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STUDY 32

A Study of Aviation Resources and Readiness Relationships

Volume I

Summary, Conclusions, and Recommendations

Center for Naval Analyses
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13. ABSTRACT

The relationship between aircraft readiness and spares usage at the squadron level, specifically for the F-4B, CH-53, and TA-4F aircraft, is analyzed. The study determines the best combination of aircraft, maintenance man-hours, and spare parts for various budgets. Since the availability of spare parts is a big factor in aircraft readiness, a detailed examination was made of the spare parts resupply system, and recommendations are made for improving this system, that is, for decreasing the time it takes for a supply requisition to be filled. Additional recommendations are made for changing the current method of estimating the quantities of spare parts needed for a specific aircraft model.

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1. In accordance with references (a) and (b), the Aviation Resources and Readiness Relationships Study examined the relationship between resource usage and aircraft readiness at the squadron level. The study developed a method to estimate the effects of changes in the numbers of assigned aircraft, maintenance man-hours available, and spare parts usage on squadron readiness. Since the availability of spare parts is one of the primary factors in determining aircraft readiness, a detailed examination was made of the spare parts resupply system.

2. The major findings of the study are:

a. The method developed, a production function technique, is a useful approach for quantifying the influence of resource utilization on readiness at the squadron level. Though the relationship between budgeting for spare parts at the Navy program level and usage of spares at the squadron level has not been investigated quantitatively, allocation of a greater share of the total resource budget to spare parts is indicated.

b. The average resupply time for Issue Group One requisitions filled in CONUS is 38 days for the Pacific Fleet and 35.5 days for the Atlantic Fleet. If about $12 million more were spent per year on the resupply system—$6 million in each fleet—this average resupply time might be decreased by up to 5 days in the Atlantic and 8 days in the Pacific.

What [illegible] the requirement system?

[illegible]

c. Only two potential improvements were more cost-effective than the purchase of additional spare parts in terms of improving the probability of supply availability; i.e., altering the percentage of issues from first line air stations, and moving to an exclusive use of air movement overseas in lieu of surface transportation. However, until the availability of spare parts in the "system" is improved, additional resources for processing and transportation are generally not desirable. Other aspects of the total resupply system must be studied if further improvements are to be made. This is especially true of the requisition submission time sub-process and subsequent inventory control point processing.

d. Spare parts allowance lists are formed, in part, on the basis of each ship's prior usage of spare parts, rather than on total fleet experience. This has often led to an over- or under-stockage of material for each deployment. In addition, the capability to resupply is not an explicit consideration in determining the number and types of spare parts to stock initially on board an aircraft carrier. Another problem is that the procurement of spare parts is based on demand estimates linearly related to aircraft flying hours. However, most spare part failures are not correlated with flying hours, and consequently the effect of current procurement policy on aircraft readiness is difficult to predict with precision.

3. The study has raised a number of questions which require further testing and research before it can be extended to other aircraft types. The possible extensions of the models are many, e.g., further stratifying the resource categories, further examining potential changes in the resupply system, etc. In future development of the methodologies and/or techniques described, careful attention should be paid to the adequacy of the data base, and to costing factors involved. The questions raised regarding the inclusion of various factors in the estimates of resource costs should be addressed in more detail.

4. The study represents an initial attempt to examine the effects of changes in major resource categories on aviation readiness. The development and implementation of better inventory management techniques are recognized as requirements for improved readiness. The study has been useful in identifying other problem areas requiring further research. The relationship between budgeting for spare parts at the Navy program level and spare parts usage at the squadron level is already a subject of further study.

5. Since the data base used in the study covered the period 1968-1969, and was in a state of change at the time this research was conducted, the numerical co-efficients derived for the production function, and the optimum solution found for this function, are useful only as examples to demonstrate the application of a technique. The study is forwarded with the understanding that the analytical results will be used for background information only.

WH Bagley

W. H. BAGLEY
Director, Navy
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CENTER FOR NAVAL ANALYSES

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Study 32

A STUDY OF AVIATION RESOURCES AND READINESS RELATIONSHIPS

VOLUME I

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

June 1970

Prepared under the direction of
S. Scott Sutton, Project Director

The work reported here was conducted under the direction of the Center for Naval Analyses and represents the opinion of the Center for Naval Analyses at the time of issue. It does not necessarily represent the opinion of the Department of the Navy except to the extent indicated by the comments of the Chief of Naval Operations.

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ABSTRACT

This is a study of the relationship between aircraft readiness and spares usage at the squadron level, specifically for the F-4B, CH-53, and TA-4F. The study determines the best combination of aircraft, maintenance man-hours, and spare parts for various budgets. Since the availability of spare parts is a big factor in aircraft readiness, a detailed examination was made of the spare parts resupply system, and recommendations are made for improving this system, that is, for decreasing the time it takes for a supply requisition to be filled. Additional recommendations are made for changing the current method of estimating the quantities of spare parts needed for a specific aircraft model.

The study is in 3 volumes, of which this summary volume is the first. Volume II is entitled "A Ready Hour Production Function for Naval Aviation;" Volume III, "The Resupply System for Naval Aviation Spare Parts." Abstracts and Tables of Contents of all volumes are also in this volume.

TABLE OF CONTENTS

FOREWORD

During the past 5 years the Not Operationally Ready Supply (NORS) rates for Navy and Marine aircraft have increased from approximately 7 percent to 17 percent for aircraft possessed by units. The high NORS rates have resulted in tactical and ASW aircraft material readiness below CNO standards. In this same period the capital investment in aircraft doubled while the value of the spares inventory increased only about 5 percent. Thus, rising NORS rates, increased complexity of aircraft, and the possibility of reduced funding for spares, generated a need for a better understanding of the relationship between aviation readiness and spare parts.

At the request of CNO, CNA undertook a project entitled "A Study of Aviation Spares and Readiness Relationships." The Study Directive upon which this research was based is presented in an Appendix to this volume. It is noted that a number of factors influencing aircraft readiness such as operating environment, maintenance skills, support equipment, technical data, and engineering design, were taken as given in the analysis, as were current Navy policies on the assignment of aircraft and personnel to squadrons and on the assignment of material priorities. This project concentrated on 3 specific questions: the relationship between readiness and spare parts usage, the operation of the spare parts resupply system, and procedures for estimating the demand for spare parts.

Graph

Use

These questions, of course, are not independent. They are interrelated and are only part of the total complex aviation support system. Squadron readiness depends not only on spare parts, but also on the aircraft employed and the maintenance support provided, among other factors. The effectiveness of the spare parts support system itself depends upon both the quality of the initial stockage decisions and the timeliness of the resupply system. To address these questions on a macro level (as opposed to the development of a large-scale multi-echelon inventory model) models of the interrelated effects of squadron level inputs - aircraft, maintenance, and spare parts - on squadron readiness and of the operation of the resupply system were developed.

use prior

This study reports on these issues in three volumes. Volume I summarizes the methodologies used and reports the principal conclusions, results, and recommendations. The purpose of volume I is to serve as a succinct statement of the results of principal interest. Volume I also discusses demand estimation procedures and the problems encountered in attempts to relate the resupply of parts to spare parts usage onboard a carrier. Volume II describes in detail the development of a ready-hour production function to study the relationship between readiness and spare parts usage. Volume III contains a detailed analysis of the resupply system. Volumes II and III can be read and used independently.

Parts I and II of this volume summarize the ready-hour production function study and the resupply system study. Part III discusses some other important aspects of the aviation support system, including the estimation of demand for spare parts and the problems encountered in relating the two studies in a formal manner. The conclusions for part I are stated on page 14, for part II on page 17, and for part III on page 25.

PART I

A READY-HOUR PRODUCTION FUNCTION FOR NAVAL AVIATION

OBJECTIVES

This part of the study is concerned with the relations among aircraft readiness and the aircraft, maintenance man-hours, and spare parts available at the squadron level. The objective was to develop and to apply a practical method that could determine the following:

1. How aircraft readiness is affected by changes in resource inputs, e.g., spares usage.
2. How to combine these resources to get the highest aircraft readiness for a given budget.

