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The George Washington University

LOGISTICS RESEARCH PROJECT

Contracts Nonr761(05), (06)
Projects NR 047 001, 347 008

OFFICE OF NAVAL RESEARCH

A PLANNING METHOD FOR ALLOCATING AIRLIFT AND SEALIFT RESOURCES FOR MOVING COMBAT TROOPS OVERSEAS UNDER MILITARY CONTINGENCIES

by

Ralph B. Hunt
Erling F. Rosholdt

Serial T-137/61
5 October 1961

THE GEORGE WASHINGTON UNIVERSITY
LOGISTICS RESEARCH PROJECT

Contract Nonr761(05)
Project NR 047 001

Office of Naval Research

Table of Contents

Objective

To develop a practical planning procedure for allocating sealift and airlift resources so as to obtain the highest over-all efficiency of movement of combat troops from continental United States (CONUS) to overseas destinations.

Summary

This study describes a systematic and flexible procedure for making allocation, at the higher levels of planning, of the transoceanic transportation resources of airlift and sealift in moving combat forces under military contingencies. Prime consideration is given to movements from CONUS to overseas destinations but, to a lesser degree, the effects of prepositioned resupply are also discussed.

It is shown that present methods of transportation planning which call for delivering a combat force in more or less equal increments per sortie result in excessive response time for airlift because excessive quantities of resupply are included in the early sorties. A substantial increase in the rate of delivery of troops and equipment is obtained if the principal of daily resupply for the troops delivered is followed. In addition, the procedure described permits the troops to be immediately available for combat as well as for further deployment or for diversion to other destinations enroute.

A method of decreasing the response time of sealift is described which would decrease the loading and unloading time for cargo ships to a level equivalent to the port times required for Navy transports.

Several aids are developed which would be useful at all planning levels which generate the composition of combat forces and/or plan for their transportation requirements.

THE GEORGE WASHINGTON UNIVERSITY
Logistics Research Project

A PLANNING METHOD FOR ALLOCATING AIRLIFT AND SEALIFT RESOURCES FOR MOVING COMBAT TROOPS OVERSEAS UNDER MILITARY CONTINGENCIES

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Introduction

The United States requires a capability to transport combat forces rapidly from the continental United States to overseas destination. The quickest means of transportation available today is airlift. However, there are limitations to airlift which must be considered in the context of any practical planning problem. These limitations include capacity, fuel consumption and its resupply, maintenance downtime, characteristics of terminal facilities, enroute stop requirements, overfly and landing rights. The effects of these limitations are felt in high cost, both procurement and operating, and lowering of potential capabilities. Strenuous efforts to reduce or eliminate these limitations are being made by incorporating greater range, capacity, and less critical terminal requirements in the latest design of cargo planes, e.g., the C-141, which is only on the drawing boards at present.

The other transoceanic transportation resource is sealift. Although ships have tremendous capacity, (3-5000 short tons each vs. 12-50 ST for planes) and are self-contained in operating requirements to a great degree, they too have limitations that must be considered in practical planning. Ships are too slow for use in movements where speed is of the essence. The loading and unloading times required in a port are principal bottlenecks to fast over-all response time. Efforts to alleviate these limitations have included roll-on, roll-off ships, prepackaging, palletized containerization, and mechanized conveyors.

Restrictions in logistical resources, budget limitations and common prudence require that the available resources of airlift and sealift be used in the manner that best makes use of the special attributes of each in obtaining the greatest over-all efficiency of movement of combat troops to the desired overseas destination.

For the purposes of this study, "over-all efficiency of movement" includes such considerations as efficient, simplified planning, rapid response time, flexibility, troop combat readiness, and actual capability of both airlift and sealift.

A Planning Method for Allocating Airlift and Sealift Resources for Moving Combat Troops Overseas Under Military Contingencies

Special Logistical Characteristics of Military Airlift

Moving combat troops by air is quite different from normal peace time military lift which usually involves sending dependents, emergency spare parts, replacement personnel or those necessary to fill existing personnel vacancies. The difference is that necessary supplies and equipment (including vehicles) must accompany the combat troops. This permits

1. Immediate deployment to combat areas upon arrival.
2. Assures that personnel have their own materiel.
3. Provides means for unloading the planes.
4. In case of diversion or emergency landings, the combat troops are self-sufficient and have mobility.
5. Prevents or reduces pilferage, borrowing, commandeering and sabotage which could re-result if the cargo went independently.

In addition, it is necessary to plan for airlifting resupply to the troops until necessary supply levels can be delivered by ships.

From the viewpoint of the operating characteristics of the airlift itself, special logistical factors required include relief air transport crews, increased maintenance and spare parts, terminal facilities at the enroute stops suitable for possible overnight lodging of the troops as well as airfield parking and refueling capabilities suitable for the required number of planes.

Major Assumptions

In the light of the foregoing, the major assumptions used in this study are:

1. Personnel, supplies and equipment must go together as quickly as possible in the initial movement from CONUS and are to be ready for combat on arrival.
2. Daily resupply required for personnel delivered will be by airlift until resupply from ships is available.
3. Resupply rate is 1.1 short tons (ST) per man per month (1/30th of this per day).
4. Average sortie load (notional) is 15 ST cargo or 100 personnel.

Transportation Intelligence and Planning

Each specific transportation problem has its own context or framework within which decisions or estimates must be made by the planners. This framework is provided by transportation intelligence which the following quotation aptly describes:

> "a. Definition. Transportation intelligence is intelligence concerning air, land, and water transportation systems and facilities of actual or potential theaters of operations. It includes data concerning the characteristics, conditions, development, organization, material, operation, maintenance and construction of such facilities.
>
> b. Role. Transportation intelligence provides data essential to strategic, tactical and logistical planning and furnishes the basis for estimates of military transportation capacities and capabilities." [1]

Elements of transportation intelligence particularly pertinent to airlift and sealift planning have been divided into four groups which bracket typical constraints on any specific airlift or sealift problem:

1. CONUS
2. Destination
3. Lift Availability
4. Enroute.

Plate 1 illustrates a typical breakdown under each group. Some observations are in order.

During the fact-finding phase of this study it became apparent that the kind of information outlined in Plate 1 is scattered among the three Services and at different responsibility levels. For example, data on

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[1] Field Manual FM-55-8, Transportation Intelligence, p. 4, Department of the Army, October 1956.

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CONSTRAINTS

CONUS

1 TRANSPORT MODE TO A.P.O.E. OR P.O.E.

2 TRANPORT AVAILABILITY

3 CAPABILITY OF A.P.O.E. OR P.O.E.

DESTINATION

1 AIRFIELD CAPABILITIES { RUNWAY, LIGHTS, WEATHER, POL, SERVICES, PARKING, COMMUNICATIONS ETC.

2 OVERFLY & LANDING RIGHTS

3 PORT CAPABILITIES { ANCHORAGE, UNLOADING FACILITIES, STORAGE, SERVICES ETC.

4 PORT CLEARANCE { RAIL ROAD. INLAND WATERWAY, ETC.

5 LOC between PORT and OBJECTIVE AREA

LIFT AVAILABILITY

PLANE AVAILABILITIES { PURE REQMTS. OPERATING HOURS MATS REQMTS.

MSTS SHIP AVAILABILITIES

ENROUTE

AIRFIELD CAPABILITIES

WEATHER

CRITICAL LEGS

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CHART 1

land transportation and port facilities are available from the Army; data on airfields, plane capacities and availabilities are the province of the Air Force, and ship data are supplied by the Navy. This diversified information input upon which sound planning discussions must be made is often a variety of ideas, opinions, estimates, generalized missions and tasks. Sound planning requires adjusting the capabilities of airlift and sealift to the realities of the constraints imposed. The required feedback of information does not appear well organized in order for rapid adjustments to plans to be made.

In order to understand the mechanics behind the airlift-sealift allocation procedure to be described, it is first necessary to consider three relationships in airlift, namely, effect of outloading or sortie rates on capacities, effect of resupply subdivision on delivery rates, and the effect of sortie rates and flying hours on total plane pipeline requirements.

