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Estimating Depot Maintenance Resources Consistent With Changing Force Structure Policies

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EXECUTIVE SUMMARY

ESTIMATING DEPOT MAINTENANCE RESOURCES CONSISTENT WITH CHANGING FORCE STRUCTURE POLICIES

The Department of Defense is downsizing its force structure after the collapse of the Soviet Union, and that downsizing will affect some elements of the support infrastructure as well as personnel and equipment. One element of the support infrastructure that will be affected is the organic depot maintenance activities that repair, maintain, and support a diverse inventory of complex military aircraft. Collectively, those maintenance depots are a significant DoD resource.

As the aircraft inventories become smaller, so should the need for depot maintenance resources. In general, the models used to translate the force structure changes into reduced depot resources now estimate depot repair workload as simple linear functions of flying hours, consumption rate per flying hour, and unit repair cost. When the force structure is decreased, current models incorrectly assume that the consumption rate and the unit repair cost are constant. Some resource models also incorrectly assume that the cost of actual depot repair actions (expressed as a rate per flying hour) can be used as a proxy for the rate at which components break and require depot repair. As a consequence of these assumptions, resources are adjusted linearly with the change in flying hours.

Consumption rates change. Mission profile changes affect resource consumption rates. By scaling historical consumption rates for differences between peacetime and Operation Desert Storm (ODS) mission profiles, we see that ODS depot repair requirement predictions for C-5 and F-15 aircraft are at least 70 percent better than predictions made under the assumption of constant resource consumption rates.

Unit repair costs change as the total depot workload changes. The unit repair costs used by DoD depots to bill customers for work performed reflect the full cost of depot repair

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operations at a specified level of work. Using those unit repair costs to estimate the savings resulting from force structure reductions implies that all depot costs change when the depot workload changes. Over the past decade, a period marked by both expansions and contractions in the total depot workload, we found no statistically valid relationship between the level of depot overhead (42 percent of the total cost in FY90) and the level of direct workload. Even though depot overhead does not necessarily shrink with reductions in the direct workload, depot management can take deliberate action to reduce overhead. If it fails to do so in the face of a declining workload, the depot unit repair cost will increase because the overhead costs will have to be spread over fewer repairs and the savings resulting from reduced force structures will be overstated by as much as 42 percent.

Actual depot repair actions are not always a valid proxy for the steady state resource consumption rate. Ideally, depot repair actions should be a reasonable approximation of resource consumption; unfortunately, many exogenous factors (funding, serviceable asset levels, etc.) affect the actual number of repair actions. Consequently, historical repair actions may not reflect repair levels that are consistent with long-run weapon system availability and sustainability requirements.

We have developed a model that demonstrates several new methodologies to overcome many limitations of the current models. It has unique characteristics of value to the force structure analyst:

- It permits flexibility in selecting the historical data to be used in the model.
- Historical consumption rates can be adjusted for changes in average sortie duration and operating cycles per sortie.
- Fixed depot operating costs can be separated from variable depot operating costs. Only variable costs are used to change depot resources when the workload is changed.
- The workload projections used for the component repair program are unconstrained by fiscal limits and are consistent with specified weapon system availability targets.

Successful development of the prototype model is a planned milestone to provide feedback on our approach and to assess the future direction of the project before we complete the Air Force model and start building the Army and Navy depot models. We recommend that the Office of the Assistant Secretary of Defense

(Program Analysis and Evaluation) consider at least two future directions for this project:

- Our work in linking resource consumption rates with mission changes has put the spotlight on a fundamental shortcoming in resource estimating methodologies within DoD: the models used ignore the effects that mission changes have on resources. That shortcoming transcends depot maintenance; it encompasses requirements for initial and replenishment spares, war reserves, and base-level maintenance manpower. While our work represents a significant step forward, additional effort will be required to mature this methodology.
- Defense Management Report Decision (DMRD) 904 has fundamentally changed the way DoD manages and provides resources for depot maintenance. After DMRD 904, total visibility of resources for depot maintenance of reparable components was lost. Instead, requirements for component repair, investment spares, transportation, and item management have been merged into a stock fund for depot level reparables (DLRs). In the stock fund environment, our prototype can be used to estimate or revise the DLR stock fund repair requirements when the force structure is changed. Because the Logistics Management Institute Aircraft Availability Model, used in the prototype model, estimates requirements for component repairs and for Air Force investment spares, a more complete model of the DLR stock fund can be developed. With some additional work, a complete model of the Air Force DLR stock fund can be developed to assist DoD in establishing the surcharge rate for Air Force customers.

CONTENTS

<i>Executive Summary</i>	<i>iii</i>
<i>List of Tables</i>	<i>ix</i>
<i>List of Figures</i>	<i>ix</i>
<i>Chapter 1. Introduction</i>	<i>1-1</i>
Limitations of Current Methods	1-1
Prototype Scope	1-3
Prototype Modeling Approach.....	1-4
Report Overview	1-4
<i>Chapter 2. Summary of Research Results</i>	<i>2-1</i>
Background.....	2-1
Research Issue One	2-1
Research Issue Two.....	2-3
Research Issue Three	2-5
Summary	2-9
<i>Chapter 3. The Prototype Model Structure and Algorithms</i>	<i>3-1</i>
Overview of the Prototype Model.....	3-1
Data Bases Used in the Prototype Model.....	3-2
Menu System	3-3
Algorithms Used in the Prototype Model.....	3-6
Verification of Algorithms.....	3-15
<i>Chapter 4. Future Research Directions</i>	<i>4-1</i>
<i>Appendix A. Mission Effects on Reliability</i>	<i>A-1</i>
<i>Appendix B. An Overview of the Aircraft Availability Model</i>	<i>B-1</i>
<i>Appendix C. Glossary</i>	<i>C-1</i>

TABLES

2-1.	Regression Results.....	2-2
2-2.	Operation Desert Storm Experience – Actual Versus Predicted Demands for Line Replaceable Units in War Readiness Spares Kits	2-8
3-1.	Model Output	3-5

FIGURES

1-1.	Key Components of Existing Models.....	1-2
1-2.	Overall Modeling Approach.....	1-4
2-1.	Aircraft Availability Model	2-5
2-2.	C-5B On-Equipment Removals.....	2-6
2-3.	Cycle-Based MTBR Model	2-8
3-1.	The Menu System	3-3
3-2.	The Option Edit Menu	3-5
3-3.	How the Prototype Works	3-7

CHAPTER 1

INTRODUCTION

In downsizing its force structure after the collapse of the Soviet Union, the Department of Defense is reducing the number of uniformed personnel, reducing the inventories of mission equipment, and scaling back plans for new weapon systems. As a result of these changes, elements of the mission support infrastructure will also be affected. One element of that support infrastructure is DoD's depot maintenance activities. Collectively, these repair depots consumed \$13.4 billion in FY91 to repair, maintain, and support a diverse inventory of complex military hardware.

Smaller inventories of weapons should translate into reduced requirements for depot maintenance resources. The objective of this research project, sponsored by the Assistant Secretary of Defense, Program Analysis and Evaluation [ASD(PA&E)], is to improve the methods used to translate aircraft force structure changes into revised requirements for depot maintenance resources.

LIMITATIONS OF CURRENT METHODS

The complexity of the methods used to estimate depot maintenance resources varies widely, ranging from models that compute individual repair requirements for each national stock number (NSN) item to larger scale approaches that use aggregate historical cost factors by weapon system. Despite the difference in complexity, existing models, as illustrated in Figure 1-1, estimate depot repair requirements as a function of activity level (the operating tempo, or OPTEMPO – usually expressed in flying hours for aircraft), the consumption rate per unit of activity, and either the historical or projected unit repair cost (URC).

$$\text{Depot resources} = \frac{\$}{\text{Repair}} \times \frac{\text{Repair actions}}{\text{Reparable generations}} \times \frac{\text{Reparable generations}}{\text{OPTEMPO}} \times \text{OPTEMPO} \times \text{Number of aircraft}$$

FIG. 1-1. KEY COMPONENTS OF EXISTING MODELS

When the force structure is changed, these models assume that the consumption rate and the URC are constant. Consequently, resource requirements are adjusted linearly in direct proportion to the change in activity level. If a force structure change reduces the flying hours by 30 percent, then depot resources are reduced by 30 percent.

Unfortunately, the assumptions underlying these linear resource adjustments are not valid.

- Consumption rates change.** During both the Operations Desert Shield and Desert Storm (ODS),¹ aircraft were operated at up to four times their peacetime OPTEMPO. The repair requirements, excluding battle damage, were much less than prewar projections obtained with linear resource models. For example, the C-5 fleet had only 40 percent of the expected requirement (at ODS activity levels) for reparable items contained in the C-5 war reserve spares kits (WRSK). We identified a relationship between the mean time between removal (MTBR) and the level of flying activity between operating cycles. Using that relationship, we developed a procedure to scale historical consumption rates for the effects that changed mission profiles have on resource consumption – effects that are ignored by the linear resource models based solely on OPTEMPO. When we considered both cycle effects and OPTEMPO changes, ODS resource consumption predictions were improved by at least 70 percent for C-5 and F-15 aircraft.
- Unit repair costs change as the total depot workload changes.** The URCs that are used by DoD depots to bill customers for work performed reflect the full cost of depot repair operations at a specified level of work. While some components of URC vary directly with the workload, we found that indirect costs, such as operations overhead and depot-wide general and administrative (G&A) costs, are inelastic over a wide range of direct workload.² As one force structure is reduced and the workload declines,

¹ODS is used throughout this document to refer to both the Operations Desert Shield and Desert Storm experiences.

²No correlation was found between indirect costs and measures of direct workload during the period 1981 through 1990.

these fixed overhead costs (42 percent of the total cost) must be spread across fewer repair actions, thus increasing the URC. To keep the URC from increasing, DoD must make other policy decisions (separate from force structure decisions) to change the indirect cost structure of its depots.

- ***Historical levels of completed depot repair actions per flying hour are not always a valid proxy for the resource consumption rate.*** All other things being equal, the number of repair actions should reasonably approximate the number of reparable generations; however, that is not always the situation. For example, funding limitations may suppress the number of items actually repaired. Repair programs can also be artificially low if the inventory of serviceable assets exceeds the forecast requirement. When that occurs, repairs will be curtailed or reduced until the inventory of serviceable items is reduced. Thus, the validity of using historical levels of repair as a proxy for the true consumption rate must be carefully considered.

Because the underlying assumptions are incorrect or questionable, current methods erroneously estimate the effect that force structure changes have on depot maintenance resources. Those errors may be acceptable for small force structure changes; however, major force structure adjustments involving downsizing DoD by up to 40 percent demand improved estimating tools.

PROTOTYPE SCOPE

In a complete model, three steps must be taken to estimate the effects of force structure changes on depot maintenance resources:

- ***Step one.*** Establish the level of depot resources already programmed by the Services to support current force structure plans.
- ***Step two.*** Determine the changes to that baseline depot resource plan caused by alternative force structures.
- ***Step three.*** Calculate the revised depot resource plan for the alternative force structure.

Logistics Management Institute (LMI) proposes significant revisions to the current methods used in Step Two for calculating the impact of force structure changes. Consequently, the prototype developed in this study focuses on demonstrating the essential methodological changes we advocate. The prototype allows the force structure analyst to model aggregate consumption rates as a function of average sortie duration and operating cycles per sortie, provides a tool for adjusting the unit repair cost when the depot workload is changed, and develops repair workload projections

consistent with weapon system availability and sustainability requirements.