The result desired was a technique that could assist budget planners in estimating the effects on aircraft readiness of changes in the usage of spare parts. The technique was illustrated by application to the A-7B, CH-53, S-2E, F-4B, and the TA-4F, using data from the aviation 3M (Maintenance and Material Management System) data system.

METHODOLOGY

These objectives were accomplished by use of a production function, a function relating output produced to the levels of inputs used. A production function was estimated, using econometric techniques explained in detail in volume II. The production function shows the level of output that can be produced for any given input combination. The effect on squadron output of a change in any input category can be determined from the estimated production function alone. When used with other relationships, the estimated production function provides a tool for further analyses. By use of the production function and a budget constraint on the inputs, a cost function, relating output to the budget for resource usage, was derived and applied to the F-4B, TA-4F, and CH-53. This procedure also determines the mix of aircraft, maintenance man-hours, and spare parts that maximize aircraft readiness for a given budget. The production function can also be used to determine the relationship between the NORS rate and the usage of spare parts. This procedure is explained below and in volume II.

The squadron was chosen as the basic unit of observation because it is the primary unit charged with combining aviation resources to produce tactically required output. Output is measured by aircraft ready hours, defined as follows:

READY HOURS = TOTAL CUSTODIAL HOURS
- (TIME IN NORS CONDITION)
- (TIME IN NORM CONDITION).

We chose ready hours because they reflect only the availability of ready aircraft. The alternative measures, such as flight hours or sorties, represent a combination of the supply of readiness by the squadron and the demand for ready aircraft for tactical purposes. Since our study was essentially concerned with the logistics system, it seemed appropriate to choose the output measure that best reflected the effectiveness of the aviation supply and logistic system itself.

[illegible]

The inputs used for the production function were aircraft, maintenance man-hours expended on corrective actions at the squadron and intermediate level, and spare parts used (measured by the dollar value of consumables and repairables).

The data used to determine the empirical relationship between the production of ready hours and the above inputs used by the squadron was obtained from the 3M system. The data was collected on a monthly basis for Atlantic and Pacific squadrons from April 1968 through September 1969. Both deployed and training squadrons were observed.

inputs are actual

Since the data used in the study represents the levels of resource usage and readiness, actually reported, the results can be interpreted as describing the actual operating procedures of supply managers and squadrons rather than the planned procedures that might be reflected in the various planning factors. On the other hand, as is the case in any study using data from a large reporting system, the results share any biases and inaccuracies inherent in the 3M system itself.

The following form of the production function was used for the analysis:

$$RH = A\left[\alpha_1 P^{-\rho_1} + \alpha_2 M^{-\rho_2} + \alpha_3 S^{-\rho_3}\right]^{-\frac{1}{\rho}}$$

where

RH = ready hours,
P = number of planes,
M = number of maintenance man-hours at the squadron and intermediate level,
S = dollar value of spares usage (consumables and repairables).

A procedure was developed and programmed to estimate the parameters A, α_1, α_2, α_3, ρ_1, ρ_2, ρ_3, and ρ of the production function from the data on resource usage and squadron output. The estimated production function provides the tool for addressing the first type of question noted above. Effects of changes in any resource category can be determined, as can the interrelationships among the various resource inputs. To address the second type of question, the production function is used to relate input levels to output levels so that trade-offs could be analyzed.

The following optimization problem was solved to determine the optimal mix of resources to be supplied to a squadron to maximize ready hours, given various funding levels for total resource usage:

$$\text{Max } RH = A\left[\alpha_1 P^{-\rho_1} + \alpha_2 M^{-\rho_2} + \alpha_3 S^{-\rho_3}\right]^{-\frac{1}{\rho}}$$

subject to

$$p_1 P + p_2 M + p_3 S = C$$

where

C = total budget for resource usage, and
p_i = per-unit prices of the various resources.

The reasons for the choice of this form of the production function and a detailed description of the methodology and its underlying assumptions are given in volume II.

The study contains two separate stages. The first is the estimation of the parameters of the production function relating measured readiness to resource usage. This part of the study is of primary importance in that it leads to estimates of how readiness will change in response to changes in input levels. From the estimates of the production function, one can predict how changes in spare parts usage will affect readiness.

It is important to note that this approach deals with inputs at the squadron level. Many factors, of course, intervene between the budgeting level and the level at which resources are actually employed, e. g., procurement, training, inventory management, etc. Furthermore, this transfer between levels can be influenced by choices of management techniques such as scientific inventory control (see Section III of this volume). Thus, while changes in the method of transfer between the budget level and the operating level will not influence the relationships between inputs at the squadron level as addressed here, they can have a substantial impact on the total costs of various remedial actions. It is important to keep in mind that this production function analysis is concerned with the relationship between resource usage and readiness at the squadron level.

The second stage of the analysis considers the problem of determining minimum cost combinations of inputs that lead to a given level of readiness. Both the production function estimates and estimates of the costs of the various inputs are required for this stage.

In the results reported here, no additional constraints on squadron size or other factors were introduced; thus we refer to a "logistically" optimal squadron as one that uses the minimum cost set of inputs to achieve a given readiness level. In practice, additional constraints on squadron size and such considerations as flexibility for rapid expansion of readiness would enter into the planner's decision. Such constraints can be introduced into the optimization procedure. It is important to note that the relation between readiness and resource usage does not depend at all on the optimization procedure or the set of resource costs used. Thus the two sections of the analysis can be employed separately.

MAIN RESULTS, CONCLUSIONS, AND RECOMMENDATIONS

This section discusses the empirical results of the ready-hour production function analysis for the five type/model/series of aircraft selected for study.

For each type aircraft, the parameters of the production function were estimated for all squadrons, for squadrons based in the Atlantic and in the Pacific separately, and, when appropriate, for training squadrons separately. These breakdowns were selected to reflect differences in the operating environments in the Atlantic, Pacific, and training squadrons. To the extent that these operating environments can be expected to continue as in the past, these separate production functions can be of value in analyzing potential changes in ready hours in these areas as a result of changes in resource usage.

In this section, a summary of results for the five types of aircraft is given. Then, the results for the F-4B, TA-4F, and CH-53, all squadrons, are discussed in detail. This is followed by a discussion of the relationships between spares usage, ready hours and NORS rates, using results for the F-4B, TA-4F, CH-53, all squadrons. The S-2E is excluded because of an insufficiency of data; the A-7B is excluded because this aircraft program was starting up during the period of observation and, consequently, the results are ambiguous.

The complete set of empirical results for the five types of aircraft is contained in volume II.

Results

For each type/model/series of aircraft studied, statistical measures, such as the coefficient of determination, R^2, and the standard t-test, showed that the production function technique was a good method for predicting ready hours from data on the three inputs.

The following were the results for the various types of aircraft:

1. The R^2 statistic, which gives the percentage of the total variance in observed ready hours explained by the variability in the three inputs, was in the range of .6 to .8. Values in this range, given the aggregate nature of the data and the imperfections in the measurement of output, are considered very high.

2. The three inputs all had coefficients significantly different from zero in almost all cases. These results were taken from the estimation of the Cobb-Douglas form of the production function, using a standard one-tailed t-test.

A more detailed discussion of these results is given in volume II.

Data Analysis for the F-4B, TA-4F, and CH-53

The means and standard deviations of the data for these three types of aircraft over the period of observation are shown in table I. The standard deviations, shown in parentheses below the means, measure the variability in the data for the squadron months observed. The maintenance man-hour data reflects only the portion of the total maintenance time that is addressed to removal, repair, and installation of parts, as reported in the 3M data files, and does not include the time spent in other activities (e. g., flight preparation, etc.). As shown in the table, large variability in spares usage on a monthly basis was observed. A large variance in the TA-4F's was observed in some squadrons, such as VA-153 and VA-155. All observations for squadrons used in the analysis relate to the type/model/series under study only. This wide range of observations on the inputs was desirable for the production function estimation. The reason is that forecasts are better if the range of observations covers the range in which one hopes to forecast.

