ANALOGUE, MECHANICAL AND ELECTRONIC DEVICES AND MATHEMATICAL TECHNIQUES

27 October 1949

CONTENTS

Page

INTRODUCTION--Mr. L. L. Henkel, Member of the Faculty, ICAF 1

SPEAKER--Mr. Marshall Wood, Assistant Director for Plans and Research, Directorate of Program Standards and Cost Control, Comptroller, Hq. USAF 1

GENERAL DISCUSSION 18

CHARTS--No. 1, Government-Sponsored Electronic Computer Construction 25
No. 2, Schematic Relationship of War Plans and Current Program 26
No. 3, Procurement Requirements for Non-Reparable Items Used on F-80 Aircraft 27
No. 4, Aircraft Model A--Supplies & Equipment for Aircraft 28
No. 5, Computation of Input and Output Coefficients 29
No. 6, Hypothetical Model of Berlin Airlift 30
No. 7, Schematic Diagram of Major Steps in Air Force Wartime Program Scheduling 31
No. 8, Rate of Pilot Production 32
No. 9, Rate of Aircraft Production 33
No. 10, Rate of Aviation Gasoline Production 34
No. 11, High Octane Aviation Gasoline Production 35
No. 12, Determination of Inventory and Production Rate at Initial Program Date 36
No. 13, Impact of Demand for Final Products 37

Publication No. L50-37

INDUSTRIAL COLLEGE OF THE ARMED FORCES

Washington, D. C.

ANALOGUE, MECHANICAL AND ELECTRONIC
DEVICES AND MATHEMATICAL TECHNIQUES

27 October 1949

MR. HENKEL: General Holman, gentlemen: Today, one of the biggest problems in logistics facing the military establishment is the matter of developing more speed in the determination of material requirements. As you know, once the Joint Chiefs of Staff sets up a plan, the time required to determine the total requirements ranges from one to two years, sometimes longer. This period of time is much too long. The different departments of our defense establishment recognize this fact and are making studies to show how improvements can be made. Various types of computing machines and mathematical techniques are under consideration.

Fortunately, we have a man with us today who has been working on this problem since 1942. He is a recognized authority in this field and is now Assistant Director for Plans and Research, Directorate of Program Standards and Cost Control. Deputy Chief of Staff, Comptroller, Headquarters, United States Air Force. Some of you, no doubt, have heard of Project SCOOP. Our speaker is the guiding genius of that study.

I take pleasure in introducing to you Mr. Marshall Wood.

MR. WOOD: Thank you, Mr. Henkel. General Holman and gentlemen: My subject this morning is "Analogue, Mechanical and Electronic Devices and Mathematical Techniques." I will touch in my talk only briefly on the devices themselves, and will devote myself mainly to the use of these devices in military program planning. I understand that there is to be a seminar later at which the devices themselves will be discussed at greater length by persons much better qualified than I to discuss them.

There are two main types of computing devices--analogue and digital. Analogue devices represent specified variables in terms of continuous physical quantities, such as electrical voltages, distances, fluid flows, etc. They operate on those quantities by means of physical linkages, such as electrical circuits, gear or lever trains, hydraulic systems, etc., and represent answers or results as continuous physical quantities which must be measured with meters of various sorts.

The best known examples are slide rules and differential analyzers. Usually, analogue computers are special-purpose devices designed to simulate particular physical systems, as, for example, guided missile flight simulators; hence, the term "analogue." The slide rule and, to a lesser extent, the differential analyzer are exceptions to this general rule since they are general-purpose devices.

RESTRICTED

Digital computers differ mainly in that they represent variables in terms of numbers; that is to say, discontinuous rather than continuous quantities. They operate on these quantities as discrete numbers or digits and represent answers in numerical form. Generally, digital computers are more accurate and more flexible in their application since there are only a few arithmetic operations and almost any relationship can be represented in terms of numbers.

Because of this generality, however, digital computers may require more preparation for solving any particular problem because of the prerequisite task of translating relationships into numerical form. The best known examples of digital computers are the common desk calculators and punch-card machines. These may be called small-scale digital computers because, in general, they perform single-unit operations, each operation being independent of the preceding and succeeding operation.

The punch-card machines may perform these single-unit arithmetic operations on a mass-production basis, but, in general, do not perform chains of different related operations except through the interposition of a human operator. Some of the newer punch-card machines are partial exceptions to this general rule.

In all complex computing operations, the necessity for interposing a human operator in the middle of the computing process materially slows down the work and greatly increases the probability of error. As the speed of the machines is increased, the proportion of total computing time lost while the machines are waiting for "instructions" from the operator increases rapidly and a point of diminishing returns is soon reached. In order to achieve increased speed, some way had to be found to eliminate this dependence of the computing machine on the operator, at least during the course of the computation. This meant the machine had to perform long chains of different but related operations under automatic control.

In order to perform these long chains of computations the sequence and type of operation to be performed must be completely determined in advance by the operator and must be furnished to the machine as instructions for the computation. Such instructions normally consist of numerical codes representing the basic types of arithmetic operation, placed usually on a punched paper tape, or magnetized tape or wire, which is fed into the machine automatically as the computation progresses. This sequence control is the outstanding feature of all large-scale digital computers.

In all large-scale computing operations, the subsequent steps in computation must use partial results produced at an earlier stage of the computation. In most such operations the types and sequence as well as the numerical values of the later states of the computation are also dependent upon partial results produced at an earlier stage. These partial results correspond to the numbers which one puts down on a piece of scratch paper for later use when one is computing a problem using a common desk calculator.

RESTRICTED

RESTRICTED

In order to save such partial results for later use, the machines had to be provided with some kind of storage system--sometimes called "memory"--in which the partial results can be stored until they are needed. This memory is the second major feature of all large-scale digital computing machines. In most machines this same type of storage, or memory, is used to store instructions as well as partial results. I won't go into the design and performance characteristics of these machines as I think that will be better covered in the seminar later. Chart 1, page 25, will give you a brief indication of the number and the wide variety of computing machines which are being produced by various agencies at the present time.

There are six machines being produced by the Eckert-Mauchly Computer Corporation of Philadelphia, called UNIVACs these are for the Army Map Service; the Air Force Comptroller; the Bureau of the Census; the Air Materiel Command (Watson Laboratories); the Prudential Life Insurance Co.; and the A. C. Neilson Co., a market-research firm.

Raytheon is producing two machines for guided missile data reduction work, one for Point Magu and one for Holloman AFB; and a third for the Office of Naval Research for general-purpose use at the National Applied Mathematics Laboratories of the National Bureau of Standards.

One machine is being produced by the Massachusetts Institute of Technology for the Navy.

The Institute for Advanced Study at Princeton has designed and is building a machine. Copies of this same machine are being produced by several different people: one at Los Alamos; one at Aberdeen; two at the Argonne Laboratories; one at the Naval Research Laboratory; and two by university groups.

Engineering Research Associates at St. Paul are producing a machine for Naval Communications.

The National Bureau of Standards is constructing two machines: one in Washington for the use of the Air Force Comptroller and one at the Institute of Numerical Analysis at Los Angeles for the use of the Air Materiel Command. It has also produced a design for a machine for the Army Security Agency, which the Army Security Agency will construct itself.

General Electric is producing a machine for its own use and is considering building another for the Air Materiel Command.

The Computation Laboratory at Harvard has just completed a machine for the Navy's Bureau of Ordnance, and is building another one for the Air Materiel Command.

RESTRICTED

The University of Pennsylvania is producing a machine for Army Ordnance, one for Signal Corps, and one for its own use.

The University of California is producing one for the Navy and one number-theory machine.

There are also a number of non-government supported projects; International Business Machines, Burroughs Calculating Company, Remington-Rand, Barber-Colman, Bell Laboratories are all working on machines.

Most of these machines which have been built, or are being built, are designed to perform engineering calculations in which the volume of basic data and the result are very small in relation to the amount of computation. As a result, most of the machines are not well adapted to logistic computations in which the volume of basic data and final results are quite large in relation to the amount of computation.

The outstanding exception to this is the UNIVAC machine being built by the Eckert-Mauchly Computer Corporation in Philadelphia, which is expected to be able to read 12-digit numbers or instructions from a magnetized tape at a rate of nearly a thousand per second, and to record answers on magnetized tape at about the same speed. This machine was designed to handle large volumes of data at high speed in accordance with specifications established by the Bureau of the Census and the Air Force Comptroller's Office, with special reference to statistical and logistic computations. The first machine of this type is expected to be available sometime next year.

All the military departments are currently using keyboard-operated and punch-card machines for logistic computations. None is presently using large-scale machines for logistic computation. The major reason for this, I believe, is that the problems involved in logistic computation have not yet been systematized and formalized sufficiently to permit effective use of large-scale computing machinery. A second reason is that there are only two or three large-scale, computing machines yet in operation.

Let me turn, then, to the formulation of the logistic planning problem. I will start with the basic problem of military program planning because that is where the logistic planning begins. A large part of the difficulty in solving logistic computations springs directly from the fact that the programs which the logistic computation are designed to support are seldom completely formulated.

Program planning may be defined as the construction of a schedule of actions to accomplish stated objectives, together with a schedule of the resources necessary to accomplish these actions. If the program is to be operationally feasible, the actions specified in such a program

must support one another, and the resources requirements must be consistent with all known external resource limitations.

Obviously, the first step in the preparation of any program is to define the objectives which the program is designed to achieve. The objective of the peacetime military establishment is conceived to be primarily the creation of conditions favorable to our winning a war if war should occur. If our potential enemy's intelligence is good, we may reasonably hope that the creation of conditions favorable to our winning a war, if it should occur, will also be effective in reducing the probability that war will occur. Only a small proportion of our establishment is engaged in activities such as policing of occupied territories, for which there is a direct peacetime requirement.

The simplest method of computing quantitatively the requirements for accomplishing these objectives is to construct a war plan showing the actions which we believe essential to ensure victory in a future war. To be usable for this purpose a war plan must define quantitatively, either explicity or implicitly, the major wartime tasks in terms of forces deployed, rates of operation, and rates of attrition and replacement, so that we may derive from it the required levels of support activities, that is, training, supply, maintenance, procurement, transportation, etc.

Since virtually all peacetime or pre-M-day actions are limited by budgets, and since the budgetary process takes about two years, this means that the assumed M-day of a war plan to be used for this purpose must be from three to four years in the future in order to allow for the budgetary process and for the subsequent accomplishment of the actions to attain the required M-day position. Such a plan is called an Intermediate Range War Plan. This is illustrated schematically on Chart 2, page 26, which shows the relationship of war plans and current programs.

Given an Intermediate Range War Plan it is possible to determine in some detail the complete schedule of actions which must be performed after M-day to accomplish the war plan. That is, we may determine from the plan, which states only the combat operations to be performed, the schedule of induction, training, construction, procurement, supply, maintenance, distribution, and other supporting activities which must be performed to back up the combat operations.

