

"Digital" is the key word. A digital computer, as opposed to an analog computer, only does arithmetic. The computer works with a numerical input, arrives at a solution by procedures involving operations with numbers, and produces a numerical output.

The classic example of the digital computer is the ancient abacus. Opposed to the abacus or digital computer is the analog computer which computes on the basis of an analogy created within the device, an analogy between physical quantities and a mathematical process. The classic example of the analog computer is the slide rule. A slide rule is constructed so that the physical distances on the rule bear a direct and precise analogy to the logarithms of the corresponding numbers. Computation takes advantage of physical, not solely theoretical, relationships. Multiplication is accomplished by the physical addition of distances on the rule analogous to the logarithms of the two numbers being multiplied.

More complex and powerful analog computers using electronic circuits and components are common. In an advanced-type analog computer, the electronics elements add, subtract, multiply, divide, differentiate, integrate, and perform other complex mathematical operations by the direct application of analogies between the physical properties of voltages, resistances, and other electronic phenomena and the computations at hand. For example, a Wheatstone bridge can balance electrical circuits; the balance permits the operator to determine the ratio between two currents. The same principle of balance through variable potentiometers is used extensively in analog computing.

ANALOG COMPUTER NOT READILY ADAPTABLE

An analog computer can be designed to do extremely complex mathematics in a relatively small space, with relatively few components. However, since the computer is designed for a particular mathematical problem or small class of problems, it is not readily adaptable to other problems. Analog computers are normally special purpose, relatively un-flexible, and applicable to a small range of problems. However, there are laboratory-type analog computers which are adaptable to many problems.

Digital computers, on the other hand, work solely in arithmetic and therefore are not restricted to any particular problem or even class of problems. You can give a digital computer a problem in business arithmetic, such as income tax, or you can give it a problem in scientific mathematics, such as the ballistics problem. Too, within a few minutes or seconds, you can change from one type of problem to another without a change of any kind in the hardware.

The heart of every digital computer is a counting device—the flip-flop circuit—which can count a million counts a second. The flip-flop circuit consists of a pair of vacuum tubes (a pair of transistors) of which only one can be conducting current at a given moment. A schematic diagram of a flip-flop circuit is shown in figure 9. Note that the plate of one tube is connected to the grid of the other. The circuit is wired in such a way that when the current first begins to flow, only one tube, for example the right-hand tube, permits the passage of current. The high voltage on the plate of the tube which is firing creates a high bias on the grid of the second tube, thus preventing current from passing through the second tube. However, when a negative pulse is sent into the system, the bias on the grid on the nonfiring (in this case the left-hand) tube falls. The current can now pass through the left-hand tube. It is not necessary to go further into the details of the circuitry. It is necessary only to note that one or the other of the tubes is conducting at any given moment, not both.

The current flow can be passed from one tube to the other and back as fast as one million times a second. A convention can be adopted such that if the right-hand tube is firing, the count is considered to be 0 and, if the left-hand tube is firing, the count is considered to be 1. With this convention agreed upon, the circuit can be made to count to 1 a million times a second—the problem is to keep track of the number of times 1 has been counted. This is not as difficult as it sounds.

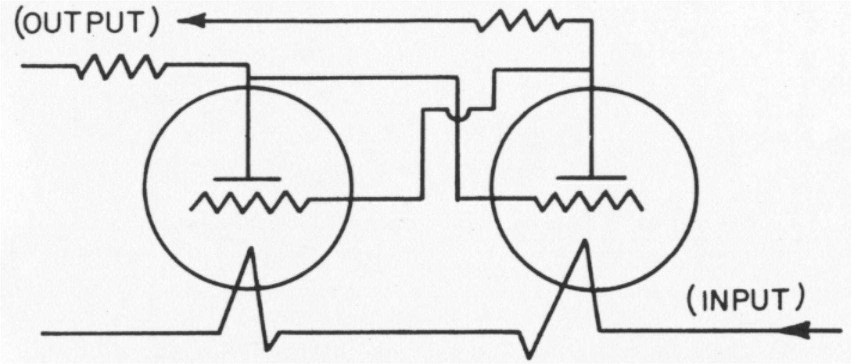


Figure 9. Schematic diagram of a flip-flop circuit.

Flip-flop circuits can be wired in series so that a count of 1 will change the tube firing in the first circuit; a second count will reset the first circuit to 0, set the second circuit to 1, etc. Figure 10 shows four flip-flop circuits hooked in series.

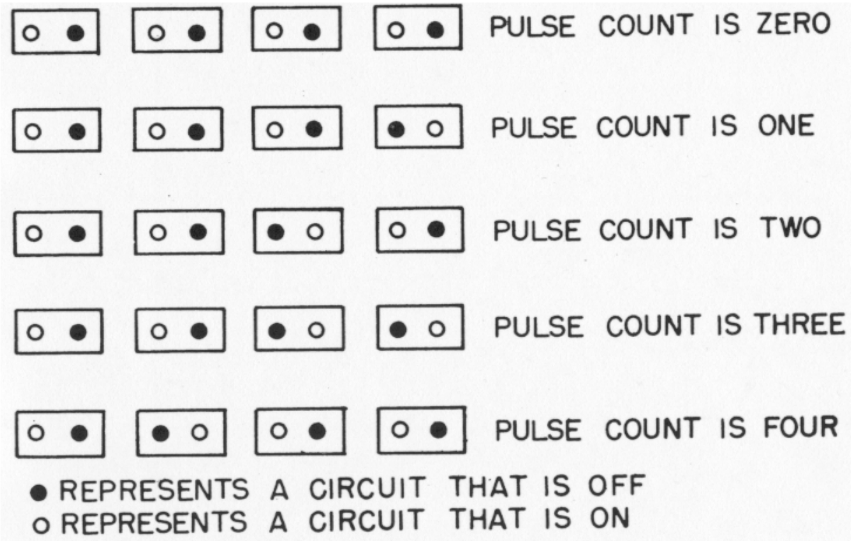


Figure 10. Four flip-flop circuits hooked in series.

Note that the rule is fairly simple. If a negative pulse (a count) is received by a circuit that is off, the circuit goes on; if a negative pulse is received by a circuit that is on, the circuit goes off but sends the pulse on to the next circuit to the left.

COUNTING WITH FLIP-FLOPS

The action of the flip-flop circuits in counting is worthy of mention for two reasons. First, it shows that digital computers deal heavily in bi-stable devices and electronic and other items in which there are only two possible conditions—on or off. From this it follows that in a digital system there are no shades of gray. It is on or off, yes or no, a count or no count. Second, it is important to appreciate the action of flip-flops because these circuits lead to an understanding of simple binary arithmetic, which in turn gives an understanding of the basic operation of the computer and its capacity for enormous speed; and it gives an appreciation of the input/output problems associated with converting from one form of arithmetic to another (binary to decimal and vice versa).

The action of the flip-flops in recording the successive counts shown in figure 10 can be represented numerically as in figure 11. Note that the position of the 0's and 1's is the same as was shown in the off and on symbols in the series of four flip-flop circuits.

0000	0	1000	8
0001	1	1001	9
0010	2	1010	10
0011	3	1011	11
0100	4	1100	12
0101	5	1101	13
0110	6	1110	14
0111	7	1111	15

Note. The count shown is from 0 to 15 (in decimal arithmetic) and was accomplished with four flip-flops, or four binary digits.

Figure 11. Binary arithmetic reflected in the count of four flip-flop circuits arranged in series.

The result is binary arithmetic, a complete, consistent, positional arithmetic system, just as decimal arithmetic is a complete, positional arithmetic system. Binary arithmetic with just two digits—0 and 1—can be used to add, multiply, subtract, and divide by following the same broad rules used in decimal arithmetic for these operations. The point to note is that binary arithmetic depends on just two digits—two states of a circuit—0 and 1. These two states can be represented by numerous binary devices, that is, bi-stable devices. Circuits that are either on or off, cards and paper tape which have either a hole punched or no hole punched at point X, magnetic drum surfaces, small magnetic cores, magnetic tapes, and numerous other devices on which magnetism (or lack of magnetism) can be recorded are all well adapted to a system of binary arithmetic. All of these are bi-stable devices.

DIGITAL COMPUTER PERFORMS FIVE MAJOR FUNCTIONS

There are five major functions which the hardware of a digital computer must perform. As a result, the components and circuitry of a digital computer are often classed as belonging to one of five "parts of the computer." The classification is convenient, but in practice it is not possible to isolate parts of a computer precisely as performing each of these functions. Many circuits perform several functions. However, if the functions are listed as "elements" of a computer, they are input, control, arithmetic, memory, and output.

Input and output are closely related. This portion of the computer is devoted to converting the key punches, tape holes, or other physical signals from the operator to the computer into electronic impulses that can be used within the computer. Conversely, the output hardware converts the electronic impulses within the machines into punched holes in tape or cards, lights, or characters on a blank page, or magnetized spots on a magnetic tape file.

With both input and output, the problem is to convert ordinary decimal arithmetic, as punched from a key on a typewriter for example, into a series of 0's and 1's in binary arithmetic. Many ingenious methods have been developed for doing this. The problem is to keep the input system simple for the human operator and yet capable of converting input to appropriate electronic impulses (or to magnetized spots on tape, drums, or disks from which the computer can later derive an electronic impulse).

COMPUTER SENSES ONLY NUMBERS

Control is more complex. A computer can sense only numbers. Therefore, a computer must be told to print a character, to move the paper in the printer, or to read punched paper tape or any of the many other things a computer might be expected to do when it is presented a number. If the computer is to react to a number (remember, in binary arithmetic a number is a series of 1's and 0's) the computer must be able to see if there is a voltage (a 1) here on this flip-flop, and the next, and the next, or the next. The only way a computer can "read" a number is to see which flip-flops are on. The circuits which the computer uses to sense the conditions of the flip-flops where information is stored as 0's and 1's are logic circuits. There are a number of kinds of logic circuits, but only two will be discussed. There is an *and* circuit which permits the passing of a voltage if there is a voltage at the first and at the second input line of the circuit. There is an *or* circuit that permits passing a voltage if there is a voltage at either one or the other of two input lines. With these two circuits, complex systems (called logical design) can be built which will pass voltages to the controls of the computer and the peripheral equipment such as printers, tape readers, lighted displays, and so on, as a result of sensing the condition of the basic flip-flops. Summarizing control, it can be said that control in a digital computer is by logic circuits; the control circuits are not all centered at one point within the computer but are scattered throughout.

The arithmetic unit of the computer is composed of two fundamental parts, flip-flops and logic circuits. The arithmetic unit is usually physically within one general area within the computer. To understand how the computer does arithmetic, it is necessary to introduce the notion of a "computer word." Earlier, it was stated that four flip-flops in a row will permit counting to 15. This is not counting very high. To count to seven decimal places would require 20 flip-flops. Assume for discussion that a system which would deal with seven-decimal-place numbers is to be designed. To achieve this, series of flip-flop circuits, each circuit 20 flip-flops long, would be created. The result would be computer words 20 binary digits (bits) long.

Next suppose that arithmetic is to be done with the system that is built. Three series of flip-flops each 20 bits long will be required. One series will be called the addend register, one the augend register, and the third will be the sum register. Assume that number 7 in addend is to be added to number 3 in augend (fig 12). Since the addend is to be added to the augend, there must be some electronic means of learning that there is a 1 or a 0 at each position in question so that the proper sum digit in the sum register can be appropriately placed. The logic circuits will sense the conditions of the flip-flops. Sensing simultaneously in the addend and augend registers, the logic circuits are in effect asking, is there a voltage here and here; is there a voltage here or here, etc? As appropriate, the logic circuits, after sensing the voltages in the flip-flops of addend and augend, permit passing a voltage to a flip-flop in the sum register. It is necessary for the designer to determine in advance the combination which should produce a digit (bit) or a 0 in each place, successively in the sum register.

Addend Register	0111	=	7
Augend Register	0011	=	3
Sum Register	1010	=	10

Figure 12. Adding with three arithmetic registers.

TWO FUNCTIONS DIFFER LITTLE

In one respect, electronic arithmetic and electronic control in a digital computer do not differ greatly. In both functions, flip-flops are read by logic circuits, and, as a result, voltages are passed. The difference is that, with control, the voltages that are passed actuate further action devices within the computer (or peripheral to it), whereas, with arithmetic, the voltages passed by the logic circuits set new flip-flops in sum registers (or product or quotient registers) where new information is to be stored.

A basic appreciation of the computer does not depend on a full understanding of computer arithmetic. The subject can be complex. The same is not true for computer memory. Even a general appreciation of computers requires a sound basic appreciation of the functions and nature of memory in a computer.

The memory in a computer is an organized space. The memory can be thought of as a map—a gridded map upon which certain information is stored in the grid squares.

Let us return to the organization of memory in a moment. Now it is necessary to consider the three functions of the memory in a computer.

First, the memory stores the program. A computer is an internally stored program machine. The steps to be taken by the computer (the program) are given to it in advance. The sequence of steps necessary to solve the problem constitute the program. The program is read into the memory in seconds, or at most a few minutes, by means of punched tape or punched cards. With a given program, the computer can solve the established problem for any number of sets of data. Therefore, placing the program within the computer is thought of first, so that it will be available for application to whatever data is presented.

EXAMPLE PROBLEM TO SOLVE

Take the following as an example of a problem to be solved: the equation $\frac{(a^2+bc)}{(e+3f)}$ = X (solve for X for a number of value of b). The sequence of arithmetic actions must be established, listed, and presented to the computer. In this example, the computer will have to square a, multiply b by c, add e *to* $3f$, divide $a^2 + bc$ by the denominator, etc., with new values of b until all prescribed values of b have been computed into the problem. Each action is a complete and integral, though small, step. The computer must have a list of the steps in its memory. The first function of the memory is to store the program.

Second, to have the computer operate on data, the data must be available to the computer. In the preceding example, if a is to be squared, there must be an a. Therefore a is stored in the memory at a known location to which the computer can be directed to go. The second function of memory then is to store data.

Third, again referring to the example, after a has been squared the memory must set it aside momentarily to multiply b by c. We can do only one piece of arithmetic at a time. The computer is tremendously fast but it can perform only one operation at a time. This is not strictly true with large modern computers but it is sufficiently accurate to use for this discussion. Therefore, a work space is needed in the memory for temporary storage as a place into which the computer can put intermediate results. So, the third function of memory is to provide a work area.

Using the example again, let us see how the organized space of a computer memory is used to solve a problem. Assume that the memory of the computer under discussion is a rectangular surface upon which magnetized spots are placed which can be sensed by the logic circuits used in arithmetic and control operations. Such a memory is shown in figure 13.

WORD	00	01	02	03	04	05	06	07	08	09
LINE 00										
01		FETCH a	a x a	STORE a^2	FETCH b	x c	$+a^2$			
02										
03		a	b	c	e	f	3	1	61	
04										
05		a^2	a^2+bc	$e+3f$						
06										
07										
08										
09										
ETC										

Note. A computer has not been designed with a flat rectangular magnetizable surface as a memory. However, many computers have rotating drums with the surface representing a rectangle, as above.

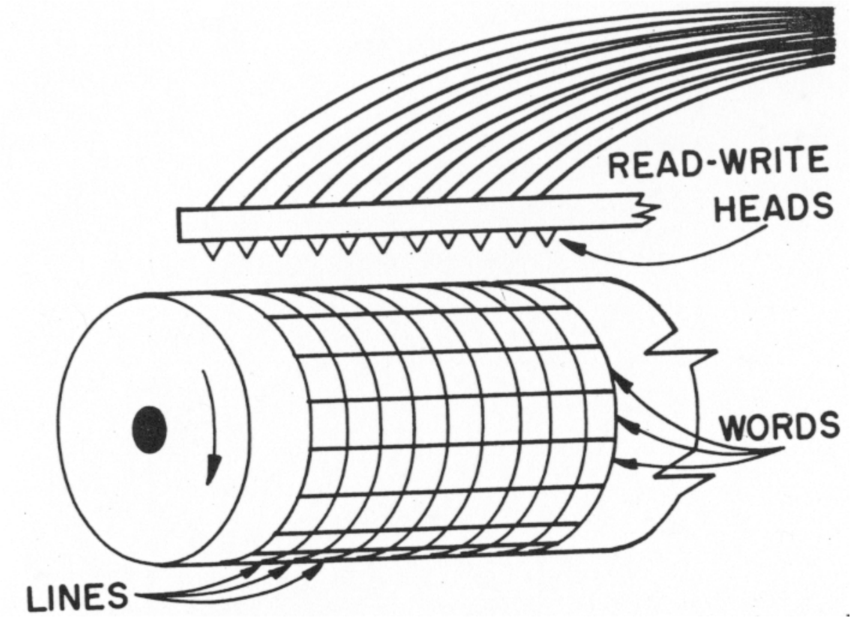
Figure 13. The surface of the computer rotating drum can be represented by the rectangle.

HORIZONTALLY MEMORY DIVIDED INTO TRACKS

Horizontally the memory is divided into tracks, or channels, or lines. The words are used interchangeably. These are shown in figure 13 as numbered from 00 to 09. There might be 64 or 128 lines (or some other number). Each line is divided into small rectangular spaces which are called words. A word space is just large enough to accommodate the 20 bits of information—the basic word length in the computer being designed. In each word in each line it is possible to store 20 "1's" or 20 "0's" or some other combination.

Exactly as is done with grid squares in a universal transverse mercator system any word in the computer can be designated by first mentioning the line number and then the word position. For two examples, in figure 13 the value *a* appears in word 0301; that is, line 3 and word position 01. The value *f* is in 0305; that is, line 3 and word position 05.

The physical memory of a computer is not a flat rectangular surface. It might be the oxide coated surface of a cylinder or drum which will accept small magnetic impulses just as a tape in a tape recorder does. The rotating drum can, for the purposes of illustration, be considered a rectangle (fig 14).



Note. A rotating memory has read-write heads, one per line, reading and writing in the line of memory opposite which the head is placed. As the memory rotates, the successive words in a line pass under the read-write head. In addressing a location in a rotating drum (or rotating disc) memory, the first two digits address a particular read-write head. The final two digits tell the computer to wait the appropriate number of word counts until the addressed word appears under the read-write head addressed.

Figure 14. The rotating magnetic drum memory.

Now let us construct a program and store that program in the computer so that the computer will be able to turn to it and learn what commands it is to execute.

The program written out in words would look something like figure 15.

Let us see how this program would be placed in the memory of the computer and how the memory would perform the three functions for which it was designed.

STEP NUMBER	ACTION TO BE TAKEN
1	Fetch *a*
2	Square *a* (i.e., multiply it by itself)
3	Store a^2 temporarily in a location to which we can return
4	Fetch *b*
5	Fetch *c* and multiply *b* by *c*
6	Fetch a^2 and add it to *bc*
7	Store $(a^2 + bc)$ temporarily
8	Fetch *f*
9	Multiply *f* by 3
10	Fetch *e* and add it to 3*f*
11	Store $(e + 3f)$ temporarily
12	Fetch $(a^2 + bc)$
13	Fetch $(e + 3f)$ and divide it into $(a^2 + bc)$
14	Print the answer
15	Repeat the process for a new value of *b* until all values of *b* have been computed with
16	Halt

Figure 15. Program written out in words.

INSTRUCTIONS ARE STORED NUMBERS

First, the instructions numbered 1 through 16 would be stored in a selected line or lines of the computer. Remember, the instructions are just numbers stored in a location to which the computer is referred, which the computer will interpret through logic circuits as commands to add, multiply, store, etc. In figure 13, the first few commands in line 01 are written in an abbreviated form.

Next is data storage. One of the commands was to fetch *a*. For the computer to fetch *a, a* must be stored somewhere. In figure 13, *a* has been stored in line 03, word position 01, and *b* is in line 03, word position 02.

Note that in line 05 of the memory diagram (fig 13), the quantity a^2 is stored as are other intermediate results. This is the location reserved for this quantity when it is created by the computer. It is the location the computer will be told to go back to when it is to find that quantity. This leads us to the next idea which is that every command to the computer must consist of two parts; an instruction and a location at which the computer will find the operand upon which it is to take action in execution of the instruction.

In addition to the memory location, the computer has arithmetic registers where the arithmetic is done. An arithmetic register will have what was left from the last operation in it, unless the register has been deliberately cleared. There is normally a command in a computer to clear the arithmetic register. With this in mind, let us use a number coding system for the commands needed and rewrite the program above in computer code. Each command will itself be stored somewhere (in this case in line 01), and each command will consist of the Operation Code (what is to be done) and the Address (place in memory where the computer will find the operand).

The following operation code (OPC) (fig 16) will be adopted.

OPC	**OPERATION**
42	Clear arithmetic register and add contents of the following address to the arithmetic register. "Clear and add."
43	Add the contents of the following address to the contents of the arithmetic register. "Add."
44	Multiply the contents of arithmetic register by the contents of the following address. "Multiply."
49	Store the contents of the arithmetic register at the following address. "Store."
48	Divide (as before with respect to address, etc.).
33	Print contents of the following address.

Figure 16. The operation code.

HOW TO SQUARE A NUMBER

To square a number, it is necessary only to place the number in the arithmetic register and then to multiply by the contents of the arithmetic register. In many computers, the arithmetic register is automatically copied into a memory location after each operation. Thus, the arithmetic register can be considered to have a memory location. To square a number, we simply give the command to multiply by the arithmetic register's location in memory. This position in memory is called the accumulator.

Recalling that the program was written in line 01 and listing the commands in sequence gives us a coded written program (fig 17).

The computer has now printed the answer to the problem with the first set of values. The problem now is how to change to a new value for *b*. The corollary question will occur: If successive values of *b* have been used and the computer has been instructed to reach for the next, and subsequent values of *b* each time it has completed one cycle, how will the computer know when to stop? The answer to this question illustrates the most powerful and significant aspect of the computer. To know when to halt, the computer must make a test; it must ask itself, have I finished? This question is asked in the same way as are the questions the computer asks itself when it is to make a truly significant decision or other important problem determination.

