AD NUMBER
AD906553
LIMITATION CHANGES
TO: **Approved for public release; distribution is unlimited.**
FROM: **Distribution authorized to U.S. Gov't. agencies only; Test and Evaluation; DEC 1972. Other requests shall be referred to HQ Dept. of the Army, Washington, DC 20310.**
AUTHORITY
OACSFER D/A Itr 23 Aug 1973

An Appraisal of CAS (Close Air Support) Capabilities

Volume IV—Development of a Simulation Model for Evaluating Systems in Prolonged Intensive Combat (EPIC)

by Joe R. Capps

Copy 21 of 55

RAC Research Analysis Corporation

Best
Available
Copy

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

TECHNOLOGICAL SYSTEMS GROUP CLIENT REPORT RAC-CR-72 Published December 1972

An Appraisal of CAS (Close Air Support) Capabilities

Volume IV—Development of a Simulation Model for Evaluating Systems in Prolonged Intensive Combat (EPIC)

by

Joe R. Capps

DISTRIBUTION STATEMENT
Distribution limited to US Gov't agencies only; Test and Evaluation; 30 November 1972. Other requests for this document must be referred to HQDA (DAFD-ZAA), Washington, D.C. 20310.

Research Analysis Corporation RAC

McLean, Virginia 22101

Area Code 703
893-5900

Published December 1972
by
RESEARCH ANALYSIS CORPORATION
McLean, Virginia 22101

RAC

CONTENTS

FIGURES

TABLES

Volume I
(Separately bound)

Volume II
(Separately bound)

Volume III
(Separately bound)

INTRODUCTION

The model development and sensitivity investigations reported here were conducted as a part of the "Appraisal of Close Air Support Capabilities" Study Program (RAC Study 012.117) and specifically directed to the EPIC model (Evaluation of Systems in Prolonged Intensive Combat).

The original version of the EPIC model was conceived, structured, and developed during the latter part of 1971. Although the structure of the model as a whole was complete and the model was operating before the end of the year, it was clear that a modest amount of additional effort would result in improvements of the detailed design and provide the users with a better understanding of the model sensitivities. Realization of benefits in these two areas has been the general objective of the effort reported here.

The sections which follow provide a general description of the EPIC model, a check out data set, model additions made during this study effort and a summary and analysis of each of the exploratory and sensitivity runs made. Detailed flow charts of the model logic and the input structure of the model are located in Appendices A and B, respectively.

GENERAL DESCRIPTION OF THE EPIC MODEL

The EPIC evaluation model was developed as a part of the ADAFSS Force Mix study by the Research Analysis Corporation to produce the daily and cumulative expected results that might be achieved by different numbers, types and mixes of attack helicopters over extended periods of combat. The model considers operational factors (limitations on flight hours per day, maintenance time required as a function of flight time, fleet attrition over extended periods, mission availability, reliability, repair times for damaged aircraft, etc.) which are generally excluded, of necessity, from high resolution simulations that focus on helicopter/target interactions within a very narrow context. Missions to be executed—which might or might not exceed the fleet capability—were to be distributed throughout successive 24-hour time periods to reflect the time and sequence of the demand as a function of the weather and the level of combat activity. The model assigns aircraft to missions on the basis of availability and in accordance with mission assignment decisions in an actual operational context.

These characteristics result in two principal design considerations:

1. To represent explicitly the many operationally interacting factors over extended periods of simulated combat, and still maintain an acceptable execution time of the model, and

2. Develop a mission assignment logic that would reflect the mission assignment decision process of intelligent, experienced personnel functioning within a dynamic operational context.

The model was designed as a system of nested loops representing a hierarchy of time resolutions. Figure 1 (reproduced here from Appendix A) illustrates the time resolution hierarchy. In all of the runs discussed in the present report the time step has been treated as a 15-minute time interval. The time step can, of course, be re-defined to either increase or decrease the maximum time resolution of the model; runs have been made, for example, using a 1-minute time step. As indicated in Figure 1 the basic overall design of the model is quite simple. It will also be apparent from the figure that a wide range of delay time values can be represented without incurring undue penalties in terms of execution time.

In response to the second principal design consideration mentioned above, a dynamic mission assignment logic was incorporated in the model. This logic makes use of feedback loops that control the expenditure of available resources (in the present application, available attack helicopter flight time) in such manner as to maximize the value of a predefined effectiveness measure. The functioning of this dynamic mission assignment logic is discussed in some detail under Model Additions and Refinements, and Results of Exploratory and Sensitivity Runs.

The detailed flow charts of EPIC presented in Appendix A and the Input Structure Description given in Appendix B should convey a good general understanding of the capabilities and limitations of the model.

The EPIC model should find application in a wide variety of situations where the requirement is to determine long-term performance (as influenced by a large number of operational factors), and where estimates of detailed performance are available from high-resolution Monte Carlo simulations and/or other sources.

EPIC is an expected value model, and, as such, produces its solution in a single run. The EPIC results have been found to be in good agreement with the mean results of multiple Monte Carlo replications.

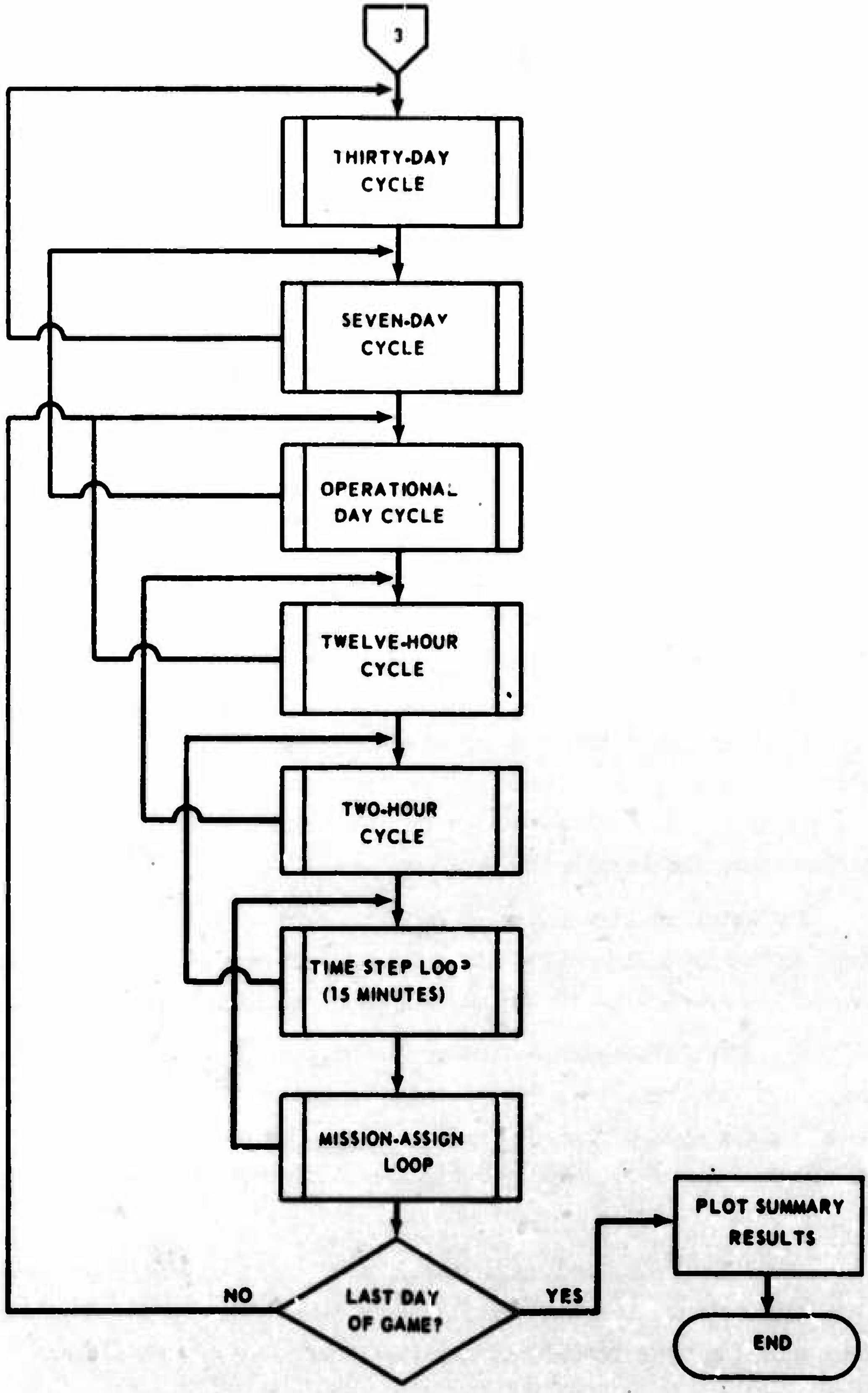


Fig. 1—EPIC Time Resolution Hierarchy

GENERAL DESCRIPTION OF THE INPUT DATA SET

An expanded data set was derived specifically for use in the exploratory and sensitivity runs reported here. The following paragraphs describe the general scope and character of the data set.

The original check-out runs of EPIC were made with a data set in which only eight mission types were described. The data set prepared for the runs discussed in this report included 66 distinct mission types, where a mission type is characterized by a target type, a target posture, a day/night condition and a weather condition. For each mission type detailed mission parameters (including flight times and total mission times, expected helicopter losses, expected target effects and expected ammunition expenditure by the friendly force) were derived (as applicable) for each of three helicopter types (AH-56A, AH-1G/TOW, and AH-1G without TOW).

These missions were represented as appearing in a demand schedule derived from the scenario sequence summarized in Table 1. It is noted here that the interpretation of the influence of the type activity day on demand density and character was inconsequential to the sensitivity runs discussed in this report. In fact, the sequence of type activity days was deliberately varied during the sensitivity runs. In brief, these runs should not be regarded as necessarily reflecting an approved scenario.

Table 1

SCENARIO SEQUENCE FOR DEMAND SCHEDULE

Day number	Type day			Type weather	
	Defense	Delay	Passive	Good	Bad
1	X			X	
2	X			X	
3	X			X	
4		X		X	
5		X		X	
6		X		X	
7		X			X
8		X			X
9			X		X
10			X		X
11			X	X	
12			X	X	
13	X			X	
14	X			X	
15	X			X	
16	X			X	
17	X				X
18			X		X
19			X		X
20			X		X
21		X		X	
22		X		X	
23		X		X	
24		X		X	
25		X		X	
26	X			X	
27	X				X
28	X				X
29	X				X
30			X		X
31			X	X	
32			X	X	
33			X	X	
34			X	X	
35			X	X	
36			X	X	

MODEL ADDITIONS AND REFINEMENTS

REFINEMENT OF MODEL RESPONSE TO MISSION DEMAND

The EPIC model incorporates a system of feedback loops whose function is to so distribute the expenditure of resources as to optimize the cumulative effectiveness of the helicopter fleet with respect to some pre-defined effectiveness measure.* In effect, this system of feedback loops may be regarded as simulating the decision process of those operational personnel responsible for assigning missions. It is assumed that such personnel are experienced and have good judgment, and that they have good working estimates of periodic demand levels as well as of approximate average results of missions of various types.

Control of expenditure of flight hours is accomplished by means of a continually adjusted Mission Acceptance Criterion. This Mission Acceptance Criterion is referenced to the distribution of expected effectiveness measure values that may be achieved by undertaking the various types of missions appearing in the demand. That is, for some limited quantity of flight hours available within some given period of time, the value of this Mission Acceptance Criterion is constantly adjusted such as to accept the more lucrative missions and to reject the less lucrative ones. The logic is depicted schematically in Figure 2.

---

*In the present application of the model, the resource whose expenditure is being controlled is specifically available helicopter flight hours. The pre-defined measure with respect to which optimization is sought is expected target effects per expected friendly dollar cost within a given regime of number of missions accomplished (or target effects achieved). The discussion will return to this measure later in this report.

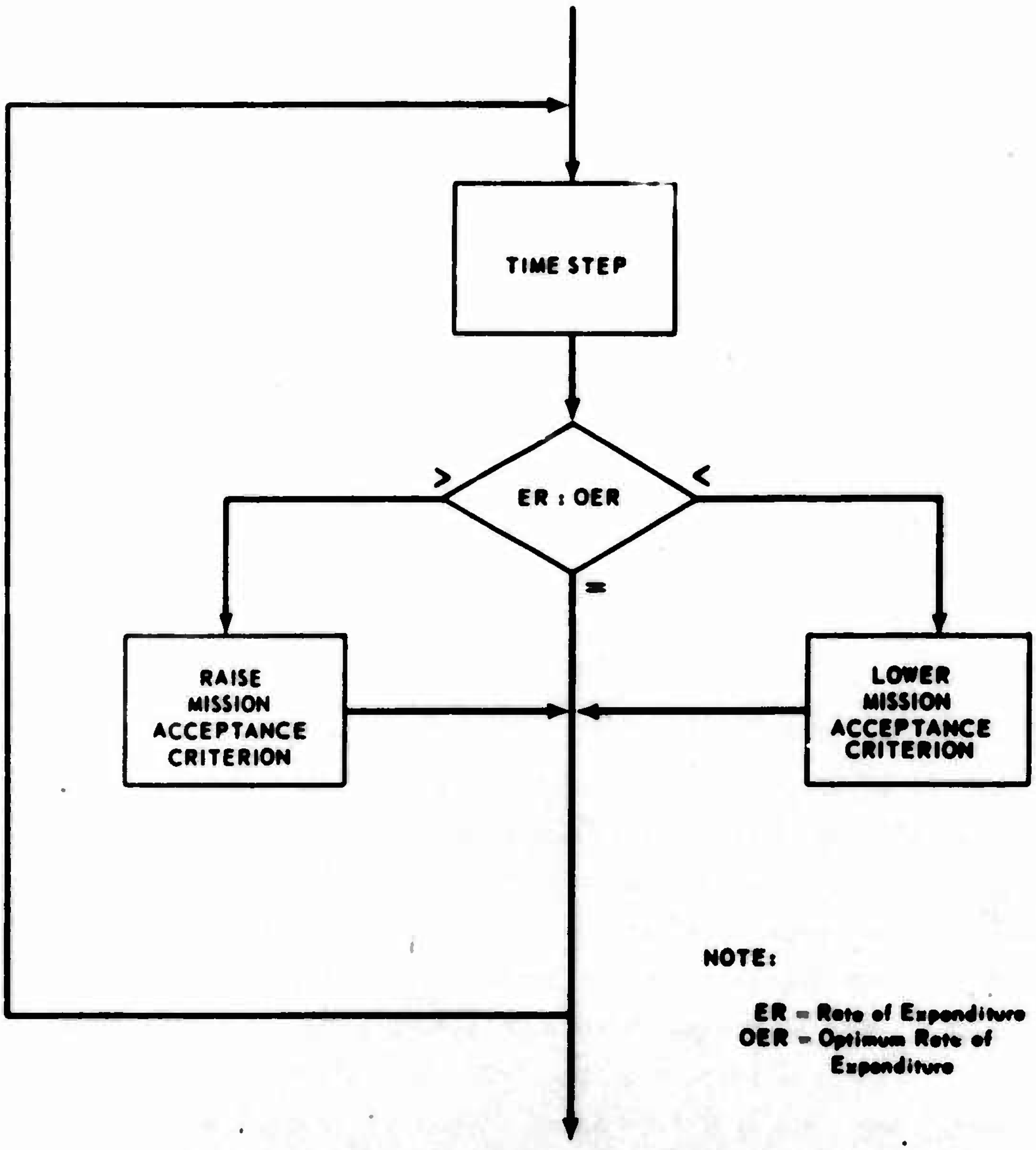


Fig. 2—Mission Assignment Feedback Logic

The original version of that portion of the EPIC logic pertinent to the present discussion contained two implicit assumptions that have required reconsideration in the course of the present effort. The first implicit assumption was that demand density would remain about uniform over a type 12-hour period (i.e., a 12-hour period characterized by a combination of weather condition, daylight/darkness condition and type activity battle day). The second implicit assumption was that the distribution of achievable effectiveness (in terms of the pre-defined measure) was identical to that of mission density. Under these two assumptions, then, the feedback logic was designed to keep the Mission Acceptance Criterion within such a range of values as would result in an approximately uniform rate of flight time expenditure over each 12-hour period. With this logic the model would not respond plausibly to a demand skewed heavily toward the early part of a 12-hour period. Rather, the feedback logic would maintain the Mission Acceptance Criterion within a range of values such as to expend available flight hours uniformly over the 12-hour period. Since few or no missions appeared in the demand during the latter portion of the 12-hour period, the Mission Acceptance Criterion was maintained at too high a range of values and missions were rejected that should properly have been accepted.

To overcome this deficiency routines were added to the model preprocessor to examine the demand associated with each type 12-hour period and calculate demand distributions at 2-hour resolution. The assumption here is that operational personnel responsible for assigning missions would have a good general estimate of how demand levels were likely to vary over a typical 12-hour period. Also, rather than simply representing numbers of missions appearing in the demand, the calculated distributions are in terms of achievable effectiveness. Here again, it was assumed that responsible operational personnel would have a reasonably good estimate of the general periods during which the more lucrative targets were likely to appear in the demand.

As a result of these modifications the model feedback logic constantly seeks to maintain the Mission Acceptance Criterion within a range of values such that the flight time allocated to each 2-hour period (such allocation having been made on the basis of the previously mentioned 2-hour resolution sketch of the demand distribution) is expended uniformly over the 2-hour period.

In addition to these modifications, investigations were also conducted to determine the most suitable method of adjusting the value of the Mission Acceptance Criterion (i.e., how great an adjustment should be made upon each feedback comparison, etc.). The results of these investigations are covered subsequently in this report under RESULTS OF EXPLORATORY AND SENSITIVITY RUNS.

AUGMENTATION OF LOGIC TO REPRESENT EXPLICITLY REPLENISHMENT OF FUEL AND ORDNANCE STORES

The initial version of the EPIC model did not provide for explicit representation of return to a rear area logistics base when fuel or ordnance onboard the aircraft fell below some specified minimum value. As a part of the effort reported here the model logic was augmented to include such representation and the operability of this added logic in the model has been successfully tested.

The implementation of this feature requires the following inputs in addition to those required in the original version of the model:

1. Maximum fuel and ordnance loads for each aircraft type
2. Fuel consumption rate for each aircraft type
3. Minimum values for onboard fuel and ordnance
4. Times required to fly to and from the rear area logistics base.

ATTRITION-LIMITING LOGIC

The logic of the model has been augmented to permit attrition limiting on the basis of input criteria.

In its present form the model demand is organized on the basis of three type activity days and two type weather days (in addition to daylight and darkness conditions), thus yielding a total of six unique type days. The input structure permits the specification of attrition-limiting criteria as a function of the type day. For example, a relatively high value for the attrition limit might be input for a high-activity, good-weather type day, whereas a relatively low value might be input for a low-activity, bad-weather type day.

An input variable determines the number of days into the game the specified attrition limits are to apply. A subsequent section of this report addresses the effect of various values of attrition limiting.

MODIFICATION TO MAKE AVAILABLE A SPECIFIED MINIMUM VALUE OF MISSION TIME FOR EACH COMBAT DAY

In the original version of the model it was possible for the entire helicopter fleet to be grounded for one or more days because of the maintenance backlog that had accumulated. This was not considered a particularly plausible phenomenon, since as a general rule operational personnel would phase in the required maintenance time such as to leave at least some time available for missions during each day.

The logic of the model has been modified to permit input specification of the minimum value of available mission time for each day of the game. This logic does not override the required maintenance routine, but rather merely postpones some specified fraction of the accumulated maintenance backlog to make available some mission time on days during which there would otherwise be no time available for missions.

This minimum value can be input, of course, as zero, in which case total shutdown could occur if the input maintenance penalty/flight hour is rather large and flight activity rather intense for several days.

GAME TERMINATION LOGIC

The original model logic terminated the game at the end of some pre-specified number of days. This logic has been modified to terminate the game when either of two conditions occur: the pre-specified number of days have elapsed, or the friendly helicopter fleet has fallen below some pre-specified minimum strength.

PLOTTING ROUTINE

A plotting routine was designed and incorporated as an output option for the EPIC game summary.

This routine plots a specified number of dependent variables (as a function of time) at game's end; dimensioning of the program at the present time limits the number of such variables to five.

The Y-scale is selected by input variable for convenient proportioning. The X-scale is selected automatically depending upon the number of coordinate pairs to be plotted.

A highly generalized switching logic (i.e., defining the dependent variables to be plotted at the conclusion of a given run) is not incorporated in the program at the present time. A suitable switching logic would best be designed in accordance with the particular application of the model. In any case, this would constitute a very simple addition to the program.

RESULTS OF EXPLORATORY AND SENSITIVITY RUNS

A summary plot (cumulative tank kills vs time) of the base case run is shown in Figure 3. For the subsequent exploratory and sensitivity runs the input values (except as noted) remained the same as those for the base case. However, detailed refinements of model logic were incorporated as the investigations progressed (particularly in the area of model response to mission demand) so that comparisons of subsequent runs with the base case run are not strictly valid. For this reason, the subsequent runs generally contain their own "base case" input set to permit assessment of model sensitivity to inputs. The input set used for the base case run is shown in Table 2.

