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TECHNICAL NOTES

FC

REPORT NO. TN-1071

fadac *

a new concept in computers for artillery. (U)

BY:

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Ordnance Project TR 5-5047 B

DA Project 5R14-03-001

FIRE CONTROL INSTRUMENT GROUP-FRANKFORD ARSENAL

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ABSTRACT

The content of this Technical Note is a condensation of a Sperry-Rand, ERA Division, report covering the initial design study of an electronic digital device for use as a field artillery fire direction computer. Also presented is supplemental information which details the superiority of digital computation over analog computation in the intended application.

Introduction..
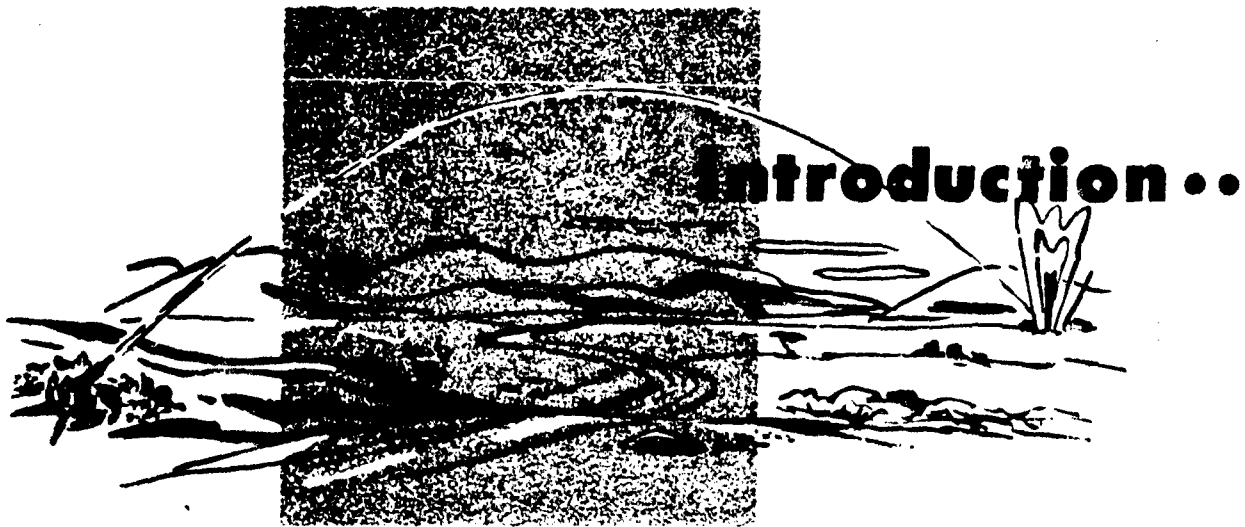
During World War I it became apparent that the time required for accurately solving certain gunnery problems by manual methods was far in excess of the time that could be permitted under combat conditions. For this reason, computational mechanisms were designed which would serve as aids in obtaining rapid and accurate solutions to these problems. During the past years, the science of designing computing machinery has advanced so rapidly that a computational system which at one time was considered the ultimate in refinement, was a few years later discarded as being obsolete. Mechanical analog computers and then electronic analog computers have each, in turn, held the attention of personnel concerned with improvement of military equipment.

During the early 1940's it became apparent that an entirely new computational method, the electronic digital computer, offered many distinct advantages over all previously available systems of computation. In the early stages of electronic digital computer development, machines of this type employed vacuum tubes as computing elements and were therefore limited by their large size and great power consumption to use in fixed installations. Computers of this class include the well known ENIAC which occupies a large room and requires many kilowatts of power.

In the early 1950's the advent of the so-called solid state devices (which include transistors), plus improved logic theory, made it appear feasible to drastically reduce both the volume and power consumption of digital computers without compromising the advantages of this type computer. The potential benefits of applying these devices to military

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usages were obvious.

For this reason, Frankford Arsenal, whose mission includes the evaluation of advances in science and technology which may have application to improvement of fire control, conducted during 1953 a preliminary study relating to the possibility of using electronic digital computers for solving the field artillery fire direction problem. The conclusions reached during this investigation indicated the great potential advantages of such a system over those previously available. As a result, a contract for a preliminary design study of such a device was placed with the Engineering Research Associates Division of the Sperry-Rand Corporation. This study is now complete and the results are set forth in a report prepared by the contractor. Because of the highly technical nature of the ERA report, this summary has been prepared to highlight that portion of the results which will be of greatest interest and significance to the ultimate users of such equipment. Also presented is such supplementary and background information as may be useful in evaluating the resul's of the study.

-3-
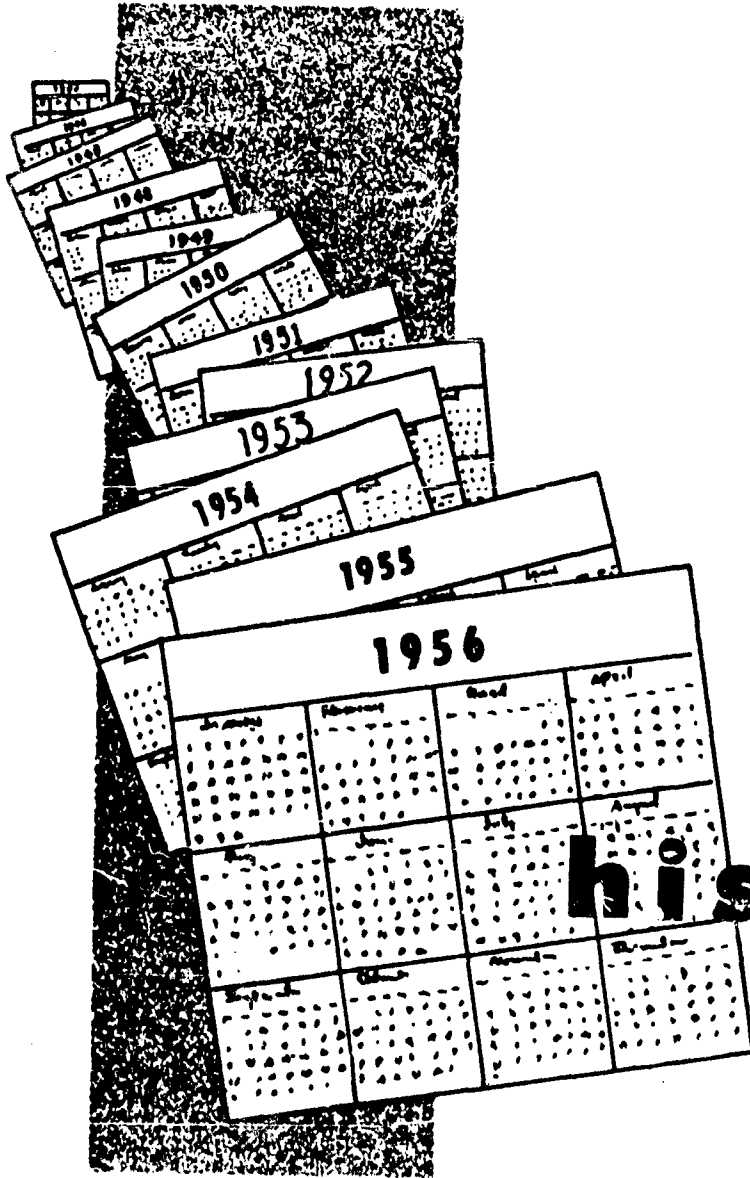
history..

Following the conclusion of World War II, it was recognized by those responsible for the improvement of military equipment that a significant improvement in the effectiveness of field artillery could only be achieved by the expenditure of considerable effort on the development of new equipment of greatly improved design. Because of the complexity of the mathematical relationships that must be handled during the computation of the field artillery fire direction problem, it became apparent that a computer, capable of automatically generating the necessary weapon laying data was one of the items requiring development.

In 1946, Military Characteristics covering an automatic fire direction center were prepared by the using services (then known as Army Ground Forces). Among other items covered, these Military Characteristics included the requirement for an automatic computer. As described by the MC's, this computer would accept all data pertinent to the firing problem as inputs. Such factors as geometric and ballistic information, meteorological data, etc., were all included. As outputs, the computer was to automatically generate weapon laying and fuze time information for a 105mm Howitzer firing seven charges at either high or low angle fire. In addition to the above, the computer was to produce replot information and would be capable of solving survey problems.