COMMAND ADDRESS	OPC	ADDRESS	QUANTITY NOW IN ACCUMULATOR	NOTES
0101	42	0301	a	Clear and add a
0102	44	2100	a^2	2100 is address of accumulator
0103	49	0501	a^2	
0104	42	0302	b	Store a^2
0105	44	0303	bc	Bring a^2 in from temporary storage
0106	43	0501	$a^2 + bc$	
0107	49	0502	$a^2 + bc$	
0108	42	0305	f	Clear and add f
0109	44	0306	$3f$	Multiply by 3
0110	43	0304	$e + 3f$	Add e
0111	49	0503	$e + 3f$	Store
0112	42	0502	$a^2 + bc$	Clear and add $(a^2 + bc)$
0113	48	0503	$(a^2 + bc) / (e + 3f)$	
0114	33	2100	$(a^2 + bc) / (e + 3f)$	Print contents of accumulator

Figure 17. A coded written program.

In this problem, the testing power of the machine will be illustrated. Tests are the computer's method of determining when it is to halt. Assume that the problem requires that values of *b* be used in the equation from 1 to 60 at intervals of 1. The computer will increase *b* by 1 each time it goes through the loop of the solution, as follows:

Note that the constant 1 is stored in location 0307 (fig 13). If a few more commands were added to the program started above, something like this would be obtained (fig 18).

COMMAND ADDRESS	OPC	ADDRESS	QUANTITY NOW IN ACCUMULAT	NOTES
0115	42	0302	b	Clear and add b
0116	43	0307	$b + 1$	Add 1 to b
0117	49	0302	$b + 1$	Store $b + 1$ (as b)

Figure 18. Result of added commands.

PROCESS OF INCREMENTING *b*

Note that *b* has been taken out of its normal home or resting place in memory, 1 has been added to it, and the result has been put back in the memory location assigned to *b*. This is called incrementing *b*. If the program is gone through again, the computer will reach into address

0302 expecting to find b but will find instead $b + 1$ which will now be called b. The computer will take what it finds at that address to be b. This is precisely what was wanted.

If each of the values of b called for have been used, it is not necessary to run through the problem again. However, b must be tested for size. A computer can tell whether the contents of the arithmetic register (hence, the accumulator) are positive or negative. Therefore, if a series of subtractions are set up, this discriminating power of the computer (recognizing plus or minus) can be used as a switching or change producing power, switching us into a different aspect of the program. In the problem at hand, values of b up to 60 are wanted. If 1 were added to b when b is 60, 61 would result and this would be too large. If 61 is subtracted from b each time through the loop, a negative quantity (0 is considered positive) would result as long as b is 61 or less. When the positive quantity b equals 61 appears, it will be time to halt. Stating the question simply, the machine will be asked: Is b — 61 negative? If it is, continue; if it is not, halt.

Three more commands which a computer will have in its repertoire are subtraction, test for negative with a transfer, and halt. Assume that OPC 41 means subtract. Assume that OPC 22 means to the machine: if the accumulator is negative, transfer control to the command you will find listed at the following address; if the accumulator is not negative, continue the program and execute the next command. Assume that OPC 67 means Halt. Figure 19 shows the completed program. Only the new commands added to the program are listed.

COMMAND ADDRESS	OPC	ADDRESS	QUANTITY NOW IN ACCUMULATO	NOTES
0118	42	0302	b	Clear and add b
0119	41	0308	$b - 61$	Subtract 61
0120	22	0101	$b - 61$	Test negative; if negative, return to start; if not negative, execute next command.
0121	67	Halt		

Figure 19. Completed program with new commands.

Notice that whenever b is 60 or less the test will result in a transfer of control back to the first command in the program. The computer will run through the problem once more. Since the test comes at the end of the program, the computation with b equal to 60 will have been completed before testing a b which has been raised to 61. Therefore, all calculations asked for will be completed.

RESULTS OF TEST FOR NEGATIVE

The test for negative made here resulted in one of two actions (Transfer control or halt) as explained. The same test can be used for giving the computer the basis for proceeding down one or the other of any two paths. A problem can be set for the computer in which an entirely new aspect of the program is initiated when a value reaches a certain point. In the article *The Computer Story, Speed and Accuracy,* the power of the test in a purely mathematical problem is illustrated. In fire planning, the test is used in determining whether a certain caliber is acceptable against a certain type of target. The analyst, the man who sets up the problem for the programer to code, can determine a great many things by a series of subtractions (tests), the results of which lead to one of two (and only two) conclusions.

If enough carefully designed questions are asked in the proper sequence, extremely subtle points can be established even though the questions are rigidly restricted to those which can be answered yes or no (Is the accumulator negative; yes or no). This is how the computer makes decisions. The computer can decide that the rules you have laid down for it in precise detail have been followed, that the criteria have or have not been met, and that therefore in accord with the rules given, the course of action should be thus or so. It will take the course of action thus determined. The man who presents the problem to the computer can set up a series of subtractions in such a way that the positive or negative condition of the accumulator causes the computer to transfer control in the program successively to instructions and further test—in a predetermined complex pattern. The full pattern of tests and transfers can produce answers to extremely complex questions.

It is the test that permits the analyst to say in his problem and flow chart if the results of this computation are thus and so, do this; if not, do that. This is the great power of the internally stored program digital computer.

●

"Among the combat arms—Infantry, Armor, and Artillery—the Artillery holds a unique place with respect to automatic digital computing. The Artillery stands at that point in the field army at which technical mathematical computing meets automatic data processing—the instrument of logistics, battlefield management, and command."

Maj Gen Philip C. Wehle

SOLUTIONS TO EXAMPLES ON PAGE 7

Example 1. Step 5 involves division by 0.

Example 2. Step 5 involves taking the square root of a minus number (4 – 9/2).

The Computer Story ——
SPEED and ACCURACY

The core of an automatic data processing and computing system is the indispensable high speed electronic digital computer. The rest of the system is meaningless without the computer. If there are difficulties with data transmission, if the ancillary equipment does not function perfectly, or if something else mars the smooth flow of data through a complete system, the high speed electronic digital computer, though momentarily unsupported by ancillary devices, remains a powerful instrument capable of instantly bringing tremendous gains in fire control to the field artillery. Fire control for both missiles and cannons will lean heavily on digital computing—though for different reasons.

In the case of missiles the digital computer is needed to speed the solution of the extremely complex mathematics. For example, to solve the Redstone gunnery problem manually for one target requires 2 1/2 to 3 1/2 hours with four men working in two teams on high speed modern electric desk calculators, not digital computers. With the Redstone fire control digital computer (Jukebox), one operator can solve the problem in less than 5 minutes. This includes the time required for the operator to enter the problem. In missile fire control, digital computers are needed to gain speed in computation.

In cannon fire control a digital computer can speed the solution of the cannon gunnery problem; but this is not the chief concern. Digital computers are needed to increase accuracy.

An increase in accuracy will bring many things. For observed fires an increase in accuracy will permit firing a greater number of immediate fire-for-effect missions. Observers will soon learn that if they locate the target with reasonable precision, the battery can place effective fire on the target immediately.

IMMEDIATE "FIRE-FOR-EFFECT" PREFERABLE

Immediate fire-for-effect missions are preferable for a number of reasons. Ammunition and time are saved and more missions can be fired. Most important, a tremendous gain in effect on the target results because your "punch" is not telegraphed. The target is caught in an attitude in which it is most vulnerable.

The digital computer will be provided accurate muzzle velocity data by the radar doppler chronograph which is expected to be issued to troop units soon (ARTILLERY TRENDS, May 1960). The computer will make more precise use of meteorological data. The computer will also be able to reckon the effect of the interaction between the different variables, for example, weather and materiel, which cannot be done in a hand solution. For these reasons, the unknown or residual correction developed from a registration with a computer will be extremely small. The residual correction will represent the variations from standard of the projectile lot used and other small errors resulting from the limits with which all measurements can be made.

Each new situation is entered with a capability for again developing extremely precise computations of the effects of weather and materiel and the interaction between them. Therefore need for registration is reduced. The residual range correction from the last registration will very nearly represent the total unknown in the new situation. The increase in accuracy for cannon artillery expected from the computer gives us the nearly perfect predicted fire technique that has been sought for many years.

A reduction in the number of registrations will result in savings in ammunition and the logistical effect required to deliver to the overseas battery position the many rounds now fired in repeated registrations.

TACTICAL SURPRISE A RESULT

Tactical surprise will also result. Units can move into position and be ready to deliver accurate, effective fire without the telltale registering of one or more batteries per battalion. The ability to move without a concurrent requirement for registration in the new position will give units greater tactical mobility. Limits of daylight or waning visibility will not bar moving a unit.

As stated previously, speed is not the chief consideration in the cannon artillery applications of digital computing; but there will be valuable gains in speed. For example, in a situation in which many fires have been plotted, planned section data must be kept current, constantly up-dated from new met messages. If the FDC is busy with missions, it is often impossible to keep corrected data for prearranged fires. The speed of a digital computer will insure a rapid, error-free, constant updating of firing data.

For observed fires there will be small gains in speed. The gains probably would not justify the expense of a computer as the cost of the presently issued graphical equipment is trivial in comparison. It is extremely important that the present manual methods of fire control be retained for "back-up" and flexibility, even after digital computers are obtained.

It has been stated that computers promise great gains in accuracy. Why? Do our personnel make gross and consistent errors? Are the firing tables in error? The answer to these questions is "No." There are two reasons that the digital computer, employed independently or in an automated system, will give a tremendous increase in accuracy. First, the digital computer will remove virtually all second-order effects (discussed below); second, the computer will permit us to use an unweighted meteorological (met) message and apply it precisely for the particular weapon and elevation being fired.

FIRING TABLES NOT IN ERROR

The firing tables are not in error. But firing tables are an abbreviated statement of an immensely complex problem. For example, when the firing tables give you a unit correction factor for a headwind it is presenting you with one-fiftieth of the correction factor for a 50-mile an hour headwind blowing in an atmosphere in which the density is standard, the air temperature is standard, and through which you are firing a standard projectile which left the muzzle at the standard muzzle velocity. Such conditions rarely exist. Further, the more the headwind varies from 50 miles per hour the greater will be the error in the wind unit correction; the more any of the other conditions vary from standard, the greater will be the error resulting from the assumption that all conditions other than wind are standard.

The effect of the variation from standard in density, for example, on the effect of the variation from standard in the wind, is called a second-order effect. A firing tables solution cannot correct for a second-order effect. The mathematical solution achieved by the computer does take into consideration second-order effects. The computer determines the magnitude of these effects through solution of the differential equations of the type shown in figure 21. Equations of this type could never be solved efficiently in the field without mathematical computing equipment. Therefore, to arrive at a truly accurate solution without a fast computer is totally beyond field capabilities.

In the full mathematical solution the computer considers first a very short flight of the projectile, during which time—a fraction of a second—all the forces are considered to work on the projectile. At the end of the short time period the projectile has new velocities (horizontal and vertical), has a new angle of travel, and is encountering new weather. The computation proceeds on this basis.

The digital computer solution of the cannon gunnery problem uses an unweighted met message. In the standard firing tables solution the message used is weighted. In the firing tables solution a single line of the met message is used; the line selected depends on the maximum ordinate. The single line presents a wind speed and direction, a density, and a temperature. The value for each of the variables presented is not the true value of the variable at any point in the atmosphere. It is an average value; an average wind, an average density, and an average temperature. The value is computed from a consideration of the time the projectile spends in each layer of atmosphere and the value of the variables at that level. The averaging is done by the met section with graphical equipment.

VALUES PRESENTED ARE APPROXIMATIONS

For at least two reasons the average values presented (weighted means) are approximations. First, the computational techniques used, which include graphical equipment, are simplified to permit speed; they must be good approximations, but not as precise as those which could be developed by more complex computations. Second, the weighting values used with the different variables measured at the different levels of atmosphere are correct, not for a group of trajectories, but, precisely

HEIGHT	LINE NUMBER		HEIGHT
METERS	COMPUTER	UNITED STATES STANDARD	YARDS
SURFACE	0	0	SURFACE
200	1	1	200
500	2	2	500
1,000	3	3	1,000
1,500	4	4	1,500
2,000	5	5	2,000
2,500	6	6	3,000
3,000	7	7	4,000
3,500	8	8	5,000
4,000	9	9	6,000
4,500	10	10	8,000
5,000	11	11	10,000
6,000	12		
7,000	13		
8,000	14		
9,000	15		
10,000	16		

Figure 20. Computer is given true weather measurements for each level shown under "Computer."

speaking, for only one type of cannon, firing at a particular elevation. Yet, the same weighting values are used for all field artillery cannon within a certain class and for a number of elevations for each. Let us look at the way in which a digital computer solves the problem.

The computer is given separate readings for wind, density, and temperature at a number of different levels. Specifically, the computer is given true weather measurements for each level shown under "Computer" in figure 20. In the hand solution just one value is used, a weighted mean for the maximum ordinate passing through the zone defined by the lines in the column labeled "US Standard." For example, with 105-mm howitzers firing charge 7 at a range of 10,000 meters, line 4 of the US standard met message would be selected. The computer would use an interpolation scheme between lines, considering each pair of lines in turn as it passes through the zones defined by those lines. The computer would thus use a number of different values where the manual solution uses one.

Another input to the computer would be the materiel data, that is, powder temperature, mean muzzle velocity for the battery (from the radar doppler chronograph), and projectile weight. Of course, the computer must be given the geometry of the problem—the coordinates in easting and northing, and the altitude of the battery and target.

$$\frac{d^2x}{dt^2} = -K_T \cdot K_p \frac{P(y)}{P(o)} \sqrt{1-y \cdot G} \left(\frac{dx}{dt}\right)$$

and;

$$\Delta X = \frac{\partial X}{\partial \varnothing} + \frac{\partial X}{\partial H}\Delta H + \frac{\partial X}{\partial V}\Delta V + \frac{\partial X}{\partial P}\Delta P +$$

$$\frac{\partial X}{\partial W_x} + \Delta W_x + \frac{\partial X}{\partial T}\Delta T + \frac{\partial X}{\partial M}\Delta M + \text{2nd and Higher Order Terms}$$

Figure 21. **A complex equation expression considered by the computer.**

COMPUTER SELECTS CHARGE, TRIAL ELEVATION

Now for the solution. First, considering the range alone, the computer selects a charge and a trial elevation. The charge is displayed to the operator who may wish to override the selection by reason of terrain considerations not given to the computer.

Once the trial elevation is determined, the computer solves the trajectory, which is to say it determines the range and altitude of the projectile for any given elapsed time. The computer considers more than 30 equations. The equations include such expressions as the following (i.e., X is range, T is time, and so on) and similar expressions for Y (altitude) except that the altitude determination includes a consideration of gravity.

Figure 21 is obviously quite unpleasant and complex, but can be generalized a little more and made to look like this:

X = F (cosine of elevation, powder temperature, muzzle velocity, projectile weight, drag, weather, time)

Y = F (sine of elevation, powder temperature, muzzle velocity, projectile weight, drag, weather time) —F (G, time). (G is the force of gravity.)

The computer now does the complex mathematics for a brief period of time; it begins with one thirty-second of a second. At the end of the first computation the computer knows how far the projectile has traveled in range (the value of X) and how far in altitude (the value of Y.) The computer also has a new (degraded) velocity, a new (degraded) angle of elevation, and it is prepared to sense the weather at the altitude represented by the Y of the projectile (fig 22).

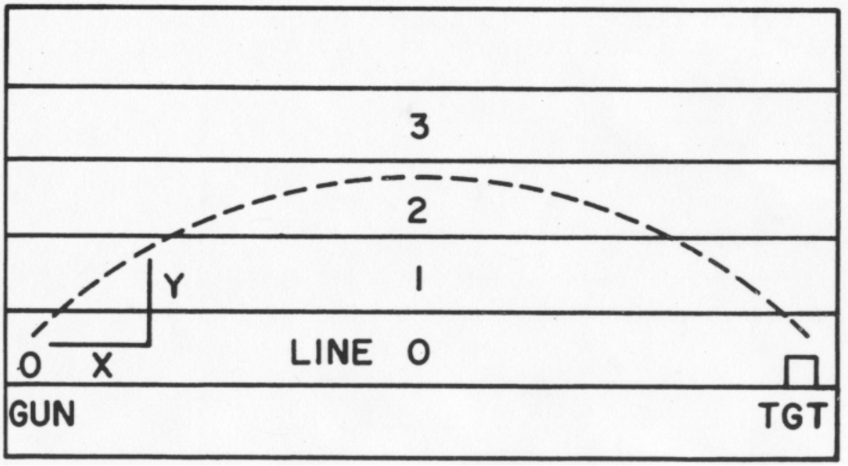


Figure 22. The computer can sense the weather at altitudes represented by the Y and X of the projectile.

The computer takes another step forward, computing for another brief period of time and combining the gain in X for this period of time with the accumulated value of previous gains in X. It now has a new X; it has likewise computed a new Y. The computer proceeds in this fashion until the projectile has been computed to reach an altitude equal to that of the target.

COMPUTER KNOWS WHEN TO STOP

It is interesting to note how the computer knows when to stop. If there were nothing to stop it the computer might continue to compute a trajectory until the shell had theoretically passed deeply into the earth.

Soon after the projectile has passed the summit, the computer begins to test to determine if the altitude of the projectile is less than the altitude of the target. It determines this by subtracting the Y of the projectile from the Y of the target after each computation. As long as the projectile is above the target the computation should proceed. The projectile will be above the target only so long as the result of the subtraction $Y_p — Y_t$ is a positive quantity. This is shown in computer language in figure 23.

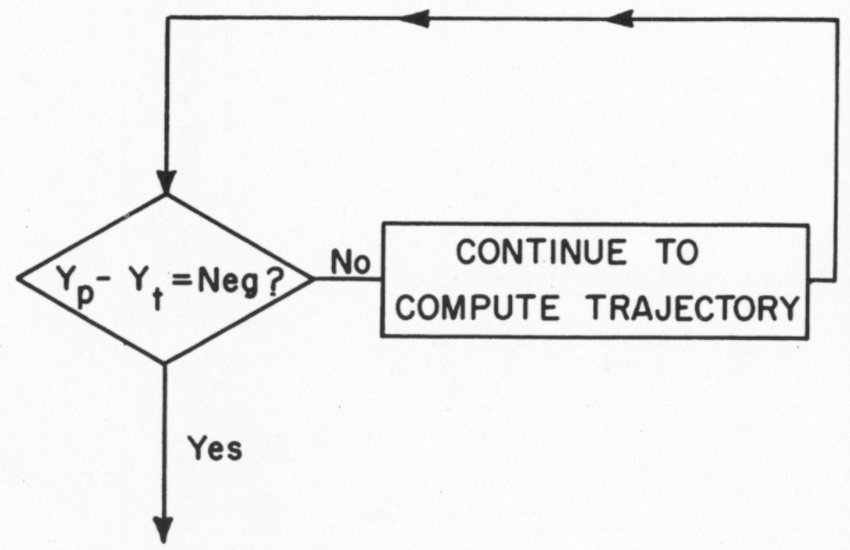


Figure 23. The computer tests to determine the relative altitude of the projectile and the target.

There will come a time in the computation when the answer to the question $Y_p — Y_t = Neg?$ will be "Yes." At that time the computer will wish to determine the location of the projectile with respect to the target.

The computer backs up a short step in the computation. Next, by a process similar to splitting a bracket, the computer determines the approximate moment at which, theoretically, the projectile passed the target in its descent. The computer must now compare target range and projectile range at this point on the trajectory. This is done by the subtraction $X_t — X_p = \Delta X$ where ΔX will represent miss distance.

And now the question is whether the miss distance is acceptably small. The computer tests the absolute value of the miss distance, without regard to its plus or minus value, against one probable error. The computer makes a comparison, that is, the classic "test," as follows: $\Delta X — PE = Neg?$

DETERMINING MISS DISTANCE

If the answer is "Yes" the miss distance is acceptably small. If the

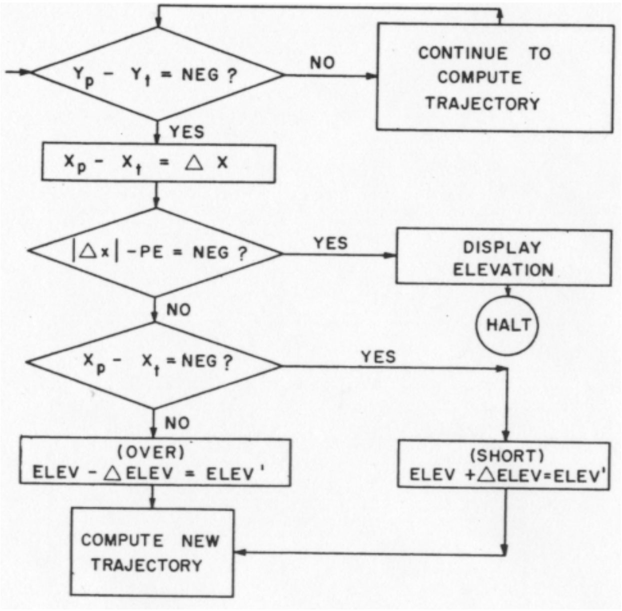


Figure 24. The abbreviated generalized flow chart.

answer is "No" the miss distance exceeds one probable error. The computer must go back and recompute the entire trajectory, applying a small change to the trial elevation used on the initial computer. Each new try is termed an "iteration." The number of iterations seldom exceeds four or five unless the weather is extreme. Regardless of the number of iterations required, the computer operates just as a good observer does. It continues to split its bracket until it is within acceptable limits of the target.

The abbreviated generalized flow chart is shown in figure 24.

A word about the time required for this computation is in order. For example, computations for the quadrant elevation, time, and deflection for ranges requiring a time of flight of 30 seconds have been computed for moderately severe weather in 5 to 10 seconds of computer time on a small tactical, prototype computer, the FADAC (see page 10). Less severe weather would shorten the time required (fewer iterations); longer time of flight does not increase the time proportionately. Unquestionably the computation can be done even more rapidly on faster machines which are well within the state of the computer art but which have not yet been presented for test.