MODEL RESPONSE TO MISSION DEMAND

A substantial fraction of the effort covered in this report was devoted to somewhat detailed investigations of the response of the EPIC model to mission demand. Particular emphasis on this area of investigation was considered justified, since the detailed response of the model in this regard was rather imperfectly understood at the beginning of this effort, and it was recognized that a clear understanding of the response characteristics was essential to the proper use of the model.

As mentioned previously, the model response to mission demand is controlled by a system of feedback loops that, in effect, simulate the mission assignment decision process of operational personnel charged with the responsibility for making such mission assignments. The investigations reported here have been guided by a two-fold objective: on the one hand, we have earnestly sought to avoid simulating stupid decisions; on the

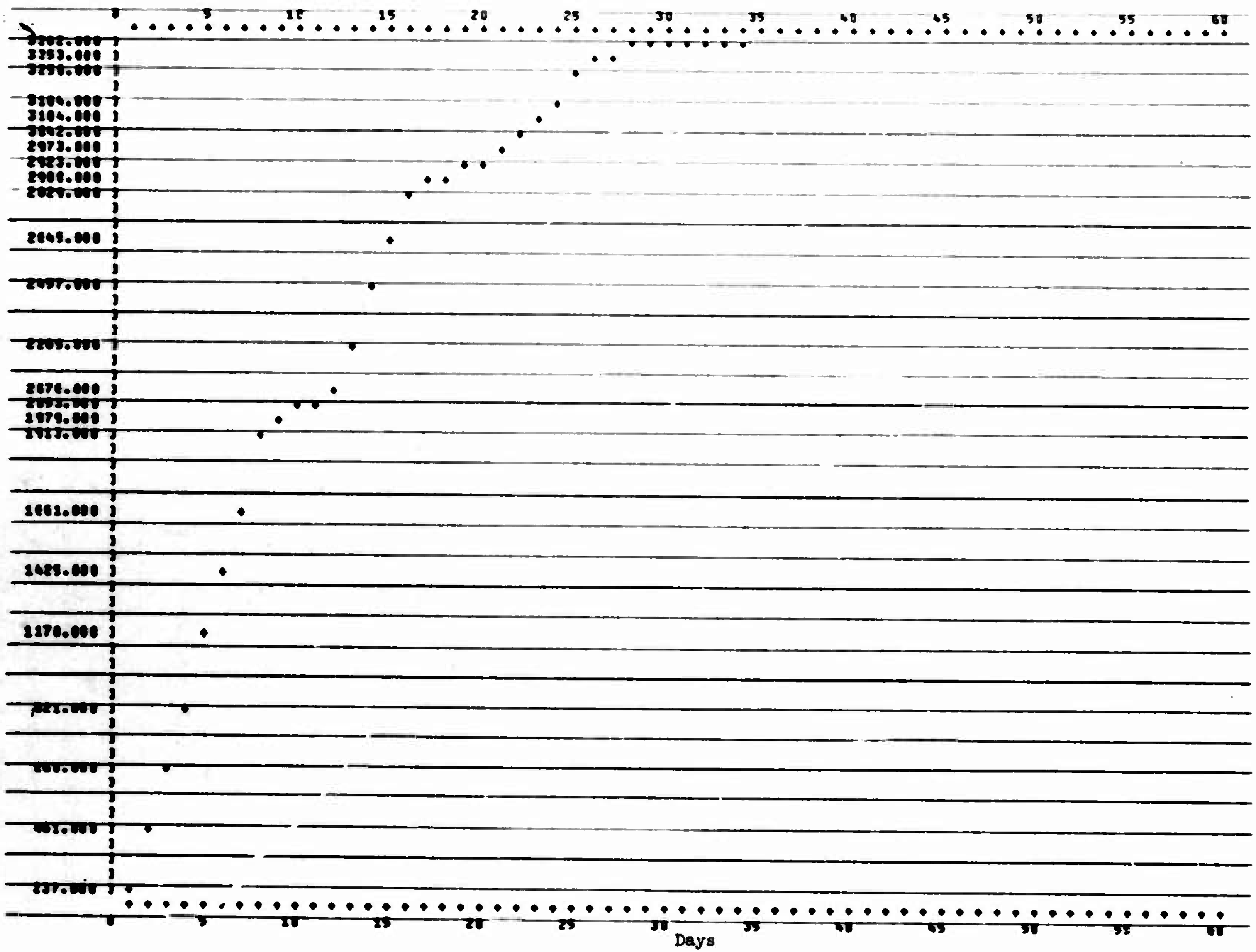


Fig. 3—Base Case, Tank Kills vs Time (Days)

Table 2

INPUT DATA SET FOR THE BASE CASE*

Fleet Composition:	30 AH-56A 120 AH-1G/TOW 50 AH-1G
Allowable Daily Attrition:	No limit.
Flight hours/helicopter/day:	1 - 4
Maintenance hours/flight hour:	5
Daily Scheduled Maintenance:	10-60 percent of available time
Aircraft Replacement Rate:	None
Stand-down Periods:	None
Mission Acceptance Criterion Adjustment Increment:	Mean
Demand Distribution:	Approximately Uniform
Minimum Specified Mission Hours/Day:	1

*See Table 1 for scenario-oriented inputs.

other, we have tried to avoid attributing a wholly unrealistic omniscience— and more particularly, prescience— to the operational personnel responsible for assigning missions. We have presupposed operational personnel who are intelligent and alert, who have some knowledge (and some uncertainty) as to the general trend of event in the near future, and who have a clear working understanding of an effectiveness measure within whose context their mission assignment decisions are to be made.

The original mission assignment logic of the model used "bang-bang" feedback control. Furthermore, the adjustment increment used was the mean value of the dollar-weighted exchange ratio (i.e., expected target effects per expected dollar cost to the friendly force) applicable to the type 12-hour period. This was the feedback logic used in the Base Case run whose summary plot (cumulative tank kills vs time) appears in Figure 3. An additional benchmark run was made in which the mission assignment feedback logic was completely short-circuited; a summary plot of the results of this run (cumulative efficiency* vs time) is shown in Figure 4. Some corresponding values for the two runs (as of D+12) are shown in Table 3.

Table 3

FEEDBACK COMPARISON VALUES

	Base case	Benchmark run with mission assignment feedback inoperable
Cumulative efficiency value	3.687	3.412
Missions accomplished	949	931
Armored vehicles killed	3483	3301
Friendly helicopters remaining	42	37

The differences appearing in Table 3 would have been substantially greater for just about any variation of the scenario sequence from that used in the two runs. The differences would also have increased substantially, of course, had the second run been permitted to continue to

*This "efficiency" value is expected armored vehicles killed/expected friendly dollar loss.

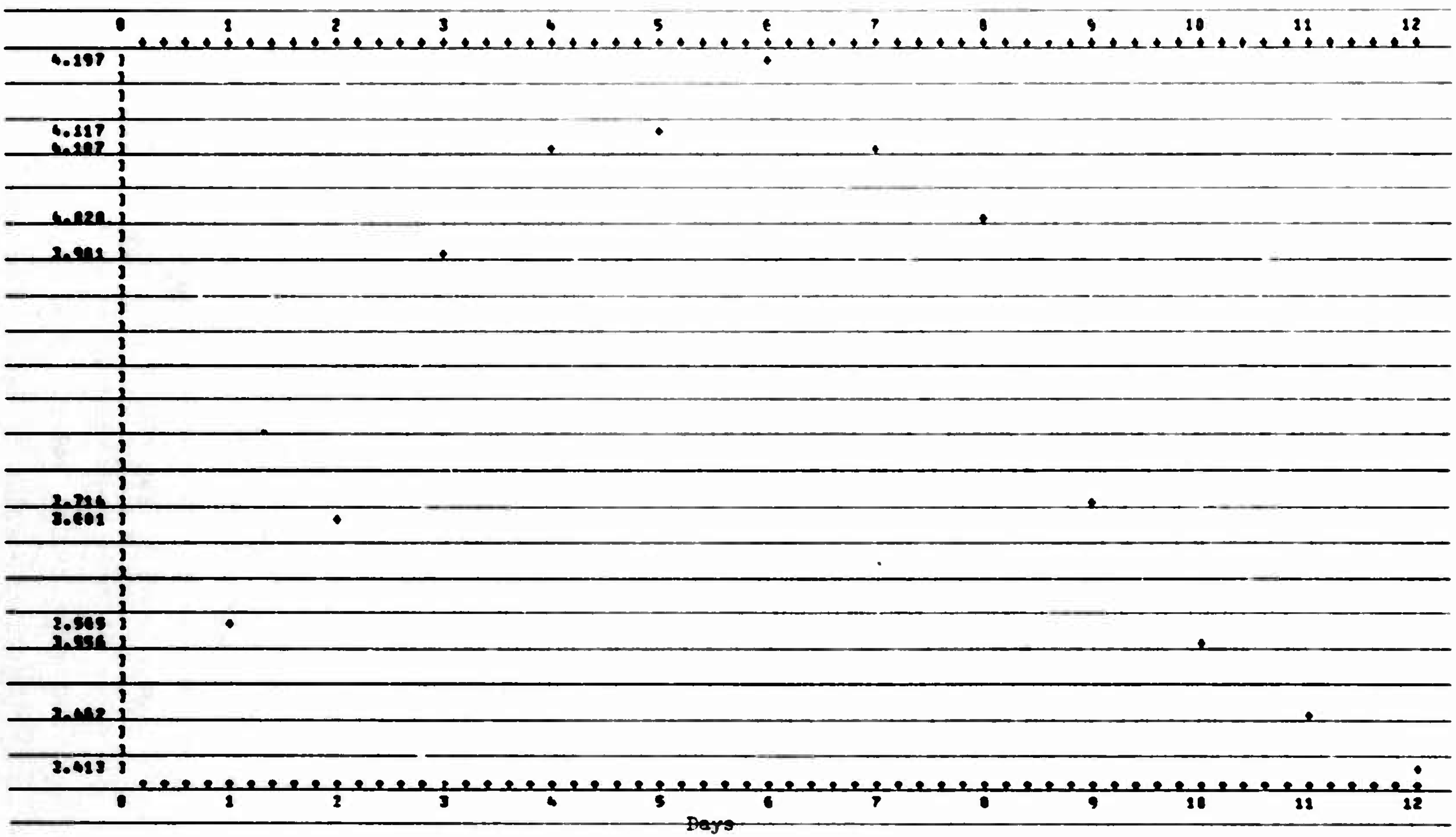


Fig. 4—Mission Assignment Without Feedback Control
(Cumulative Performance Efficiency vs Time)

exhaustion of the friendly fleet (as was the case with the Base Case run). Finally, the mission assignment decision process as it is represented in the logic of the Base Case run falls considerably short of the capabilities of competent, experienced operational personnel. In summary, it is fair to say that the simulation of truly stupid decisions is reflected in Figure 4 and the corresponding values appearing in Table 3.

One of the first experiments conducted after the expanded data set became available was one in which the feedback adjustment increment was varied across a wide range of values and the model response noted. Figure 5 shows a family of curves (cumulative efficiency vs time) showing the effect of four widely spaced values of this adjustment increment. It would appear that for this particular demand distribution— and assuming that efficiency of performance were the sole characteristics of interest— an adjustment increment value of about mean/128 is a good choice. But is efficiency of performance the only characteristic of interest? Is not the number of missions accomplished (or the quantity of target effects achieved) also a necessary component of the effectiveness measure? It is interesting to note that the adjustment increment value producing the highest cumulative efficiency resulted in the accomplishment of only 657 missions over the 12-day period examined; the value producing the next highest efficiency resulted in accomplishment of 729 missions; the value producing the next highest resulted in 857 missions; and, finally, the value producing the lowest cumulative efficiency resulted in accomplishment of 928 missions.

The family of curves shown in Figure 6 was produced with the dependent variable defined not simply as efficiency but rather as the product of efficiency and the fraction of total missions that were accomplished. It will be noted that the curves have reversed their order. Two conclusions suggest themselves from studying the runs represented in Figures 5 and 6. First, we are seeing the not infrequently encountered situation where the mode of performance resulting in the highest efficiency also produces the lowest value of accomplishment within some given period of time. Second, the mission assignment logic of the model is not functioning as it was intended to function.

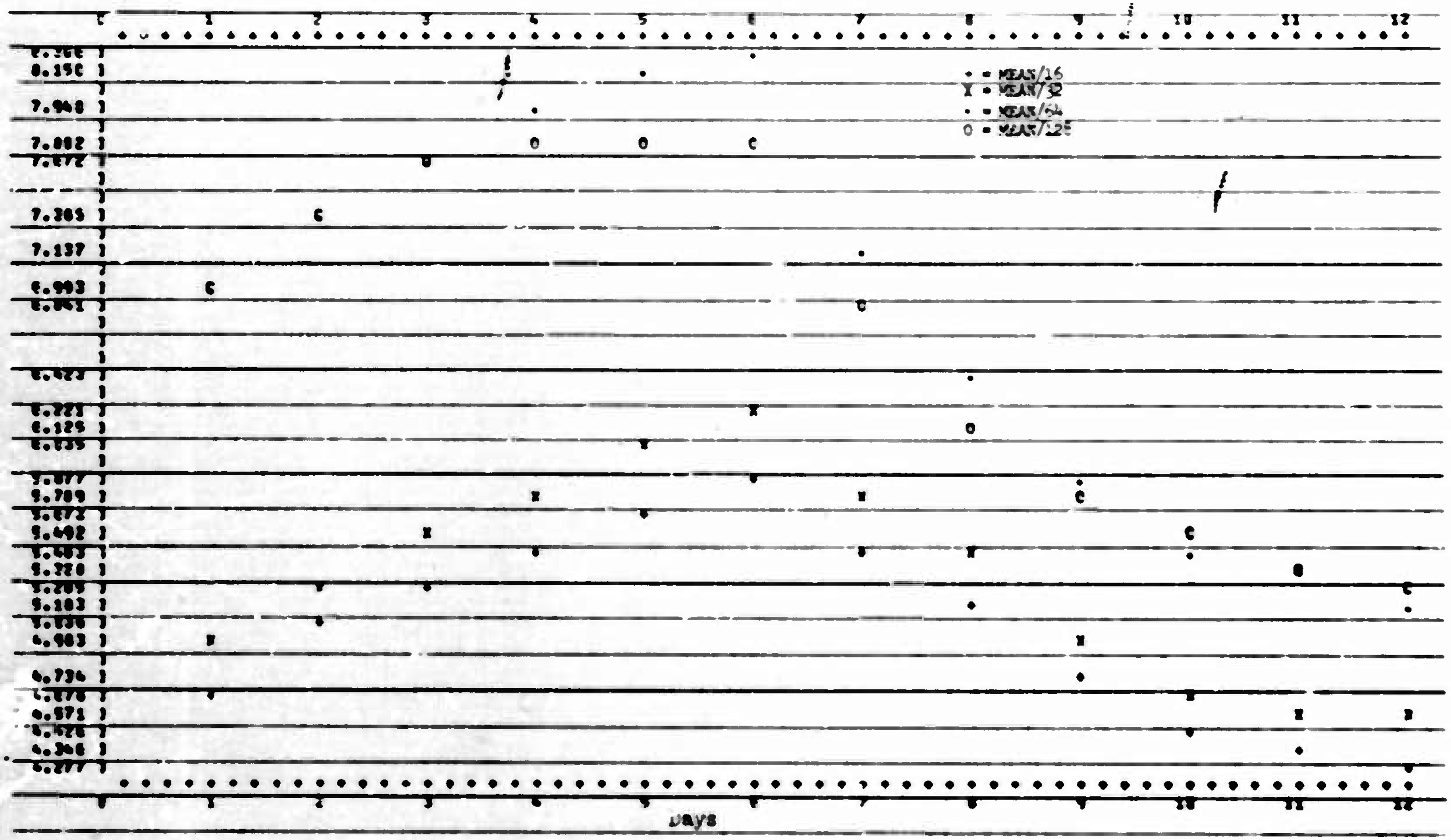


Fig. 5—Effect of Variation of Mission Acceptance Criterion Adjustment Increment
(Cumulative Performance Efficiency vs Time)

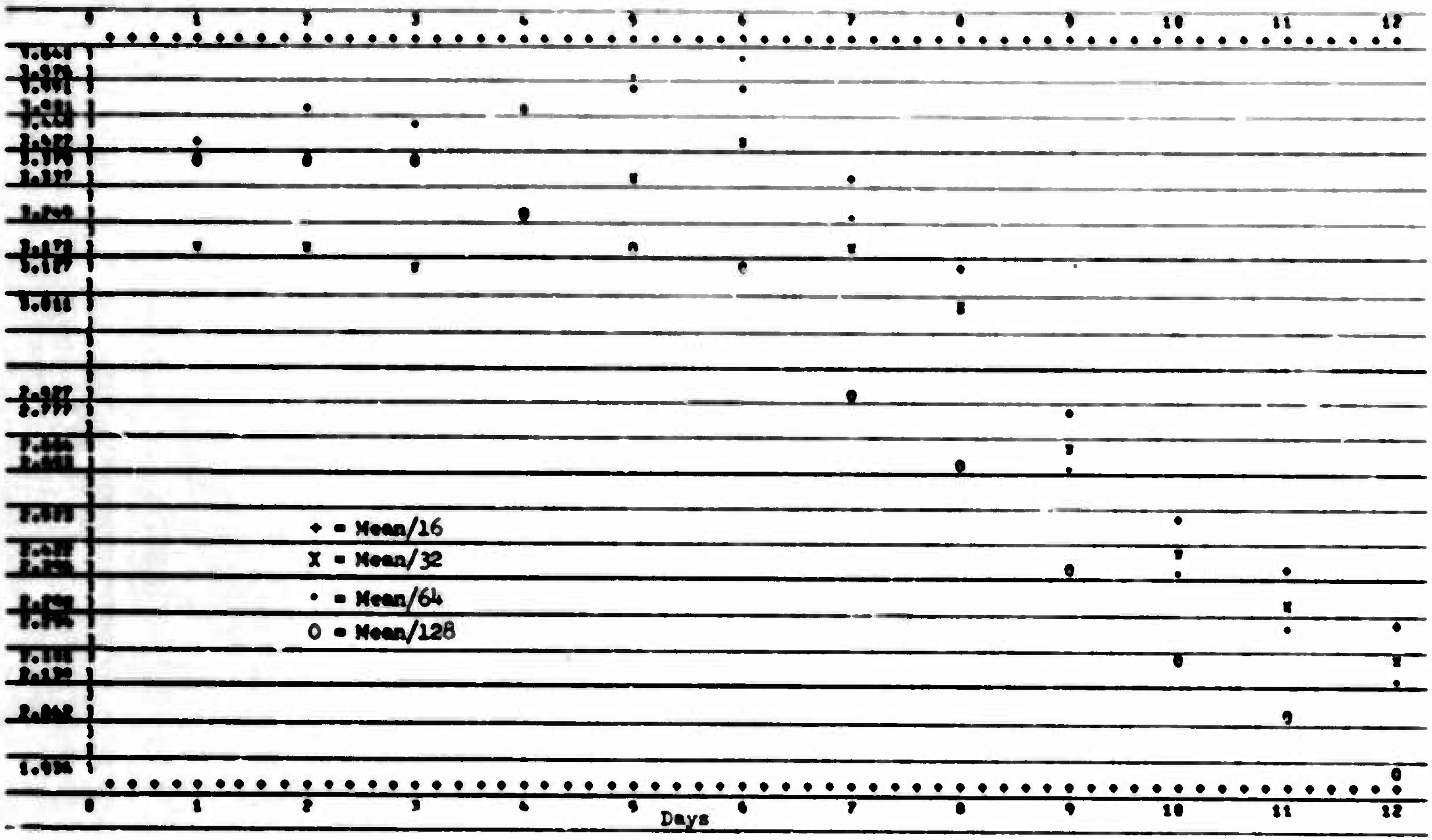


Fig. 6—Effect of Variation of Mission Acceptance Criterion Adjustment Increment
(Efficiency Times Fraction of Missions Accomplished vs Time)

Before we begin to consider this second conclusion in some detail it may be worth while to remind ourselves that the curves in Figure 5 do not represent the efficiency values achieved by four different helicopter fleets. Rather, these curves represent the efficiency values achieved by one specific helicopter fleet under four different representations of how that fleet is utilized operationally. More specifically, we are looking at the results of four trade-off compromises concerning the efficiency of utilization on the one hand and the number of missions accomplished (or target effects achieved) on the other. Furthermore, we have not consciously dictated these trade-off compromises by input (as would be the case where friendly attrition rates were limited by input criteria, as discussed subsequently); rather, they have occurred as a result of the inadequacy of the mission assignment control logic.

Figure 7 shows schematically the mechanism resulting in the trade-off compromises reflected in the curves of Figure 5. The figure on the left represents the case where a large adjustment increment is used (in this case, an increment equal to the mean dollar-weighted exchange ratio). The figure on the right represents the case where a very small adjustment increment is used. In both cases the Mission Acceptance Criterion is initialized at the mean value of the dollar-weighted exchange ratio. In the figure on the left the Mission Acceptance Criterion value drops abruptly at the end of the first time step to a value well below that which would result in uniform expenditure of available flight time. In the figure on the right the Mission Acceptance Criterion is driven downward slightly with each successive time step but is adjusting so slowly toward the ideal value (the dashed line) that markedly fewer missions are undertaken than could be with the flight time available. In the figure on the left, the adjustment increment is so gross that many missions below the dashed line are accepted and many above it are rejected.

