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An Evaluation of Macro Methodologies Used by OSD and the United States Air Force to Estimate Acquisition Support Funding for New Aircraft Systems

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This research evaluates Initial Spares estimating methods used by OSD and the Air Force. Two macro estimating approaches were studied: factor based approaches that use historical percent of flyaway cost to estimate Initial Spares funding for new aircraft and the Logistics Support Cost (LSC) model – a detailed build-up method that uses aircraft equipment and operational characteristics to estimate Initial Spares.

Findings: (1) Factor based approaches ignore important considerations that affect the requirement for spares. Historical Initial Spares requirements must be adjusted to reflect new budget definitions and revised Air Force computational procedures as well as the operating tempo, equipment configuration, reliability, and operational availability of the new system. LMI demonstrates an improved approach that makes these adjustments. (2) The LSC model version 2.2 closely approximates requirements calculated using the Air Force D041 system. However, the model is very sensitive to the accuracy of input variables such as Mean Time Between Removal – variables that have significant uncertainty. Procedures used to estimate subcomponent requirements have not been validated. An approach is suggested to improve the subcomponent estimates.

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PREFACE

Task PA103 evaluates the methodologies used by OSD and the Services to estimate Initial Spares and Support Equipment requirements for major new weapon systems. The research document presents the findings from our review and evaluation of OSD and Air Force methodologies used to estimate Initial Spares. Separate documents will report on Navy and Army methods for Initial Spares and for methodologies used by all Services to estimate Support Equipment.

LMI

Executive Summary

AN EVALUATION OF MACRO METHODOLOGIES USED BY OSD AND THE UNITED STATES AIR FORCE TO ESTIMATE ACQUISITION SUPPORT FUNDING FOR NEW AIRCRAFT SYSTEMS

Both DoD's 5000 series acquisition management documents and Office of Management and Budget's Circular A-109 clearly establish life-cycle cost as a criterion on which all major acquisition program milestone decisions are to be based. As a result of this requirement, projections of the logistics investment necessary to support new weapon systems are needed very early in the acquisition cycle – a time when there is considerable uncertainty about the final equipment configuration, about many operating and support policies, and about the subsequent spares consumption rate. Macro estimating methods must be used at this time because detailed data are not available to run the conventional estimating models that are used to develop spares budgets. Because such early estimates must be made using fragmentary data, they are subject to considerable uncertainty. Even so, historically the divergence among logistics support estimates has been so large and so difficult to explain as to cast doubt on the credibility of these macro estimating tools. As a result, the Defense Acquisition Board has come to question logistics support investment estimates as reasonable bases for decisions.

The Assistant Secretary of Defense (ASD) (Program Analysis and Evaluation) requested that Logistics Management Institute (LMI) review the methodologies used by the OSD Cost Analysis Improvement Group (CAIG) and by Service program managers and independent cost analysis teams to estimate acquisition logistics funding requirements for new aircraft systems. The goals of this study are (1) to determine how realistic these macro estimates have been when compared to actual requirements and (2) to recommend modification to these macro methods if required. This report provides the results of our study of the macro methods used by OSD and the Air Force to estimate Initial Spares.

The two macro methods used most commonly to estimate Initial Spares are factors based on a percentage of recurring flyaway cost and a more detailed build-up method based on engineering estimates of aircraft components known as the Logistics Support Cost (LSC) model. Each method has useful aspects, but both need improvement.

Factor-based approaches to projecting Initial Spares funding requirements suffer from three empirical problems.

- In 1985, OSD changed and expanded the definition of the term Initial Spares to include initial stockage requirements for new weapon systems that previously had been bought from the Replenishment Spares budget category. Pre-1985 data cannot be used as a base for projection factors without adjustment for this significant policy shift. For the Air Force, this change dramatically reduced the availability of historical data that could be used for factor development, because the initial stockage requirements bought in the Replenishment Spares budget cannot be separated from normal replenishment activity in the pre-1985 spares expenditure data.

- While it is easy to estimate an appropriate investment in spares inventory and to calculate component flyaway cost consistent with the flight configuration and spares consumption of an existing aircraft, this version of the aircraft may differ significantly from the original equipment configuration contemplated at the time the spares inventory was acquired and may also differ from the original flyaway cost. Onboard aircraft equipment is in constant transition, and the Air Force does not completely update the aircraft flyaway cost for each configuration change. Thus, the validity of using percent-of-flyaway factors cannot be checked without being able to normalize the configuration. When estimating spares funding requirements for new aircraft, it seems clear that this normalization cannot readily be achieved at the flyaway vehicle level because the costs of major subsystems change over time. Instead, we suggest that the cost of major aircraft subsystem configurations – airframe components, propulsion, and avionics – be tracked separately and separate investment spares factors be developed for each. This would remove a major impediment to estimating investment spares as a function of flyaway cost for aircraft with extensive onboard avionics.

- Regardless of the base used to derive factors, Initial Spares factors must be adjusted for differences in the operating tempo; the system level reliability; and the relative changes in costs of engine, avionics, and other aircraft components. Without these adjustments, the use of Initial Spares factors obtained from an existing weapon system can introduce estimating errors of over 100 percent into the analysis. We outline an approach to make these adjustments that can be verified and is consistent with the methods used by the Air Force to prepare budgets for follow-on procurement of prime mission equipment and spares. This approach makes use of LMI's Aircraft Availability Model to derive Initial Spares factors that match present aircraft configuration characteristics adjusted for the assumed performance and spares consumption values planned for the new aircraft. Such adjusted Initial Spares factors can then be used to evaluate estimated aircraft Initial Spares for new aircraft using the same configuration and performance assumptions.

The LSC model emulates the logistics support system required for an Air Force weapon system. While using this model requires much more information than using the factors approach, it still requires much less data than does the Air Force budget model for spares. The parameters that drive the separate elements of the LSC model are adjustable to account for differences in operating tempo, reliability, and the onboard equipment configuration of the new weapon system.

- Unlike previous versions of the LSC model that were found to underestimate Initial Spares requirements by almost 20 percent, LMI found that LSC Version 2.2 comes within 3 percent of the actual computations from the Air Force budget model when the same data are used in both models.
- The accuracy of the LSC model can be judged only when a full set of line replaceable units (LRUs) and shop replaceable units (SRUs) becomes available. When SRU data are unavailable, the accuracy of the LSC model depends on using a set of adjustment factors for each two-digit work unit code to approximate the additional spares investment needed for SRUs. Each SRU factor is based on, at most, four data points. Many SRU factors have not been verified empirically, and most are assumed to have the value of 1.0. Existing Air Force data bases identify the hierarchical relationship between components removed from an aircraft, the LRUs, and their sub-components, or SRUs. LMI suggests that the Air Force exploit this hierarchical relationship to calculate SRU factors for both spares and depot maintenance. We see two advantages to this approach: (1) the SRU factors will be more representative because of the significantly increased sample size and (2) standard descriptive statistics will be available to assist in evaluating the uncertainty in the overall spares estimate.

Both the factors approach and the LSC model are dependent on realistic estimates of certain key input parameters. Based on past experience, the most difficult variable to estimate is the frequency of removal of items for maintenance. Uncertainty in removal rate parameters affects requirements for base level maintenance manpower and maintenance materials, depot maintenance repair, support equipment and automatic test equipment, and both Initial and

Replenishment Spares. To help identify unrealistic reliability assumptions, we suggest a simple exhibit that: (1) compares actual reliability from fielded equipment with both the reliability goal for the new aircraft and the reliability levels assumed in the acquisition program cost estimate and (2) requires a description of the design and engineering differences that explains significant improvements in reliability over current field reliability levels.

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CHAPTER 1

INTRODUCTION

BACKGROUND

In order to field combat-capable weapon systems, it is essential that sufficient quantities of spares be acquired. Without spares, sophisticated avionics-intensive aircraft systems are transformed into static displays waiting for broken parts to be repaired. Preliminary estimates of the capital investment required to buy initially this inventory of spares must be developed and incorporated into the weapon system program cost estimates 5 to 10 years before the spares are needed.

While final capital investment requirements for weapon system spares will be determined by detailed, item-specific, computational models, such data are not available to run these models when the preliminary Initial Spares estimates must be made to support major acquisition program milestone decisions. Early in the acquisition program, the Services and OSD must rely on broad-gauge macro methods to develop and review weapon system cost estimates as part of the Defense Acquisition Board's (DAB's) review of the affordability of a new weapon system. Frequently, these same methods also are used by the Services to prepare the program objective memorandum (POM) and Service budget estimates, directly affecting the initial support of new weapon systems for up to 5 years by placing financial bounds on the spares that can be provisioned.

When DoD changed its definition of Initial Spares in 1985, the amount of Initial Spares was nearly doubled by linking millions of dollars of spares investment requirements to a weapon system that had been previously "invisible" to DAB reviews and congressional oversight. The increased size of the spares requirement also highlighted the macro methods used to prepare these preliminary estimates. At the same time, the new definition made historical accounting data virtually useless as a source to develop or validate these macro methods because the historical data could not be restructured to meet the new definition.

Within the Air Force and OSD, two macro methodologies are commonly used to estimate aircraft Initial Spares. The first approach is a cost factor based on the percent of the recurring flyaway cost. This approach calculates a factor based on the relationship of Initial Spares cost to recurring flyaway cost for a past acquisition program. Then, to estimate Initial Spares for a new weapon system, this factor is applied to its estimated recurring flyaway cost.

This factor methodology can be applied early during the weapon system acquisition and development phase when the only information available is its estimated flyaway cost. While simple to use, critics argue that the factor methodology is insensitive to design and operational characteristics specific to the new weapon system.

After the aircraft becomes more clearly defined, the Air Force uses a more detailed estimating methodology, the Logistics Support Cost (LSC) model,[1] to build up a spares estimate based on the equipment components installed on the airframe. While this approach explicitly considers the design and operational considerations missed by the factor methodology, it too has limitations: (1) The full set of data required to run the LSC model generally is not available until late in the acquisition cycle (i.e., milestone IIIB) and (2) The model does not use the same algorithms as do the approved models that will be used after the weapon system has been fielded and actual field data become available.

In view of the significantly expanded role these macro methodologies play in making weapon system acquisition decisions and in establishing initial levels of support, the Assistant Secretary of Defense (Program Analysis and Evaluation) [ASD(PA&E)] requested Logistics Management Institute (LMI) to review the macro methodologies used by OSD and the Services. LMI set out to determine if currently used macro methods provide realistic estimates of funding levels that will meet specified operational requirements and support objectives and, if not, to recommend new approaches.

SCOPE OF RESEARCH

Our research was limited to an investigation of the macro methods used to prepare preliminary estimates of Initial Spares and Support Equipment funding

[1]The Air Force has two LSC models. One LSC model is used to support weapon system design tradeoff studies. The other model, the subject of this research project, it used to prepare weapon system Operating and Support cost estimates. It is distributed by the Headquarters Air Force Logistics Command Financial Management organization.

requirements used through the DAB milestone IIIB full-rate-production decision point. This report summarizes the study of macro methods used by OSD and the Air Force to estimate Initial Spares. Specific emphasis was placed on identifying valid macro methodologies that could be used by ASD(PA&E) to cross-check Service estimates for reasonableness.

RESEARCH APPROACH

Early in this effort, we decided it would not be meaningful to evaluate these macro methods by comparing the actual estimates for Initial Spares used during the DAB milestone process with the actual cost of spares bought during the deployment phase. Changes in maintenance concepts, new procedures for calculating spares, revised operating tempos, etc., have all changed the level of spares needed to support a fleet of aircraft. Inst[illegible], our approach normalizes all these changes by focusing on fielded weapon systems as configured and operated today and the spares calculated using the current inventory policies and algorithms.