To the field artillery, the digital computer is a powerful mathematical tool which can give us accuracy that cannot be achieved any other way. The increase in accuracy can come as part of a system of automation, or it can come from a relatively isolated computer operating well forward in small tactical units in communication with the observer and gun. The field artillery desires the gains of an automated system but if under the pressures of the battlefield the system fails to function in its entirety, gains from digital computers programed for fire control are still desired.

●

TACTICAL ADPS DESIGN OBJECTIVES

Objectives for tactical ADPS design:

1. Common-user facilities
2. Integrated data files
3. Simple, foolproof input devices
4. Interrogation—immediate reply
5. General purpose, building block hardware
6. Automatic operation
7. Completely flexible output

USAEPG ADP Department

As of 1 June 1960, Combat Development Agencies of the Department of the Army and US Continental Army Command were conducting a total of 50 ADPS studies.

Inside An Automated FDC

The forward observer (FO) with the infantry commander in the attack is moving forward with the company commander. Suddenly, the two men drop down behind a small outcropping of rock. They see that the advance is being held up by fire from automatic weapons about 2,000 meters to their left front.

The FO quickly positions the small box he has been carrying, then sets the dials on it and presses a button. In less time than it takes to tell about it, he has set up a complete fire request. Then, taking his telephone in his hands, he transmits the fire mission to the fire direction center (FDC), 2 miles to the rear.

Ninety seconds later a volley from each of three artillery batteries falls in the target area. Observing the effect of his fire, the FO adjusts several dials and again pushes the button. This time he announces to the FDC, "Fire for effect!" The box on which the FO has been manipulating the dials and button is called a Message Entry Device (MED).

In the FDC tent, the S3 turns to the battalion commander, who has just entered, and says, "That's our 15th fire-for-effect mission this morning. The maps are good, the observers are spotting the targets with excellent accuracy, and the computers are giving us firing data with deadly precision. We're sure laying the steel on the enemy."

DATA ON MISSION MONITOR PANEL

The battalion commander pauses to study the original report of target and the surveillance data on the Mission Monitor Panel (MMP). Numbers and symbols on indicator wheels are set in message rows; one row displays the latest transmission from each observer whose mission is being processed. The battalion commander remarks, "The observer's surveillance report says that the target has been destroyed by the fire we placed on it. I'm sure he is correct."

"I agree with you, sir," says the S3, "There will be no need to fire on that target again, and we have no further need for the full target description. But, we may need the location of the target and the concentration number. The FO may use the target as a known point from which to shift."

Turning to the operations sergeant, Sergeant Black, the S3 asks, "Did you transmit the description of the target to division artillery as soon as it was accepted as a valid mission?"

"Yes sir," Black replies, "we checked the mission out on the Mission Monitor Panel and the Electronic Tactical Map (ETM)."

"Fine! Now, store the abbreviated description of the target, its coordinates, type, and concentration number in the Target Reference Group in the Gunnery Officer's Console (GOC) of the Mission Monitor Panel."

TARGETS CAN BE TRANSFERRED TO COMPUTER

"Sure is handy isn't it, sir. All this data can be stored by just pushing a button on the Mission Monitor Panel. Any of the 64 targets stored here can be transferred to the computer with these two buttons. There is also storage in the computer for 10 to 20 reference targets."

Stepping over to the MMP, the S3 presses a button and a light comes on in the computer. "That button transmitted the target surveillance report to the computer's memory; it's in temporary storage there. The full report on the target was sent to division artillery when we fired on it. Now, I am ready to transmit the surveillance data to division artillery by pressing some more buttons on the computer. You are familiar with what happens to the target information at division artillery, sir?"

"Yes," replied the battalion commander. "If the observer's report is valid, it is treated in one of two ways. At battalion, we either fire on the target or omit firing on it. Next, each report is placed on a magnetic tape at division artillery and becomes a part of the master target file—the artillery intelligence file. The target lists are updated periodically at division artillery just as an inventory is taken in a commercial warehouse."

While the battalion commander and S3 are talking, Sergeant Black transmits, "End of mission," from the GOC of the MMP to the batteries. The command is displayed in each battery on the Battery Display Unit (BDU) in the executive officer's command post and at each howitzer.

AMMUNITION REPORTS ALSO RECEIVED

Black also receives ammunition expenditure reports from the batteries, as he calls for them. The report is transmitted directly from the battery to the computer in the FDC. The operations sergeant monitors the reaction of the battalion computer where expenditures are immediately deducted from onhand figures, and new onhand figures are stored in the computer's memory and reported to division artillery.

Sergeant Black clears the display on the ETM and on the MMP. The FDC is ready for another mission. However, the FDC can process more than one mission at a time. The MMP, the GOC, and the ETM play a part in the processing of one mission while holding and displaying information for others. The critical action on each mission, that is, ballistic computing, is done only by the battery or battalion commander. Because of the speed of the separate devices and the speed of the complete system, several missions can be processed so rapidly that they appear to be computed simultaneously. But, the human element is a limitation; that is, how quickly the operator can convey to the machine what he wants it to do. Throughout the system, specially designed faceplates are labeled

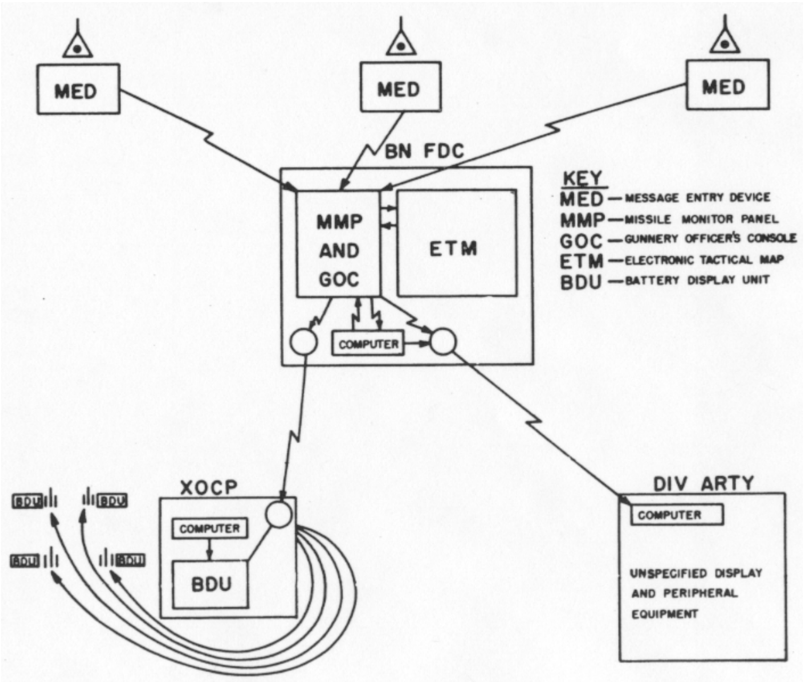


Figure 25. A schematic diagram of computers and input/output devices in fire control.

in artillery terms to make the operation as quick and as foolproof as possible. Although electronic devices are fast, we are limited by the proficiency of the operator.

This article gives you a preview of the complete system of computers and input/output devices in fire control. A schematic diagram appears in figure 25. Depending on the scheme of operation of a particular unit, computers might be employed at battery level with the mission of computing firing data, while the battalion computer and its operator are left free for the switching, command actions, and other computing or data processing tasks; or the computers might not be employed below battalion level, in which case all fire control computing would be done at battalion. Firm tables of organization and equipment, operational and training doctrine, and unit standing operation procedures are yet to be developed. Much time and study will be required to fix all of the details.

To follow up this quick glance at the complete system of automated fire control, a brief study is needed on the function of the ancillary items in the system, the MED (under development), the MMP (to be recommended for development), with its GOC (under development), the ETM and the BDU (both under development). The following article covers these ancillary items.

●

HOW FIELDATA COMPUTERS ACHIEVE TACTICAL CAPABILITIES

FIELDATA Computers achieve tactical capabilities by means of:

—Solid-state circuits

—Miniaturized, ruggedized, and mobilized equipment

—Circuit-card or encapsulated circuit construction of computers

—Standardized peripheral equipment

—Wide operating temperature range of —25 to 125 degrees Fahrenheit

—Shock and vibration mounting of all equipment

—Air-conditioning of all shelter-mounted computers for operator comfort. FIELDATA computers do not require air conditioning.

—Gearing of FIELDATA equipment to the high-priority demands peculiar to tactical situations. Real-time devices, such as the output of aircraft detection systems, can ordinarily interrupt routine computer operations for high-priority processing.

ADPS Book—3
"FIELDATA Equipment"
USA Signal School

Pushbutton Fire Control

"Stee-rike three!" The batter is out and the Tigers have won again. At the moment, the winning team's manager would insist that his pitcher is indispensable, as the latter struck out 14 men. The computer can be likened to the pitcher—it too has value, with or without ancillary equipment. However, reasoning shows that the pitcher was given superb support by the eight fielders backing him up. This article discusses the ancillary equipment as visualized for an automated battalion fire control system and how it "backs up" an automatic data processing system (ADPS) for more perfect functioning.

The five items of ancillary equipment discussed below are the Message Entry Device (MED), Mission Monitor Panel (MMP), Gunnery Officer's Console (GOC), Electronic Tactical Map (ETM), and Battery Display Unit (BDU). All items are not at the same stage of development. Automatic reaction is not complete with this equipment. Human beings are active in decision-making and control.

Message Entry Device

A large proportion of all fire missions start with a fire request from a forward observer (FO). In the article *Inside An Automated FDC,* the FO used a small box, called the MED, to transmit his fire request and to report the results of his surveillance of the fire for effect. Precise functions of the MED have been defined by the US Army Artillery and Missile School; the forms of the MED are being considered and the details of design are proceeding.

The "box," as the Med is familiarly called by ADPS personnel at the School, is not restricted to use by FO's. Survey and reconnaissance parties might also have use for it.

To date, two different approaches to the MED have been suggested (figures 26 and 27). For either device, the messages that are to be sent must be standardized. This is a simple matter in the case of a FO's fire request, since procedure has always dictated a relatively fixed format. Surveillance reports are a little less precisely prescribed in current manuals but can reasonably be put into a fixed sequence for standard reporting.

The speed and simplicity which the MED promises us comes from the fact that the message is set up in advance. The observer has only to put a number or symbol into a labeled position appearing opposite windows in the box. For example, if the observer is shifting from a known point, the label KNOWN POINT (fig 26) will appear opposite three small windows in which the observer can place numbers, by turning a wheel to represent the known point from which he is shifting. A

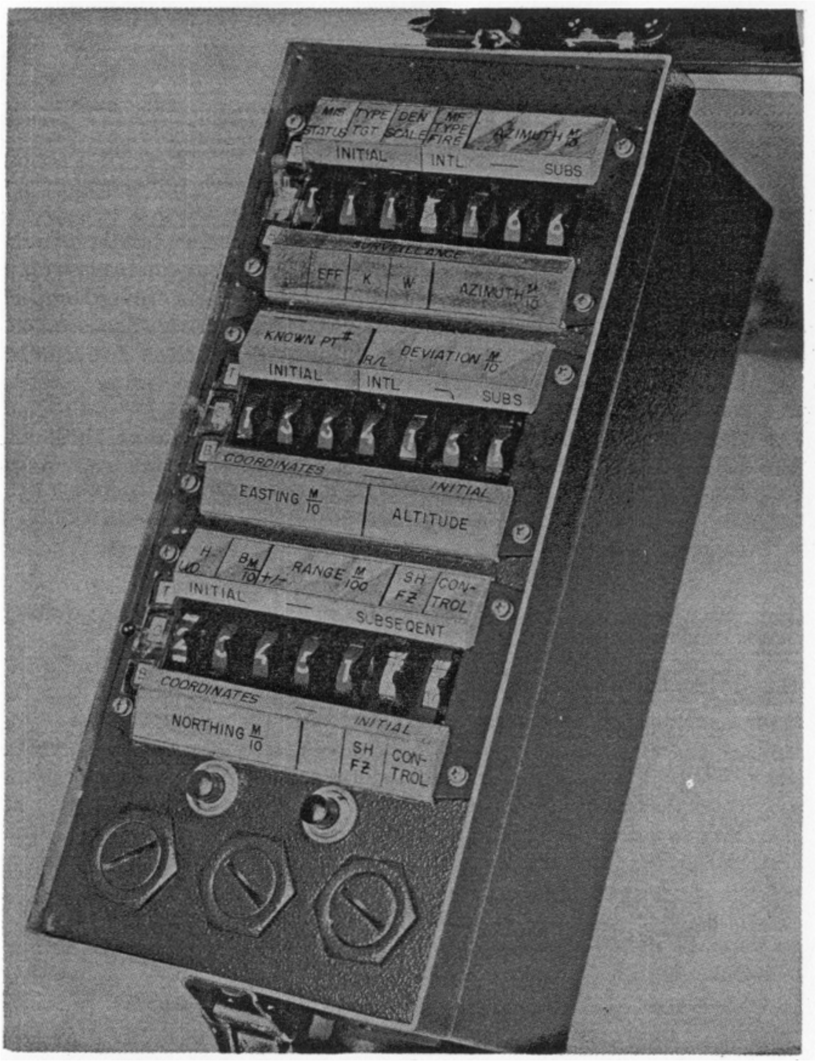


Figure 26. The Message Entry Device, used by the forward observer for fire missions and fire-for-effect surveillance.

number as high as 999—which should be ample—can be accommodated. If the observer identifies the location of his target by coordinates, labels reading EASTING and NORTHING (fig 26) appear opposite four windows for each direction and the observer can set his coordinates into these windows. The same system is carried on to provide windows for each item in any standard fire request. Labels are also provided to be

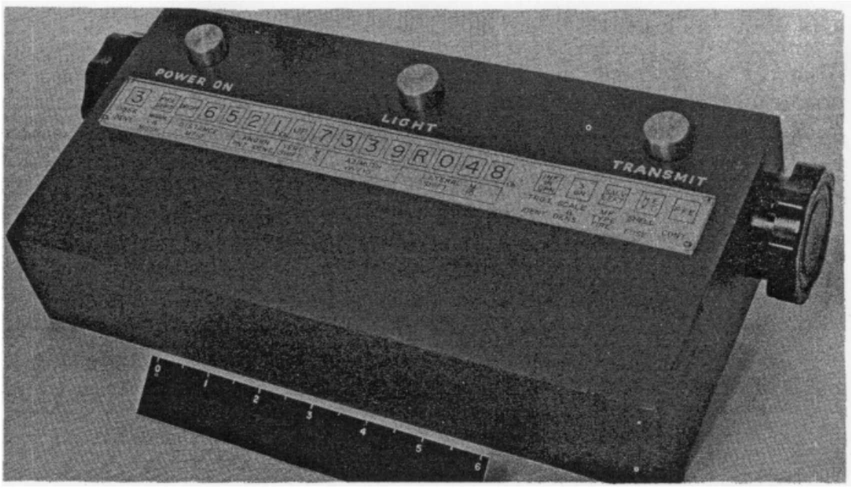


Figure 27. Another approach to the Message Entry Device.

used for reporting the scale and density of the target, these items are required in automated fire planning.

TWO DEVICES ARE SIMILAR

The two devices in figures 26 and 27 have a number of points in common. The labels are in well-known, standard artillery terms. There is no problem of having to work out a complete message in alphabetical characters or abbreviated codes. However, one fundamental difference in the two devices is in how the labels are selected. In figure 26, there are two sets of labels for each row of small switches. The switch on the extreme left is the "mode switch" with which the operator indicates that he wishes to send a message in the terms of the labels above the other small switches or that he wishes to send in terms of the labels below the small switches.

Transmitting with the device in figure 26, the operator sets an individual switch (actually, it is a small wheel with protruding spokes) for each digit in the message. Speed may be attained even though the operator has had limited practice. He will learn quickly the position of each label and his finger will move deftly to the correct spot. This device permits great flexibility because any wheel, that is, any digit, can be changed at any time.

In the device in figure 27, the knob at the left is turned until a red arrowhead moving horizontally along the row of windows is opposite the appropriate window. At this time the knob on the right can be turned until the proper set of labels appears in the lower row of windows. By again turning the knob on the left, the red arrow is moved to the position opposite the labels, in turn, or opposite any label desired. When the red arrow is in the proper upper window, a turn of the knob on the right will change the digit in the upper window. The observer moves the red arrow along, stopping at each window to set in the desired digit, until his message is set up.

With both devices, once the message is set up, the observer pushes a TRANSMIT button and the message is transmitted to the fire direction center (FDC). Both devices are being studied. One or the other, or a third one being designed to accomplish the same task, may be adopted. The MED is designed to supplement, not replace, the radio and the telephone. The transmission will be over normal voice channels provided by the radio or telephone. With the two devices now under study the transmission is through the radio or telephone. A voice conversation can be carried on at the same time that the message is transmitted. It takes only 2 or 3 seconds to transmit the train of pulses representing the message.

BOXES ARE CODED

Each box is coded and transmits its own identification as a prefix to the message. The prefix designates the observer and can be displayed on the MMP in the FDC. Consideration will be given to security.

Both devices are designed so that there is a check of the message. The "total bit count" method of check might be used. This method operates as follows: When the original message is transmitted, the transmitting device counts the bits (binary digits) and sets itself electronically to recognize this number. The receiving device counts the bits as received and transmits back to the sending device the number of bits in the message. If the FO's box receives the current count from the FDC, the box will emit a low squawk or tone (or possibly light a small lamp). This gives the operator a high assurance that the message was received correctly. If, after a short time, the observer does not receive the acknowledge signal, he should try to transmit again. He needs only to push the TRANSMIT button again.

It is hoped that the MED will give rapid, error-free transmissions of fire requests and simple artillery target intelligence. The present slow readback and the repeated copying and time-consuming oral repetition of fire missions should be eliminated.

Perhaps even more important in an ADPS is that the intelligence aspects of the FO's message will now be adequately dealt with. Presently, new messages must be generated through the artillery S2 when it is desired that the FO's information reach division artillery and become part of the overall target list. With the MED, the target is already in the electronic system when the S3 decides to fire. Pushing two or three buttons on the MMP sends the information back to division artillery, where more sophisticated routines process it for inclusion in an updated target list and for retransmission to higher headquarters for further intelligence action.

To make sure that the observer's information is suitable for inclusion in the target system, care has been taken to design the MED to include labels for TARGET TYPE, SCALE, and DENSITY, in the same terms as are used in the fire planning computer program.

MED IN SURVEY OFFERS PROMISE

The possible application of the MED to artillery survey also offers promise. There is no reason that other labels cannot be designed and the box coded to advise the receiving system of the type of message being sent. Reconnaissance and operational data could well be included.

At the present time, the fire control application is the furthest advanced and is possibly the most promising.

Mission Monitor Panel

The MMP is the display device in the FDC which receives and displays the FO's transmission. The S3 may add to the display a view of some of the same information shown on the ETM. The display aids the S3 in making his decision and in issuing his fire order. The MMP is not yet under development but the requirement appears to exist and is under study. The GOC aspects have been actively developed and will probably be available soon for test in the form of a separate GOC. The following paragraphs provide more detail on the MMP as it might be employed in the fire control family of equipment.

The concept of what the panel (display) element of the MMP may look like is in figure 28. Rows of small wheels on which digits and symbols are printed are shown. The wheels position themselves automatically to correspond to the position of the wheels on the observer's MED. The MMP is also connected to the ETM and the computer so that messages displayed on the MMP can be sent to the map for display or to the computer for retransmission to other computers, for storage within the computer for future reference, or for immediate computations. Switching buttons on the GOC perform two tasks; transmit data and transmit commands. For easy reference, the combination of the GOC and MMP will at times be referred to as the monitor panel.

It may be helpful to analyze the contents of a message which may be received from the observer. Considering the three types of messages—initial fire request, subsequent fire request, and report of surveillance—there are four possible functions which may be served by parts of a message. Elements of each message are applicable to one or more of the functions, as shown in figure 29.

SEQUENCE OF EVENTS

Now, note the sequence of events in connection with the use of elements of the messages.

(1) Observer identification is made automatically by the panel and displayed to the S3.