The Emergency War Plan is theoretically based on current capabilities. This war plan stems from the present condition of the various components of the program. The Intermediate Range War Plan provides the objectives toward which we are scheduling major components of the peacetime program, with the partial exception of research and development and construction, which should be related to a long-range, war plan with a longer interval involved because of the longer lead time in accomplishing the action.

Given the Intermediate Range War Plan we can back this up to a statement of the M-day position, which then becomes the objective of our peacetime programming in all major areas. This statement of the required M-day position provides the bridge between the war plan and the mobilization program on the one hand and the peacetime program on the other. It states, in terms of inventory and production or training rates for the equipment, personnel, and other items used by the military establishment, the status which must be attained in peacetime in order to provide the capability of carrying out the war plan.

Having defined this required M-day position we may then determine the action necessary to proceed from our present status to the required M-day position. This, then, is the peacetime operating program. Annual segments of this program for the three- or four-year span between the present status and the assumed M-day are, or should be, the primary basis for developing the budget for any fiscal year within the span.

In the construction of this peacetime program to attain the M-day position, it frequently appears that it is not possible to program the attainment of the required M-day position as defined by the war plan and the derived mobilization program, within budgetary and personnel ceilings and other limitations.

We are then faced with choosing among four logical alternatives. First, we may attempt to raise or remove the limitations of budget or other resource; secondly, we may review our planning factors and attempt to develop new methods of operation which will permit accomplishment of our objective with reduced amounts of funds, personnel, or other limited items; or failing these, we must either, thirdly, revise the war-plan objectives; or fourthly, defer the time by which we seek to attain the required M-day status.

Under present program planning procedures, the programming of any of these four alternatives would require a great deal of time, so that in practice it has seldom been possible to adopt any of them. The result has been that operating programs and budgets have been developed largely independent of strategic guidance. Such strategic guidance as was available led to requirements that could not be met, and it was not possible to revise war plans and mobilization programs so as to provide effective guidance at a level consistent with peacetime budget limitations.

Under present procedures the complete process of developing a war plan, translating it into a mobilization program and a required M-day status, and translating this, in turn, into a peacetime program and budget takes well over two years. Under these conditions it is obviously impractical to repeat this process as a basis for revising the detailed composition of the budget estimates, when the over-all budget estimates resulting from the original war plan are cut. Yet, unless these steps

are performed somehow we can have no assurance that we are accomplishing our basic objectives to the maximum extent possible within our means. Clearly some method of reducing the time required for these operations is needed.

Early in 1947 the Air Force undertook a concerted attack on this problem, establishing the Planning Research Division in the Comptroller's Office, under the Director of Program Standards and Cost Control. The work of this division, now designated as Project SCOOP, a short title for "Scientific Computation of Optimum Programs," was devoted to four main problem areas:

> First, the systematic and comprehensive identification and quantitative evaluation of interrelationships among Air Force activities, objectives, and limitations, usually expressed in the form of planning factors.
>
> Second, the development of a system of equations or "mathematical model" of operations, expressing these relationships explicitly in mathematical form.
>
> Third, the development of mathematical computing techniques for the solution of these systems of equations so as to construct a program which will accomplish our objectives to funds, industrial capacity, etc.
>
> And, fourth, the development and construction of high-speed electronic computing machines adequate to perform in a few days the computations required for the solution of the equations for a complete Air Force program.

In the first problem area, the definition and quantitative evaluation of interrelationships, a great deal has been accomplished. Many of these relationships are, of course, contained in published documents, such as Tables of Organization and Equipment, Tables of Distribution, Tables of Allowances, Replacement Factor Bulletins, etc.

Some of this information is of questionable accuracy. A large proportion of the missing data has been developed by the Planning Research Division over the last two years. Outstanding examples of this work are contained in Air Force letter 150-10 in the field of peacetime factors, and registered document WPF-48 in the field of wartime planning factors. Many more factors have been developed and published in a series of Standards Evaluation Branch studies. Many others which have been developed are, as yet, unpublished.

The central problem in all this factor work is to devise a satisfactory method of aggregation. Even with an electronic computer, we cannot hope to deal individually with millions of items; yet we must consider all the items which are, or may become, limiting factors. We need not consider them individually if we can construct aggregates of items, such that the over-all characteristics of the aggregate can be meaningfully described in relation to the program as a whole. And we must, of course, provide means for translating every such aggregate into item detail when we are ready to develop detailed operating programs,

An outstanding example of an aggregation problem is the computation of budget estimates for procurement and overhaul of supplies and equipment. Formerly, this work required about six months of detailed computation after the over-all Air Force program was determined. Prior to this another three to six months were required for preparing the over-all operating program. Thus, nearly a year elapsed after basic program decisions were made before we knew their implications in this major field. I think there is a similar time lag in the other services. This, in effect, has precluded any precise consideration of supply and maintenance limitations and capabilities in the preparation of Air Force programs, since limitations of other factors which could be more readily computed, such as aircraft and personnel, forced program changes at more frequent intervals. This also resulted in a supply and maintenance program which was always out of phase with the rest of the Air Force program.

As one phase of Project SCOOP, the Planning Research Division recently developed a new procedure which has been successfully employed by the Air Materiel Command in overcoming these difficulties. Fundamentally this was simply a technique of aggregation based on relating the requirement for every item to that particular characteristic of the program which generates the requirement. Although there are hundreds of thousands of items, there are found to be only a little over a hundred major characteristics of the Air Force program, or "program elements," which generate the requirements for supply items.

We, therefore, do not lose any information in computing requirements if we group the items into aggregates corresponding to the program element to which their consumption is related. You might call these packages of items. This procedure is somewhat similar to procedures which have been proposed and used before, which involved computing costs per flying hour, per man-year, etc. Although this type of aggregation results in no loss of information on requirements, it does create certain problems on the resources side if stock levels of the various items comprising an aggregate are unbalanced, in the sense that the inventories of the different items within an aggregate will support widely differing sizes of programs.

However, if we are able to relate each item to one and only one program characteristic, or "Program element," we may overcome this difficulty by expressing the cost per flying hour or per man-year as a variable function of the size of the program instead of assuming it constant, as is usually done. This is illustrated on Chart 3, page Thus we have an increasing cost per unit of program element as the inventories of the various items comprising the aggregate are exhausted. The inventory of each item is expressed in terms of the program level or amount of program which can be sustained entirely from inventory. This value is called the "normalized inventory." Procurement for any item will then be required if the program to be supported is larger than the normalized inventory of the item.

On Chart 3, we have a schematic representation of the procurement requirements for three items which are related to the number of F-80 flying hours in the program. On item A we have inventory sufficient to sustain 2,000 F-80 flying hours. For a program of less than 2,000 flying hours, therefore, no procurement is required. On item B we have inventory sufficient to sustain a program of 3,000 flying hours. No procurement is then required on item B unless the program is more than 3,000 flying hours. Similarly, on item C no procurement is required unless the program is greater than 4,000 flying hours because the inventory of the item is sufficient to sustain that much program without procurement.

If we list these items in order from the smallest to the largest normalized inventory, the procurement requirement for item A will be a straight line. The slope in the line is the consumption rate per flying hour. Similarly with the other items.

We then get a composite curve represented by the upper line, which is the total requirement in dollars for procurement of all items related to F-80 flying hours. If there had been no inventories, the procurement requirement would have been a straight line parallel to the uppermost line. Chart 4 will illustrate what this curve looks like after it is actually computed for a group of items. Usually, there will be thousands of items related to each program element.

On Chart 4, page 28, these are actual data taken from the machine computations used in computing fiscal 1951 budget estimates. I have not identified the aircraft model on this chart. We computed three curves, based on three different assumptions as to stock level and lead time. If we take a normal assumption of a 7-month stock level and a 6-month lead time, the procurement requirement for all items related to this model will be represented by the upper line. All this computation, as you see, may be done before we have any information regarding the size of the program under consideration. Incidentally, this computation was done in a couple of months, with about 45 people, as compared with about six months

and over 500 people under preceding manual methods. Moreover, this computation was done entirely before the program was determined, whereas the other computation was done entirely after the program was determined, So that we not only get a substantial saving in man-hours but we also get a saving of about six months in elapsed time in getting answers.

When we determine the program here, at any level, expressed in terms of flying hours, we have only to read off the curve to determine the dollar value of the procurement required. If funds are arbitrarily cut, or are cut for any reason, we then can determine immediately the effect of that cut on the program.

We have a choice which we may make as a policy decision if we wish. Supposing we had a requirement on that program of 300,000 flying hours. We see then that we would require 4.6 million dollars to support that program. If funds were arbitrarily cut, say, to three million, we then see that if we maintain our policy of a 7-month stock level and a 6-month lead time, we can support a program of only 240,000 flying hours. On the other hand, if we are willing to take a calculated risk and accept a certain reduction in our stock level and lead time policy (which is what the Services, I think, commonly have done without recognizing it under such circumstances), we might then support a program here of 270,000 flying hours if we wipe out the lead time altogether and retain the 2-month stock level. We could support the original program of 300,000 flying hours if we were willing to reduce our allowance for stock level and lead time combined to a total of four months.

There are about 25 of these curves required to cover the entire Air Force supply program, exclusive of a few thousand items on which individual computations are required.

Thus we are able to determine in a matter of a few minutes exactly what the impact of any budget cut is and make decisions as to the program which we wish to support and the policy that goes with it. These policy decisions, on stock level and lead time also provide guidance to the operating personnel in Procurement in determining in detail how to cut the original budget estimate item by item.

Mechanical procedures have also been devised for computing rapidly the item by item requirements for procurement. These have been combined in a book known as "The Buyer's Guide." These item by item computations are based on the policy decisions as to stock level and lead time which are derived in the manner just discussed. This procedure also results in a very definite saving in personnel, a reduction in time, and an increase in accuracy and in top-management control, since reconciliation of requirements and resources is made in terms of broad decisions by top management on stock level and lead time instead of by clerical personnel in the property class sections.

RESTRICTED

Similar aggregation techniques have been applied to other items, such as military personnel, where we have been able to reduce the 700-odd military occupational specialties to about 150 family groups for the purpose of over-all programming. Here the criterion was the amount and kind of training required to produce the various skills, coupled with some consideration of association and interchangeability of skills in use.

We have been discussing techniques of aggregation used in the development of factors expressing interrelationships, the first major problem area. The second major problem area is the construction of a mathematical model of operations expressing all these interrelations between Air Force activities. These interrelationships arise from the sharing between two or more activities of limited amounts of an item, or group of items, such as personnel, equipment, supplies, or funds; from the production by one activity of an item, such as trained personnel or serviceable equipment, which is used by another; or by the production of two or more activities of an item which is used by still another activity. These interrelationships must all be evaluated numerically before a mathematical model can be constructed. The systematic and comprehensive evaluation of these factors is perhaps not the most difficult but is certainly the most laborious and the most time-consuming part of the entire operation.