The basic data shows wide variations in ready hours over the squadrons observed. Statistical measures showed that a large part of this variation could be explained by relating it to the use of aircraft, maintenance man-hours, and spare parts. For the TA-4F, CH-53, and the F-4B, 81 percent, 69 percent, and 56 percent, respectively, of the variation in ready hours was explained by relating it to the use of these inputs. Consequently, the production function technique appears to be a good method of predicting changes in ready hours associated with variations in these three inputs, given that the Navy continues to conduct its business as it has in the past.

Of course, even higher levels of the R^2 statistic, indicating that a greater percentage of the variation in readiness was explained by the independent variables, would be desirable. Two factors may produce this result in future analyses: more accurate data on both inputs and readiness, and greater stratification of the inputs, say, into distinct categories of spare parts and maintenance labor. However, the fact that the current results, based upon highly aggregated data and only three categories of inputs, explain so much of the wide variation in readiness (see table I) that was observed suggests that the technique and current results can be of significant value as a planning input.

TABLE I

MEANS AND STANDARD DEVIATIONS OF OBSERVATIONS: SQUADRON/MONTH

	TA-4F	F-4B	CH-53
Ready hours	3,462.3 (2,931.3)	4,228.9 (1,506.2)	4,182.3 (1,858.0)
NORS rate	26%	11.4%	25.2%
Organizational and intermediate level maintenance labor:			
Report (3M) total for removal, repair, and installation of parts	1,583.5 (1,708.4)	6,216.5 (2,782.4)	3,453.6 (2,649.9)
Planning factor total for all types of maintenance activity	13,151	25,275	20,003
Spares usage	$63,792 (71,717.8)	$305,828.4 (542,033.7)	$136,979.4 (118,335.5)
Planes	10.3 (8.9)	12.5 (2.2)	17.4 (8.0)
Period	April 68- Sept. 69	April 68- Sept. 69	April 68- Sept. 69

Results for the F-4B, TA-4F, and CH-53

Two important types of output are generated by the production function technique: (1) the change in ready hours as a result of variations in one input while holding the other two constant, and (2) the cost function, which relates the maximum level of ready hours that can be achieved to the total budget for resource usage, and the optimal mix of resources for that output level. When maintenance man-hours and numbers of aircraft in a squadron are held constant at some level, it is possible to show the relationship between ready hours and NORS rates as the level of spares usage is varied. The purpose of the next section is to present these results for the F-4B, TA-4F and CH-53.

Relationships Between Spare Parts Usage, Ready Hours, and NORS Rates

The purpose of this section is to show how the NORS rate can be calculated from the ready-hour production function with respect to variations in spare parts usage for any type/model/series of aircraft. The calculation is illustrated with results for the F-4B, TA-4F, and CH-53. None of the results reported here depend on the cost estimates or the optimization procedure.

The NORS rate is the more generally understood measure of supply effectiveness in the Navy compared with the ready-hour measure developed in this study. Therefore, the results of this section are of direct interest to the Navy resource manager and further illustrate how the technique can assist him in evaluating alternative budgets that affect spare parts usage at the squadron level.

[The ready-hour production function shows the relationship between spare parts usage and ready hours by varying spare parts usage while holding aircraft and maintenance man-hours constant at some specified level. The constant values used were the averages over the sample range of observations. It seems reasonable to presume that an increase in ready hours that follows an increase in spare parts usage results from a reduction in NORS hours. This, in turn, results in a reduction in the NORS rate. The effects of higher levels of spare parts usage on utilization of maintenance labor are accounted for by the production function, which, due to the complex algebraic form selected, takes account of the fact that additional spare parts (say) will lead to greater effectiveness of aircraft and labor. Thus each unit of spare parts results in a decreasing (although positive) change in readiness. Increasing maintenance and spare parts concurrently would, of course, lead to proportionately greater changes in readiness than increasing either separately.

The number of squadron ready hours per month is equal to total available hours per month (number of planes x 720 hours) less (NORS hours + NORM hours). Since the number of aircraft is held constant, the number of total available hours is also constant. Also, NORM hours would be expected to remain stable when spare parts usage is increased, since NORM hours are mainly dependent on maintenance man-hours, also being held constant. Thus, an increase in ready hours associated with an increase in spare parts usage will be due almost entirely to a reduction in NORS hours. The NORS rate associated with a reduction in NORS hours is then calculated.

The results for the F-4B are shown in table II. The results are based on a 12-plane squadron, using 6216 maintenance man-hours for corrective purposes. The NORS hours, NORS rate, and spare parts usage in the first row of table II are the average values obtained from the sample data. Ready hours in the first row were derived from the production function, using the average values for all three resources. The next rows show the predicted increase in ready hours and reduction in NORS rates resulting from an increase in spare parts usage. For example, an F-4B squadron could be expected to increase ready hours from 5928 to 6221 if spare parts usage were increased from $305, 800 to $400, 000. This would reduce NORS hours from 984 to 691 and the NORS rate from 11. 4 percent to 7. 9 percent.

The results for the TA-4F are shown in table II for a 10-plane squadron using 1583 maintenance man-hours. The results for the CH-53 are shown for a 17-plane squadron using 3454 maintenance man-hours.

These results can be used to analyze the effects of a given change in spare parts usage across aircraft types. For example, given the present system, analysis shows a 10 percent increase in spare parts usage will reduce the NORS rate for the F-4B about 16 percent; for the CH-53, about 2. 3 percent; and, for the TA-4F, about 8. 3 percent. Again, the relationship between spare parts usage and the NORS rate can be determined only if aircraft and maintenance man-hours are held constant at some specified level. For the cases analyzed, these inputs were fixed at the average values observed over the fleet for 18 months.

TABLE II

RELATION BETWEEN NORS RATE, READY HOURS, AND SPARE PARTS

F-4B

Ready hours	NORS hours	NORS rate (percent)	Spares usage
5,928	984	11.4	$ 305,828
5,977	935	10.8	320,000
6,043	869	10.1	340,000
6,105	807	9.3	360,000
6,221	691	7.9	400,000
6,327	585	6.7	440,000
6,470	443	5.1	500,000

Average Value of the Data:

Planes = 12
Man-hours (removal, repair, and installation of parts) = 6,216
Man-hours (planning level for all maintenance activities) = 24,264

TA-4F

3,415	1,873	26.0	$ 63,792
3,756	1,532	21.3	100,000
4,315	974	13.5	200,000
4,659	630	8.7	300,000
4,910	378	5.3	400,000

Average Value of the Data:

Planes = 10
Man-hours (removal, repair, and installation of parts) = 1,584
Man-hours (planning level for all maintenance activities) = 12,768

CH-53

4,333	3,084	25.2	$ 136,979
4,535	2,882	23.5	200,000
4,657	2,760	22.6	250,000
4,757	2,660	21.7	300,000
4,918	2,499	20.4	400,000
5,045	2,372	19.4	500,000
5,149	2,268	28.5	600,000
5,238	2,179	17.8	700,000
5,385	2,032	16.6	900,000
5,447	1,970	16.1	1,000,000

Average Value of Data:

Planes = 17
Man-hours (removal, repair, and installation of parts) = 3,454
Man-hours (planning level for all maintenance activities) = 19,543

ESTIMATION OF RESOURCE COSTS

To interpret the empirical results of the optimization analysis, one must understand how the prices of the resources were estimated. The specific price estimates were based in part on classified data and are reported in a separate document (reference (a)). The purpose of this section is to explain the methodology used in estimating the prices, the conceptual problems involved, and the elements of the cost estimates. Again, we note that none of the results reported earlier depend upon these estimates.