When the project for the development of an automatic device for computing the field artillery fire direction problem was initiated, two types of the basic computing mechanisms were sufficiently developed to be worthy of consideration. These were the mechanical analog computer and the elec-

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trical-mechanical analog computer. The development of the two other basic types of computers, the mechanical digital and electronic digital had not sufficiently advanced to be given serious consideration. After evaluating all the requirements in the military characteristics, it was decided, after careful analysis of various factors involved, to proceed with an electro-mechanical analog computer. This computer performs the basic computation electrically; however, some of the operations and minor calculations such as addition and subtraction are done mechanically through gearing systems. This approach has resulted in the T29 series of computers, pilots of which are currently undergoing tests. During the course of the above computer development, studies were made continually to determine whether advances in other types of computing systems had enhanced the possibility of devising a field artillery computer with characteristics that would be superior to those of the electro-mechanical analog device. On two occasions studies of the possibility of using a mechanical-digital computer for field artillery use confirmed the original conclusion that a mechanical dig'.al computer was not practical for the intended purpose because of its large size, heavy weight and mechanical complexity (which would result in high cost and poor reliability).

During 1953 the state of the design ait for electronic digital computers was again investigated. Through these studies it became apparent that a computer of this type had now become feasible and that the possibility existed of designing a computer which, by full exploitation of the new solid state device and techniques, would use a very small number or

no vacuum tubes. During this phase of the program, it was also deter-
mined that in addition to the other noteworthy benefits to be derived
from electronic digital computation, this type of device made it possi-
ble to achieve an extremely desirable feature that had not previously
been obtainable. This feature is the possibility of developing a fam-
ily of "building blocks" of standardized design that may be used inter-
changeably between various computers whether they be for tank, anti-
aircraft, missile or field artillery applications. This type of inter-
changeability is obviously not possible in the analog computer since
most components such as potentiometers, cams, etc. are designed for the
specific problem to be solved by the individual computer. This family
of "building blocks" once developed would greatly simplify and expedite
the process of designing future computers whose usages cannot even be
visualized at this time.

In June 1954 a contract for a design study of an electronic digital
field artillery computer was entered into with the Engineering Research
Associates (ERA) Division of the Sperry-Rand Corporation. The contract
covering the development specified that the computer design be based on
solid state devices with speed capabilities consistent with the solution
times of anti-aircraft fire control problems. The specification also
stressed the desirability of basing the ballistic solution of the computer
on the basic equations of projectile motion. As described below and in
the ERA report, achievement of this objective opens the way to many sig-
nificant advantages including great flexibility, elimination of weighted

"Metro" messages, etc.

When the study resulting from the contract was approximately 80% complete, the results achieved were so encouraging that ERA was requested by Frankford Arsenal to publish their findings in an interim report which would set forth their accomplishments to date. At this writing the study is 100% complete. While the remaining 20% of the work accomplished clarified certain details of the design, the interim report presents a complete picture of the major findings. The contents of the ERA report thus forms a valid technical basis for the discussion presented below.

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summary
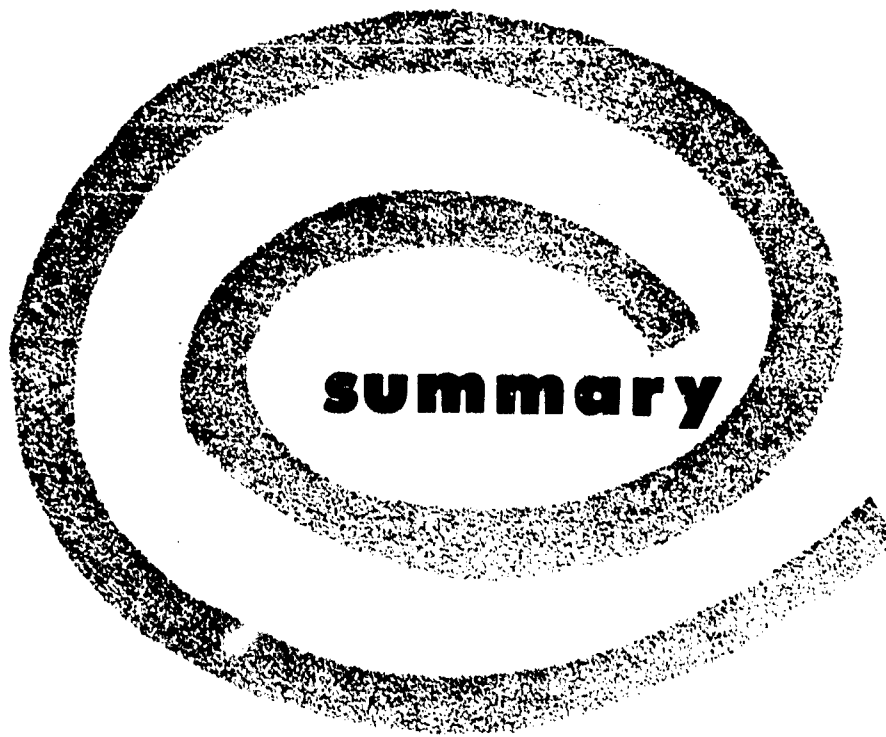
of conclusions

As described in the condensation of ERA's findings presented herein, the preliminary design evolved from the study indicates quite strongly that a digital computer possesses many advantages over other computational methods in intended application. These advantages are many and include both improved operational and logistical characteristics. In summary, it is concluded that the device described in the ERA report would have the desirable characteristics listed below:

a. The proposed computer would have high accuracy.

b. High overall precision is obtainable without the necessity of holding close tolerances on components.

c. The machine, while being designed primarily as a field artillery fire direction computer, can be adapted to other uses with a minimum of physical rearrangement.

d. In solving the field artillery fire direction problem, the ballistics of any existing or future weapon of conventional design can be accommodated without any physical change in the machine.

e. The ballistic solution of the machine is as accurate as the best current exterior ballistic theory permits.

f. There is no necessity of using weighted Metro messages, hence, one ten line message would be usable for all calibers of weapons.

g. The design of the computer lends itself to use of automatic assembly methods in manufacture.

h. The design of the computer can lead to the stocking of a relatively small variety of sub-assemblies that may be used for a large num-

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ber of computers performing different functions.

i. In times of emergency, components will be more readily available than for a comparable analog device.

j. Means can be provided for not only automatically detecting, but also anticipating potential sources of troubles. In addition the design will be such that defective units can be automatically "pinpointed".

k. Because of the construction, defective parts once located can be easily replaced under field conditions.

l. The cost, weight and volume of the device will be roughly the same as the T29E1. Power consumption will be considerably less.

m. Because of the design, it is believed that once developed, the FADAC (Frankford Arsenal Digital Artillery Computer) will provide a means of computing many field artillery problems which are at present not solved, or only approximately solved, because of limitations of existing equipment.

discussion..
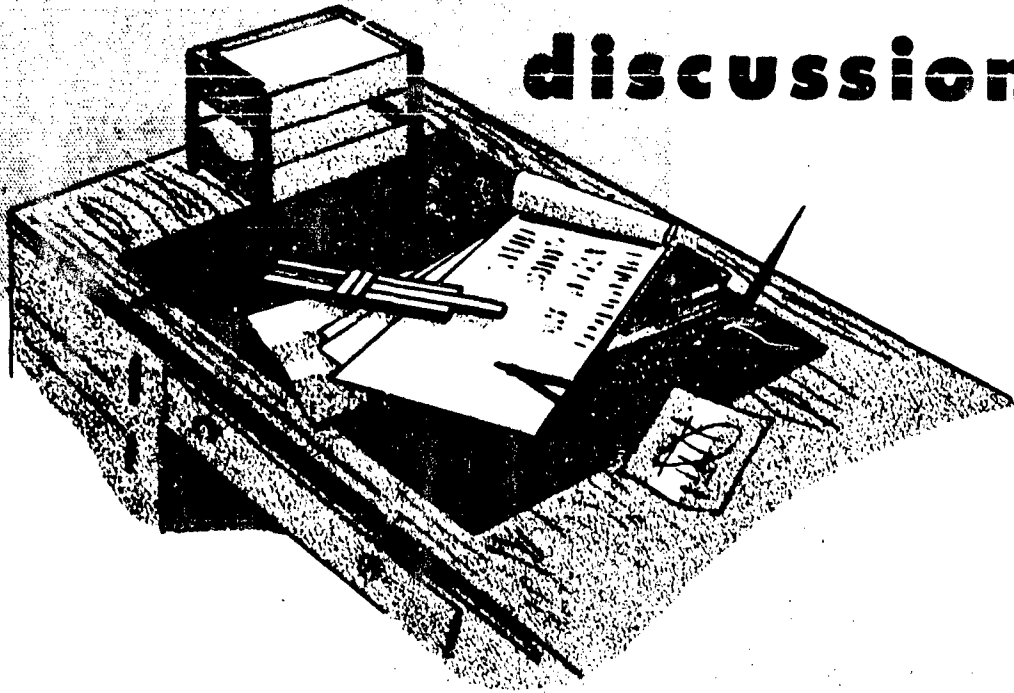
During June 1954 a contract was placed with Engineering Research Associates Division of the Sperry-Rand Corporation for a design study of an electronic digital computer for a field artillery fire direction center. The results of this study are contained in a report prepared by the contractor dated 1 August 1955. Although this report is referred to an "Interim", it presents a complete picture of the major achievements resulting from the study.