(2) Considering the identification and the rest of the message in the

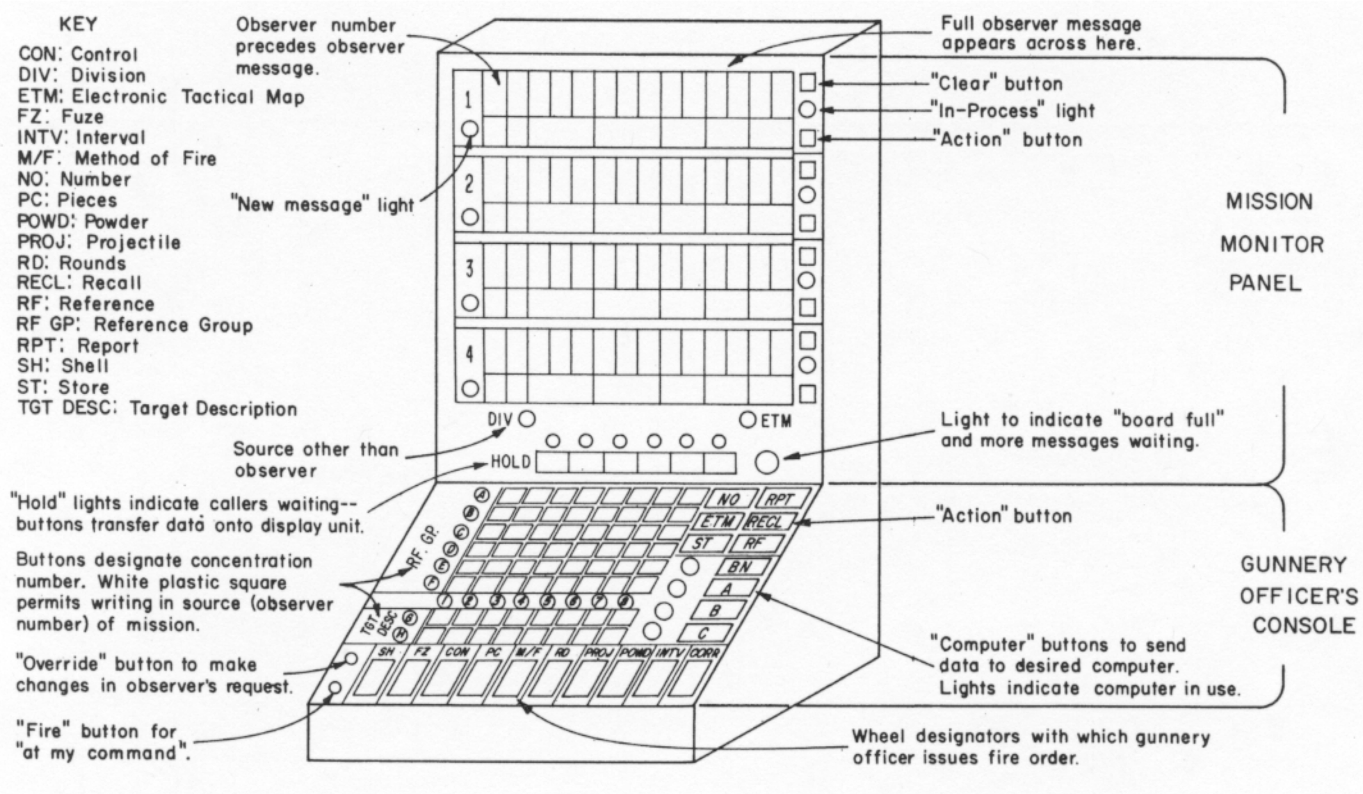


Figure 28. **A concept of the Mission Monitor Panel and the Gunnery Officer's Console.**

FUNCTIONS	ELEMENT OF MESSAGE UPON WHICH BASED	TYPE OF MESSAGE
A. Identification	1. Observer's identity automatically coded by MED.	Initial request: subsequent request; report of surveillance.
	2. Concentration number added by Monitor Panel on initiative of S3.	All.
B. Decision as to fire to be placed	All elements.	Initial request; subsequent request.
C. Geometry necessary to compute firing data.	Location data.	Initial request always; subsequent request frequently: report of surveillance when report contains (1) revised estimate on location of target requesting additional fire; or (2) information on movement of target; (3) data for plotting.
D. Target intelligence for file.	All elements.	All.

Figure 29. Elements of each type message are applicable to one of the four functions shown here.

context of the tactical situation and his knowledge of the observer, the S3 accepts the message as valid or invalid. He may do this before or after transmitting the message to the ETM for display. Function A (fig 29) has been partially served.

(3) The S3 presses a button on the monitor panel which causes the panel to tag the mission with the next concentration number, which is now displayed. Again, the mission may or may not be displayed on the ETM depending on the S3's desires. Function A is now completely served.

(4) The S3 decides to fire the mission with a battalion volley. Function B has been served.

(5) By pressing the "batteries to fire" and the "volume of fire" buttons on the GOC element, the S3 sends the concentration number and location to the computer for computation of firing data (at battery or battalion). Function C has been served.

(6) Again, using the GOC of the MMP, the S3 issues a complete fire order to the computer and to the battery.

(a) The appropriate computer takes action to generate firing data (charge, deflection, fuze setting, and quadrant elevation).

(b) Instantly, the appropriate BDU's display the fire commands, less the firing data being computed; in a few seconds the data has been computed and automatically transmitted to the display devices. The display is now complete at all BDU's.

(7) When the S3 pressed the buttons to send the mission to a computer for computation he also pushed a REPORT button (fig 28) which transmitted the complete message to a temporary storage area in the GOC; it will be transmitted later to division artillery as a piece of target intelligence, where it will be held until the end of the mission. Function D has been served.

(8) At the end of the mission, the observer will make his surveillance report and the S3 will decide whether he should store the target permanently as a possible future target, or merely hold it as a known point from which an observer may shift. If the S3 believes the target should serve only as a known point he will store permanently only the identity, type, and location of the target. These items will be stored within the GOC of the MMP or within a computer in the TARGET REFERENCE GROUP (fig 28).

(9) The mission is complete. The observer reports the surveillance, and the S3 decides to store the target in the reference group only. He pushes the TARGET REFERENCE GROUP button to store the target in the GOC.

(10) Finally, he pressed a TRANSMIT INTELLIGENCE button on the computer to send the complete surveillance report to division artillery.

(11) For this particular mission, function D was completely served at division artillery. Division artillery received the initial request before fire was completed ((7) above). The complete surveillance report has now been transmitted to division artillery.

(12) All action on this mission is complete.

DEVICES PLUS OBSERVER SPEED FIRING

The preceding steps show how the MMP, working with the observer, the ETM, and a computer, speeds firing and assists in reporting fires and target information to division artillery (normally, an S2 task).

The full target information will be at division artillery where a larger computer with more file-type storage—in the form of magnetic tapes—and more complex programs will permit a full treatment of target information. Large quantities of information can be sorted, sifted, and fitted into summaries, patterns, and consolidations which will permit discarding or placing in relatively dead files the item by item fragmentary information gained throughout the day from the several battalions.

It is impossible at this time to say with finality just how the system will work, but it is believed that, generally, the battalions will have limited computer storage facilities. For example, magnetic tape units are not contemplated at battalion. Therefore, the amount of information stored at battalion will normally have to be confined to active or imminently active targets.

A vital function of the MMP will be to permit the S3 to see the different missions pending in a single display. This will assist him in determining priorities of action.

The overall function of the MMP, used in conjunction with the ETM, is to permit the S3 to see the entire mission in its context as it progresses.

The monitor panel will also assist the S3 in deciding what to store permanently or temporarily in the GOC element of the MMP and in the computers. The GOC will assist the S3 or gunnery officer in conveying his decisions to those who are to execute them—men or machines; it will provide him with the capability for generating orders and switching commands and data between parts of the system. A prototype for the GOC has been designed but its precise employment has not yet been determined. The functions described for the MMP are an extension of those initially conceived for the GOC.

The MMP performs the functions listed in figure 29 and discussed above. It can be used with or without an ETM. In many instances, a sound decision can result only from a reference to a map—automated or not automated. It would be possible to position a plain paper map in the FDC where it could serve the person reading displays on the MMP. In a complete system, however, the ETM is the logical aid for the S3 working with the MMP.

Electronic Tactical Map

The ETM (fig 30) is desired at battalion level, but the problem is to design one which is sufficiently simple and inexpensive to permit its use at that echelon. The ETM has an application at division artillery and corps artillery where the mass of data and the size of the headquarters probably justify the present complexity and high cost, which at present appear to be somewhat inescapable.

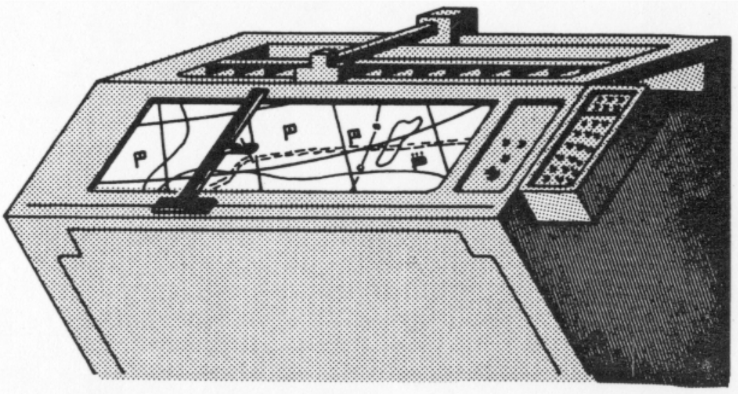


Figure 30. A concept of an Electronic Tactical Map.

The ETM should be designed to display "on-call" targets held in the GOC of the MMP or targets held in the computer's memory. The display requested might be for a single target, for a combination of targets, or for all targets meeting a certain description.

The single prototype ETM constructed to date was designed for battalion use but appears limited even in that application. Only a single target can be displayed at one time. Decisions with respect to the volume of fire and the urgency of fire on different missions is dependent on the tactical situation, which can be considered best from a view of a map. A map permits concurrent consideration of targets—past, present, and potential.

At echelons above battalion, the commander or operations officer will certainly wish to look at targets all together or in selective groupings. He may wish to view all targets of a certain target type, those falling within specified areas, or those reported within certain time intervals. The ETM must be equipped to display targets by category.

ETM NEEDS OWN MEMORY

Returning to a consideration of the ETM at the battalion, where fire control can be said to originate, the ETM will probably have to have a memory and certain logic circuits of its own to permit continuous display of designated target categories. The ETM will have to be closely linked with the MMP and the computer so that data can be passed back and forth among the three devices as directed by the gunnery officer. If the map were to be without rudimentary memory and logic of its own, the computer could communicate directly with the map and display items thereon; but the computer might be neutralized and unable to perform other functions while the map was displaying information. The ETM should be able to display targets from the MMP and the computer equally readily.

The design and plans for an ETM of the type described above are still at an early stage of development. Schemes under consideration are cathode ray tube projection, such as that in TV and electroluminescence.

The device under discussion here is not strictly speaking an ETM. It is an electronic display on a map. There is no plan for the device to produce a map; the device will display information on a map provided to it. The map will be either a standard paper map as produced by the Army Map Service (AMS), or it will be a transparency produced from an AMS map. By any one of a number of projection schemes, the desired tactical information can be displayed electronically on plastic or glass on which the viewer believes he also sees the map.

A critical factor in the design of an ETM and its integral electronic components is the amount of storage, that is, memory, required. This factor is, in turn, controlled by the amount of information that must be stored for each target. As in fire planning, it may be necessary to allocate three or four computer words to each target to store all the identification, geometry, description, and time tagging required.

TOTAL MEMORY REQUIREMENT IN TWO PARTS

Total memory requirement can be considered in two parts. First, there is a requirement for storage locations for the targets, the friendly and enemy situations, and possibly markings for key terrain features within weapon capability limits. Second, certain empty storage space is required for use during the sorting and stacking procedures, which are prerequisite to display of targets by specified categories.

Though this is little more than a guess, it is difficult to see how an effective map can be designed with less than 1,000 words of active memory for battalion use, and with less than 4,000 to 6,000 words for division artillery use.

It may be desirable to be able to change the scale of the projection of targets, especially at division artillery or corps artillery where the total area covered will be large. It may be desired to scrutinize a portion of the target area. To be able to see the target array without obscuring the map with symbols it will be necessary to enlarge the map. At battalion level, a single scale will probably suffice.

As mentioned in the discussion on the MMP, the S3 at battalion may place some targets in the TARGET REFERENCE GROUP of the GOC or computer where only the concentration number and the location are stored. Other targets possessing more lasting intelligence value may be placed in the "full intelligence file" of the computer. The present estimated requirement for three to four computer words for each target in the "full intelligence file" limits the number which can be placed there. In displaying targets on the ETM, there should be appropriate symbols to distinguish between the two types of targets files: full intelligence or target reference. There are numerous categories and methods of sorting targets which the S3 or the commander might wish to employ. If the information with respect to the target is in the basic target word and has been carried into the computer working with the ETM, the computer can sort and display the targets on the ETM in the categories specified.

The first complete ETM developed will undoubtedly be used in an automated FDC in the fire control role. Later, the ETM will serve operational functions. Throughout the discussion and development period much will be learned of the potential of the ETM and the problems associated with it.

Battery Display Unit

The BDU is the "end of the line" in the fire direction and fire control automated system. If automation begins with the FO and his MED, it ends at the firing battery with the BDU's.

The BDU's display the complete fire commands to the battery executive officer. If BDU's can be made inexpensive enough to permit it, the devices might be extended to the individual howitzers where each member of the gun crew can see the portion of the commands and data applicable to him. One form of BDU has been designed and will soon be available in prototype.

The BDU is similar to the MMP in appearance but it does not have a GOC. It is a display only, not a switch device. There are rows of small wheels on which digits or symbols are displayed. A sketch of the BDU currently being developed is shown in figure 31.

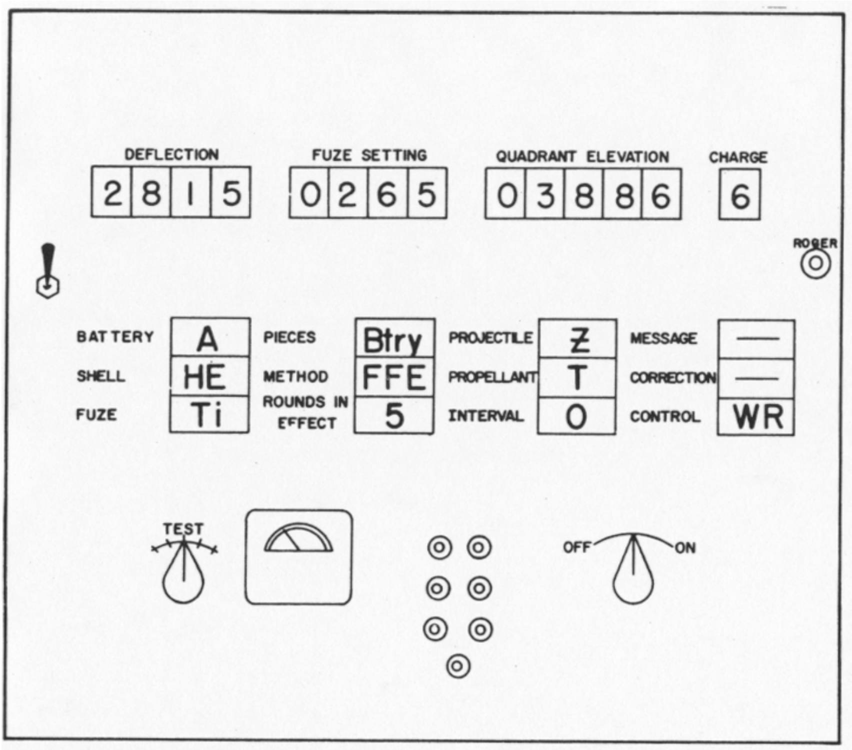


Figure 31. A sketch of the Battery Display Unit currently being developed.

The wheels spin and the S3's initial fire order appears on the BDU as a direct transmission from the GOC, the control element of the MMP. It is also possible to direct the mission from the fire control panel of a battery computer. As soon as the computation of the remaining fire commands is completed by the digital computer, the commands appear on the BDU—deflection, time, quadrant elevation, and charge.

BUTTON FOR BATTERY EXECUTIVE OFFICER

The battery executive officer is provided an "acknowledge" button on the BDU that permits him to transmit back to the gunnery officer the fact that the transmission has reached the battery in intelligible form.

Little power is required to operate the BDU. The wheels spin on the power supplied by dry cell batteries, or the BDU can be hooked to a 1/4-ton truck battery. It should only be necessary to run the motor occasionally.

There are "New Message" indicators at appropriate points in the numerical array. The indicator—a small neon bulb—lights each time a new element of the fire command is received. This is to remind the battery executive officer or the chief of section that a change has been made. The recipient of the message can extinguish the light by pressing a small button over the light. He presses this button as soon as he has acted on the change in data or commands. Other minor refinements may be developed. For example, the battery executive officer's BDU might have a small panel included that would permit him to see by neon indicators which of the pieces have acknowledged the message. For the largest caliber cannon, it will probably be desirable to split the BDU into parts so that portions of the display can be placed where the affected members of the gun crew can see them.

As with all the other items in the automated fire control system, the standard two-wire field wire system or standard voice radio channels are being planned for use. Having computers on either end of a battalion to battery line or a computer at battalion and a BDU only at battery will not obstruct normal voice channels. Filters will be provided to eliminate interference.

Just as with the FO's MED, it is not believed that the BDU can eliminate the need for direct voice communication. The battery executive officer will frequently have occasion to talk with his gun crews; the battalion FDC personnel will have a need to talk with the battery executive officer. But a MED, a simple switching at battalion, and a rapid computation of data by the computer, followed by a fast and accurate display of the commands generated, will remove many sources for error. A minimum of four voice transmissions, usually many more, are replaced by one manual input of digits from a keyboard (observer at his MED) and a few switchings with control-type buttons.

The BDU is not indispensable—accuracy and the consequent benefits from the computer can be gained without a BDU. However, the BDU speeds the operation and removes error sources.

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Basic elements used in computers are the printed circuit cards which eliminate the need for a great amount of wiring. The card material is prepared in the required size and shape. The circuitry is outlined in ink on the cards, after which they are copper plated. Components required for each circuit are inserted, and a dip soldering process is used to complete the manufacture. The cards may then be used in computers to provide highly reliable circuitry.

Future Shooting ——

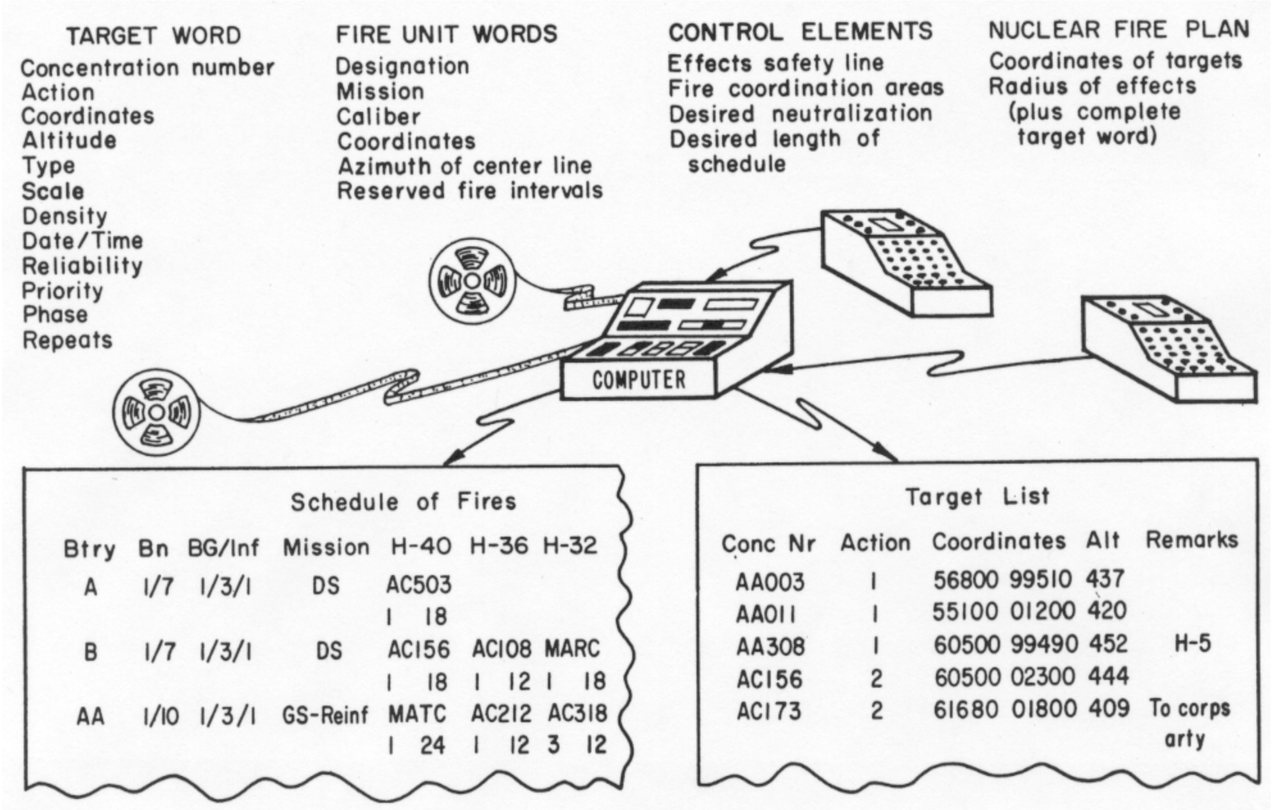
AUTOMATED ARTILLERY

The greatest challenge yet in exploring the application of automatic data processing (ADP) to a major artillery function is in fire planning. Currently, the procedures and techniques involved in this function demand human thought and judgment at almost every step. The question might be asked: "Why even consider automation in this area then if human decision is required or if the job can be performed more efficiently manually?" The answer, based on studies and experience, is that the majority of the decisions involved can be programed into the computer, so that fire planning can be automated to the extent that the results would be extremely advantageous to artillery in combat.

This answer, in turn, raises two points which should be clarified. First, there is an understandable tendency to question the idea of a machine making decisions which can have a definite impact on fire support and, subsequently, the operations of a force. The answer lies in the *type* of decisions made. For example, no one would object to the computer telling whether a target falls within the fire capabilities of a certain unit or deciding whether a fire unit must shift in deflection to attack a certain target. These are typical decisions which the machine can be required to make.

The next point in question concerns the advantages that can be expected in automating fire planning. Generally, two are most important. First, a significant saving in time will result. Fire plans at higher echelons, such as division artillery and corps artillery, will be produced in a matter of minutes—once the process is started—rather than the hours or days which are needed with present means. Second, human error in the mechanical manipulations currently required for analyzing and scheduling targets will be eliminated.

The project team for fire planning (representatives of the US Army Artillery and Missile School, the Signal Corps, and the contractor) has been faced with the problem of automating a subject which, until now, has largely required handling matters in the abstract; what, then, has been the approach to the problem? The solution lies in establishing the appropriate man-machine relationship; that is, requiring the machine to perform the functions it can best do while human guidance is applied where it becomes the ruling factor. As a result of studies beginning in 1957 in which fire planning requirements were analyzed in detail, a systems analysis was developed. This means that, based on guidance provided by qualified artillerymen, the analysts, engineers, and computer programers can take over the technical tasks which will result in the



Schedule of Fires

Btry	Bn	BG/Inf	Mission	H-40	H-36	H-32
A	1/7	1/3/1	DS	AC503 1 18		
B	1/7	1/3/1	DS	AC156 1 18	AC108 1 12	MARC 1 18
AA	1/10	1/3/1	GS-Reinf	MATC 1 24	AC212 1 12	AC318 3 12

Target List

Conc Nr	Action	Coordinates	Alt	Remarks
AA003	1	56800 99510	437	
AA011	1	55100 01200	420	
AA308	1	60500 99490	452	H-5
AC156	2	60500 02300	444	
AC173	2	61680 01800	409	To corps arty

Figure 32. Input requirements and an example output of the fire planning portion of the field artillery subsystem, SS1.

production of a taped program that will enable a computer to produce a complete fire plan in the field.