For the purpose of estimating the resource costs, the production function discussed above was taken as given. The total budget equation for resource usage is given by

$$p_1 P + p_2 M + p_3 S = C,$$

as defined above. The problem was to estimate p_1, p_2, and p_3, the price per unit of aircraft, maintenance man-hours, and spares usage. These estimates were based on information contained in standard service documents. Neither discount nor inflation factors were used and all costs were stated in 1970 dollars. The observations on spares usage were on a monthly basis. The monthly aircraft cost was simply estimated by prorating the cost of the aircraft over its operating life. The maintenance man-hour cost was derived from a weighted average of pay grades and ratings peculiar to the aircraft, and the prorated cost of maintenance personnel equipment (tools, test boxes, etc.). Thus the costs employed are <u>average</u> costs, not <u>marginal</u> costs. For an already deployed T/M/S of aircraft, costs previously incurred should, of course, be disregarded. A more complex cost function that includes costs of existing resources and costs of procuring additional resources can be estimated and used in the analysis.

The Price of Spares

The unit price of a spare part is reported in the Material Data Bank (60 Series) from which observations on monthly usage of spare parts by squadrons were obtained. Thus, accepting these prices, there was no problem in estimating the value of spare parts usage at the squadron level. The total cost of spare parts used was calculated as twenty percent of the value of the repairable parts used plus the price of the consumable parts used (see appendix B of volume II):

$$S = \sum_i c_i s_i,$$

where

c_i = unit price of the ith type spare used, and

s_i = quantity of the ith type spare used.

Thus, in the budget equation above,

$$p_i s = \sum_i c_i s_i$$

and $p_3 = 1$ since S is the total value of spares usage.

The cost estimates of the other two inputs, however, were not so simple.

The Price of Aircraft

The monthly unit cost of aircraft is the sum of the following cost elements:

1. investment cost of a unit equivalent (U.E.) aircraft, and
2. investment cost of support aircraft.

These costs were estimated for the A-7B, F-4B, A-6A, CH-53A, TA-4F, and S-2E.

The investment cost of a U.E. aircraft can be broken down as the sum of the following additional cost elements: flyaway costs, cost of investment spares (as opposed to replenishment spares), and cost of peculiar ground support equipment (P.G.S.E.). Thus,

Investment cost of a U.E. aircraft = flyaway costs + cost of investment spares + cost of P.G.S.E.

Estimates of flyaway costs were obtained from Naval Air Systems Command, and the cost of investment spares were estimated as a percentage of flyaway costs. The investment cost of a U.E. aircraft used in this study did not include the cost of P.G.S.E. The cost of P.G.S.E. was used in estimating maintenance costs. Thus, in this study,

Investment cost of a U.E. aircraft = flyaway costs + cost of investment spares

This sum was divided by the aircraft's operating life (which excludes time spent in Progressive Aircraft Rework (PAR) and other Special Rework) to obtain a monthly cost. For five of the six aircraft, the Navy has recently lengthened the planned operating life: the effect is a reduction in the per-month aircraft costs.

When a U.E. aircraft is purchased, "support" aircraft must be purchased as well. The investment cost of support aircraft can be broken down into the investment costs of a Readiness Carrier Air Wing (RCVW), pipeline aircraft, and attrition aircraft.

If a squadron's number of U.E. aircraft is increased, aircraft must also be provided, so that crews can be trained for that squadron's mission. For each group of four operating squadrons, there is a readiness (or training) squadron (the RCVW). Since the ratio of RCVW to U.E. aircraft is not always a constant 25 percent, historical averages were used to obtain the estimates for this study.

Navy planners appear to assume that the demand for pipeline aircraft is a positive function of the sum of U.E. and RCVW aircraft. This assumption raises another conceptual problem for the analysis. Suppose that in future squadrons the number of aircraft were reduced. This could lead to a higher utilization rate of the remaining aircraft and, thus, an increase in demand on all pipeline facilities for any given time horizon. If this were the case, then pipeline aircraft costs should be included in the total monthly cost of aircraft. If a reduction in future squadron size did not induce a higher utilization rate and increased demand for pipeline aircraft, then these costs should be excluded. In the present study, pipeline aircraft costs are included.

COST CONSTRAINS

Estimation of investment costs for attrition aircraft, however, may be the most controversial aspect of the cost estimation procedure used in this study. An examination of Navy budget submissions clearly reveals the allowance for RCVW and pipeline aircraft but not for aircraft that may crash and be replaced. Historical evidence suggests, however, that as the number of operational aircraft (U.E. plus RCVW aircraft) increases, the absolute number of attrited aircraft increases. Estimates of attrition from Navy sources, which reflect such factors as reliability of equipment, type of landing (land or carrier), and type of mission, were used to derive the cost of attrition aircraft. Thus, the cost estimates of this study assume that if the aircraft inventories of squadrons are reduced, any increased utilization rate of remaining aircraft will not lead to an increase in aircraft fatigue and a higher attrition rate.

An illustration of how these cost elements were used to estimate the monthly price per unit of aircraft illustrates the cost procedures used in this study. The relevant inputs of the cost estimation are shown in table III. The data is merely illustrative; exact figures are contained in reference (a).

TABLE III

INPUTS FOR ESTIMATING AIRCRAFT INVESTMENT COSTS

Row	Element	Input
1	Type aircraft	F-1A
2	Flyaway cost	$2.2 million
3	Investment spares (5% of row 2)	$110,000
4	Operating life	100 months
5	Prorated flyaway cost (row 2 divided by row 4)	$22,000
6	U.E. monthly cost (sum of rows 2+3 divided by row 4)	$23,100
7	RCVW factor	25%
8	Attrition factor	0.3%/month

Using the inputs in table III, estimation of the investment costs of U.E. aircraft and support aircraft proceeds in the following steps:

1. The monthly cost of RCVW aircraft is (.25) x ($23,100) = $5,775.

2. The monthly cost of operating aircraft (U.E. aircraft + RCVW aircraft) is ($23,100) + ($5,775) = $28,875.

3. The cost of pipeline aircraft is obtained by first multiplying the pipeline factor by the operating aircraft and then multiplying this result by flyaway costs. Thus, the monthly cost is (.20) x (1.25) x ($22,000) = (.25) x ($22,000) = $5,500.

4. The cost of attrition aircraft is obtained by first multiplying the attrition factor by the operating aircraft and then multiplying the result by flyaway costs. Thus, the monthly cost is (.003) x (1.25) x ($22,000) = (.004) x ($22,000) = $88.

5. Thus, the total monthly investment cost of an aircraft is: (investment cost of a U.E. aircraft) + (investment cost of support aircraft) = ($23,200) + ($5,775 + $5,500 + $88) = $34,463 per month. Note that this figure excludes such operating costs as

petroleum and number of pilots in a squadron, which were assumed to be constant for purposes of this study. Maintenance costs are a subcategory of general operating costs, however, and the cost estimate of this resource is discussed next.

The Price of Maintenance Man-Hours

The monthly cost of maintenance man-hours is equal to the sum of the cost of maintenance personnel and the prorated cost of their equipment. Data on peculiar ground support equipment (P.G.S.E.) was used as a surrogate measure of the cost of total maintenance equipment.

P.G.S.E. is probably a function of the number and location of the type of squadrons. P.G.S.E. is most often estimated, however, as a percentage of flyaway cost. Several factors made it difficult to obtain accurate estimates. First, most P.G.S.E. is charged to early "buys." Second, some of the costs of P.G.S.E. may be contained in spare parts data since equipment also wears out and requires repairs.

Maintenance personnel costs were estimated from Navy data sources (see reference (a)) which list the number of enlisted personnel by rating required at the intermediate and squadron level to maintain and operate a specific model aircraft for a given period of time. From this data, the percentage of maintenance time accounted for by personnel in specific ratings was derived. These percentages were then multiplied by weighted averages summarizing the paygrade distributions of the ratings.