The ERA report, being a complete technical summary of the project, contains a vast amount of detailed engineering data. Because of the great amount of data presented, it is believed advisable to abstract from the report that information which is of particular interest to the users of the proposed equipment. For this reason, there is given below a condensation of the data contained in the ERA report which should be of significant importance in determining the future course of the project. Also given is certain supplementary information that may be of help in better evaluating ERA's results.

The condensation plus the supplementary information described above constitutes the "Discussion" of this report.
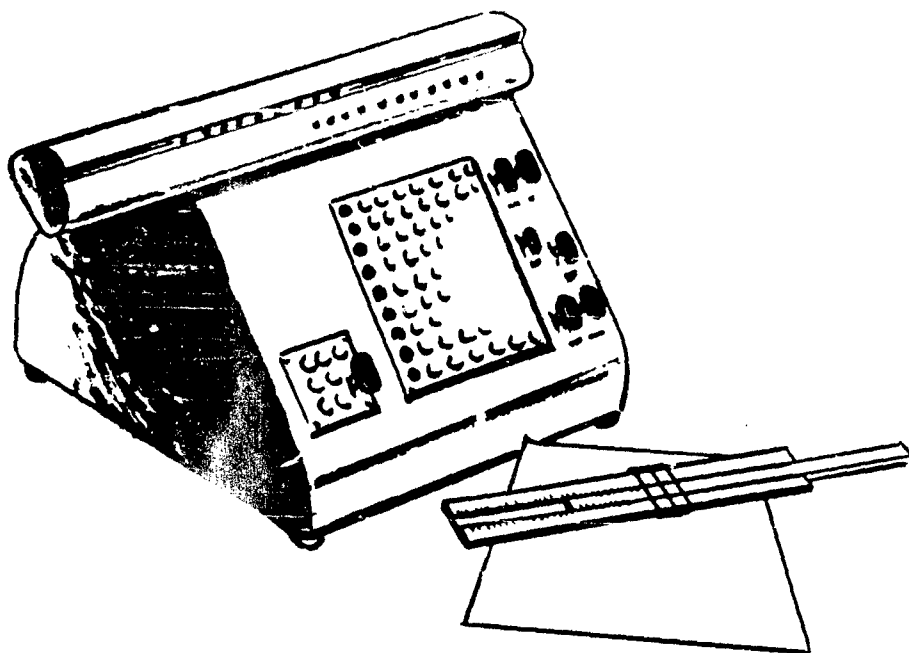
general characteristics

To understand the basic difference between a digital computer and an analog computer, it is only necessary to compare a desk type calculator with an ordinary engineer's slide rule. In the slide rule, distances are used to REPRESENT the logarithm of a number. (Hence, distance is a mechanical ANALOG of the logarithm.) The desk calculator on the other hand, is a device which adds or subtracts arbitrary units or DIGITS.

The weakness of the slide rule is that to increase accuracy, by say a factor of 10, it is required that the precision of the graduations be increased by a factor of 10. (Reading of the scales to the increased precision of the engraving would be so difficult that this approach is of little practical value.) The alternative method of increasing the slide rule accuracy would be to increase its length by a factor of 10, which would be extremely cumbersome. Increasing the precision of a desk calculator by a factor of 10 merely requires the addition of another bank

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of numbers and indicators. This expedient obviously does not require any increase in the accuracy of the component parts of the machine nor does it complicate the reading. In addition, another bank of digits does not materially increase the bulk of the machine.

Another point to be remembered is that nearly all analog devices for military uses are built for a specific purpose and cannot be used for any other purpose without considerable physical modification. This holds true whether the device be a simple graphical firing table or a complex system such as the M33 anti-aircraft fire control system.

In considering a digital computer, even a device as large and complex as the ENIAC, it must be realized that in reality it performs a function similar to that of a desk calculator plus its operator. Many engineering organizations employ full time desk calculator operators to carry out repetitive numerical computation in accordance with a step by step computing program prepared by a supervisor and who, by following in detail the prescribed steps of the program, arrive at a numerical solution to a problem. In the course of solving the problem, the machine operator may refer to mathematical tables (trig functions, logarithms etc.) or he may refer to tables of empirical or experimental data (such as a firing table). By this process he can solve any problem programmed for him by his supervisor that lies within his capabilities and the capabilities of his equipment.

As previously stated, a general purpose digital computer such as the ENIAC serves the same purpose as the desk calculator plus its operator.

The difference is, however, that in the case of a machine such as the ENIAC the entire computation program is entered into the machine at one time, thus eliminating the necessity of entering individual portions of the problem into the machine piecemeal such as was the case with the desk calculator. In addition, the machine has built-in provisions for refering to mathematical, empirical or test data thus considerably speeding up the process of obtaining an answer. Nevertheless, the types of problems the machine can do, as was the case with the desk calculator are limited only by the capacity of the equipment and the ingenuity of the supervisor who must devise a computing program capable of solving the problem. This gives rise to the term "General Purpose" which is used from time to time in this document since the computer is in no material case limited to the solution of only one type of problem.

One other property of modern digital computers should be noted prior to a discussion of the ERA design. This is the arithmetic system employed which is known as binary arithmetic. When in decimal arithmetic a notation is made to de..ote the number one hundred and twenty-four, it is written as 124. The meaning of such a notation is generally understood even though a more mathematically correct notation would be 1×10^2 / 2×10^1 / 4×10^0. The difficulty in using this notation in an electronic machine is that there are ten possible coefficients (0, 1, 2, ----------9) for each of the powers of 10.

In the binary system on the other hand, 124 would be represented by the number 1111100 which in actuality means 1×2^6 / 1×2^5 / 1×2^4 /

$1 \times 2^3 \neq 1 \times 2^2 \neq 0 \times 2^1 \neq 0 \times 2^0$. As may be seen in this notation, the coefficients of the powers of 2 are either 1 or 0 which means that a series of simple devices that are either off or on (such as common relays or crystal diodes) will completely define any number to any degrees of precision, depending on the number of elements used. This is a direct contrast to the decimal system, wherein it is necessary to determine precisely whether a coefficient is for example 4 or 5.

While a greater number of elements are required to define a number in the binary system than are required in the decimal system (7 in the binary system for the example shown as compared to 3 in the decimal system), an important simplification is achieved since there is no longer any requirement for precision operation of the components.

The computer design proposed by ERA has all the desirable characteristics of a modern electronic digital computer which are in summary:

a. High precision

b. General purpose flexibility

c. No precision components

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$$\ddot{Y} = -E\dot{y} - g$$

$$\ddot{X} = -E\dot{x}$$
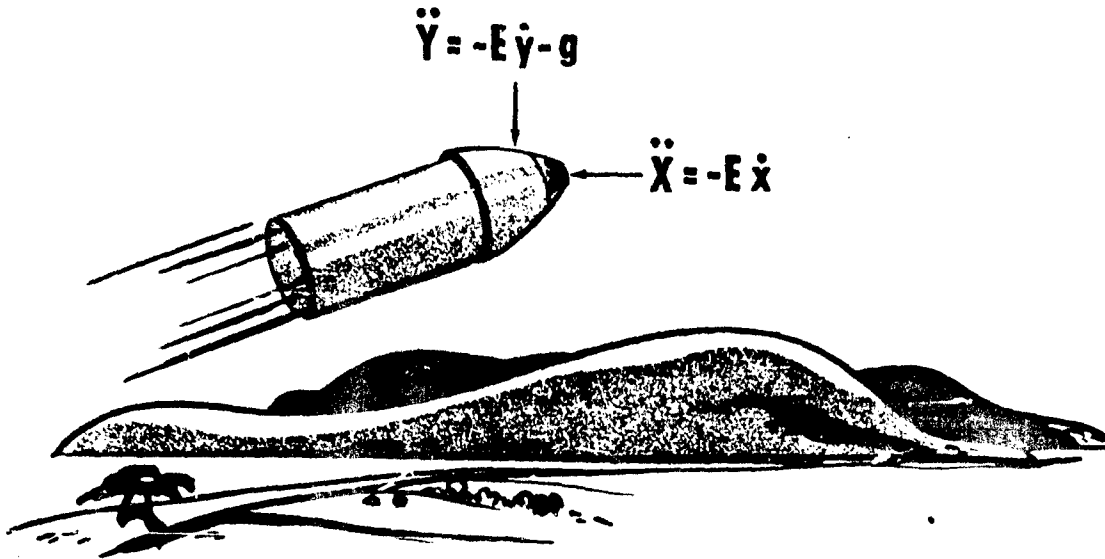
method of computation ··