Effect of Outloading (Sortie) Rates on Airlift Capacities

A typical effect of the outloading rates of aircraft on the capacities of an airlift and the lift completion time is illustrated in Plate 2. The example used assumes a cargo-to-personnel ratio in the initial movement of 0.6 short tons per man and different rates of outloading in

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EFFECT OF OUTLOADING RATES (SORTIES) ON AIRLIFT CAPABILITIES

(INITIAL LIFT RATIO OF CARGO TO PERSONNEL = .6 S/T PER MAN)

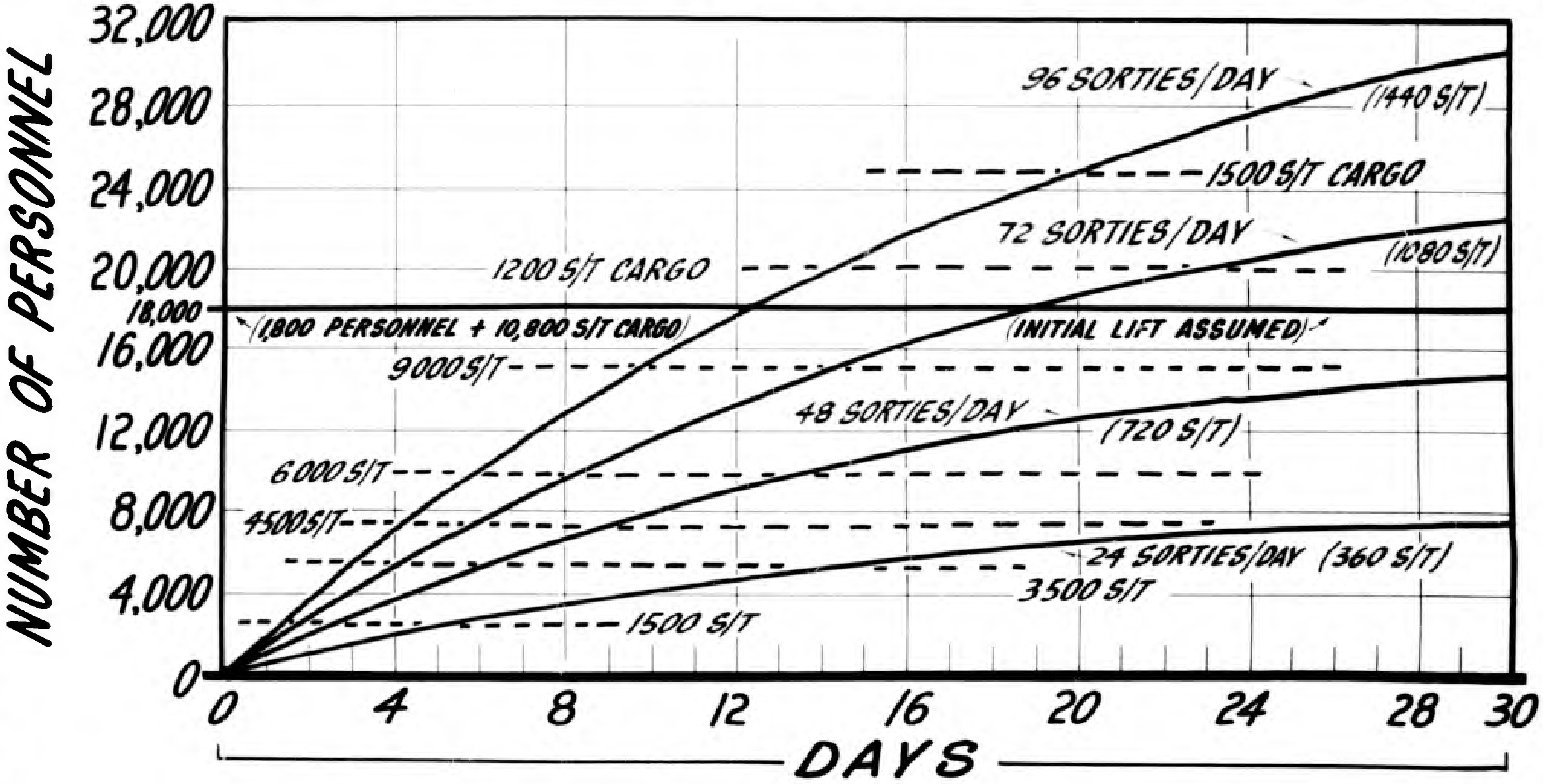

CHART 2

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units of short tons per day or notional sorties. Two facts are apparent from the curves:

a. The higher the outloading rate the faster the lift is completed,

b. The curves are non-linear.

The completion times for the airlift can be obtained by simply adding the transit time plus unloading time to the outloading time indicated in Plate 2.

The non-linearity of the outloading curves is due to the increase in resupply cargo. As more and more troops are delivered, the daily resupply requirements increase at the expense of the quantity of troops and cargo outloaded in the initial movement. This behavior is illustrated in Plate 3 for a cargo to personnel $(\frac{c}{p})$ ratio = 1.1 and an outloading rate of 540 ST/day.

The composition of the daily lift is given by

$$K_n = (f + a)P_n + r \sum_{i=1}^{n-1} P_i$$

where K_n = short tons lifted on the nth day

P_n = number of personnel lifted on nth day

r = resupply rate (ST/man/day)

$\sum_{i=1}^{n-1} P_i$ = cumulative number of personnel outloaded through the (n-1)-th day

f = ratio of cargo to personnel (ST/man)

a = conversion factor for men to tons, (tons/man)

K , r , a and f are constants.

For a detailed derivation see Appendix A.

DAILY AIRLIFT OF PERSONNEL, CARGO & RESUPPLY

@ 540 SHORT TONS/DAYS RESUPPLY @ 1.1 S/T MAN/MONTH

RATIO OF CARGO TO PERSONNEL = 1.1 S/T PER MAN

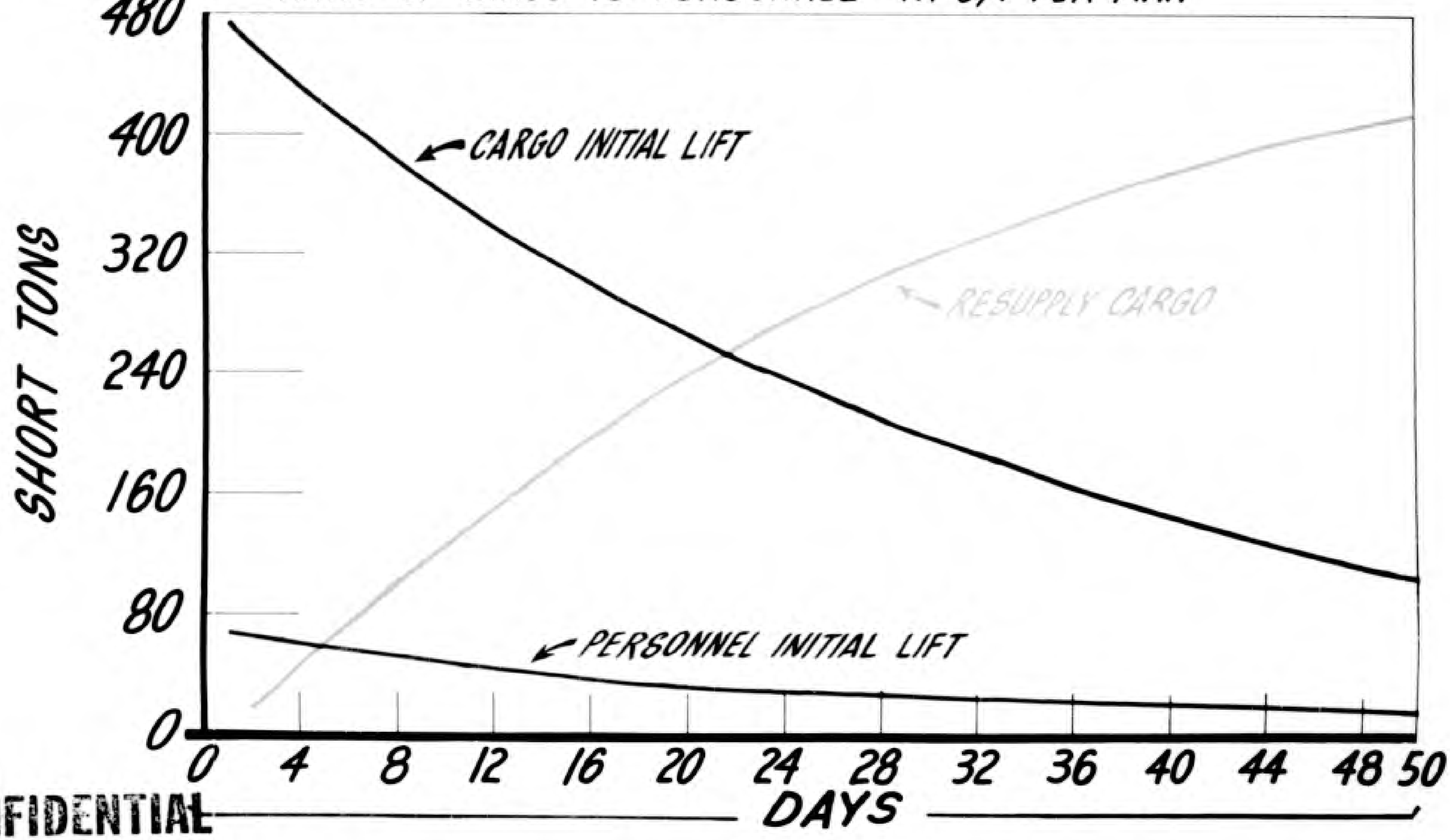

CHART 3

A Planning Method for Allocating Airlift and Sealift Resources for Moving Combat Troops Overseas Under Military Contingencies