The research approach is straightforward. Some adjustments were made to accommodate requirements of specific methods, but these are explained later.

- *Step One. Develop Initial Spares baselines (ISB) for fielded weapon systems.* Identify the total investment in spares needed to support selected weapon systems at actual operating tempos and levels of availability. The total investment was developed, as closely as possible, to the item-specific computational procedures and data that are used by the Air Force to calculate spares budgets. From these total requirements, only those requirements that are consistent with the 1985 definition of Initial Spares, as implemented by the Air Force, were included in the ISB for each weapon system. Other than reviewing and correcting obvious data anomalies, these baselines represent the calculated requirement without the influence of any management review. Each weapon system ISB is predicated on the current weapon system configuration and reflects the planned operating tempos, basing concept, and maintenance policies planned for FY92.

- *Step Two. Develop Initial Spares estimates with macro methodologies.* Estimate Initial Spares requirements for the weapon systems as currently configured and operated using existing Service methodologies.

- *Step Three. Compare baselines with estimates.* Compare these estimates developed using Service and OSD macro methodologies with results from step one to identify how well the macro estimating methodologies approximate the ISB.

- *Step Four. Evaluate weak macro methodologies.* Review methodologies that significantly over- or underestimate the ISB and make recommendations on how to improve them.

OVERVIEW OF REPORT

Chapters 2 and 3 set the stage for assessing the adequacy of the macro methods used by the Services and OSD. Chapter 2 reviews the function that inventories play in supporting weapon system combat capability and identifies major cost drivers that affect the magnitude of the capital investment needed to stock this inventory.

Chapter 3 relates these initial stockage requirements to the budget categories used to finance the acquisition of the initial stockage requirements. Only one category, Initial Spares, is included in the weapon system acquisition program budget. Chapter 3 presents the current definition for the Initial Spare budget category. This is important for three reasons:

- In 1985, OSD changed the definition of Initial Spares used for weapon system budgeting and Selected Acquisition Reporting (SAR) to Congress.
- Since OSD changed the definition in 1985, the Air Force has made refinements to the categories of items included in Initial Spares.
- While performing this research, we found confusion existed over the terms initial provisioning, initial support, and Initial Spares.

By changing the definition of Initial Spares, OSD also increased the importance of and reliance on the use of macro methods to prepare estimates for the DAB and for Congress. Chapter 3 also examines the changing role of macro methodologies in preparing weapon system cost estimates before and after the new definition and highlights the methodology problems the new definition has caused the Air Force.

Using the material presented in Chapters 2 and 3 as a frame of reference, Chapter 4 evaluates the two macro methods most commonly used by OSD, the Service's Program Offices, and the independent cost analysis (ICA) teams to develop early estimates of Initial Spares funding requirements. Chapter 5 summarizes the major observations and outlines alternatives to improve the macro procedures used to estimate Initial Spares. The appendices tabulate the detailed ISB's and the operations and maintenance data collected on each weapon system.

CHAPTER 2

INVENTORY REQUIREMENTS FOR NEW WEAPON SYSTEMS

By estimating the funding requirements for a weapon system's Initial Spares, DoD planners are essentially developing estimates of the capital investment needed to acquire the spares inventory necessary to support that new system. Fundamentally, their questions are the same as most businesses: "How big should inventories be?"[1] and "How do we finance this capital investment?" This chapter sets the stage for the analytical chapters that follow, by reviewing the purpose of inventories and identifying the key cost drivers that must be considered when estimating the initial stockage investment.

FUNCTIONS OF INVENTORY

Most business textbooks on inventory theory agree that the primary purpose of any inventory is to "... *decouple* successive stages in the production-distribution-consumption chain."[2] There are two aspects to this *decoupling*. First, inventories are necessary because it takes time to complete repairs and move the item from one location to another. Second, inventories allow two or more organizations to operate more or less independently of each other.[3] Inventory has the same decoupling effects within DoD.

In terms of aircraft operations within the Air Force, inventories allow operations to schedule aircraft sorties relatively independent of the scheduling of the repair of broken parts on the aircraft. Without a spare part, when a component fails, the entire airplane becomes unavailable to operational planners until maintenance

[1]Magee, John F., and David M. Boodman. *Production Planning and Inventory Control.* New York: McGraw-Hill, 1967, p. 6.

[2]Budnick, Frank S., Richard Mojena, and Thomas E. Vollmann. *Principles of Operations Research for Management.* Homewood, Illinois: Robert D. Irwin, Inc., 1977, p. 389.

[3]Magee 1967, p. 20.

schedules the repair, completes the repair, and reinstalls the repaired part on the "down" aircraft.[4]

With adequate inventory levels, aircraft downtime is limited to the time needed to isolate the failed component, remove that part, requisition a serviceable replacement from the inventory, install the good component on the aircraft, and verify that the "remove and replace" action fixed the problem. The aircraft can then be scheduled for operational sorties and the maintenance schedulers can schedule the repair of the failed component. One can easily see the important role that inventory levels have in the concept of "sparing to availability"[5] – without spares, failures reduce the time an aircraft is available to perform its missions.

HOW MUCH INVENTORY IS ENOUGH?

Conceptually, on-hand inventory should equal the number of expected demands for an item during the time it takes to replace or repair the item and return it to the inventory plus an operating level that protects against variations in either expected demands or repair times. In practice, this calculation is very complicated because:

- Inventories must be established for thousands of different items. An old saying in the logistics community reflects the magnitude of the task: "An airplane is a collection of 30,000 national stock numbers flying in close formation."
- Multiple operating locations are usually physically dispersed.
- Multiple echelons of repair exist, each with its own repair capabilities and repair times.
- Items removed from the aircraft may contain subcomponents that may have to be replaced. These subassemblies require spares.
- Inventories may be replenished by either repair or procurement actions.
- Failure rates and repair times are not known with certainty.

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[4]There are work arounds that maximize aircraft availability when spare parts are unavailable: maintenance crews "borrow" items from spares pools reserved to support wartime operation or they cannibalize items from other aircraft.

[5]Sparing to availability is the term generally applied to models that compute stockage levels required to support peacetime and wartime readiness levels. From *Integrated Logistics Support Guide*, published by Defense System Management College, May 1986.

The real-world complexities of multi-echelon, multi-indenture inventory models are not needed to understand what factors affect the size of the inventory of spares needed to support complex modern weapon systems. The simple model discussed below illustrates the factors that must be considered.

A SIMPLE SPARES MODEL

Assume a situation where (1) all operations are flown from one base, (2) only one part on the airplane will break, and (3) all repairs are made at this same base. Further assume that items fail and are removed from an airplane at a rate of one per day and it takes 10 days to repair each item. Figure 2-1 illustrates this simple model.

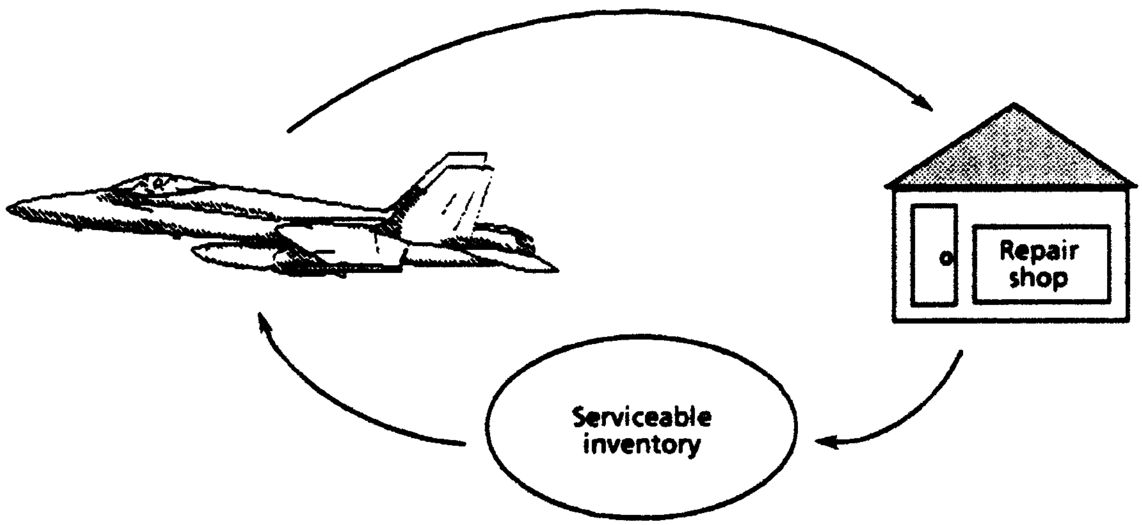

FIG. 2-1. TYPICAL REPAIR CYCLE

Pipeline Requirements

After 10 days of operations, 10 items have been removed from the aircraft and sent to the maintenance shop for repair. To keep the aircraft flying, 10 items also have been withdrawn from the inventory and installed on the aircraft. If initial inventory stockage was 10 items, at this point there are no more serviceable components to replace tomorrow's removals. However, maintenance is expected to complete repairs today on the item removed on day 1, and that repaired item can be used to fill the requisition for tomorrow's removal. If, however, initial stockage had been 8 items instead of 10, the airplane would be grounded after day 8 for 2 days while maintenance repaired the item removed on the first day. For aircraft, the pipeline is approximately half of the spares investment.

Clearly, sufficient inventory is needed to cover expected demands until the flow of repaired items from the repair process begins to keep up with the demands. Inventory analysts refer to this inventory requirement as "filling the pipeline" or just "pipeline requirements." Other spares inventories are needed to effectively decouple maintenance repair shops from the flightline.

Safety Stocks

Unfortunately, removals cannot be scheduled so that exactly one removal occurs every day. The average may be one, but some days no items may be removed, other days it may be four. Repair times also fluctuate: test equipment may be broken, personnel with the needed skills may be on leave or sick, there may be no replacement for the airman who just departed for his new assignment, or parts needed to repair the items are not in stock. Because of these variations, additional items referred to as "safety levels" are procured to add a measure of protection against having serviceable components unavailable when needed.[6] Figure 2-2, taken from an output of the Air Force Aircraft Availability Model (AAM), shows the impact on availability of changes in the size of the spares inventory. Increased levels of safety stocks provides more availability. Investments in safety level are approximately 30 to 40 percent of the total spares investment.

Other Requirements for Spares

Not all requirements for spares will be based on demands. Management usually considers it prudent to buy some "insurance" items just in case, for example, a fuel truck backs into a wing and damages a strut. Other "special" requirements may be needed because of special circumstances.[7] These requirements account for 10 to 20 percent of the total investment in spares inventory.

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[6]The Services use mathematical models such as the Air Force Aircraft Availability Model (AAM) or the Army Selected Essential Item Stockage for Availability method (SESAME) model to calculate the range and depth of items needed to reasonably assure that a specified number of aircraft are available for operational missions. AAM is discussed in detail in Appendix A.

[7]For example, the Military Airlift Command must buy additional spares to provide enroute support for its airlift aircraft operating world-wide.