PROTOTYPE MODELING APPROACH

The overall goal of our research is to develop a model that will estimate the effect that different aircraft force structure policies (e.g., number of aircraft, OPTEMPO, number of sorties, mission profiles) will have on the depot maintenance activities of all three Services. Our strategy, in developing the model, was to start with the Air Force and then expand the model to the other Services. Because of our multi-Service requirement, we had to find data bases and develop methodologies that can be applied to any Service.

The overall modeling approach, summarized in Figure 1-2, is to collect historical weapon system data for depot maintenance consumption, force structure, and OPTEMPO; use these data to develop realistic consumption rates; and then calculate the change in depot maintenance resources by applying these consumption rates to the force structure changes.

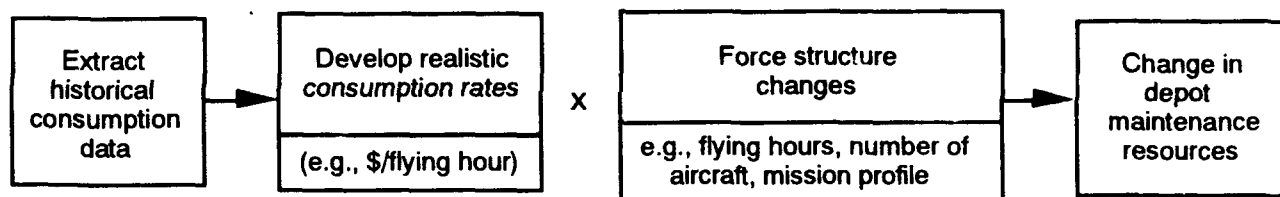


FIG. 1-2. OVERALL MODELING APPROACH

REPORT OVERVIEW

This report describes the features of the prototype model and the supporting research. Chapter 2 summarizes the research findings underpinning the methodological changes demonstrated in the prototype. Chapter 3 describes the prototype's menu system and the processing flow used to develop and modify a force structure option. (A separate users manual is also available.)³ Chapter 3 also details the algorithms used in the prototype and how these algorithms were verified. In Chapter 4 we discuss future directions for this research project.

³LMI Report PA101RD2. *Users Manual for the Depot Maintenance Model Prototype Version B*. Wallace, John M., and Robert O. Allman, September 1992.

CHAPTER 2

SUMMARY OF RESEARCH RESULTS

BACKGROUND

Conventional approaches for estimating depot resources rely on using historical resource consumption rates as realistic measures of the recurring workload for a particular weapon system and then multiplying that consumption rate by the OPTEMPO changes. As summarized in Chapter 1, there are three assumptions implicit with that approach:

- There are no fixed costs with respect to workload changes.
- Actual repair actions are not limited by funding limitations.
- The rate at which components break is not affected by force structure policies.

Because the validity of those assumptions directly affects the design of the prototype model, LMI investigated each assumption as a separate research issue. This chapter summarizes the results of each research issue. Additional details of the research on mission profile changes are provided at Appendix A.

RESEARCH ISSUE ONE

Do indirect depot costs vary with changes in direct workload?

APPROACH

Using the Department's depot cost accounting data base,¹ LMI used regression analysis to examine the relationship between funded direct and funded indirect cost of Air Force depot operations over the period 1981 through 1990. During the first 4 years, direct funded expenditures (in constant FY90 dollars) grew 34 percent. Following that period of growth, direct depot expenditures

¹A data base of depot cost accounting data prepared in accordance with Chapter 76 of the DoD Accounting Manual DoD 7220.9-M. (These data were formerly referred to DoD 7229.29-M data.)

steadily declined each year until 1990 when expenditure levels were approximately the same as those experienced in 1981.

FINDINGS

- Indirect costs are recorded in two separate groups: operations overhead (nondirect costs within a production work center) and G&A (nondirect costs that benefit more than one production work center).
- Within DoD, indirect depot costs account for 42 percent of the total organic costs reported in FY90.²
- Some categories of indirect costs contain elements that logically could vary with workload (for example indirect production materials/operating supplies);³ however, many indirect cost categories (such as security, real property maintenance, and equipment depreciation/amortization) are not expected to vary with workload.
- We found no statistically valid relationship between measures of direct workload and indirect costs. Table 2-1 summarizes those results. Even variations in direct labor hours, frequently used in the depot cost accounting system to allocate indirect costs to job orders, explained only 41 percent of operations overhead costs and only 27 percent of the variation in G&A cost. There is almost no relationship between total direct depot costs and the amount of indirect costs.

TABLE 2-1

REGRESSION RESULTS
(Coefficient of Determination - R²)

Category	Direct labor hours	Direct labor cost	Total direct cost
Operations overhead	.41	.31	.08
G&A	.27	.27	.001

- With pressure to control the depot URC, management emphasis has been placed on reducing overhead cost. As a result, the Air Force projects that FY96 indirect personnel requirements will be reduced 31 percent from FY90 levels

²Defense Depot Maintenance Committee. *Depot Corporate Business Plan, FY91 through FY95.*

³Defense Depot Maintenance Council Cost Comparability Committee. *Cost Comparability Handbook*, 9 August 1991.

even though the direct workload is projected to grow 5 percent over FY90 levels.⁴

- Air Force Logistics Command (AFLC) personnel use several "rules of thumb" to adjust end-item sales rates for workload changes. Those rules of thumb recognize that indirect costs are not proportional to workload changes.
 - Zero to 50 percent of operations overhead is variable with changes in direct workload levels. In general, zero is used if workload is an incremental change to an existing workload level. The higher percentage is used for new work.
 - G&A does not vary with workload changes.

CONCLUSIONS

- Many overhead functions behave as though they are staffed at a specified level of effort. Indirect costs do change over time; however, those changes appear to be related more to management policies than to workload changes.
- Direct and indirect depot repair costs must be treated separately. Analysts need a capability to adjust indirect costs for changes in overhead policies and, when appropriate, for changes in workload. For example, if management plans to reduce overhead cost by 31 percent over the next 5 years, then the model must be able to reduce the historical levels of overhead costs to reflect the new overhead structure and separately adjust for workload changes.

RESEARCH ISSUE TWO

How well do historical repair program levels reflect the long-run recurring repair requirement necessary to meet weapon system availability and sustainability requirements?

APPROACH

The number of items actually repaired may be less than the number of items that break. Actual work levels may be temporarily reduced because of budget shortfalls or because there is a surplus of serviceable items. We interviewed Air Force depot workload planners to determine if historical repair programs can be used to project future workloads.

⁴Assistant Secretary of Defense (Force Management and Personnel). *Five-Year Civilian Employment Plan: A Report Required by Section 322(b) of the Fiscal Year 1991 DoD Authorization Act*, 29 April 1991.

FINDINGS

- By policy, aircraft overhaul and engine overhaul programs (historically funded at or near 100 percent of the requirement) are the last depot repair programs to be cut back because of short-run funding limitations.
- Historical levels for exchangeable repairs have the most potential for not representing the recurring workload. Within the Air Force, the impact of budget shortfalls is concentrated in the exchangeable repair program. Also because the many components are common to several aircraft, force structure reductions in one aircraft may generate a surplus of serviceable items. That surplus can be used to offset the repair requirements for types of aircraft, thus temporarily reducing the repair requirement until that surplus is consumed.
- As an alternative to historical data for estimating realistic exchangeable repair programs, Air Force personnel suggested using a computed workload based on the expected number of repair generations times the unit repair cost.
- The Aircraft Availability Model (AAM)⁵ computes an expected repair program for exchangeables that is not constrained by repair budget limitations. That estimated repair program can be used as a realistic proxy for the recurring workload needed to support both the availability and the sustainability targets for each weapon system. Figure 2-1 highlights some of the information used by the AAM to estimate the repair requirement for each NSN.

CONCLUSIONS

- Historical data for engine overhaul (expressed in dollars per flying hour) and aircraft overhaul (expressed in dollars per aircraft) can be used to approximate realistic depot workloads.
- AAM workload projections (expressed as dollars per flying hour) can be used as realistic estimates of the recurring workload for exchangeables.

⁵The AAM was developed in 1972 by LMI for the U.S. Air Force. It is primarily used for formulating and evaluating BP15 Replenishment Spares requirements for peacetime operating stocks (POS) as part of the planning, programming, and budgeting system (PPBS). The scope of the model was broadened in 1974 to include repair considerations. An overview of the AAM is provided in Appendix B.

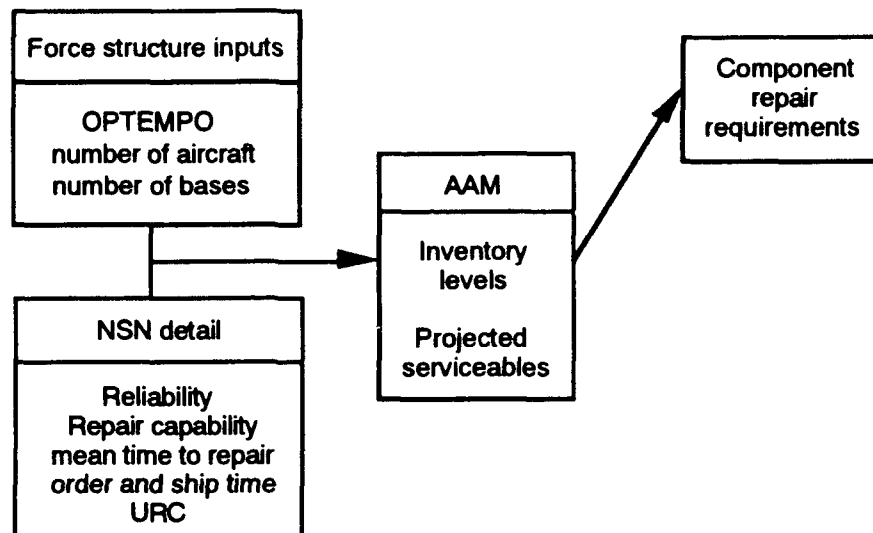


FIG. 2-1. AIRCRAFT AVAILABILITY MODEL

RESEARCH ISSUE THREE

Do mission changes affect resource consumption rates?

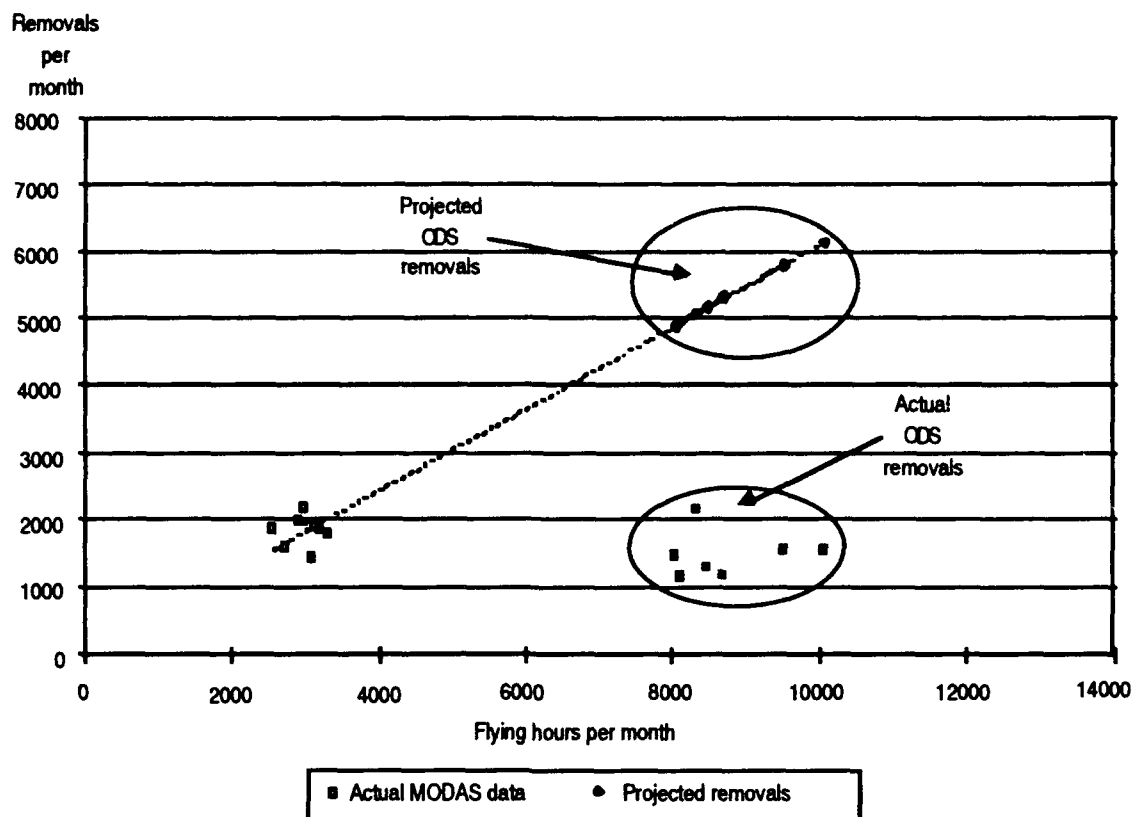
INTRODUCTION

The discussion presented in this chapter summarizes the research on how mission changes affect resource consumption. Appendix A provides a more detailed account of this research.