FIELD ARTILLERY'S LONG-RANGE GOAL

Under the Army's ADP program, the long-range goal of the field artillery is a subsystem, the SS1, which will be an integrated part of a field army tactical ADP system. Fire planning will take its place in the program by producing complete fire plans to meet any tactical need for any combat condition. The steppingstone to this objective is the SS1a, the "sampling," or prototype, system. In this more immediate program, artillery fire plans will be produced which will show the feasibility of automating this function. A short list of standard target types has been prepared. Division artillery fire plans on a scale involving 80 to 90 nonnuclear targets and around 15 nuclear targets will be turned out, the final products being a detailed target list and an integrated schedule of fires (fig 32). As the target list is built up (targets will be acquired and fed into the computer), the S3 will apply the commander's guidance and criteria, such as the desired effect on each target type, the time limits of the preparation or counterpreparation, and the list of available fire units. Each target will be analyzed and, when appropriate, will be scheduled in its proper place. The S3 will maintain control throughout the process, overriding decisions when necessary and guiding the analyses at appropropriate points for a balanced man-machine relationship.

In this fashion, the artilleryman will be able to plan his fires—the attack on targets in the future—in an optimum time and an efficient manner because of the efforts of the ADP project team. The first demonstration of automated fire planning is being readied at this writing and is slated to be shown at the US Army Electronic Proving Ground early this Fall. In a planned sequence, later demonstrations will take place in the field under combat conditions.

Another area of significance to artillerymen, one which ties into fire planning and fire direction, is the automation of ammunition accounting and control. With ADP this function is a "pushover"; after all, today's accounting procedures are based upon simple "grocery store arithmetic." The necessary programs are being completed and will be part of the feasibility demonstration early this Fall. Although the analyses and programing for this function are relatively simple when compared to other functions, the real impact of automation on the overall ammunition resupply system has yet to be realized. Imagine a system of ammunition control and resupply which can operate smoothly and automatically from theater depots direct to the artilleryman at the gun or howitzer. Many of the existing "middlemen" and their ammunition supply points, which are essential in today's combat operation, could be eliminated. The overall effect on this vital and far spread logistical function is locked in the future.

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SPEEDING NUCLEAR RESPONSE VIA ADP

Nuclear artillery will provide the field army of the future with overwhelming firepower, which may be employed quickly and decisively to influence the battle. However, the present method of numerical nuclear target analysis is too time consuming because of the many mathematical computations. The simplified method of target analysis at best is an "educated guess" and is inaccurate, since it does not consider all delivery errors.

Automatic data processing (ADP) and computers are essential to give us more accuracy and greater speed in the employment of nuclear weapons. The computer can solve in minutes a problem that now takes the nuclear weapons employment officer (NWEO) hours to solve in nuclear fire planning. With the present method of analysis the NWEO can produce a workable nuclear fire plan, but it is not always the best fire plan because of insufficient time in which to consider all the variables and combinations. A computer, by figuring all the combinations, can produce the optimum overall nuclear fire plan much faster.

Many commanders ask, "Why is it necessary for a detailed numerical analysis; why can't a template be placed on the map to quickly determine a yield?" Several reasons why this cannot be done are—

(1) Nuclear cost—Because of the limited availability of nuclear material, weapons cannot be wasted. Optimum results must be received from all bursts.

(2) Troop safety—The prospective use of nuclear weapons on the battlefield demands more accurate and careful prediction of the total dose of radiation exposure to friendly personnel and the damage to friendly materiel. This can be accomplished only through detailed target analysis.

(3) Contingent requirements—Commanders will have requirements for both bonus damage and/or nondamage to key locations. This will require more detailed numerical target analysis.

(4) Preinitiation—The possibility of preinitiation of one weapon by the nuclear radiation of another must always be checked. This is accomplished by determining the distance between bursts and comparing that distance to a predetermined minimum safe distance (MSD) after considering the delivery errors of the weapons. If the bursts are too close together, they must be separated by either time or distance. A detailed analysis is necessary for this evaluation.

(5) Delivery errors—The new missile systems require computation of delivery errors for every tactical situation. It is no longer possible to look into a firing tables for a range and quickly determine a circular probable error (CEP). The data for combined radar and mechanical

time fuzing and guidance station control cannot be rapidly compiled from firing tables. Optimum consideration of the many variables must be accomplished in detailed analysis.

NEED FOR COMPUTATION SPEED

The requirement for speed in computation is obvious. In a rapidly changing situation, reaction must be quick. Realistic warning times must be given to our troops, so they can be prepared for each nuclear burst. Dose rates in an induced radiation or fallout area must be predicted or determined and consolidated.

Nuclear fire planning must be completed prior to nonnuclear fire planning so that the two plans may be integrated. For maximum utilization of artillery, the nuclear and nonnuclear fire plans must be integrated to achieve maximum efficiency. In the present manual solution of fire planning, very little integration of fires is accomplished because of time limitations. With ADP, complete integration of the two fire plans will become a reality.

How does a computer formulate a nuclear fire plan? First, it makes a detailed target analysis of each target and determines the best yield and burst height to meet the commander's requirements. Then, by considering the allocation of weapons and the minimum distance or time between bursts, it computes a nuclear schedule of fires. Last, it sends the coordinates of the burst and the effects radius to the nonnuclear fire planning computer for integration of the two fire plans.

The inputs into the system are a nuclear target word (fig 33), a nuclear fire unit word (fig 34), an allocation when given, and meteorological data. More information is needed in the nuclear target word than in the nonnuclear target word. More than the 10 types of targets to be used in nonnuclear fire planning will be available for listing. The radius of the nuclear target and the distance to the frontlines will be placed into the target word. The other information in the target word consists of the commander's criteria for damage, troop safety, and contingent requirements.

THE FIRE UNIT WORD

The fire unit word will have the coordinates of the fire unit and guidance station and the azimuth of the center line for weapon delivery units. Reaction time is the time required by a unit from the receipt of a mission until it is ready to fire. The number of nuclear weapons on hand will be placed into the fire unit word as coded yields. The code can be changed as desired, thus simplifying the problem of handling security data.

The steps in which a computer determines a schedule of fires for a fire plan are shown in figure 35. First, the fire units capable of firing at each target are determined. Then, each target is analyzed for the yields available. The computer determines the best burst height and maximum radius of damage for each yield in a delivery system. It considers

Target number
Coordinates
Radius of target
Type
Priority
Phase
Time of casualties

Probability (P)
Fraction of damage (f)
Troop safety criteria
Troop safety buffer distance
Distance to front lines
Contingent requirements

Figure 33. A nuclear target word.

Unit designation
Coordinates fire unit
Coordinates guidance station

Azimuth center line
Reaction time
Weapons on hand

Figure 34. A nuclear fire unit word.

INPUTS	STEPS IN COMPUTER	OUTPUTS
Target word **Fire unit word** **Allocation** **Meteorology data**	Compute capabilities Compute delivery error Compute radius of damage, height of burst and yield Compute P (f) Compare P (f) with required P (f) Compute minimum safe distance Compare frontline distance with minimum safe distance Compute contingent minimum safe distance Compare contingent minimum safe distance with contingent distance Compute actual distance Compute revised P (f) Compare yields with allocation Compute minimum waiting time Compute schedule of fires Compute nonnuclear effects radius	**Schedule of fires** **Unit designation** **Coded yield** **—Height of burst** **—Desired ground zeros** **—Time on target** **Maximum CEP**

Figure 35. Computer steps in determining a schedule of fires for a fire plan.

the computed delivery errors of the system throughout the analysis. It computes the probability (P) of achieving a certain fraction of damage

(f) for each yield. It compares this P(f) with the commander's required assurance of damage. If the yield meets the commander's requirements, it is then checked for troop safety by comparing the MSD with the distance to the frontlines (D). The MSD is determined by considering the commander's troop safety criteria. Contingent requirements are then checked to meet the commander's requirements. If any of the contingent requirements or troop safety requires an offset of the original ground zero from the target center, then the computer determines a revised P(f) by considering this offset (d). This revised P(f) is again checked against the required P(f) stated by the commander.

After all the targets are analyzed, the computer checks the distance between desired ground zero's (DGZ's) and makes up a schedule of fires by considering preinitiation, allocation, and phases of the preparation.

In the schedule of fires, the computer lists the delivery means by unit, the coded yield, the height of burst, the desired ground zero, and the time on target. It also lists a maximum allowable delivery error for missile units, so that those units will have flexibility in the selection of their launcher positions.

Finally, the computer computes a radius of effects for nonnuclear fires, so that this information can be integrated with the nonnuclear fire plan.

COMPUTER CAN DETERMINE ALLOCATION

In addition to computing a fire plan, the computer can determine a recommended allocation during the planning stage of a campaign. This allocation can be forwarded to the next higher headquarters. The actual allocation is inserted into the computer before the fire plan is computed.

The computer can also rapidly compute the best unit to fire and the yield to be used on a target of opportunity. If no fire units are in range of the target, the NWEO can insert into the computer the travel time it will take certain units to displace to a new position. The computer can then compute a yield and state the earliest time that a unit will be able to fire. The commander then makes a decision to move a fire unit or to call on other available means to destroy the target.

Maximum flexibility has been placed in the computer program. If the computer cannot meet the commander's requirements, it will type out an exception at that point in the program. For example, an exception will be typed out if a fire unit and a yield cannot be found to meet the commander's requirements for assurance of damage. The exception will list the unit and yield that can produce the greatest damage and the P(f) that the unit can achieve. The commander can then decide whether to use the fire unit or call on other means to destroy the target.

As with all computers, the machine will do only what it is instructed to do. The computer makes only computational decisions in nuclear fire planning. Its outputs are recommendations to the commander and his staff. Since the computer arrives at these recommendations in a fraction of the time it takes a staff to accomplish them in the manual method, the staff will have more time for evaluation, for determining other courses of action, and for warning troops.

Automatic data processing will increase speed in nuclear response through faster analysis and through faster communications. Nuclear weapons will be coordinated and controlled at all command echelons. Target acquisition will be controlled by the same echelons so that the response time will be minimized. With these new developments, nuclear artillery should become the predominant arm on the battlefield.

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COMPATIBILITY IMPORTANT IN AUTOMATIC DATA PROCESSING

One of the most important features of an automatic data processing system is "compatibility." This term refers to the capability of any one of the items of equipment in the system to operate directly with another without requiring manual intervention or the use of any intermediate translation devices.

A standard group of 64 operations codes has been prepared to provide this capability for the FIELDATA family of equipment. Each computer in the family uses a subset of these codes as instructions in its internal program. This means that one FIELDATA computer may direct another computer without any significant changes in programing and without a human operator being required to step in and "think" for either machine.

All machines possess the same electrical characteristics for external operations. This facilitates communication within the system by permitting direct contact between equipments without the use of special devices, the sole function of which is to provide the ability for the transfer of data by means of conversion processes.

A final element of compatibility is found in the FIELDATA code which makes possible a standard language for system use. The code permits direct transmission of data through established communication links without the use of a Communication Converter. It is also used for computational functions within the computer.

Because of the high degree of compatibility which will exist in the FIELDATA equipments, it is expected that most programs for field use may be prepared in a garrison or laboratory environment. This would eliminate a need for personnel to write "instructions" for the machinery in the field.

Airborne Target Identification

A limitation of all target-locating sensors, with the exception of sound ranging, is the need for line-of-sight operation. The sensor must detect some portion or a direct product of the target to determine the location of the target. This leads to a conclusion that to acquire deep targets, a sensor should be airborne. Several proposals for airborne sensors or sensor systems have been made and some of these are being developed. Whether the sensor is a man's eyes, a radar, an infrared device, or a television device, the mathematical problems remain basically the same. First, the location of the aerial sensor platform must be known at the time sensings are made; second, the sensor must locate the target with respect to the air vehicle.

The air vehicle may carry its own navigational reference system or there may be a ground radar continually tracking the air vehicle. In either case, the position of the air vehicle must be computed. The airborne sensor may only have a means of measuring horizontal and vertical angles to a target or it may also possess a ranging capability. To get an accurate three-dimensional location of the target, horizontal and vertical angle readings on the target from a known position in the air must be reported. The airborne sensor then moves to at least one other location and the process is repeated if there is no ranging capability. This is the procedure which will be used in airborne target location systems now in development. With the requirement for rapidly locating targets at great ranges, a manual solution to the above problems becomes almost impossible within the time available—therefore, a computer is required.

The type of ground radar now used in a target acquisition battalion for locating artillery weapons and in a division for locating mortars samples a portion of the trajectory of a projectile. From this sample, the radar identifies the sample as a portion of a particular trajectory and makes an extrapolation of the sample to the weapon location. The sampling technique used by the AN/MPQ-10 radar is to track the projectile. The AN/MPQ-4 radar uses a dual beam intersection technique and an analog computer for extrapolation.

The problem of tracking a low-angle weapon projectile and extrapolating back to its origin demands a digital computer to solve the problem with speed and accuracy. Even the problem of which projectile to track requires a computer. The AN/MPQ-32 counterbattery radar (fig 36) now in development will use digital computers.

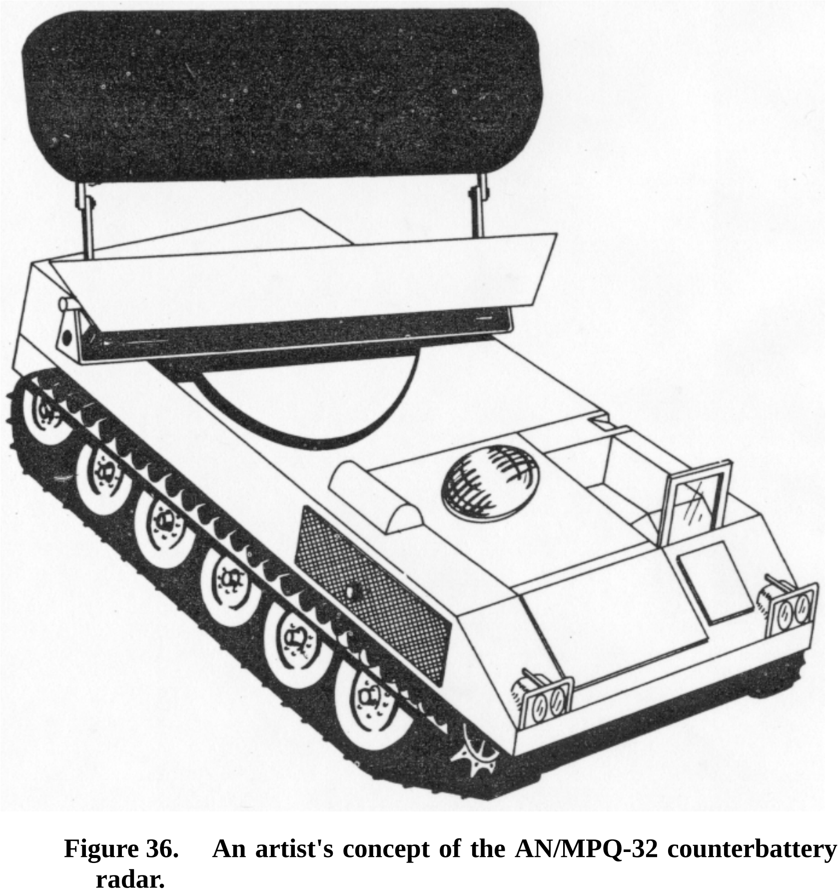

Figure 36. An artist's concept of the AN/MPQ-32 counterbattery radar.

With new ground and airborne sensory devices (fig 37), target information will be generated in such quantities that current manual systems of data reduction and data display will be "swamped." Equally

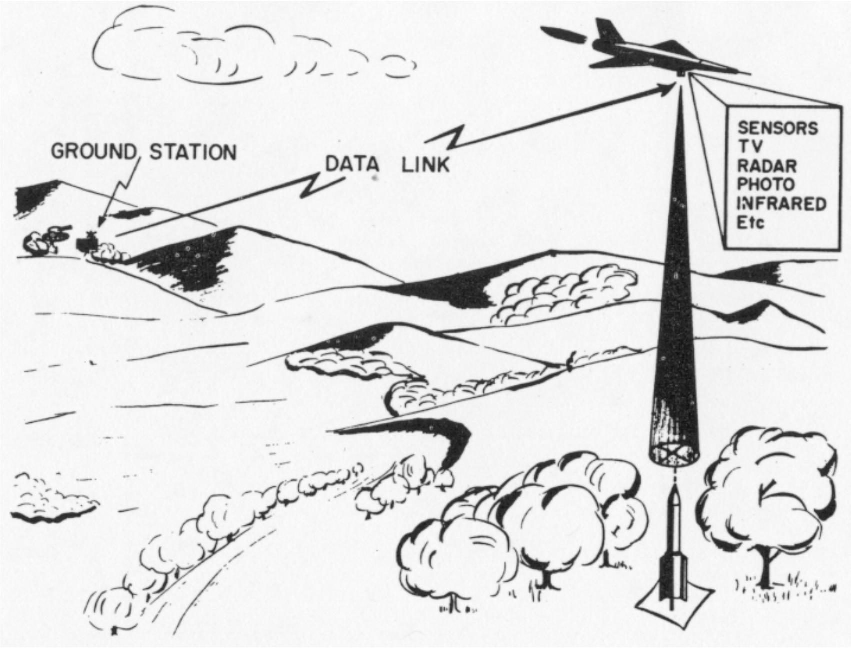

Figure 37. An artist's concept of new ground and airborne sensory devices.

important, but often overlooked, are electronic methods for imagery scanning, for data transmission to computers, and for data display systems to enable the commander to bring down timely fire. Research is continually seeking to produce this ancillary equipment, for the ability to deliver effective fire with the first round is of little value unless the target information is equally accurate and timely and displayed in a manner readily understood by the commander.

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ADPS cannot replace human judgment. But it is a powerful aid to the decision maker. It quickly provides extensive, complete, up-to-date, and accurate information upon which to base decisions. It will enable the field commanders and the staff officers to consider a multitude of alternative courses of action, leading to rapid, astute decisions.

AID TO DECISION

TARGET COMPILER

Target Compiler is the name given a concept for a complete system of target acquisition and target data processing for the field artillery. The heart of the target compiler is a digital computer program under development at the US Army Artillery and Missile School. The objective is to have a computer program that will accept fragmentary information from many target acquisition agencies, human and inanimate, and compile a reliable target list from them. The Compiler, as conceived at the School, will be a complete, integrated system of sensing equipment, observers, data transmission devices, and computers and will be able to work "on-line" constantly by updating and revising the target list.

Manual methods of processing target information used in World War II and the Korean conflict represented little material change from methods used in the Civil War. With the advent of automatic sensory devices, masses of fragmentary information will flood the artillery with inconclusive detail if a way is not found to digest and compile the bits and pieces into whole targets.

The title Target Compiler covers three interrelated study areas, and each permits definition and separate study. First is the analysis and logic of that portion of the digital computer program that will accept fragmentary information and present the targets upon which fires can be planned; this article is chiefly concerned with this portion of the Compiler. Second is the development of a system of digitizers, small devices to convert analog readings and sensings of automatic equipment into digital data for transmission and presentation to a computer. Third is the study of the reliability of acquisition agencies, human or inanimate, so that valid factors may be obtained with which to properly interrelate the multitude of fragmentary reports that will be received on the modern battlefield.

All three studies must be complete to have complete and reliable working systems. However, the logic of the basic analysis and digital computer program can be developed and tested for reliability by comparing data obtained from a consistent set of carefully considered hypothetical figures with the common sense and good judgment of experienced officers. The problem statement, to include the definition of many logical rules to be applied by the computers and the logic and flow charting of a full first run program, have been completed. The flow charts will be coded into a computer program for a series of test runs on the School's commercial model digital computer. The first run should be ready within the next few months.

STUDIES TO RUN CONCURRENTLY

Study in the other two areas will proceed concurrently with the development of the computer program. However, a first run computer program to test the consistency and common-sense results of logical rules can proceed without dependence on the other two study areas.

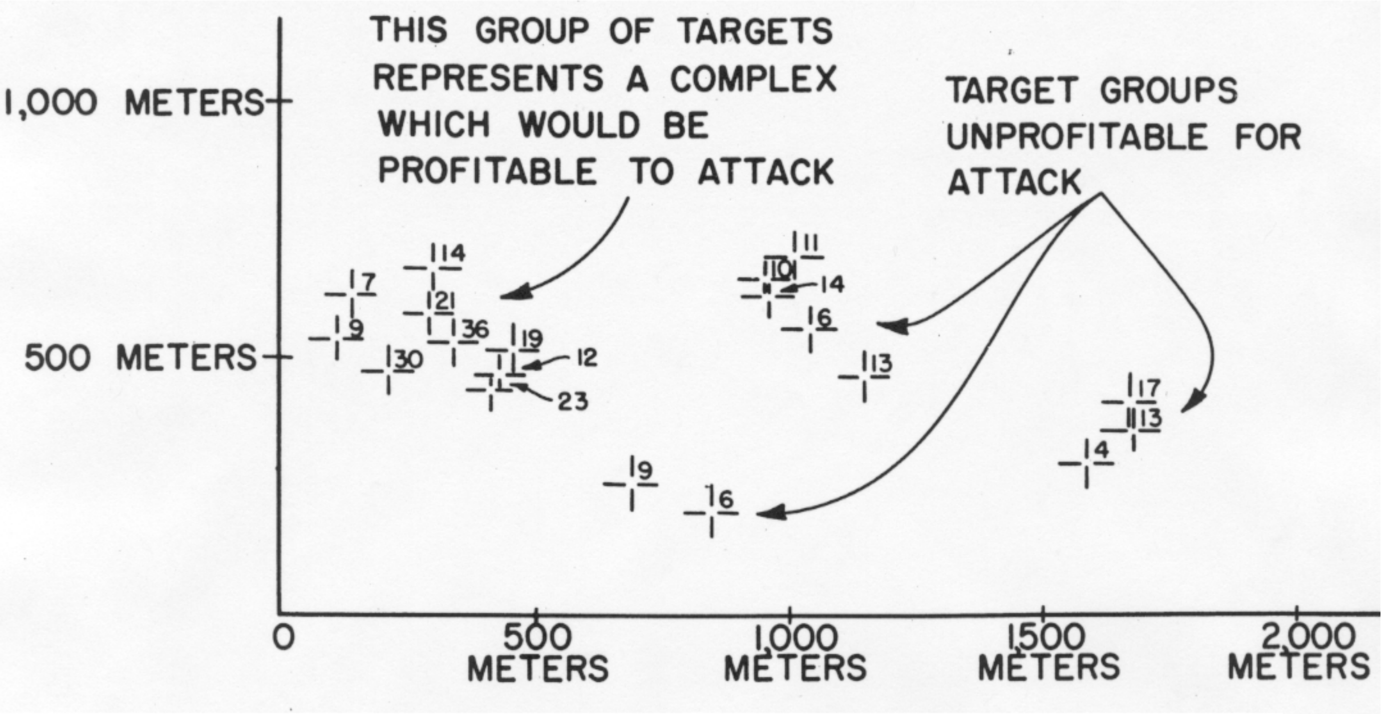
Returning to the digital program, it is now necessary to define the problem more precisely. There will be many acquisition agencies; for example, air and ground observers, infrared, several types of radar, sound bases, and flash bases. Each agency will submit fragmentary information concerning targets. Usually, the reports submitted by human observers are thought of as being complete, not fragmentary; however, to have a single mathematical scheme for digesting data from human and non-human agencies, it is convenient to consider that a complete report is made up of a series of fragmentary reports. These partial reports will consist of at least three elements—a probable location in coordinates, an indication of size (called weight), and an indication of the type of target.