As previously noted, the electrical analog GDC T29E1 solves the ballistic relationships for the 105mm Howitzer M2A1 by storing as a number of empirical formulas that have been built into the machine, the ballistic relationships of the projectile which were originally computed by the ENIAC. While in the design of a computer for the 105mm Howitzer, this is a satisfactory method, it does have certain limitations which are as follows:

a. To change the ballistic mechanism of the T29E1 so as to obtain a solution of the problem for some other weapon, such as the 8" Howitzer, it is first necessary to develop the empirical equations from the ENIAC data for that weapon. This would be an extremely costly process that would take many months, after which the computer must be physically redesigned as indicated by the empirical equations. This involves com-

putation of new resistance values, designing new potentiometers and per-
haps adding amplifiers. After this process, the machine must be physi-
cally rebuilt to accept the new parts. In addition, a chance exists
that for some weapons empirical equations that will fit the plan of the
present machine cannot be derived with suitable precision and a com-
pletely new machine must then be designed.

b. While an empirical solution is usable for the 105mm and 155mm
Howitzers, it does not correct completely for interactions between var-
ious non-standard conditions. As an example of interaction, let it be
assumed that the only non-standard condition acting on a projectile is
a 50 mile/hour range wind. To correct weapon elevation for this condi-
tion during the firing of a specific problem, a certain elevation cor-
rection must be made for the wind. Now let it be assumed that both a
50 mile/hour range wind and a 10% non-standard air density are present
simultaneously. In this condition, corrections must be made for both
wind and air density, but because of the presence of the non-standard
air density, the correction for wind will not be the same as it was when
range wind was the only non-standard condition present. This is known as
interaction. In a computer that operates on either stored firing table
data (as on cams) or by solving empirical formulas (as in the case of the
T29E1), complete compensation for interaction is, because of the approx-
imations required in order to keep the machine to a practical size,
either impossible or very difficult. While the T29E1 does not complete-
ly correct for this effect, the solution is satisfactory for the 105mm

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& 155mm Howitzers. For larger weapons, significant errors are likely to be experienced.

c. The use of empirical formulas (or stored firing table data) introduce errors into the solution of the problem due to weighting of the Metro data. If, for example, a target is to be engaged at 10,000 yards by a 105mm using charge 7, line 4 of the Metro message would be used in the computation of the solution. As currently computed by the Signal Corps, the Metro data given for line 4 is actually the metro data at the maximum height of the trajectory, averaged together with the metro data at lower levels. In the averaging process, the time that the projectile spends at each altitude level is used as a weighting factor. The difficulty in this procedure is that one Metro message is used by several types and calibers of weapons firing many different charges, thus making exact weighting impossible.

In contrast with existing field computers, which operate on either stored firing table data or empirical equations, the solution of the FADAC is based on fundamental equations of projectile motion. These equations which are described in detail starting on page 10 of the ERA report are based on Newton's Second Law, which states that deceleration of a body in motion is proportional to the summation of the retarding forces.

Because all factors are entered into the equations in terms of their basic physical significance, data relative to the projectile and propellant being utilized is limited to the following:

a. Projectile weight

b. Muzzle velocity

c. The drag function of the projectile

d. The ballistic coefficient of the projectile

These data are entered into the computer on punched tapes similar to those shown on Figure 31 of the ERA report.

Because of the relatively small amount of ballistic information that must be entered into the computer, flexibility of the device would be materially increased over that which is obtainable from a T29 type device. Only a few minutes would be required to convert a computer that had been used in conjunction with one weapon for use with another weapon with completely different ballistic characteristics. While not included in the original ERA study, it is conceivable that a slight increase in machine data storage capacity will permit one computer to provide data, on a time-shared basis, for weapons of two or three different calibers. (If such a feature appears desirable, a study of how the required increase in storage capacity will effect size. cost and complexity will be conducted during later phases of the program.)

The flexibility described above is in direct contrast with the great amount of effort required when converting a computer such as the T29E1 for operation with a new ammunition.

In addition to the above, it should be noted that prior to computation of firing table data, Aberdeen Proving Ground must obtain the ballistic parameters described above. If these parameters are immediately translated into punched tape, it is quite possible that the FADAC can be avail-

able for use in the field with an entirely new ammunition prior to pub-
lication of the firing tables.

Examination of the equations given on page 20 of the ERA report shows
that the solution of the ballistic problem consists of a step by step in-
tegration of the accelerations of the projectile in the X and Y directions.
This means that the Y coordinate (height) of the projectile is available
at every point of the computation and hence the actual unweighted met mes-
sage may be used.

It should be noted that the double integrations required for ob-
taining a solution require great machine accuracy and are therefore not
suitable for use with an analog type machine for field use. In fact, the
only analog machine known to have successfully solved these equations was
the well known Bush Differential Analyzer, which is now obsolete and
which, by virtue of its enormous size, was limited to use in fixed in-
stallations.

While the discussion presented above is primarily concerned with
generation of gun elevation data, which is by far the most difficult func-
tion performed by a field artillery computer, it should be noted that the
FADAC will provide all data required of a device of this type. This in-
cludes fuze time and azimuth outputs. The superiority of the basic
method of computation is also reflected in these outputs. Fuze time
generated by the machine is based on the same fundamental projectile
flight equations and as a result, accurately accounts for such factors
as height of target above the weapons and interactions between non-

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standard conditions. The azimuth solution will, when necessary, take into account rotation of the earth and under all conditions utilizes the unweighted cross wind.

In addition to other functions, the machine can be utilized as a survey computer. In this connection, it should be noted that because of the high inherent accuracy of a digital machine, firing problems involving the longest ranges encountered by conventional artillery can be solved with great precision. For reasons previously stated, an analog machine giving comparable accuracies at extreme ranges would probably be of such great size and complexity that it could not be feasibly used under field conditions.

In summary, it can be said that the proposed method of computation, which is only practical with a digital computer, has the following advantages over other known types.

a. The computer can be modified to accommodate any ammunition in the shortest possible time with the least effort. (In addition, it may be feasible to provide a computer that will handle weapons of mixed caliber.)

b. There are no errors due to interactions between non-standard conditions.

c. There is no necessity for using a weighted Metro message.

d. Maximum computation accuracy of a field artillery fire direction problem.

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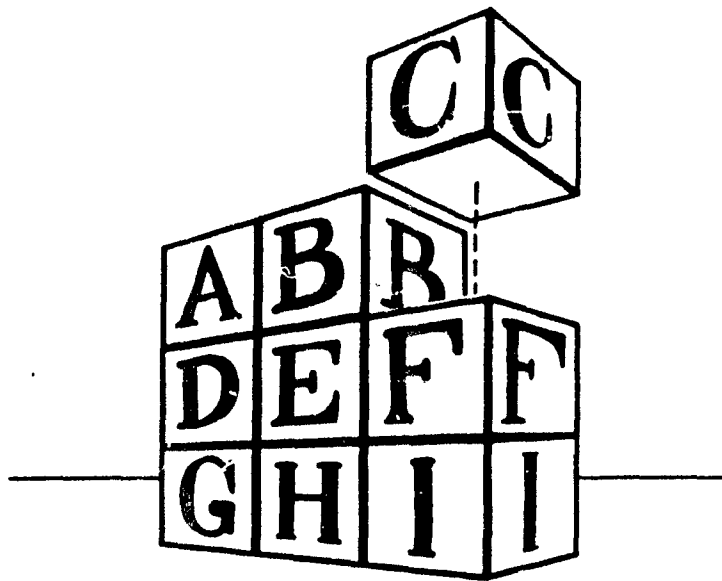
ease of production··

One of the advantages of digital computers is that the basic arithmetic operations to be performed are rather limited. Despite the limited number of these functions, which are listed on page 7 of the ERA report, the FADAC, just as in the case of a desk calculator, which basically performs only addition and subtraction, is capable of solving a large variety of prob'ms, since all problems can be reduced to a series of operations in terms of the basic arithmetic functions.

In addition to the arithmetic functions, there are so called control functions required for directing the machine to perform the desired steps in the computing program in the correct sequence. Fortunately, because of a similarity between control and arithmetic functions, (in an electronic digital computer these are both essentially switching operations), it is possible to construct a relatively complex device from

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a rather limited number of basic "building blocks" which to a large extent are duplicates of each other. As described on page 5 of the ERA report, there would be only thirteen basic types of building blocks required. Photographs of some of these units are shown full size on figures 1 and 2 of this report. In addition to the basic building blocks, the computer, as currently devised, would require only a storage drum and an input-output mechanism.

As may be implied from the above, the digital computer is in reality an assemblage of numerous small sub-assemblies which are in general identical. Because of this, it can be foreseen that if the computer were ever produced in large quantity, all sub-assemblies could be fabricated automatically on a machine such as pictured on figure 3. As claimed by its manufacturer, one 15 station machine operated by two people can perform the same work in one minute as can be accomplished manually by one operator in an entire day.