The man-hours used in the analysis represent an aggregate value, which is the sum of man-hours generated from different maintenance skills within the squadron. Therefore, it is not possible to relate the man-hours expended directly to personnel requirements within the squadron. It would have been valuable to stratify the maintenance labor input to the production process into more than management and worker categories, i.e., into various technical categories as well, but the time available for the study and the data we were able to gather made it impossible for us to do this. It is clear, however, that the more this production process can be stratified by inputs, the more valuable the implications to the decision-maker can be. It would clearly be of interest to know the trade-offs among various levels of maintenance skills and the other inputs to the squadron's production process. Even though the data is highly aggregated, it is still possible for the analysis to show the relative importance of the inputs in producing squadron ready-hours.

Results of the Cost Function Analysis: Comparison of Present and Optimal Resource Use

The cost function is defined as a function that shows the maximum level of ready hours that can be obtained for various total budget levels for aircraft, maintenance man-hours, and spare parts usage. The results presented in this section are shown for only one value of the total budget, a value derived from average values of the resources used over the period of observation.

Table IV shows a comparison of the logistically optimal mix of resources for the F-4B, CH-53, and TA-4F with the present monthly averages of these resources for the same total budget.

TABLE IV

COMPARISON OF THE PRESENT AND OPTIMAL MIX

		Planes	Intermediate and squadron man-hours used *	Spares usage	Ready hours
F-4B					
	Present	12	6212	$305,828	4229
	Optimum	11	5837	$382,884	5963
CH-53					
	Present	17	3453	$136,979	4182
	Optimum	15	8723	$227,451	4504
TA-4F					
	Present	10	1583	$ 63,792	3462
	Optimum	10	956	$ 70,932	3473

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*These figures are maintenance man-hour totals for removal, repair, and installation of parts only. Total planned maintenance levels for squadrons of the present size are as follows: F-4B - 24, 264; CH-53 - 19, 543; TA-4F - 12, 768.

For the current estimated total budget for the F-4B, there should be, from a logistics point of view, one less aircraft per squadron, a 7 percent decrease in maintenance man-hours, and about a 25 percent increase in spare parts usage. If this resource mix were used, ready hours per squadron would increase approximately 41 percent and ready hours per aircraft by 54 percent.

For the CH-53, the results indicate that the logistic size of the squadron should be reduced by two helicopters, maintenance man-hours more than doubled, and spares usage increased by about 66 percent. This would result in a predicted increase in ready hours per squadron of about 8 percent for the same total budget.

For TA-4F squadrons, as noted in table IV, the optimum level of ready hours is very close to the average values observed. However, the optimal allocation of resources indicates that maintenance man-hours should be reduced by 627 man-hours and spare parts usage increased by 11 percent.

The notion of the "logistic size" of the squadron in the above discussion requires careful interpretation. It is meant to suggest the changes in squadron size (in the above case, a reduction with the exception of the TA-4F) resulting from a strictly economic consideration of the best use of resources available to a squadron to produce ready hours. There are certainly other considerations, outside the cost function analysis, such as tactical, strategic, and technical requirements, that would make it undesirable to alter squadron size. Reference to the "logistic size" as opposed to the "tactical size" of the squadron is meant to stress this distinction.

The results of the cost function analysis on squadron size do not point to an unqualified recommendation to reduce the number of aircraft per squadron. If there were no overriding tactical or other constraints on squadron size, and only the best economic mix of squadron resources were at issue, one would want to consider the changes indicated by the cost function analysis. More important than this result are the following two major conclusions which can be drawn from the cost function analysis: (1) if current total resource usage budgets were maintained in the future, a larger percentage of these budgets should be allocated to spare parts usage and a smaller percentage to aircraft and maintenance man-hours, with the exception of the CH-53, where man-hours more than doubled; and (2) even if squadron size remained unchanged, the results indicate a need for more spare parts support. Thus the results of the analysis give strong support to an increase in spare parts funding.

It is important to note that results similar to those of table IV could be determined for any specified budget. This would permit determination of how to allocate a total budget cut or increase across numbers of aircraft per squadron, man-hours, and spare parts usage in order to achieve the smallest reduction or largest increase in ready hours. Arbitrary cuts in specific budget categories, such as spare parts, could reduce the level of ready hours far below the level obtained by an efficient allocation of the budget reductions.

It should also be noted that other specifications of the input costs can be considered reasonable and thus, in further use of the methodology, more attention should be directed to the costing problem. Empirical results of the type presented in this volume can be obtained for any set of cost data. Since the production function estimates do not depend upon the costing equations used, it is only the optimization problem that is affected by these cost estimates. The optimization procedure has been implemented on the computer and can be run for any particular set of cost values that the Navy finds reasonable. The particular values that we used were those arrived at after analysis by a member of CNA's Cost Analysis Division. In deriving these costs, we have been careful to specify exactly what decisions were made about the inclusion of various factors, so that Navy planners can order them in a way more consistent with their views and then run the programs with their cost inputs. As the production function methodology is implemented and extended, an important side study will be an accurate determination of the costs of the various inputs to the production process.

Proper Use of the Technique

One important observation should be made on the proper use of these results in analyzing alternative budget programs for aircraft, maintenance man-hours, and spare parts usage: Ready hours were related to the dollar value of spare parts actually used at the squadron level in the production of ready hours and not to the dollars budgeted for spares. Many steps in the inventory management of spares intervene between the budgeting for spares and the type, number, and value of the spares actually used by the squadron. Thus, the user of the production function technique cannot assume that the value of spares actually used at the squadron level to produce an output of ready hours is the precise dollar amount to budget to achieve the same level of ready hours. The problems involved in closing this gap between spares usage and spares budgeting are discussed further in part III of this volume. However, for present purposes, the ready-hour production function technique can still be useful in analyzing budget programs by assuming, say, a linear relationship between changes in the budget for spare parts and usage of spare parts at the squadron level. With such an assumption, the production function technique can then be used to relate changes in the budget for spare parts to changes in ready hours by type/model/series of aircraft.

CONCLUSIONS

The important conclusions from this analysis are:

1. The results indicate that the production function methodology can be valuable in examining squadron operations. Much of the observed variance in squadron readiness is explained as a function of resource usage.

2. If current resource budgets are maintained, a larger percentage of these budgets should be allocated to the usage of spare parts at the squadron level. For each type/model/series of aircraft studies, the results showed that higher levels of aircraft ready hours could be obtained.

3. Even if the number of aircraft in a squadron is maintained at current planning levels, the results also indicate a need for more spare parts.

4. For any type/model/series of aircraft the ready-hour production function technique can be used to allocate total resource budgets among the three resources of aircraft, maintenance man-hours, and spare parts for any type/model/series of aircraft in order to achieve maximum ready hour production.

5. Assuming a proportional relationship between spare parts used at the squadron level and dollars budgeted for spares, changes in the spares budget can be related to changes in ready hours and NORS rates by type/model/series of aircraft. The study has not attempted to determine this proportional relationship, however. As noted in Part III of Volume I, to forecast the level of readiness that will be achieved on the average for a given spares support budget requires an estimate of the percentage of the funds allocated that will in fact become available to the user in the form of parts actually required and used. Assuming that management decision processes are unchanged, this percentage may be estimated by determining the dollar value of material actually used in spare part support of the system from the preceding year 3M or ASO demand data as a percentage of the funds allocated for spare part support of that system in that year. Unfortunately, this estimate was not available for fiscal year 1969, the period for which the production functions were estimated. Fiscal year 1970 is the first year in which funds were allocated to specific weapons systems.

6. There are a large number of possible extensions of the production function technique. Further stratification of the input resource categories could be of even greater use in planning, as trade-offs among various categories of maintenance labor and spare parts could then be considered. Development of an output measure which differentiated among different levels of readiness could be another extension. Finally, extension of the technique to other aircraft types would provide additional input to the budget planning process.

PART II

THE RESUPPLY SYSTEM FOR NAVAL AVIATION SPARE PARTS

The resupply system for Naval aviation spare parts is an important factor in determination of aviation readiness in the fleet. Volume III of this study summarized here, documents a structure developed for investigating the various processes that constitute resupply. The study uses this structure to determine the improvements in resupply time which are obtainable for alternative budget levels.