Some agencies can give a high degree of assurance that a sensing is based on the presence of a particular target type. Other agencies can make virtually no discrimination between types. Again, the mathematical concept of the special case of a general rule can be resorted to. The agencies which report no type or complete type identification are special cases, the extremes.

The problem is to convert the fragments into usable target information. If the use of powerful weapons such as tactical nuclear weapons is being contemplated, the location of a single target such as a platoon of infantry or an artillery battery and the centers of target complexes which will be profitable to attack, will be sought. With this in mind, a method of finding the centers of target complexes must be developed. Graphically, the situation is shown in figure 38. Fragments of varying weights are indicated. Assume, for example, that a weight of 100 is considered necessary to indicate the presence of a profitable nuclear target. The particular nuclear yield has an effective diameter of 750 meters. All figures used are hypothetical. The problem is to find centers from which circles 750 meters in diameter can be drawn to give a total number of included fragments adding to a weight of 100 or more. If the targets were plotted on a map, it would be a simple matter to determine the centers by manual operation of a small plastic template or similar device.

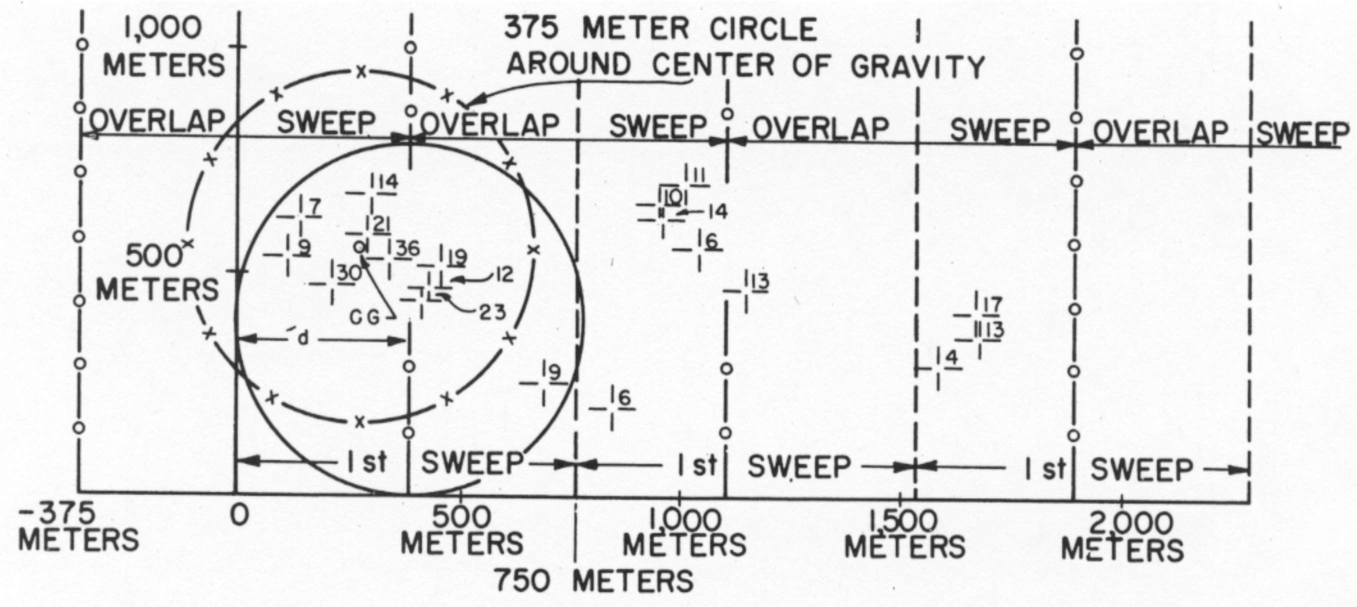
COMPUTER CANNOT "SEE" A MAP

However, the computer cannot "see" a map. Each fragment is stored in the computer in terms of coordinates and weight. Therefore, the computer must be instructed to sweep from a starting line, for example a Y gridline, and consider each fragment along the X axis, multiplying each fragment by its X distance from the starting line. When the sweep has included a total distance of 750 meters, the computer should stop and



Note. The numbers in the upper right of each plot point represent fragment weight. The criteria for a profitable target is a weight of 100 or more within a radius of 375 meters or less.

Figure 38. Graphic display of weighted target fragments.



Note. Numbers opposite plot points represent weight of fragment; *d* is the distance to fragment from starting point; the center of gravity (CG) is a function of distance and weight. An overlap sweep of 50 percent is used to insure that all fragments within the basic circle (solid-line circle), regardless of CG, will be included in two sweeps per dimension, X and Y, at maximum.

Figure 39. Establishing target complex centers by center of gravity and 50 percent overlap sweeping.

calculate the center of gravity of the fragments accumulated (fig 39). Next the computer will swing an arc of 375 meters from that point to see if it can include within a circle of that radius (750 meters diameter) a total number of fragments with a weight of at least 100. This is the general idea which will be used. There are several problems in how far to sweep; for example, what about weights beyond the boundary of the area swept when a center of gravity falls closer than 375 meters to the boundary? Such problems are not insurmountable. Most of them are solved by a system of 50 percent overlapping and again sweeping certain areas. The result of the operation is an output of target complex centers including the total weight of the fragments within each center.

Nothing has been said about target type or reliability—reliability in location and identification. Accuracy of location is a problem in mathematics. If it is assumed that an air observer reports a target at certain coordinates and a ground observer reports the same target at other coordinates, the two reports must be reconciled. The relative reliability of the two observers is considered. It also must be established how large a circle must be drawn around the coordinates reported to give an 80 percent assurance of including the true coordinates of the target. For example, in the trial program it will be assumed that any target reported by an air observer has an 80 percent assurance of lying within 100 meters of the coordinates reported and that a target reported by a ground observer has an 80 percent assurance of lying within 400 meters of the coordinates reported.

The computer will draw a line between the two circle centers and, based on the relative size of the two circles, will fix a new center and draw a circle within which there is an 80 percent assurance that the fragment lies. It is assumed the air observer's circle is four times as likely to be accurate as the ground observer's circle.

The Target Compiler is not a complete intelligence system designed to consider all the factors which are of interest to the G2. To keep the program small enough for a tactical computer at division artillery or corps artillery, it is necessary to keep the number of fragments under consideration within a reasonable limit. Thus, when data from two fragmentary reports have been combined, the program from then on considers only the new fragments created by the combination. Whether the original fragments will be discarded, kept on magnetic tape, or passed forward to the next higher echelon for inclusion in the G2 programs has not been determined. It is not an artillery Target Compiler problem.

If two fragments are not close enough to be combined into a single fragment, considering reliability of the acquisition agencies, the two fragments are retained. The computer will consider them as reports on different items.

PROGRAM IS FORMIDABLE

Even after the restriction of considering only combinations and discarding fragments not contributing to the combinations has been imposed, the program is a formidable one in terms of memory space required.

As a rough guide, to compute the program for a corps front on the basis of 3,000 fragments a day—which may be conservative—will require a main memory of about 12,000 words. Several computer words will be required for each fragment, as it is now seen.

Only location and the creation of a single "combined" fragment, whenever that is possible, have been discussed. A more complex problem is that of target type identification. Target type will be developed by reconciling or at least combining two reports as was done with location. Ultimately, the same short list of standard target types will be used in the fire plan formulator and Target Compiler.

In the case of the human observer, air or ground, there appears to be no problem at first glance but this is not so. With the mechanical devices there is a problem of some magnitude. In the solution adopted, each fragment will be assigned a fragment word composed of possibly four computer words in sequence in the computer or on magnetic tape. Included in the fragment word are a number tag, a probable location, a probable weight, a date/time group, and a scale of probable types (fig 40). The probable weight is a result of considering the reliability of the weight determined by each agency.

Weight is the only common denominator between reports from human observers and the mechanical devices. Weight is used as an aid in target identification through reference to a scale. For example, a man is assumed to have a weight of 1 and a recoilless rifle a weight of 4. Next it was necessary to work out a system which would define what the mechanical devices might "see." Two men might stand so close together that the radar will "see" a weight of 2. Three men might stand that close also. However, it is extremely unlikely that 40 men will present a single sensing to a short-range radar. Tables were developed to state this within reasonable limits for each of 10 target types and 10 types of acquisition agencies.

EACH TARGET TYPE CONSIDERED

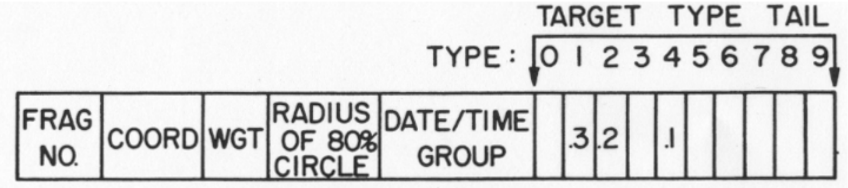
Also, it was necessary to consider each of the 10 target types and decide which type might display fragments that are part of a continuous target. Infantry in the open is a continuous target. There may be one man standing a few meters away from another man, then another, then another. It is not possible to say what is a reasonable length for the string of men (fluid, extending target). It is not possible, after sensing even a large number of such one-man fragments, to say that at this point or at that point the string must be cut and say that a new unit has begun to be sensed. On the other hand, with mortars and artillery, defined as "discrete" targets, it must be said there is one battery, or two, or more. One howitzer is sensed at a set of coordinates. A second is sensed 80 meters away. These two howitzers might be part of the same battery. However, a third, of the same caliber, is sensed another 80 meters from the second and a fourth 80 meters farther on, etc.

To retain any resemblance between the picture the computer is drawing of the enemy situation and the known order of battle, the computer must be instructed to seek cutoff points and state with some measure of assurance that these howitzers probably belong to one battery, these to another.

If weight is the common denominator between human and inanimate observers, it is necessary to convert the human observers' sensings to weight. Tables have been developed to do this and will be used in fire planning. An observer can be trained to report a platoon of infantry as being a certain scale, and a company another scale, and so on. For the problem statement, tables are used to present conversion factors for observer sensings to a target weight for each of the 10 types of standard targets. The weight is a function of scale and density as well as of type.

When an air observer sees one howitzer, one aiming circle, and one truck which might be the battery executive officer's vehicle, he will probably assume the presence of a battery. Yet, if only the weight of the items sensed was considered, for example, 12 for the howitzer, 1 for the aiming circle, and 15 for the truck, a total weight far less than that of the battery would be obtained. What has happened is that the observer has permitted the sensings of a fraction of a target to imply the presence of a whole target. The computer should have the same privilege. This concept is called "fraction implies whole" and has been worked into the program from a set of tables developed from judgment and just "plain, raw, intuitive" figures.

This leads to the basic problem of target type determination. The fragment word, which has been built from successive combinations of fragment reports close enough for combination, carries a long tail in which a figure representing the probability that a fragment is of a certain target type (fig 40) is stored in a small compartment; there is a



Note. *Each acquisition agency has a radius of circle which has 80 percent assurance of including targets that the agency reports at coordinates of center of circle. Combining two reports gives a new radius which will be used to combine the fragment word with the next report. The numbers in the compartments of the fragment word tail represent the probability that the fragment is of the type target shown, considering all fragment combinations accomplished to the time the tail is inspected.

Figure 40. The fragment word.

	TARGET TYPE :	0	1	2	3	4	5	6	7	8	9
0											
1											
2											
3											
4											
5											
6											
7		0	0	0	0	0	0	0	.87	07	0
8											
9											

Note. Assume that target type 7 is artillery and target type 8 is armor. Probabilities for one acquisition agency (air observer) and one type report (artillery) are shown. The table has been developed for all agencies for all type

The above figure would be completely filled out during the research phase and then the constants would be stored in the computer as part of the program. Constants can be changed if experience indicates it as desirable.

Figure 41. Acquisition agency target type identification.

compartment for each target type. The difference between the total of all the components and unity (or 1) is the probability that the fragment represents no target type and that the acquisition agency has been completely fooled. This figure will not be disregarded for the mechanical devices.

To make the tail of the fragment word operate, it is necessary to use set theory. When an observer reports a target as armored artillery, he may have mistaken tanks for armored artillery. Therefore, when an observer or any target acquisition agency reports a fragment by type, he is only making that fragment a candidate for membership in a set of target types which normally includes the type reported.

The tail of the fragment word with its compartment for each target type is a convenient device for application of this form of set theory to type identification. The constants that are made part of the program are illustrated in figure 41. From figure 41, if an air observer reports artillery, there is an 87 percent chance that it is artillery; a 7 percent chance that it is tanks; and a 6 percent chance that it is no target at all. By changing the percentage figures, the degrees of assurance which research and good judgment require may be established. By retaining the idea of a set of figures (probability of type identification) for all agencies, human or otherwise, a single, simple, mathematical approach to the problem can be retained. The computer must have a mathematical statement of the problem to achieve a solution.

As successive reports are received on a single fragment, the type identification is modified. Each reporting agency makes the fragment a candidate for membership in a set of types. In the case of human observers, the set of types is small and the probability is high that the target is the type specified by the observer. As reports accumulate, the probability begins to go heavily to the type most frequently reported by a reliable agency.

When successive reports are received on the same fragment they are combined but not by addition. The first agency reporting has established the existence of 80 percent certainty. The next report can be brought to bear only against the remaining uncertainty, nothing else. Assume that the next agency can state that a fragment is present with an assurance of 75 percent. This agency eliminates 75 percent of the remaining 20 percent of uncertainty. Therefore, with the two reports combined there is a 95 percent assurance of the fragment's existence. This is the reasoning used in the computer. It is simple to apply. The results will be the same whichever agency reports first.

DETERMINING TARGET TYPE

Just prior to output, the computer determines the target type. This is done by a random number technique (fig 42). Think of the total probability as a football field 100 yards long. The probability that the fragment is of a particular type of target, or of no type, is a certain number of yards on the field. The first step is for the computer to generate a random number. There is completely equal chance that the number will be from 01 to 100. Assume that a ball will fall on the football field on the yard stripe corresponding to the random number generated. In figure 42, since artillery occupies 65 yards of the field, there is a 65 percent chance that the ball will fall on artillery; mortars have a 25 percent chance of catching the ball. This is the method used by the computer to determine target type.

The output of the computer can be expressed as target complex centers of any size desired. The program could present target complex centers of 100 meters radius which would be suitable for standard high explosive concentrations. The program could first print target complex centers of large diameter, then subtract the fragments within the centers from the total list, and compile a new list showing smaller target complex centers—targets which lie in the interstices between the complexes just printed. The subtraction can be omitted and each run—no limit to the number of runs—can show target complex centers of the diameter specified. The two possibilities are illustrated in figure 43.

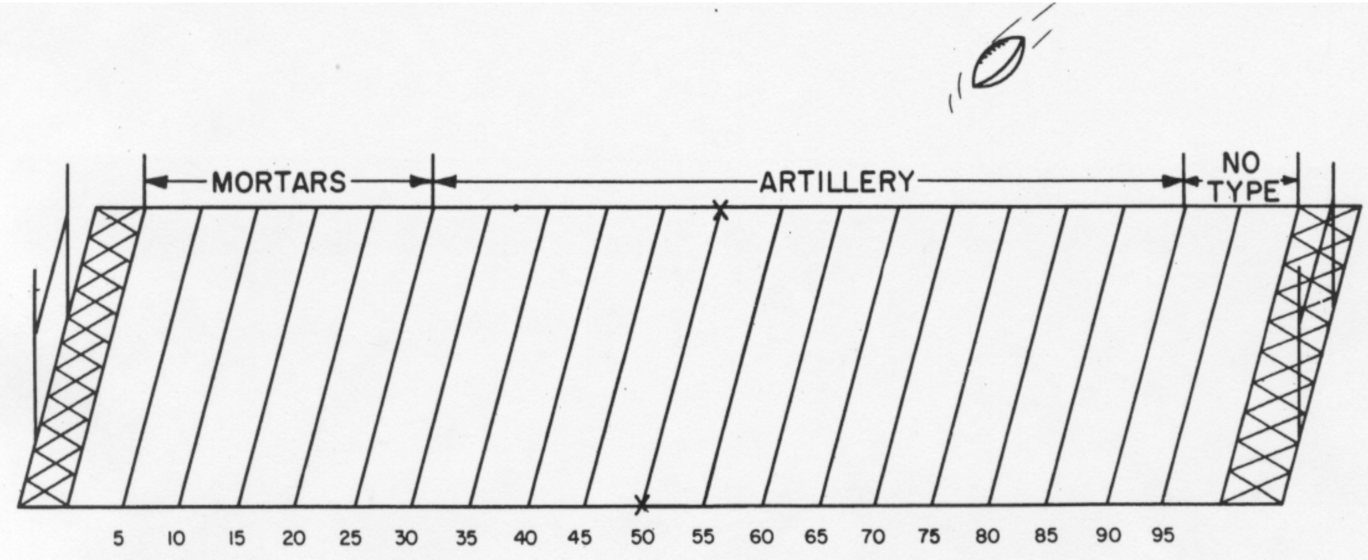
The Target Compiler bears an important relationship to the fire plan formulator which will be used in fire planning. The Compiler produces the list from which the formulator will work. The Compiler frequently has small fragments within it which have not been built up into significant targets; it will include targets that are trivial. Therefore, the Compiler will produce a great many priority 3 targets, targets which would be discarded in a manual solution. The list will probably be too long for manual editing before presentation to a fire planning program. This makes it virtually imperative that the fire planning program develop priorities of fire automatically, by reference to geometric and other criteria.

The Compiler is an on-line program, a program that should be kept plugged in all the time. Target acquisition data will be fed back continuously; it should be assimilated by the Compiler on a frequent schedule. The automatic data processing system FIELDATA family of equipment with their "interrupt feature" may be well suited to this application at division and corps artillery. The Compiler program is such a large one, even for a small force, that a medium scale computer (namely, the BASICPAC) with direct access to magnetic tapes appears to be required.

PROCESS IS A CONTINUING OPERATION

Accepting fragmentary reports from a number of target acquisition agencies and combining the reports into new fragments is a continuing operation. However, it has meaning only when stopped long enough for the computer to apply the center of gravity test as well as other test procedures.

Stopping fragment combination and printing out targets can be an automatic process. This makes it possible to build the Target Compiler into an alarm system. The computer can be instructed to test at intervals for the weight of fragments within given areas and to print out target complex centers if that weight reaches a specified minimum.



Note. Only two target types are shown as having some probability of existence in this situation. However, many sensings result in a fragment that might be in any of three or more target types, or no type. This could be shown by another apportionment of the football field.

Additional reports from acquisition agencies will be combined with reports on hand to create new fragments. Reapportionment of the yardage on the field will result. The random number (ball) is thrown in just before determining targets contributing to target complex centers.

Figure 42. Determining target type.