Obviously, the economic feasibility of manufacturing the required special tooling such as punches and dies must be determined by careful analysis. Looking into the future when it is visualized entire families of computers (some for tanks, some for missiles, some for AA, etc.) may employ the same basic "building blocks", it is fairly safe to predict that use of such automatic assembly processes would be economical. In this same connection, the economy of stocking similar "building blocks" for machines performing a large variety of functions cannot be questioned. This can be contrasted with present stocking of parts for analog computers
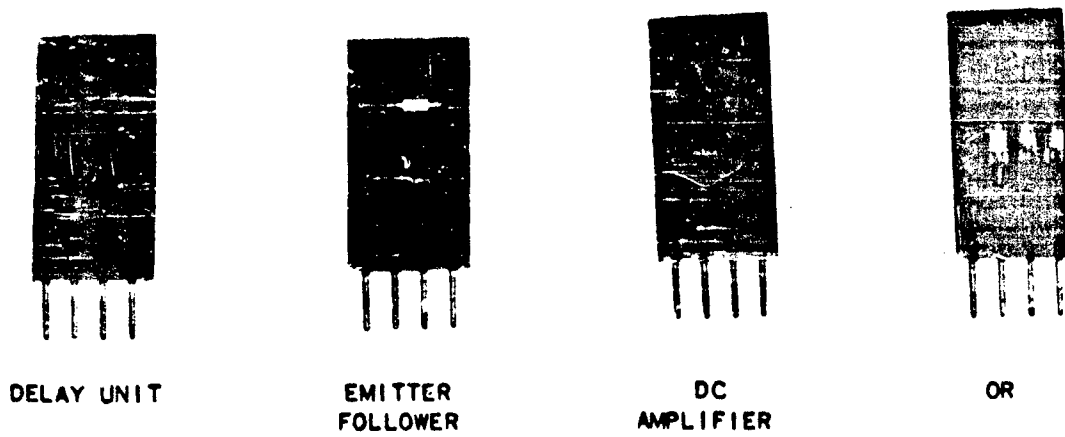
-25-

where it is safe to assume that with the exception of simple hardware, such as screws etc., no two computers employ the same parts.

In addition to the above, it should be reiterated that a digital computer based on binary arithmetic does not require precision components as does an analog device. This is a significant point, particularly in times of national emergency when facilities for manufacturing high precision components will be overloaded.

In summation, the following advantages in economy may be claimed for FADAC:

a. Distinct possibility of automatic assembly.

b. Distinct possibility of stocking a relatively few varieties of parts for a large number of computers performing different functions.

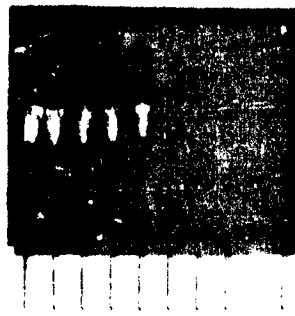c. In times of emergency, components will be more readily available than for a comparable analog device.

DELAY UNIT EMITTER DC   OR
      FOLLOWER AMPLIFIER

PULSE   WRITING-HEAD PULSE
SHAPER   SWITCH   AMPLIFIER
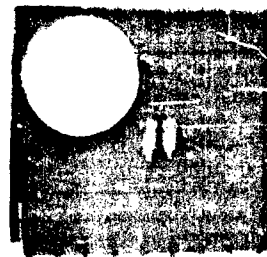
FLIP-FLOP   AND NOT   AND

Figure 1. "Building Block" Circuit Units (Component Side)
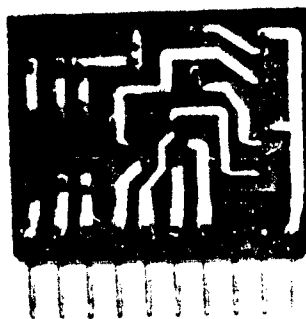
-27-

DELAY UNIT EMITTER FOLLOWER DC AMPLIFIER OR
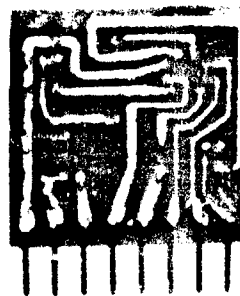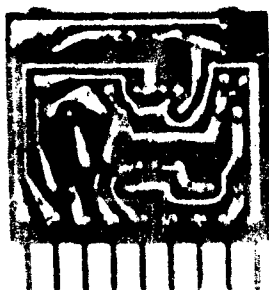
PULSE SHAPER WRITING-HEAD SWITCH PULSE AMPLIFIER

FLIP-FLOP AND NOT AND

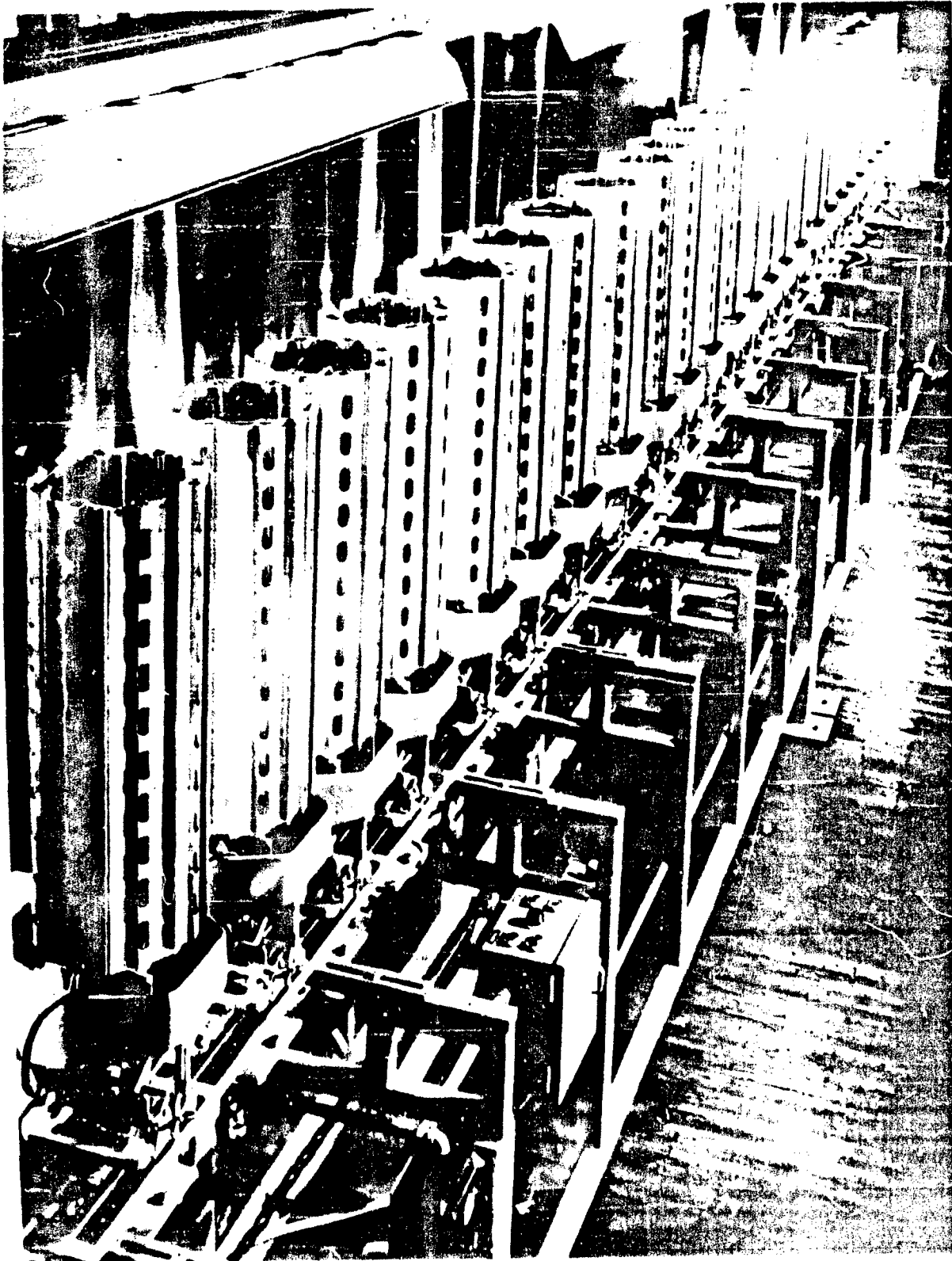Figure 2. "Building Block" Circuit Units (Wiring Side)

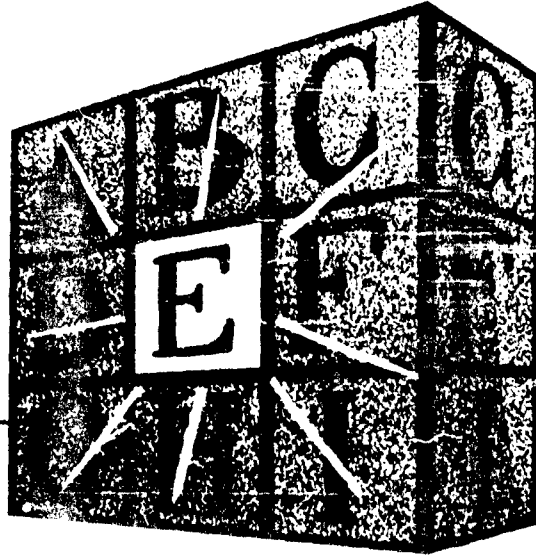Figure 3.   Automatic Component Assembly Machine

ease of maintenance··

Throughout the ERA report there are numerous references to the problems associated with maintaining the computer in operating condition. These problems fall into three general categories which are as follows:

a. Provisions of means whereby the operator can determine whether or not the computer is operating correctly. This includes provisions for anticipating potential failures prior to the time they would be encountered during normal operation.