The reason for dynamic control of the Mission Acceptance Criterion is two-fold: (1) the criterion should remain within a range of values sufficiently low that the flight time allocated to a given time period will be expended during that time period, and (2) the criterion should remain within a range of values sufficiently high that the less lucrative

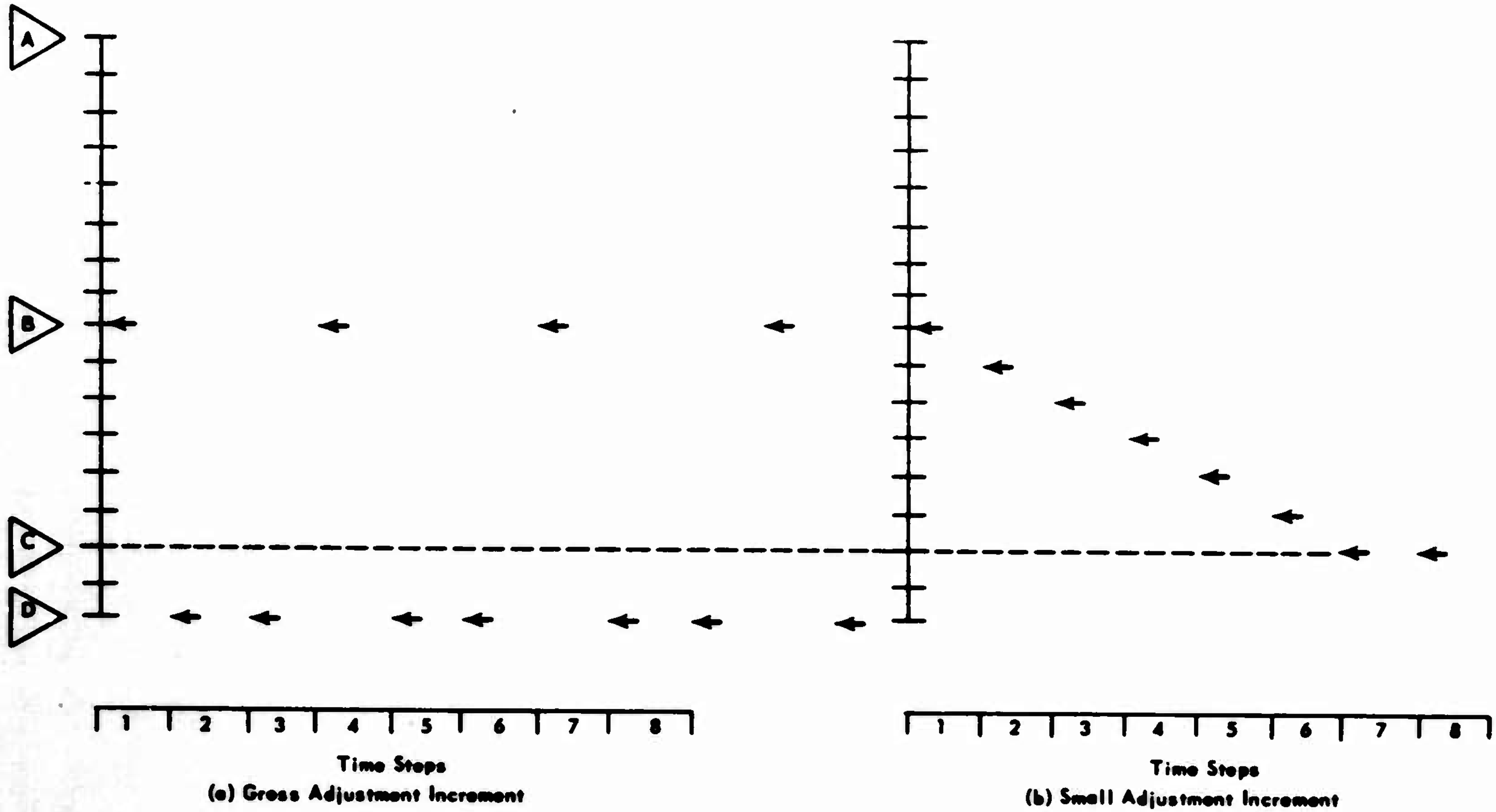


Fig. 7—Fixed-Increment Adjustment of Mission Acceptance Criterion

← = Mission acceptance criterion position.

(A) = Maximum dollar-weighted exchange ratio value.

(B) = Mean dollar-weighted exchange ratio value.

(C) = Ideal mission acceptance criterion position (to achieve maximum efficiency of expenditure of allocated quantity of resource such as flight hours, etc.).

(D) = Minimum dollar-weighted exchange ratio value.

missions will be rejected and the available flight time spent on the more lucrative missions. Bang-bang control, as represented by the two extremes depicted in Figure 7, is a rather imperfect method of maintaining the Mission Acceptance Criterion within an approximately optimum range of values.

During the earlier stages of model development some consideration had been given to the use of proportional control for constantly positioning the Mission Acceptance Criterion, but the concept was shelved by one of the many quick decisions made during the development of the model. Figure 8 depicts schematically how the Mission Acceptance Criterion should behave when driven by proportional feedback control. In this case the magnitude of adjustment is always approximately proportional to the magnitude of the sensed error.

The slight modifications required to convert the mission assignment logic to proportional feedback control were made and the run represented by the curves in Figure 5 was repeated; in this case, however, the four values used were those for the scaling constant used to determine the absolute magnitudes of the adjustments. The result is shown in Figure 9.

Pertinent values associated with the run plotted in Figure 9 are tabulated below.

Value of Scaling Constant	Cumulative Efficiency Value	Missions Accomplished
Mean/16 (+)	4.175	986
Mean/32 (X)	4.175	978
Mean/64 (•)	4.214	997
Mean/128 (O)	4.279	998

The cumulative efficiency values in Figure 9 do not compare at all favorably with those in Figure 4, of course. However, what is notably lacking in the Figure 9 run is any evidence of a trade-off compromise between efficiency of performance and missions accomplished (or target effects achieved). In fact, for the run plotted in Figure 9 the value of the scaling constant resulting in the highest efficiency of performance also produced the greatest number of missions accomplished. It

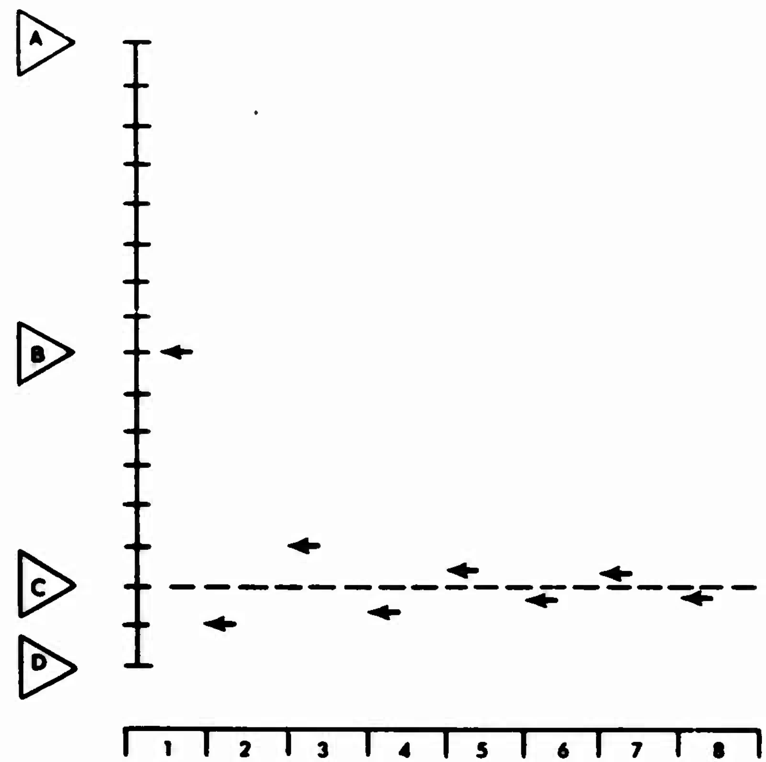


Fig. 8—Proportional Control of Mission Acceptance Criterion

← = Mission acceptance criterion position.

A = Maximum dollar-weighted exchange ratio value.

B = Mean dollar-weighted exchange ratio value.

C = Ideal mission acceptance criterion position (to achieve maximum efficiency of expenditure of allocated quantity of resource such as flight hours, etc.).

D = Minimum dollar-weighted exchange ratio value.

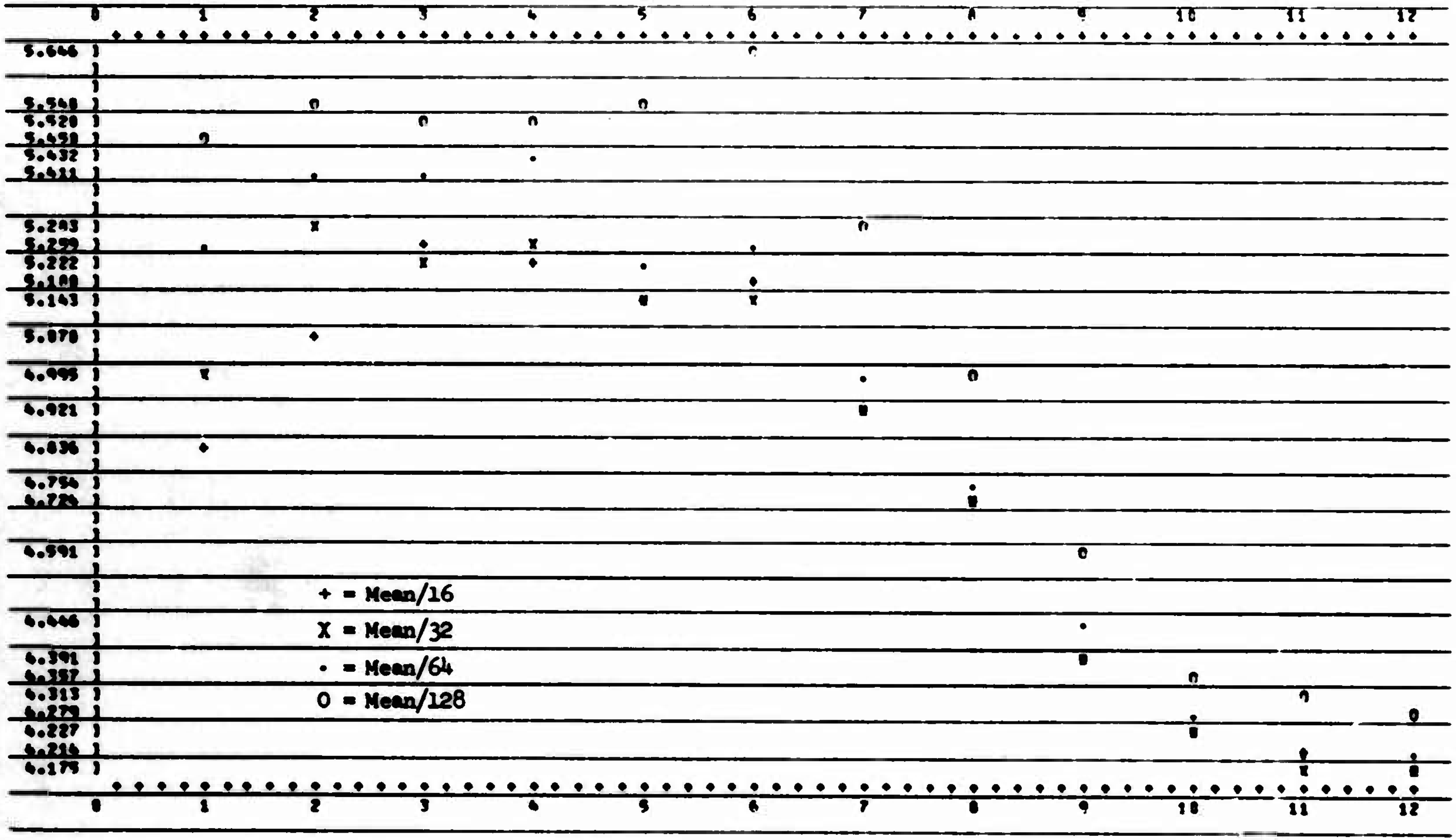


Fig. 9—Effect of Proportional Feedback Control
(Cumulative Performance Efficiency vs Time)

will also be noted that the number of missions accomplished does not vary greatly for this range of values of the scaling constant, and that the lowest number of missions accomplished is substantially greater than the highest number accomplished when a fixed-increment adjustment of the Mission Acceptance Criterion was being used (Figure 5).

It appears, in fact, that the mission assignment logic is now functioning as it was intended to function. That is, the more lucrative missions are being selected from the demand and at the same time the implied constraint (that resources allocated for expenditure during a given period of time are in fact expended during that period of time) is being enforced. It is clear, for example, that if this run were repeated with the dependent variable defined as it was for Figure 6, no reversal of the ordering of the curves would result.

The curves of Figure 9 suggested, of course, that a further reduction of the value of the scaling constant might result in the accomplishment of more missions without loss of efficiency of performance. This was not, however, the case, as shown in Figure 10. Corresponding values from the two runs are tabulated below.

	Scaling Constant Value	Cumulative Efficiency	Missions Accomplished
Figure 9 run:	Mean/16	4.175	986
	Mean/32	4.175	978
	Mean/64	4.214	997
	Mean/128	4.279	998
Figure 10 run:	Mean/128	4.279	998
	Mean/256	4.321	966
	Mean/512	4.379	909
	Mean/1024	4.565	821

The efficiency of performance increases as the value of the scaling constant decreases, but only at the expense of fewer missions accomplished (at least, that is, for the gross reductions used in the run

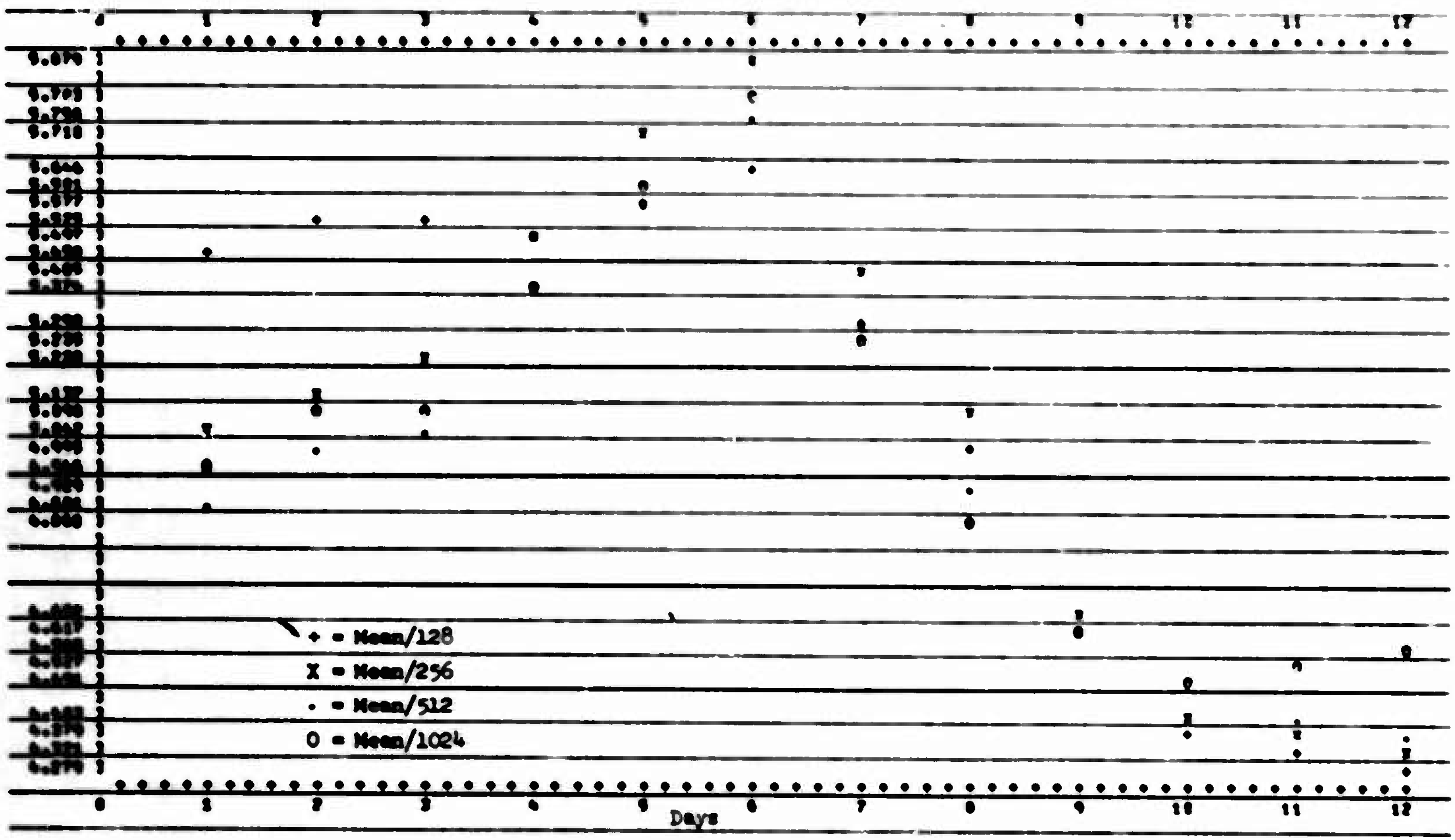


Fig. 10--Effect of Wider Range of Scaling Constant Values in Proportional Control
(Cumulative Performance Efficiency vs Time)

plotted in Figure 10). It will be noted that th number of missions accomplished does not really vary in a wholly orderly fashion as the value of the scaling constant is decreased. In particular, the value of 978 missions accomplished (when the scaling constant has a value of Mean/32) is an unexpected result. This sort of thing reflects the rather gross discontinuities that occur in the dollar-weighted exchange ratios associated with the missions appearing in the demand. It will be recalled that the dynamically adjusted Mission Acceptance Criterion (whose value at any point in time determines whether a mission appearing in the demand at that point will be accepted or rejected) is referenced to the ordered array of dollar-weighted exchange ratios characterizing the missions in the demand. If this array of dollar-weighted exchange ratios were a virtual continuum extending from some minimum to some maximum value, then the problem of feedback control of the Mission Acceptance Criterion would be a relatively simple one. For the data set used in these runs, however, very appreciable discontinuities occur among these values (and it appears quite likely that the same characteristic would be present in any reasonably large set of mission types considered suitable for the attack helicopter). As a result of the untidy nature of the distribution of dollar-weighted exchange ratios, a given adjustment of the Mission Acceptance Criterion can have a wide range of consequences (in terms of missions accepted or rejected) depending on the value of the Criterion before the adjustment was made. That is, in some cases a relatively small adjustment can result in a marked increase (or decrease) in mission acceptance rate (this being the case within those regions where the dollar-weighted exchange ratios are not widely different in value). In other cases a relatively large adjustment of the Mission Acceptance Criterion can have little or no effect on the rate of mission acceptance or rejection— this being the case when the Criterion is adjusted from a value lying within or near one of the abrupt discontinuities that occur within the array of dollar-weighted exchange ratios.

When these vagaries of the data characterizing the demand are considered, the question naturally arises as to just how near we have come to optimum utilization of the helicopter fleet in question (under the input assumptions) through use of proportional feedback control of the Mission Acceptance Criterion. An unequivocal answer to this question would require analysis not possible within the scope of the effort reported here, but some pretty good guesses can probably be made.

To consider, for example, a closely related question but one considerably less complex: What is the maximum possible number of missions that can be accomplished by this fleet within a 12-day period (and under the input assumption)? We know from the run whose summary plot is shown in Figure 4 that a simple-minded "take-'em-as-they-come" mission assignment policy results in the accomplishment of 931 missions during the 12-day period. We know from the runs whose summary plots appear in Figures 9 and 10 that use of proportional feedback control with a scaling value of Mean/128 results in the accomplishment of 998 missions. It may be of value also to consider the results of several runs made in which the demand distribution was deliberately skewed.

The runs whose summary plots are shown in Figures 11, 12, and 13 were made to determine the model's response to extreme cases of non-uniform demand distribution. In each figure the (+) curve shows response to the approximately uniform demand, the (X) curve shows response to a demand in which all missions appearing in each 12-hour period appear within the first 6 hours of the period, and the (·) curve shows response to a demand in which all missions appearing in each 12-hour period appear within the last 6 hours of the period. The three runs differed one from the other as follows: the run of Figure 11 used proportional feedback with a scaling value of Mean/128 (identical to the run plotted in Figure 9); the run of Figure 12 used logic similar to that of the Figure 9 run, except that the value of the scaling constant was made to increase as a function of the maximum peak-to-peak amplitude of variation of demand level (as measured at 2-hour resolution); the Figure 13 run used logic identical to that of Figure 12 run except that the initial scaling constant value was Mean/160 instead of Mean/128.