The mathematical model of operations stands in the same relationship to a program as an airplane model or a link trainer does to an airplane. It permits assessing the effects of external forces upon the mechanism; it permits training operators to run the mechanism, through giving them practice in assessing the results of varying manipulations of the controls. It represents relationships in the form of equations rather than through mechanical simulation, although consideration has been given to the construction of a physical model in the form of an electrical analogue computer. We have decided on mathematical models and digital computers for this work because they seemed to provide greater flexibility and capacity for a given cost.

Similarly, airplane and missile designers have been turning increasingly to mathematical models for use with digital computers as being cheaper, more flexible, and of greater capacity than wind-tunnel models.

The mathematical model consists of a large system of simultaneous equations in which the variables are the quantity of the activities to be performed (and accordingly must be non-negative), the coefficients are the requirements of a unit quantity of each activity for each item, and each equation expresses the sum of the requirement of all activities for a single item. There is a set of these equations for each time period in the program under consideration which balances the inventory or status at the beginning of the time period with the consumption or production during the time period and the status at the end of the time period.

RESTRICTED

On Chart 5, page 29, is a sample model of the Berlin airlift. It is grossly oversimplified, as you will see. It may serve, however, to illustrate the equations and interrelationships. The airlift flying operation itself produces supplies in Berlin. It requires crews, aircraft, and runways for its operation. It consumes funds for gasoline and for pay of personnel. It also uses up part of the aircraft as a result of crashes and normal wear and tear.

These facts are represented by two coefficients for each item. These coefficients completely define the activity. We call these coefficients "input coefficients" and "output coefficient." The input coefficients define the amounts of each item required at the beginning of a unit time period or consumed during the time period to permit unit quantity operation of the activity. The output coefficients define the amounts of each item left over at the end of a unit time period as a result of unit quantity operation of the activity.

The input coefficient is obtained as the sum of the capital equipment, the attrition, and the consumption, all of which must be on hand at the beginning of the time period. The output coefficient is the sum of the capital equipment and the production per unit of the activity, all of which are available at the end of this time period.

The capital equipment comprises such items as real estate, aircraft, and operating personnel which are used in carrying out the activity but which remain essentially unchanged at the end of the operation.

Chart 6, page 30, illustrates the derivation of these coefficients. The coefficient for the 95,000 tons of supplies delivered in Berlin is put into the consumption column and given a minus sign because under the rule which I just described, the output is considered to be one time unit later than input, whereas the delivery of supplies by air is a continuous process involving a negligible time lag. This time lag is the essential distinction between output and input coefficients.

Chart 7, page 31, gives the input and output coefficient for each activity within the group of activities supporting the airlift operation. The equations which you see at the bottom of the chart comprise the mathematical model of the airlift operation.

Now, what we have here is a series of activities comprising the airlift operation and the supporting activities. One activity is actually supplying Berlin. The second activity is the actual flying operation. The third one is the constructing of runways. The fourth activity, an arbitrary activity, which is put in to balance the equations, is merely wasting runway capacity in the event we have more runways than we need; the other activities cover the use of the crews in the airlift activity, and the training of crews for the activity. For each of these we have

a set of input and output coefficients and the equations at the bottom define the relationships between these activities, and comprise the mathematical model. We will get into that in detail in the seminar, later on.

Mathematical procedures for the solution of systems of this sort have been developed but they involve many millions of multiplications to solve even a relatively small program problem. We are procuring several large-scale digital electronic computers which will have computing capacity to solve this type of problem.

Development and construction of these machines are being handled for the Air Force by the National Bureau of Standards, which is handling computer development for a number of government agencies.

We have two machines presently under construction: one being built in the laboratories of the National Bureau of Standards, the so-called Interim Computer, which we expect to have available for our problems in a few months. The second one is the UNIVAC, which I mentioned earlier in my talk. A third one, called the Superspeed Systematic Computer, will be undertaken sometime this year. It is designed to perform computations at the rate of about 10,000 per second, and will have input and output equipment capable of feeding information in and out at approximately the same speed.

We also have under development--actually underconstruction, I guess, at the moment--a high-speed printer to print out answers. This will be capable of printing out about 100 lines of information per second directly on film, using a television tube.

Pending availability of the large-scale digital electronic computers, we have tried to find ways of improving our programming procedure with presently available equipment. Computational procedures have been developed and tested utilizing the presently available punch-card equipment which makes possible the computation of a complete mobilization program and the determination of the required M-day position in a few days, starting directly from a war plan. We expect to put this technique into practical use by the end of this year.

This interim procedure for program computing, which does not give us optimum programs but does give us a consistent program designed to support a specified war plan, is based on a systematization of the long-used staff procedure. This is an essential first step in the development of a procedure for computing optimum programs, and the model set up for this purpose is fundamentally similar to the one we will use for the computation of optimum programs when we have the computing capacity.

In this interim procedure we have arranged the work in a series of stages. The first step is to compute the item requirements of the activities specified in the war plan; that is to say, the combat activities.

The second step is to comput the item requirements of the supporting activities, such as combat-crew training, whose output is utilized only by the specified combat activities. The third step is to compute the requirements of those supporting activities whose output is utilized only by the specified activities and by those activities whose levels were computed in the second step, and so on. The result is a straightforward computing procedure which is readily adaptable to machine computation. We have already computed several small mobilization plans using this procedure and have come out with answers which would have taken perhaps some six months to compute under normal staff planning procedures.

This procedure is adapted generally to use in the feasibility testing of war plans. The feasibility testing of a war plan in the strict sense, however, is possible only if the M-day position is completely defined, as in the case of a short-range or emergency war plan, where the M-day position is assumed to be the actual position as of the date the plan is prepared, or within a very short period thereafter.

With peacetime program planning, as we saw from the earlier chart, we are concerned with the use of Intermediate Range War plans to provide a statement of peacetime program objectives to determine the action necessary in peacetime to ensure the feasibility of the war plan.

This determination is made in two stages: First, the determination of the wartime mobilization program and the M-day position which must be attained in peacetime in order to make the war plan feasible; and, secondly, the action necessary in peacetime to attain the required M-day position from the present status. This M-day position is defined in terms of the inventory of the various items on hand on M-day and the production rates of the various production activities on M-day.

Again I use the word "item" broadly, to include supplies, equipment, installations, personnel, or organizations. The quantity of an item on hand in initial inventory at any date includes quantities in use, in the pipe line, in stock, held in storage, or as a war reserve. The quantity on hand on M-day is the quantity on hand at present less depreciation, obsolescence, or attrition, plus the quantity produced between now and M-day from current production. Since the present quantity on hand is known, the determination of the quantity to be on hand on M-day thus determines the unknown quantity to be produced between now and M-day, along with the rate of production which must be in effect on M-day.

The quantity of an item needed in inventory on M-day must be at least adequate to meet the requirements of the operation to be undertaken immediately after M-day. If it is possible to operate the factories or training centers producting the item after M-day at a rate equal to the post-M-day consumption requirement, the M-day inventory need only provide the requirements for operations to be undertaken within a time period after M-day equal to the production pipe line of the producing activity.

RESTRICTED

In most types of production activities, however, as you will see in the Chart 8, whether it is pilot training, aircraft production, gasoline refining, or what have you, there appear to be inherent limitations on the maximum rates of expansion which can be attained. Analysis of World War II experience, together with industrial planning studies made since the war, has revealed that most industries or activities can expand at approximately a geometric rate from the rate of production in effect on M-day after a time lag of varying lengths.

Chart 8, page 32, shows actual pilot production during the last war, as indicated by the dots, plotted on semilogarithmic paper and compared with the theoretical geometric expansion curve, which would be a straight line. As you see, up to the point where pilot production exceeded requirements, this was a very close approximation to the theoretical geometric expansion rate.

Chart 9, page 33, shows the same picture for aircraft. This, again, is based on actual World War II aircraft production, as compared with the theoretical geometric expansion. The fit is very good, up to the time where the capacity of the industry exceeded our military requirements and production was leveling off.

Chart 10, page 34, shows the same picture for aviation gasoline. Here, again, the fit is very good up to the point where production capacity exceeded requirements and was leveled off.

Thus we might find for the pilot training that after an initial lag of ten months it could double its output every five months. Similarly, the aircraft industry might double its output every eight months, after a lag of perhaps a year. This type of relationship seems to hold equally well for many smaller components, such as the production of landing-gear struts, propellers, engines, etc.

The extent to which post-M-day requirements of an item can be met from current production after M-day depends on the production rate in effect on M-day. For since the maximum cumulative production at any point in time is approximately the sum of a geometric series, therefore, the total cumulative amount which can be produced by any date after M-day is directly proportional to the M-day production rate. This is illustrated in Chart 11, page 35.

The principal problem of peacetime program planning is to schedule peacetime production and training activities so that the quantity of each item on hand on M-day, plus cumulative amounts available from maximum expansion of the production activity, will just meet the post-M-day requirements generated by the war plan up to the point where production capabilities exceed requirements.

RESTRICTED

RESTRICTED

Chart 12, page 36, is a schematic diagram which might apply to any of the items involved. It might be aircraft, or it might be pilots. The origin is the date on which the program is being constructed. At this point we know the actual inventory, which we will call b. We know also the production rate, which we will call a. The initial date of the program being constructed, which is some M-day after that date, will be determined by the war plan.

The cumulative requirements for the item is the lower curve. We seek, then, to find the production rate which must be in effect on M-day and the inventory which must be in effect on M-day in order that the cumulative amount available from production, plus the amount on hand in inventory, will exactly equal requirements up to the point where requirements level off.

If we express these expansion curves, which we looked at a few minutes ago, as a geometric function, starting from a level of unity--"level of unity" means a hundred aircraft per month or a hundred pilots per month, or any other convenient quantity--then the amount available from production after M-day is the curve f (t) multiplied by the constant k, where k is the production rate in effect on M-day. The total cumulative availability after M-day will be the quantity k plus the M-day inventory expressed on Chart 12.

The M-day inventory, however, is merely the present inventory, depreciated over the time period between now and M-day, plus the quantity produced between now and M-day, which is the quantity d. But this quantity d is the cumulative production over this period between now and M-day.

If we are willing to make some assumptions as to a smooth rate of change of production between now and M-day--perhaps a straight line--we may then determine uniquely the M-day inventory and production rate.

Thus, given this basic relationship between the M-day production and the post-M-day production availability, we can determine that particular combination of war reserve and production rate on M-day which will meet the requirements of any given plan at a minimum cost. This is a simple mathematical problem which can readily be solved by the computer.

In some areas, principally training, the limiting production rates which so largely govern our wartime capacity are within the military establishment and, therefore, under our direct control. In other areas, such as aircraft or engine production, the activity is a part of the civilian economy but indirectly under our control through our procurement programs. In still other areas, such as steel and aluminum production, electric power generation or railroad transportation, the industries concerned are producing primarily for civilian consumption in peacetime and are not even indirectly under our control. Yet we must, somehow,

RESTRICTED

RESTRICTED

make provision for bridging the gap between production capabilities and wartime production requirements, either through industry preparedness measures or through stockpiling, or by revising our plans to reflect these limitations. These activities may impose major restrictions on our program which must be considered in any adequate program computing procedure.