BACKGROUND

Most resource estimating models do not explicitly consider the impact that different missions can have on resource consumption. Those models linearly project resource consumption proportional to OPTEMPO. Aircraft flown in support of ODS were operated at two to three times their peacetime OPTEMPO; however, they consumed resources at rates much lower than anticipated if resources are assumed to be proportional to OPTEMPO.

Typical is the C-5B experience during the first 7 months of ODS (see Figure 2-2). Before ODS, the C-5B fleet experienced approximately 2,000 removals each month. If this peacetime rate is increased in proportion to the OPTEMPO flown during ODS, the number of components removed from the C-5B during ODS should have been in the range of 5,000 to 6,000 removals per month. Instead, the actual removals were one-third to one-half of that amount.



Source: Air Force Maintenance and Operational Data Access System.

FIG. 2-2. C-5B ON-EQUIPMENT REMOVALS

A possible explanation for the change in removal rate is the different mission profile flown during ODS. Engineering considerations of failure phenomena suggest that some failure modes are affected by the number of operating cycles that place stress on the equipment. For example, studies of avionics equipment have shown that the number of on-off cycles per operating time affects the failure rate: as the number of cycles per operating time is increased, equipment failure rates increase.

Mission profile changes can affect the number of cycles per operating hour and consequently affect the rate at which components fail and must be removed from an aircraft. During ODS, the effect of C-5B mission profile changes⁶ was to decrease the number of cycles per flying hour; consequently, the number of removals should be less than expected.

⁶The number of sorties and the average sortie duration for C-5B both increased during ODS. In addition, the type of flying switched from "training" missions that averaged three to four landings per sortie to "airlift" missions that averaged only slightly more than one landing per sortie.

Because of the obvious consistency between the ODS experience and the engineering considerations, we built a model to predict reliability as a function of cycles and operating hours.

APPROACH

We used ODS data to identify mission profile parameters reflecting the number of cycles incurred during a sortie. A regression model describing behavior of the weapon-system-level MTBR as a function of cycles and operating hours was developed using peacetime data. The model was then tested by comparing its predictions of ODS experience with actual ODS experience to see the impact of considering mission effects on resource consumption.

FINDINGS

- ODS data in Air Force maintenance data systems are not complete. The Air Force does not have a deployable capability that can be used to enter maintenance data at austere locations. As a result, many maintenance transactions were not reported when they occurred.⁷ Off-line procedures were used to capture many of these transactions – many of which were later entered into the data systems. In spite of this effort to recover the missing data, the data during the months of ODS remained unchanged from that originally reported in Maintenance and Operational Data Access System (MODAS). As a result, not all maintenance transactions were reported in the month that the transaction occurred. We also determined that maintenance data for airlift aircraft were also under-reported during ODS.⁸
- Item managers viewed ODS data as an anomaly and were primarily concerned with removing ODS data from their spares computations. Consequently, little effort was made to get valid ODS data. A tape was prepared that contained a history of all the supply transactions during ODS; however, that tape was overwritten by mistake.
- LMI has access to only limited amounts of valid ODS resource consumption history.⁹ Those snapshots of data are the same ones used by the Air Force to evaluate the effectiveness of war readiness spares kits (WRSK) during ODS.

⁷Department of the Air Force, Headquarter Tactical Air Command, Deputy Chief of Staff Logistics. *Desert Shield/Desert Storm Logistics Data*, September 1991.

⁸Based on a comparison of Air Force MODAS removal data and standard baselevel supply system (SBSS) demand data for line replaceable units (LRUs) in the C-5 WRSK.

⁹The Logistics Management Center at Gunter Air Force Base (AFB) is the repository for ODS data. They may have maintenance transaction data that could be used for further analysis; however, using these data would require a larger effort than could be supported within the limits of this research project.

- Because sufficient ODS data were not readily available, we revised our approach and tried to predict MTBR with just peacetime data. This resulted in a reasonable model (see Figure 2-3) that uses flying hours per operating cycle as the independent variable (using landings per sortie as a proxy for operating cycles) to scale historical consumption rates.

$$MTBR = b_1 \cdot \left(\frac{\text{Flying hours}}{\text{Sortie}} \cdot \frac{\text{Landings}}{\text{Sortie}} \right)^{.5}$$

FIG. 2-3. CYCLE-BASED MTBR MODEL

- We estimated ODS resource consumption during the same ODS snapshot periods using the cycle-based model to scale historical consumption rates and using linear estimates obtained from the Recoverable Consumption Item Requirements System (D-041) (peacetime consumption rates) and from the D-040 (the consumption rates used to build the WRSK). When these estimates were compared to the actual ODS experience, we found that the cycle-based model reduced the estimating error by at least 70 percent in every case (see Table 2-2).

TABLE 2-2

OPERATION DESERT STORM EXPERIENCE – ACTUAL VERSUS PREDICTED DEMANDS FOR LINE REPLACEABLE UNITS IN WAR READINESS SPARES KITS

Snapshot period	Actual demands	D-041 (peacetime)	D-040 (WRSK)	Cycle-based model
C-5 FLEET 7 August 1990 7 September 1990	3,964	13,393	13,128	6,846 (30.6% of D-041 error)
C-5 FLEET 7 December 1990 7 January 1991	5,076	12,757	12,504	6,001 (12.0% of D-041 error)
F-15C (only deployed units from Eglin AFB) 24 January 1991 28 February 1991	667	1,338	1,960	615 (6.4% of D-041 error)

CONCLUSIONS

- We cannot continue using linear models and assuming that missions do not change. Certainly with major force structure changes and new organizational structures like the Air Force's composite wings, aircraft are not likely to fly the same mission profiles they fly today. If a new family of cycle-based models is developed, the resource impact of mission effects can be recognized and planned.
- Mission effects adjustments for C-5A, C-5B, and F-15C/D aircraft should be included in the prototype model to demonstrate the impact that mission effects can have on resource consumption.

SUMMARY

Chapter 3 discusses structure of the prototype model and the specific algorithms that are used to implement the three research findings discussed in this chapter.

CHAPTER 3

THE PROTOTYPE MODEL STRUCTURE AND ALGORITHMS

This chapter provides an overview of the capabilities that have been included in the prototype model. The data bases used by the prototype are listed. The menu system that is used to define a force structure option and to run the model is described. Finally, the chapter concludes with a summary of the algorithms used in the model and how these algorithms were verified.

OVERVIEW OF THE PROTOTYPE MODEL

The prototype can be used to estimate and price the workload changes caused by force structure decisions. In the prototype version, only aircraft with force structure changes are modeled. Force structure changes are usually expressed in terms of the number of combat units (e.g., the number of tactical fighter squadrons or wings). That level of detail is not sufficient to estimate resources because those units can have different numbers of aircraft, different OPTEMPOs, and different mission profiles.

To run the prototype model, the force structure change for each aircraft must first be defined in the following terms:

- The change to the total annual flying hour program,
- The change to the total authorized inventory (TAI), and
- The changes to two mission profile parameters: the average sortie duration and landings per sortie.

Features of the model give the analyst complete flexibility in defining the force structure option, selecting the historical data, and formatting the output. The standard output completely documents each model run: total results and results for each weapon system included in the total, the baseline force structure for each weapon system group and the changes thereto, and all assumptions and data selection criteria are provided.

Not all features of the model are implemented for all aircraft. The mission effects adjustment is functional for only the C-5A, C-5B, F-15A, F-15B, F-15C, F-15D, and F-15E aircraft.

The LMI AAM data are also available for only those same aircraft; however, if the analyst selects another aircraft, the prototype will use historical cost data in place of AAM data to estimate component repair costs.

In addition to estimating force structure changes, the prototype also provides other capabilities and uses:

- Grants access to actual annual depot repair costs and program data for all aircraft in the Air Force inventory from 1975 through 1990.
- Prepares independent estimates of program changes in the budget or program objective memorandum (POM) process.
- Develops cost factors for reference aircraft in support of Defense Acquisition Board weapon system cost estimates.
- Prepares or cross-checks depot level reparable workload assumptions used to establish the stock fund surcharge rates.

DATA BASES USED IN THE PROTOTYPE MODEL

Four data sources were used in the prototype model:

- The Weapon System Cost Retrieval System (WSCRS)¹ is an Air Force data system based on DoD 7220.9 depot cost accounting data. In the prototype, that data base was used to identify the direct and indirect depot repair costs and, where appropriate, to approximate the recurring workload associated with individual weapon systems. All three Services report actual costs of depot maintenance to OASD Production and Logistics (P&L) in a consistent format prescribed by DoD 7220.9M. Eleven years of 7220.9 data (1981 through 1991) are available in a computerized data base. (WSCRS data go back to 1975.)
- The Air Force AAM² is a Service-unique model developed by LMI for the Air Force. It is used to project component repair requirements consistent with availability and sustainability goals for each weapon system. Similar models exist in the Army and Navy.

¹Headquarters, Air Force Logistics Command. *AFLCM 173-264: Weapon System Cost Retrieval System (DSD H-036C)*, 31 May 1990.

²The AAM was developed by LMI for the U.S. Air Force. It is used for formulating and evaluating BP15 Replenishment Spares requirements for POS as part of the PPBS. In 1982, a modified version of the AAM was adapted for AFLC use in preparing budget allocations; it is now fully integrated in the Recoverable Consumption Item Requirements System (D-041). An overview of AAM is provided in Appendix B.

- Visibility and Management of Operating and Support Cost (VAMOSOC). The prototype uses VAMOSOC to obtain historical flying hour and inventory data by weapon system. VAMOSOC may also be a source of data for component repair costs if the Army or Navy does not have an AAM equivalent.
- The Air Force MODAS³ is used to obtain operational reliability indicators (such as MTBR) and information on sorties, landing, and on-equipment removal actions. Similar systems are available in the Army and the Navy.

MENU SYSTEM

Figure 3-1 shows the menu system that the analyst will use to navigate through the prototype. This section summarizes the main features of each menu. A companion LMI report⁴ documents each menu and all the screens that will appear after selecting each menu option.