<u>Effect of Resupply Subdivision on the Rate of Delivery of Combat Troops</u>

Two concepts of outloading troops and cargo for airlift are illustrated by the curves in Plate 4. It is assumed there that an initial movement consists of 37,118 men and 18,560 short tons of cargo. At an outloading rate of 1440 ST/day, fifty days are required to outload such a force. Daily resupply requirements over that time would cumulate to 47,873 ST. The total tonnage of the initial movement of personnel, cargo and resupply amounts, therefore, to 72,000 ST. For purposes of illustration, it is assumed that sealift is not available until after the 50th day, hence airlift must carry the total movement.

The straight lower curve illustrates the effect of outloading (or delivering) the total tonnage in equal increments per day as compared (upper curve) to outloading personnel and cargo and only the daily resupply requirements to maintain supply levels corresponding to the cumulative number of personnel actually delivered (outloaded) up to each particular day. The advantage of the latter procedure is evident by comparing the two curves. Thus, for example, if we look at the 20th day, with daily resupply the upper curve shows that 25,000 combat troops with their equipment will have been airborne as compared to only 14,800 troops with their equipment when the equal

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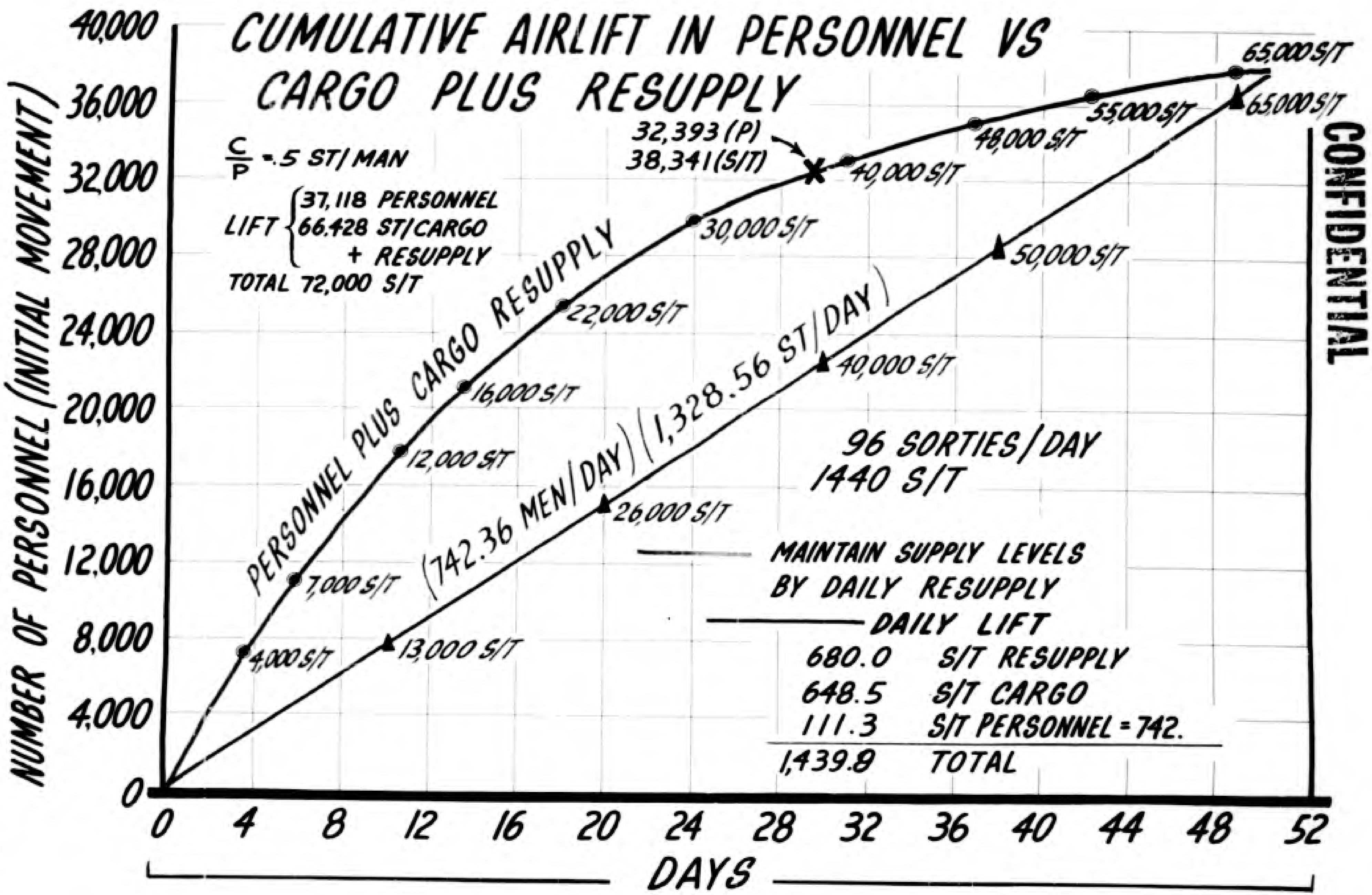

CHART 4

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increment procedure is used. In addition to slowing down the rate of delivery of the combat troops and their equipment, the equal increments procedure has the further disadvantage of producing a tremendous excess of resupply in the early days of the lift when the build-up of troops is just beginning. For example, as indicated in Plate 4, 680 short tons of resupply would arrive each day while the troop build-up would amount to only 742 men per day. Six hundred eighty tons of resupply is equivalent to one day's resupply for approximately 18,500 troops which would not have been airborne until the 25th day. This excess of resupply could seriously impede the mobility of the troops on arrival as well as being conducive to pilferage, commandeering, borrowing or sabotage, as well as the headaches of establishing effective resupply depots or dumps.

The chief merit of the equal increment procedure is that it requires only simple arithmetic by the planner to convert the lift into sortie loads. To enable the planner to use the daily resupply concept in as simple and quick a manner, a complete set of tables have been computer-generated which give in detail, up to fifty days, the quantity of personnel, cargo and daily resupply to be outloaded each day and also the respective cumulative totals for the range of cargo/personnel ratios from 0.1

to 1.4 in 0.1 increments and outloading ratios from 360 to 2880 ST per day in increments of 180 ST per day. Notional sortie loads based on 15 ST per plane are also given. Plate 5 outlines such a table. It will provide answers to such questions as:

> How many combat troops with their equipment can be loaded out in _____days at _____ST/day (or sorties)? How long will the total initial movement take? What tonnage of resupply is required each day?
>
> What outloading rate must be used to deliver _____troops and _____tons of cargo with daily resupply in _____days?