Many of the areas where bottlenecks may occur are in the industries which are not producing directly for military demand, such as railroad transportation and electric power. The indirect effect of military procurement programs on such industries is not commonly appreciated. Chart 13, page 37, gives an illustrative example of this. The chart illustrates the indirect effects throughout the economy as a whole of direct purchases of a billion dollars' worth of motor vehicles. We don't have similar data for tanks or aircraft, but the same kinds of relationships would obtain.

The motor vehicle industry will, as a result of this billion dollars' worth of final output, make direct purchases of some 570 million dollars, distributed as follows: 142 million to ferrous metals; 34 million to steam railroad transportation; 72 million to iron and steel not elsewhere classified; 69 million to rubber; and so on down through a wide list of industries. These industries, however, in turn must make substantial purchases from themselves and from other industries in order to meet this first impact. The second impact which contains the purchases of these industries from other industries as the result of the purchases of the motor vehicle industry, adds up to 271 million dollars. The third impact, which is the impact of these purchases again, is 126 million dollars. The fourth and higher impact is 95 million dollars. Thus, as a result of this original billion dollars' worth of purchases of motor vehicles, there are more than a billion dollars of purchases from other industries reflected throughout the rest of the economy.

In some industries these indirect effects may be much greater than the direct effects. Coal I think is an outstanding example. Here the direct impact, that is to say the first impact, is only four million dollars, the second impact is four times as large, or 16 million dollars; but even the third impact is larger than the first impact; and the fourth one is nearly as large.

When we compute the direct military requirements for a military program, we reflect only a small fraction of the total impact throughout the economy.

To reflect such limitations properly in our planning--and also limitations on manpower which may be even more important if war should commence in a period of full employment--a detailed examination of the interrelationships between industries in the economy of the country is required. These can be formulated into a mathematical model similar to the model we are building for our internal program planning operations.

RESTRICTED

We have attempted to initiate, concurrently with work on the Air Force model, development of a similar mathematical model of the economy of the country to facilitate the rapid evaluation of the industrial feasibility of military programs. Initial work on some of the coefficients for this model is being undertaken by the Bureau of Labor Statistics, under a grant of funds from the National Security Resources Board. The work being done by the Bureau of Labor Statistics is on a model which is essentially a static or equilibrium model without any time dimension.

The Air Force has sponsored research on problems of developing dynamic models of the economy through a contract with Harvard University. As I said before, further work in this area, especially in the field of military and industrial manpower requirements in relation to national manpower resources, has been strongly recommended by the Research and Development Board to the military departments. Primary responsibility for coordinating this research has been allocated to the Air Force, on behalf of the Department of Defense, by the Research and Development Board. An extensive research program in this area is planned for the fiscal year 1950-51.

Obviously, successful utilization of these techniques will require the development of integrated programs by all three military departments, since it would be of little use to evaluate merely the Air Force requirements against total national capabilities. An urgent need exists, therefore, for development by the Departments of the Army and Navy of comparable mathematical models of their operations which can be integrated with those of the Air Force and those of the civilian economy.

Thank you.

MR. HENKEL: Gentlemen, I understand there has been some question about when we will have the next seminar. The next seminar, which will cover the different mathematical techniques, will be held the afternoon of the fourth of November. That is the one to which Mr. Wood made reference.

Who has the first question?

QUESTION: May I ask why you use dollars as your reference parameter? It seems to me that would be a very flighty and changing element. Perhaps man-hours or something else would be better.

MR. WOOD: Well, what we were concerned with was the procurement of supplies and equipment. The dollar is the unit in which we express our equipment when we wish to come out with a budget estimate, or wish to reflect a budget cutback. We have followed that same technique in the area of overhaul of supplies and equipment.

Following that same system we do get out a form similar to the one I illustrated showing direct man-hour requirements for overhaul of supplies and equipment for any particular flying-hour program at any desired stock level.

But when you talk about procurement, you can only express the answer in dollars, I believe.

QUESTION: Yes, but the value of the dollar varies from time to time, depending upon the whim of the Congress. How can you plan ahead?

MR. WOOD: The price levels, of course, are varying continuously. We have to reflect those in re-computations. But if at any given time we have to express our procurement in dollars, that is what we do, based on our best information as to prices.

QUESTION: After seeing the machine at Aberdeen, the thought occurs to me that the capacity of the machine is possibly limited by the personnel who are qualified to operate and repair it and put the data into it. Do you have any trouble getting qualified personnel? How long does it take to train them?

MR. WOOD: We do have trouble in getting personnel. Of course, the machine at Aberdeen is not a fair example. That was the first large-scale electronic computer built. It has some 20,000 vacuum tubes, whereas the machines which are presently being built, which have a much greater capacity than the machine at Aberdeen, are small enough to fit comfortably on the stage here, and use only 2,000 to 5,000 vacuum tubes.

A great deal of improvement has been made in the development of the machines. However, there is always the problem of having qualified people to operate them properly. In addition, there is some problem in connection with electronic engineers for machine maintenance, although that isn't so serious a problem.

QUESTION: With reference to the problem of converting your programs into formulae that the machine can handle, can you give us any dangers or pitfalls as to how the programs are properly interpreted in terms of different formulae? That always has been a problem.

MR. WOOD: Well, the basic problem is getting accurate basic data on the requirements of each basic activity, for personnel, supplies, equipment, and installations--all the things they use.

The formulae which we use are individually very simple. They are simple linear equations. The mathematical model as a whole is complex only because there are a great many such equations with a great many variables. It is a system of simultaneous equations in which we

may have several thousand variables and several thousand equations. But the form of each equation is basically quite simple. It is implied in the construction of Tables of Organization and Equipment, Tables of Allowances, Tables of Distribution, and many other operating documents. We merely say if one unit takes so many people, or so many supplies, then two units will take twice as much.

That is essentially all that is required to set up the linear equations to get a statement as to the consumption rates per man per month, or per item per month, and the attrition rates on the items which you use. There are no complicated relationships involved anywhere except in the case of limitations on rates of expansion and production, and even those have been reduced to relatively simple functions.

QUESTION: Maybe my question wasn't clear. How do you convert a war plan into a simple equation?

MR. WOOD: The war plan is stated in terms of a specification of the levels of combat activities over a period of time. In the first month, say, perhaps we want five heavy-bomber groups operating at a rate of six sorties per unit equipment aircraft per month. The operation is such that we expect to lose approximately 20 percent of our aircraft and 18 percent of our combat crews per month. That is the basic specification of the problem. From there on, the computation is mechanical.

There is a problem, of course--and a serious problem--in translating the conditions of the combat operation into an adequate or correct statement of the attrition and replacement rates. This is probably the most difficult problem of all. It is one on which we have spent a great deal of time, utilizing both our World War II experience and theoretical studies of speeds, turning radii and many other factors of the individual pieces of equipment which we may use.

There is no way around that problem except better information as to the nature of the combat operation. That is a job we have to do anyhow regardless of the method by which we do the rest of the computation.

QUESTION: During the war it took about three months to compute the requirements for three materials--steel, copper, and aluminum. Those were then put on a quarterly basis as the basis for allocation. But by the time you finished up the second quarter, you were in the third one.

I'm wondering whether this electronic computer system and the mathematical techniques which you have been describing will be usable to compute requirements for materials, on the assumption that in another war we might have to have those requirements computed more rapidly?

MR. WOOD: We expect to be able to compute all basic requirements in terms of several thousands, or even tens of thousands, of items, and

for manpower requirements, both military and industrial, by occupational specialty groups, within, say, a few days after the basic operational plan is determined.

There is no great difficulty in doing that except getting the basic data on which to base the computation. In the aircraft field, for example, we have been getting good data from the bills of material which we have been getting from the manufacturers. Ordnance has similar data on some major items. Other agencies working on the inter-industry relationship study will provide similar data for the civilian industries not producing directly for military demand.

QUESTION: It is my understanding that feasibility tests have been so long and so complicated that we never have been able to test the feasibility of any plan completely through to the very last element, including industry and industry's ability to produce.

Now will these machines take care of that situation? Will the computers be able to make a complete feasibility test of a plan that was evolved, say, by the Joint Chiefs of Staff?

MR. WOOD: Assuming that similar techniques are developed by the Army and Navy, or other similar data, as I think no new techniques are involved--assuming the Army and Navy can produce data comparable to that which we now are developing in the Air Force, there should be no difficulty in handling a complete feasibility test in less than a week. I won't say how much less. That would include testing all the basic materials involved, clean down through the complete economy--perhaps thousands of items--as well as the details on manpower by occupational groups.

After all, the end result will be only as good as the basic data which you put into it. But so far as the computation itself is concerned, it is fairly straightforward.

QUESTION: In your mathematical model of the value of each variable, I notice, is the optimum amount of an item that must be provided and is also a part of the input that determines the optimum amount or value that will be solved for the other variables. In many cases, in actually setting up a large-scale operation, due to various conditions, you will have to find the optimum amount.

Command decisions will have to be made as to the amount that the operation can go on. For the commander to make a logical decision he needs to have two parameters, it seems; one is the optimum and the other is the rock-bottom minimum. Having made his decision between those two limits, then, in order to keep the whole thing in balance, it would seem necessary to be able to introduce an arbitrary figure which would represent the increment or the difference between the optimum and the amount decided upon in order to use the correct input in evaluating the other variables.

RESTRICTED

From what you have told us, will your attitude toward the problem accommodate those two conditions?

MR. WOOD: If the commander, or whoever else is making this policy decision, can determine in advance the two things involved, that is, optimum requirements and minimum requirements, and if he is able to supply some quantitative criterion, some quantitative measure of the cost, then we can determine what particular point between those two will give us the minimum over-all cost for the total program or the maximum accomplishment of a stated objective.

The mathematical model does not care whether the quantities are minimum or optimum quantities. It assumes only that the quantities which you put in are fixed. It will compute with either one or the other, or with both, provided you are able to introduce a specific criterion, which could be used for making a selection between the two.

I think the example I gave of the budget estimates for supplies and equipment shows the way in which we have, in that case, computed both optimum and minimum requirements, that is, requirements with the full optimum stock level and lead time and rock-bottom minimum requirements, or rather a little bit below the minimum, with no stock level or lead time.

QUESTION: Are the other services working on formulae? If so, do they concur in the validity of this process to the extent the Air Force believes it is valid?

MR. WOOD: The Munitions Board has set up a Joint Committee on Electronic Computers, whose prime function is to coordinate the development of this technique in the three services.

The Navy Department has set up a Logistics Research Branch in the Mathematics Division of the Office of Naval Research, whose prime function is the development of this technique within the Navy Department. So far there have been relatively few personnel assigned to it and the work is proceeding rather slowly.

They are attempting to get their factors developed, because of personnel limitations and other reasons, on a contract basis, by an outside contractor. That has proved not to be, so far, a very rapid operation. Admiral Carney and the Under Secretary have expressed enthusiastic support of the basic ideas involved.