b. If a failure or a potential failure is detected, means must be provided whereby the faulty part can be located.

c. After location of the faulty part, means must be provided for rapidly and easily replacing the defective part. ERA's approach to the maintenance problem is partially stated on page 90 of their report. This statement is as follows:

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"Maintenance in·the field will be relatively simple, and, could conceivably be performed by the operator. The operator or maintenance man should run a sample problem, for which the answers are known, each 24 hour period in which the computer is to be used. Marginal checking features such as voltage variation will be provided to show up marginal units. The extensive checking features built into the machine will give a continuous check on all major units. The trouble indicators should pinpoint the trouble to 2 or 3 chassis. The chassis in question can be removed and spare chassis inserted to clear the fault (fig. 4). The questionable chassis can then be sent to a repair area for detail checking and servicing. If a switch is faulty, simple repairs such as cleaning contacts could probably be accomplished in the field. However, replacement of switches would probably be a repair base operation. Fuses and indicator lamps are items that may be replaced in the field. The bearings used on the magnetic drum may require semi-annual or annual lubrication. Since this detail can be scheduled in advance, this should probably be considered a repair area operation. Lubrication of switch detents, if required, can probably be done at the repair area on a semi-annual or annual basis. The design goal for this computer is an average of 200 hours operation before a component failure occurs necessitating chassis replacement. The figure of 200 hours appears to be realistic based on present-day reliability estimates of transistors and diodes."

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In addition to the above, other sections of the ERA report discuss other aids to error detection and maintenance. These are as follows:

a. As noted in several sections of the report, one type of check which is simple, from the point of view of the mechanism required, is the so called odd-parity check. This check continuously monitors every operation of the machine but has the disadvantage of not detecting errors if they occur in multiples of two. This is not, however, considered a major disadvantage as the possibility of a single digit error is low which in turn makes the probability very small that two or more errors will occur simultaneously during a single arithmetic operation.

b. On page 10 of the ERA report, it is mentioned that the machine could be provided with a self-checking feature that would not only indicate a malfunction but would also indicate by a light, which subassembly has caused the error. This system of checking would be based on a self-checking routine that would be initiated by the machine itself at fixed intervals of time. While this method of checking should prove most satisfactory to the user, it would result in certain complications to the equipment.

c. A partial, but important, check of the computer is automatically provided by the method of inserting data. As indicated on figure 4, data is inserted into the computer by the operator entering the data into a keyboard. This figure also shows that the number entered into the keyboard is recorded on a large counter type display. In the proposed design, pushing the numbered keys does not directly activate the dials.

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Rather, pushing the key enters the data into the computer in decimal form, the machine converts this information to binary form, it is entered into the drum storage, it is read out of the drum, reconverted to decimal digits and then displayed on the counter. Thus, if the number displayed on the dial is the same as that entered into the keyboard a large portion of the computer has been checked.

In summary, it can be stated that the basic design provides adequate means for minimizing maintenance problems. This conclusion is based on the following considerations:

a. Adequate means are provided for detecting sources of trouble. In addition, by means of the periodic test at high and low voltages described by ERA, potential sources of trouble can be detected prior to the time that actual failure occurs.

b. The design will be such that defective units can be automatically pinpointed.

c. Because of the "building blocks" type of construction, defective parts once located can be easily replaced possibly under field conditions.

d. Because of the relatively few types of "building blocks" required, as described under "Ease of Production", the problem of stocking spare parts will be minimized.

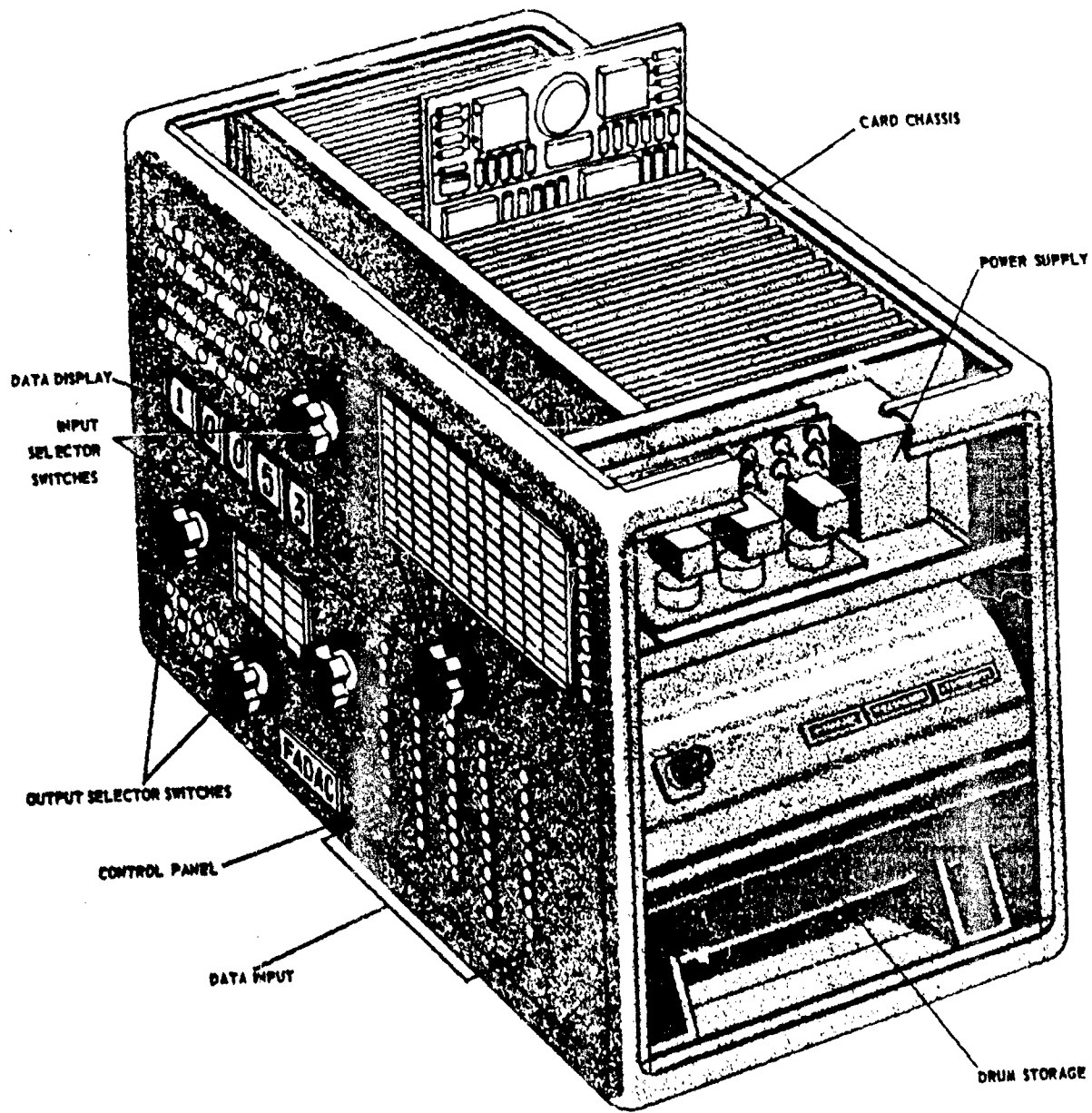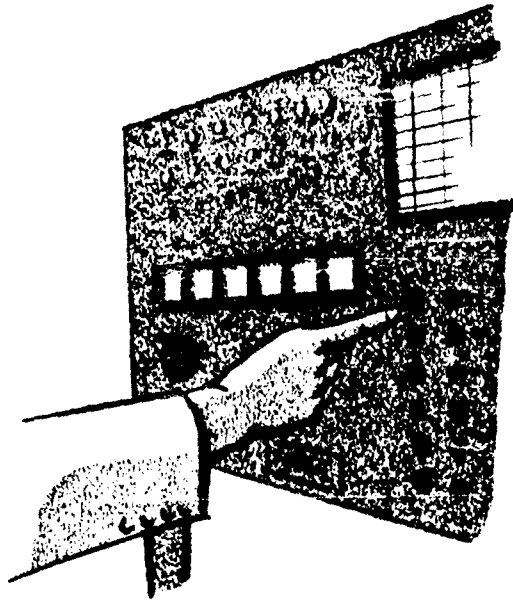Figure 4. FADAC Computer, Cutaway View

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operating characteristics

Basically, the problem of adequately "human engineering" the control section of a digital computer arises from the fact that data must be inserted into the machine by a digital device such as a keyboard similar to that of a desk type computing machine, or a telephone dial. As it is not feasible from either the space or economy standpoint to provide an input device for each element of data, all data must be entered into the same mechanism. Thus, in principle, the computer will have one input mechanism with means provided by which the machine can recognize which element of data is being inserted.