It will be noted that in all three of these runs the number of missions accomplished was greatest when the demand appeared approximately uniformly across each successive 12-hour period. It will also be noted

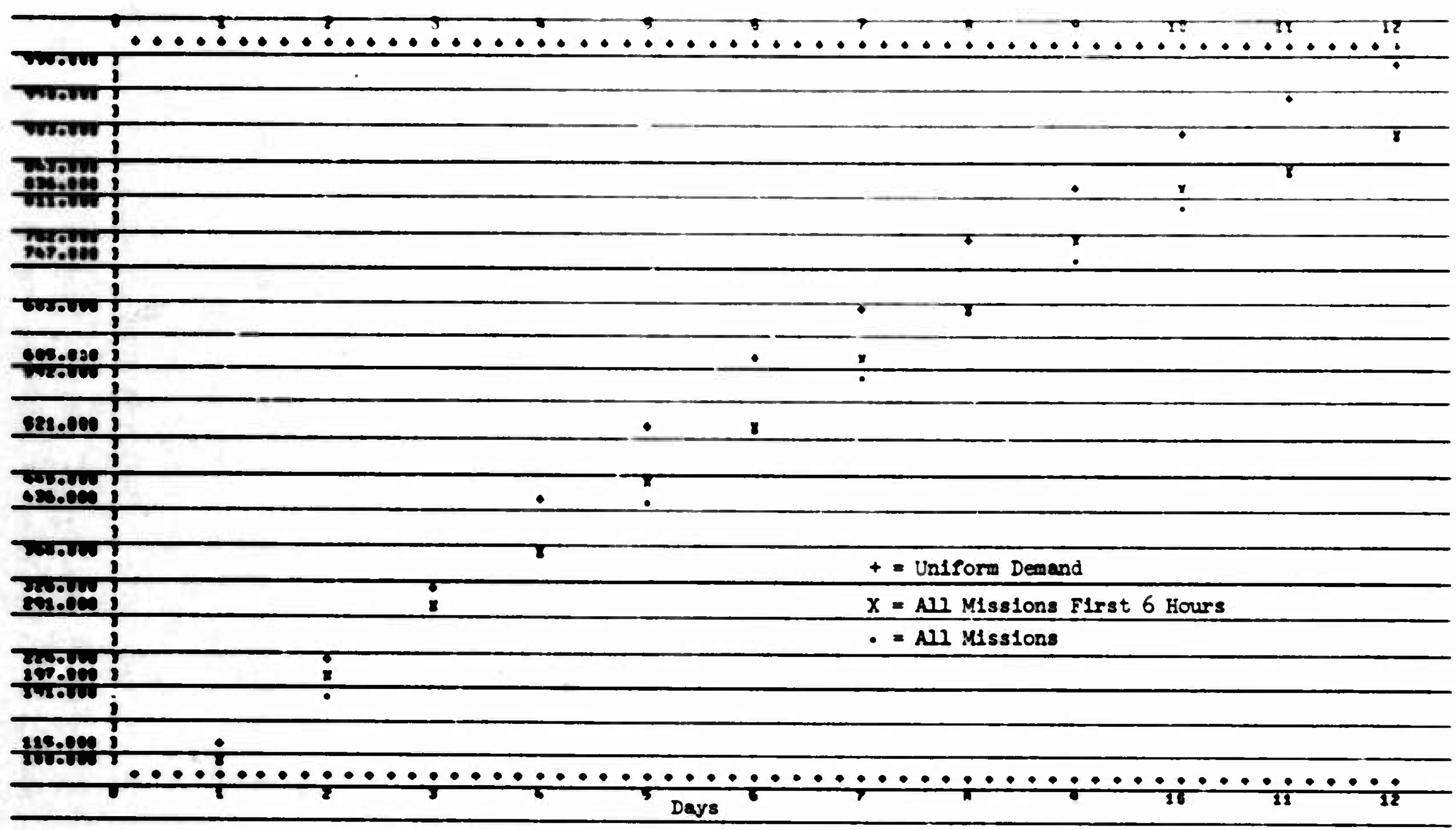


Fig. 11—Proportional Feedback Response to Skewed Demand
(Missions Accomplished vs Time)

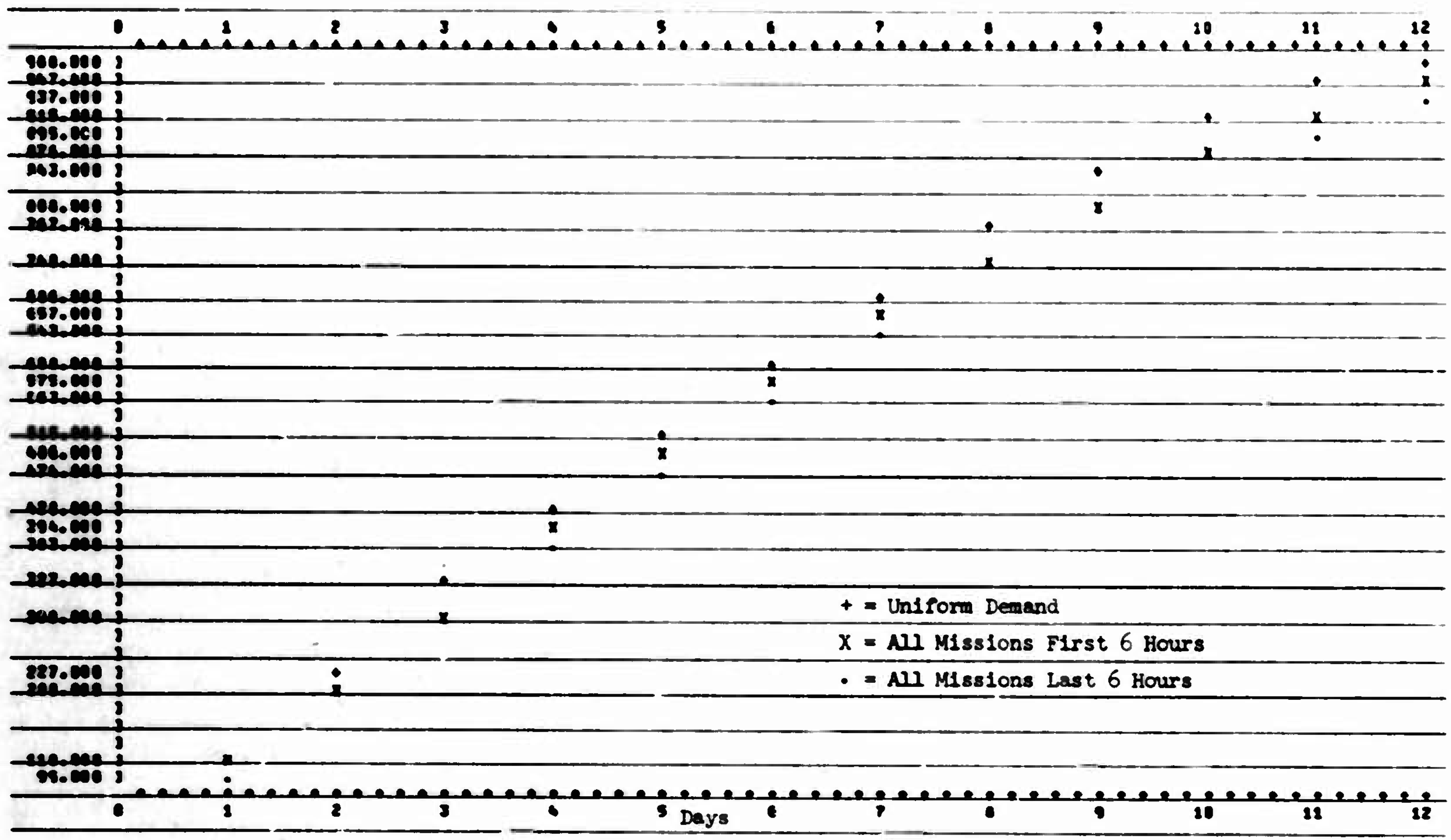


Fig. 12—Effect of Peak-to-Peak Compensation on Response to Skewed Demand
(Missions Accomplished vs Time)

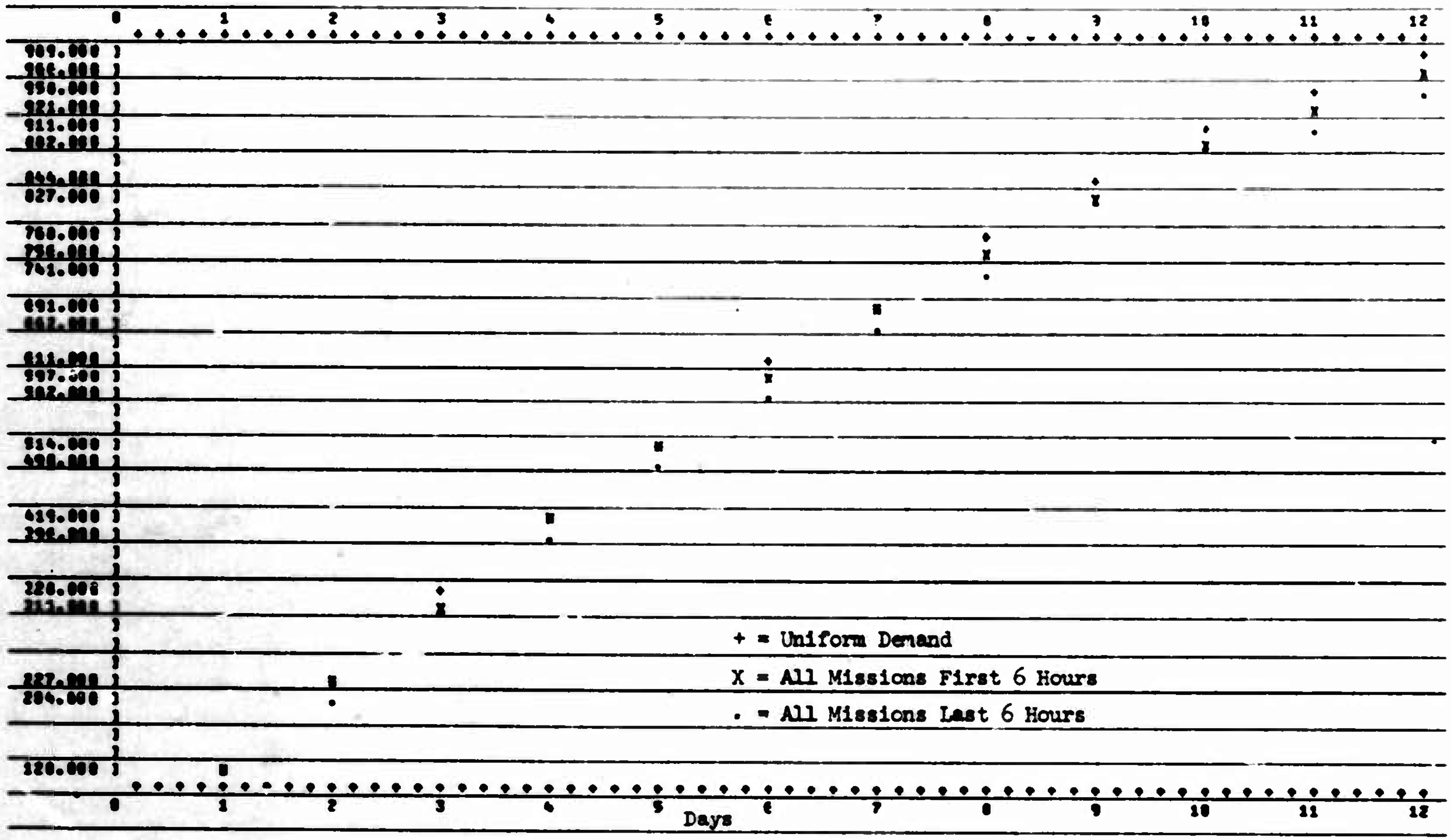


Fig. 13—Response to Skewed Demand with Adjusted Peak-to-Peak Compensation

that the logic leading to the higher number of missions accomplished from the uniform demand will not necessarily lead to higher numbers of missions accomplished from the non-uniform demands. If we sum the missions accomplished from all three demands of each run we find the following:

	Total missions accomplished
Figure 11 run:	2804
Figure 12 run:	2872
Figure 13 run:	2913

With these perhaps extreme distortions of the demand distribution it appears that the logic incorporated in the Figure 13 run would offer the best compromise solution.

As for the number of missions that could be accomplished with truly optimum utilization of this fleet under these conditions, a good guess would probably be slightly over 1000. At the same time, the number of missions accomplished cannot, strictly speaking, be equated with a cumulative target effects value. To return briefly to Figure 9, the following values apply:

	Missions accomplished	Tank kills	APC kills	23mm kills	Total target kills
(0) curve	998	2057	1662	150	3869
(•) curve	997	2155	1558	161	3874

Not only were more target elements killed by fewer missions, but clearly the distribution of type targets engaged were appreciably different for these two cases.

From the investigations reported here it appears that proportional feedback control of the Mission Acceptance Criterion provides the most suitable model response to mission demand. That is, this form of feedback logic tends to maximize cumulative target effects per friendly dollar cost while enforcing the constraint that resources allocated for expenditure during a given period of time are in fact expended toward the objective of achieving target effects. The value of the scaling constant used will need to be determined empirically for a given data set and with due regard for elements of the effectiveness measure involved. Any adjustment of this scaling value as a function of demand variability will also need to be determined empirically for a given data set.

EFFECT OF ATTRITION LIMITING

For the run whose summary plot appears in Figure 14 four levels of attrition limiting were specified by input criteria. Pertinent values are tabulated below.

Attrition limit	Cumulative efficiency	Missions accomplished
5%	8.626	229
10%	7.940	366
20%	6.212	539
100%	5.312	729

This run was made before the mission assignment logic was modified to incorporate proportional feedback control. The Mission Acceptance Criterion adjustment increment was Mean/64. It will be noted that even with no limitation on attrition the fleet here accomplished far fewer missions than it could have with the resources available (729 missions as compared to a maximum possible number of about 1000).

Whether or not attrition limiting increases the effectiveness of the fleet depends altogether, of course, on how the time factor is treated in the predefined effectiveness measure. If, for example, the effectiveness measure is taken to be the product of the efficiency of performance and the fraction of the total demand met, then the fleet will look better without any attrition limiting (that is, for this fleet performing within the context of this demand). If, on the other hand, the effectiveness measure is taken to be the cumulative target effects

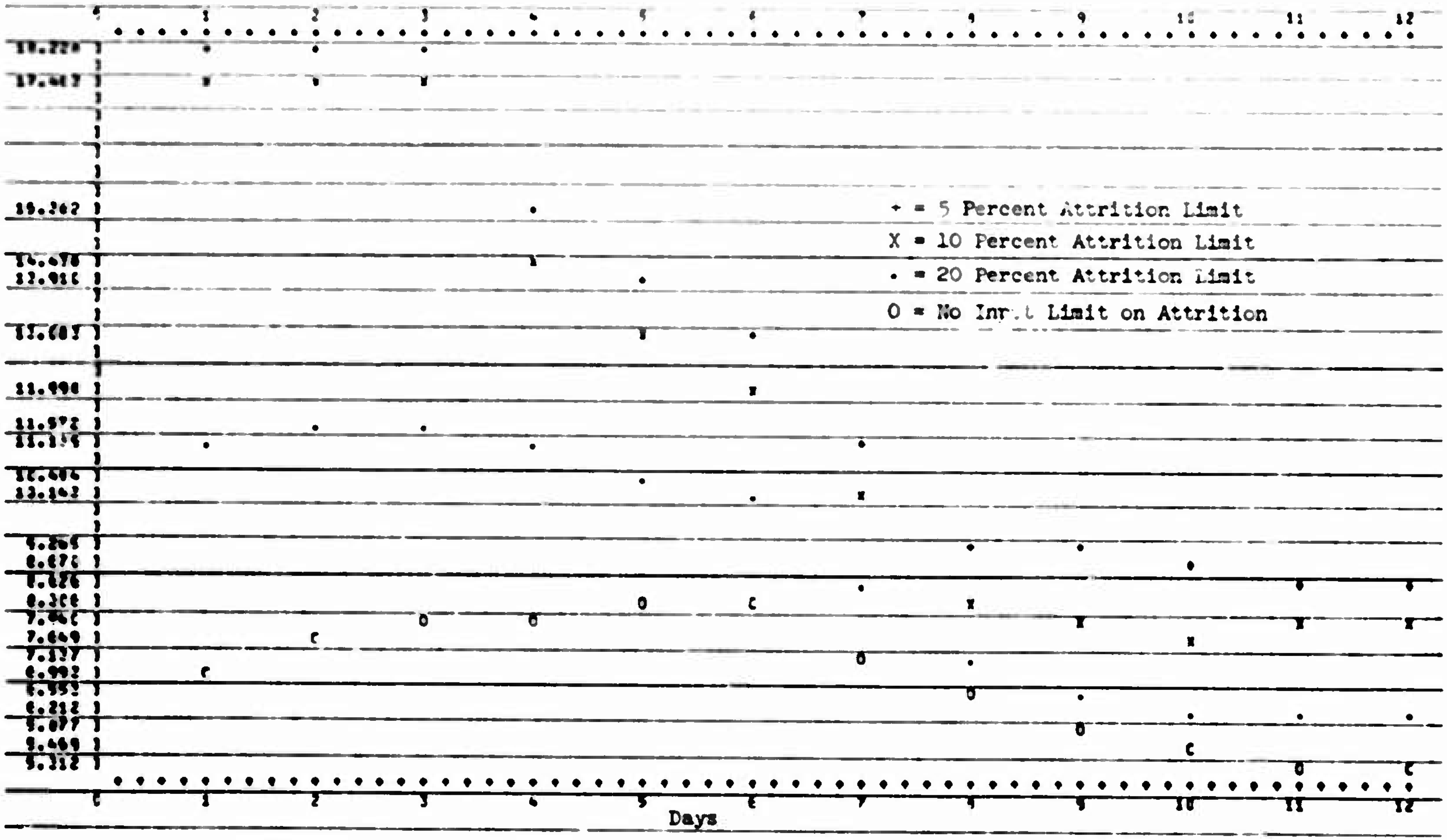


Fig. 14—Effect of Input-Specified Attrition Limiting (Cumulative Efficiency vs Time)

at (say) D+40, then we can be quite sure that some input-specified limiting of attrition will cause the fleet to look better than would no attrition limiting.

EFFECT OF MAINTENANCE PENALTY/FLIGHT HOUR

A run was made in which required (clock) maintenance hours/flight hour was varied from 5 hours to 10 hours to 15 hours. The summary plot of this run (missions accomplished vs time) is shown in Figure 15. The values appearing in Figure 15 are not to be compared with those of the previous plots. This run was made with a total fleet of only 45 helicopters (15 of each of the three types). The demand for this run was characterized by only two (of a total of twelve provided for in the input structure) type 12-hour periods. Input values for maximum flight hours/helicopter/day varied from 1 to 3 hours across the 12 days shown in the plot. Cumulative missions accomplished and efficiency of performance are tabulated below.

Maintenance penalty	Mission accomplished	Efficiency value
(+) 5 hrs/flight hr	557	12.131
(X) 10 hrs/flight hr	453	12.017
(•) 15 hrs/flight hr	400	12.046

The effect of maintenance penalty does not manifest itself in Figure 15 for the first three days, since the model permits some maximum maintenance delay specified by input, and the input value for these runs is 72 hours. The (X) and (•) curves remain parallel from D+4 through D+6 because in both cases a saturated condition exists; that is, in both cases maintenance required would have shut down the fleet completely except for the logic providing a minimum mission time each day (in these runs the input value is one mission hour/helicopter/day).*

It will be noted that the performance efficiency value remains essentially flat across the three cases, and at a level much higher

*In such cases of saturation required maintenance time equivalent to the minimum specified mission time is further delayed.