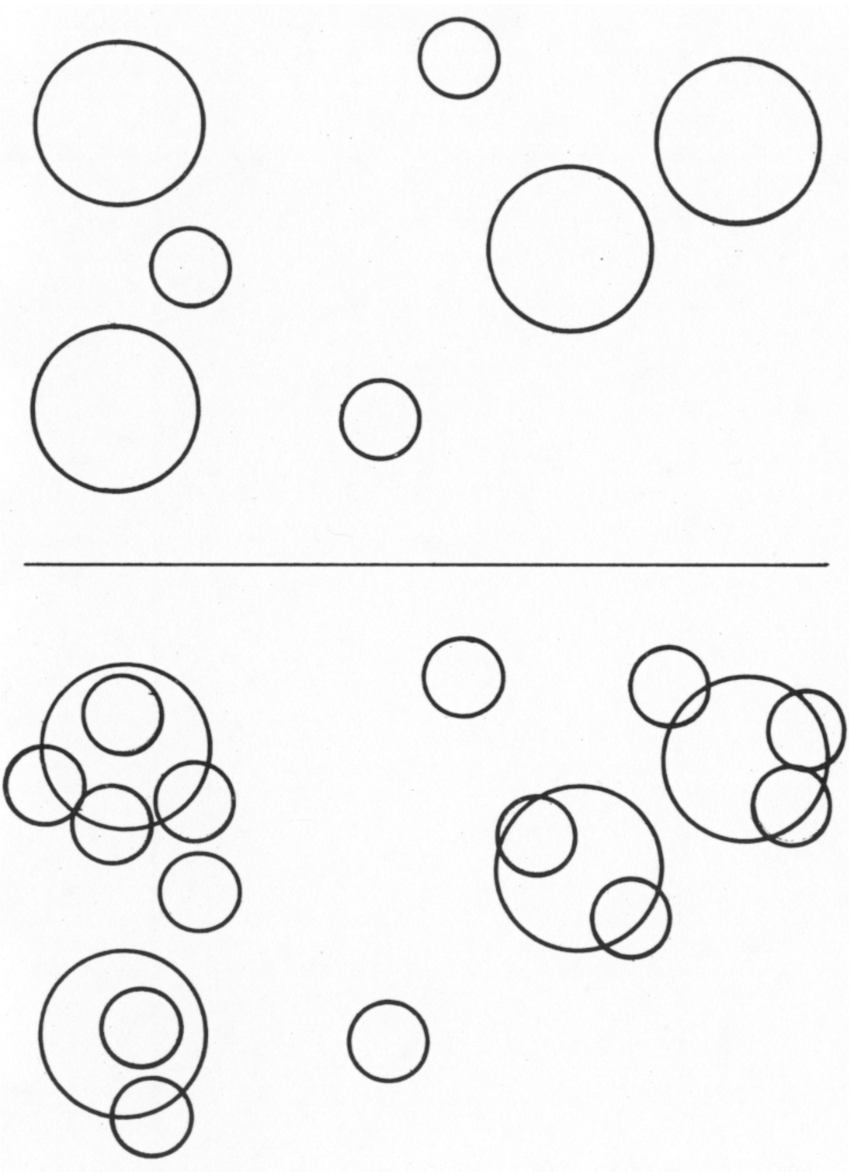


Figure 43. Forms of output. (Upper) Large target complex centers and small target complex centers from remainder of fragments. (Lower) Large target complex centers and small target complex centers, both considering all fragments.

As a potential alarm system and an automatic feeder for the fire plan program, the Target Compiler appears to have great potential. Perhaps its greatest potential is as an aid to the artillery commander in forming his basic decisions as to employment of his supporting artillery force as a whole. The program as outlined briefly above will be test run at the School and used as a study vehicle.

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PROGRESS BRINGS TWO NEW SOLID STATE DEVICES

Today, in the electronics field the standard vacuum tube is being replaced, in many applications, with two solid state devices, the transistor and the semiconductor diode. These new devices consist of a single element or multiple layers of different elements firmly bound together. There is no envelope, vacuum, or gas added to the unit, hence the name "Solid State Devices." These devices are extremely small, the largest usually being about the size of a lump of sugar. The resultant weight saving and overall size reduction are the two most important physical advantages gained. On the technical side of the picture, there are numerous benefits. The new devices are very reliable, require little or no maintenance, and should give appreciably longer life than vacuum tubes. Unlike vacuum tubes, solid state devices require no electrical heating circuit to operate, thereby reducing circuitry and considerable heat. Since no warmup period is needed, immediate operation of equipment utilizing all solid state devices can be obtained. Further, these devices require very little power to operate. This, however, brings us to one of the several disadvantages which must be considered.

Since our devices are small and power requirements are small, their maximum power handling capacity is also small. Conditions of extremely high temperature or extremely high humidity can cause the devices to degenerate. From the viewpoint of computer design, these considerations are not critical. Our biggest problem is difficulty of maintaining uniformity of characteristics in the mass production of these devices. In some computer circuits, this is unimportant; in other type circuits, devices must be frequently tested and only those that adhere to strict specifications can be used. This, of course, increases the cost considerably but not prohibitively. Further perfection of manufacturing techniques should continue to reduce costs as significantly as has been done in the past few years.

The numerous advantages far outweigh the disadvantages and the electronic computer is an ideal equipment to exploit the usefulness of today's solid state devices.

Pinpoint Survey Control With Computers

Artillery survey objectives are to obtain direction, range, and difference in height from gun-to-target. To accomplish this, survey provides the locations of the weapons and target acquisition sensory devices. Target acquisition devices can be considered survey devices which provide target locations. These locations must be three-dimensional within allowable tolerances of the weapon system and must be furnished in a timely manner. With the target and weapon located on common control, determination of differences in direction, range, and height are routine mathematical computations.

When the extent of survey to be established is considered, its apparent simplicity disappears. A corps area will vary greatly in size, but an average of 65 kilometers in width and 65 kilometers in depth can be expected. Initial survey control is given to the artillery by the Corps of Engineers, which either establishes an actual point on the ground or furnishes a trig list, if available, of points throughout the corps area. From this control, the corps artillery target acquisition battalion carries control throughout the corps area, furnishing a control point for each

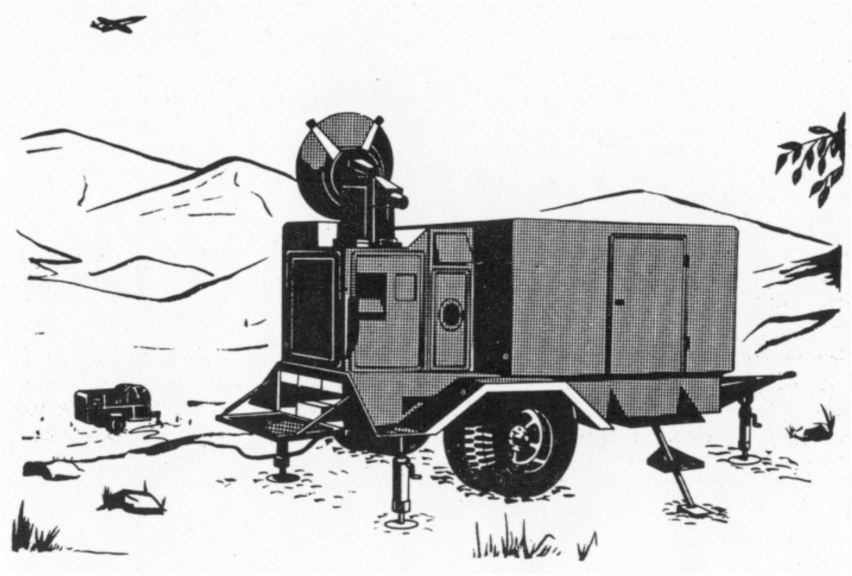

Figure 44. An artist's concept of a drone aircraft target location sensor system.

division artillery and for each corps artillery battalion within the corps. The target acquisition battalion also has an extensive internal survey requirement. It must locate accurately each target acquisition device to include the microphones in sound bases, spotting instruments in the flash bases, and counterbattery radars. A drone aircraft target location sensor system will be added to this battalion in the future (fig 44). This will require the surveyed locations of tracking radars.

In the past, reduction of survey time has been sought by attacking

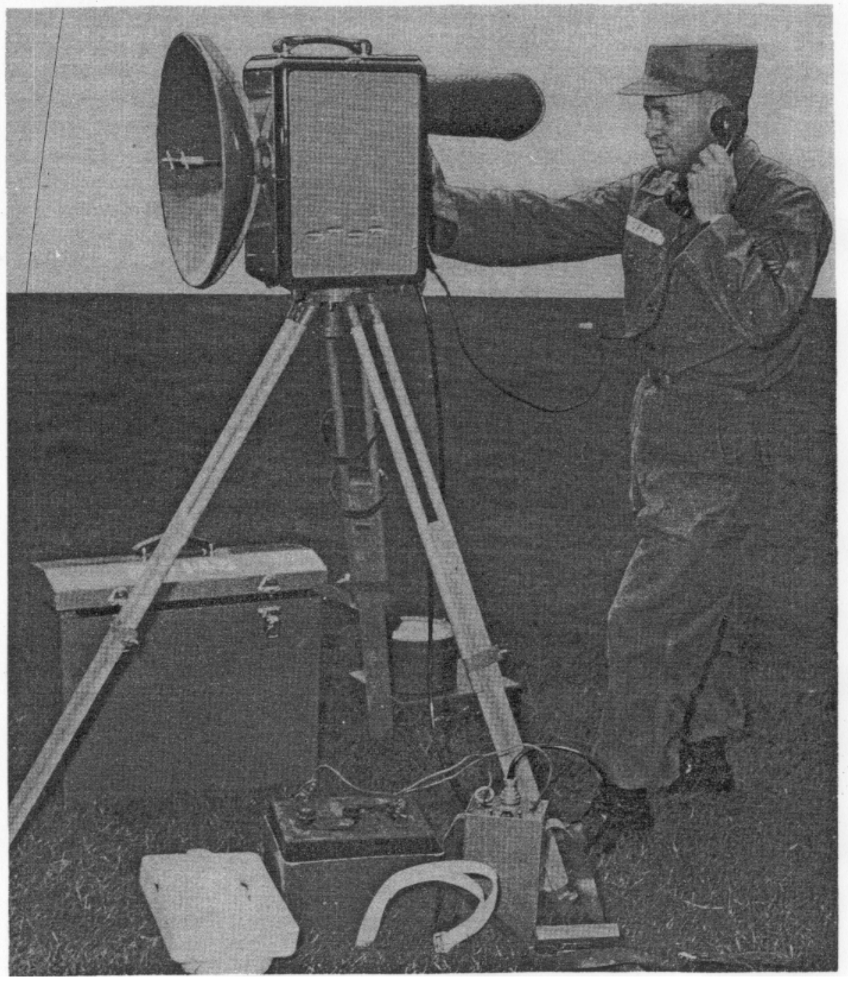

Figure 45. The Tellurometer master unit with station equipment.

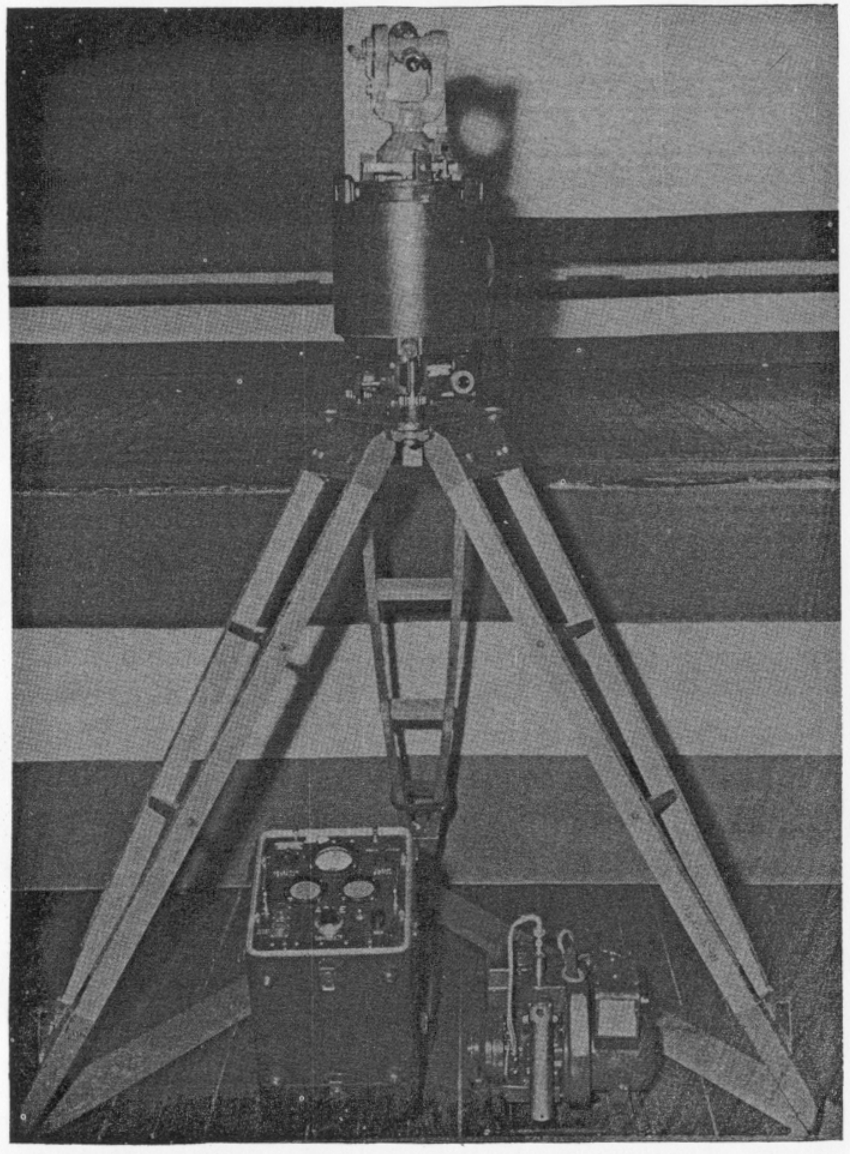

Figure 46. The Survey Instrument, Azimuth, Gyro, Artillery, will help lessen survey time.

the problems encountered in determination of field data—angles and distances—and in the computational process. The Tellurometer (fig 45), an electronic distance measuring device capable of rapid and accurate measurement of distance to about 40 miles, is now being issued. The Survey Instrument, Azimuth, Gyro, Artillery (fig 46), a gyro azimuth determining device, will soon be available for issue. These two items and computers will help make tremendous strides in lessening the time required for survey. However, they will alter the basic procedures. In fact, their speed will require additional computational and data transmission equipment if their potential is to be realized.

A study performed by the US Army Artillery and Missile School entitled, *The Application of ADPS to Artillery Survey,* was completed and approved by USCONARC in 1958. This study indicated the feasibility of using the FIELDATA family of computers in the survey application. The study envisioned the flow of survey data from the Corps of Engineers via digitized trig lists down through all echelons of artillery survey. It visualized appropriate computations and transmissions being handled by the BASICPAC computer and associated data transmission system at the corps artillery survey information center (SIC) and division artillery and by a small scale FIELDATA computer at battalion.

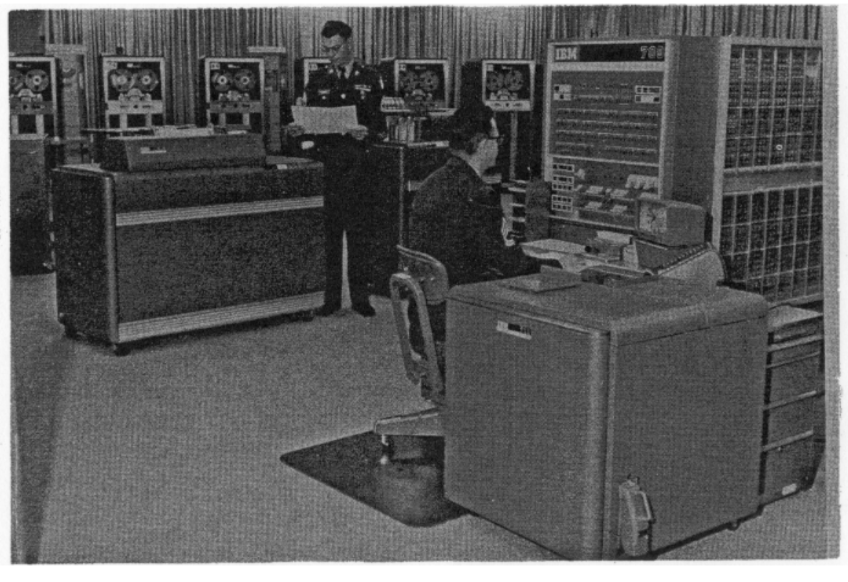

Figure 47. The IBM 709, a large scale, fixed-plant computer, with related equipment.

ARTILLERY SURVEY PROBLEMS SELECTED

As a result of the Signal Corps effort to design an artillery subsystem in the field army automatic data processing system, 32 artillery survey problems have been selected for programing in FIELDATA code. These problems are presently being programed for the IBM 709 (fig 47), a large scale, fixed-plant computer located at Fort Huachuca, Arizona, and will be converted to FIELDATA language prior to receipt of FIELDATA hardware.

Throughout the development of the prototype fire support system (SS1a) one important area of the equipment development program has been very closely monitored, and in some instances guided, by the Artillery and Missile School — the area of operator control panel development. The current programs to develop a small-scale general purpose computer, COMPAC-type or FADAC, and the BASICPAC (medium scale general purpose) computers provide for the design of two types of control panels to be used with the computers; a general purpose control panel for use in program "debugging" and computer maintenance and a special-purpose or operator control panel for use by an operator in problem solution.

To utilize the computational capability of the computer to the utmost, it may be desirable to automatically transmit certain critical items of survey information to all users. To permit the transmission of this data in a digital form over present wire and radio communication channels, data transmission devices located between the computer and the communications terminal will be required. These devices are being developed along with the computers and will provide the capability of receiving and storing survey data.

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At best, ADPS is an extremely fast, accurate moron with a fabulous memory. The use of its resources is limited only by the ability of the individual to tell it what to do. Therefore, its application increases, rather than decreases, the need for human intelligence and initiative.

Automatic data processing equipment developed for, or to be used by, the field artillery must be capable of operating over the tactical radio and wire nets of the artillery and the area communication system applicable to the time frame.

Weather Forecast By Rocket

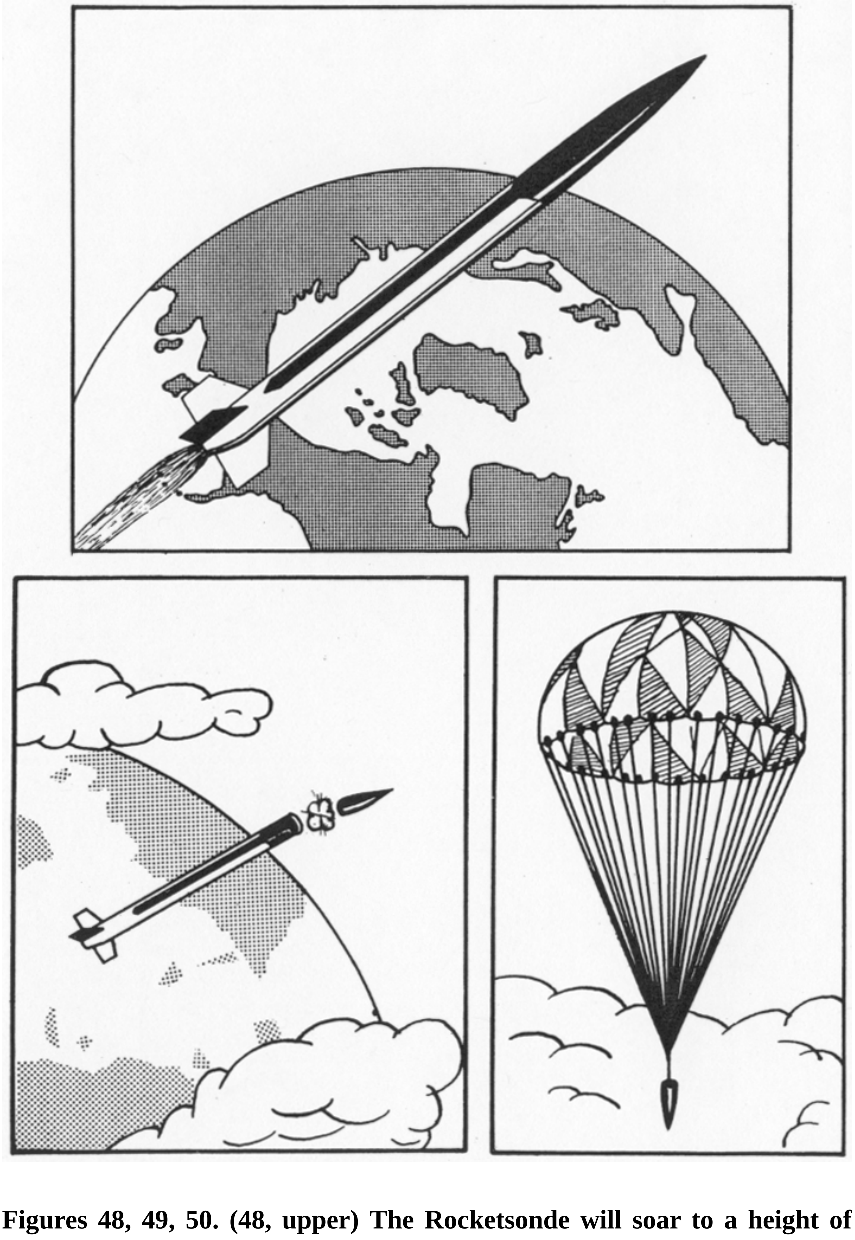
Artillerymen are familiar with the effects which the atmosphere and its varying conditions have on the flight of a ballistic projectile. Meteorological (met) observations are of a perishable nature—a point well understood by the artillery met sections in the division artillery headquarters and the headquarters battery of the target acquisition battalion. To provide fire direction centers with usable met data, met personnel must work "around the clock" and launch a new radiosonde flight almost as soon as they complete the ballistic messages from a previous flight. This requires constant computation and a high degree of efficiency.

Presently, a new system for the collection of met data is being considered. The new system—called Rocketsonde—may employ a small free rocket with a built-in radiosonde. The Rocketsonde (fig 48) will be fired from the earth's surface and reach a height in excess of 102,000 feet in a matter of seconds. At the top of its trajectory, the radiosonde will be expelled from the nose of the rocket (fig 49) to descend by parachute (fig 50). The rocket-borne radiosonde can electronically probe the atmosphere to a height of 40 miles for weather data. Experimental models of the Rocketsonde are being tested and show great promise as a means of rapidly gathering met data. The parachute's rate of descent of about 6,000 feet a minute far exceeds the capabilities of the fast rising balloon now in use. The Rocketsonde system, providing a rapid means of obtaining data and improved dissemination and application, would give firing units more timely information.

This new system is a tremendous improvement over the present system; however, even it seems primitive when one considers what might be attainable in the more distant future. The almost instantaneous receipt of met data is visualized—a rocket equipped with sensing devices and ground receiving equipment capable of measuring meteorological parameters while the Rocketsonde is on the ascending leg of its trajectory. The data from the Rocketsonde will be gathered by the improved ground receiving equipment and entered as input data to an automatic data processing system (ADPS).