The Logistics Division of the Army General Staff has so far taken the position that they will wait to see what the Air Force and Navy develop before they do anything actively about it.

RESTRICTED

MR. HENKEL: Mr. Wood, you have certainly given us a clear picture of some of the possibilities of mathematical formulae and digital devices.

On behalf of the Commandant and the Industrial College, I thank you for a very valuable and instructive lecture.

(18 January 1960--650)S.

Chart 1
Government-Sponsored Electronic Computer Construction*

Eckert-Mauchly Computer Corporation (UNIVAC)
- (1) Army Map Service (N.B.S. Monitored)
- (2) USAF Comptroller "
- (3) Census "
- (4) Nepa - A.E.C. "
- (5) USAF AMC (Watson Lab.)
- (6) + (2 non-government machines)

Raytheon
- (1) Point Magu (O.N.R. Monitored)
- (2) Alamagordo "
- (3) Navy "

M.I.T.
- (1) Navy (Whirlwind)

Institute for Advanced Study
- (1) Los Alamos (Design only by I.A.S.)
- (2) Aberdeen "
- (3) Argonne Lab. "
- (4) Navy Research Lab. "
- (5) + (2 non-government machines)

Engineering Research Associates
- (1) Naval Communications

National Bureau of Standards
- (1) Interim (USAF Comptroller Sponsored)
- (2) Zephyr (USAF AMC Sponsored)
- (3) Army Security Agency (Design only by N.B.S.)

General Electric
- (1) USAF AMC
- (2) (+ 1 for G.E.)

Harvard
- (1) Navy Bureau of Ordnance - Mark III
- (2) USAF AMC (Mark IV)

University of Pennsylvania (EDVAC)
- (1) Army Ordnance
- (2) Signal Corps
- (3) (+ 1 for Univ. of Penn.)

University of California - Berkeley
- (1) Navy
- (2) (+ 1 number theory machine)

Non-Government Supported*
- (1) International Business Machines
- (2) Burroughs
- (3) Remington-Rand
- (4) Barber-Colman
- (5) Bell Laboratories

* Items in parenthesis and the last group are non-government projects.

Chart 2

SCHEMATIC RELATIONSHIP OF WAR PLANS AND CURRENT PROGRAM

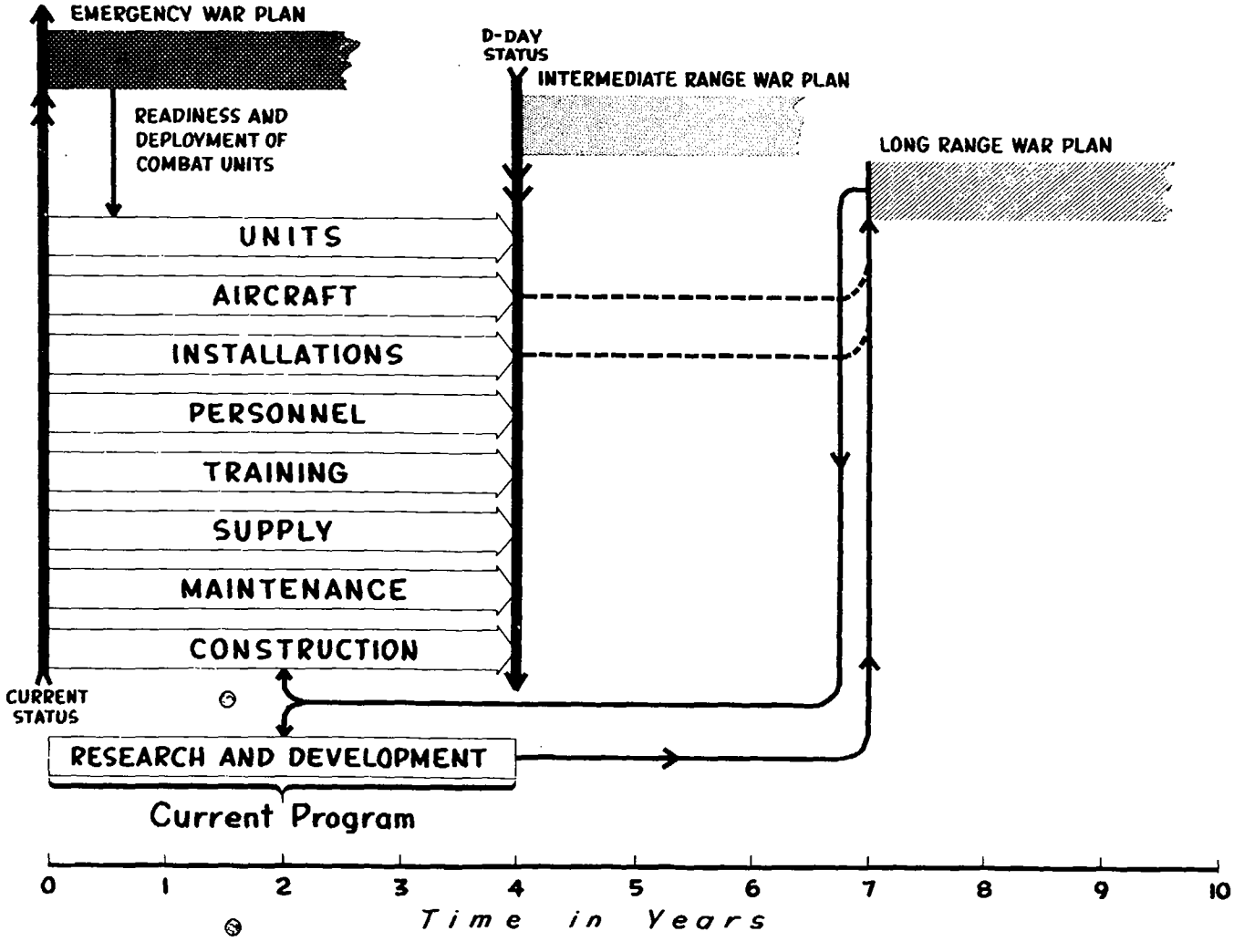


Chart 3

PROCUREMENT REQUIREMENTS FOR NON-REPARABLE ITEMS USED ON F-80 AIRCRAFT.....