OBJECTIVES

The purposes of this part of the study are to develop a model of the resupply system for high-priority Naval aviation spare parts, to determine the expected resupply time for parts in the current system, and to determine the costs and benefits of improvements in the resupply system. The result desired is the identification of the greatest possible improvement in resupply time, appropriately defined, for a given budget.

An ultimate objective was to relate expenditures on improvement of the resupply system to the tradeoff of dollars spent on initial stockage of spare parts aboard a carrier. This was not possible (the problem is discussed in part III of this volume); however the costs and benefits of improvements in the resupply system were analyzed.

METHODOLOGY

This study had four tasks:

1. To investigate and structure the resupply system for aviation spare parts.

2. To estimate expected completion times for different categories of parts. (The primary data source for this task was the MILSTEP (Military Supply and Transportation Evaluation Procedures) system, which contains the vital dates in the history of requisitions for all types of spare parts. The data is discussed further in volume III.)

Requisitions were grouped according to the following characteristics:

- Type of material ordered. Requisitions are considered to be either for an end-use component (repairable) or bit-and-piece (consumable) material.

- Origin of requisition. Only requisitions from deployed carriers – Atlantic or Pacific fleets – are of interest.

- Priority of requisition. We consider only Issue Group 1 (IG-1), which consists of priorities 1-3 and thus includes almost all NORS requisitions, and Issue Group 2 (IG-2), which is primarily used for the replenishment of stock.

3. To determine the costs and benefits of improvements to individual sub-processes in the system.

4. To determine the optimal combination of improvements for several budget levels. This optimization was performed with respect to two measures of effectiveness: expected (average) resupply time, and the probability of completion of resupply by a given day.

Description of the CONUS Resupply System

These tasks were achieved by constructing a model of the resupply system. The details of this model and the mathematical optimization procedure developed for it are described in volume III. In this section, a descriptive account is given of the sequence of activities on which the model is based. This is sufficient to understand the main results based on its analysis.

The resupply system can be viewed as a sequence of activities resulting in the delivery of spare parts to deployed carriers, either from local sources or from the continental United States (CONUS). Only the CONUS resupply system is discussed here. A detailed description and flow chart of this process are contained in volume III. These activities involve requisitioning, processing, and transportation, more specifically described as follows:

1. Submission of a requisition to an inventory control point (ICP). The Aviation Supply Office (ASO) is the primary ICP for aviation spare parts and is the only one considered in this study.

2. ASO processing. ASO will locate the part if it is available in the system or else institute procedures to obtain the part - usually by backordering against a buy or against the production of a Naval Air Rework Facility (NARF).

3. Stock control processing. The stock point selected by ASO to issue the material will first search their inventory control file to locate the part. They will then cut the issue documents.

4. Warehouse processing. In the warehouse the item will be picked, packed, and prepared for shipment.

5. CONUS hold. After packing, the item is turned over to a transportation officer.

6. CONUS transportation. The material is shipped from the issuing stock point to its overseas port of embarkation (POE) in the United States.

7. Overseas hold. At the POE the material is repacked and subjected to a hold before transportation overseas.

8. Overseas transportation. The material is then shipped from the POE to the forward supply point or overseas port nearest the requisition carrier.

9. COD to carrier. At the forward supply point, the material is sent, usually by Carrier Onboard Delivery (COD) aircraft to the carrier.

ASSUMPTIONS

The principal assumptions on which analysis of the resupply system outlined above is based are:

1. The percentage of IG-1 requisitions filled locally and in CONUS remain fixed.

2. The system operates under the current policy on the use of forward supply points in the pre-screening of requisitions.

3. The rate at which requisitions are generated in the fleets as well as the mix of requisitions, by type and by priority, remains constant.

The resupply system, of course, interacts with other aspects of Naval aviation support. The results reported here hold only under the assumptions of the study. These assumptions also led to a consideration of only the CONUS resupply system, since local resupply could not be affected.

MAIN RESULTS, CONCLUSIONS AND RECOMMENDATIONS

The major conclusions from this analysis are:

1. The average resupply time for IG-1 requisitions filled in CONUS is 38 days for the Pacific fleet and 35.5 days for the Atlantic fleet. When about $12 million is spent per year on the resupply system – $6 million in each fleet – this average resupply time is decreased by about 5 days in the Atlantic and by 8 days in the Pacific fleet.

2. Only two potential improvements were more cost-effective than purchase of spare parts to increase the probability of availability of spares at ASO: altering the percentage of issues from 1st-line air stations, and eliminating surface overseas transportation. Until the availability of spare parts is improved, resources for processing and transportation (with the minor exception noted in volume III) do not seem desirable.

3. In order to improve resupply time for CONUS-filled requisitions beyond the improvements noted above, other aspects of the total resupply system must be studied, especially the submission time sub-process and the inventory control point processing sub-process.

4. Almost 98 percent of requisitions filled overseas are for consumables. This indicates that, while some repairables are fixed overseas, almost all are simultaneously ordered from CONUS. The incentive for this action is that carriers are not charged for repairables. Supporting arguments on this point are given in volume III, chapter II. The cost to the system is large, since the average cost of a repairable is $2810.

5. Availability of parts requisitioned by carriers overseas is significantly lower than generally acknowledged. Only about 50 percent of CONUS-filled IG-1 parts were ready-for-issue when the requisition was processed by ASO. This indicates a severe problem in the range and depth of spares purchased at ASO.

6. For parts not immediately available, either on the carrier or at local supply depots, the expected resupply time is about 33 days. There is virtually no chance that these requisitions will be filled within the current standard of 7 days. Even if a part is ready-for-issue when the requisition arrives at ASO, the probability of completing a requisition by the 7th day is only between .12 and .15.

7. Time delays for requisitions issued by a 2nd-line air station (e.g., a master jet base) are significantly greater than for items issued by a 1st-line air station, averaging 2-1/2 days. The costs of transferring the issues to 1st-line air stations are small.

8. The bounceback of requisitions to ASO also puts a strain on the system and is another reason for reducing use of 2nd-line air stations for off-station issues. "Bounceback" refers to returning a request to ASO, if a search of inventory files at the stock point reveals the item is not in stock. The 2nd-line air stations, charged with support of on-station squadrons, also have an incentive to protect their reserves and will return a requisition as not in stock when it is.

9. The easiest way to reduce CONUS transportation time is to assign issuing responsibility to the stock point closest to the MAC/MSTS port of embarkation. This is done only in a small number of cases, especially for parts destined for the Atlantic fleet. To the extent that ASO can choose between two potential issuers of an item, future movements in the item should be anticipated, and the appropriate issuing activity selected.

10. Although only 1 percent of IG-1 items were sent by ship, these items had long delay times, especially in the Atlantic fleet. The estimated cost of shipping by air is low; therefore this improvement is recommended.

Recommendations

An important conclusion of this study is the limited potential for improvement of the resupply system when policies on purchase and positioning of spares in the system are taken as given. Excessive submission times and low availability of parts are two striking features of the system. The bounceback problem was also noted.

A study of more efficient purchase and placement of spares - both overseas and within CONUS - is therefore recommended. This study could utilize the data on the resupply system and the structure of the CONUS resupply system developed in volume III.

PART III

SOME IMPORTANT ASPECTS OF THE AVIATION SUPPORT SYSTEM

This part of the study focuses attention on some other important problems in the aviation support system that were noted during the course of the analyses presented in volumes II and III. These other aspects deal primarily with management policies and current procedures for purchase of spare parts, repeatedly shown in this study to be a critical resource. These aspects of the system were singled out for special study, and the results are reported here.