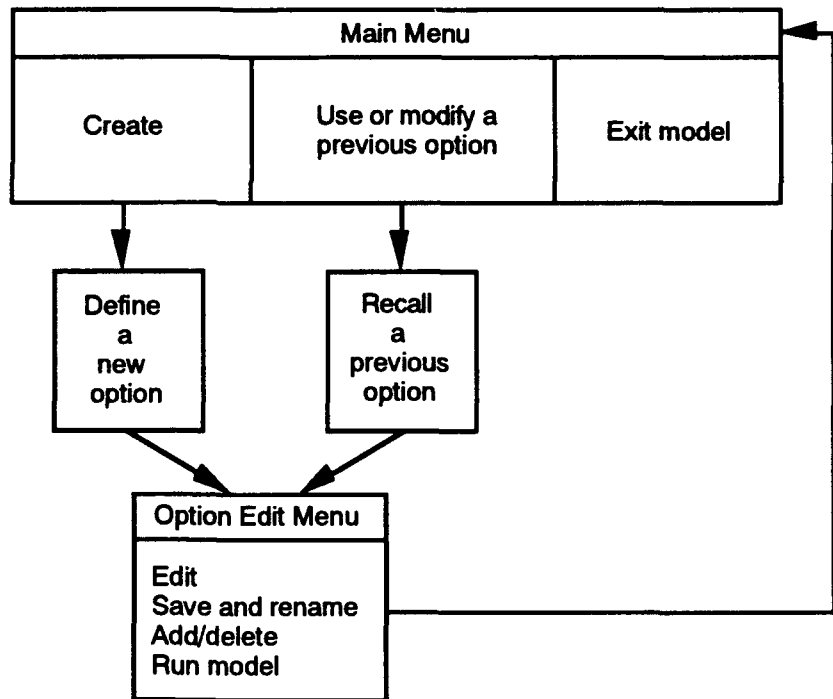


FIG. 3-1. THE MENU SYSTEM

There are two major menus: the Main Menu and the Option Edit Menu.

³MODAS is scheduled to be replaced by the reliability and maintainability information system (REMIS). Equivalent information will be available from REMIS.

⁴LMI Report PA101RD2. *Users Manual for the Depot Maintenance Model Prototype Version B*. Wallace, John M., and Robert O. Allman, September 1992.

THE MAIN MENU

First appearing on the screen is the Main Menu. From that menu, the user has three options:

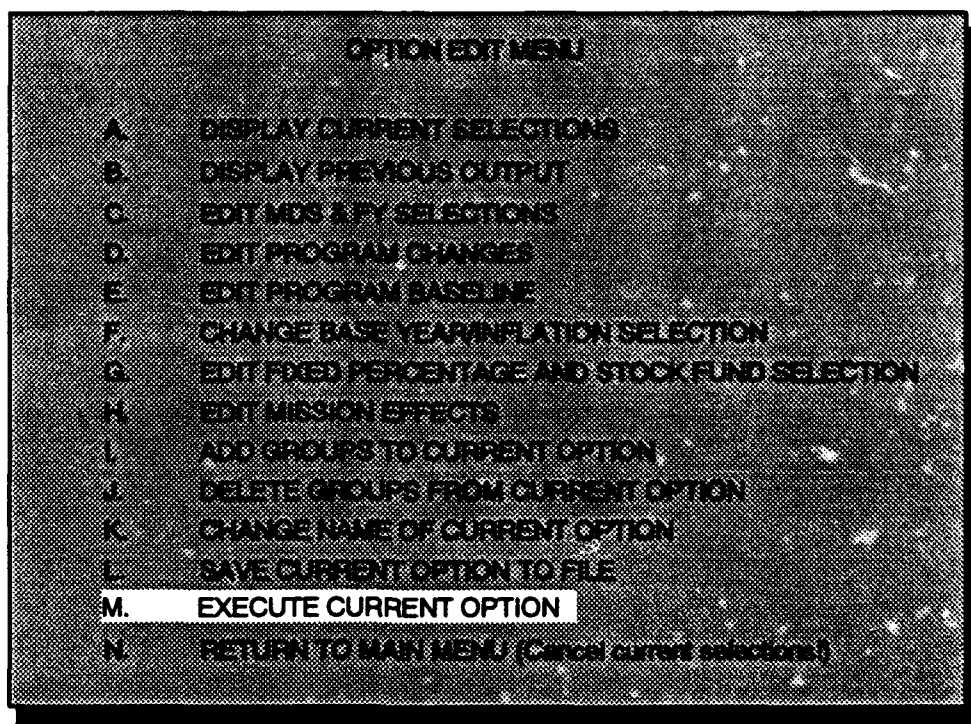
- **Option 1. Create a New Force Structure Option.** If that option is selected, the model will lead the user through a series of screens that, when complete, will fully define the force structure changes being studied.
- **Option 2. Use or modify a Previously Defined Option.** Considerable time can be saved if after defining a force structure option the user saves that option with a unique name. If saved, a force structure option name can be used to recall that option and avoid reentering the data.
- **Option 3. Exit the Model**

THE OPTION EDIT MENU

If either Option 1 or Option 2 is selected from the Main Menu, the model proceeds to the Option Edit Menu after all information has been entered. As seen in Figure 3-2, the Option Edit Menu is used to run the model and to provide the analyst with many editing features.

Using the Option Edit Menu, the user can review and edit the entries for each aircraft group in this force structure option, add or delete aircraft groups, save or rename the current force structure option, change to or from base year or then-year dollars, respecify the base year dollars used in the output, or run the model after all changes are made.

After the analyst is satisfied with the input values for a specified force structure option and runs the model, the results are then displayed to the user as shown in Table 3-1. The algorithms used to perform these calculations are presented in the next section.



Note: MDS = mission design series.

FIG. 3-2. THE OPTION EDIT MENU

TABLE 3-1
MODEL OUTPUT

Depot Maintenance Model Option – First Option totals – all costs in constant 1990 millions of dollars					
Cost categories	1994	1995	1996	1997	1998
Total Baseline Force					
Airframe	33.872	33.872	33.872	33.872	33.872
Engine	14.189	14.189	14.189	14.189	14.189
Exchangeables	84.144	84.144	84.144	84.144	84.144
Install Class IV Mods	1.221	1.221	1.221	1.221	1.221
Total	133.426	133.426	133.426	133.426	133.426
Alternative Force Total					
Airframe	32.397	32.397	28.575	28.575	28.470
Engine	12.485	12.485	11.905	11.796	11.667
Exchangeables	79.157	79.157	72.300	65.891	71.937
Install Class IV Mods	1.152	1.152	0.841	0.841	0.838
Total	125.191	125.191	113.621	107.103	112.912
Total Delta for Option					
Airframe	-1.475	-1.475	-5.297	-5.297	-5.402
Engine	-1.704	-1.704	-2.284	-2.393	-2.522
Exchangeables	-4.987	-4.987	-11.844	-18.253	-12.207
Install Class IV Mods	-0.069	-0.069	-0.380	-0.380	-0.383
Total	-8.235	-8.235	-19.805	-26.323	-20.514

ALGORITHMS USED IN THE PROTOTYPE MODEL

This section presents the details of the algorithms used to calculate the change in depot workload. The algorithms are presented as a series of steps. Those steps are presented to facilitate understanding of the process shown in Figure 3-3. The model does not necessarily process the data in exactly the same order.

STEP 1

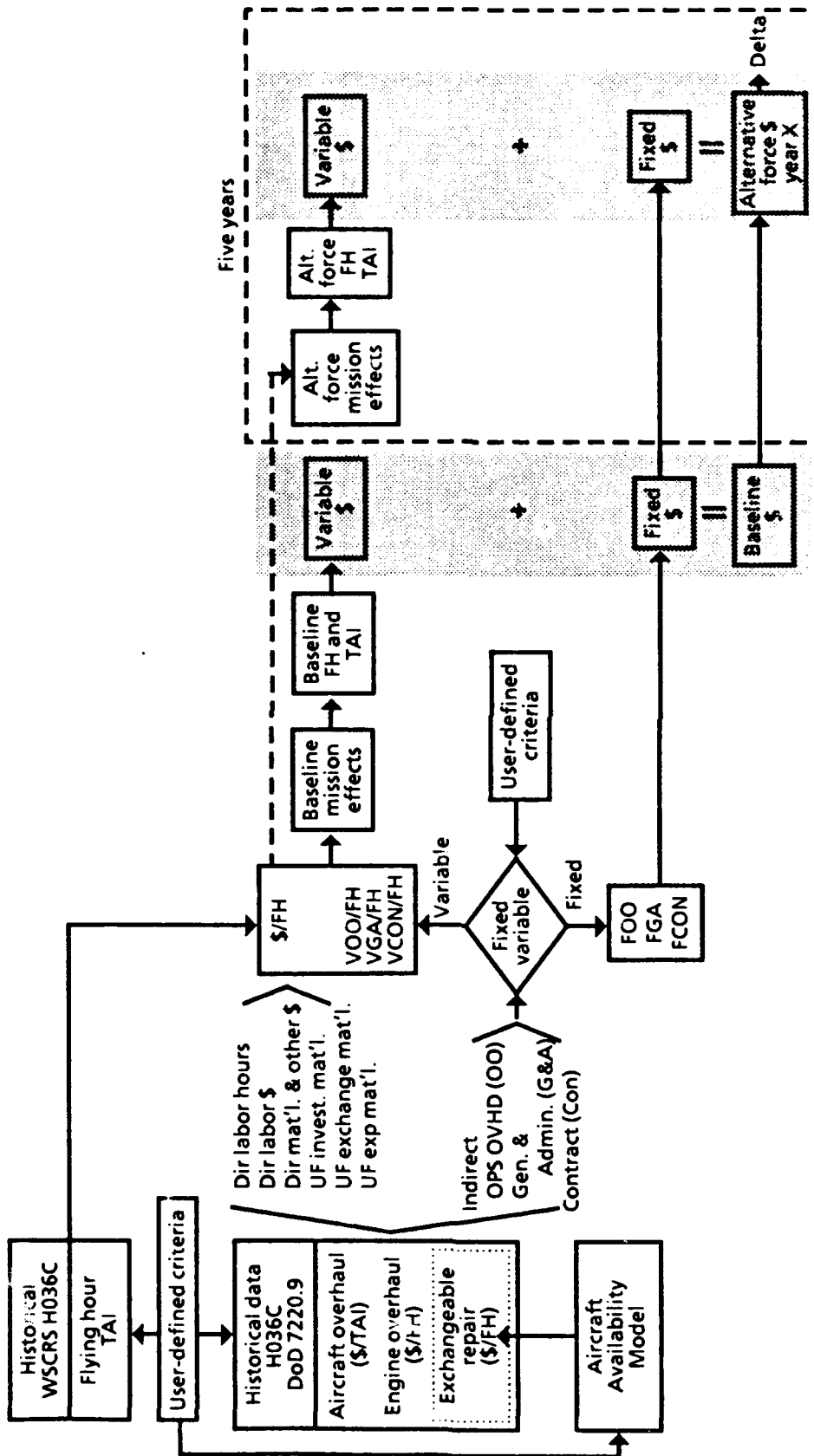
Based on user-specified criteria, historical cost, flying hour, and inventory data are extracted from the WSCRS data base for each mission design series (MDS) aircraft included in each defined weapon system group. Included are only cost records for industrially funded or contractor-provided depot maintenance. Costs for interim contractor support, contractor logistics support, and Classes IV and V modifications are excluded. Using the WSCRS work breakdown structure (WBS), the cost records are separated into three work groups:

- Airframe (WBS = AFOB). That work category includes all maintenance performed on the aircraft while the aircraft is at the depot. For example, this would include periodic depot maintenance, analytical condition inspections, and speed-line work.
- Engine (WBS = EOOB). That work category includes all maintenance performed on whole engines and engine modules returned to the depot for overhaul or repair.
- Exchangeable repair (WBS = VCEXB – avionics communications, VIEXB – avionics instruments, VNEXB – avionics navigation, AREXB – armaments, EAEXB – engine accessories, AAEXB – airframe components, and EAOB – auxiliary power unit (APU) overhaul). That work category includes the repair of all components removed from the aircraft (either at the depot or in the field) and repaired at the depot.