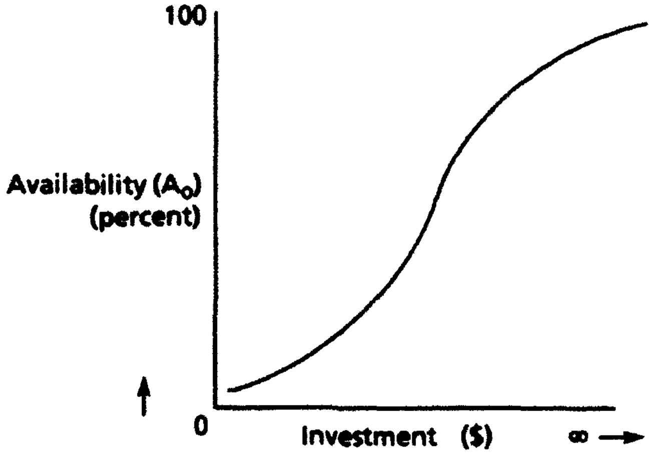

FIG. 2-2. INVENTORY INVESTMENTS VERSUS AVAILABILITY

To summarize, this simple spares example illustrates that three factors affect the size of the capital investment needed to procure sufficient inventory levels to support planned aircraft operations:

- How rapidly demands will be generated. The more demands for the item per unit of time, the larger the inventory of pipeline spares that is required.
- How long it takes to replenish the inventory. The longer it takes to repair or replace a broken item, the larger the inventory of pipeline spares needed.
- How much uncertainty exists in the first two factors. The more uncertainty and variation in demands and repair times, the larger inventory level required to meet a specific availability goal.

In the next two sections, we discuss the factors that affect the number of demands and repair times.

FACTORS AFFECTING THE DEMAND FOR SPARE PARTS

Demands for spare parts usually occur when an item fails and must be removed from the aircraft for repair. In models used to calculate spares requirements, removals are assumed to occur as a function of how much time an item is used. With most aircraft systems, units of time are measured as flying hours. In these models, flying hour changes produce proportional changes in the number of removals.

Peacetime flying hours change as the result of policy changes or in response to budgetary changes. The rates at which parts are removed per flying hour are affected by three factors:

- The inherent reliability of the item
- The incidence of secondary damage, e.g., a flight data computer may become damaged if its cooling unit fails
- The level of maintenance efficiency, e.g., being able to isolate the failure to the correct item – a major problem when 25 to 35 percent of the digital avionics boxes removed from aircraft are found to have been serviceable when checked on automatic test equipment.[8]

FACTORS THAT AFFECT REPAIR TIMES

Many factors affect the length of repair cycles: the nature and extent of the failure, availability of sub-components and piece parts needed to fix the fielded item, availability of accurate repair instructions and support equipment, and the availability of personnel with the right skills and training. As a composite proxy for these factors, we will look at two variables, depot repair cycle time (DRCT) and base repair cycle time (BRCT), to determine how sensitive the total spares inventory is to changes in these variables.

If an item is damaged beyond economic repair and has been condemned, a new item is bought to replace it. When this occurs, the time required to replenish the inventory will be the amount of time it takes to make the determination that the item cannot be repaired plus the procurement lead time (PLT).

THE MAJOR COST DRIVERS

Clearly, many factors affect the magnitude of the capital investment needed for initial stockage. Macro models used to estimate the funding requirements should be sensitive to the most important factors. In the remainder of this chapter, we identify the factors with the most significant impact on funding requirements for spares. These cost drivers will be used to evaluate the macro models used by OSD and the Air Force to estimate funding requirements for a new aircraft.

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[8]Data provided by F-16 System Program Office indicate that for some avionics items, the rate exceeds 50 percent.

Approach

The factors that affect spares demand and repair time are evaluated by looking at the changes in the value of the spares inventory when the factors are changed by predetermined amounts. Elasticity ratios were calculated by dividing the percent change in the spares inventory by the percent change in the factor variable. Thus, an elasticity ratio of 1.0 would indicate that the spares inventory changed the same percentage as the factor variable.

To calculate these elasticity ratios, we used the LSC model version 2.2. and a data base[9] of representative items that was used to validate this model. By utilizing the sensitivity analysis feature of this model, we could change inputs to the model and observe the change in the total spares requirement calculated by the model.

Findings

We found three parameters for which a 10 percent change in the input parameter produced at least a 6 percent change in the spares investment: the flying hour program, the mean time between removals (MTBR) (i.e., the reciprocal of the removal rate), and the DRCT (the time required to repair the item at the depot). In addition, we added unit cost to the list of cost drivers because simple algebra will show that if all prices are increased 10 percent, the cost of the spares inventory will increase 10 percent. Table 2-1 summarizes the results of these sensitivity excursions.

The BRCT and the procurement lead time parameters were not significant cost drivers. While more items are repaired at base level, the repair cycle is much shorter than the depot repair cycle. Consequently, when the base repair cycle is changed 10 percent from the nominal values in the test data set, the total spares requirement only changes 1.3 percent. Similarly, while procurement lead time is much longer than the depot repair cycle, the condemnation rate for the expensive line replaceable units (LRUs) is usually very low.

UNCERTAINTY IN ESTIMATES OF THE COST DRIVERS

The remainder of this chapter examines in more detail the uncertainty in the top three variables affecting the requirement for spares. These top three cost drivers

[9]Elasticity ratios depend on the initial values of each variable. To develop elasticity ratios that reflect current Air Force logistics practices, we used the same representative mix of equipment items that was used to validate the LSC model. Chapter 4 describes the data used in more detail.

TABLE 2-1

IMPACT ON TOTAL INITIAL SPARES OF A 10 PERCENT CHANGE IN THE NOMINAL VALUE OF THE LSC MODEL INPUT PARAMETERS

Parameter	Elasticity ratio
Unit cost	1.00
MTBR	0.91
Flying hours	0.85
DRCT	0.61
BRCT	0.13
PLT	0.1 – 0.3[a]

[a] The LSC model does not have a sensitivity analysis option for this variable. Instead, we looked at AAM outputs for a wide range of aircraft documented in the appendices to this report and calculated the percent change in total spares if the condemnation pipeline were increased 10 percent.

will be used in Chapter 4 to evaluate the methods used by the Services to estimate funding levels for new weapon systems.

- *Unit cost.* Of the three cost drivers, total spares investment is the most sensitive to changes in this variable. We believe that traditional cost analysis methods of evaluation are sufficient to judge the uncertainty contained in this parameter, particularly as the new system approaches the full-rate production milestone.

- *Flying hour program.* As already discussed, once established, the peacetime flying hour program for an aircraft seems to change because of exogenous factors. Table 2-2 illustrates that flying hour programs vary among aircraft with essentially the same missions. The C-17A is programmed to fly at over three times the C-5A flying hour rate. The implication is that if spares are based on analogous historical weapon systems with significantly different operating tempos (OPTEMPOs), the flying hour differences could introduce significant errors into the analysis because a different amount of spares is needed to support different OPTEMPOs.

- *Removal rates.* Unfortunately, demands for parts removed from aircraft are not only high cost drivers, but they are also difficult to reliably estimate and are subject to large variations over time.

TABLE 2-2

TYPICAL ANNUAL FLYING HOUR PROGRAMS

Aircraft	Hours/PAA
C-5A	456
C-5B	696
C-141B	1,049
C-17A	1,432

Sources: Air Force Recoverable Consumption Item Requirement System (D041) program data and C-17 operating and support cost estimate.

Note: PAA = primary aircraft authorization.

Experience has shown that reliability predictions made during the equipment design phase have correlated poorly with field results.[10] Unfortunately, the close relationship between the removal rate and the inherent failure rate implies that uncertainty in predicting the failure rate will also be applicable to estimates of the removal rate. Table 2-3 shows a comparison of the MTBR and the mean time between maintenance required for inherent failures MTBM(I). The ratio MTBR/MTBM(I) was remarkably consistent across all weapon systems. This same ratio held for peacetime operations as well as the Operation Desert Shield/Desert Storm experience when the airlift aircraft were operated at high OPTEMPOs for 6 months.

Adding to the uncertainty of estimating the mean removal rate of a new equipment item is that actual data for fielded parts vary significantly over time. A recent RAND note[11] found that over a 4-year period, demand rates for items varied by plus or minus 50 percent or more for at least 30 percent of the items in each of the four groups studied: F-4 items, F-15 items, F-16 items, and items in Air Force System management code 999 that include items common to a wide spectrum of weapon systems. While this is a new study, the wide variations in demand rates for individual components have been known for years.

[10]Wrisley, Russ, et al. *Reliability and Maintainability Operational Parameter Translation II.* IIT Research Institute RADC-TR-89-299 Vol. 1. December 1989, pp. 1–3.

[11]Lippiatt, Thomas F. *Variability in the Budget Forecasts for Depot-Level Component Repair.* RAND N-2390-P&L. January 1991, pp. 13 – 17.

TABLE 2-3

COMPARISON OF MTBM(I) AND MTBR
FOR FIELDED AIRCRAFT SYSTEMS

Aircraft system	MTBM(I)	MTBR	MTBR/MTBM(I)
C-5A	0.49	0.68	1.39
DS/DS	2.19	3.01	1.37
C-5B	1.16	1.64	1.41
DS/DS	4.33	6.02	1.39
KC10	2.81	3.21	1.14
DS/DS	7.78	8.85	1.14
C-141B	1.46	1.93	1.32
DS/DS	3.70	4.76	1.29
B-1B	1.23	1.51	1.23
A-10	3.32	3.43	1.03
DS/DS	6.24	7.08	1.13
A-7D/K	2.35	2.81	1.20
DS/DS	2.71	3.31	1.22
F-16A	2.57	2.50[a]	0.97
DS/DS	2.93	2.84	0.97
F-16C	3.54	3.65	1.03
DS/DS	4.88	5.32	1.09
F-15A	1.70	1.72	1.01
DS/DS	1.79	1.86	1.04
F-15C	2.07	2.11	1.02
DS/DS	4.13	4.36	1.06
F-15E	2.73	2.99	1.10
DS/DS	3.67	4.79	1.31
F-111E	1.44	1.64	1.14
DS/DS	1.93	2.78	1.44

Source: Air Force Maintenance and Operating Data Access System.

Note: DS/DS = Desert Shield/Desert Storm.

[a] If an item is removed and later found to be serviceable, it will count as a removal but not as a failure. Quick turn arounds for fighter aircraft sometimes force maintenance crews to remove all black boxes within an ambiguity group. This practice also causes more removals than failures.

SUMMARY

In this chapter, we reviewed the functions of inventory and identified three cost drivers that affect the size of the investment needed to initially stock that inventory. One cost driver, the MTBR, is difficult to accurately forecast even for fielded equipment items and must be considered as a significant source of uncertainty in any estimate based on this parameter. In the next chapter, we translate initial stockage requirements into budget terminology to understand how DoD budgets for the capital investment in spares inventory.

CHAPTER 3

HOW DoD FUNDS INITIAL STOCKAGE REQUIREMENTS FOR NEW AIRCRAFT WEAPON SYSTEMS

DoD must budget enough money to fund initial stockage requirements and budget enough money each year to replace worn out assets. Within DoD, each Service has two budget accounts to finance the initial acquisition and replacement requirements: (1) Initial Spares and (2) Replenishment Spares.[1] While the titles of these accounts are deceptively similar to the functions of initial stocking and replacing, there is not a one-to-one relationship. For example, DoD policy places all requirements (both initial stockage and replacements) for whole engines in the Initial Spares budget, procures all war reserve material (WRM) (both initial stockage and replacements) from the Replenishment Spares budget, and obtains some replacement items from the Initial Spares budget. Detailed accounting rules determine whether a particular inventory requirement is financed from the Initial Spares or the Replenishment Spares budget category.

In this chapter, we focus on the way that DoD translates an aircraft's total requirement for spares into the aircraft acquisition budget for Initial Spares. In 1985, significant policy changes occurred that changed the rules DoD uses to budget for initial stockage requirements. This chapter first describes how initial stockage requirements were financed prior to 1985, then discusses how DoD changed these arrangements, and then explains how the Air Force implemented these changes. Finally, this chapter presents the significant effects these budget changes had on the cost analysis function throughout DoD.