MANAGEMENT ASPECTS OF THE AVIATION SUPPORT SYSTEM

Management of material for naval air support has been the subject of considerable study in recent years. Studies have ranged from broad descriptions of the system to detailed studies of discrete system parameters. In addition, a great volume of research in fields directly related to logistic support of complex systems has been published in technical literature. In particular, there has been spectacular growth of knowledge in areas of scientific inventory control, commodity demand estimation, information networks, and optimal decision making in the face of uncertainty. Unfortunately, a large gap still exists between theoretical development and operational use.

Throughout the study a lack of analytic staff support for management was observed. This support is needed to aid in complex and potentially costly decisions constantly required in a system of this size. Policy recommendations resulting from previous studies in this area are frequently of a highly technical nature. The pertinent technical literature is by its nature highly specialized and does not typically address the problem of implementing such procedures as would exploit research conclusions. In order to bridge the gap between theoretical development and practical application, management needs a specialized staff that can interpret research results in terms of the operational requirements of the support system. In the absence of technical staff support, study recommendations are rarely implemented, and management is forced to rely on ad hoc procedures that have little or no theoretical foundation.

The most notable effect of this low level of analytic capacity has been the failure of all levels of management to recognize or come to terms with the most important single quality of the system: the inherently stochastic nature of the demands for support which the system is supposedly designed to satisfy. It has been demonstrated repeatedly that the demand for spare parts is only marginally correlated to program factors – such as flying hours – currently used in planning support. In fact, researchers in this area generally conclude that demand for the majority of parts is uncorrelated with any identifiable program factor (references (b), (c), and (d)).

On the other hand, the characteristics of the underlying probability distributions of demand are well understood, and an abundance of data exists from which they may be estimated. Thus, the information and theoretical tools exist to make reliable estimates and forecasts, if a competent statistical staff were available. In view of the very large financial and operational readiness implications of faulty estimation in this area, expansion of technical staff support should not be ignored as a means of improving aviation support.

Among the more obvious effects of current procedures are two of special importance: the setting of readiness goals that are unrealistic within existing budget constraints, and the inefficient utilization of resources in over-responding to random fluctuations in demand. In addition, the high cost of supporting modern weapon systems is due in part to the failure to recognize the potential cost of marginal degradation of design reliability. Systems and components have been and continue to be procured on the basis of naive assumptions as to expected system performance when a systematic analysis would reveal that support costs might, with very high probability, exceed available resources.

In addition, there are institutional factors within the system that act as incentives to suboptimal behavior. At a relatively high level in the system, the Aviation Supply Office is subject to considerable pressure to commit the funds allocated to it as rapidly as they are made available, thus ignoring the dynamic nature of the system and the potential for more effective allocation as demand data is accumulated. The separate funding of major components and of the consumable parts needed to repair them deprives management of the capacity to effect potentially profitable tradeoffs. At a much lower level in the system, each aircraft carrier is permitted to prestock parts in its inventory in excess of the quantity computed by the Aviation Supply Office, provided only that the excess is justified on the basis of that ship's prior usage experience. Thus, a demand estimate based on total fleet experience is rejected in favor of one based on limited data. Recent analyses have shown that less than 30 percent of the line items in an individual ship's inventory are demanded on a typical deployment, while, fleet-wide, approximately 80 percent of line items show usage. It would thus appear inevitable that the response of this policy to random fluctuations of demand from deployment to deployment must lead to ever-increasing inventories being carried on board. Experience would indicate that this is indeed the case.

Finally, there is the matter of the information on which budget requests and procurement decisions are based. Most decisions are made on the basis of demand or of asset disappearance from inventory. Demand information is of itself incomplete, however, because it is generated only when stocks have been depleted. The best predictor of potential demand for a part or component is the rate at which failures are occurring.

The preceding general discussion of support system management is given to point out one of the major difficulties of predicting the output of the system – ready hours – on the basis of its input – funds allocated to spare part support. Intervening between the final user of resources (whose performance may be predicted on the basis of his production function) and the initial allocation of funds to those resources, is the hierarchy of management decision makers who determine how the resources will be expended, which parts will be purchased, and how they will be conveyed to the final user.

The process may be considered in two parts. First there is the procurement decision, and then the decision of how much material to prestock on site and how much to hold centrally for transportation to site when demanded. Now, if the pattern (probability distribution) of demand over time is well understood, then a rational decision process may be designed that minimizes NORS time for a given budget constraint. Such a policy would trade off the added costs of prestocking parts at every site against the expected delay and consequent NORS time in effecting resupply. In other words, in the presence of a budget constraint, the decision to stock a part at many sites incurs the penalty of foregoing purchase of alternative parts, and the rational decision as to on-site stockage or resupply must represent a balance between the alternative risks. For any such decision process it is possible to estimate the outcome in terms of the quantity of spare parts that will be available when demanded by the user and the ready-hour production he will effect. In other words, one may estimate a transfer function that separates from the total funds allocated to a weapons system the usable quantity available to produce the system ready hours.

Unfortunately, the current management decision processes do not lend themselves to such estimation, for several reasons. First, the probability structure of demand assumed by management is incorrect, and the estimates based on it are unreliable. This would not be serious, in that estimates of the real outcome could be derived, were it not for the fact that additional extraneous factors are introduced. Among these are:

1. The assumption that demand is linearly related to flying hours. It has been repeatedly demonstrated that this assumption is invalid, and yet in computing procurement quantities it continues to be employed. The net effect of such an unwarranted assumption is to make the true effect of management policy on readiness virtually unpredictable, except in grossest terms.

2. In determining the range and depth of parts to be prestocked (AVACL), resupply capability is not explicitly considered.

3. The inventory that is prestocked (net AVCAL) is subject to the random variation induced by the most recent experience of each ship.

4. There is no systematic means of allocating resources over the range of present and potential demands. Procurement appears to be conducted on a first-come, first-served basis until funds are partially depleted. Thus, the quantity of a specific part procured is as much a function of the period in which failures occur, which is random, as it is a function of the ultimate effect on readiness of a failure to procure it.

The production functions developed in volume II have been estimated on the basis of 3M data generated from operations over a period of 18 months. An input value of the spares variable can represent either prestocked material or material made available through the resupply system. Thus, the output of ready hours reflects the cumulative effects of support decisions for the particular weapons system over time and the existing capacity of the resupply system.

To the extent that management decision processes remain unchanged, it is reasonable to assume that the spares made available to the final user over an extended period will vary linearly with the total of resources allocated for spares support of the weapons system. Thus, as a management tool, the production function may serve to forecast the average change in readiness that may be anticipated over a complete budget cycle when spare part support is increased or decreased. To forecast the level of readiness that will be achieved on the average for a given spares support budget requires an estimate of the percentage of the funds allocated that will in fact become available to the user in the form of parts actually required and used. Under the assumption that management decision processes are unchanged, this percentage may be estimated by determining the dollar value of material actually used in spare part support of the system from the preceding year 3M or ASO demand data as a percentage of the funds allocated for spare part support of that system in that year. Unfortunately this estimate is not available for fiscal year 1969, the period for which the production functions were estimated. Fiscal year 1970 is the first year in which funds were allocated to specific weapons systems.

ESTIMATION OF DEMAND FOR SPARE PARTS

The fundamental and most critical prerequisite of an effective support system is a reliable estimate of the future demand for parts. All other management functions depend for their effectiveness on the accuracy of this estimate. There are many deficiencies in other areas of resource management, some of which were noted in the preceding pages. Substantive improvement in the system is unlikely, however, unless preceded by the implementation of rational estimation techniques.

The anticipated demand for a part is currently computed at the Aviation Supply Office by computing the average past year's demand per maintenance cycle, multiplying by anticipated maintenance cycles derived from the projected flying hour program and adding a safety factor which is expressed in terms of an anticipated requirement for some preset period of operations, typically 30 days.

An estimate of this type is highly unreliable for the following reasons.

1. Demand for spare parts is typically uncorrelated with flying hours.

2. The average of previous demand is not always a good estimator of the true mean demand. It would be statistically appropriate, for example, if the nature of the demand process was such that two or more simultaneous demands for the part in question were extremely unlikely. If simultaneous demands are likely, then the average will typically underestimate the true mean.