STEP 2

Each cost data record from WSCRS contains all the detail specified in DoD 7220.9M. While all this information is carried forward in the prototype, only selected fields are used to classify the costs into four categories:

- Direct costs. Direct costs are the resources that are consumed in the repair of an end item. Those resources are easily identifiable and chargeable to unique work orders. Included in that category are direct civilian and military labor costs, funded direct material costs, and funded other direct costs.



Note: FH = flying hour; UF = unfunded.

FIG. 3-3. HOW THE PROTOTYPE WORKS

Excluded are costs incurred by the depot but not included in the sales rate charged to customers (e.g., investment material procured by another appropriation are not included in direct materials).⁵

- Operations overhead. This category includes all indirect costs incurred within a production center that cannot be directly identified to a specific work order. Only operations overhead costs included in the sales rates charged to customers are included in this category (i.e., only funded operations overhead costs).
- General and administrative. G&A includes all funded G&A costs. Those are indirect costs that benefit more than one production center. Only funded G&A costs are included.
- Contractor and inter-Service. Some depot workload is performed by contractors or by other Services. The cost of that work is reported as a single entry without the detailed breakout provided for organically performed work. To be consistent with WSCRS breakout between funded and unfunded costs, that category also includes Government-furnished services and Government-furnished expense materials.

STEP 3

Using the data extracted from Step 1, average consumption rates (expressed in dollars) are calculated for each cost category (direct, operations overhead, G&A, and contract), for each work group (airframe, engine, and exchangeable repair), and for each weapon system group. If a weapon system group is comprised of more than one MDS aircraft, the data within that group are combined before the average is computed. That procedure results in an average representing all aircraft within that group. Although the computations described in Steps 3 through 6 are done for each weapon system group, individual weapon system notations are not provided to facilitate clarity.

For engines and exchangeables, the average consumption rate is expressed as a rate per flying hour. That approach is consistent with procedures used by the Air Force. If the user specified that FY88, FY89, and FY90 data were to be used to compute the consumption

⁵These unfunded costs are carried forward in the model and could be used to restructure historical depot cost to reflect stock funding of depot level reparables.

rate, the algorithm sums all the cost data (within each cost category) and divides by the sum of the flying hours for those years.

$$\text{Direct cost per flying hour} = \frac{\sum \text{Total_direct cost Yr}_i}{\sum \text{FHR Yr}_i}$$

(DCPFH_{Eng}, DCPFH_{Exch})

$$\text{Operations overhead per flying hour} = \frac{\sum \text{Total_OO Yr}_i}{\sum \text{FHR Yr}_i}$$

(OOPFH_{Eng}, OOPFH_{Exch})

$$\text{G\&A per flying hour} = \frac{\sum \text{Total_G\&A cost Yr}_i}{\sum \text{FHR Yr}_i}$$

(G\&APFH_{Eng}, G\&APFH_{Exch})

$$\text{Contract per flying hour} = \frac{\sum \text{Total_contract cost Yr}_i}{\sum \text{FHR Yr}_i}$$

(CPFH_{Eng}, CPFH_{Exch})

For the airframe cost category, the average consumption rate is expressed as a rate per total authorized inventory (TAI). TAI is used instead of flying hours because on-equipment airframe workload is driven by scheduled events that occur independently of the OPTEMPO. The use of TAI is consistent with Air Force procedures.

$$\text{Direct cost per TAI} = \frac{\sum \text{Total_direct cost Yr}_i}{\sum \text{TAI Yr}_i}$$

(DCPTAI)

$$\text{Operations overhead per TAI} = \frac{\sum \text{Total_OO Yr}_i}{\sum \text{TAI Yr}_i}$$

(OOPTAI)

$$\text{G\&A per TAI} = \frac{\sum \text{Total_G\&A Yr}_i}{\sum \text{TAI Yr}_i}$$

(G\&APTAI)

$$\text{Contract per TAI} = \frac{\sum \text{Total_contract Yr}_i}{\sum \text{TAI Yr}_i}$$

(CPTAI)

STEP 4

If a selected aircraft has consumption rate data from the LMI AAM, the following calculations are performed. The AAM output expresses the total cost of an exchangeable repair program for a weapon system as a rate per flying hour. That consumption rate (LMI_\$/FH) is prorated among the four cost categories using the historical factors developed in Step 3 for exchangeable repair (DCPFH_{Exch}, OOPFH_{Exch}, G\&APFH_{Exch}, and CPFH_{Exch}). (For clarification, the prefix WSCRS_ is appended to the variable names from Step 3.) The allocated LMI consumption rates will be used in Step 5 when costs are separated into fixed and variable categories.

If no AAM costs are found, Step 5 will use the exchangeable consumption rates calculated in Step 3.

If LMI_\$/FH data are available, then,

$$DCPFH_{Exch} = LMI_ \$ / FH \times \frac{WSCR S_ DCPFH_{Exch}}{WSCR S \text{ Total } \$ / FH_{Exch}}$$

$$OOPFH_{Exch} = LMI_ \$ / FH \times \frac{WSCR S_ OOPFH_{Exch}}{WSCR S \text{ Total } \$ / FH_{Exch}}$$

$$G\& APFH_{Exch} = LMI_ \$ / FH \times \frac{WSCR S_ G\& APFH_{Exch}}{WSCR S \text{ Total } \$ / FH_{Exch}}$$

$$CPFH_{Exch} = LMI_ \$ / FH \times \frac{WSCR S_ CPFH_{Exch}}{WSCR S \text{ Total } \$ / FH_{Exch}}$$

If LMI_\$/FH is not available, then:

$$DCPFH_{Exch} = WSCR S_ DCPFH_{Exch} \text{ (from Step 3)}$$

$$OOPFH_{Exch} = WSCR S_ OOPFH_{Exch} \text{ (from Step 3)}$$

$$G\& APFH_{Exch} = WSCR S_ G\& APFH_{Exch} \text{ (from Step 3)}$$

$$CPFH_{Exch} = WSCR S_ CPFH_{Exch} \text{ (from Step 3)}$$

STEP 5

In Step 5, costs are separated into fixed and variable categories. Only variable costs will be used to compute the cost of workload changes. All direct costs (DCPTAI, DCPFH_{Eng}, and DCPFH_{Exch}) are specified to vary with workload changes. By default, all indirect costs are assumed to be fixed. The analyst can choose to override the default assumption by providing different assumptions (user inputs) for the percent of operations overhead and/or G&A costs that will vary with workload. The following algorithms are used to separate operations overhead and G&A costs into fixed and variable costs with respect to the workload. The default value for user input is zero. (Variable names with the prefix 'Total_' are from Step 3.)

- Operations overhead (the letter V denotes variable, the letter F denotes fixed.)

$$VOOPTAI = OOPTAI * (\text{User Input}_{00})$$

$$VOOPFH_{Eng} = OOPFH_{Eng} * (\text{User Input}_{00})$$

$$VOOPFH_{Exch} = OOPFH_{Exch} * (\text{User Input}_{00})$$

$$FOO_{Eng} = Total_OO_{Eng} * \{1-(User\ Input_{oo})\}$$

$$FOO_{Exch} = Total_OO_{Exch} * \{1-(User\ Input_{oo})\}$$

$$FOO_{TAI} = Total_OO_{TAI} * \{1-(User\ Input_{oo})\}.$$

- G&A (the letter V denotes variable, the letter F denotes fixed).

$$VG\&APT_{AI} = G\&APT_{AI} * (User\ Input_{g\&a})$$

$$VG\&APFH_{Eng} = G\&APFH_{Eng} * (User\ Input_{g\&a})$$

$$VG\&APFH_{Exch} = G\&APFH_{Exch} * (User\ Input_{g\&a})$$

$$FG\&A_{Eng} = Total_G\&A_{Eng} * \{1-(User\ Input_{g\&a})\}$$

$$FG\&A_{Exch} = Total_G\&A_{Exch} * \{1-(User\ Input_{g\&a})\}$$

$$FG\&A_{TAI} = Total_G\&A_{TAI} * \{1-(User\ Input_{g\&a})\}.$$

- Contract and inter-Service costs. Like the AAM outputs, there is no breakout between direct and indirect costs for contract and inter-Service costs (referred to as contract costs). For contract costs, the user may either specify the percent of the total contract costs that is considered variable with the workload or use a default value calculated by the model. If the user chooses to specify the percent (User Input_C), the following algorithms are used (the letter V in the first position of the variable name denotes variable, the letter F denotes fixed):

$$VCPT_{AI} = G\&APT_{AI} * (User\ Input_C)$$

$$VCPFH_{Eng} = G\&APFH_{Eng} * (User\ Input_C)$$

$$VCPFH_{Exch} = G\&APFH_{Exch} * (User\ Input_C)$$

$$FC_{Eng} = Total_Contract_{Eng} * \{1-(User\ Input_C)\}$$

$$FC_{Exch} = Total_Contract_{Exch} * \{1-(User\ Input_C)\}$$

$$FC_{TAI} = Total_Contract_{TAI} * \{1-(User\ Input_C)\}.$$

If the analyst chooses the default for contract costs, the model calculates the percent of total organic repair that is variable with workload and applies this percentage to the contract cost. This is accomplished by substituting the following expression for (User Input_C) into the above equations for contract costs:

$$User\ Input_C = .58 + .25 * (User\ Input_{oo}) + .17 * (User\ Input_{g\&a})$$

where⁶

.58 is the historical percent of total organic depot costs that are direct costs, and

.25 is the percent of total organic depot costs that are operations overhead costs, and

.17 is the percent of total organic depot costs that are G&A costs.

STEP 6

At this point, the individual consumption rates for each cost category, derived in Steps 3 through 5, are combined within each work group into a single variable consumption rate, VAR, and a total fixed cost, FIX\$. (The subscript AF will be used to denote the airframe work group.)

$$VAR_{AF} = DCPTAI + VOOPTAI + VG\&APTAI + VCPTAI$$

$$VAR_{Eng} = DCPFH_{Eng} + VOOPFH_{Eng} + VG\&APFH_{Eng} + VCPFH_{Eng}$$

$$VAR_{Exch} = DCPFH_{Exch} + VOOPFH_{Exch} + VG\&APFH_{Exch} + VCPFH_{Exch}$$

$$FIX\$_{AF} = FOO_{TAI} + FG\&AP_{TAI} + FC_{TAI}$$

$$FIX\$_{Eng} = FOO_{Eng} + FG\&AP_{Eng} + FC_{Eng}$$

$$FIX\$_{Exch} = OO_{Exch} + FG\&AP_{Exch} + FC_{Exch}$$

STEP 7

The model calculates the baseline variable cost for each aircraft group in the force structure option being estimated. The variable cost factors from Step 6 are multiplied by the TAI and annual flying hour program. The subscript i is added to the variables defined in Step 6 to indicate the weapon system groups.

$$VAR_{AF}\$(i,j,k) = VAR_{AF}(i) \times TAI(i,j,k)$$

$$VAR_{Eng}\$(i,j,k) = VAR_{Eng}(i) \times FH(i,j,k)$$

$$VAR_{Exch}\$(i,j,k) = VAR_{Exch}(i) \times FH(i,j,k)$$

⁶The weights used in this equation are derived from a sample of 642 NSNs. The percent of indirect cost from this sample is within 1 percent of population totals reported in the *Depot Corporate Business Plan* published by OASD(P&L).

where

i = aircraft group,

j = year, and

k = baseline or alternative force.