As shown on figures 4 and 5 (and in greater detail on the drawing inclosed in envelope No.1 in the ERA report), ERA has proposed that the element of data (or "item") to be inserted be determined by the operator
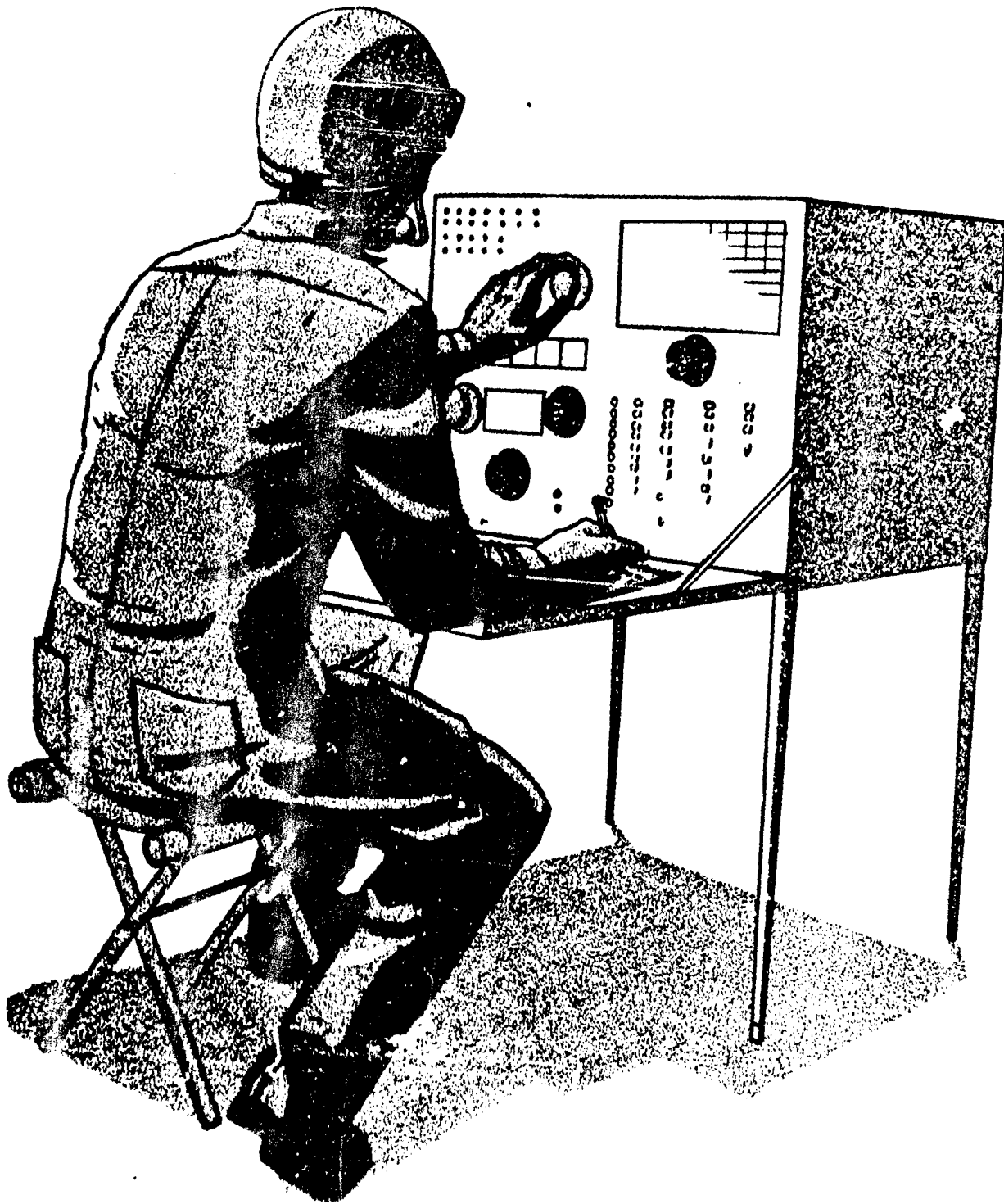
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Figure 5.   FADAC Computer in Field Use.

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positioning two input selector switches. After selecting the item of in-
formation to be entered, the numerical value of the "item" is entered into
the keyboard. This number, displayed on the large counter dial, serves as
check on both the operator and, as previously described, a large propor-
tion of the mechanisms within the computer. It should be noted that the
majority of these "items" (such as battery coordinates and Metro data) are
not changed for each new problem. The switching system would therefore be
less complicated to use than might be inferred from the total number of
"items" covered by this input system.

After all elements of data are entered, the operator presses the com-
pute button. Following the computation cycle, an answer will appear on
the counter dial. The number shown on the dial is then the answer for one
element of the output, such as Quadrant Elevation. The element of the
output to be displayed is, as in the case of the input, dependent on the
position of the two output selector switches.

If one element of input data, such as observers "Add-Drop" correction
requires a change, only the one new element of data need be inserted into
the device prior to recalculating the problem.

While the control mechanism depicted is technically correct, it is
feared that operation of the selector switches may confuse the operator and
possibly result in errors or loss of time. Figure 6 shows alternate ar-
rangements of the control panel which, while considered superior to that
proposed by ERA, do not necessarily represent the optimum in human engi-
neering.

One problem associated with the ERA panel is the great quantity of data that must be entered. For this reason, it is felt that if the inserted metro message data which is only changed periodically were removed from the front panel, operation would be considerably simplified. Figure 6 (c) shows Metro message data being inserted into the rear of the machine on punched paper.

Figure 6 (b) shows another possible configuration. In this scheme, input data is inserted into the computer by means of a telephone dial. In this system, identification of the element of data (or "item") being inserted would be accomplished by dialing two code letters prior to the number just as code letters representing an exchange are dialed into a telephone ahead of the numbers. In this configuration, Metro data could again be entered into the rear of the machine if so desired. Dial insertion of data could permit the forward observer to control the computer directly with a remote telephone dial.

Another possible configuration is shown on figure 6 (a). In this arrangement, the front panel includes a teletype writer keyboard whereby the operator types-in both the element code and the data in a manner which is basically similar to that employed when using the dial. While this system will occupy more space than the dial, it has the advantage of greater speed in that there is no dead time encountered between insertion of digits as is encountered while waiting for the telephone dial to return to zero.
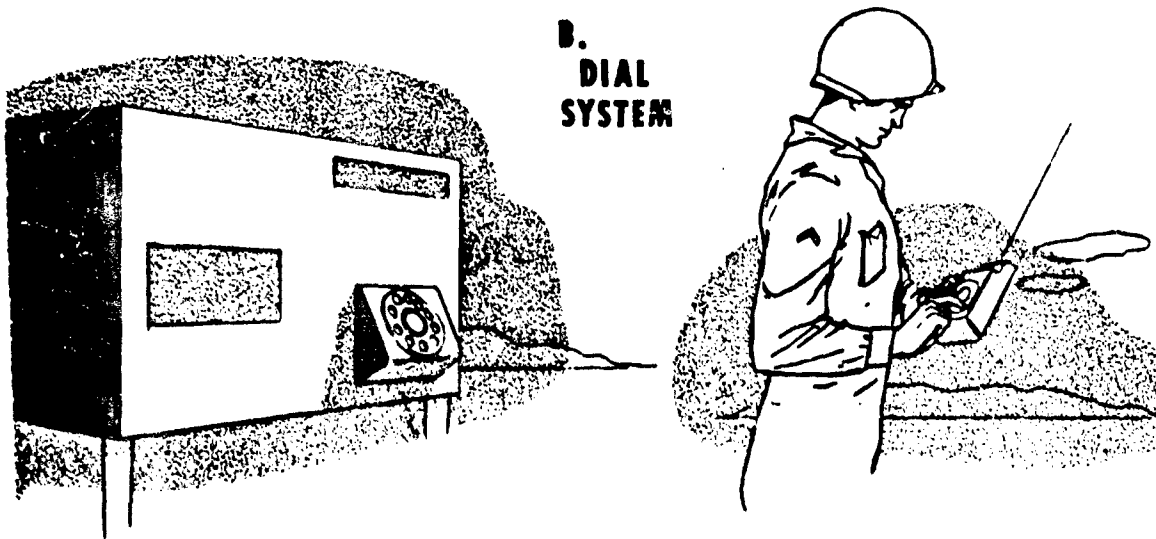
While not illustrated, the possibility exists of printing the computer outputs on a roll of paper such as used for adding machine outputs. With