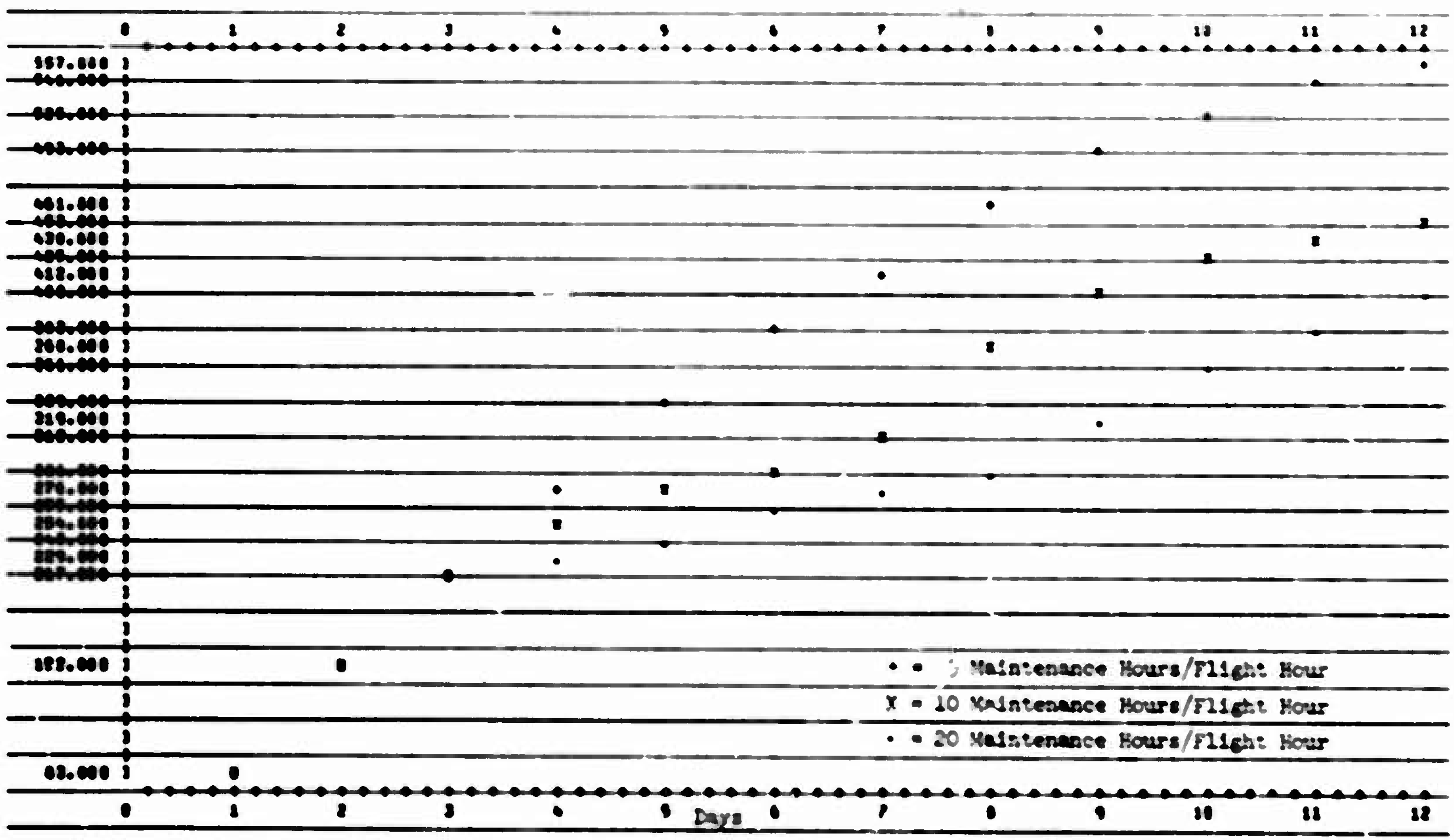


Fig. 15—Effect of Maintenance Required as a Function of Flight Time
(Missions Accomplished vs Time)

than is generally seen in the previous plots; this high efficiency of performance results from the particular segment of the total demand used for these runs.

It is noted in passing that for an effectiveness measure that considered only efficiency of performance (e.g., armored vehicles killed/friendly dollar loss) the maintenance penalty/flight hour (within the range considered in these runs) would be of little importance. However, for an effectiveness measure that also took into account the fraction of missions accomplished (or cumulative target effects achieved) over some specified period of time the value of the maintenance penalty would make a very substantial difference.

EFFECT OF SYSTEM RESPONSE TIME

Figure 16 shows a summary plot (cumulative missions accomplished vs time) of a run in which alternative values of system response time were input. Note that actual mission flight times were not varied in this run, but only those non-flight components of total mission time such as would be required for pre-flight check-out, fueling and loading of ordnance, pilot briefing, etc. Specifically, the (+) curve reflects the total mission time estimates as they were derived for the data set used in the base case; the (X) curve reflects total mission times that are 1.5 times the base case estimates; and the (•) curve reflects total mission times that are twice the base case estimates. Here again the total fleet is only 45 helicopters (15 of each of the three types). Pertinent values for the 12 day period are tabulated below.

System response time	Mission accomplished	Cumulative efficiency
Base case estimates	557	12.131
1.5 X estimates	527	11.210
2 X estimates	512	11.634

The maintenance penalty value used here was 5 (clock) maintenance hours/flight hour; the same limited demand segment was used that was used for the runs whose summary plots appear in Figures 15 and 19.

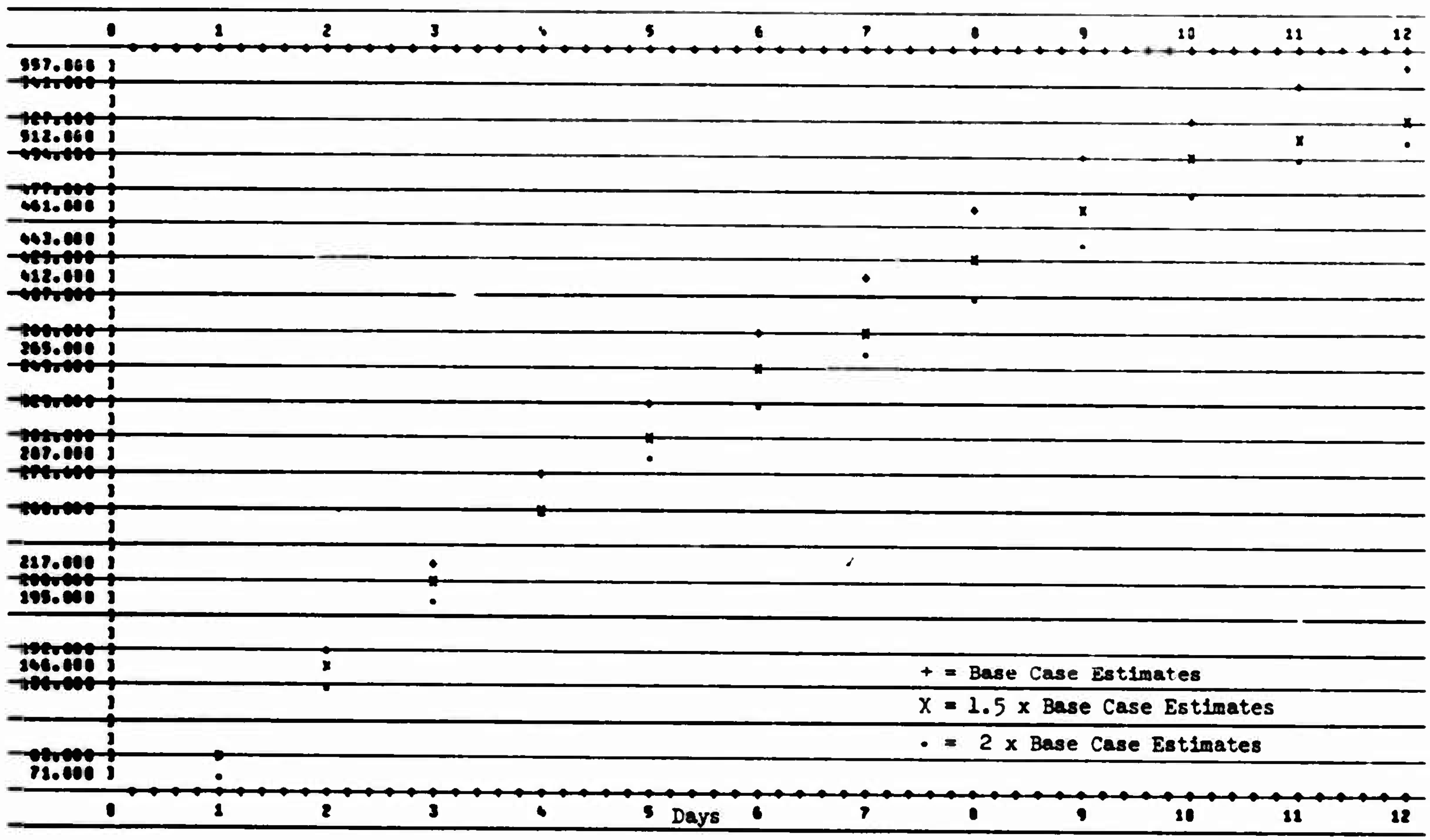


Fig. 16—Effect of System Response Time
(Missions Accomplished vs Time)

The variation of number of missions accomplished is about what had been expected. With the schedule of maximum flight hours/aircraft/day used and with the base case total mission times, an increase of the maintenance penalty from about 5 hours/flight hour can be expected to influence the number of missions flown. Similarly, of course, if the maintenance penalty is held at 5 hours/flight hour and the total mission times are increased appreciably from those of the base case estimates, the number of missions flown during the 12-day period will decrease.

It will be noted that the cumulative efficiency values for both cases of increased mission time are lower than that for the case using the base case estimates. It may also be noted that these values differ slightly for the two cases using increased mission times, and in a way that cannot be called an obvious result. The first of these differences (that between the case using base case estimates and the cases using increased mission times) is a characteristic result of the functioning of the mission assignment logic of the model. The second difference (that between the two cases of increased mission time) reflects a sensitivity to the demand sequence.

The first of these differences results from the functioning of the proportional feedback that controls mission assignment. Briefly, when aircraft are available for mission assignment less frequently (as in the cases of increased mission time) the mission acceptance criterion tends to oscillate at relatively large amplitudes about the value that would result in the most efficient utilization of the fleet in the assignment of missions. This results in some loss of selectiveness in mission assignment.* It is interesting to note that this result may not be altogether spurious in the practical sense. Assuming that targets exist only very briefly, it is probably true that helicopters available for assignment less frequently will be used less efficiently.

*Although this phenomenon is characteristic of the assignment logic, the degree to which it is exhibited for a given data input set can probably be controlled so as to avoid any practical difficulties.

As for the sensitivity of results to the detailed demand sequence, this aspect of the functioning of the model is regarded as of considerable importance. The sensitivity of concern here is not that which might be exhibited when a single specific candidate is evaluated within the context of alternative demand sequences. Rather, the concern here is with the possibility that two candidates may, because of response time characteristics, etc., be in effect exposed to differing portions of the demand in such a way as to bias the results appreciably in favor of one or the other. The first run made in which mission times were varied produced wholly implausible results. The responsible mechanism was identified and the model logic modified to produce the run discussed here.

All of the runs discussed in this report have treated missions appearing in the demand as if they had to be undertaken during the time step (15 minutes) within which they appeared or not at all. This may or may not reflect a realistic treatment of target persistence. In any case, it provided a favorable condition under which to examine sensitivity of results to demand sequence, since, other factors being equal, the more briefly the target is assumed to persist the more likely is the detailed sequence of demand to influence the results appreciably. A second principal factor expected to influence the sensitivity of the results to the detailed demand sequence is the range of pay-offs associated with the missions appearing in the demand. ("Pay-off" here is meant to denote simply expected target effects per expected dollar loss.) For the input data set used in these runs this range is very great. The lowest value is .0491 and the highest is 94.971.

The demand schedule input to EPIC is organized into type 12-hour periods; there are 12 such type 12-hour periods, representing the possible combinations of two type weather days, two day/night conditions, and three type activity days. Because of the make up of the fleet and the characteristics attributed to the helicopter types represented in these runs, the AH-56A was represented as flying only at night (because of the ratio of number of AH-56A to the total number of helicopters in the fleet and the ratio of night missions to total missions); the other two helicopter types were represented as flying day missions only because no night flight capability was attributed to them. Thus, according to the logic of the model as it was originally designed, at the beginning of each new 12-hour period all remaining helicopters of a type that would be flying missions during that period were represented as available and ready for mission assignment. With this treatment, the particular points in time during the succeeding 12-hour period at which the helicopters were or were not available for mission assignment influenced the severity of the demand to which the fleet was exposed. Thus, gratuitous differences in results were produced that reflected nothing more than the distribution of the more and less lucrative targets in the demand schedule. Alternative response time values, of course, resulted not only in alternative values of expected aircraft availability but also tended to determine the particular points within a given 12-hour period at which helicopters were available for mission assignment and thus the severity of the detailed threat associated with the missions they undertook.

The logic was modified such that all strictly day-flying helicopters that were on a mission at sunset were frozen in mid air and remained that way until sunrise, whereupon they completed their missions (now within a new 12-hour daylight period) and became available for mission assignment. Similarly, all strictly night-flying helicopters were frozen at sunrise and continued their missions at sunset. Although this treatment may suggest rather bizarre helicopter behavior if taken literally, it has the fortunate effect of eliminating to a great extent the synchronous patterns of availability and particular portions of the demand schedule. The effect is still present, however, in the run represented in Figure 16 and the associated tabulated values, although to a greatly reduced extent. Examination of the detailed summaries indicates that the first and third cases of this run reflect a more nearly comparable detailed demand sequence than do those two cases compared with the second case. The ordering of the cumulative efficiency values at D+12 also tends to confirm this. This appears to result from the fact that the mission times for the third case were exact multiples of the corresponding base case mission times.

As mentioned previously, both the represented target persistence and the wide range of pay-off values (and the abrupt discontinuities among these) present in the demand schedule used for these runs tend to highlight any sensitivity (in the sense under consideration here) to the detailed sequence of demand. It appears certain that any extending of target persistence would reduce this sensitivity appreciably. Although no investigation was conducted along this line in the course of the present effort, it appears likely that establishing upper limits (based on the character of the input data set) for the mission acceptance criterion value could also reduce this sensitivity substantially.

EFFECT OF WEATHER SEQUENCE VARIATIONS

The run whose summary plot is shown in Figure 17 incorporated five alternative weather schedules over the 12-day period, as follows:

(+) All good-weather days
(X) All bad-weather days
(·) Six good-weather days followed by six bad-weather days
(O) Six bad-weather days followed by six good-weather days
(•) Alternating good- and bad-weather days, respectively.

Some cumulative values pertinent to the five curves are tabulated below.

	Missions accomplished	Cumulative efficiency	Aircraft remaining
(+)	1022	4.795	60
(X)	850	3.083	37
(·)	965	4.195	50
(O)	929	3.325	38
(•)	942	3.823	44

The outcomes are, of course, quite sensitive not only to the proportions of good-weather and bad-weather days over the period, but also to the sequence in which the good- and bad-weather days occur. The "Aircraft remaining" values in the tabulation represent the total number of helicopters remaining after the 12 days of combat; these values are approximate, since "B" and "C" kills undergoing repair are not included.

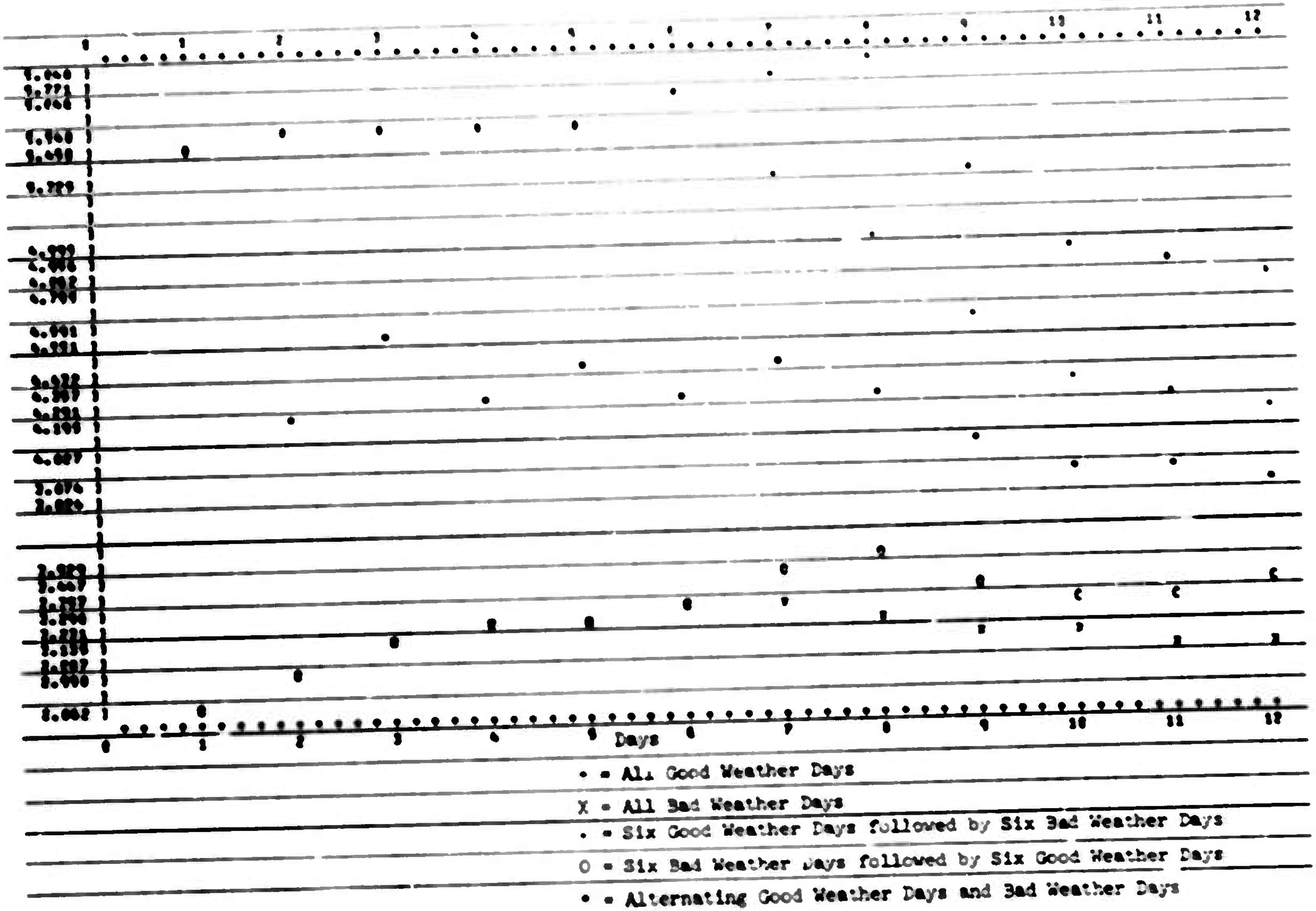


Fig. 17—Effect of Sequence of Weather Conditions
(Missions Accomplished vs Time)

It would be interesting to re-run this experiment with some attrition limiting specified by input. Attrition limiting (say, to 5 percent per day) should drastically reduce the sensitivity of the outcomes to the weather schedule sequence.

EFFECT OF TYPE DAY SEQUENCE

For the run whose summary plot is shown in Figure 18 three alternative schedules of type day were used.* For the (+) curve the first 10 days were high-activity days and the last 10 days were low-activity type days. For the (X) curve the first 10 days were low-activity days and the last 10 high-activity days. For the (•) curve the days alternated low-activity and high-activity, respectively. Cumulative efficiency of performance and missions accomplished values are tabulated below.

	Missions accomplished	Performance efficiency
Curve (+)	1112	3.351
Curve (X)	1264	4.084
Curve (•)	1201	3.794

The results of this run tend toward the same direction, of course, as the corresponding values resulting from the run whose summary plot appears as Figure 17 (where variations of the weather schedule were input). Here, again, attrition limiting could be expected to render the result less sensitive to the type day sequence schedule.

EFFECT OF VARYING MAXIMUM FLIGHT HOURS/HELICOPTER/DAY

Figure 19 shows a summary plot (cumulative missions accomplished vs time) of a run wherein the range of permissible flight hours/helicopter/day was varied. In the base case run, helicopters were permitted to fly

*In the demand used for all of these runs the high-activity type days not only had more missions appearing in the demand but also generally missions whose expected target effect/expected friendly dollar loss values were relatively low.