INITIAL STOCKAGE FINANCING PRIOR TO 1985

Prior to 1985, the Services used a variety of budget accounts to fund initial stockage requirements. The two most commonly used were (1) Initial Spares and (2) Replenishment Spares. Of the total initial stockage requirements, only the

[1] Recent decisions to stock fund depot level repair of components have moved most of the requirements for this budget account into other areas of the budget. Since the focus of this study is on the Initial Spares funding, we will continue to use the term Replenishment Spares to collectively refer to spares requirements not financed with the Initial Spares budget account.

funding for the Initial Spares budgetary account was included in the weapon system acquisition program[2] cost estimate reviewed by the DAB and provided to Congress. Even for this one category, the Services did not use the same definition of Initial Spares to prepare their budgets. Some Services included nearly all initial stockage requirements in the weapon system SAR, while others only included the initial stockage spares for a specified period of time. For items other than whole engines,[3] initial stockage spares acquired after that initial support period were not reported in the weapon system SAR, nor were they included in the weapon system cost baselines subject to Nunn-McCurdy ceilings.[4]

The Air Force Initial Spares budget primarily included engine requirements and those spares needed to support the aircraft delivered during an initial support period (usually defined to be the first 2 years after the first operational aircraft is delivered). After the initial support period, the Initial Spares budget for a new weapon system was used only to fund (1) the procurement of whole engines and whole engine modules and (2) the initial stockage requirements for new components introduced after the initial support period.

THE NEW DEFINITION OF INITIAL SPARES

In an effort to standardize the definition of Initial Spares used throughout the Department, then-Deputy Secretary of Defense Taft signed in 1985, a memorandum that changed the budgetary definition of Initial Spares used throughout DoD. Each Service was to use this new definition for programming and budgeting as well as for Selected Acquisition Reporting provided to Congress:

> Initial spare parts will include those reparable components, assemblies, or subassemblies required as initial stockage at all levels including the pipeline in support of newly fielded end items.[5]

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[2]Initial stockage requirements contained in the Replenishment Spares accounts are included in the life-cycle cost estimate but are included in the operations and support segment of the estimate.

[3]Whole engines are defined as an end item. As such, procurement of whole spare engines is always funded with Initial Spares (IS) funds. The new IS definition had no impact on funding for whole engines.

[4]A reporting requirement for major acquisition programs to help control cost overruns and production delays.

[5]Memorandum for Secretaries of the Military Department. From William H. Taft, IV, Deputy Secretary of Defense. Subject: *New Budget Definition for Initial Spare Parts*. 28 March 1985.

The intent of this new definition was to strengthen DoD's credibility with Congress and the press by providing total visibility of the entire spares investment associated with aircraft acquisition decisions.[6] Although the change did not increase the total cost of a weapon system, by moving additional millions of dollars of requirements from the Replenishment Spares budget into the weapon system acquisition program budget, the new definition brought these previously "invisible" costs into the spotlight of DAB reviews and congressional oversight.

These changes had both intended and unintended consequences. In the following sections, we summarize how the Air Force implemented the new definition and what problems these changes have caused the cost analysis community.

HOW THE AIR FORCE IMPLEMENTED THE NEW DEFINITION

This definition change dramatically affected the way the Air Force viewed Initial Spares. With the old definition, initial stockage required to support aircraft delivered after the initial support period was procured with Replenishment Spares monies (for aircraft acquisitions, this is Air Force Appropriation 3010, Budget Program 1500, or simply BP15). Expenditures for the Replenishment Spares budget program were not reported in the weapon system SAR. The new definition merged some of the initial stockage requirements previously funded with Replenishment Spares monies into Initial Spares funding where it became visible in the weapon system SAR provided to Congress.

To accomplish this funding transfer, the Air Force continues to calculate spares requirements in the same manner as they did before the change, but the resulting spares "buy" requirement[7] is now prorated between the Initial Spares and Replenishment Spares budget programs. New Acquisition Spares, the portion of the buy requirement that is prorated to Initial Spares, is calculated as a simple percentage of the buy requirement for each item based on the number of new aircraft delivered that year as a percentage of the cumulative number of aircraft delivered through the end of that year. Adding New Acquisition Spares to the old definition of

[6]This definition applies only to investment items (i.e., reparable items). Additional investments for consumable parts (i.e., throwaway items) are not included in this definition.

[7]The buy requirement is the difference between the projected numbers of items required and the projected number of on-hand assets.

Initial Spares approximates the investment needed for the initial stockage requirement.

As originally implemented, New Acquisition Spares were calculated only for items peculiar to a new weapon system.[8] If a component on a new aircraft system was used on another Air Force weapon system, the item was considered to be a "common item" and New Acquisition Spares were not calculated. Over time, the Air Force has gradually refined its own definition of New Acquisition Spares.[9] Table 3-1 summarizes the categories of spares that the Air Force includes in its definition of Initial Spares and indicates changes from the definition used prior to 1985. This definition is used throughout our study to build Initial Spares baselines (ISBs) for selected aircraft.

COST ANALYSIS IMPLICATIONS OF THE NEW DEFINITION OF INITIAL SPARES

From a cost analysis perspective, the new definition of Initial Spares had other consequences.

A New Definition Emphasizes Macro Methodologies

With the migration of millions of dollars from the Replenishment Spares budget into Initial Spares, the percent of the Initial Spares estimate based on macro models grew significantly.

Prior to the change in definition, most of the Initial Spares funding requirements reviewed by the DAB and reported to Congress in the SAR were for whole spare engines and modules. Those estimates were obtained using approved models with inputs based on engineering estimates. Then, the accuracy of the macro methodologies was not of overriding importance since they essentially put a planning wedge in the budget only big enough to support operations over a very limited time. Because of the extended duration of most aircraft delivery schedules, the final range and depth determinations for final initial stockage requirements were still developed

[8]HQ AFLC/MMMI Memorandum for Record, Subject: *New Acquisition Spares*, 27 June 1988.

[9]In LMI Report AF601R3, *Estimating Initial Spares Funding Levels*, by Craig C. Sherbrooke, and, Virginia A. Mattern, October 1987, policy decisions were discussed indicating that changes were being considered that would include common items and condemnations in the definition of Initial Spares.

TABLE 3-1

IMPACT OF INITIAL SPARES DEFINITION CHANGE

Requirement type	Definition	Initial support period	Beyond initial support period
Peacetime operating stocks (POS)			
Whole engines	New Old	IS IS	IS IS
Peculiar components	New Old	IS IS	IS RS
Common components	New Old	IS RS	IS RS
Condemnations (2 years for each delivered aircraft)	New Old	IS IS	IS RS
New items introduced after initial support period	New Old	IS IS	IS RS[a]
War Reserve Material (WRM)			
Whole engines/engine modules	New Old	IS IS	IS IS
Components[b]	New Old	RS RS	RS RS

Note: IS = Initial Spares, RS = Replenishment Spares.

[a] Additional pipeline beyond 2 years after a new item has been introduced.

[b] Starting in FY93, readiness requirements will be funded in Initial Spares.

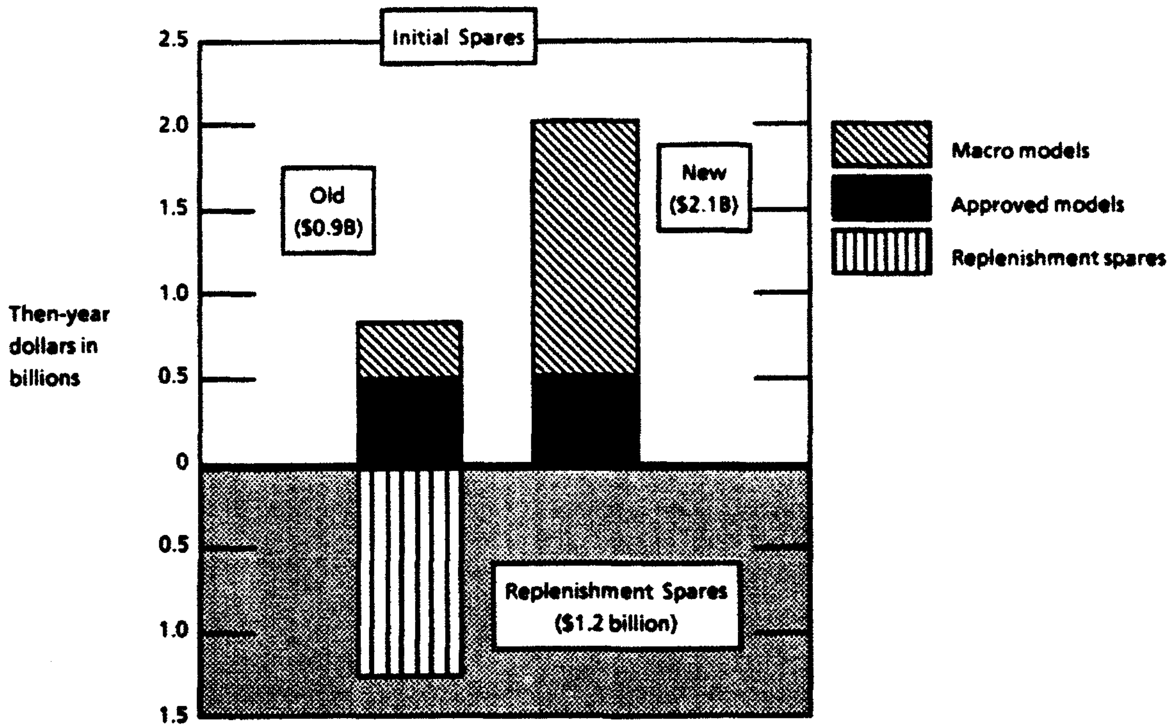
using approved budget models such as the D041 and funded in the Replenishment Spares budget account.

Now, because of the additional pipeline and other spares requirements included in Initial Spares as a result of the new definition, as much as 72 percent[10] of a significantly larger Initial Spares funding allowance is now derived from macro models that only approximate the D041 system. Figure 3-1 illustrates the effect of this funds migration.[11] Using the old definition, macro methods were used to estimate only one-third of a much smaller Initial Spares allowance. From a budgeting viewpoint, these macro methodologies are used only until the official

[10]Based on preliminary Air Force cost estimate submitted to ASD(PA&E) for the C-17 acquisition program.

[11]Initial Spares data provided by ASD(PA&E) from the FY91 C-17 Program Office Estimate were restructured to conform with the old definition.

spares estimating methodology can be used. However, from an OSD CAIG perspective, the information that the DAB uses to make weapon acquisition decisions is increasingly reliant on these macro methodologies.



Note: The new definition has doubled IS and increased percent of IS estimated with macro methods.

FIG. 3-1. IMPACT OF NEW DEFINITION ON ESTIMATES PRESENTED TO THE DAB

Data Problems Caused by the New Definition

At the same time that the new definition increased the importance of macro methods, it made most historical accounting records virtually useless as a source for developing or validating new factors or models because these old data could not be restructured to match the new definition. Consequently, data are available on only a few of the most recent acquisition programs that used the new definition. This data problem primarily affects factor-based macro methods and is discussed more fully in Chapter 4.

SUMMARY

While the new definition of Initial Spares had no real impact on the total DoD budget, it did draw attention to the accuracy of macro estimating methods by providing better visibility into the total investment cost of new weapons. In the next chapter, we evaluate two macro methodologies used most frequently to prepare Initial Spares estimates for the DAB.

CHAPTER 4

EVALUATION OF MACRO METHODOLOGIES

For all reparable components, (other than whole engines and engine modules).[1] The range and depth requirements and the final budget for initial stockage requirements are calculated using the Air Force Recoverable Consumption Item Requirements System commonly referred to as the "D041."[2] Unfortunately, data needed to run the D041 are not available when initial weapon acquisition decisions must be made.[3] In the meantime, the Air Force uses macro methods to prepare preliminary estimates of nonengine initial stockage funding for new weapon systems. The two most commonly used macro methods are:

- Initial Spares factors methodology (percent of recurring flyaway cost) is the macro method used most frequently to estimate Initial Spares funding for new aircraft systems. This approach looks at what historical aircraft programs spent for Initial Spares, as a percent of recurring flyaway cost, and then uses this percentage (sometimes adjusted) to estimate funding requirements for the new aircraft.