STEP 8

If the mission effects adjustment is functional for a selected aircraft group, engine and exchangeable costs are adjusted by the mission adjustment. For the C-5 and F-15 aircraft groups, the following model is included:

$$MTBR = b_1 \cdot \left(\frac{\text{Flying hours per sortie}}{\text{Landings per sortie}} \right)^{.5}$$

The mission effects adjustment (MEA) is calculated as follows:

$$MEA_{(i,j,k)} = MTBR_{(i,history)} / MTBR_{(i,j,k)}$$

where

MTBR = mean time (flying hours) between removals,

i = aircraft group,

j = year,

k = baseline or alternative force, and

b₁ = a unique coefficient derived for each MDS aircraft.

As a default, both the numerator and denominator of the mission effects adjustment are calculated with the historical values for sortie duration (flying hours per sortie) and landings per sortie; consequently, no adjustment is made. If, however, it is determined that the historical values are inappropriate and the analyst changes either or both of the parameters, then $MTBR_{(i,j,k)} = MTBR_{(1,history)}$ and the variable costs are scaled by the MEA.⁷

$$VAR_{Eng\$}_{(i,j,k)} * MEA_{(i,j,k)}$$

$$VAR_{Exch\$}_{(i,j,k)} * MEA_{(i,j,k)}$$

⁷Algebra will show that the mission adjustment simplifies to the following scaling factor:

$$\frac{\left(\text{Flying hour / landing}_{T_0} \right)^{.5}}{\left(\text{Flying hours / landing}_{T_1} \right)^{.5}}$$

where

i = aircraft group,

j = year, and

k = baseline or alternative force.

STEP 9

The fixed costs from Step 5 are then added to the variable costs calculated in Steps 7 and 8 to derive the total cost for the baseline force.

$$\text{TOT\$}_{AF(i,j,k)} = \text{VAR}_{AF\$}(i,j,k) + \text{FIX\$}_{AF(i)}$$

$$\text{TOT\$}_{Eng(i,j,k)} = \text{VAR}_{Eng\$}(i,j,k) + \text{FIX\$}_{Eng(i)}$$

$$\text{TOT\$}_{Exch(i,j,k)} = \text{VAR}_{Exch\$}(i,j,k) + \text{FIX\$}_{Exch(i)}$$

where

i = aircraft group,

j = year, and

k = baseline or alternative force.

STEP 10

In addition to the recurring repair and maintenance workload, the depot also makes modifications to the aircraft. The labor cost for modification labor is estimated using a cost estimating relationship (CER) from the Air Force Cost and Planning Factor Regulation (AFR 173-13).⁸ This CER estimates the average annual investment cost of Class IV modification kits for an aircraft. The Air Force programs 10 percent of the kit cost to cover the labor cost of installing the modification in an airplane. The algorithm used to estimate that cost category is described below:

$$\text{TOT\$}_{MODS(i,j,k)} = .1 \times 6003 \times \text{FAC}^{.7834} \times \text{TAI}(i,j,k)$$

where

i = aircraft group,

j = year,

k = baseline or alternative force,

⁸Material costs that are acquired from the procurement appropriations are not included as a depot maintenance cost. Class V modification costs are not included in the prototype.

FAC = flyaway cost in millions of FY89 dollars, and

TOT\$MODS = the labor cost to install Class IV modifications (expressed in whole dollars).

STEP 11

The total costs from Steps 9 and 10 are then escalated to either the base year specified or the appropriate then-year value using approved DoD inflation indices for the Operations and Maintenance Appropriation.

STEP 12

This step calculates the costs of the alternative force structure. Steps 5 through 11 are repeated, but values for the alternative force structure are used in the calculations.

STEP 13

The delta is calculated as follows: alternative force – baseline force. Thus, a negative delta indicates that resources can be taken away from the baseline.

STEP 14

Steps 7 through 13 are repeated for each of 5 years.

VERIFICATION OF ALGORITHMS

To assist in verifying the model's algorithms, the prototype saves the cost and program data extracted from the WSCRS data base in two temporary dBaseIII files (TMP_WBS.DBF contains the cost data, and TMP_PD.DBF contains the flying hour and inventory data). Using those files, the model's calculations can be audited by running the model for a weapon system at historical inventory and activity levels and then comparing the model output with the official WSCRS data base. Other features were verified by performing manual calculations on the data in the .DBF files and comparing those results with the model outputs.

We did find a minor rounding error (.21 percent) in the algorithms used to allocate LMI consumption rates to the cost category. That will be fixed in the final model.

CHAPTER 4

FUTURE RESEARCH DIRECTIONS

The prototype is intended to be a milestone at which both the sponsor and LMI can assess the key features of the final model. As part of that milestone, LMI suggests the following research areas for the next phase of the project.

- Expand the prototype model to include all Air Force aircraft currently in the force structure. With the exception of mission effects, that effort should involve expanding the use of AAM repair estimates for component repair requirements. Currently, AAM repair data are aggregated at the mission design (MD) level of detail for most weapon systems. If MDS level of detail is required for additional weapon systems, modifications will have to be made to the AAM.
- Validate and calibrate the mission effects adjustment (MEA). The MEA is a significant methodological step forward, affecting a wide range of DoD resource areas.¹ While it has been shown to significantly improve resource forecasts, MEA still must be viewed as a preliminary research finding requiring further validation and calibration.
 - Collect additional data at various surge levels (sortie lengths, landings per sortie, etc.) to generate a sufficient data base to develop and validate models by aircraft type. (While we did not look at base-specific data, there may be enough variation in mission characteristics by base to model mission changes without adding surge exercise data).
 - Calibrate the MEA with other surge exercise experience to broaden the basis of its validation.
 - Use multivariate models to investigate the impact that individual factors, such as average sortie durations or the number of sorties, have on reliability.

¹MEA affects the requirements for base maintenance manpower and materials, depot level reparable (both repairs and procurement), initial spares for new weapon systems, and WRSK. In addition, a valid MEA methodology would raise questions about DoD procedures used to predict reliability characteristics for new weapon systems, to establish reliability improvement warranties, to perform product acceptance tests, and to calculate mission success probabilities.

- Identify better quantitative descriptors of cycles. Landings per sortie is most likely just one proxy for the number of cycles. Other measures may be better indicators of cycles.
- Explore the need for different measures of cycles for different types of equipment (i.e., engines, avionics, airframe components).
- DMRD 904 established a stock fund for the repair, procurement, and management of components repaired at the depot. After assisting the Air Force in evaluating the financial impacts of two-level maintenance, LMI believes that significant improvements can be made in forecasting cash requirements and establishing pricing and surcharge policies for the repairable stock fund division (RSD). From that experience, our experience with the depot maintenance prototype, and our involvement over the last 20 years in the development of the AAM, we believe that the major components already exist within LMI to develop a complete model of the RSD for the Air Force.
- The Air Force decision to implement the two-level maintenance concept will increase the depot maintenance workload by moving to the depot work that was previously performed by the base. The depot maintenance prototype implicitly assumes a traditional three-level maintenance concept. The final model must include a capability to "cross walk" between the historical data collected under three-level maintenance and the requirement to predict resources for a two-level maintenance concept.

APPENDIX A

MISSION EFFECTS ON RELIABILITY

SUMMARY

Mission changes do impact the rate at which parts are consumed. When mission profiles are considered, the 70 percent improvement in forecasting Operation Desert Storm (ODS) requirements highlights the serious limitations of using any individual measure of resource consumption when future mission profiles are likely to change. Techniques used for predicting future resource requirements for component repairs, WRSK, etc., can be improved by revising resource calculations to consider the effects of anticipated mission changes (e.g., removals per flying hour).¹

INTRODUCTION

There is much folklore about the influence that mission changes have on consumption rates. Typical of that folklore is the notion that as an airplane is flown more, it becomes more reliable and consumes fewer resources. The engineering community recognizes that the way a piece of equipment is operated affects its reliability. It has taken action to adjust reliability predictions for operating conditions.² However, models that estimate resources revise empirical reliability measures only after the mission changes (e.g., sortie lengths decrease, number of sorties increases, or number of takeoffs and landings change) and sufficient historical data are available.

If mission changes are minor or if they occur over a long period of time, then waiting for a resource model to react to them will cause only minor errors in predictions of resource requirements. If, however, the changes are large (such as the force structure reduction currently anticipated) or sudden (such as ODS), then serious, near-term, resource planning errors can occur.

¹The term Operation Desert Storm will be used to refer to both Operations Desert Shield and Desert Storm – unless we must distinguish data obtained strictly from only one of the operations.

²The type of mission (e.g., fighter, airlift) and the influence of operating cycles (i.e., power on/power off per unit of operating hours) are considered when predicting component reliability.

This appendix presents preliminary findings about the efforts made to quantify the effect that mission changes have on resource consumption; this appendix also demonstrates how, in the face of those changes, *a priori* adjustments can be made to historical consumption rates.

BACKGROUND

Reliability predictions are the basis for many decisions affecting the level of resources programmed to support DoD's force structure. Initial and replenishment spares, base maintenance manpower, consumable materials, and depot maintenance requirements are all estimated as some function of the projected workload:

$$\text{Estimated requirements} = f(\text{projected workload}) \quad (\text{Eq. 1})$$

Typically, the projected workload in Equation 1 is estimated by expressing measures of reliability (e.g., removals, demands, failures, and maintenance actions) as functions of operating time. For aircraft, operating time is usually measured in flying hours (FH) as shown in Equation 2:

$$\text{Projected workload} = (\text{flying hours} \times \text{failure rate}) \quad (\text{Eq. 2})$$

Modeling requirements in this manner implicitly assumes that all equipment malfunctions are caused by equipment stresses related to the flying hour program – hence, workload is generated as a function of flying hours. That assumption implies that resource requirements change linearly in direct proportion to flying hour changes.

While it is simple to implement, the linear model represented by Equation 2 does not explicitly account for failures caused by equipment stresses other than operating time. Both Wrisley, et al.,³ and Krantz and Richter⁴ found that increasing the number of on-off cycles usually increases the failure rate of electronic components. Takeoffs and landings, g-loadings, and pressure changes are known to produce mechanical stresses that affect reliability. Maintenance personnel have also observed that when aircraft are not flown, reliability may deteriorate because of the

³gathering of moisture on components during off periods [mentioned by almost every maintenance group interviewed by Krantz and Richter] . . . [and] . . . excessive equipment heating,

³Wrisley, Russ, A. J. Recchio, et al. *Reliability and Maintainability Operational Parameter Translation II*. IIT Research Institute: Rome Air Development Center Technical Report RADC-TR-89-299, Vol 1, December 1989.

⁴Krantz, F. M. and M. W. Richter. *Mission/Maintenance/Cycling Effects on Reliability*. Westinghouse Electric Corp.: Rome Laboratory Technical Report RL-TR-91-402, December 1991.

which results from high ambient temperature or operation on ramps with limited cooling capacity.⁵

Because some failure modes are affected by factors other than operating time, actual depot requirements will generate as a function of a multivariate process similar to that shown in Equation 3:

$$\text{Actual workload} = \frac{\partial R}{\partial FH} \times FH + \sum_{i=1}^{\text{All}} \frac{\partial R}{\partial \text{stress}_i} \times \text{stress}_i \quad (\text{Eq. 3})$$

where

FH is the number of flying hours,

stress_i designates each nonflying-hour-related stress, and

R is the total system level failures.

Using Equation 2 to estimate the process described above is tantamount to estimating a multivariate process with only one of its dimensions. Implicit in that formulation is the requirement to express each nonflying-hour-related stress (stress_i) as the frequency of stress_i per flying hour. Thus, the simple requirements formulation shown in Equation 2 implies the following in Equation 4:

$$\text{Projected workload} = \left(\frac{\partial R}{\partial FH} + \sum_{i=1}^{\text{All}} \left(\frac{\partial R}{\partial \text{stress}_i} \times \frac{\text{stress}_i}{FH} \right) \right) \times FH \quad (\text{Eq. 4})$$

When historical resource consumption data are used in Equation 2 to estimate resources for future flying hour programs, one further implication is that each stress_i will occur with the same frequency as it did in the historical data. That is not always a valid assumption.