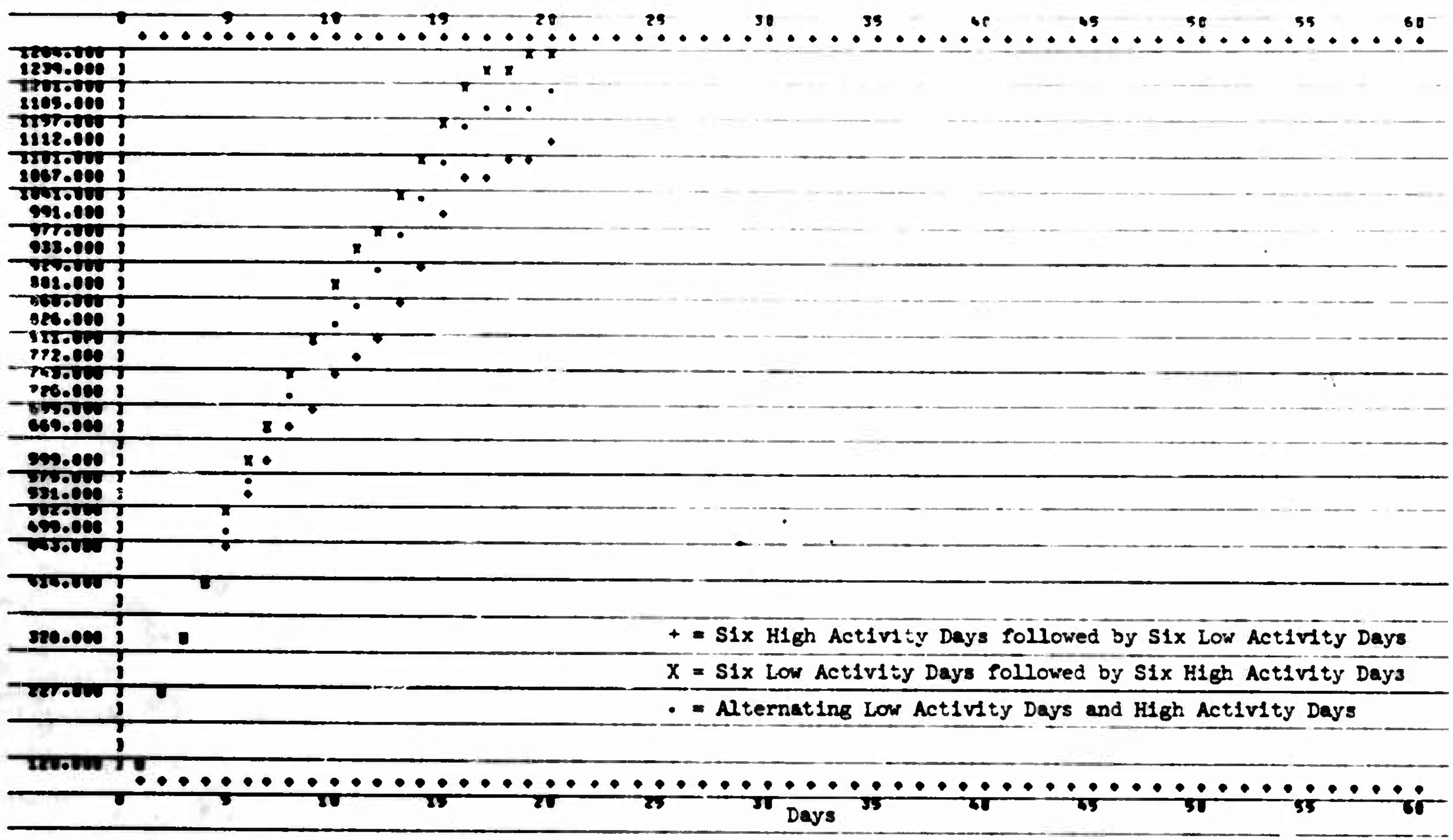


Fig. 18—Effect of Sequence of Type Activity Days

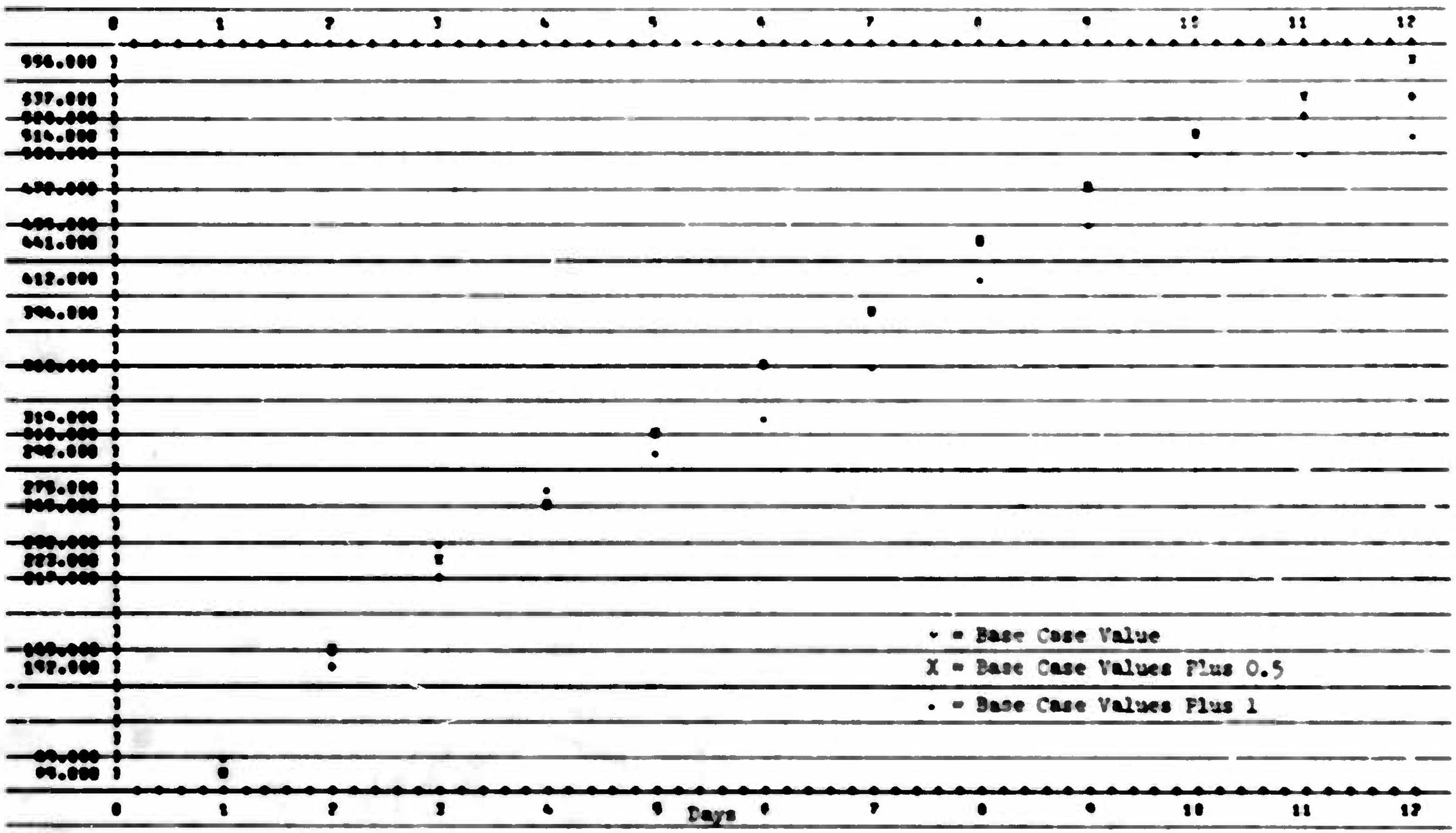


Fig. 19—Effect of Maximum Flight Hours Per Helicopter Per Day

from 1 to 4 hours/day, depending on the type activity day and type weather. The actual values used for this run are shown in Table 4.

Table 4

FLIGHT HOURS/HELICOPTER/DAY VARIATIONS

Day No.	(+) Curve	(X) Curve	(•) Curve
1	3	3.5	4
2	3	3.5	4
3	3	3.5	4
4	3	3.5	4
5	3	3.5	4
6	3	3.5	4
7	2	2.5	3
8	3	3.5	4
9	2	2.5	3
10	2	2.5	3
11	1	1.5	2
12	1	1.5	2

A maintenance penalty of 7 (clock) hours/flight hour was used for the run. Cumulative missions accomplished and performance efficiency values resulting from the run are tabulated below.*

Flight hours/ helicopter/day	Missions accomplished	Performance efficiency
(+) 1 - 3	537	12.994
(X) 1.5-3.5	556	12.324
(•) 2 - 4	514	11.447

The reader may find these results altogether unexpected. Several inter-actions within the model, together with the particular input values used, have produced these results.

*The demand segment used for this run was the same as that used for the runs whose summary plots appear in Figures 15 and 16.

The tabulated values indicate that as flying hours/day are increased efficiency of performance (that is, expected armored vehicles killed/expected friendly dollar loss) decreases. It should be borne in mind that the same demand was used for all three cases. Furthermore, the missions appearing in the demand varied considerably as regards dollar-weighted exchange ratio. Therefore, in order to fly more missions within a given 12-hour period, mission assignment had to be made on a less selective basis. In this regard, it should be noted that there are far more missions in the demand for a given 12-hour period than this helicopter fleet could undertake (again, a total fleet of 45 was played—15 of each helicopter type) within the period. Thus, the mission assignment logic had considerable latitude for selecting or rejecting missions, depending on how much flight time had been allocated for expenditure during a given 12-hour period. And as a general rule, of course, in the cases where more flight hours/day were allocated, the helicopter fleet suffered higher attrition per mission accomplished.

At D+3 in Figure 19 the cumulative missions accomplished are ordered in accordance with the flight hours/helicopter/day allocations for the three cases. As mentioned previously, a 72-hour permissible maintenance delay was input for these runs; thus the only maintenance influence during these first three days was that of scheduled maintenance. At this point in the game the ordering of cumulative efficiency values for the three cases was opposite to that of allocated flight hours/helicopter/day, and remained so throughout the 12-day period.

Following D+3, in all three cases maintenance backlog inhibited flight activity from time to time during the succeeding 9 days—this effect being more pronounced, of course, for the cases where more flight hours/helicopter/day had been allocated. This sporadic flight activity had the effect of degrading efficiency of performance, since on some of the days there was very little flight activity (because of maintenance backlog) and on days of intense flight activity relatively costly missions were being flown.

The results of this run were largely determined, of course, by the input value of the maintenance penalty (7 clock hours/flight hour). A reduction of this value to five would probably change the ordering of the values of cumulative missions accomplished, although the ordering of the performance efficiency values would be expected to remain the same.

SCHEDULED MAINTENANCE, AIRCRAFT REPLACEMENTS, AND STAND-DOWN

Although the original work plan envisioned variations of these three EPIC inputs, they have not been varied in the course of these exploratory and sensitivity runs. The input values have remained those specified for the base case.

Although the values assigned these inputs may be of considerable importance within the context of a particular, closely specified evaluation environment and a particular, carefully defined effectiveness measure, it did not appear that their variation would be particularly enlightening in experiments that could be designed within the scope of the present effort.

The principal influence of these three inputs is the distribution (in time) of target effects achieved and friendly losses sustained. The rather simple experiments conducted in the course of the present effort have not attempted to take into account, for example, the utility of target effects achieved on D+3 as compared to that of target effects achieved on D+12. Essentially, the selection of values for hours/day of scheduled maintenance (as a function of type activity day and weather) and/or the stipulation of stand-down (in which available time is devoted exclusively to eliminating maintenance backlog) have the effect of concentrating available resources to achieve maximum target effects during one or more relatively brief periods that occur within the context of a relatively prolonged operation. Any scheduled replacements will, of course, have the effect of maintaining a higher level of capability of the friendly force during a prolonged operation.

SOME PRECAUTIONS TO BE OBSERVED IN EXERCISING THE EPIC MODEL

It goes without saying that any computer simulation combining a wide variety of inputs and representing rather obscure interactions must be thoroughly understood before it can be properly used. Experience with EPIC in the course of the effort reported here has provided abundant confirmation of this general principle.

The usual crop of silly mistakes in design detail came to light, of course, as we examined the results of successive runs and probed the web of interactions leading to these results. Aside from these, however, unforeseen results (and sometimes invalid results) were frequently produced simply because the full implications of the feedback system incorporated in the model had not been thought through completely. A typical example of this sort of thing was encountered during the maintenance penalty experiment whose final plot appears in Figure 15. The first time this run was made the resulting numbers of missions accomplished were plausible enough, but the performance efficiency values were utterly implausible. The results indicated a marked decrease in efficiency of performance as the maintenance penalty was increased. (It should be remembered that in the terminology used here "performance efficiency" is intended to mean simply the expected number of armored vehicle kills per expected friendly dollar loss.) This result was a manifestation of a flaw in the model logic. The mechanism responsible was, briefly, as follows. For both the 10 hour/flight hour and the 15 hour/flight hour case the limiting resource was mission time available (rather than flight time available). The mission assignment logic, on the other hand, was treating available flight time as the resource whose expenditure was to be so controlled as to (approximately) optimize efficiency of performance. Thus, in the cases where available mission time was the actual limiting factor as regards number of missions undertaken in a 12-hour period, missions were being accepted that should properly have been rejected. That is, mission assignment was not so selective as it should have been in light of the quantity of the actual limiting resource, which was mission time.

This example illustrates a general principle that must guide the use of EPIC if valid results are to be obtained: The reference value against which feedback comparisons are made must represent the available quantity of the limiting resource. This is a very simple principle, but one that is easy to violate inadvertently. In the present application of the model this limiting resource may be available helicopter flight time, available mission time, acceptable attrition, etc.* In each case, the quantity of the limiting resource is regarded as being available for expenditure over some defined period of time. The correlative presupposition is that the quantity of the limiting resource available for expenditure over the defined period of time is, in fact, to be expended during that period. It is within the context of these assumptions that the model seeks to assign helicopter mission in such a way as to utilize the fleet most efficiently.

From the investigations reported here it appears that proportional feedback control provides an adequate mechanism for positioning the Mission Acceptance Criterion (in the runs conducted for the investigations reported here three such criteria were being adjusted dynamically) as the game progresses, provided the analyst studies his input data carefully and conducts such experiments as may be required to determine suitable values for the scaling constants. These runs have generally registered the Mission Acceptance Criterion at the mean value of the dollar-weighted exchange ratio at the beginning of each 12-hour period and then permitted feedback adjustments to determine its value during the remainder of the period. Whether the mean value is the most suitable initial value for the criterion may depend to a great extent on the character of the specific input data set.

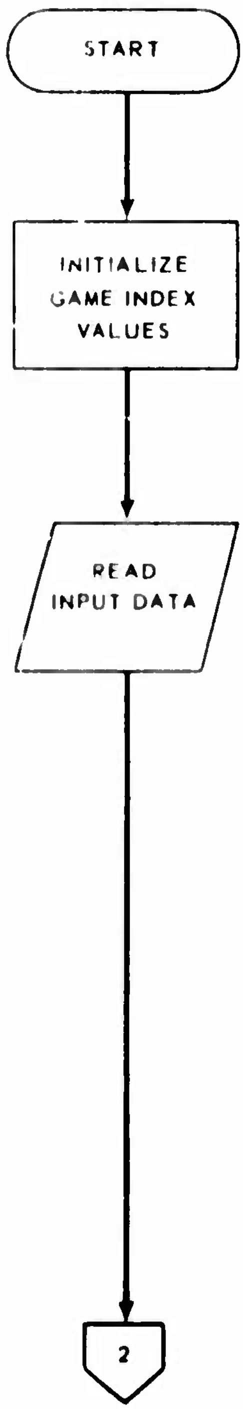
For any application of EPIC where target persistence is represented as being very brief and where missions appearing in the demand vary widely as regards expected results, particular attention should be given to the detailed sequence of the demand schedule. Any required modifications of mission assignment logic and/or detailed input demand schedule will need to be undertaken in light of the results of appropriate sensitivity runs.

*And, of course, the identity of the limiting resource may change from one period to another in the course of the game.

APPENDIXES

Appendix A

EPIC MODEL FLOW CHARTS



INPUT DATA

Number of each type helicopter making up the total fleet, and costs for each type.

Percentage values indicating distribution of fleet (CONUS, Theater, Floats).

Maximum flight time/helicopter for each day, week, month of the game.

Maintenance hours/flight hour required for each helicopter type.

Scheduled maintenance time as function of type activity day and type weather.

Maximum and minimum fuel and ordnance loads and logistics base return delay times, and fuel and ordnance expenditure rates.

Schedule of helicopter replacements (if replacements are to be played).

Schedule of stand-down periods for maintenance backlog catch-up.

Reliability factor for each helicopter type.

Maximum acceptable attrition per day.

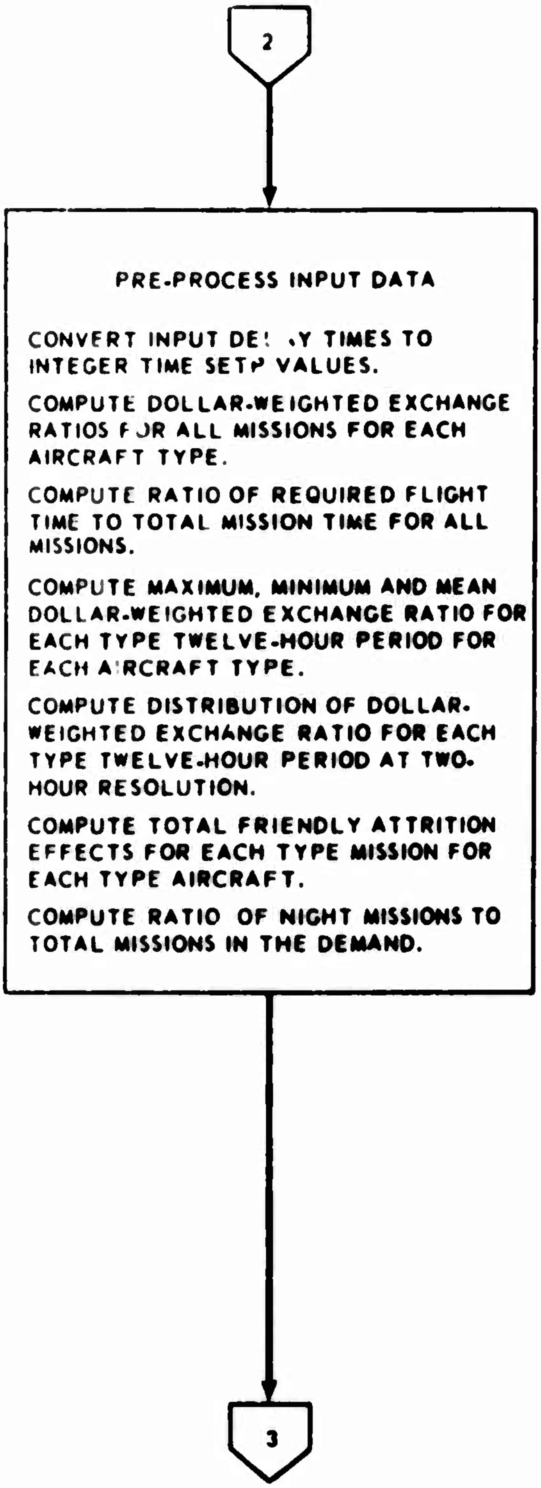
Minimum time per day to be allocated to missions.

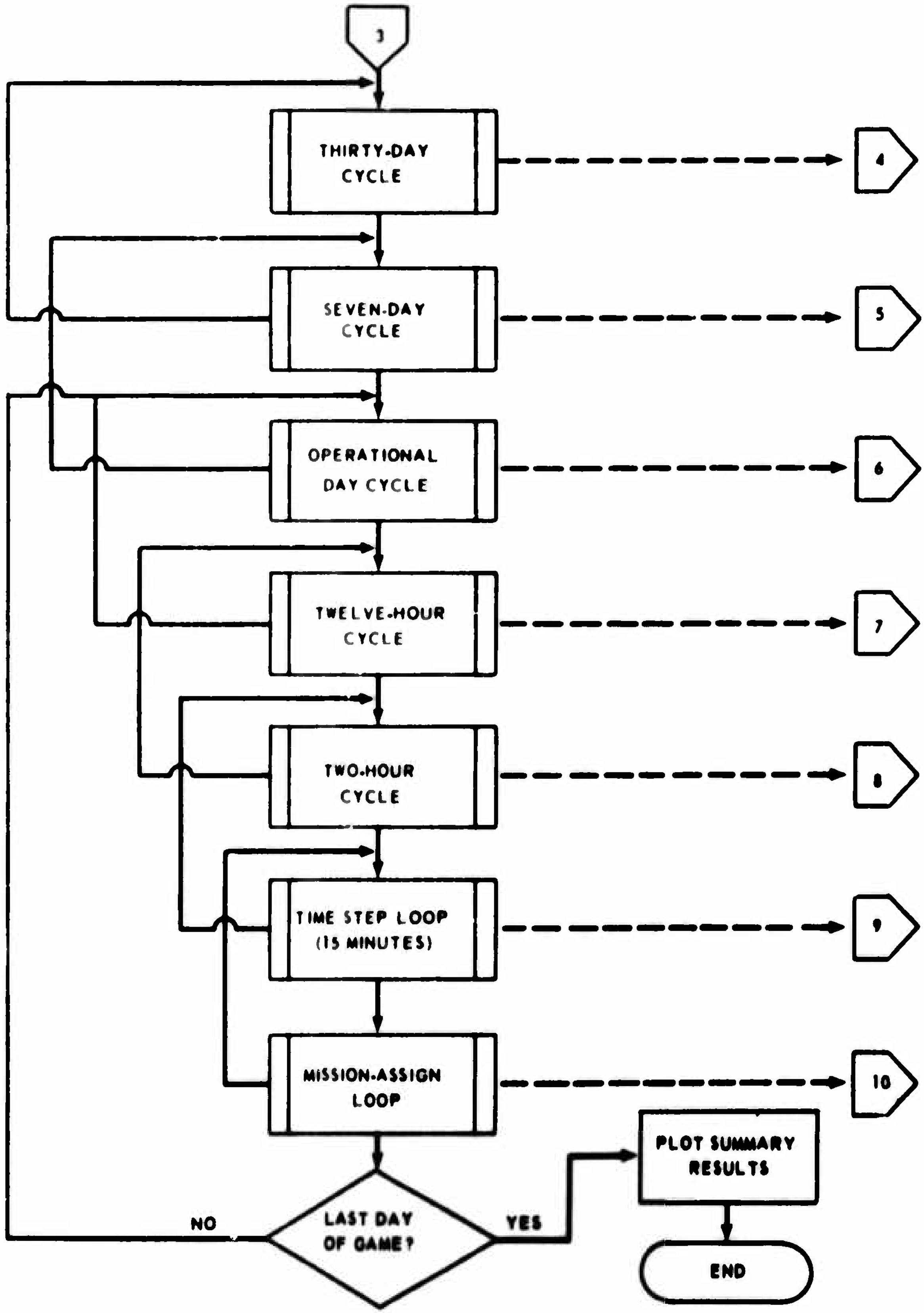
Mission results tables: flight and total mission times, expected friendly attrition, expected target effects, expected ammunition expenditures.