- Later in the acquisition cycle, as more information is learned about the new aircraft design, the Logistics Support Cost (LSC) model[4] (a more detailed, demand-based model) is used to estimate funding requirements for Initial Spares. While it uses engineering estimates for many input parameters, the LSC model does not calculate spares funding the same nor does it require the

[1]For whole engines and engine modules, requirements are computed in accordance with Air Force Regulation 400-1. The same calculations and models are used throughout the weapon system life cycle. However, during the weapon system acquisition, actual engine data are approximated with engineering estimates referred to as "block data" developed for each major new engine being acquired.

[2]Effective FY94, the D041 will also estimate engine modules. Because of stock funding, this will change the timing for financial outlays but will not change the total capitalization requirements for spares.

[3]The D041 is used to estimate spares for items that have accumulated at least 2 years of actual field demand rate history. Because of interim contractor support for selected items, and because of lead times required to prepare budgets, budgets based on D041 computations seldom affect weapon system operations until 5 or 6 years after the first operational aircraft is delivered – well after the weapon system production decision has been made.

[4]The Air Force has two LSC models. One LSC model is used to support weapon system design tradeoff studies. The other model, the subject of this research project, is used to prepare weapon system Operating and Support cost estimates. It is distributed by the Headquarters Air Force Logistics Command Financial Management organization.

same level of detailed data as does the D041. The LSC model has been used primarily by ICA teams as a crosscheck on program office estimates. However, more recently, models like the LSC are now the preferred method for the program office to estimate weapon system Initial Spares funding requirements.[5]

This chapter evaluates these macro methodologies to determine how well they approximate actual D041 computations. First, we discuss the percent-of-flyaway approach. Then, we present the evaluation of the LSC model. Chapter 5 summarizes the findings and suggests alternatives.

INITIAL SPARES PERCENT-OF-FLYAWAY FACTORS

Summary of How Methodology Is Used

Both OSD and the Air Force use the factor methodology. OSD uses data from analogous weapon systems to estimate the acquisition logistics support costs of new weapon systems. Cost factors are developed by individual analysts using the reported expenditures for various acquisition support categories and expressing these costs as a percent of recurring flyaway cost. These cost factors are then used to estimate the new weapon system's Initial Spares funding. For example, one CAIG report used factors derived from the C-5A acquisition program to estimate acquisition support funding for the C-17A aircraft. In this example, the historical C-5A factors were applied without making adjustments for either flying hours or reliability differences.

Within the Air Force, Headquarters, Air Force Logistics Command (AFLC) is responsible for publishing Initial Spares factors. The current set of factors is shown in Table 4-1. These factors exclude spares for whole engines and whole engine modules. Those requirements are computed using procedures detailed in AFR 400-1.

Based on our interview with the AFLC office of primary responsibility (OPR), the factors are intended to be applied to the total recurring flyaway cost delivered in a particular fiscal year. Thus, if 10 aircraft each costing $50 million were delivered in the third year, the aircraft initial spares calculation is $10 \times 50 \times 0.10$. If delivered after the first 3 years, the factor becomes 0.07.

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[5]Assistant Secretary of the Air Force for Cost and Economics message, DTG R021455Z. Subject: *Spares Calculation Methodology for Program Office Estimates (POE) and Independent Cost Analyses (ICA)*. October 1990.

TABLE 4-1

INITIAL SPARES FACTORS

(Applied to cost of end items delivered during a fiscal year)

Equipment category	First 3 years	Next 3 years	Factor base
Whole engines/engine modules	N/A	N/A	Calculations done IAW AFR 400-1
Aircraft components			
Engine	10%	7%	Total recurring flyaway cost
Avionics	10%	7%	Total recurring flyaway cost
Other	10%	7%	Total recurring flyaway cost
Peculiar support equipment/automatic test equipment (PSE/ATE)	7%	5%	Recurring PSE/ATE cost

Note: N/A = not applicable; IAW = in accordance with.

According to the OPR, the published factors are to provide a starting point for a program office. The OPR recommends that these factors be adjusted for unique system features; unfortunately, there are no published guidelines to indicate what adjustments should be made or to prescribe the procedures to make these adjustments. In effect, each program office is left to its own devices to estimate Initial Spares and there are no approved criteria to judge the validity of adjustments made to the published factors.

LMI Analysis of the Factor Methodology

The three facets of our analysis of the Initial Spares factor methodology are discussed in the following order: (1) the sensitivity of the percent-of-flyaway cost methodology to the significant factors affecting the spares inventory investment, (2) the effect that the new Initial Spares definition has on the data used to develop Initial Spares factors, and (3) the impact of advanced avionics technology on the factor methodology.

Sensitivity of the Factor Methodology to Significant Cost Drivers

Of the three major cost drivers identified in Chapter 2, the factor approach is sensitive to only one: flyaway cost. When flyaway cost changes, the estimate for Initial Spares changes proportionately. Implicitly, the approach assumes that there is a high correlation between flyaway cost and the unit cost and quantity of spares. Flyaway cost changes, resulting from changes in the cost or number of components installed on the airframe, should have a direct effect on spares. However, the causal link between increased cost to manufacture the airframe structure and increased spares is not easy to see. (Because this may represent an increased process cost and not more spares.)

The factor approach does not explicitly consider the two other cost drivers: OPTEMPO and system reliability. If the OPTEMPO and the reliability of the historical system are nearly the same as that of the new aircraft, then the affect of omitting these two factors may be insignificant. However, based on the elasticity ratios for these two omitted cost drivers, even modest differences are likely to be significant.

Approach. Since the Air Force has not prescribed a methodology to adjust published Initial Spares factors, we cannot test their methods directly. Instead, we looked at baselines for three airlift weapon systems and determined the effect on Initial Spares factors when changes are made to reliability and OPTEMPOs. This analysis approach was used (1) to verify if factors from analogous systems could be used for a new weapon system without adjustment and, if not, (2) to determine the types of adjustments needed.

The Aircraft Availability Model (AAM)[6] was used to calculate the spares investment baseline needed to support the C-5A, C-5B, and C-141B aircraft at currently approved operating levels. This baseline includes only requirements consistent with initial stockage requirements. (For example, preferred spares requirements were excluded.)

To accomplish this, two modifications were made.

- The AAM was changed to focus on the total Initial Spares investment instead of the "buy" requirement. The "buy" requirement is calculated as the difference between the projected total requirement for spares and the projected spares inventory position. By setting the inventory position for

[6]The AAM was developed by LMI for the U.S. Air Force. It is used for formulating and evaluating BP15 Replenishment Spares requirements for peacetime operating stocks (POS), as part of the programming, planning, and budgeting system (PPBS). In 1982, a modified version of the AAM was adapted for AFLC use in preparing budget allocations; it is now being fully integrated into the Recoverable Consumption Item Requirements System (D041). An overview of AAM is provided in Appendix A.

every item to zero, the AAM computes total inventory investment required to support an aircraft under specified conditions.

- Each baseline is constructed so that each aircraft type is independent of the others. This compensates for the high degree of commonality between the C-5A and C-5B aircraft, so that the spares baselines more closely approximate the requirements associated with the introduction of a new weapon system.

The AAM was also used to calculate baseline excursions that reflect variations in flying hours and reliability found in existing aircraft. The resulting estimates were computed at a level that provides an 82.5 percent aircraft availability. These results were used to calculate Initial Spares factors from the baseline data and from the revised baseline data. Insignificant differences between these revised factors and the baseline factors would support the use of historical factors without adjustment. On the other hand, significant differences would indicate that analogous factors must be adjusted.

Findings of Sensitivity Analysis. Table 4-2 summarizes the Initial Spares factors calculated for the baseline and three excursions.

TABLE 4-2

NONENGINE/ENGINE MODULE INITIAL SPARES COST AS A PERCENT OF RECURRING FLYAWAY COST

Aircraft	Baseline	At C-5B OPTEMPO	At C-5B OPTEMPO & reliability	At C-17 OPTEMPO actual reliability
C-5B	3.45	3.45	3.45	5.92
C-5A[a]	5.18	7.29	4.07	13.35
C-141B[b]	6.99	4.82	N/A	N/A
Column range as a percent of C-5B	100.00	111.30	17.97	125.51

Source: Weapon System Budget Estimate Form 1537.

Note: N/A = not available.

[a] Original C-5A recurring flyaway cost. Does not include the cost of either the wing modification or the 1a to 1c engine modification.

[b] Flyaway cost does not include the stretch modification.

The baseline column shows the resulting Initial Spares factors obtained by dividing recurring flyaway cost into the Initial Spares baselines for three airlift aircraft. Simply picking the wrong historical aircraft as the analogous weapon system could cause an estimating error of up to 100 percent. The next column displays Initial Spares factors if each fleet of aircraft were operated at the C-5B OPTEMPO. Note that the C-5A Initial Spares factor increases 40.7 percent as a result of changing the utilization rate. Column four shows the C-5A Initial Spares factor when it is adjusted to have the same reliability and operating tempo as the C-5B. The final column shows the effect of operating the C-5A and the C-5B aircraft at their actual reliability but at the planned C-17A annual OPTEMPO of 1,432 flying hours per primary aircraft authorization.

These data suggest that serious errors can be encountered by simply using historical factors from one system to estimate Initial Spares for a new weapon system. Even for as closely analogous systems as the C-5A and the C-5B, if the C-5A had been used as the reference system for estimating the C-5B, the estimating error would have been 50.1 percent. Had the C-5A been flown at the same OPTEMPO as the C-5B, the estimating error would grow to 111.3 percent. Varying the OPTEMPO and equipment reliability and maintainability (R&M) characteristics can change the Initial Spare factor for the same aircraft by up to 157.7 percent. Making adjustments for OPTEMPO and reliability differences can reduce the estimating error to approximately 20 percent. While not ideal, this represents a significant improvement over unadjusted factors.

Data Problems Caused by the New Definition

At the same time that the new definition increased the importance of macro models, it also voided much of the data that could be used to develop or validate Initial Spares factors. Replenishment Spares expenditure data include expenditures for purposes other than initial stockage. Without detailed information to reconstruct how many and why each item was bought, historical Replenishment Spares expenditures for only initial stockage cannot be isolated. Consequently, historical accounting records are virtually useless as a source for developing or validating new factors or models because they cannot be restructured to reflect the new Initial Spares definition.

As an alternative, the D041 system (the official Air Force spares estimating model) can be used to calculate the spares required to support a fielded aircraft. Since these spares requirements reflect the current configuration of the fielded systems, the flyaway cost of the current configuration of the fielded system is needed to express the spares requirement as a percent-of-flyaway cost.

Within the Air Force, the historical flyaway costs reported in the *Air Force Cost and Planning Factors Regulation* AFR 173-13, reflect the cost of the airplane when it was built. Historical flyaway cost is not updated, except for inflation, unless, the mission design series designation of the aircraft is changed as a result of a modification. Significant modifications, such as the Offensive Avionics System/Cruise Missile Integration modification made to the B-52 fleet, the wing and engine modifications made to the C-5A fleet, and the F-111 Avionics Modernization Program, did not cause an update of the historical flyaway cost for these systems. Considering the volume of configuration changes that occur over the life cycle of a weapon system, it is difficult to quantify the error introduced by using a spares baseline representing today's aircraft configuration and a flyaway cost reflecting a 20-year old configuration.