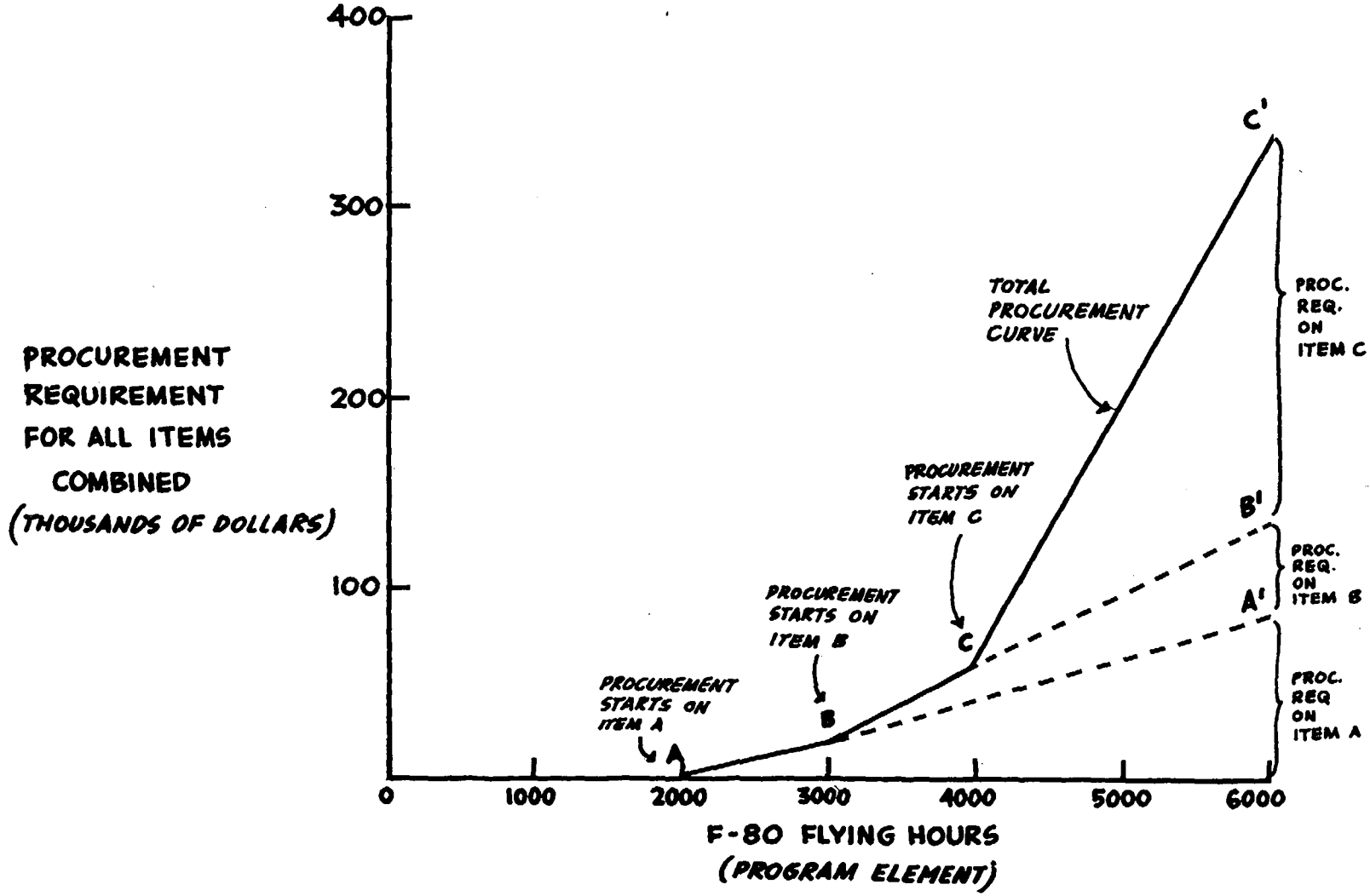


Chart 4

Aircraft Model A
SUPPLIES & EQUIPMENT FOR AIRCRAFT

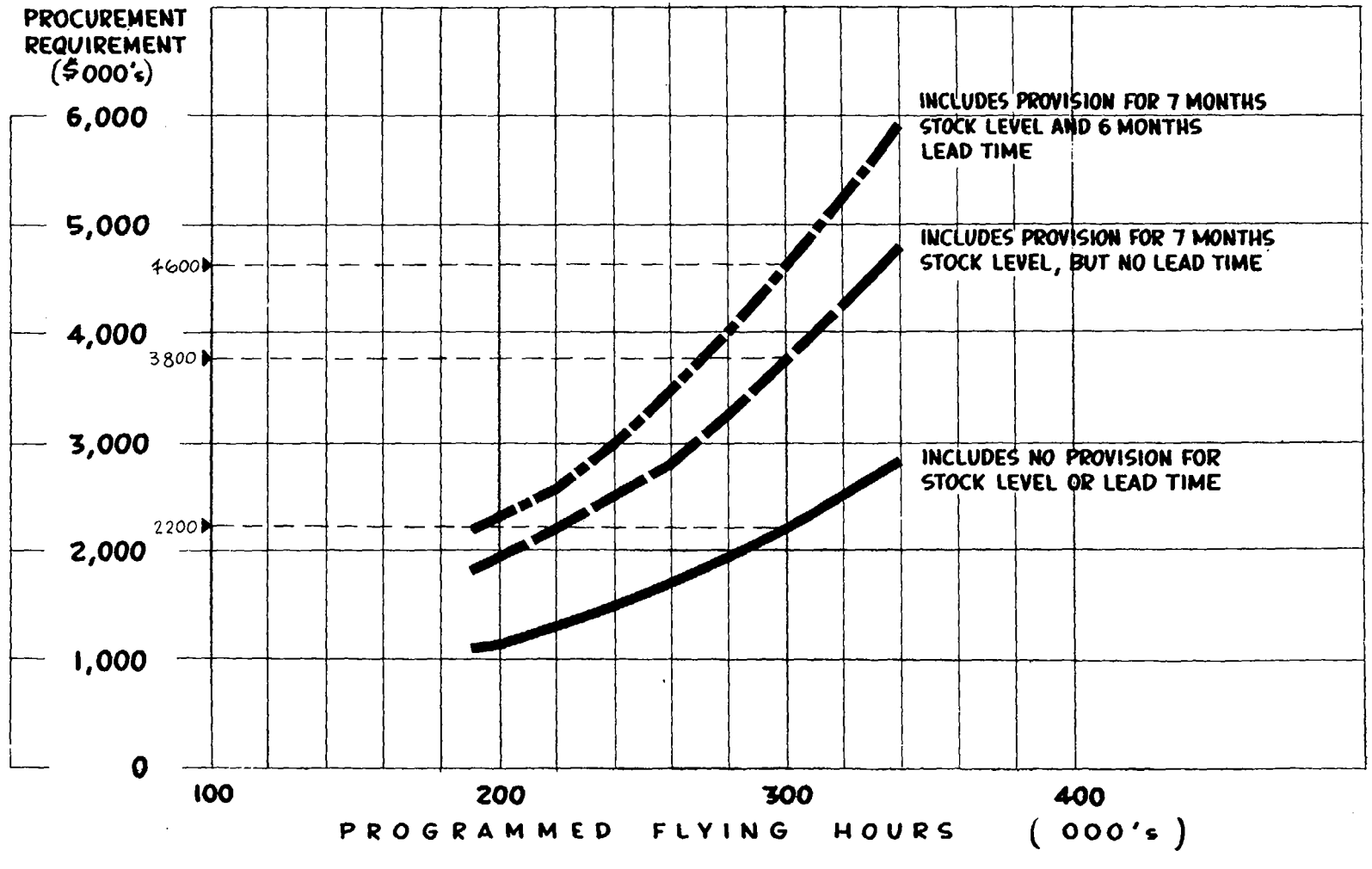


Chart 5

COMPUTATION OF INPUT AND OUTPUT COEFFICIENTS
ACTIVITY II - FLYING THE AIRLIFT
UNIT OF ACTIVITY = 10,000 FLIGHTS
UNIT OF TIME = THREE MONTHS

ITEMS	UNIT OF MEASURE	REQUIRED AT THE BEGINNING OF TIME PERIOD				AVAILABLE AT END OF TIME P		
		Capital Equipment	Attrition	Con-sumption	Total Input Coefficient	Capital Equipment	Production	Total put C ficie
Supplies in Berlin	(Thousands of tons)			-95	-95			
Runways	(Number of runways)	1			1	1		1
Crew Capacity	(Number of crews)			134	134			
Aircraft	(Number of aircraft)	39	5		44	39		39
Money	(Millions of dollars)			8.7	8.7			

DECLASSIFIED

RESTRICTED

Chart 6

HYPOTHETICAL MODEL OF BERLIN AIRLIFT

Flow Coefficients of Basic Activities for 3 Month Period 1/

Item	Unit of Measurement	I Supplying Berlin (per thousand tons) I*	I Supplying Berlin (per thousand tons) O*	II Flying the Airlift (per ten thousand flights) I	II Flying the Airlift (per ten thousand flights) O	III Constructing Runways in Berlin (per runway) I	III Constructing Runways in Berlin (per runway) O	IV Slough-off of Unused Runway Capacity (per runway) I	IV Slough-off of Unused Runway Capacity (per runway) O	V Using Experienced Crews (per hundred crews) I	V Using Experienced Crews (per hundred crews) O	VI Using New Crews (per hundred crews) I	VI Using New Crews (per hundred crews) O	VII Slough-off of Unused Crew Capacity (per hundred crews) I	VII Slough-off of Unused Crew Capacity (per hundred crews) O	VIII Training New Crews (per hundred crews) I	VIII Training New Crews (per hundred crews) O	IX Storing of Unused Aircraft (per aircraft) I	IX Storing of Unused Aircraft (per aircraft) O	X Exogenous Supply (t-1)st period I	X Exogenous Supply (t-1)st period O
1. Supplies in Berlin*	Thousands of Tons	1		-95		2															
2. Runways in Berlin	Number of Runways			1	1		1	1	1												
3. Experienced Crews	Number of Crews									101			100								
4. New Crews	Number of Crews											101				67	1000				$C^{(0)}$
5. Crew Capacity*	Number of Crews			134						-100		-100		1							
6. Aircraft	Number of Aircraft			44	39											47	43	1	1		$A^{(t-1)}$
Money	Millions of Dollars			8.7		1.2								.024		2.9					$B^{(t-1)}$

Symbol for Quantity of Activity during t^{th} Time Period

$X_1^{(t)} \geq 0$ $\quad X_2^{(t)} \geq 0$ $\quad X_3^{(t)} = 0,1,2,$ $\quad X_4^{(t)} \geq$ $\quad X_5^{(t)} \geq 0$ $\quad X_6^{(t)} \geq 0$ $\quad X_7^{(t)} \geq 0$ $\quad X_8^{(t)} \geq 0$ $\quad X_9^{(t)} \geq 0$ $\quad X_{10}^{(t)} \geq 0$

Equations Represented by Above Table

(1) $X_1^{(t)} + 2X_3^{(t)} = 95X_2^{(t)}$

(2) $X_2^{(t)} + X_4^{(t)} = X_2^{(t-1)} + X_3^{(t-1)} + X_4^{(t-1)}$

(3) $101X_5^{(t)} = 100X_6^{(t-1)}$

(4) $101X_6^{(t)} + 67X_8^{(t)} = 1000X_8^{(t-1)} + C^{(0)}\delta_1^t$ $\quad (\delta_1^t = 1$ if $t = 1$, and 0 if $t \neq 1)$

(5) $134X_2^{(t)} + X_7^{(t)} = 100X_5^{(t)} + 100X_6^{(t)}$

(6) $44X_2^{(t)} + 47X_8^{(t)} + X_9^{(t)} = 39X_2^{(t-1)} + 43X_8^{(t-1)} + X_9^{(t-1)} + A^{(t-1)}$

(7) $8.7X_2^{(t)} + 1.2X_3^{(t)} + .024X_7^{(t)} + 2.9X_8^{(t)} = B^{(t-1)}$

*I represents total Input (per unit of activity) at the beginning of period, O represents Output at end of period.
However for starred items it is flow during 3 month period where + sign means flow consumed by the activity and - sign means flow produced by the activity.

1/ The figures shown in chart are illustrative and are not to be used in planning.