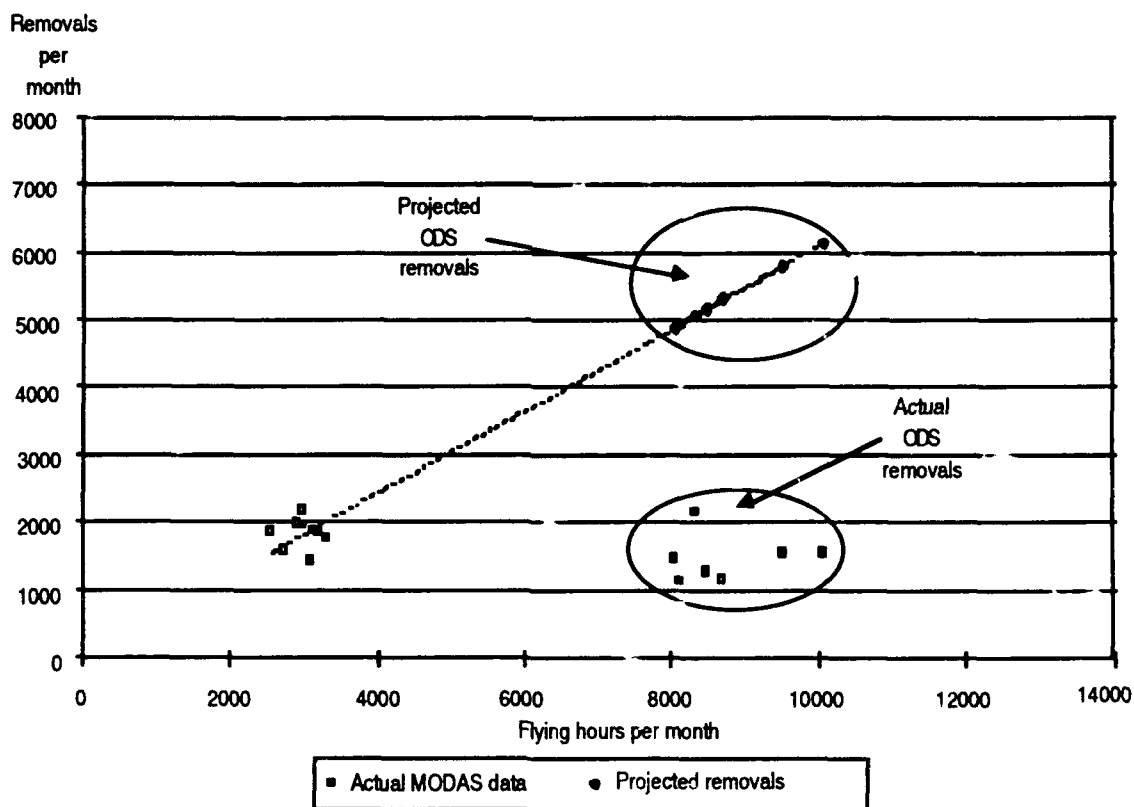
Where changes are made to the mission profile, the frequency of failure-causing stresses can change (or be changed) independent of the total number of flying hours. For example, if an aircraft typically flies 200 sorties taking 1,000 hours per year, the landing gear may be cycled (i.e., raised and lowered) 250 times. However, a commander who decides that inexperienced air crews need more landing practice may require three "touch and go" landings for each training sortie. While that policy decision does not change the number of flying hours, it does change the number of times the landing gear is cycled during each sortie to four, a 220 percent increase. Thus, all stresses that are related to increased touch-and-

⁵Krantz and Richter, p 51.

go landings would have to be increased or else the requirements projection will understate the revised workload.

Ideally, resource models should consider the magnitude and frequency of all stresses causing equipment malfunctions; however, when the effects of nonflying-hour-related failure modes are minimal or if flying hour programs remain unchanged, then the simple linear estimating models (like Equation 2) are adequate to estimate resources. If, however, the effects of nonflying hour related failure modes are significant *and* flying hour programs are changed (e.g., more sorties, more flying hours, or different mission profiles), then more complex resource models similar to Equation 4 may be appropriate.

Field data on airlift aircraft operating during ODS do not support modeling resource requirements as a simple function of flying hours. During the first 7 months of ODS, the C-5B monthly flying hour program was almost triple the peacetime flying hour activity level. The simple requirements formulation predicts that on-equipment removals (items removed directly from the aircraft) would also triple. However, actual removals declined slightly as shown in Figure A-1.



Source: Air Force Maintenance and Operational Data Access System.

FIG. A-1. C-5B ON-EQUIPMENT REMOVALS

Besides increased operating tempos (OPTEMPOs), other factors changed during ODS: the number of sorties per aircraft increased, the sortie length increased, and the number of landings per sortie decreased – any one of which theoretically could improve reliability over the levels experienced during peacetime operations.

Because these observations are consistent with the more complex resource model formulation, we investigated the relationship between mission changes and aircraft reliability to identify key mission parameters that explain the observed changes in reliability. The remainder of this paper documents that investigation.

APPROACH

We used the following two-step approach to assess the relationship between mission changes and aircraft reliability:

- *Step one.* We developed a regression model that captures the effects that key mission parameters (such as decreased sortie lengths, increased number of sorties, or changes in the number of takeoffs and landings) have on the mean time between removals (MTBRs).⁶ Originally, we planned to combine some ODS data and peacetime data to develop the mission effects model and then test that model using the remaining ODS data. However, we found that ODS removal data were underreported during ODS. Consequently, the models were developed using only pre- and post-ODS removal data.
- *Step two.* We validated the model by estimating the ODS experience for selected aircraft and comparing those estimates with snapshots of actual ODS experience for line replaceable units (LRUs) in the WRSK.

INDEPENDENT VARIABLES

We tried to identify independent variables that would relate to the types of stresses placed on an aircraft. We categorized these stresses into three groups: failures that occur as a function of operating time, failures that occur as a function of cycles, and failures that occur because of dormant failure modes. For each

⁶The mean time between removal was chosen as the indicator of reliability because it accounts for only failures that must be removed from the aircraft for repair. When a removal occurs, it places a demand on the logistics system for an item to replace the one removed. The logistics systems use the rate at which these demands occur to forecast requirements for depot maintenance and spares procurement; however, monthly demand data were not readily available.

failure mode, we identified the candidate independent variables shown in Table A-1.⁷

TABLE A-1
INDEPENDENT VARIABLES

Operating time Flying hours per month Sorties per month
Cycle effects Flying hours per TAI Flying hours per sortie (sortie duration) Number of sorties per TAI Landings per sortie Landings per TAI Mean flying hours between landings
Dormant effects Sorties per aircraft month Mean calendar days between sorties

Note: TAI = total authorized inventory.

DATA

The Air Force's Maintenance and Operational Data Access System (MODAS) was used to obtain monthly data on the C-5A and C-5B aircraft. On-equipment removals, flying hours, sorties, inventory, and landings for November 1989 through July 1990 and July 1991 through March 1992 were used to build the regression models.

Operation Desert Shield/Storm Snapshot Data. There is widespread concern that MODAS data were underreported during ODS. To verify this, we compared MODAS removal data from Operation Desert Shield with demand data from Hq MAC/LE for LRUs contained in the C-5 WRSK. Theoretically, the quantities should be identical, but as shown in Table A-2, MODAS reports

⁷There are other candidate independent variables; however, they could not be supported with the data bases available to Logistics Management Institute.

only 37 percent of the demand data. This example seems to confirm the fears that MODAS data are underreported.⁸

TABLE A-2
COMPARISON OF REMOVAL AND DEMAND DATA
FOR C-5A/B WRSK ITEMS

Reporting period	MODAS removals	Demand data
September 1990	947	1,982
December 1990	729	2,538
Total	1,676	4,520

Because the MODAS removal data from ODS are suspect, we relied on several snapshots of actual ODS supply demand experience that the Air Force used to evaluate the adequacy of C-5 and F-15 WRSK during ODS. The following snapshots of ODS data were used to calibrate and validate the models:

- Data about C-5A and C-5B demands on supply collected during Operation Desert Shield (in August and December 1990). Source: Hq MAC/LE (those data were collected by the Air Force Logistics Management Center).⁹
- Data about C-5A and C-5B flying hours, sorties, and landings (during August and December 1990). Source: MODAS.
- Data about F-15C aircraft demands on supply collected during Operation Desert Storm (January 1991 through February 1991) for aircraft deployed from Eglin Air Force Base (AFB). Source: HQ TAC/LG.
- Data about F-15 daily flying hours, sorties, and landings during ODS for aircraft deployed from Eglin AFB. Source: HQ TAC/LGP.

⁸ODS evidenced the need to have available a portable computer terminal for inputting data into the maintenance reporting systems from a remote location. After ODS, the Tactical Air Command (TAC) required its units to reconstitute the data that were maintained within many off-line reporting systems. These data are now consolidated at the Air Force Logistics Management Center; they may be a valuable source of information for further research.

⁹Crimiel, Dennis M. *Desert Shield Analysis (C-5/C-141)*. Air Force Logistics Management Center Report LS902055, September 1991. These data were used to evaluate WRSK/BLSS requirements for the C-5 and C-141 aircraft.

DISCUSSION

Because of the different types of stresses placed on equipment, we hoped to develop multivariate models using one or more independent variables from each of the failure categories. However, the correlation between the potential independent variables made the variance inflation factor (VIF)¹⁰ too large to include more than one independent variable. As a result, univariate models were developed in this phase of the research.

Adequate univariate regression models by individual aircraft mission design series (MDS) could not be developed. We found little variation in the monthly fleet-wide average operational flying program elements (e.g., flying hours, sorties, landings) for individual aircraft types. To obtain a data base with more variation in the independent variables, we combined data for the C-5A and C-5B aircraft. Although these are very similar aircraft, the C-5B fleet is operated at nearly twice the C-5A peacetime utilization rate.¹¹

Using the combined C-5 data base, several regression models were built using the monthly MODAS removal data before and after ODS.¹² The best of those models estimated MTBR as a function of the OPTEMPO¹³ (i.e., flying hours per TAI). Those OPTEMPO models explained approximately 70 percent of the variance in MTBR (the R² ranged from .69 to .72). We added a dummy variable to the OPTEMPO model to test for differences between the C-5A and C-5B that were not accounted for by the model. The coefficient for this dummy variable was not statistically different from zero, which implies that the model is adequate for either of the aircraft and that combining the data for these two types of aircraft is appropriate.

The intercept term was removed from the model because it is not statistically different from zero. Without the intercept term, the ratio

¹⁰VIF is a measure of multicollinearity (i.e., the degree to which the independent variables in a regression model are correlated with each other). The VIF of an independent variable is defined as $1/(1-R^2)$, where R² is the coefficient of determination obtained when that independent variable is regressed on all other independent variables in the model.

¹¹While the C-5B aircraft is an updated version of the original C-5A, the C-5A aircraft has undergone extensive modifications (including replacing its wing and upgrading its engines) to bring it to nearly the same equipment configuration as the newer C-5B. As a result, there is a high degree of commonality across the two aircraft, as demonstrated by the fact that components representing 79 percent of the total C-5A demands for reparable components are common to both aircraft. Source: LMI Report PA103RD1. *An Evaluation of Macro Methodologies Used by OSD and the United States Air Force to Estimate Acquisition Support Funding for New Aircraft Systems*, Wallace, John M., January 1992.