Effect of Outloading Rate (Sortie/Day) and Operating Hours per Day on Plane Pipeline Requirements

The total number of planes required to maintain a pipeline over a given route is given by the equation:

Number of Planes in Pipeline =

$$\text{Sorties/Day} \times \frac{\text{Round Trip Flying Hours}}{\text{Flying Hours per Plane per Day}}$$

This relationship is illustrated graphically in Plate 6 for different sorties per day. For capability planning, the relationship can give a quick estimate of

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INITIAL AIRLIFT OUTLOAD TIMETABLE

DAILY LIFT 1,080 S/T **SORTIES PER DAY = 72**

RATIO = .9 S/T PER MAN

TIME	INITIAL AIRCRAFT		RESUPPLY	CUMULATIVE TOTALS		
DAY	PERSONNEL	CARGO	CARGO	PERSONNEL	CARGO	CARGO AND RESUPPLY
1	1,029	926	0	1,029	926	926
2	993	893	38	2,021	1,819	1,857
27	408	367	651	18,173	16,356	26,434
28	394	355	666	18,567	16,710	27,455
29	380	342	681	18,947	17,053	28,478
50	180	162	891	24,474	22,026	50,329

CHART 5

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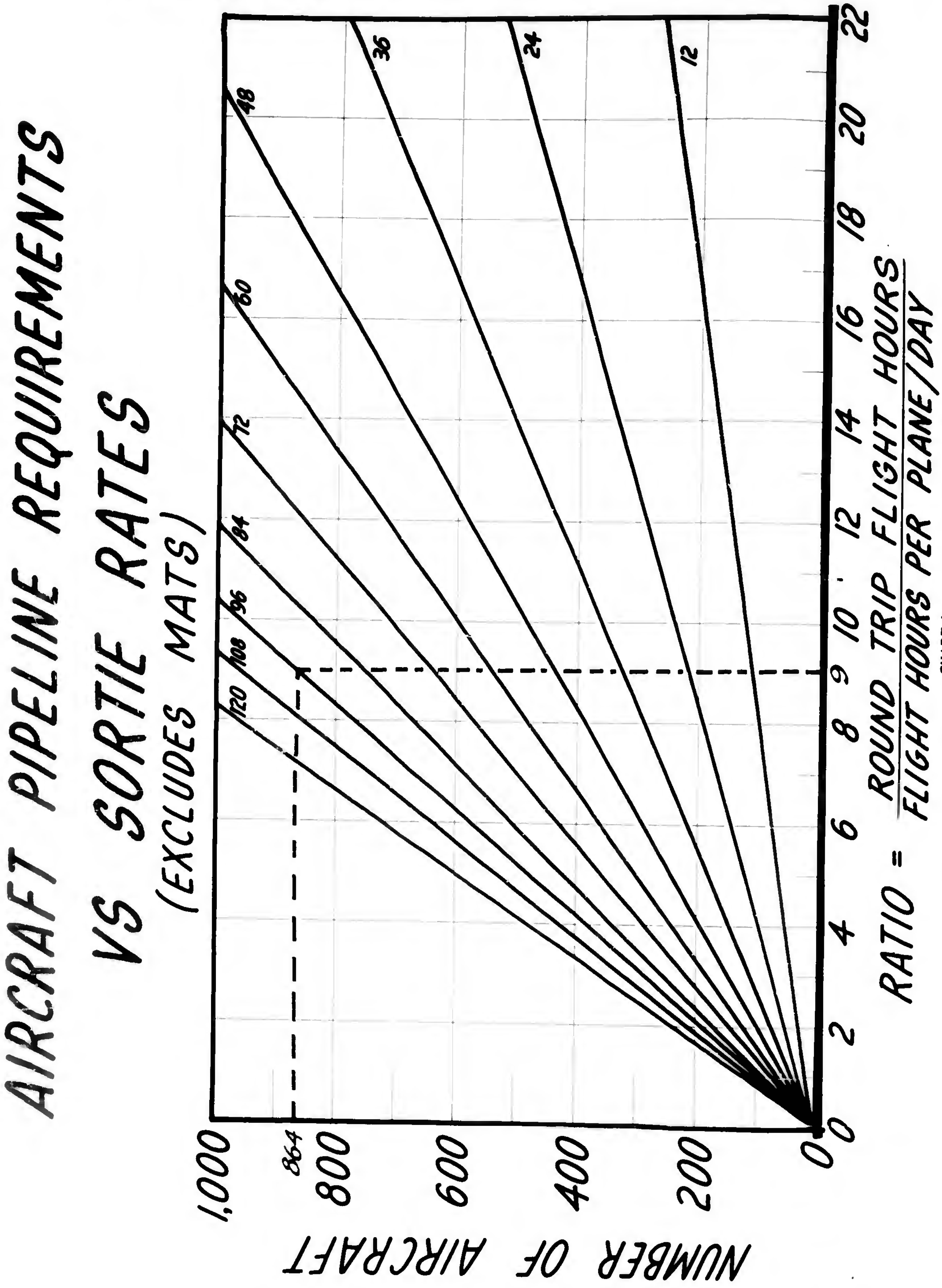
AIRCRAFT PIPELINE REQUIREMENTS
VS SORTIE RATES
(EXCLUDES MATS)
NUMBER OF AIRCRAFT
1,000
864
800
600
400
200
0
0
2
4
6
8
9
10
12
14
16
18
20
22
12
24
36
48
60
72
84
96
108
120
RATIO = ROUND TRIP FLIGHT HOURS / FLIGHT HOURS PER PLANE/DAY
CHART 6

what daily sortie level can be maintained with the total number of planes available when flown over a particular route. Thus, if 864 planes were available and the airlift route required 72 flying hours per round trip at 8 hours/day operating level, then $864 \times \frac{8}{72} = 96$ sorties per day could be maintained. Converting the sorties to equivalent capacity in short tons would provide the daily outloading rates to be used in selecting the proper table of those previously described or in selecting the proper curve such as illustrated in Plate 2 or the proper set of curves illustrated for a particular outloading rate by Plate 7.

The effect of variable flying hours per day on the maximum size of a pipeline is illustrated in Plate 8 for an assumed turnaround time and round trip flying time when the sortie rate is constant. Additional requirements for administrative use of MATS are also shown. Plate 9 illustrates the effect of variable flying hours on the sortie rate when the total number of planes in the pipeline is constant (i.e., the airlift must be operated within the capacity of the number of planes allocated to it). The situations represented in Plates 8 and 9 are those which might be the result of a "surge" in the beginning of a lift followed by a tapering off to some final average level of operation.