Even when flyaway costs are updated in AFR 173-13, the resulting costs may still lack the necessary accuracy to develop Initial Spares factors. Procedures used to update flyaway costs in AFR 173-13 simply add the cost of the modification to the old flyaway cost. As a result, the updated flyaway cost includes the cost of procuring and installing the old items being removed, the cost of removing the old items, plus the cost of procuring and installing the new items.

To get an indication of the problem, we looked at the C-5A and C-5B aircraft. Production on the last C-5A aircraft production lot was started nearly 21 years ago. In comparison, production on the last lot of C-5B aircraft was started only 4 years ago. Over the intervening years, the C-5A has undergone extensive modifications, including replacing its wing and upgrading the engines to the same configuration as the newer C-5B. Across the two aircraft there is a high degree of commonality, as demonstrated by the fact that components representing 79 percent of the total C-5A demands for spare parts are common to both aircraft.

The high degree of commonality between the current configuration of the C-5A and the new C-5B and the fact that a shipset cost of spares (in FY90 dollars) varies by only 7 percent for both aircraft, suggest that the C-5B flyaway cost might be a better indicator of the "true" flyaway cost of the current configuration of the C-5A. To test this, we extrapolated the C-5B recurring flyaway cost to the size of the C-5A procurement (76 aircraft), and using this as a proxy for the C-5A flyaway cost, computed Initial Spares factors using the C-5A ISB that assumes the C-5B OPTEMPO and reliability.[7] The results support the idea that the original C-5A flyaway cost understates the cost of the current configuration. See Table 4-3.

TABLE 4-3

INITIAL SPARES FACTORS BASED ON C-5B OPTEMPO AND RELIABILITY

C-5A Factors		Actual C-5B factor
Original C-5A cost	C-5B cost as proxy for C-5A cost	
4.07%	3.25%	3.45%

Effects of Distribution of Flyaway Cost

Using a simple factor to estimate Initial Spares implicitly assumes that a change in flyaway cost will have the same spares impact regardless of whether the increase results from changes in avionics, engines, or airframe components. Table 4-4 shows the distribution of flyaway costs for selected aircraft. With modern aircraft systems becoming more and more reliant on avionics, avionics is increasing as a percent of total flyaway cost. If avionics require a higher percent-of-flyaway cost for spares than other segments of flyaway cost, then even adjusted aggregate historical percent-of-flyaway factors could underestimate the capital investments required to support a new weapon system with the same total flyaway costs but a different cost distribution.

To analyze this effect, we partitioned AAM output into the three recurring flyaway categories commonly found on the Air Force Form 1537: Engine, Avionics, and Airframe. Engine and avionics items were identified by using the Federal Supply Classification coding contained within each stock number in the D041 data

[7]The ISB used to calculate the C-5A data is from column 4 of Table 5-2.

TABLE 4-4

DISTRIBUTION OF FLYAWAY COSTS

(Percent of total recurring flyaway less engineering change orders)

Aircraft	Engine	Avionics	Other
C-5A	14.2	0.1	85.7
C-5B	12.0	2.0	86.0
C-17A	12.9	5.4	81.7
B-1B	10.4	21.7	67.9
F-16 C/D	27.3	21.5	51.2
F-15 C/D	24.6	19.8	59.6
F-15E	22.0	25.7	53.3

Source: Weapon System Budget Estimate, Air Force Form 1537.

base; airframe components were all other items not categorized as either engines or avionics. (Remember that spares for whole engines and whole engine modules are not calculated with factors and are not being discussed at this time.)

The partitioned AAM output was used to create Initial Spares cost factors for the three categories of recurring flyaway cost. The cost for engineering change orders (ECO) was not included in the analysis. The resulting factors are shown in Table 4-5.

TABLE 4-5

INITIAL SPARES FACTORS BY CATEGORY OF FLYAWAY COST

(Percent of recurring flyaway)

Aircraft	Engine	Avionics	Airframe	Total
C-5A	13.2	955.2	2.8	5.2
C-5B	8.9	26.7	2.2	3.5
B-1B	12.0	15.3	2.3	6.2
F-16 C/D	12.2	28.3	3.7	11.3
F-15 C/D	7.8	14.3	2.3	6.0
F-15E	7.6	25.3	2.8	9.6

Tables 4-4 and 4-5 show some data anomalies. First, there may be reporting problems that categorize recurring vehicle cost into the wrong category. Some C-5A avionics costs in Table 4-4 could be reported in the airframe category which could explain the absurdly high spares factors for this airplane.[8] Also, given the firm, fixed-price nature of the C-5B contract, the flyaway cost distribution reported in the Weapon System Budget Estimate, Air Force Form 1537, was allocated based on limited Cost Performance Report and Contractor Cost Data Report data. While a potential source of error, making these allocations based on data at the work breakdown structure level of detail could make this cost distribution more realistic. Second, at the time the D041 data base used in this study was assembled, many B-1B avionics black boxes were under interim contractor support (ICS) and may not have been in the data base. Consequently, the B-1B avionics spares baseline may be understated.

Recognizing that these data may not be perfect, the C-5B factors at least approximate avionics sparing "rules of thumb" this author developed by comparing avionics spares estimates from the LSC model with computed flyaway cost estimated by independent Air Force cost analysis teams. Assuming that the C-5B Initial Spares factors by category of flyaway cost are correct, then what are the implications for the factor approach?

To answer this question, we used the C-5B factors for each equipment category from Table 4-5, weighted these factors with the flyaway distribution factors for the C-17A aircraft from Table 4-4, and compared this weighted Initial Spares factor with the overall total factor from Table 4-5. The C-17A was chosen because it is the latest airlift aircraft being procured by the Air Force and may be more representative of the differences in flyaway cost distribution likely to be encountered between systems being estimated and the historical aircraft in the database. The calculations are as follows:

	C-5B Factor (Table 4-5)	×	C-17A Weight (Table 4-4)	=	Weighted factor
Engines	0.089	×	0.129	=	0.0115
Avionics	0.267	×	0.054	=	0.0144
Airframe	0.022	×	0.817	=	0.0180
Total					0.0439

[8]The Navy also pointed out this problem.

When the historical factors are weighted with a different flyaway cost distribution, the overall Initial Spares factor increases 25 percent (4.39 percent vs. 3.5 percent). If we assume that the B-1B spares factor for avionics is correct and rework the mathematics, the Initial Spares factor still increases 12.8 percent. Clearly, distributional changes in flyaway cost can have a significant impact on the spares factor selected.

Summary of Findings – Factor-Based Macro Methods

To have validity as estimating methodologies, factor-based approaches must incorporate procedures to adjust historical factors at least for differences in OPTEMPO, reliability, and flyaway cost distribution between the new system and the historical reference system. In addition, using flyaway cost as the base for spares factors is risky because the Air Force does not routinely or totally adjust flyaway costs for configuration changes, and there may be reporting inconsistencies in the categories reported.

We believe that an alternative to flyaway cost should be pursued. One possibility is the shipset cost. Shipset cost data, reflecting the current configuration of the aircraft (or at least the configuration used to build the spares baseline), can easily be obtained for all Air Force aircraft.

THE AIR FORCE LOGISTICS SUPPORT COST MODEL AS USED TO ESTIMATE WEAPON SYSTEM INITIAL SPARES

The second category of macro methodologies used to estimate funding levels for Initial Spares is the detailed "bottoms up" models. While these models require significantly more data than Initial Spares factors, they are still macro approaches in the sense that they require significantly less data than do the official budget estimating models. Air Force ICA teams and weapon system programs use the LSC model to make these estimates. While the LSC model estimates other categories of cost, the focus of our review is the equations used to estimate Initial Spares funding.

This section of Chapter 4 documents the findings from our review of the LSC model. As part of our review of the LSC model for ASD(PA&E), we reviewed Management Consulting and Research, Inc.'s, (MC&R's) study of the spares equations in the Version 2.0 of the LSC model and verified that changes made in Version 2.2 corrected those deficiencies.

Background

The LSC model was originally designed as a tool to evaluate the relative operating and support (O&S) cost of competing aircraft designs. It is a deterministic mathematical model of the Air Force three-level maintenance system. Given a set of input variables describing a weapon system's OPTEMPO, aircraft beddown, maintenance concepts, and hardware characteristics, the LSC model calculates a requirement for logistics funding. Used initially as an evaluation tool, the model matched neither the budget structure nor the cost element structure directed by the OSD CAIG. For example, the model categorized spares as either pipeline or condemnation but lacked the rules needed to restructure these analytical categories into the budget categories Initial Spares and Replenishment Spares.

In the middle 1970s, the cost analysis function of AFLC began to modify the LSC model to align the model output with budget definitions in order to support estimating requirements directed by the DoD CAIG. Since then, the LSC model has evolved into the primary tool used by ICA teams to develop weapon system cost estimates and more recently by weapon system program managers to develop their program office estimates for Initial Spares.

Despite the widespread use of the LSC model, it was not until the Air Force Cost Center was established in 1986 that any serious questions about the model's accuracy were raised. MC&R was tasked by the Air Force Cost Center to evaluate the LSC model's equations used to calculate spares requirements. This study evaluated the logic and mathematical correctness of the equations, developed a reference data set to calibrate the LSC estimates with Air Force requirements obtained from approved procedures, and assessed the accuracy of LSC model estimates when detailed data were not available for all reparable components.

Summary of LMI Findings

- Using the database developed to validate the LSC model, we found that when exactly the same data are used, estimates from the LSC model Version 2.2 are within 2.7 percent of Air Force calculated requirements obtained from data systems used to prepare the Air Force budget. This represents a significant improvement in accuracy from LSC model Version 2.0, which understated Air Force calculated requirements by 20 percent. When complete information is available at the Line Replaceable Unit (LRU) and shop replaceable unit (SRU) level, the LSC model will develop realistic estimates assuming accurate estimates of the input variables are used.

- While many weapon systems meet or exceed their system-level reliability goals, the ability to accurately estimate realistic values for reliability input parameters has not been demonstrated. Consequently, the reliability estimates used in the LSC model contain significant uncertainty. While the model has provisions to perform sensitivity excursions, it does not have the capability to explicitly quantify the uncertainty associated with an estimate developed by combining several hundred separate estimates, each with its own uncertainty.

- The LSC model has internal data checks that warn the user of some data inconsistencies; however, it does not flag unrealistic values for reliability parameters.

- The Achilles heel of the LSC model is that a complete set of data for every item on the aircraft is not normally available when the model is used before the full-rate production decision at DAB milestone IIIB. The LSC model can run when information is known about the reparable LRUs that are removed from the aircraft at the flight line. These LRUs, in turn, may have subcomponents called SRUs. If data about the SRUs are unknown or unavailable, the LSC model is run at the LRU level of detail, and the outputs are adjusted using SRU factors to account for the additional investment in SRUs needed to support the repair of the LRU. MC&R concludes that using the current default SRU factors may not be realistic and that a simple factor methodology may not be the best way to provide the needed capability.[9] Since the MC&R report, the Air Force Cost Center has updated the SRU factors used in Version 2.2. However, this update is limited in scope. LMI believes the Item Application File contained in the D041 could be used to develop SRU factors. This file indicates those items that are removed from an airplane and up to four levels of indenture of parts below the removed item. Chapter 5 discusses how SRU factors can be developed by Federal supply classification codes and possibly by two-digit work unit codes (WUCs).

Discussion

Major findings reported by MC&R are summarized in Appendix B. Each finding discussed is indexed to an MC&R report paragraph.

[9]Alexander, Arene B., et al. *Logistics Support Cost Model Validation.* Management Consulting and Research, Inc., TR-8907/32-1. 15 May 1990.

Condemnation Requirements

Besides the pipeline requirements noted by MC&R, the Initial Spares budget buys spares to cover expected condemnations. This requirement, similar to other pipeline requirements, covers the expected number of condemnations that will occur over the procurement lead time. Neither MC&R nor the LSC model documentation refers directly to this Initial Spares requirement. Fortunately, this documentation omission is not carried over into the model.