RESTRICTED

Chart 7

SCHEMATIC DIAGRAM OF MAJOR STEPS IN AIR FORCE WARTIME PROGRAM SCHEDULING

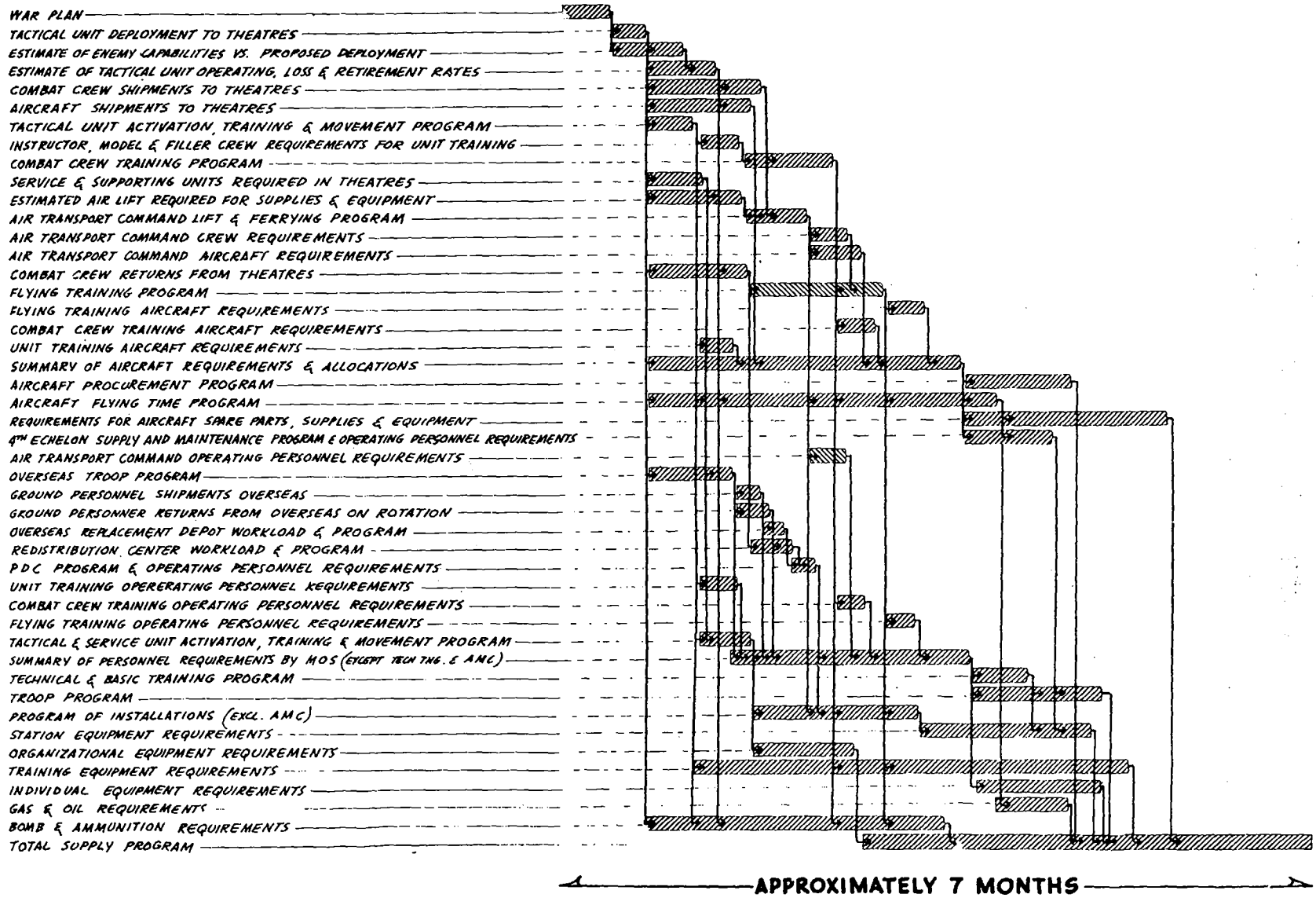
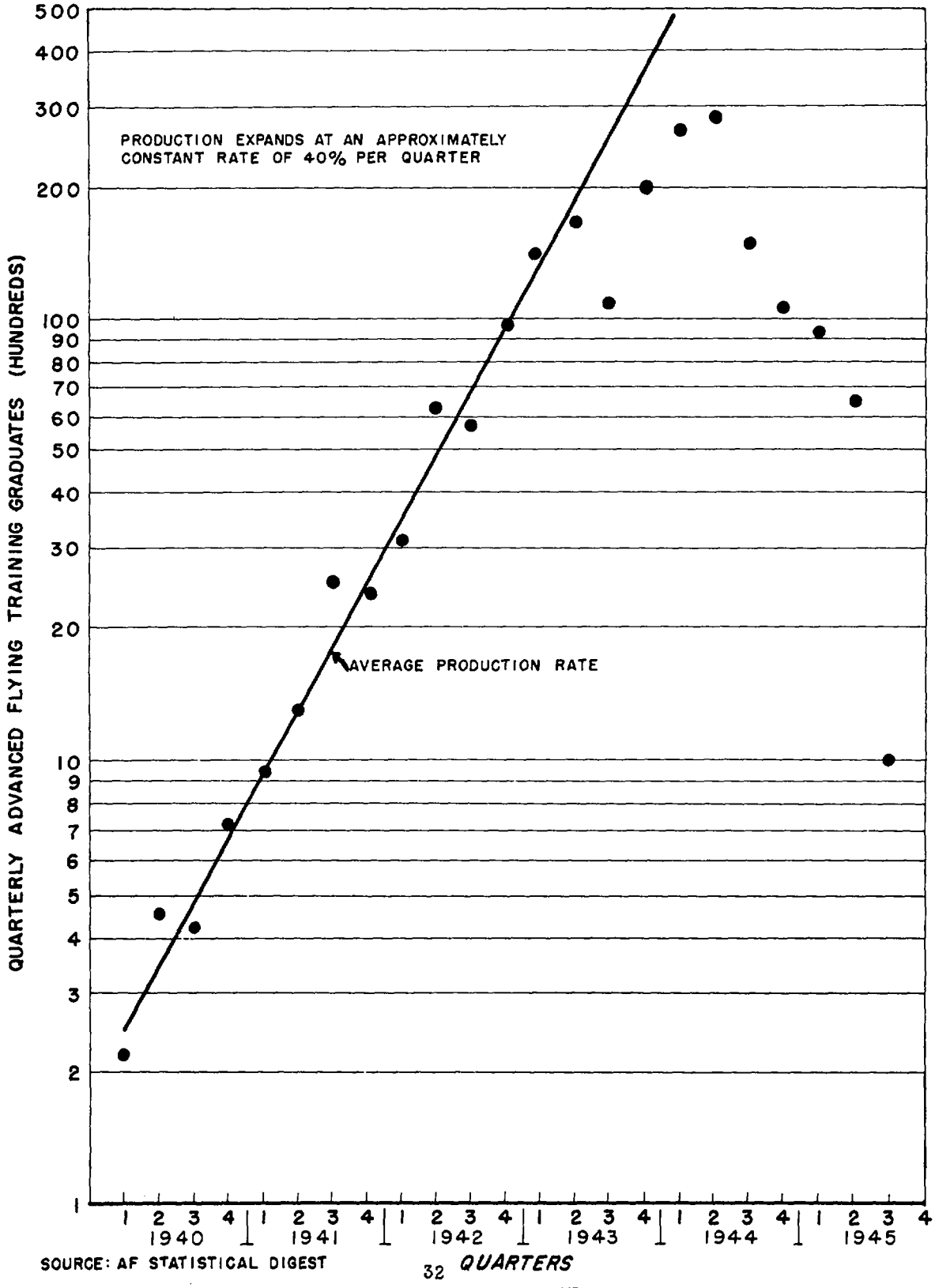