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CUMULATIVE PERSONNEL AND CARGO OUTLOADED BY AIRLIFT

VS TIME

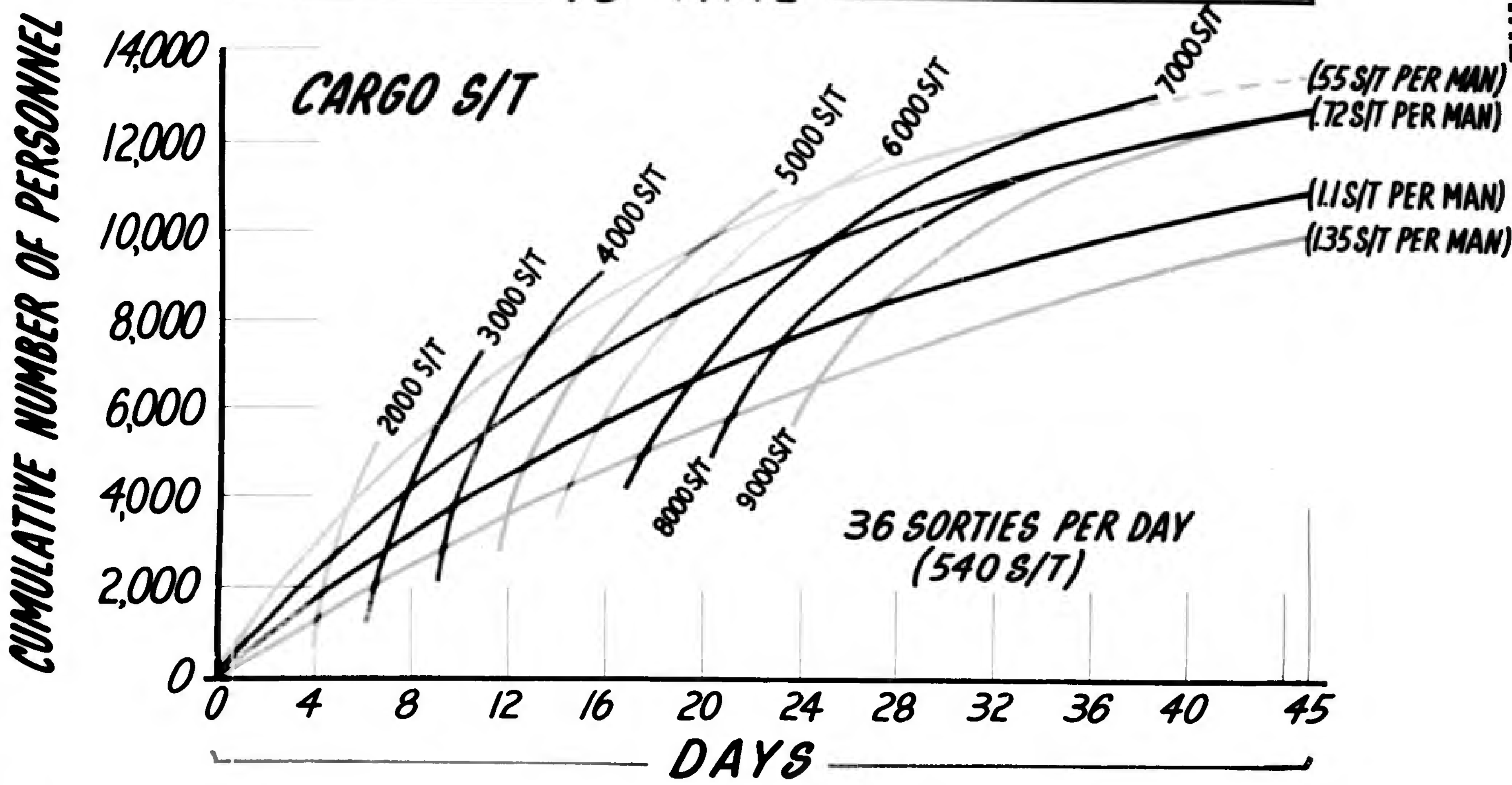

CHART 7

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EFFECT OF VARIABLE FLYING HOURS/DAY ON A/C PIPELINE (CONSTANT SORTIE RATE)

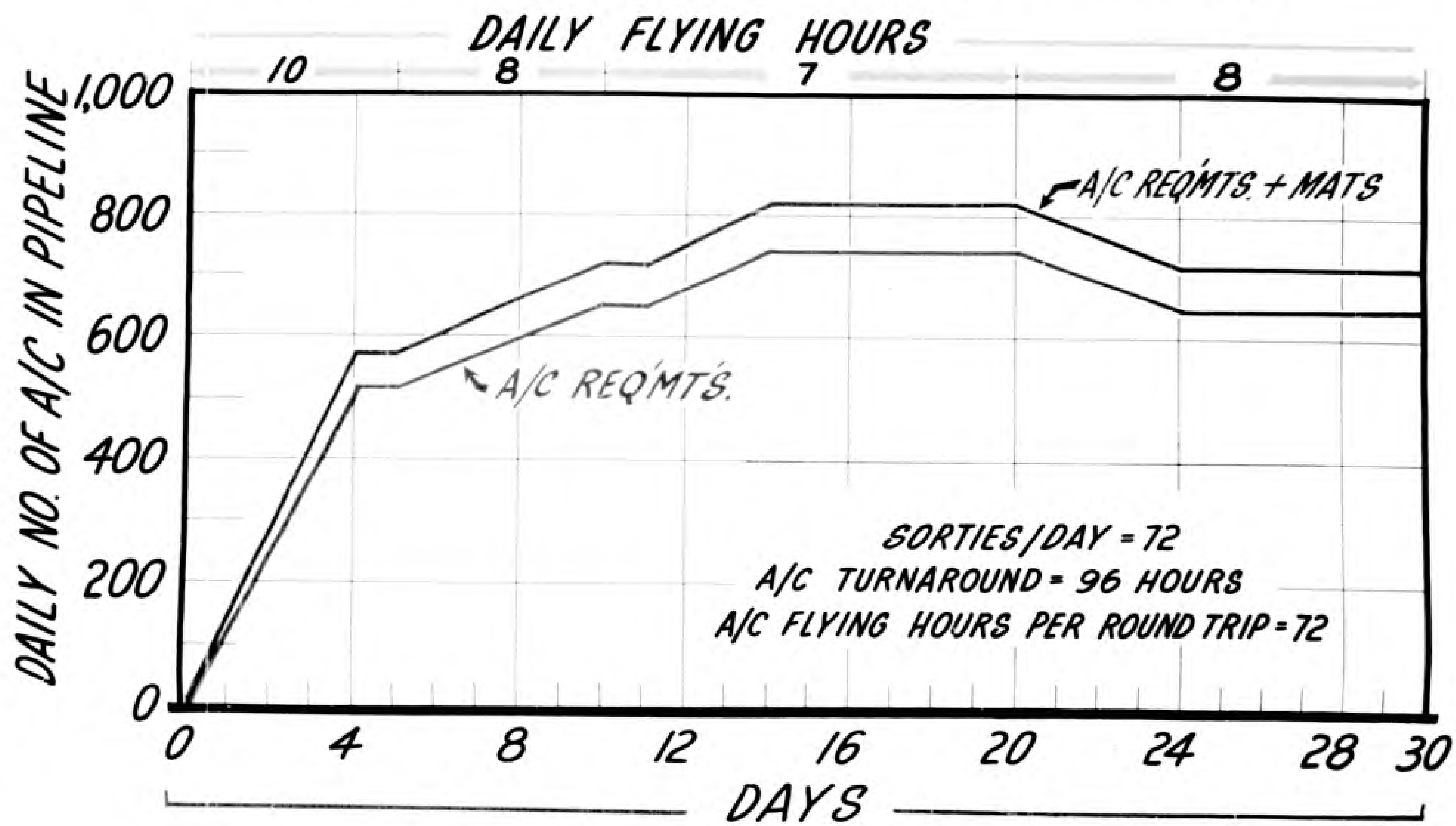

CHART 8

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EFFECT OF VARIABLE FLYING HOURS/DAY ON SORTIE RATES (TOTAL AIRCRAFT CONSTANT)