STUDY MADE ON ADPS, METEOROLOGY

A study was made on the application of ADPS to meteorology in the field army (USCONARC ADP Study Number 53). The objective of this study was to develop operational concepts and organization required within the field army to use ADPS for timely and effective collection, processing, and dissemination of data. All aspects of met data processing in the field army were reviewed, and it was determined that the application of automatic data processing (ADP) to the processing of simultaneous



Figures 48, 49, 50. (48, upper) The Rocketsonde will soar to a height of 102,000 feet (+) in a matter of seconds. (49, lower left) The radiosonde is expelled from the nose of the rocket. (50, lower right) Radiosonde in parachute descends at rate of about 6,000 feet a minute.

ballistic meteorological observations offers immediate and promising benefits to the Army. The technique of objective analysis proposes a mathematical description of the distribution of a ballistic parameter—wind speed, wind direction, density, and temperature—by fitting the observations to an equation. Values of the parameter between observation sites may be readily obtained from the equation. This will permit the artilleryman to interrogate the ADPS ballistic meteorological conditions in the region through which his shells will actually pass. The ADPS may produce the desired information by solving the descriptive equation for the designated region of interest. The resulting data should be more accurate and reliable than the data produced under the present system, which uses the observations of the nearest artillery met section, often located miles away.

Graphical means for accomplishing the same result are available, but excessive cost in time and manpower preclude their use in a manual system. The artillery needs data on wind speed, wind direction, density, and temperature for each of 16 different line numbers and for three different types of messages. All this data does not have to be produced at the same time. However, nearly 50 different computations must be made (or charts drawn) every 2 hours. Only the application of ADP would make it possible to obtain accurate data for a weapon positioned some distance from one or more met stations. It has been recommended as an interim measure that met data be transmitted and receipted for by radio teletypewriter means. If approved, an AN/GRC-46 radio teletypewriter (RATT) (fig 51) would be placed in each artillery ballistic meteorological section.

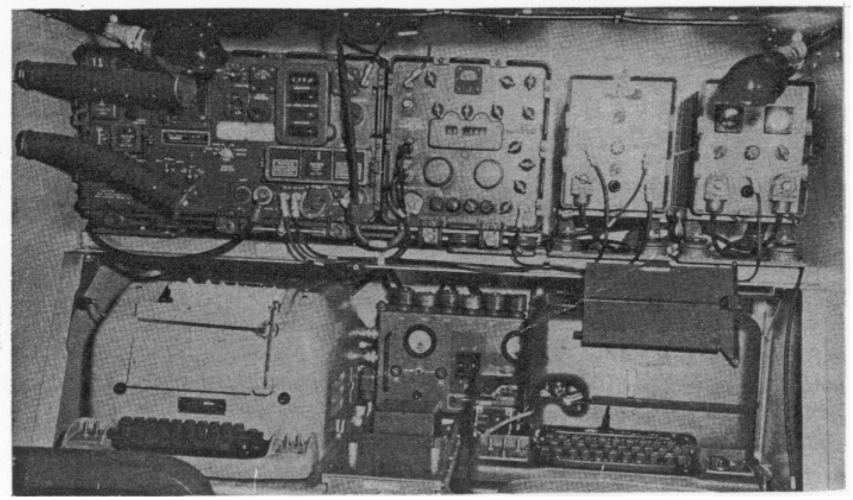


Figure 51. The AN/GRC-46 radio teletypewriter with its lightweight, electrical shelter.

The AN/GRC-46 (fig 51) cuts a punched paper tape containing a computer met message in artillery computer language (such as FADAC) and provides a printed record of the data on a sheet of paper. The punched paper tape is read directly into the artillery computer, and met corrections are applied to the artillery firing problem.

It can be seen that ADPS, a rapid sounding system, and a new communication net will save considerable time and give the artilleryman greatly improved met data.

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THE ORIGINAL COMPUTER—THE ABACUS

In the course of the years, the art of calculation has progressed through many stages of complex machines and has earned the attentions of famous men like Napier, Pascal, and Charles Babbage. But the art that has now involved large complex electronic machines began so long ago that its originator and even its time and place of origin are unknown.

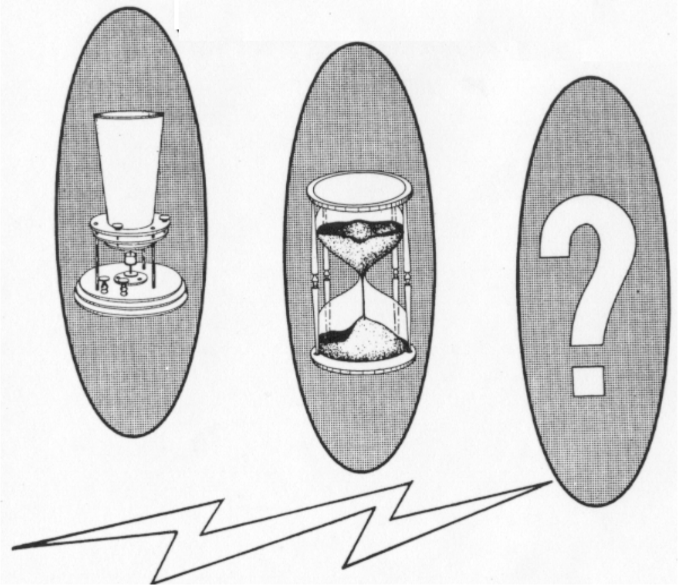
It is commonly accepted that the abacus was the first computing machine, excluding the original "digital" computer, the human hand. It is also believed that the Chinese invented this instrument. However, it would appear that the countries of the Mediterranean area also developed a type of abacus, at least, concurrently with the oriental world.

The abacus was originally a device for tracing numerals in the dust; the word itself comes from the Semitic *adq,* meaning "dust." The final form, known today in China, Korea, and Japan, evolved from the following three types: a board covered with dust on which counters were moved; a table or chart marked by lines or spaces in which counters of some type were placed; and, finally, a form on which beaded counters are fastened in grooves or on rods.

At least one of these types was in use before 450 BC by the Egyptians. The Romans are known to have employed all three types. The earliest abacus in China consisted of bamboo rod "counters" and was known as early as the sixth Century BC. The *suan pan* or computing tray, as we know the Chinese abacus of today, has been in general use in China since the 12th century and in Japan (the *soroban*) since the 16th century. The efficiency of this instrument in expert hands has long been recognized and it is still widely used throughout the Orient.

While the modern world develops large, complex, expensive electronic machines to perform its calculations, many places still have a need for a small, simple, cheap, rugged, lightweight computer—the ABACUS.

COMPUTER CODE — By The Numbers



The development of present communication equipment can be traced back to the day in 1876 when Alexander Graham Bell said to his assistant, Thomas Watson, "Mr. Watson, come here; I want you." Bell, with his discovery that an electrical current could be varied in a manner analogous to pressure variations of a speech wave, had invented the first telephone. The development of the switchboard provided the means for connecting in a flexible manner the many telephones that operated on two-way circuits. The use of radio for voice, code, teletype, and facsimile transmissions was a natural development to fulfill a particular need. Over the years, scientific development has been required to provide communication facilities for an ever increasing number of users over ever increasing distances.

The need for transmission of information has reached such a volume that the addition of more circuits of conventional types may exhaust the supply of money before the demand for communication can be satisfied. Indications are that present developments may soon encounter overpowering difficulties.

A more efficient communication system, to be based on a more efficient method of handling the information to be transmitted, may be expected. Such a system is much closer to the stage of practicality than is generally appreciated. The new method for handling information uses the digital technique. There is evidence to support the belief that this technique may be used for the bulk of message traffic in the future.

For years, solutions to certain communication problems have been appearing that suggest the use of the digital technique. The communication engineer has been confronted with longer distances, noise accumulation, frequency and phase distortion, and regulation problems. Many telephone trunk circuits in use are engineered to the standard approached by better quality high-fidelity systems to overcome some of these difficulties. The use of the long distance dialing telephone system and the Army area communication system have introduced new requirements that must be satisfied—or a lowering of the quality of transmission will result. Digital techniques would produce a system permitting information to be carried over long distance with little degradation. With suitable relays and repeaters, information could be transmitted with a low error rate.

DEVELOPMENT DIFFICULTIES THREEFOLD

Difficulties encountered in the development of a digital communication system have been threefold. First, the lack of available data links suitable for digital transmission has retarded development. Second, digital techniques require a fairly wide bandwidth which the communication engineer finds objectionable. Third, a lack of suitable switching devices and analog to digital conversion devices has hindered development. Recent developments in communication and other related areas are helping to solve these problems.

The trend in the computer industry toward digital computation methods has increased the importance of a feasible communication system for interconnecting computers and for connecting input and output devices at remote points to the computers. The experience and circuitry available through computer development will be of great importance to the development of suitable switching devices and input-output devices.

The art of transmitting digital data has a direct bearing on the ability of manufacturers to furnish equipment for a field army automatic data processing system (ADPS). The equipment for an ADPS consists of digital computers, auxiliary equipment to support computer installations, and communication equipment. The development of each of the three types of equipment must proceed concurrently. The fallacy of producing computers and auxiliary equipment to perform the many applications of automatic data processing without due consideration to providing suitable communication equipment must be avoided. Without suitable communication links between the computers and between the input-output devices and computers, a true system will not be realized. The development of suitable communication equipment for timely integration into the overall system deserves a high priority.

For computation purposes, a digital computer uses a language or system of numbers called the binary numbering system. In this system, the computers count by powers of 2 (either 0 or 1) instead of the powers of 10 (0 to 9), used in the common decimal system. Each binary digit in this numbering system is referred to as a bit. It is more convenient for computers to count using this system because of the many electronic circuits and components designed to operate in one of two given states or conditions. For example, a transistor is basically a nonlinear device—a uniform variation of input does not produce an output which varies accordingly. On the other hand, a transistor can easily represent a 1 in a circuit when it conducts and a 0 when it is not conducting. Similarly, a magnetic core or a spot on the surface of a memory drum or disc may be saturated in one direction to represent a 1 or in the opposite direction to represent a 0. Since the numbers used in the binary system determine the stop-go or on-off conditions for computer computation and are the type of data stored in the computer memory, a code has been developed for computer instructions and for data transmission.

STANDARD FIELDATA CODE DEVELOPED

A standard FIELDATA code has been developed for use with the FIELDATA family of computers presently under development by the US Army Signal Corps. When used for transmission, this code consists of eight binary digits or bits per character to be transmitted. This character may be compared to the five-digit character Baudot code used in radioteletype systems. Each bit in this character is either a 1 or 0. There are enough code combinations for all letters of the alphabet, the 10 decimal digits, and the necessary signs and functional symbols. In the eight-bit character, six bits are used for transfer of information and two bits are used for control purposes. One control bit is used for error control and the other control bit is used to indicate whether the information contained in the six information bits is in computer control language or data language. For computation purposes, the computer uses only the six information bits and deletes the control bits. When the bits of each character are transmitted they are converted to voltage-level signals. A binary 1 is represented by —3 volts, and a binary 0 is represented by 0 volts. By utilizing standard FIELDATA terminal devices, the eight-bit code may be transmitted over standard transmission facilities with a 3-kilocycle bandwidth. To use this relatively narrow bandwidth, the speed of transmission must be reduced to a slow rate in comparison to the operational speed of the computer. Employing the special control characters of the FIELDATA code, a computer can interrogate other computers in the system. The terminal devices allow the temporary interruption of a computation in progress on a computer for the input or output of data. The terminal devices used with each computer will depend on its tactical application. A standard group of terminal devices is being developed by the US Army Signal Research Development Laboratory in an effort to avoid a "hodge-podge" of dissimilar devices. While the transmission system under development for use with the FIELDATA computers does not use the true digital technique and does not provide transmission at computer output speed, the experience gained in the proposed system will be of vital importance to the development of the ultimate digital communication system.

The artillery requires suitable terminal equipment to transmit digital information with acceptable accuracy over its present communication system, both wire and radio. Transmission over present frequency-modulated radio nets and normal wire systems is envisioned in Fire Support Subsystem 1. Standard radio, wire, and radio-wire integration equipment is anticipated for the digital transmission links.

EQUIPMENT UNDER DEVELOPMENT

Two items of equipment under development and of interest to the artilleryman will be used to provide terminal facilities for FIELDATA computers. These two devices are the Communication Converter and the Digital Data Terminal AN/TYC-1. To consider the function of these devices, assume that two computers are in contact with each other. The FIELDATA computers which the artillery expects to use have a rapid rate of output. The purpose of the output portion of the Communication Converter is to send a stored word from the core memory of the computer to a data terminal device, such as the AN/TYC-1. The Communication Converter functions with fixed memory locations as a buffer with the core memory of the computer. Words are stored in fixed memory locations for transmission and assembled in fixed memory locations upon reception prior to being stored in the core memory. The Communication Converter will provide control for computer program interrupt and a parity check for error control information concerning data transferred.

The AN/TYC-1 data terminal is a digital receiver and transmitter and is used with standard communication equipment. It accepts eight-bit FIELDATA characters from the Communication Converter at the rate of 150 characters a second, converts the eight bits into a serial train of pulses, and transmits them as a frequency shift signal. The receiver portion of this device demodulates the frequency shift signal, performs a serial to parallel conversion, and provides the parallel eight-bit FIELDATA character as its output to a Communications Converter input channel. The AN/TYC-1 provides the master clock or synchronization signals for the system. The FIELDATA characteristics call for a ready-strobe method of automatically sending and receiving information. With this method, the sender and receiver must be in a state of readiness prior to the transmission of data. However, this does not infer that the computers cannot continue calculating while transmissions are in progress.

The significance of the development, by the Army, of an "on-line" communication system permitting interruption of computation for input or output of data and operating with computers for field use, cannot be fully appreciated without considering the state of development of similar commercial systems. Presently, no equivalent commercial system is available to compare with the system being developed. The results of tests to be conducted on data transmission over the relatively low grade circuits and radio channels available to artillery users will serve as a milestone in the development of this area of communication. The field artillery is fortunate in having its communication system serve as a basis for these initial tests.

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NO 'MAGIC' STILL FITCAL

Maintenance of the field-type digital computer begins with the realization of one elementary fact—a digital computer *must* be maintained. In this sense it is no different from other electronic equipment with which the operator and maintenance personnel have probably had experience. The digital computer is simpler in nature and considerably easier to maintain than most electronic equipment. A sensible approach to computer maintenance is based initially on an absence of the mystery or "magic" element, plus a respect for the simple truth that all functional equipment, electronic or otherwise, requires a certain amount of maintenance and servicing.

Although the digital computer is the principal subject here, it is perhaps worthwhile to mention the M15 gun data computer, an analog device. Even considering the greater accuracy, simplicity, and reliability of the digital system, an interim computer was still necessary to meet a pressing need for an automatic data processing device for fire control computations. The M15, an operational, in-the-field computer, has met this requirement during the development stage of digital equipment. Many of the lessons learned in maintaining this analog computer are valuable and will apply to the digital computer maintenance problems.

The ideal solution for maintenance problems of digital computers is to embody maintenance functions in the concept of integral testing. A computer with the built-in capability of checking for internal errors, by such means as diagnostic routines, marginal tests, and logic-testing tapes, would facilitate the isolation of a component malfunction. Regardless of the inherent desirability, such a solution is not considered feasible from an economic standpoint—not to mention the increase in size which automatically accompanies built-in testing equipment. Perhaps an optimum solution of the testing problem at the present time is that employed by the Field Artillery Automatic Data Computer (FADAC). The FADAC uses a small auxiliary item of equipment called the FADAC Automatic Logic Tester (FALT) (see page 12) to completely check out the computer logic step-by-step. By use of test tapes in conjunction with the memory loading unit, a photoelectric tape recorder (FALT) checks all logic gates and flip-flop circuits in the computer.

Another area in which FADAC simplifies the maintenance problem is standardization of component circuits. The FADAC uses the modular concept, where a single etched-circuit board may contain from one to eight or more identical circuits. The circuit boards, of which FADAC has 21 types, are notch-coded so that a board receptacle may accommodate only one type of circuit board. Within a type, all boards are identical and completely interchangeable. Although 21 types of boards exist, just

3 types constitute 76 percent of the total number of boards in the computer—this is significant when visualizing replacement spaces. Further, FADAC minimizes the variety of possible maintenance problems by incorporating several built-in protective devices in the computer itself. Examples are the high- and low-temperature cutout, line frequency variation detection, 3-phase power circuit breakers, high- and low-voltage detection, and fusing of all unregulated power supplies.

FADAC TROUBLESHOOTING IS SIMPLE

Troubleshooting the FADAC is simple. During a checkout of the computer with FALT, any error indication results in a visual number display, which is referred to as test listing. The test listing indicates, in terms of circuit board, the area in which the error exists. This isolates the malfunction to one or more of five etched-circuit boards. Should the test listing indicate a single board, replacement is simple. Should the listing indicate that the malfunction is in more than one of the five boards, trial-and-error substitution of boards may be employed, or spares may be substituted for the boards indicated.

The relative simplicity of digital computer maintenance, using FADAC as an example, permits the use of present organic artillery personnel for the performance of maintenance. It is felt that the artilleryman is fully capable of performing modular replacement at the using unit level—a feasible concept to insure maximum operating time from the equipment. A certain amount of additional training will be necessary, but, in comparison to training a maintenance man from "scratch," there is an impressive saving of time as well as economy of personnel.

In the future field-type digital computer, it can be observed that the design and manufacturing techniques display a definite trend toward simplifying maintenance at all levels. The desirable aspects of maximum operating time through maximum maintenance at the user level is evident. Better and more efficient computers are on the way, and one fact is already clear—they will be simple to operate and maintain!

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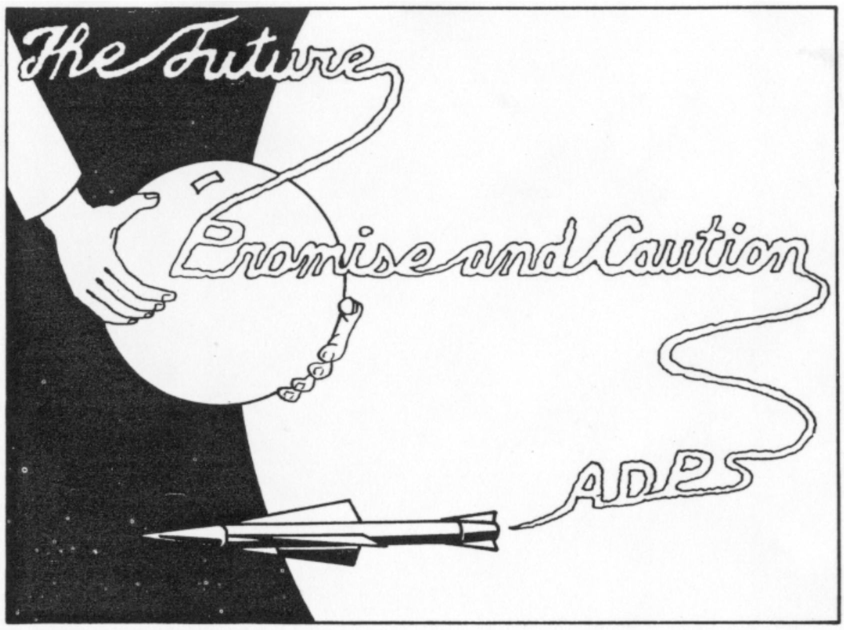
The ADPS will be designed to accept administrative, logistical and intelligence data down to the lowest echelon, and the system must respond instantaneously to priority missions.



The preceding articles have given you a concise summary of the artillery effort in automatic data processing. A great amount of work has been done during the past year—but much remains to be accomplished. Automated techniques hold high promise for improving fire support; however, it would not be proper to end this issue without a word of caution.

Computers and the required ancillary power devices and-communication, maintenance, and display equipment are expensive. The maintenance effort will be considerable. Additional transportation may be required in some instances. Before a new technique is embraced wholeheartedly it must represent a real operational gain at a reasonable price in terms of money, personnel, and equipment.

Our present, simple, flexible manual skills must not be allowed to wither away from lack of use, for they will most certainly be needed on occasion as "backup" for automation. A computer used in fire control, for example, will require survey and meteorological data and known three-dimensional target locations as prime inputs. Without these, a "simple-minded" computer is nothing more than a fast and accurate calculating machine; the computer cannot magically produce "first round accuracy."

With this in mind, it is clear that almost any computer application must be used as a part of an overall system to derive any real benefits. Fire control functions, target acquisition, survey and meteorological means, and fire planning techniques must be integrated into a sound fire support subsystem which is tactically viable. We must not permit over automation. The progress made in the past year provides evidence that the artillery is on the threshold of significant advances.

GLOSSARY

Ancillary—subordinate, auxiliary.

Automation—a system or method in which many or all of the processes are automatically performed or controlled by electronic devices.

BASICPAC—a medium-scale multi-purpose Computer of the FIELDATA family.

Battery Display Unit (BDU)—a device which would display the complete fire plans to the battery executive officer and possibly to members of individual howitzers.

Binary numbering system—counting by powers of 2 (either 0 or 1).

Bit—each binary digit in the binary numbering system.

Digitizers—small devices to convert analog readings and sensings of automatic equipment into digital data for transmission and presentation to a computer.

Effect, second-order—effect of the variation of one factor on the effect of the variation of another factor.

Field Artillery Data Automatic Computer (FADAC)—a solid-state (no vacuum tubes) general purpose electronic digital computer.

Field Artillery Data Computer Automatic Logic Tester (FALT)—a small auxiliary item of equipment used to completely check out the FADAC logic step-by-step.

FIELDATA—A family of automatic data processing equipment.

Flip-flop circuits—a pair of vacuum tubes (or transistors) of which only one can be conducting current at a given moment.

Fragment word—successive combinations of fragment reports.

Gunnery Officers' Console (GOC)—a switching device that will assist the S3 or gunnery officer in conveying his decisions to those who are to execute them.

Iteration—a process of repetition.

Message Entry Device (MED)—a device used by the forward observer for fire missions and fire-for-effect surveillance.

Miss distance—symbol Δ X.

Mission Monitor Panel (MMP)—the display device in the FDC which receives and displays the forward observer's transmission.

Residual—that which is left by the subtraction of one number from another.

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