The LSC model approximates this requirement by calculating the number of expected condemnations that will occur over a specified period of time and by adding this amount to the other requirements for Initial Spares. In the LSC model Version 2.2, the variable ISYR is used to specify the number of years of condemnations that are to be included in Initial Spares. The value of this variable is usually initialized at the value of 2, indicating that 2 years of condemnations for each aircraft are included in the computation of Initial Spares.[10] Two years is consistent with the budget definition for Initial Spares provided by the program element monitor. The average PLT calculated from D041 condemnation pipeline requirements for the aircraft, shown in the appendices to this report, indicate that actual PLTs are somewhat longer than 2 years. Table 4-6 summarizes the calculated PLT and the maximum error in the total Initial Spares estimate caused by assuming PLT is 2 years. While this understates Initial Spares, the balance is included in the Replenishment Spares calculation so that the total weapon system estimate is correct.

Model Calibration

To validate the LSC model, MC&R developed a test data set of 27 F-16 items that contains the actual data inputs for each item needed to run either the D041 or the LSC model. This reference data set was used to calibrate the LSC model with D041 results.

By looking at individual equations and the errors attributed to specific causes, MCR's report does not provide a sense of the cumulative impact of all these errors. To better assess the bottom-line effect on potential spares estimates, we calculated the product of the unit differences and the unit cost and then summed these costs across

[10]In the software we were provided, ISYR did not work as stated here. We were informed that ISYR had been changed to function as stated, except that ISYR was set to 1 after initial operating capability + 2 years.

TABLE 4-6

ACTUAL PROCUREMENT LEAD TIMES (PLT)
AND THE IMPACT OF ASSUMING PLT TO BE 2 YEARS

Aircraft	Actual PLT in years	Maximum error assuming PLT = 2 (% of total IS)
C-141B	2.13	1.43
C-5A	2.35	3.15
C-5B	2.35	2.45
F-16A/B	2.03	0.32
F-16C/D	2.21	1.58
F-15A/B	2.12	1.08
F-15C/D	2.12	1.08
F-15E	2.11	0.50
B-1B	2.14	0.77

all items in the data base. The results of these calculations are summarized as Case 1 in Table 4-7.

TABLE 4-7

COMPARISON OF LSC MODEL AND D041 PIPELINE ESTIMATES
(FY90 $ millions)

Case	LSC Initial Spares	Actual D041 Initial Spares	Percent error
Case 1 LSC model, Version 2.0, 1 base	88.6	118.3	– 25.1
Case 2 LSC model, Version 2.0, 10 bases	94.7	118.3	– 19.9
Case 3 LSC model, Version 2.2, 10 bases	115.1	118.3	– 2.7

Note: To be comparable with D041, all LSC runs were made with no allowance for ECO.

In making their calculations, MC&R simply assumed that all flying activity occurred at one base. Because of the procedure that the LSC model uses to compute safety stocks, this assumption reduces the safety stock requirement computed by the model. Thus, when these LSC estimates are compared to the actual D041 computations, the differences may not reflect the true accuracy in the LSC model.

In Case 2, we reran the LSC model assuming a more representative number of 10 bases and found that the percent error was reduced by 20 percent. While much better than previous results, the corrected results indicate that the LSC model Version 2.0 output still understates D041 calculations by 19.9 percent (when the same data are used).

Recently, HQ AFLC released Version 2.2 of the LSC model. This new release implements many of MC&R's recommendations. We did not look in detail at the new release of the model but rather checked only its bottom-line accuracy. With the help of the HQ AFLC Cost Analysis Directorate, we converted the reference test data set to be compatible with new record formats for the Version 2.2 model. In Case 3, the LSC model was rerun with the reference data set, again assuming 10 bases. The LSC model output now approximates the D041 pipeline calculations to within 2.7 percent.

Engineering Change Orders

In addition to the above requirements, the LSC model adds an allowance for ECOs to cover the replacement of spares made obsolete by configuration changes made during production. While this is a valid requirement, it is not normally included in the weapon system Initial Spares estimates. This cost is usually absorbed in the Replenishment Spares budget. The latest Air Force estimates do not refer to adding ECO to the estimate. Instead, these estimates refer to a "risk factor" that includes undefined requirements, pipeline times that exceed standards, and insurance item contingencies. These additions to Initial Spares estimates seem justified.

CHAPTER 5

SUMMARY OF OBSERVATIONS AND SUGGESTED ALTERNATIVES

Improvements are needed in the two most commonly used macro methods that were evaluated in Chapter 4. The first three observations apply to the factor-based methodology, the fourth pertains only to the LSC model, and the fifth applies to both the factor approach and the LSC model.

- Aggregate factors do not capture the sparing requirements that differ by type of equipment.
- Flyaway cost cannot be used as the basis for the factor-based macro method.
- Factor-based macro methods must be adjusted for differences in significant cost drivers between the reference weapon system and the new aircraft.
- The LSC model approach needs extensive work to improve its credibility to make estimates before a complete set of components are available.
- Both the adjusted Initial Spares factors and the LSC model approach require more realistic estimates of new weapon system reliability.

In the following discussions, we review each of these observations and suggest improvements. Finally, we present a road map for changes ASD(PA&E) can make to their macro estimating methods.

AGGREGATE COST FACTORS

When spares inventories are partitioned into equipment categories, significant differences appear in the percentage of spares required. The cost of avionics spares inventories as a percent-of-flyaway cost is much higher than any other equipment category. Because modern military aircraft rely heavily on avionics, aggregate methods were shown to underestimate spares requirements by failing to recognize this fact.

We suggest that OSD use macro approaches that estimate spares requirements by equipment type. Separate estimators can be developed for these three equipment categories: engines, avionics, and airframe components. Data bases used by the Air

Force can be partitioned into these groups by either Federal supply classifications or by WUCs.

ALTERNATIVES TO FLYAWAY COST

Data problems that occur during the development of percent-of-flyaway, Initial Spares factors require that the factor methodology be rebaselined. Historical spares expenditures, that reflect the aircraft configuration when it was acquired, cannot be reconstructed to meet the new definition of Initial Spares. Aircraft flyaway costs are not updated to reflect all the configuration changes that must be explicitly considered when developing factors with current spares inventory requirements.

A possible alternative to flyaway cost is the shipset cost of reparable items installed on the airframe. The advantage of using shipset cost to develop Initial Spares cost factors is that both the numerator and the denominator of the cost factor are based on the same aircraft configuration. While the use of shipset cost may sound like a significant change in approach, in reality, the change will only affect spares factors for airframe components. (The reported flyaway cost for engines and avionics is already nearly identical to the shipset cost.)

ADJUSTING FACTOR-BASED MACRO METHODS

Regardless of how the factor is redefined, the fundamental problem still remains: how to adjust the factor to reflect the unique characteristics of the aircraft being estimated? The methods used to develop the analytical data bases in this study offer one approach.

The LMI self-contained version of its Aircraft Availability Model (AAM), hosted on a micro computer, can calculate spares requirements for an aircraft at specified levels of availability using the D041 database.[1] LMI has modified the AAM software so that changes to other costdriver variables are easier to make and has expanded the model output so that spares requirements can be stratified by type of requirement and by equipment group.

[1]The D041 data base used in this study includes neither whole engines nor engine modules.

Specific changes made to the AAM software allow the following cost drivers to be normalized between the reference weapon system and the new weapon system:

- Flying hour program.
- Number of aircraft (PAA).
- Adjust demand rate data for reliability changes. With this feature, reliability improvements can be explicitly considered in the analysis. If a new aircraft is supposed to be 20 percent more reliable, actual demand rates can be adjusted by either assuming the same percent improvement for all items or if, data are available, individual adjustments can be made for engines, avionics, or airframe component categories.
- Change the number of bases that support a given aircraft. While not a major cost driver, the number of bases and their locations (i.e., overseas or CONUS) do affect the number of spares, and the base activation schedule does impact the time-phasing of requirements for initial stockage.
- Model outputs are separated into three equipment groups: engines, avionics, and airframe components. This breakout was accomplished using the Federal supply classification contained in each national stock number (NSN). (See Appendix C for an example of the level of detail to which the AAM model calculates spares requirements.)

To illustrate how these features can be used to build an estimate, we chose to adjust the C-5B data to reflect characteristics of the C-17A aircraft and compare this macro estimate with the Initial Spares estimate developed for the C-17A annual program office cost estimate. (Details of the computations are discussed in Appendix D.) At the bottom line, when the Air Force C-17A MTBR is used, the adjusted factor methodology nearly duplicates the Air Force estimate that was built up component by component:

Air Force estimate: $2.054 billion (then-year dollars)
Adjusted C-5B data: $2.019 billion (then-year dollars).

ENHANCE LSC MODEL'S CAPABILITY TO DEVELOP ESTIMATES BEFORE MILESTONE IIIB

Before milestone IIIB, data on the new aircraft design are not normally available for the SRUs within an LRU removed from the aircraft for repair. The LSC model approximates the investment for these SRUs by multiplying the estimated requirement for LRUs by an SRU factor. The empirical basis for these factors is limited at best. Part of the problem is finding data on complete pieces of fielded equipment including all LRUs and SRUs so that the LRU and SRU relationships can be developed.[2] Attempts to develop the hierarchical relationships between LRUs and SRUs have used WUCs to NSN cross-references. These cross-references are difficult to build and do not always produce cross-references that allow data from the D041 system to be used.

There is an alternative way to generate SRU factors that are less sensitive to small sample variations. The D041 Item Application File shows the hierarchical relationship between items removed directly from the aircraft (i.e., the LRU) and up to four subassembly levels of parts below that LRU. Using these hierarchical relationships, the total spares required for each hierarchical group in levels 1 to 5 can be identified. From this total requirement can be found the subset of spares associated with just the level 1 requirements (those LRUs removed directly from the aircraft). The ratio of the total to the level 1 spares will approximate the SRU factor. Using this approach, SRU factors can be developed for every level 1 item in the D041 database. These LRU and SRU data can be grouped to develop average SRU factors for each Federal supply classification. If the two-digit WUC is required, additional time will be necessary to relate the level 1 component to the two-digit WUC.

REALISTIC RELIABILITY ESTIMATES FOR NEW WEAPON SYSTEMS

Both the LSC model and the factors approach require realistic estimates of how often a component will be removed from the airplane for repair. The size of the investment to initially stock the spares inventory is very sensitive to the reliability of the aircraft: other things being equal, the more reliable the aircraft the smaller the investment in inventory. Unfortunately, reliability estimates appear to be optimistically biased.

Reliability estimating procedures have been changed in response to many well publicized horror stories about fielded reliability being much worse than predicted. For example, MIL-HDBK-217,[3] used to calculate avionic equipment reliability, has undergone several revisions. As a result, failure rate predictions made with the original MIL-HDBK-217A would have to be increased by a factor 1.96 to be

[2]If readily available, data from analogous equipment types (adjusted for design differences) could be used in lieu of SRU factors.

[3]Military Handbook. *Reliability Prediction of Electronic Equipment*, (MIL-HDBK-217). This handbook standardizes procedures, used within DoD, for predicting electronics equipment reliability.

comparable with results calculated using procedures from the MIL-HDBK-217D version.[4]

Other studies[5] suggest that, even with large, item-by-item variations, overall weapon system level R&M goals might be a reasonable starting point to corroborate initial R&M inputs for individual components. This recommendation seems inconsistent with *a priori* conclusions that reliability estimates are optimistically biased. We looked at original reliability goals for selected weapon systems and then compared them with actual field reliability information extracted from the Air Force Maintenance Data Collection System (D056). A 1983 LMI report,[6] looking at ways to improve weapon system support, was a valuable source of the D056 data that were used to see how well field data from the first 4 years of operation compared with reliability goals for the A-10, F-15, and F-16 aircraft.