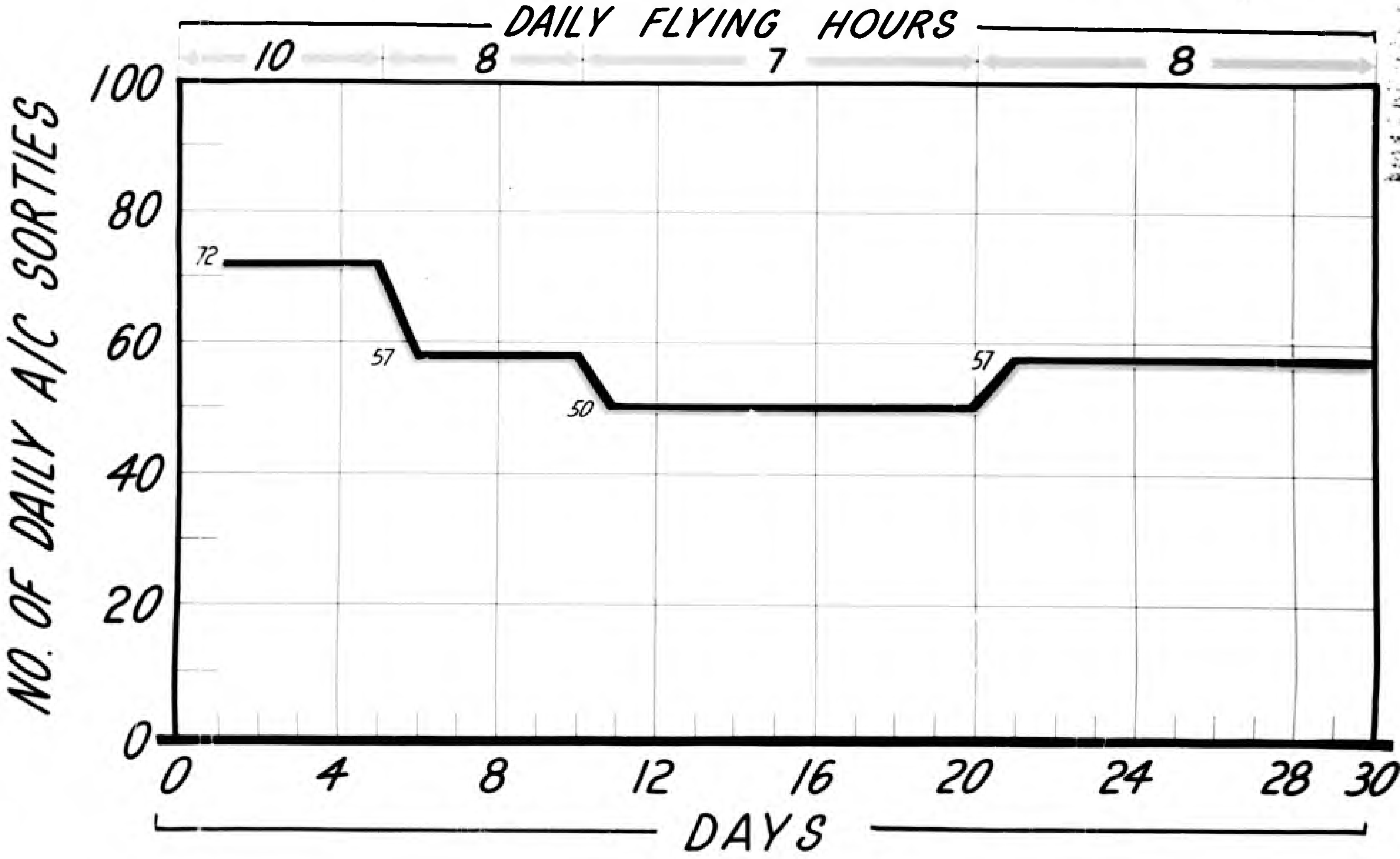

CHART 9

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A Planning Method for Allocating Airlift and Sealift Resources for Moving Combat Troops Overseas Under Military Contingencies

The Airlift-Sealift Allocation Procedure

The procedure developed in this study for allocating an initial movement of combat troops with their equipment between airlift and sealift is illustrated by the flow chart in Plate 10 and graphically in Plate 11. The procedure consists, in essence, of (a) comparing the time required for delivery by sealift (SL) against the completion time required for delivery by airlift (AL) and, (b) if the latter time is greater than the sealift completion time, then the undelivered part of the initial movement not yet airborne by the end of the sealift response time is allocated to sealift at the start of the airlift operation and arrives at the objective area to join up with the cumulated personnel and equipment that had been airlifted. In addition to the troops and equipment aboard, the ships can also carry bulk resupply adequate for the troops until the ships carrying the resupply build-up arrive.

Reference to Plate 11 will clarify the procedure. Along the horizontal axis, the completion time required by sealift is divided into its principal components:

a. Delivery time to P.O.E. (Port of Embarkation)

b. Port time (loading, miscellaneous delays)

c. Steaming time to destination

ALLOCATION BETWEEN AIRLIFT & SEALIFT

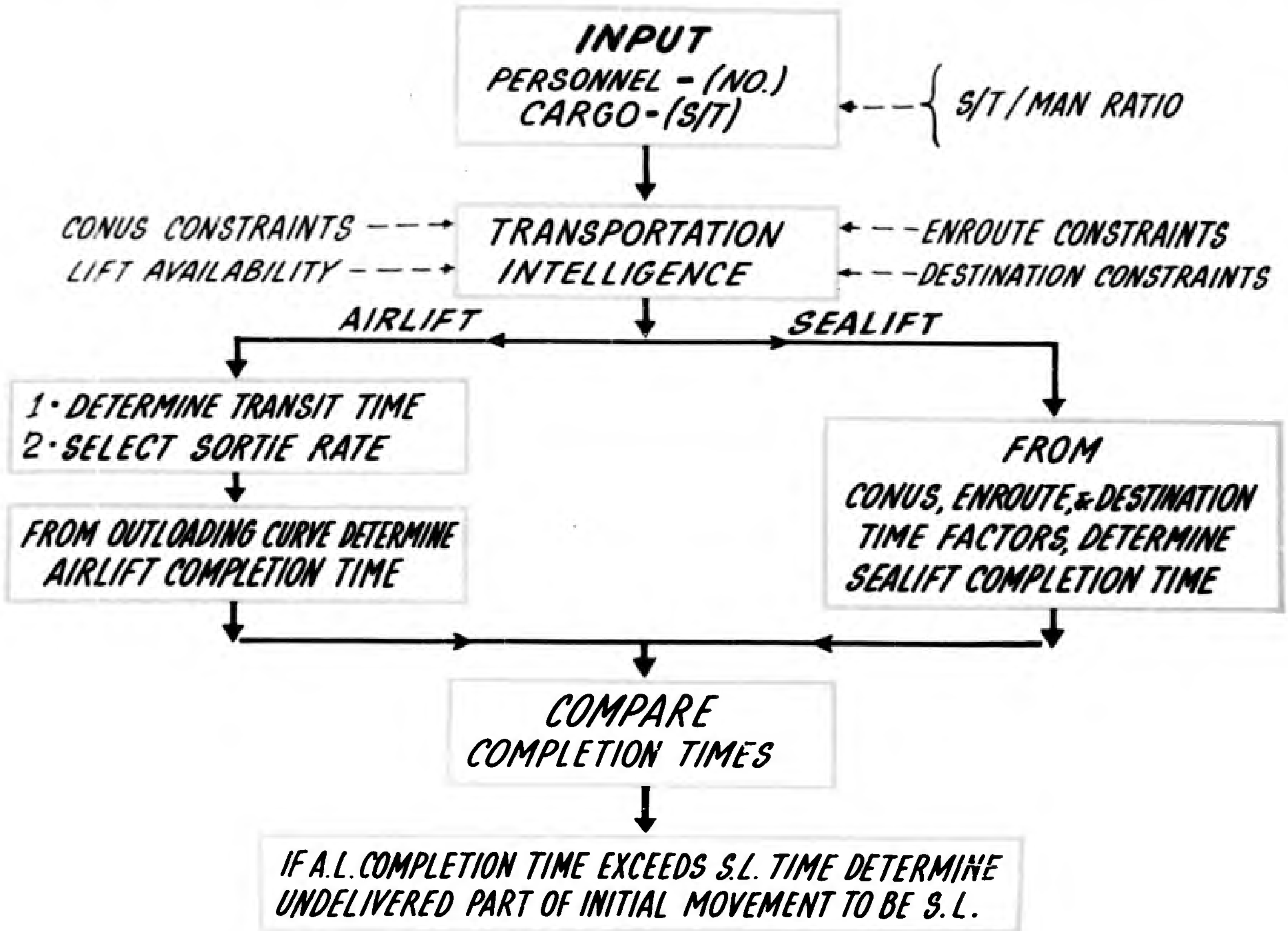

CHART 10

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CARGO ALLOCATION BETWEEN AIRLIFT and SEALIFT