¹²The data base included data for November 1989 through March 1992. July 1990 and ODS data (August 1990 through May 1991) were not used.

¹³Because $FH/TAI = FH/sortie \times sorties/TAI$, this model implies that changing the average sortie duration (ASD) or changing the number of sorties has the same effect on MTBR (i.e., $dMTBR/dASD = dMTBR/d(sorties \text{ per } TAI)$). Ideally, we would want to model these separately; however, with the data bases available to us, these two factors were highly correlated with each other and could not be accurately estimated with ordinary least squares methods.

of two MTBRs can be calculated, as shown in Equation 5, without knowing the full MTBR model.

$$\frac{MTBR_i}{MTBR_j} = \frac{b_1 \times OPTEMPO_i^5}{b_1 \times OPTEMPO_j^5} = \frac{OPTEMPO_i^5}{OPTEMPO_j^5} = \frac{(FH / TAI_i)^5}{(FH / TAI_j)^5} \quad (\text{Eq. 5})$$

where

$MTBR^*$ = the mean time between removal for LRU_k adjusted for the quantity per application and the application percentage (the percent of this aircraft type with this item installed),

TAI = the total authorized inventory of aircraft,

i = values from baseline period, and

j = values for alternative period.

As shown in Equation 6, if we assume that the functional form of the model is valid for all types of aircraft, then the resource demands for any aircraft can be revised by scaling its historical resource consumption rate with the OPTEMPO ratio from Equation 5.¹⁴ The accuracy of the OPTEMPO model was calibrated by comparing ODS snapshot data with resource estimates, revised with the OPTEMPO ratio.

$$\frac{(FH / TAI_i)^5}{(FH / TAI_j)^5} \times \sum_{k=1}^{All} \frac{FH / TAI_j \times TAI_j}{MTBR^* (i, k)} = \text{revised demands} \quad (\text{Eq. 6})$$

where

$MTBR^*$ = the mean time between removal for LRU_k adjusted for the quantity per application and the application

¹⁴Following a similar line of argument, the adjustment can also be applied to resource consumption rates expressed as dollars per flying hour, because the \$/FH for a given weapon system is also related to removals as follows:

$$\$/FH = \frac{\sum_{k=1}^{All} (Q_k \times DEMANDS_k \times URC_k)}{\text{flying hours}}$$

where

Q_k is the fraction of LRU_k removals that are sent to the depot and are repaired,

URC_k is the average unit repair cost for LRU_k , and

$$DEMANDS_k = \frac{FH / TAI \times TAI}{MTBR^* (i, k)} \quad (\text{from Equation 5}).$$

percentage (the percent of this aircraft type with this item installed),

TAI = the total authorized inventory of aircraft,

i = values from baseline period, and

j = values for alternative period.

We used the OPTEMPO model to adjust D-041 projections of C-5 demands during two 30-day snapshots of ODS experience and then compared actual demands for these same periods with the adjusted D-041 projection, the D-041 projection (based on peacetime demand experience), and the D-040 projection (based on estimated wartime demand rates) of the ODS demands. For those comparisons, the OPTEMPO model $MTBR = b_1 \times (FH/TAI)^{-5}$ has the smallest estimating error. While this model had only 30 percent of the D-041's estimating error for the C-5, it still underestimated the actual MTBR. However, when we performed the same test on similar data for the F-15C, the model seriously overestimated the actual MTBR. Had this OPTEMPO model been used for the F-15C, insufficient resources would have been procured.

These findings were puzzling. The OPTEMPO of both aircraft significantly increased during ODS. The increases resulted from the same two factors for each aircraft: the average sortie duration was increased and the utilization rate (sorties per month) was increased. A former C-5 pilot noted that sorties flown by the C-5 during peacetime were different from those flown during ODS in at least one other aspect: there were many fewer landings per C-5 sortie during ODS.

We reviewed the data base and found that while the number of C-5 sorties nearly doubled during ODS, the total number of landings declined slightly from peacetime levels. However, for the F-15, both the number of sorties and the number of landings increased by nearly the same proportion during ODS. If landings are a proxy for the number of cycles put on the airframe, then the F-15 results could be explained by the fact that the F-15 incurred relatively more cycles for each additional flying hour than did the C-5. As a result, the F-15 did not experience the same level of improvement in its MTBR as was experienced by the C-5 fleet.

To test the effect of increased cycles, we modified the OPTEMPO model as shown in Equation 7 to include a measure of the number of cycles:

$$MTBR = b_1 \times \left(\frac{FH / TAI}{cycles / TAI_j} \right)^{.5} \quad (\text{Eq. 7})$$

Again, we can avoid estimating the coefficient by addressing just the change in MTBR ratios. We also made the following algebraically equivalent substitutions: average sortie duration (i.e., FHs per sortie) for flying hours per TAI and cycles per sortie for cycles per TAI. Using landings as a proxy for cycles, the mission effects adjustment (MEA) is calculated as follows:

$$MEA = \frac{(\text{flying hours per landing}_{\text{historical}})^{.5}}{(\text{flying hours per landing}_{\text{alternative}})^{.5}} \quad (\text{Eq. 8})$$

During their research on the effect of on-off cycles on avionic equipment reliability, Krantz and Richter found an inverse relationship between failure rates and aircraft mission length and a direct relationship between failure rates and the number of cycles.¹⁵

The behavior of the cycle-based MEA from Equation 8 is consistent with their findings:

- When the average sortie duration is increased over historical levels (more hours between cycles), the MEA decreases the historical resource consumption rates, and
- When landings per sortie are increased above historical levels (more cycles per flying hour), the MEA increases the historical resource consumption rates.

The MEA (Equation 8) was tested using the same procedures and data as described for the OPTEMPO model. The results, summarized in Table A-3, were dramatically different. Using the mission effects adjustment, estimating errors were reduced by at least 70 percent for *both* the C-5 and F-15 aircraft.

¹⁵Krantz and Richter, pp. iii - v.

TABLE A-3

OPERATION DESERT STORM EXPERIENCE – ACTUAL VERSUS PREDICTED DEMANDS FOR LINE REPLACEABLE UNITS IN WAR READINESS SPARES KITS

Snapshot period	Actual demands	D-041 (peacetime)	D-040 (WRSK)	Mission effect adjustment
C-5 FLEET 7 August 1990 7 September 1990	3,964	13,393	13,128	6,846 (30.6% of D-041 error)
C-5 FLEET 7 December 1990 7 January 1991	5,076	12,757	12,504	6,001 (12.0% of D-041 error)
F-15C (only deployed units from Eglin AFB) 24 January 1991 28 February 1991	667	1,338	1,960	615 (6.4% of D-041 error)

CONCLUSIONS

Mission changes do impact the rate at which parts are consumed. The 70 percent improvement in forecasting ODS requirements highlights the serious limitations of using any individual measure of resource consumption when the mix of mission profiles on which those measures are predicated is likely to be different in the future. Techniques used for predicting future resource requirements for component repairs, WRSK/BLSS kits, etc., can be improved by incorporating into resource calculations the effects of anticipated mission changes.

The MEA is only indicative of how knowledge of mission changes can be used to adjust resource consumption rates. Even though MEA is a significant improvement, at least the following additional work must be completed:

- Additional data must be collected for various mission profiles (e.g., sortie lengths and landings per sortie) to generate a sufficient data base to develop models by aircraft type. (While we did not look at base-specific data, there may be enough variation in mission characteristics, by base, to model mission changes.)
- MEA must be calibrated with other surge exercise results.

- Multivariate models are needed to investigate the impact that individual factors, such as average sortie durations or the number of sorties, have on reliability.
- Better measures of cycles may be possible. Landings per sortie is most likely only one possible proxy for the number of cycles.

Armed with a valid methodology for adjusting resources needed for mission effects, DoD should re-examine the procedures used to estimate the following resource areas:

- Base maintenance manpower,
- Base maintenance material,
- Depot level reparables,
- Initial spares requirements, and
- WRSK/BLSS requirements.

Also, the relationship between reliability and mission profile raises significant questions about the conditions under which reliability testing is accomplished for

- reliability improvement warranties,
- product acceptance procedures, and
- operational test and evaluation.

APPENDIX B

AN OVERVIEW OF THE AIRCRAFT AVAILABILITY MODEL

THE MODEL DESCRIPTION

The AAM is a two-echelon, multi-indenture inventory control model for recoverable (reparable) aircraft components. It is founded on economic and probabilistic concepts. The AAM calculates base and depot resupply pipelines for each recoverable component, identified by national stock number, for a procurement lead time beyond the fiscal year being considered, on the basis of a given inventory status position. The AAM pipeline calculations are based on the D-041 methodology in order to ensure the maximum possible compatibility with the results generated by the D-041 central secondary item stratification subsystem, which is used to derive the Air Force Logistics Command (AFLC) budget estimate submission for investment spare parts procurement.

FUNCTION

The AAM developed by the Logistics Management Institute for the U.S. Air Force is used to formulate and evaluate investment spares requirements for peacetime operating stock, as part of the planning, programming, and budgeting system. The AAM relates supply and maintenance actions to a measure of materiel readiness called "aircraft availability." An aircraft is "available" if it is not awaiting completion of a resupply action such as repair, replacement, or shipment of a recoverable (reparable) component. The AAM forecasts future year costs and availability rates by aircraft type – on the basis of data derived from several Air Force data systems, including the Recoverable Consumption Item Requirements System (D-041) and the Aerospace Vehicles and Flying-Hour Programs.

DEVELOPMENT OF THE AAM

The AAM's conceptual development was sponsored by the Assistant Secretary of Defense for Installations and Logistics in 1972 in order to develop a method for measuring military essentially in defense inventory/stock control policy. The initial model provided a method for measuring materiel readiness in procurement plans for recoverable components so that the best balance of operational weapon systems could be obtained within funding constraints. Model feasibility was demonstrated in a test at the AFLC in 1973-1974. Repair considerations were added in 1974 to broaden the model's scope. The model were further refined in 1976 to take into account the effect of common components shared by two or more aircraft types. The revised model concept was tested again at AFLC in 1978, before the model was put into regular use in evaluating U.S. Air Force budget and program objective memorandum submissions. In 1982, the AAM was adapted for AFLC use in preparing budget allocations; it is now being fully integrated into the Recoverable Consumption Item Requirements System (D-041).

APPENDIX C

GLOSSARY

AAM	=	Aircraft Availability Model
AFB	=	Air Force base
AFLC	=	Air Force Logistics Command
ASD(PA&E)	=	Assistant Secretary of Defense, Program Analysis and Evaluation
CER	=	cost estimating relationship
DLR	=	depot level reparable
DSD	=	data system designator
FH	=	flying hours
G&A	=	general and administrative
LRU	=	line replaceable unit
MD	=	mission design
MDS	=	mission design series
MEA	=	mission effects adjustment
MODAS	=	Maintenance and Operational Data Access System
MTBR	=	mean time between removal
NSN	=	national stock number
OASD(P&L)	=	Office of the Assistant Secretary of Defense (Production and Logistics)
ODS	=	Operation Desert Shield/Desert Storm
OPTEMPO	=	operating tempo
POM	=	program objective memorandum
POS	=	peacetime operating stocks

PPBS	=	planning, programming, and budgeting system
REMIS	=	reliability and maintainability information system
RSD	=	reparable stock fund division
SBSS	=	standard baselevel supply system
TAI	=	total authorized inventory
URC	=	unit repair cost
VAMOSC	=	Visibility and Management of Operating and Support Cost
VIF	=	variance inflation factor
WBS	=	work breakdown structure
WRSK	=	war readiness spares kits
WSCRS	=	Weapon System Cost Retrieval System

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