Chart 8

RATE OF PILOT PRODUCTION

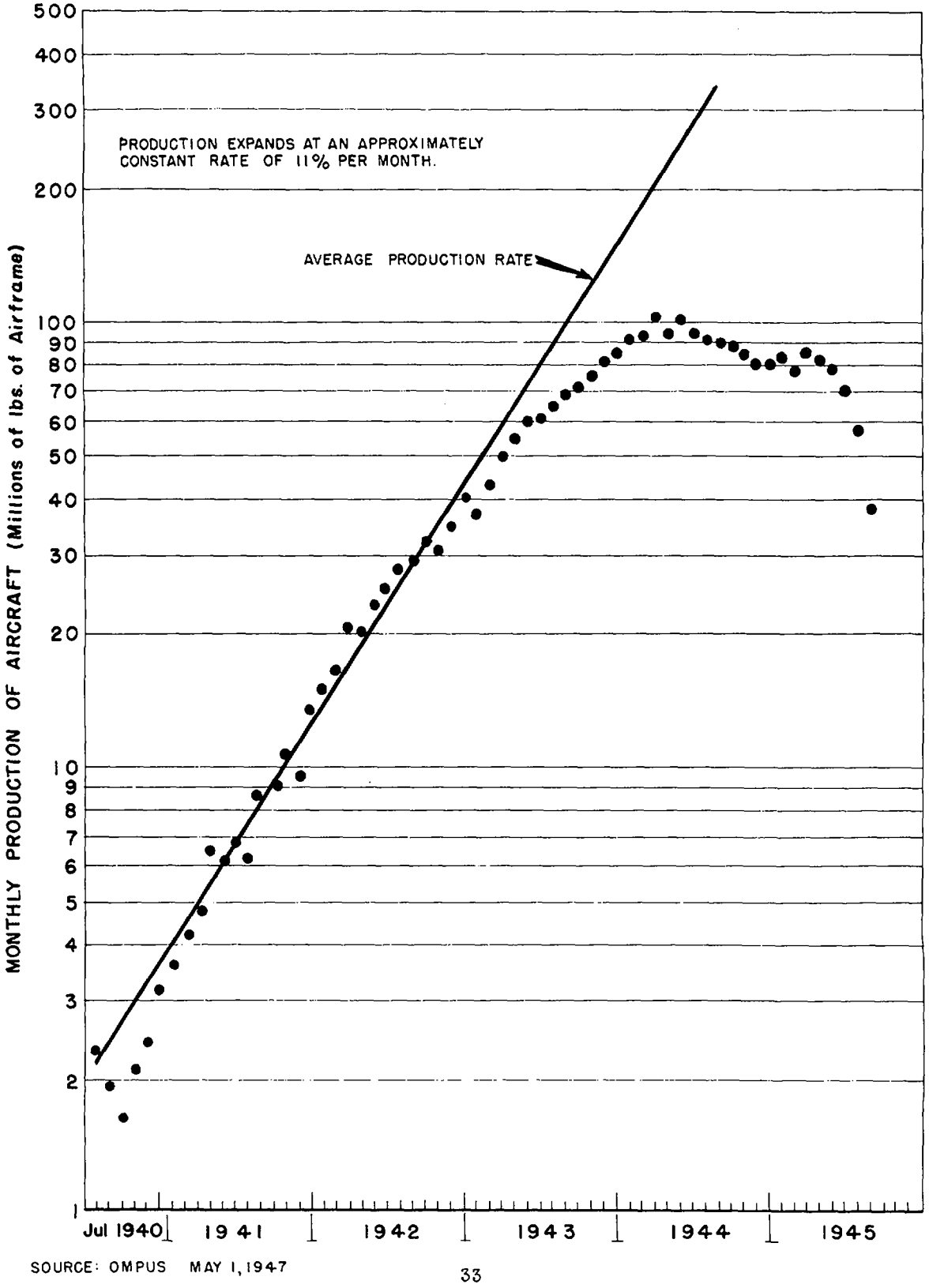
1st Qtr 1940 THRU 3rd Qtr 1945



SOURCE: AF STATISTICAL DIGEST

Chart 9

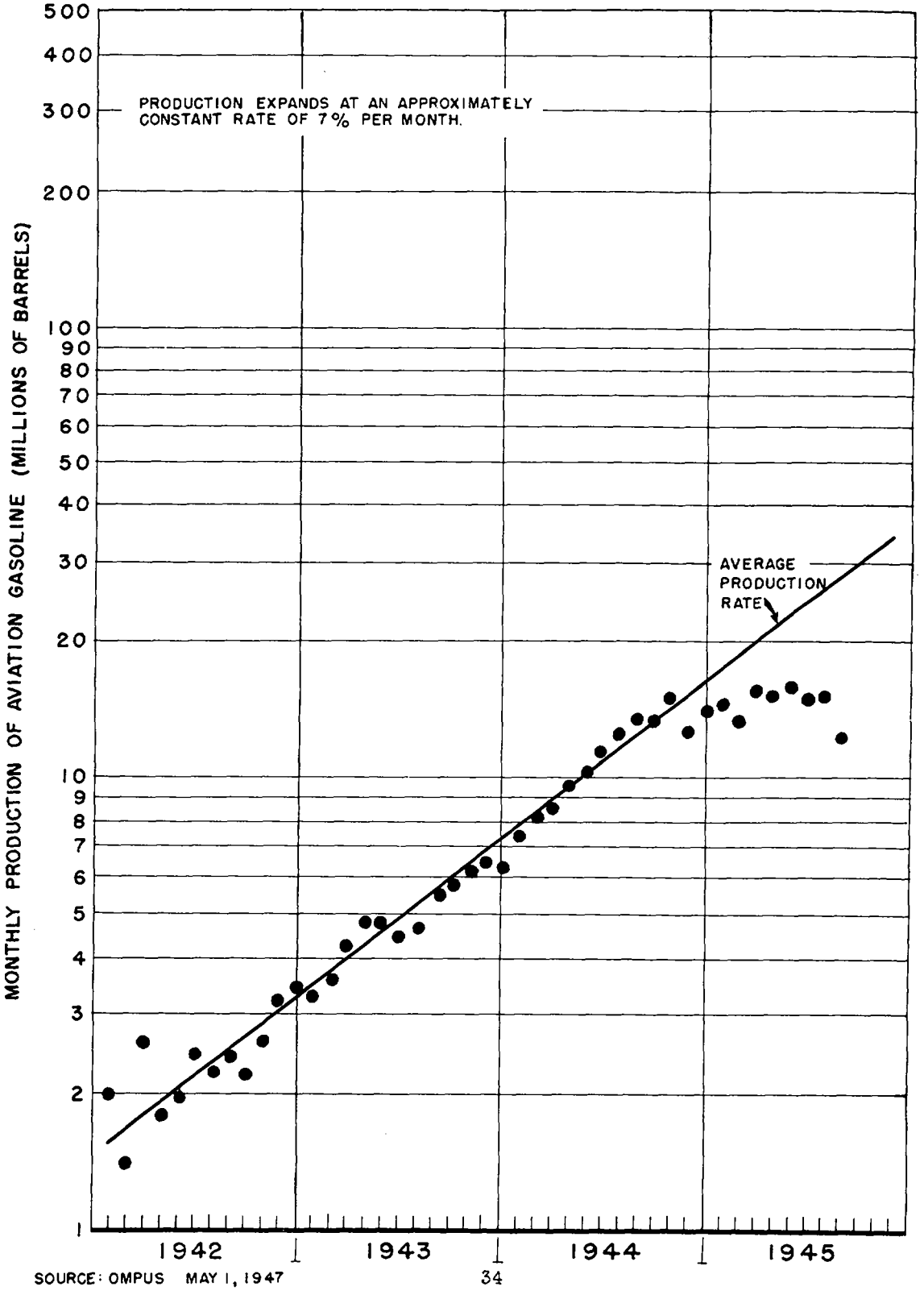
RATE OF AIRCRAFT PRODUCTION



SOURCE: OMPUS MAY 1, 1947

Chart 10

RATE OF AVIATION GASOLINE PRODUCTION

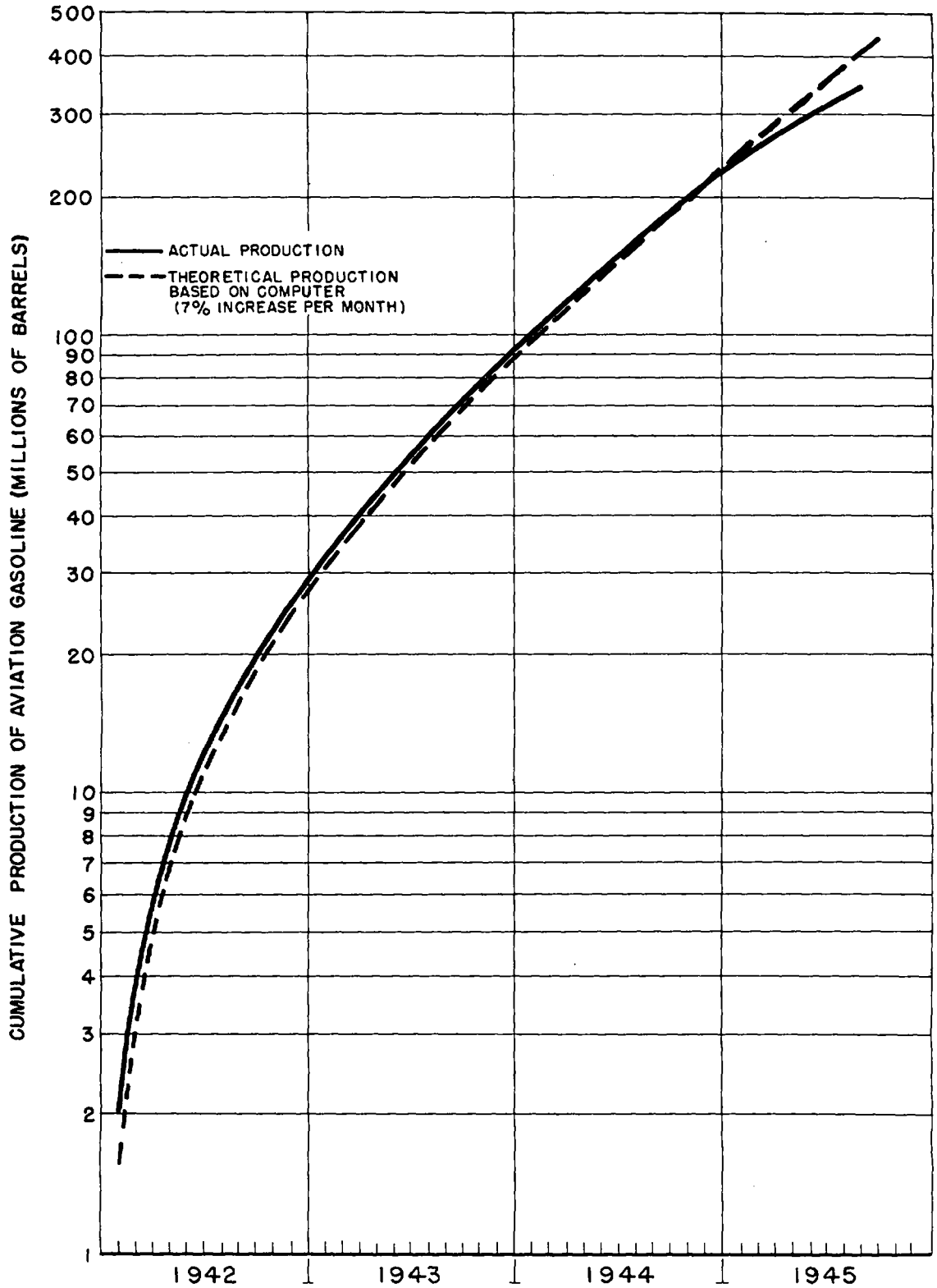


SOURCE: OMPUS MAY 1, 1947

Chart 11

HIGH OCTANE AVIATION GASOLINE PRODUCTION

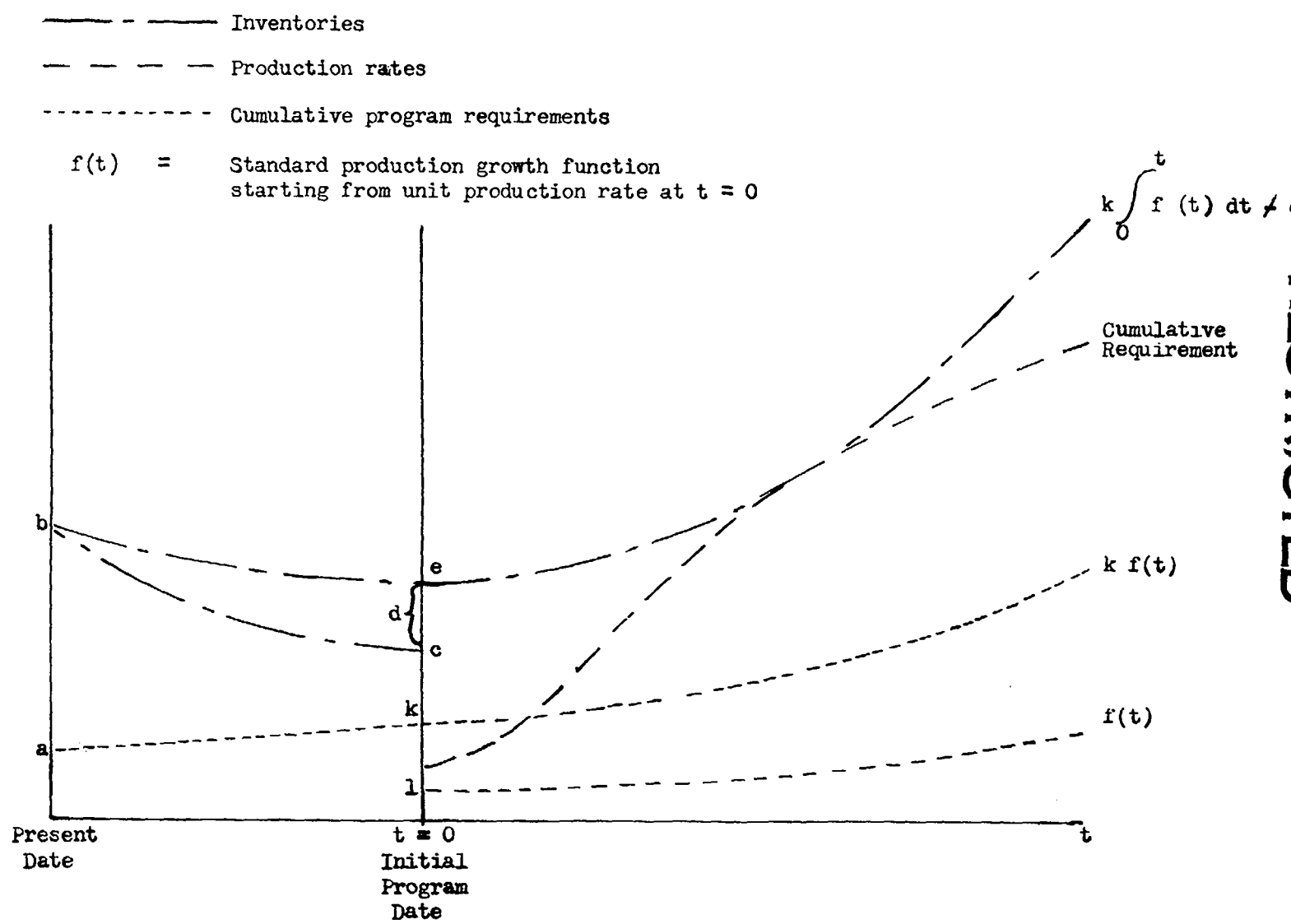
JANUARY, 1942 THRU AUGUST, 1945



SOURCE: OMPUS MAY 1, 1947

Chart 12

Determination of Inventory and Production Rate at Initial Program Date



RESTRICTED

Chart 13

IMPACT OF DEMAND FOR FINAL PRODUCTS

LEVELS OF OUTPUT REQUIRED IN OTHER INDUSTRIES TO PRODUCE
ONE BILLION DOLLARS WORTH OF MOTOR VEHICLES
(MILLIONS OF 1939 DOLLARS)

$1,000,000,000 WORTH OF MOTOR VEHICLES REQUIRED PURCHASES FROM THESE INDUSTRIES:	DIRECT PURCHASES 1st IMPACT	INDIRECT PURCHASES 2nd IMPACT	3rd IMPACT	4th & HIGHER IMPACTS
Ferrous metals	142	26	3	4
Steam railroad transportation	34	24	14	5
Iron and steel, n.e.c.	72	2	3	1
Rubber	69	-	1	1
Iron and steel foundry products	48	1	1	1
Distribution	28	6	11	5
Nonferrous metals and their products	33	10	3	2
Business and personal services	25	7	9	6
Electrical equipment, n.e.c.	31	-	2	1
Textile mill products	24	6	2	1
Coal mining and manufactured solid fuel	4	16	5	3
Petroleum production and refining	6	9	6	4
Manufactured gas and electric power	7	7	7	3
Miscellaneous transportation	-	5	3	3
All other industries	47	152	56	52
TOTAL	570	271	126	95

Data from: Productivity and Technological Development Division,
U. S. Bureau of Labor Statistics

RESTRICTED

50 18880