3. The assignment of a safety factor as is done here leads to stock levels providing protection against stock-outs that varies widely among individual parts. The probability that a stock-out will occur is naturally sensitive not only to the mean demand rate but also to the variance of the demand distribution. (Variance is a measure of the degree to which we might expect to observe demand fluctuations well above or below the mean.)

Now if several demands for a part do not arrive simultaneously, as discussed above, variance and mean may be assumed to be identical, and in such a case it is not unreasonable to assign protection levels that are linearly related to the mean. If, however, demands do arrive simultaneously as one would certainly expect when many systems are being supported and demand rates are high, then the variance will not be linearly related to the mean. In fact, the variance is likely to be proportional to the square of the mean, and protection levels should be raised accordingly.

In summary, the current method of estimation is arbitrary; it depends on factors unrelated to demand, it is likely to be inaccurate, and it is not designed to respond to the objectives of management. The objective of the support system is to minimize the time that aircraft are down due to the unavailability of parts, subject to the constraints imposed by budgetary limits. Current estimation procedures virtually guarantee that this objective will not be met.

Table V is an example of the implications for readiness of the current estimation procedures. The table depicts the quantity of a particular part which would be procured under various projections of flying hour programs. The part has displayed relatively low usage and has limited applications, so that the effects noted are less severe than would typically be the case.

TABLE V

EXAMPLE OF ESTIMATION PROCEDURES

Projected flight hours	Quantity procured	Assumed protection	True protection
20,000	39	0.7	0.9
15,000	29	0.66	0.68
10,000	19	$\boxed{0.6}$	0.54
8,000	16	0.83	0.47
6,000	12	0.81	0.38

The quantity procured was computed on the basis of the ASO formula. The assumed protection is the probability that no stock-out will occur under the assumptions of perfect demand -- flying hour correlation, and the equality of mean and variance. The true protection is the probability that stock-out will not occur under the more realistic assumptions of independence of flying hours and demand and a variance proportional to the square of the mean.

The base of 10,000 hours is close to the FY-1969 experience for this part. Note that in the examples of procurement based on reduced flying hours, the quantity procured is actually below the median of the demand distribution.

Good estimation procedures are well known and are not difficult to implement. A detailed discussion of the relative merits of various estimation schemes is not given here because it is treated extensively in the statistical literature. The most appropriate method in this context is known as Baysian estimation. The Baysian method provides a means of incorporating into the estimate all prior knowledge of the probable behavior of a system, such as experience with similar systems and pre-acceptance testing. The initial estimate is continuously updated as demand data is accumulated.

Estimation of the demand distribution for a part begins before the initial provisioning conference. The manufacturer is required to produce an estimate of the expected mean time between failures (MTBF) for the part. If few systems are to be procured or if the MTBF is very large, then this one estimate is adequate. If, as is more typically the case, many systems require the part or a moderate MTBF is predicted, then an estimate of the anticipated demand variance should be required.

A complete analysis of this kind is required if a reasonable projection of system reliability is to be realized. The potential for erroneous management decisions in this area is particularly great when a manufacturer fails to achieve design specifications. If, for example, a manufacturer finds he can guarantee only half of the MTBF required, it is tempting to conclude that twice as many parts will be required and decide on the outfitting quantity accordingly. In fact, however, a quadratic increase in demand variance should impose a much larger requirement if the planned stock-out protection is to be achieved. Alternatively, a more complete analysis of this kind might demonstrate that the system in question could not be supported at an acceptable level of readiness within existing budgetary limits and that redesign or rejection of the system are the correct alternatives.

The purpose of estimation is to determine as accurately as possible the underlying probability structure of demand. Once this is known, the decision maker may choose the level of protection against stock-out that he desires or can afford and determine the quantity of an item necessary to provide it. The choice of protection level desired for a specific part should be made in the light of part cost and the potential down time implied by failure to procure it. Current allocation procedures do not permit a determination of this kind. A potentially fruitful development has been the incorporation at ASO of an allowance list formation model designed by the ARING Corporation. An extension of this or some similar model to the entire procurement planning process would provide management with a means of determining the limits of protection attainable within a limited budget. Further, the incorporation of such decision models and rational estimation procedures would permit investigation of the potentially large tradeoffs available between prestockage and resupply.

CONCLUSIONS

The major conclusions of this part of the study are:

1. Management lacks the analytical support to implement technically complex procedures necessary for improvement of aviation readiness.

2. Estimates of demand for spare parts is not based on total fleet experience but on each ship's prior usage of parts. This leads to overstockage of parts for each deployment.

3. Procurement of spare parts is based on demand estimates related to flying hours of aircraft. Most spare part failure is not related to flying hours, and consequently the effects of current procurement policy on aircraft readiness is difficult to predict with precision.

4. The capability to resupply spare parts is not an explicit consideration in determining the number and types of parts to stock initially onboard a carrier.

RECOMMENDATIONS

Reliable estimation of the future demand for spare parts is a critical prerequisite to development and use of inventory and budgeting models necessary to improve management of the aviation support system. Construction of improved probability distributions of demand, not based on flying hours, is possible with existing techniques and data. It is recommended that these procedures be developed by the Fleet Material Support Office in close cooperation with ASO. CNA could provide the necessary technical consultation for the Fleet Material Support Office and ASO.

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ABSTRACTS AND TABLES OF CONTENTS FOR ALL VOLUMES

Volume I - Summary, Conclusions, and Recommendations

ABSTRACT

This is a study of the relationship between aircraft readiness and spares usage at the squadron level, specifically for the F-4B, CH-53, and TA-4F. The study determines the best combination of aircraft, maintenance man-hours, and spare parts for various budgets. Since the availability of spare parts is a big factor in aircraft readiness, a detailed examination was made of the spare parts resupply system, and recommendations are made for improving this system, that is, for decreasing the time it takes for a supply requisition to be filled. Additional recommendations are made for changing the current method of estimating the quantities of spare parts needed for a specific aircraft model.

The study is in 3 volumes, of which this summary volume is the first. Volume II is entitled "A Ready Hour Production Function for Naval Aviation;" Volume III, "The Resupply System for Naval Aviation Spare Parts."

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Volume II - A Ready-Hour Production Function for Naval Aviation

ABSTRACT

This volume examines the relationship between aircraft readiness and the aircraft, maintenance labor, and spare parts available at the squadron level. A production function, which shows the relationship between aviation resource use and squadron readiness, was estimated for the A-7B, CH-53, S-2E, F-4B, and TA-4F from 3M data. The production functions and derived cost functions for the F-4B, TA-4F, and CH-53 were used to determine the mix of aircraft, maintenance labor, and spare parts that will maximize the level of readiness for a given budget. Finally, the relationship between the NORS rate and the investment in spare parts is estimated for these type/model/series of aircraft. The methodology employed in this study can be applied to other aircraft types.

Volume III of this study develops a model of the Navy's aviation resupply system and examines various means of increasing the effectiveness of the system using two measures: decreasing the length of time between submitting a requisition and receiving the part, and maximizing the percentage of requisitions filled by a certain day.

Volume I is a summary volume and contains a description of the project, the methodologies used, and the principal conclusions and recommendations.

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Volume III - The Resupply System for Naval Aviation Spare Parts

ABSTRACT

The resupply system for Naval aviation spare parts is an important factor in fleet aviation readiness. This volume documents a resupply structure used to investigate the various processes that constitute the resupply system. The investigation determines the improvements in resupply time that are obtainable under alternative budget levels. The major results are that the performance of the CONUS resupply system for high priority aviation spares is poorer than is acknowledged and that the critical resource in the system (of those we could examine) is spare parts for filling incoming requisitions.

Volume II of this study examines the relationship between aircraft readiness and the aircraft, maintenance labor, and spare parts available at the squadron level.

Volume I is a summary volume and contains a description of the project, the methodologies used, and the principal conclusions and recommendations.

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