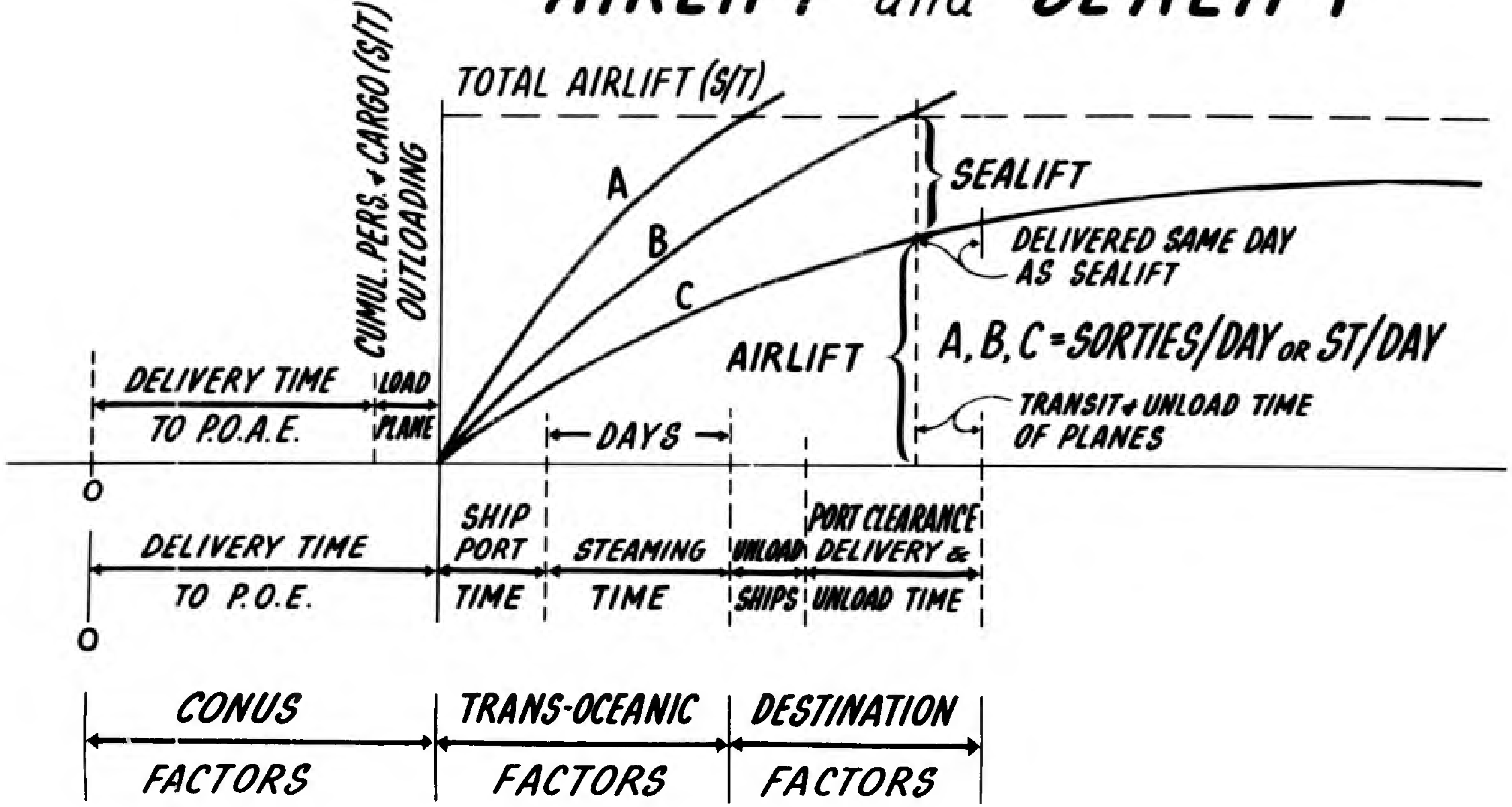

CHART 11

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d. Unloading time in port

e. Port clearance time and delivery to objective area.

When the transit and unloading time of the airlift is subtracted from the total response time for sealift and the corresponding intercept is made with the proper out-loading curve, the part of the initial movement which would be delivered by airlift at the same time as sea-lift can be determined. The part that would be undelivered by airlift is the quantity to be allocated to ships at the start of the operation. The total initial movement in airlift and sealift would thus arrive at the objective area at the same time. This joint movement would thus preserve the advantage of rapid movement of the bulk of the force by air consistent with the airlift capability available at the time. The usual 30-day re-supply build-up would arrive at a later date.

It appears feasible to reduce appreciably the response time of sealift. Since the time spent in port loading and unloading ships constitutes a large portion of over-all response time, a way to reduce this port time would be to partially load cargo ships at the expense of using more cargo ships for a particular lift. To illustrate the possibilities, suppose 12,000 men and 11,000 ST cargo were to be sealifted. The normal capacities of a Navy transport (AP) is 3500 men and 1000 ST cargo. The port time (load and unload) would be about 6 days. A cargo ship (AK) with a capacity of 15,000 measurement tons or about 5000 ST would require about 17 days total port time. For the example cited, 4 APs and 2 AKs would be required and the total port time would be about 12 days since full capacity is not required. However, if the number of AKs is doubled to 4, and each of these is loaded to one-half the level of the first two, the total port time would be reduced to 6 days which is the port time of the APs. Therefore, both transports and cargo ships could leave together. For this size of initial movement, the additional requirement for cargo ships and pier space is modest compared to the time-saving gained.

The Effect of Prepositioned Resupply on Airlift Response Time

Prepositioned resupply increases the rapidity of outloading an initial combat force by virtue of the fact that it means that a greater quantity of personnel and cargo can be moved per day since resupply does not have to compete with them for the available plane capacity. The over-all rate of delivery of the initial movement, i.e., personnel, cargo and resupply can also depend on the distance of the resupply depot from the objective area. This is illustrated by the curves in Plate 12 which is based on the assumption that personnel and cargo arrive from CONUS and that the resupply required for the cumulated personnel that has been delivered is picked up from the depot which, in the illustrated example, is one and two round trip days away by using a necessary number of the planes which arrived from CONUS. In other words, this is the kind of situation where the TAC planes in the theater are not available for the resupply lift and the whole job must be handled by the initial available pool of planes assembled for the airlift. Since the resupply requirements increase each day as the number of personnel delivered increase, the number of planes entering the resupply lift increase and since the available pool of planes is assumed fixed, the number of planes returning to CONUS for successive trips progressively decreases and hence the outloading rate from CONUS decreases. Plate 13 illustrates the effect on the daily delivery rate for cargo and resupply.

It is interesting to note that, referring to Plate 12, a considerable quantity of troops and equipment can be delivered before a 1-day difference in the round trip flying time between the resupply depot and

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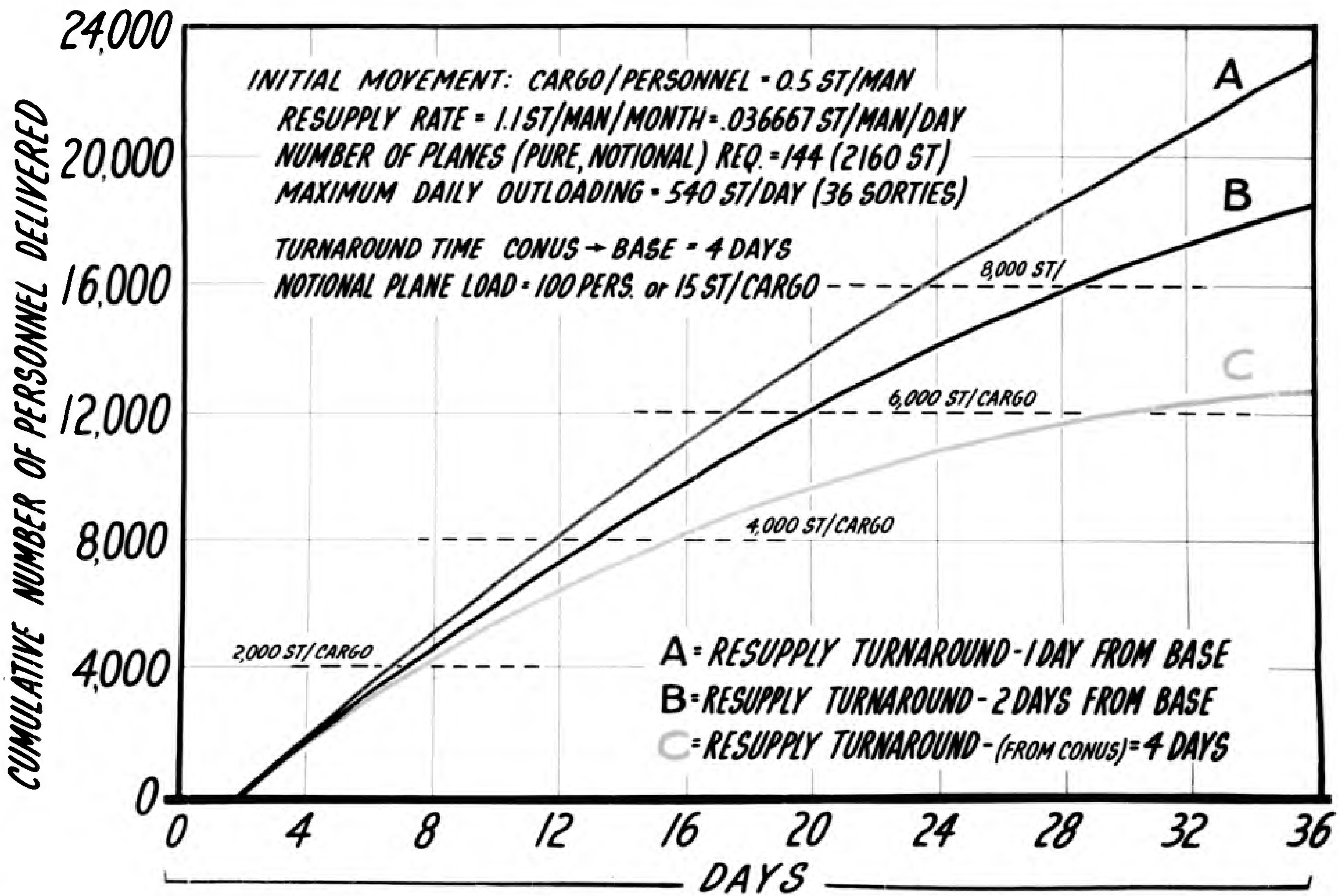