Schedule of type activity days (defense, delay, passive) for total duration of game.

Schedule of weather conditions for total game.

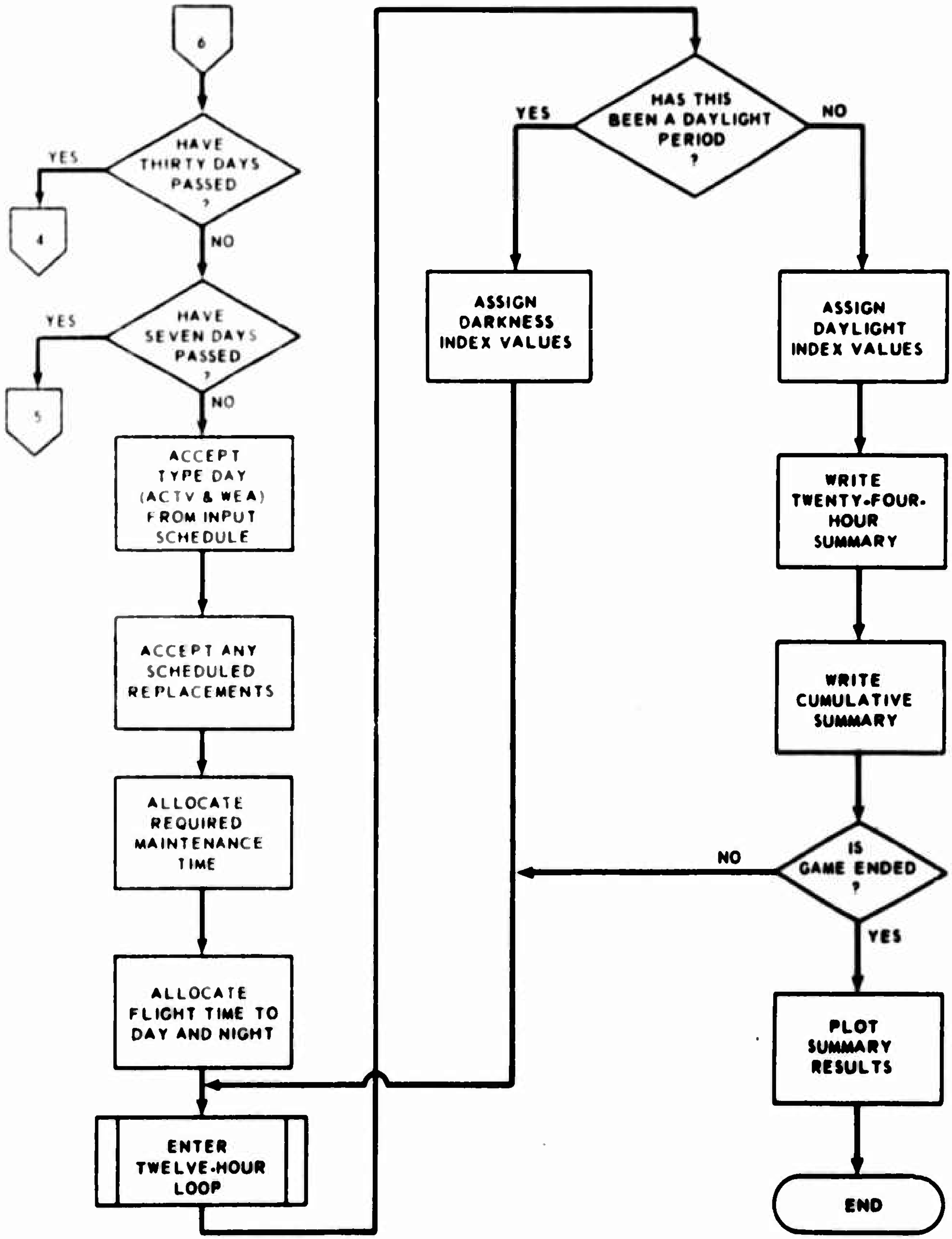
Mission demand schedule for each type 12-hour period (as determined by type activity day, weather condition, and day/night condition).

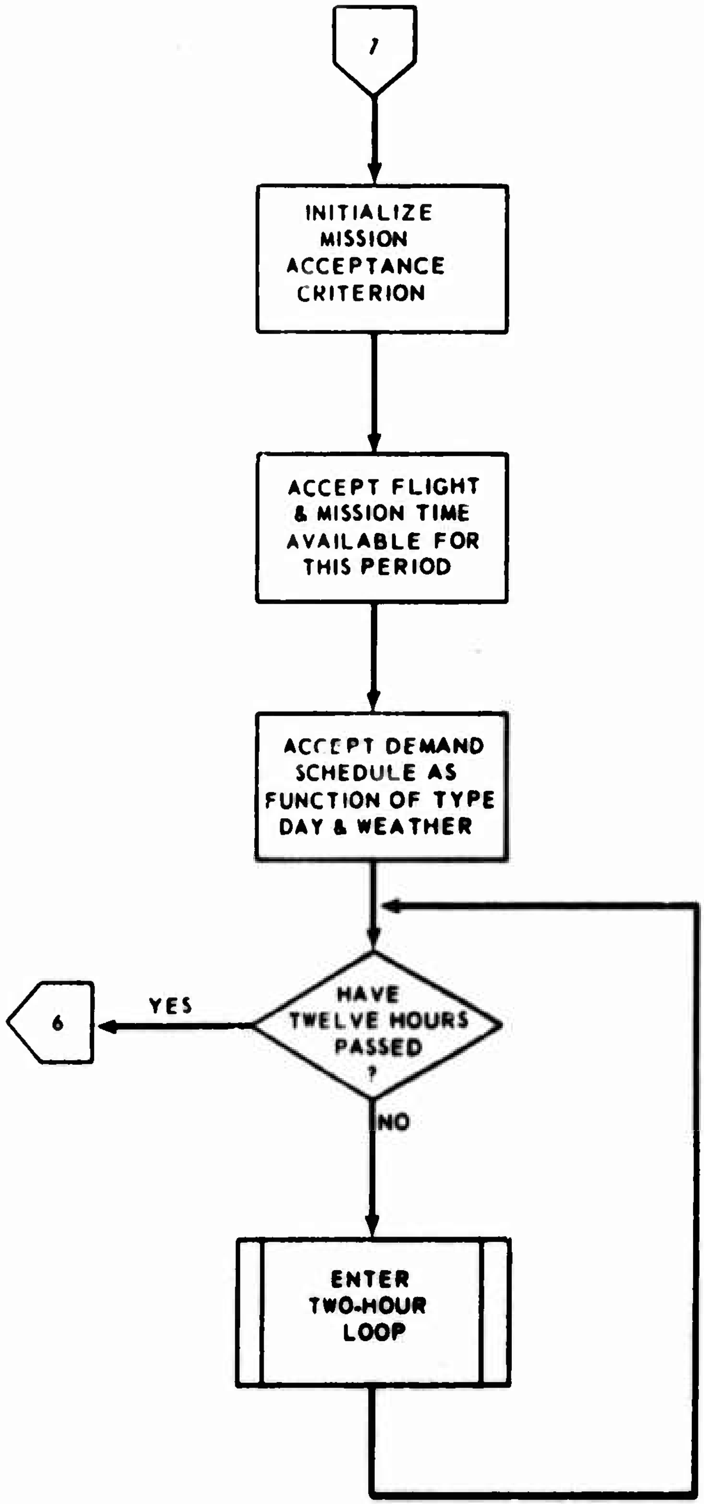

2
PRE-PROCESS INPUT DATA
CONVERT INPUT DELAY TIMES TO INTEGER TIME STEP VALUES.
COMPUTE DOLLAR-WEIGHTED EXCHANGE RATIOS FOR ALL MISSIONS FOR EACH AIRCRAFT TYPE.
COMPUTE RATIO OF REQUIRED FLIGHT TIME TO TOTAL MISSION TIME FOR ALL MISSIONS.
COMPUTE MAXIMUM, MINIMUM AND MEAN DOLLAR-WEIGHTED EXCHANGE RATIO FOR EACH TYPE TWELVE-HOUR PERIOD FOR EACH AIRCRAFT TYPE.
COMPUTE DISTRIBUTION OF DOLLAR-WEIGHTED EXCHANGE RATIO FOR EACH TYPE TWELVE-HOUR PERIOD AT TWO-HOUR RESOLUTION.
COMPUTE TOTAL FRIENDLY ATTRITION EFFECTS FOR EACH TYPE MISSION FOR EACH TYPE AIRCRAFT.
COMPUTE RATIO OF NIGHT MISSIONS TO TOTAL MISSIONS IN THE DEMAND.
3

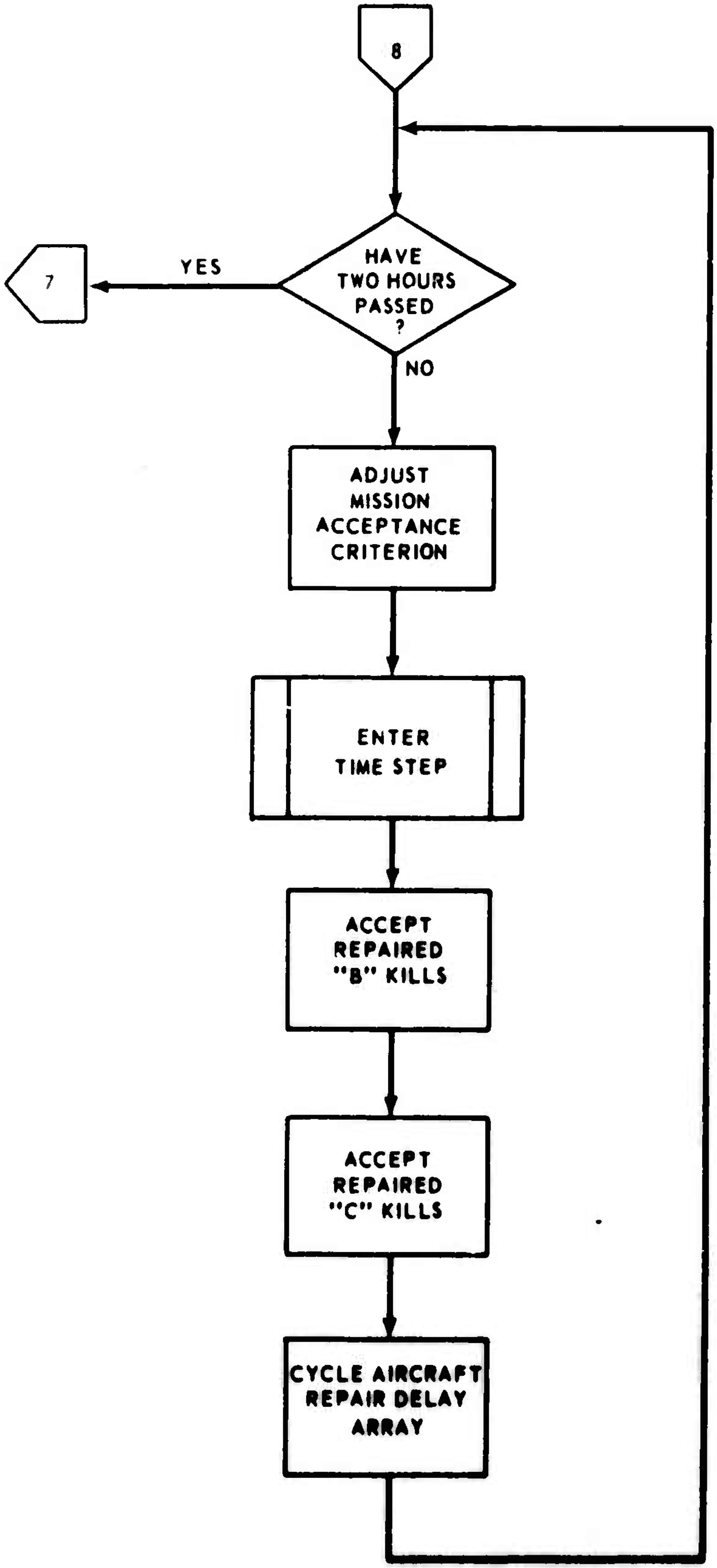

3
THIRTY-DAY CYCLE
4
SEVEN-DAY CYCLE
5
OPERATIONAL DAY CYCLE
6
TWELVE-HOUR CYCLE
7
TWO-HOUR CYCLE
8
TIME STEP LOOP (15 MINUTES)
9
MISSION-ASSIGN LOOP
10
LAST DAY OF GAME?
NO
YES
PLOT SUMMARY RESULTS
END

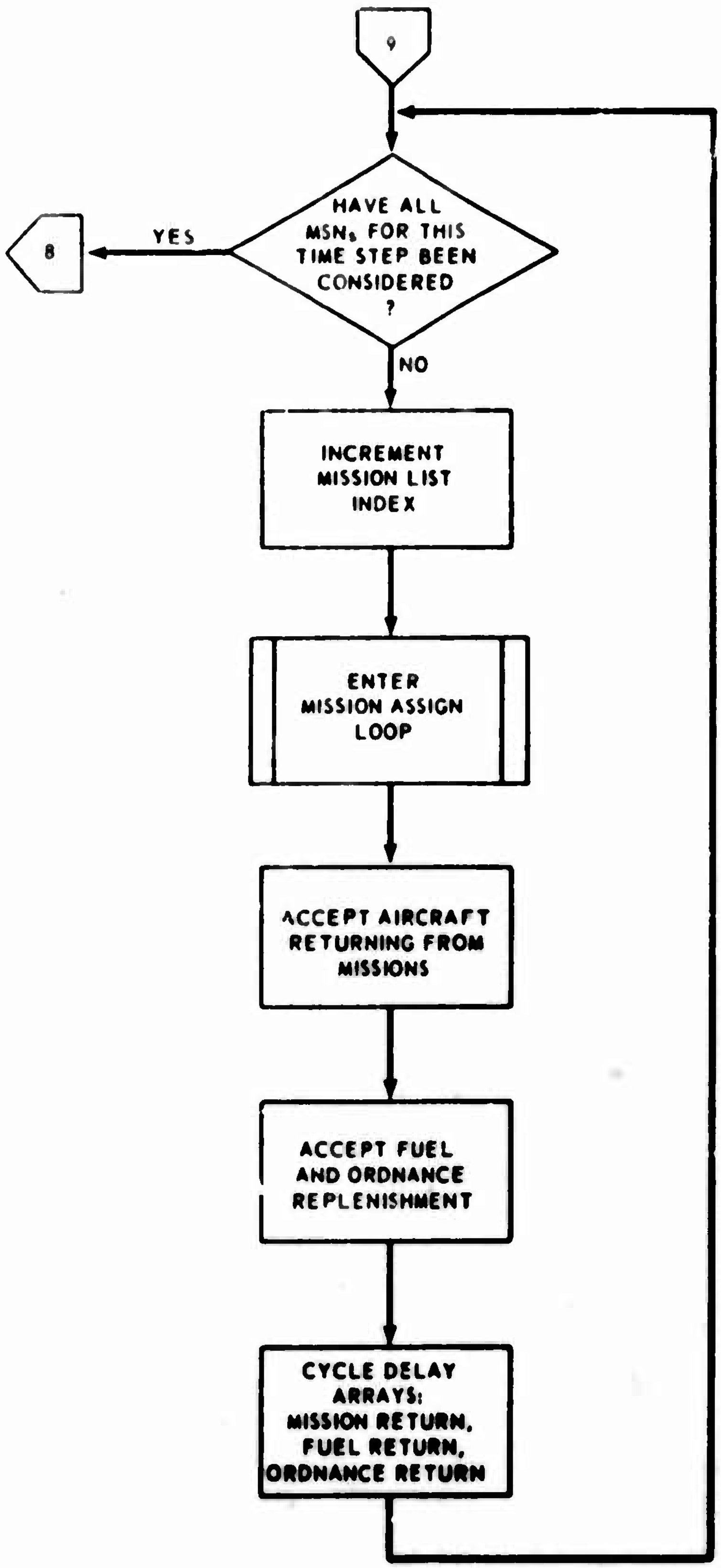

4
ACCEPT 30-DAY ALLOCATION OF FLIGHT HOURS/ HELICOPTER
6

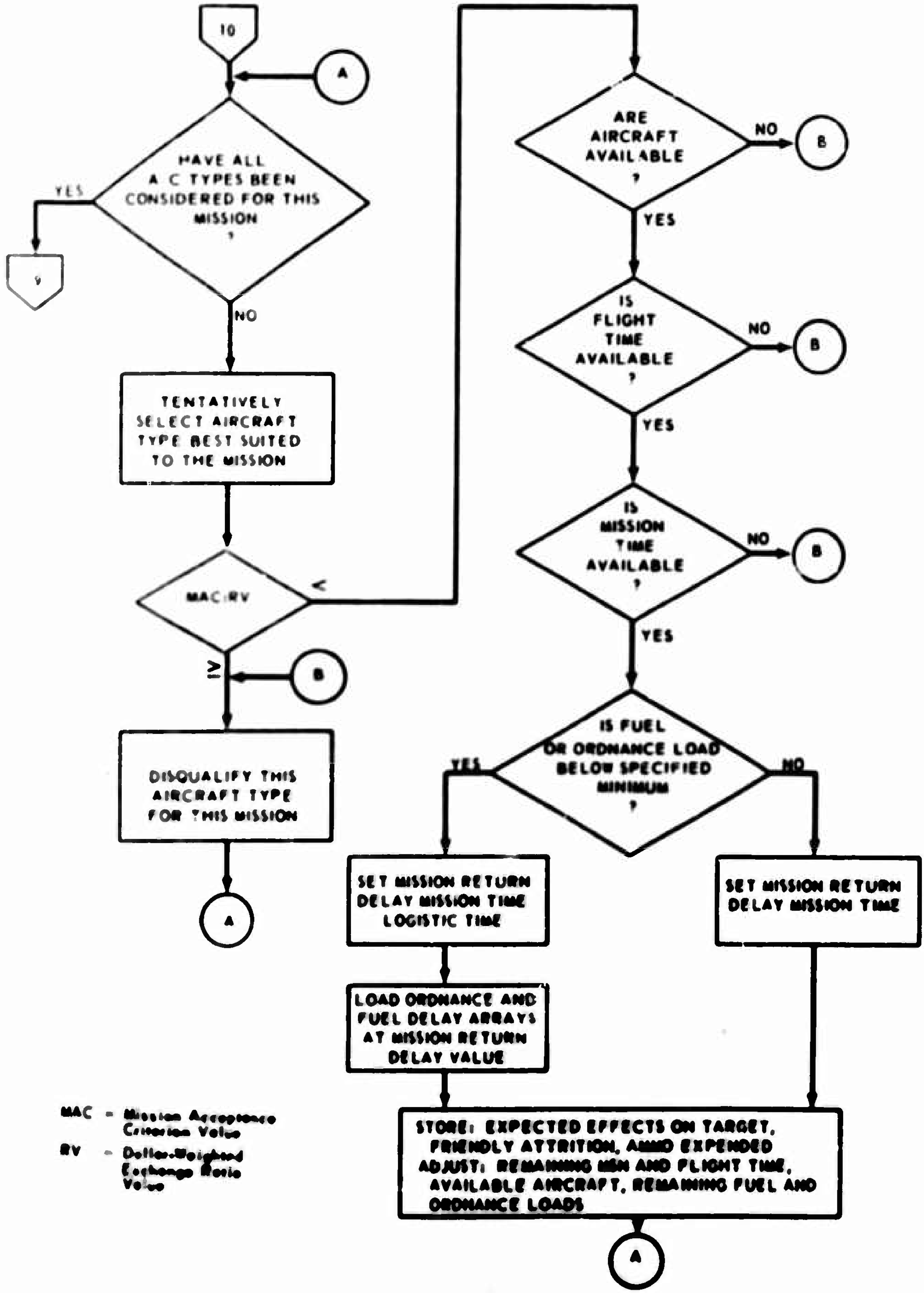

5
ACCEPT 7-DAY ALLOCATION OF FLIGHT HOURS/ HELICOPTER
6


6
HAVE THIRTY DAYS PASSED ?
YES
4
NO
HAVE SEVEN DAYS PASSED ?
YES
5
NO
ACCEPT TYPE DAY (ACTV & WEA) FROM INPUT SCHEDULE
ACCEPT ANY SCHEDULED REPLACEMENTS
ALLOCATE REQUIRED MAINTENANCE TIME
ALLOCATE FLIGHT TIME TO DAY AND NIGHT
ENTER TWELVE-HOUR LOOP
HAS THIS BEEN A DAYLIGHT PERIOD ?
YES
NO
ASSIGN DARKNESS INDEX VALUES
ASSIGN DAYLIGHT INDEX VALUES
WRITE TWENTY-FOUR-HOUR SUMMARY
WRITE CUMULATIVE SUMMARY
IS GAME ENDED ?
NO
YES
PLOT SUMMARY RESULTS
END


7
INITIALIZE MISSION ACCEPTANCE CRITERION
ACCEPT FLIGHT & MISSION TIME AVAILABLE FOR THIS PERIOD
ACCEPT DEMAND SCHEDULE AS FUNCTION OF TYPE DAY & WEATHER
HAVE TWELVE HOURS PASSED ?
YES
6
NO
ENTER TWO-HOUR LOOP


8
HAVE TWO HOURS PASSED ?
YES
7
NO
ADJUST MISSION ACCEPTANCE CRITERION
ENTER TIME STEP
ACCEPT REPAIRED "B" KILLS
ACCEPT REPAIRED "C" KILLS
CYCLE AIRCRAFT REPAIR DELAY ARRAY


9
HAVE ALL MSNs FOR THIS TIME STEP BEEN CONSIDERED ?
YES
8
NO
INCREMENT MISSION LIST INDEX
ENTER MISSION ASSIGN LOOP
ACCEPT AIRCRAFT RETURNING FROM MISSIONS
ACCEPT FUEL AND ORDNANCE REPLENISHMENT
CYCLE DELAY ARRAYS: MISSION RETURN, FUEL RETURN, ORDNANCE RETURN



10
A
HAVE ALL A C TYPES BEEN CONSIDERED FOR THIS MISSION ?
YES
9
NO
TENTATIVELY SELECT AIRCRAFT TYPE BEST SUITED TO THE MISSION
MAC:RV
<
≥
B
DISQUALIFY THIS AIRCRAFT TYPE FOR THIS MISSION
A
ARE AIRCRAFT AVAILABLE ?
NO
B
YES
IS FLIGHT TIME AVAILABLE ?
NO
B
YES
IS MISSION TIME AVAILABLE ?
NO
B
YES
IS FUEL OR ORDNANCE LOAD BELOW SPECIFIED MINIMUM ?
YES
NO
SET MISSION RETURN DELAY MISSION TIME LOGISTIC TIME
SET MISSION RETURN DELAY MISSION TIME
LOAD ORDNANCE AND FUEL DELAY ARRAYS AT MISSION RETURN DELAY VALUE
STORE: EXPECTED EFFECTS ON TARGET, FRIENDLY ATTRITION, AMMO EXPENDED ADJUST: REMAINING MEN AND FLIGHT TIME, AVAILABLE AIRCRAFT, REMAINING FUEL AND ORDNANCE LOADS
A
MAC = Mission Acceptance Criterion Value
RV = Dollar-Weighted Exchange Ratio Value

Appendix B

INPUT STRUCTURE OF THE EPIC MODEL

The general structure of the EPIC input is shown in Figure B1. The paragraphs that follow identify the input data set array within the context of this general structure.