A.
TELETYPEWRITER
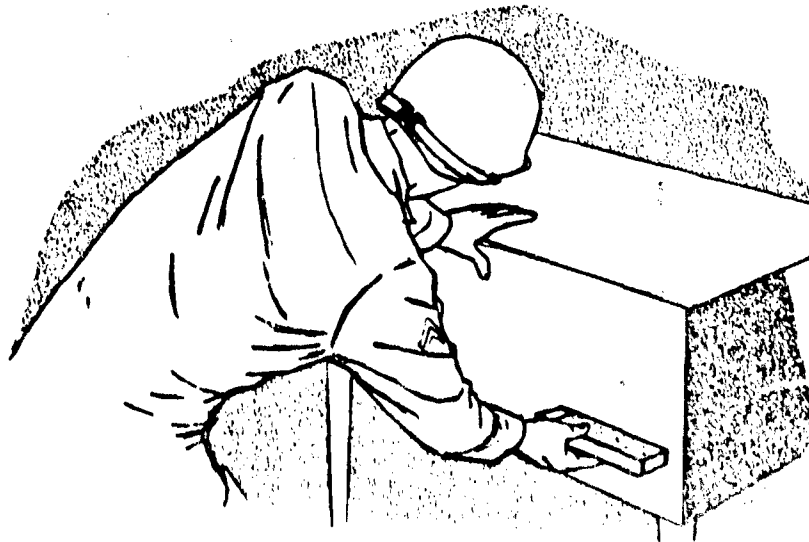**KEYBOARD**
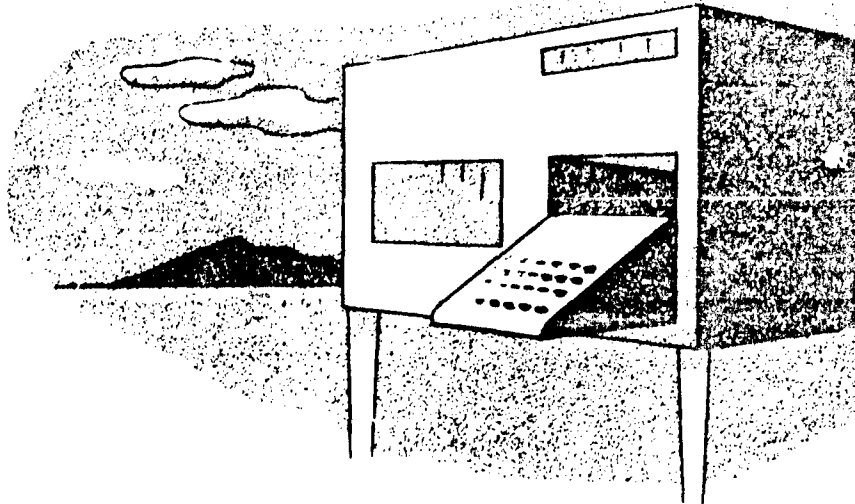
B.
DIAL
SYSTEM

C.
MET
DATA
(REAR VIEW)

Figure 6. FADAC Computer, Alternate Configurations.

such a mechanism provided, the entire problem including both inputs and outputs could be printed and filed for future reference. Despite these advantages, the printer would, however, add weight and bulk to the computer and would consume considerable power.

While no firm conclusions can be drawn at this time relative to the ultimate configuration of the control panel, it is certain that a comrehensive study of the problems will result in a computer that is both economically feasible and easily usable by enlisted personnel with a minimum of training. This is a subject worthy of considerable study which would include consultation with the using services prior to finalization of the panel design.

physical characteristics..

It is estimated by ERA that the computer shown on figure 4 will have outside dimensions of 32 x 16 x 19-5/8 inches. This results in a volume that is slightly under 6 cu. ft. The corresponding dimensions are 25 x 18 x 19 inches (5 cu. ft.) for the T29E1 without auxiliary equipment such as the power conversion unit (an additional ½ cu. ft. not required by the ERA computer). Thus, the digital computer occupies only slightly more volume than the T29E1 plus the power conversion unit. As analyzed on page 92 of the ERA report, the computer will weigh 200 pounds as compared to a total weight of 250 pounds for the T29E1 with power conversion unit.

As analyzed on page 93 of the ERA report, the complete equipment will consume 180 watts of power as compared with 450 watts for the T29E1. It

should be added that if a core memory is developed to the point where a storage drum is no longer required, total power consumption will be reduced to under 100 watts. This same substitution would of course also reduce the size and weight of the device. (Intensive development is in progress on this type memory unit and it is quite likely that a suitable unit will be feasible within the next few years.)

Manufacture costs of the digital computer are discussed starting on page 97 of the ERA report. The significant statement of this section is that the computer, if built in quantities of 1000 units, would cost approximately $20,000 per unit, which is about the cost estimated for the T29E1's in similar quantity.

In summary, it can be stated that the digital computer with all its advantages would have a cost, weight and volume roughly equal to the T29E1. Power consumption will be considerably less.
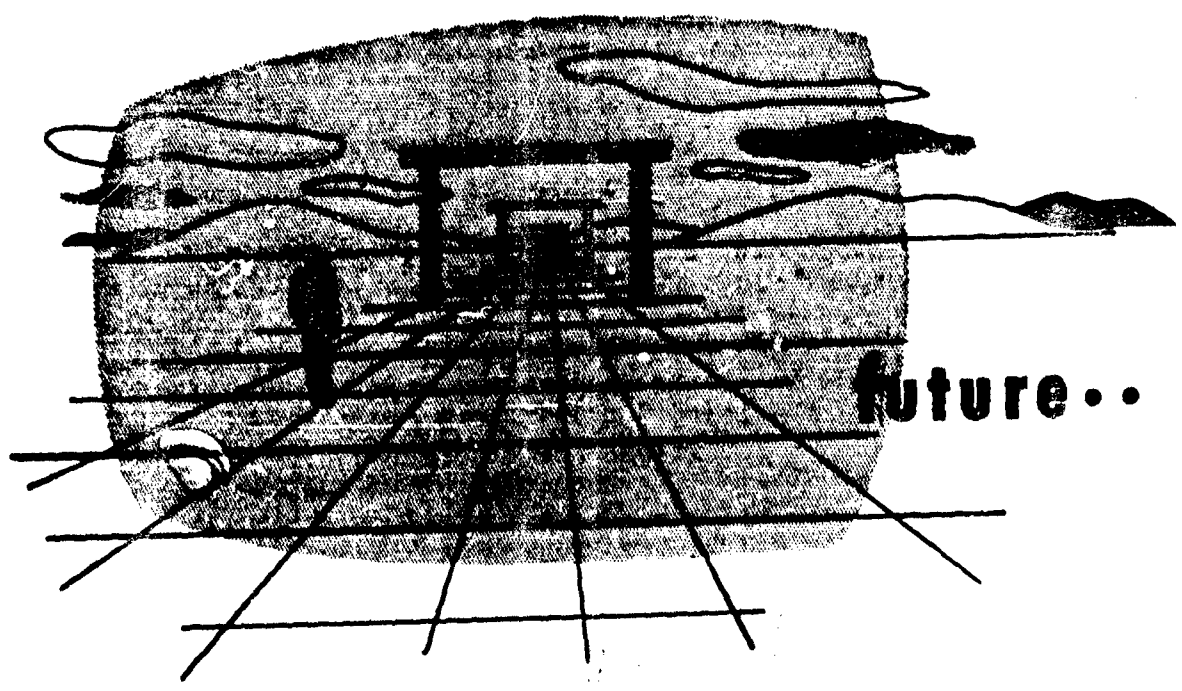
future..

FUTURE EXTENSIONS OF THE PRESENT PROGRAM

As may be seen from the preceding discussion, development of a digital computer to be used for computing field artillery firing orders presents many attractive possibilities. Because of the nature of the device proposed, it is, however, believed that computation of field artillery firing data is but the first step in a much more comprehensive program for improving the efficiency of solving many other field computing problems.

As previously mentioned, the "building block" construction of the computer provides a firm foundation for the ultimate development of a family of "building blocks" which can be used in a large variety of computers performing greatly varying functions. It can be visualized, for example, that computers providing logistic data, battlefield command decisions, computation of missile and anti-aircraft directing data, tank fire control, etc., could all be constructed with common parts. This would undoubtedly result in more rapid development of end items and simplified maintenance in the field.

Aside from the concept which includes the family of common parts, the computer devised by ERA has many potential uses not currently associated with fire direction computers. For example, when used in conjunction with shell tracking radars currently being developed by the Signal Corps, the computer could be used to compute, with an accuracy hitherto unobtainable, the location of enemy artillery batteries. Employing the same radars and this computer, it may also be visualized that the tracking of trial fire

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rounds can be used for generation of Metro messages in cases where such data might not otherwise be available.

In summary, it can be stated that the application of the techniques being developed in connection with FADAC can, with further extension of the program, produce as by products many significant improvements that will ultimately be of great benefit to the military services.

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