CHART 12

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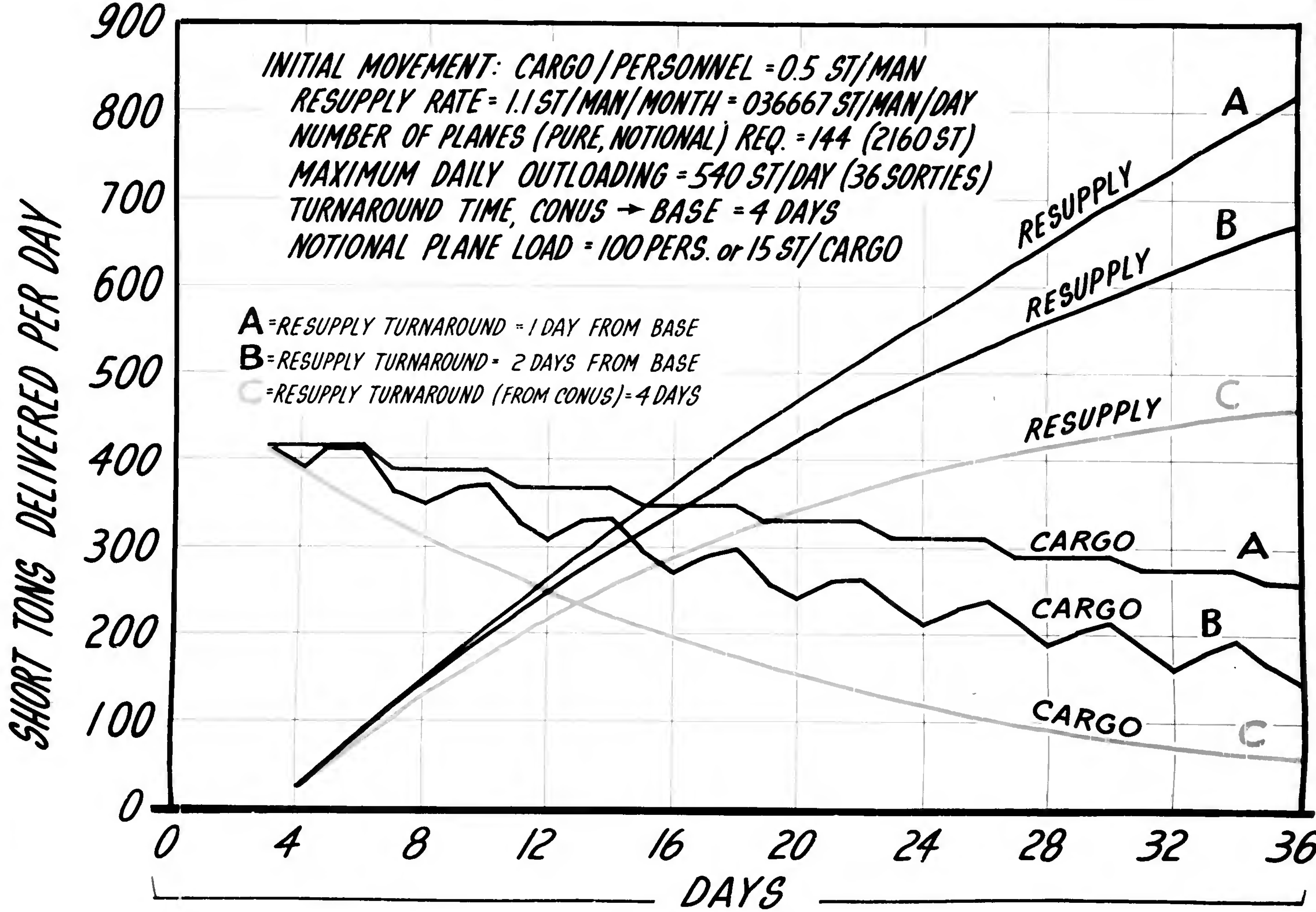

CHART 13

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the base appreciably affects the delivery time of the troops from CONUS. In the example in Plate 12, approximately 8000 troops and 4000 ST cargo can be delivered before the delivery times of curves A and B show a 1-day difference.

Appendix A*

Some Relationships in Airlifting Cargo, Personnel and Resupply

Let: K_i = daily lift capability on the i-th day (tons)

P_i = number of personnel delivered on the i-th day (men)

C_i = amount of cargo (not resupply) delivered on the i-th day (tons)

R_i = amount of resupply delivered on the i-th day (tons)

r = resupply rate (tons/man/day)

a = conversion factor for men to tons (tons/man)

f = ratio of cargo/personnel (tons/man)

TL_n = total lift on the n-th day

Conditions: K, r, a, f are constants, so that

(a) $TL_n = nK$

(b) $fP_i = C_i$

(c) $r \neq 0$

The composition of the daily lift will be as follows:

$$K_1 = C_1 + aP_1 + 0$$

$$K_2 = C_2 + aP_2 + rP_1$$

$$K_3 = C_3 + aP_3 + r(P_1 + P_2)$$

$$\vdots \qquad \vdots \qquad \vdots \qquad \vdots \qquad \vdots$$

$$K_n = C_n + aP_n + r \sum_{i=1}^{n-1} P_i$$

or, using condition (b):

(1) $$K_n = (f + a)P_n + r \sum_{i=1}^{n-1} P_i$$

---

*These derivations were developed by Commander W. L. Wilkinson, USN, Office of Naval Research.

Taking advantage of the equivalence in the set of equations for K_i given above, we can write the following recursion formula:

(2) $$P_n = \frac{(f + a - r)}{f + a} P_{n-1}$$

and the series, letting $\frac{(f + a - r)}{f + a} = Q$

(3) $$\sum_{i=1}^{n} P_i = P_1 \ (1 + Q + Q^2 + \ldots\ldots Q^{n-1})$$

which is a geometric series with a sum for the nth day:

(4) $$\sum_{i=1}^{n} P_i = \frac{(f + a)}{r}(1 - Q^n) \ P_1$$

and in the limit, the sum is,

(5) $$\sum_{i=1}^{\infty} P_i = \frac{(f + a)}{r} P_1 = K/r$$

or, stated differently, the maximum number of men that can be delivered and supported is:

(6) $$P_{max} = K/r \quad .$$

For computing, the following form appears to be most convenient:

(7) $$\sum_{i=1}^{n} P_i = K/r \ (1 - Q^n)$$

and, solving for P_n from (1), we have

(8) $$P_n = KQ^n/(f + a - r) = KQ^{n-1}/(f + a) \quad .$$

On the nth day, the load distribution looks like this:

(9) $$K_n = fKQ^n/(f + a - r) + aKQ^n/(f + a - r) + K(1-Q^{n-1})$$

where the fraction of lift devoted to each is independent of K but depends on n.

And to compute how much of each we have delivered by the n-th day we have:

(10) $$nK = \underbrace{fK/r(1 - Q^n)}_{\text{Cargo}} + \underbrace{aK/r(1-Q^n)}_{\text{personnel (tons)}} + \underbrace{nK-(K/r)(a + f)(1-Q^n)}_{\text{Resupply}}$$

As an application of (8), suppose the planner is not willing to schedule airlift when the delivery rate/day for personnel falls below some number, say w. He wants to know on what day this will occur. That is, when

$$(K/r)\ (Q^{n-1} - Q^n) < w \ .$$

Solving for n,

(11) $$n < \frac{\ln w + \ln r - \ln K - \ln (1-Q)}{\ln Q} + 1 \ .$$

If we take, for example, $w = 100$, $K = 540$, $r = .037$, $f = 1.1$, $a = .15$, and $Q = .97$, then $n = 48$.

Another question that may be of interest to the planner is "what day will my resupply tonnage begin to exceed that of cargo and personnel?" This can be easily answered by solving the inequality:

$$Q^{n-1} < 1/2$$

or

$$n < \frac{-\ln 2}{\ln Q}$$

which suggests a simple plot of Q versus n for a practical range of Q.

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Logistics Research Project

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