The broad scenario of the simulation is defined by a schedule of type activity days, a weather schedule and the alternating of day and night conditions accomplished by the model logic. The type day schedule (input array ITYPE) contains codes indicating for each day of the game whether it is a defense day, a delay day or a passive day. The weather schedule (input array MET) contains codes indicating either good weather or bad weather for each day of the game, these descriptors being referenced to visibility and ceiling conditions.

The three type activity days and two type weather days, taken together with the two day/night conditions, yield twelve unique type 12-hour periods to be played in the game. For each such 12-hour period a mission demand list is provided in the mission input table (input array MISTAB).

The demand lists appearing in the mission table contain codes which in turn denote index values for the expected mission results tables. These are: a table describing expected target effects for each mission appearing in the total demand (input array EFFECT); a table describing expected friendly losses for each mission (input array ATTRIT); a table describing expected ammunition expenditure for each mission (input array AMMO); a table containing flight time and mission time values for each mission (input array TIMREQ).

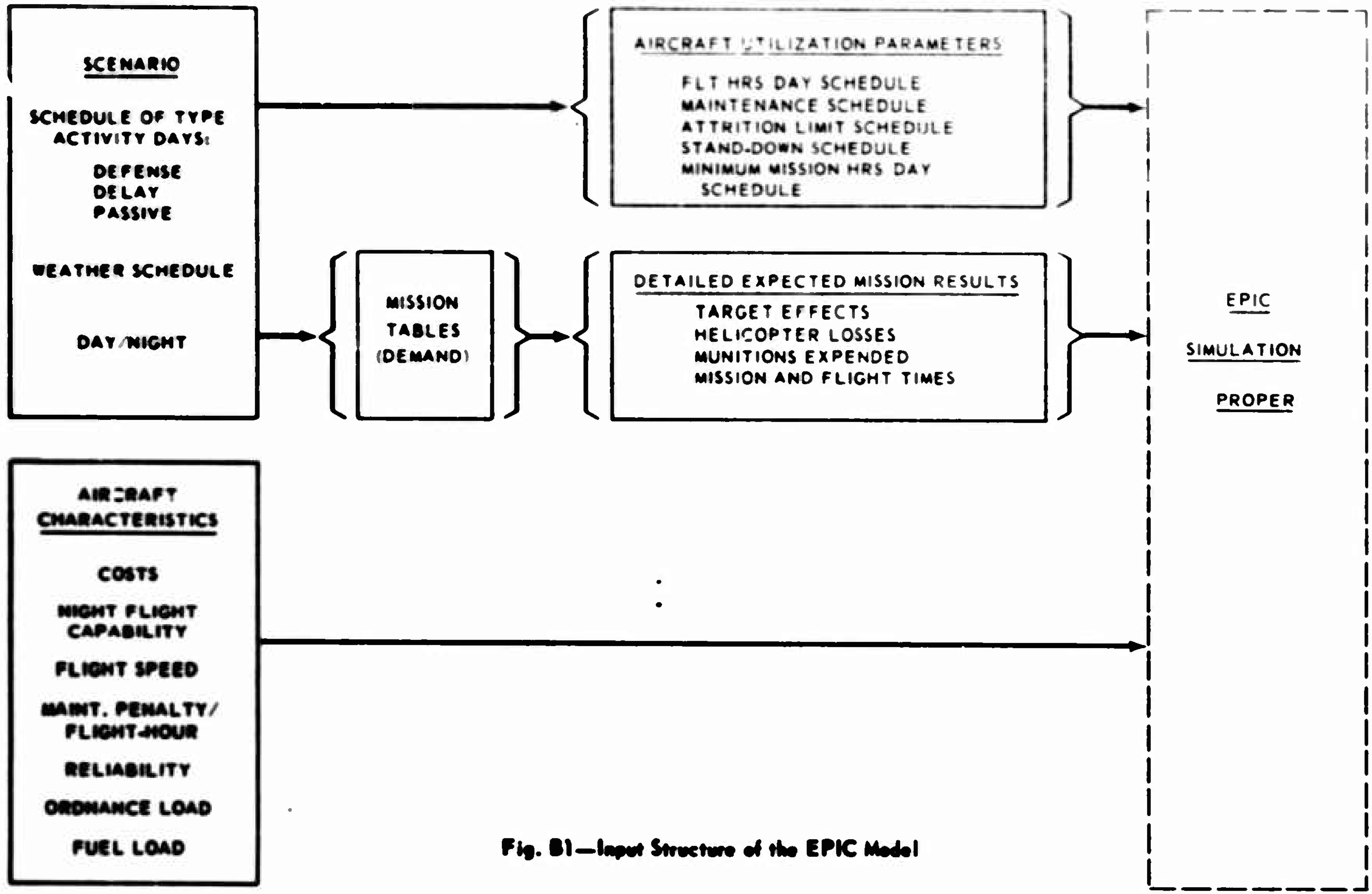


Fig. B1—Input Structure of the EPIC Model

Given three type activity days and two weather conditions, six unique type days are played in the simulation. For each such type day input tables specify helicopter utilization parameters. These tables are: flight hours/helicopter/day to be flown (input array QUAN)*; daily hours to be devoted to scheduled maintenance, as a function of the type day (input array TIMNT); maximum percent aircraft attrition to be sustained per day (input array PTRIT); schedule of stand-down day during which all mission time is devoted to catching up on the maintenance backlog (input array ISTND); and the specified minimum number of hours/aircraft to be available for missions during each day (input array TMIN).

In addition to the performance characteristics implicit in the values appearing in the detailed expected mission results tables previously described, the following aircraft characteristics are defined in separate input tables; helicopter costs (input array COST); whether or not a night flight capability exists (NITFLT); aircraft speed (input array TIMLOG); aircraft reliability (input array RELFAK); aircraft maintenance hours/flight hour (input array FAKMNT); aircraft ordnance capacity (input array ORDCAP); and aircraft fuel capacity (input array FULCAP). Input arrays ORDMIN and FULMIN define minimum values for ordnance and fuel loads, respectively, with which the aircraft are to undertake a mission. Input array FULCON specifies aircraft fuel consumption.

The input array HELMIX specifies the number of each type of helicopter making up the total fleet. The input array XCONUS specifies the percentage of each helicopter type in the total fleet to be allocated to CONUS (or other locations). The input array XFLOT specifies the percentage of each helicopter type to be held in maintenance floats. The input array REPLAC is a schedule of helicopter replacements (or losses from attacks on ground bases), by helicopter type, for each day of the game.

*Arrays QUAN2 and QUAN3 specify, respectively, weekly and monthly flight hours.

RAC DISTRIBUTION LIST B 1 October 1972

Recipients of this document are indicated by ☒

	Address code	Agency	Number of copies
		DEPARTMENT OF DEFENSE	
☒	A2	Director of Defense Research and Engineering	1
☐	A3	Assistant Secretary of Defense, (International Security Affairs)	1
☒	A9	Assistant Secretary of Defense, (Systems Analysis)	2
☐	B2	Joint Chiefs of Staff	1
☐	B4	Studies Analysis Gaming Agency	1
☒	B5	Weapons Systems Evaluation Group	1
☒	C1	Advanced Research Projects Agency	1
☐	C2	Defense Nuclear Agency	1
☐	C3	National Security Agency	1
☐	C4	Defense Communications Agency	1
* ☒	C6	Defense Documentation Center	2
☐	C9	Defense Intelligence Agency	1
☒	D1	National War College	1
☐	D2	Industrial College of the Armed Forces	1
☒	D3	Armed Forces Staff College	1
☐	D5	Defense Information School	1
		HEADQUARTERS, DEPARTMENT OF THE ARMY	
☒	E2	Office, Under Secretary of the Army (OR)	1
☐	E4	Assistant Secretary of the Army (R&D)	1
☐	E7	Deputy Chief of Staff for Personnel	1
☒	E8	Deputy Chief of Staff for Military Operations	2
☒	E9	Deputy Chief of Staff for Logistics	1
☐	E10	Assistant Chief of Staff, Intelligence	2
☐	E11	Directorate of Military Support	1
☐	E14	Comptroller	1
** ☒	E15	The Army Library, Attn: ASDIRS	1
☐	E16	Office of the Provost Marshal General	1
☐	E18	Office of the Surgeon General	1
☐	E19	Assistant Chief of Staff for Communications-Electronics	1
☐	E22	Office of Personnel Operations	1
☒	E23	Assistant Chief of Staff for Force Development	1
☒	E27	Chief of Research and Development	1
☐	E32	Office of Reserve Components	1
☒	E33	Assistant Vice Chief of Staff	4
		ARMIES	
☐	H2	First US Army	1
☐	H3	Third US Army	1
☐	H5	Fifth US Army	1
☐	H6	Sixth US Army	1
☐	H8	Eighth US Army	1
		UNIFIED COMMANDS	
☐	L5	Commander in Chief, Alaska (CINCAL)	1
☐	L6	Commander in Chief, Pacific (CINCPAC)	1
☐	L12	Commander in Chief, Europe (CINCEUCOM)	1
☐	L16	US Strike Command, MacDill Air Force Base (CINCSTRIKE)	1
		ARMY COMMANDS (CONUS)	
☐	J11	US Army Security Agency	1
☒	L1	US Army Air Defense Command	1
☐	L61	US Continental Army Command	2
☐	M19	US Army Strategic Communications Command	1
		ARMY COMMANDS (Overseas)	
☐	L8	US Army, Alaska	1
☐	L9	US Army Forces Southern Command	1
☒	L10	US Army, Europe and Seventh Army	1

* Required IAW AR 70-11 and AR 70-31.

** Normally required; exclusion must be justified by Sponsor (AR 1-28).

	Address code	Agency	Number of copies
☐	L11	US Army Pacific	1
☐	R11	US Army Concept Team, Vietnam	1
		ARMY MATERIEL COMMAND	
☒	L3	Hq US Army Materiel Command, Washington, D.C.	1
☐	I5	US Army Munitions Command, Edgewood Arsenal	1
☒	J4	US Army Armor and Engineer Board, Ft. Knox	1
☐	J5	US Army Field Artillery Board, Ft. Sill	1
☒	J6	US Army Aviation Test Board, Ft. Rucker	1
☐	J8	US Army Infantry Board, Ft. Benning	1
☐	M7	US Army Electronics Command, Ft. Monmouth	1
☐	M10	US Army Missile Command, Redstone Arsenal	1
☐	M13	US Army Munitions Command, Dover	1
☒	M22	US Army Aviation Systems Command, St. Louis	1
☐	M24	US Army Weapons Command, Rock Island	1
☐	M25	US Army Mobility Equipment Command, St. Louis	1
☐	M26	Management Information Systems Directorate	1
☐	M29	USA Advanced Materiel Concepts Agency, Alexandria	1
☐	M30	US Army Army Tank-Automotive Command, Warren	1
☐	M32	US Army Test and Evaluations Command, Aberdeen Proving Ground	1
☐	R6	Dugway Proving Ground, Dugway	1
☐	R9	White Sands Missile Range, Las Cruces	1
☒	G25	Director, Army Materiel Systems Analysis Agency, Aberdeen Proving Ground	1
		COMBAT DEVELOPMENTS COMMAND	
☒	L2	Hq USA, Combat Developments Command, Ft. Belvoir	1
☒	G2	USACDC Air Defense Agency, Ft. Bliss	1
☒	G3	USACDC Armor Agency, Ft. Knox	1
☐	G4	USACDC Field Artillery Agency, Ft. Sill	1
☒	G5	USACDC Aviation Agency, Ft. Rucker	1
☐	G7	USACDC Chemical, Biological, and Radiological Agency, Ft. McClellan	1
☐	G11	USACDC Communications-Electronics Agency, Ft. Monmouth	1
☐	G12	USACDC Engineer Agency, Ft. Belvoir	1
☐	G13	USACDC Infantry Agency, Ft. Benning	1
☐	G16	USACDC Military Police Agency, Ft. Gordon	1
☐	G19	USACDC Transportation Agency, Ft. Eustis	1
☐	G20	USACDC Intelligence Agency, Ft. Huachuca	1
☐	G22	USACDC Nuclear Agency, Ft. Bliss	1
☐	G26	USACDC Special Operations Agency, Ft. Bragg	1
☐	G28	USACDC Maintenance Agency, Aberdeen Proving Ground	1
☐	L44	USACDC Concepts and Force Design Group, Alexandria	1
☐	L45	USACDC Systems Analysis Group, Ft. Belvoir	1
☐	L69	USACDC Intelligence and Control Systems Group, Ft. Belvoir	1
☐	O26	USACDC Strategic Studies Institute, Carlisle Barracks	1
☒	P2	USACDC Combat Systems Group, Ft. Leavenworth	1
☐	P3	USACDC Personnel and Logistics Systems Group, Ft. Lee	1
		SCHOOLS, US ARMY	
☐	G27	US Army Military Police, Ft. Gordon	1
☐	M17	US Army Ordnance, Aberdeen Proving Ground	1
☒	O2	US Army Air Defense, Ft. Bliss	1
☐	O3	US Army Armor, Ft. Knox	1
☐	O4	US Army Field Artillery, Ft. Sill	1
☐	O5	US Army Chemical, Ft. McClellan	1
☐	O6	US Army Engineer, Ft. Belvoir	1
☐	O7	US Army Finance, Ft. Benjamin Harrison	1
☐	O8	US Army Infantry, Ft. Benning	2
☐	O9	US Army Intelligence, Ft. Huachuca	1
☐	O10	Medical Field Service, Brooke Army Medical Center	1
☒	O11	US Army Command and General Staff College, Ft. Leavenworth	1
☒	O12	US Army Aviation, Ft. Rucker	1
☐	O16	US Army School, Europe	1
☐	O19	US Army Missile and Munitions Center and School, Redstone Arsenal	1

	Address code	Agency	Number of copies
[ ]	O21	US Army Quartermaster, Ft. Lee	1
[ ]	O23	US Army Institute of Military Assistance, Ft. Bragg	2
[X]	O24	US Army War College, Carlisle	1
[ ]	O25	US Army Transportation, Ft. Eustis	1
[X]	O27	USMA, West Point	1
[ ]	O29	US Army Adjutant General, Ft. Benjamin Harrison	1
[ ]	O30	US Army Combat Surveillance School and Training School, Ft. Huachuca	1
[ ]	O31	US Army Signal Center and School, Ft. Monmouth	1
[ ]	O32	US Army Southeastern Signal School, Ft. Gordon	1
[ ]	O33	USWAC School, Ft. McClellan	1
		MISCELLANEOUS ARMY (CONUS)	
[ ]	E34	US Army Intelligence Threat Analysis Detachment	1
[X]	E37	Logistics Doctrine, Systems and Readiness Agency, New Cumberland Army Depot	1
[ ]	E38	Engineer Strategic Studies Group	1
[ ]	K11	US Army Logistics Management Center	2
[X]	P9	US Army Strategy and Tactics Analysis Group	1
[ ]	R4	US Army Behavioral and Systems Research Laboratory	1
		US AIR FORCE	
[ ]	T4	Hq, US Air Force (AF SAMID)	1
[X]	T8	Air University Library, Maxwell Field	1
		US NAVY	
[ ]	S1	Chief of Naval Operations, OP-96	1
[ ]	S2	Chief of Naval Operations, OPO3EG-CNO	1
[ ]	S9	Naval War College, Newport	1
[ ]	S35	Naval Postgraduate School, Monterey	1
		US MARINE CORPS	
[X]	S23	Marine Corps Development and Education Command, Quantico	1
		US GOVERNMENT AGENCIES	
[ ]	U1	Central Intelligence Agency	1
[ ]	U6	Department of State, Foreign Affairs Research Documents Center	3
[ ]	U9	Department of State, Office of Science and Technology	1
		DEFENSE CONTRACTORS AND UNIVERSITIES	
[ ]	C216	Center for Naval Analysis	1
[ ]	V2	Human Resources Research Organization, Inc	1
[ ]	V3	Institute for Defense Analyses	1
[ ]	V5	RAND Corporation	1
[ ]	V6	American Institute for Research	1
[ ]	V7	Stanford Research Institute	1

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) RESEARCH ANALYSIS CORPORATION McLean, Virginia 22101	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE
AN APPRAISAL OF CLOSE AIR SUPPORT CAPABILITIES (U), Volume IV, DEVELOPMENT OF A SIMULATION MODEL FOR EVALUATING SYSTEMS IN PROLONGED INTENSIVE COMBAT (EPIC) (U)

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Client report January-August 1972

5. AUTHOR(S) (First name, middle initial, last name)
Joe F. Cupps

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
December 1972	75	None

8a. CONTRACT OR GRANT NO. DAHC-19-69-C-0017	9a. ORIGINATOR'S REPORT NUMBER(S) RAC-CR-72, Volume IV
b. PROJECT NO. 017.[illegible]	
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10. DISTRIBUTION STATEMENT
Distribution limited to US Gov't agencies only; Test and Evaluation; [illegible] November 1972. Other requests for this document must be referred to HQDA (DAFD-ZAA), Washington, D.C. 20310.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Assistant Chief of Staff for Force Development, HQ, Department of the Army

13. ABSTRACT

The study objectives were: to analyze many of the factors which affect or constrain close air support operations; to assist the Army in developing and applying criteria for evaluating close air support command, control, basing, and logistics concepts; to review a number of studies and experiments which pertain to the subject of close air support, and to broadly structure an analytical procedure for evaluating close air support resources under conditions of prolonged combat.

The factors or constraints analyzed were in such areas as the influence of the characteristics of the threat, air-to-ground weapons technology, and the effects of environmental, operational, and economic factors on close air support operations.

Criteria were developed for command, control, and basing concept evaluation in the categories of close air support responsiveness, survivability, accuracy, lethality, and availability.

Sixteen reports were reviewed and described according to report content in a common format containing eleven areas of possible interest to the research analyst. These areas include threat analysis, cost and effectiveness comparisons, and force structure or mix determinations.

An expected-value, time step simulation model was developed to evaluate attack helicopter performance over prolonged periods of combat. Sensitivity runs were made to determine the effects of variations in demand sequence, weather, maintenance penalty, attrition, and response time.

DD FORM 1 NOV 65 1473

UNCLASSIFIED

Security Classification

UNCLASSIFIED

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
accuracy						
availability						
basing and logistics						
close air support						
command and control						
environmental effects						
flexibility						
model						
operational factors						
responsiveness						
sensitivity analysis						
simulation						
survivability						

UNCLASSIFIED

Security Classification