The data in Table 5-1 do not necessarily mean that all equipment are meeting performance or R&M specifications. Because of the mathematics involved, a system can meet the overall system-level reliability goals and still have "bad actor" components that adversely affect supportability (999 items may work perfectly and 1 bad actor can ground an airplane).

Because failure-prone components exist and system-level reliability goals are still being met, some components are performing better than their reliability predictions. We found that while it is easy to obtain information on the weak items, few system managers[7] had information at their finger tips on items that perform well.

In another ongoing project, LMI obtained data from the LANTIRN program office that corroborated that some items are exceeding reliability predictions. Like the systems in Table 5-1, the LANTIRN MTBM(I) goal of 49.9 hours is being exceeded. While still meeting its system-level reliability goal, 20 LRUs and SRUs had actual failure rates 2 to 20 times higher than predicted. In spite of these higher

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[4]Wrisley 1989, Table 4.3-2, page 4-13.

[5]LMI Report ML108. *Toward Improved Initial Provisioning Strategies: The F-16 Case.* Abel, John B., et al. April 1982.

[6]LMI Report ML210. *Improving Weapon System Support, Vol. II.* Kaiser, Robert D., and Thomas A. White. May 1983.

[7]The KC-10A system coordinating officer used his list of failure-prone parts to show how well his airplane performed. There were only three items on the KC-10A parts list with an MTBM(I) of less than 1,000 hours.

TABLE 5-1

COMPARISON OF RELIABILITY GOALS WITH FIELD EXPERIENCE

Aircraft	Goal MTBM(I) (hours)	Early D056 MTBM(I) (hours)	Current D056 MTBM(I) (hours)
A-10	1.5	4.2 – 3.6	3.32
F-16A/B	1.75	2.0 – 3.2	2.57
F-16C/D	3.0	N/A	3.54
F-15A/B	3.5[a]	1.1 – 1.55	1.70
F-15C/D	N/A	2.0 – 2.4	2.07
UH-60A	4.0	4.6 – 5.1	n/a
B-1B	1.0	0.9	1.23

Note: MTBM(I) = Mean time (in flying hours) between maintenance for inherent failures.

[a] *Reflects "relevant failures" only. These are not directly comparable to D056 data.* D056 computes all data based on flying hours, relevant failures are usually expressed in terms of operating hours.

rates, 8 of the 11 LANTIRN navigation pod subsystems are performing better than predicted.

Using the system-level reliability values contained in the weapon system specification, a form similar to that shown in Figure 5-1 can be developed that relates the allocation of the system-level R&M goals to the individual subsystems. These allocations are then compared to the actual subsystem R&M data. Finally, the most important step is to provide an explanation of the differences between the reference weapon system, the proposed weapon system goal, and the reliability parameter used in the current estimate. This explanation must address the design, technical, and operational differences that support significant differences from the reference weapon system R&M data.

The information entered into the form in Figure 5-1 can be used not only to judge the reasonableness of specific reliability estimates, but also to develop estimates of the uncertainty and risk associated with specific estimates. Adding a Monte Carlo simulation routine to the LSC model could help quantify the overall risk in the Initial Spares estimate encountered when 800 – 1,000 separate estimates, each

MTBR (on-equipment)	***Definition***: Mean flying hours between component removals from the aircraft ***Source for actuals***: D056 (excludes removals to facilitate other maintenance) ***Cost elements affected***: Initial Spares, Replenishment Spares, depot maintenance, etc.				
Work unit code	**Reference system (actuals)**	**Best actual system**	**Proposed system goal**	**Basis of current estimate**	**Rationale for differences between reference system and current estimate**
11XXX **Total MTBR** Investment MTBR Expense MTBR					
23XXX **Total MTBR** Investment MTBR Expense MTBR					
• • •					
99XXX **Total MTBR** Investment MTBR Expense MTBR					
System total MTBR Investment MTBR Expense MTBR					

FIG. 5-1. SAMPLE FORMAT FOR R&M CALCULATIONS

with its own uncertainty, are added together. Information from this form could be used to establish upper and lower boundaries around each individual estimate needed for such a simulation.

OBSERVATIONS

- OSD needs to refine its estimating methodology for Initial Spares. Current estimating methodologies are not empirically verifiable nor are they sensitive to the major cost drivers affecting the size of the spares inventory.

- Detailed models like the LSC model require too much data and require too much time to be used to support OSD CAIG analysts. More macro methods are appropriate to develop crosschecks of Service estimates.

- ASD PA&E should pursue more parametric methods that are less reliant on large data bases. There are two options:

  - *Option 1.* Use models like the AAM to develop ISBs for a reference weapon system based on the characteristics of the new aircraft (OPTEMPO, MTBR, basing concept, etc.). The ISB is converted to factors (such as percent of shipset cost) and these specific factors are used to estimate this specific new aircraft. (This option is, in effect, replicating for each DAB aircraft review, the multi-dimensional factor-scaling procedure documented in Appendix D.)

  - *Option 2.* Develop a more general estimating methodology that would produce the Initial Spares estimates directly from parameters of the new weapon system. More similar to cost estimating relationships than to factors, this methodology will capture the elasticity of the Initial Spares investment to changes in the cost driver variables.

Either option should give OSD the capability to crosscheck Service estimates and provide a rational basis for the OSD CAIG finding. Option 1 will initially cost less but will require OSD to be dependent on outside organizations to develop the specific factors for each weapon system. Initially, option 2 will cost more to develop because of the data base that must be built to support the statistical analysis. However, once developed, OSD can develop estimates independent of outside organizations.

APPENDIX A

AN OVERVIEW OF THE AIRCRAFT AVAILABILITY MODEL

AN OVERVIEW OF THE AIRCRAFT AVAILABILITY MODEL

THE MODEL DESCRIPTION

The Aircraft Availability Model (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 D041 methodology, to ensure maximum possible compatibility with the results generated by the D041 central secondary item stratification subsystem used to derive the Air Force Logistics Command (AFLC) budget estimate submission for Budget Program 1500 (BP15).

FUNCTION

The AAM developed by the Logistics Management Institute (LMI) for the U.S. Air Force, is used to formulate and evaluate Budget Program 1500 (BP15) Replenishment Spares requirements for peacetime operating stocks (POS), as part of the programming, planning, and budgeting system (PPBS). 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 projects costs and availability rates by aircraft type in future years on the basis of data derived from several Air Force data systems, including the Recoverable Consumption Item Requirements System (D041) 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 essentiality 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 was 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 (POM) 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 (D041).

APPENDIX B

MAJOR OBSERVATIONS FROM MANAGEMENT CONSULTING & RESEARCH, INC., REPORT *LOGISTICS SUPPORT COST MODEL VALIDATION*

MAJOR OBSERVATIONS FROM MANAGEMENT CONSULTING & RESEARCH, INC., REPORT *LOGISTICS SUPPORT COST MODEL VALIDATION*

Management Consulting & Research, Inc., (MC&R) reviewed the equations used in the Logistics Support Cost (LSC) model Version 2.0.[1] This appendix summarizes their findings that relate to estimating Initial Spares.

PARAGRAPH III-12 SAFETY LEVEL CALCULATIONS

The FMOD is a variable used in the LSC model to calculate base safety stocks. FMOD is a real number (expressed in standard deviations above the mean demands) used to calculate the stock level required to obtain a specified probability that demands will not exceed supply (i.e., parts will be available when needed). MC&R states that FMOD is based on the normal probability distribution; however, because the mean demands are assumed Poisson distributed in the LSC model, FMOD should also be Poisson distributed. Because of differences between the two distributions, the size of the safety level (given a specified level of protect) is dependent on which distribution is used for FMOD.

Because the Poisson approximates the normal distribution for large values of the mean, the largest errors are concentrated in items with small mean demand rates. Consequently, MC&R notes that the total inventory impact is within one unit of the normal distribution. These errors occur at each base; thus, an error of one $1.5 million item at each of 10 bases is a $15 million error for that item.

PARAGRAPH III-21 REPAIR TIME CALCULATION

Base repair times should be increased to allow for additional delays not covered in order and ship times or base repair cycle times (BRCTs). MC&R states that two additional delays should be considered. First is the base level processing time needed to determine that an item cannot be repaired at base level. This base processing factor should be added for every item returned to depot for repair and for every item condemned at base level. Second, base maintenance is sometimes delayed because of

[1]Alexander, Arene B., et al. *Logistics Support Cost Model Validation.* Management Consulting & Research, Inc., TR 8907/32-1. 15 May 1990.

unavailability of parts. Air Force Logistics Command Regulation (AFLCR) 57-4 allows unusual delays caused by parts unavailability to be used in the requirements computation when the awaiting parts time is larger than average and affects sparing levels. Depending on the time characteristics, repair times could be understated by as much as 36 percent. These errors also are additive across all bases for each item.

PARAGRAH III-32 DEPOT PIPELINE

The MC&R identifies several problems with this variable: (1) Safety stock is not calculated. This is not consistent with either the Recoverable Consumption Item Requirement System commonly referred to as the D041 computations or other life-cycle cost models like the LSC model. (2) Depot repair cycle time needs to be changed to reflect the weighted average of CONUS and overseas bases and increased to account for the time expended on items before they are found to be unreparable. (3) Include and consider additional spares required to support depot repair programs such as programmed depot maintenance, engine overhaul, and repair of lower indentured items. (4) As with base stock, delays for awaiting parts should be added to the model. (5) Finally, the effects of "cannot duplicates" should be considered when computing the number of items being returned to depot.

PARAGRAPH V-1 ENGINEERING CHANGE ORDER FACTOR

The Engineering Change Order (ECO) factor is not applied to the cumulative spares inventory. (We concur this needs to be changed, but it raises a policy question as to whether this is a charge to Initial Spares or an inventory cost that will be charged to the stock fund.) Before program office estimates for ECO can be used in the LSC model, they must be reduced for ECOs that do not affect equipment configuration. If spares are delayed until design changes are made, ECO may have a less significant impact on spares.

PARAGRAPH VI-7 SRU FACTORS

Shop replaceable unit (SRU) factors are included in the LSC model to account for costs associated with SRU repairs and SRU spares when information is available only at the line replaceable unit (LRU) level.

- No SRU factors are developed for half of the two-digit work unit codes (WUCs). For these WUCs, the SRU factor is set to the default value of 1 (i.e., this implies that there are no SRUs).

- No validating studies exist for any of the SRU factors used in the model. This is important because SRU factors have a direct multiplicative effect on Initial Spares and should have a direct effect on condemnation spares and depot maintenance. (MC&R notes that because of coding errors, the LSC model does not use SRU factors to calculate condemnation spares.)
- SRU factors vary by type of LRU, but there is potential for estimating this variability.
- The overall validity of SRU factors has not been established.

APPENDIX C

AIRCRAFT BASELINE DATA

AIRCRAFT BASELINE DATA

TABLE C-1

C-5A OPERATIONAL AND MAINTENANCE DATA

C-5A	February 1990 – July 1990	Desert Shield/Storm August 1990 – January 1991
	Maintenance data	
MTBM(I)	0.49 hours	2.19 hours
MTBR	0.68 hours	3.01 hours
FMC High	57.15%	57.49%
Low	44.6%	27.04%
	Operational data	
Flying hours (FH)	12,817	55,029
FH/AC/month	29.67	120.41
Sorties	3,687	9,556
Sortie length (hours)	3.47	5.76
Sorties/AC/month	8.6	20.9
Landings/sortie	3.7	1.1

Source: MODAS = Air Force Maintenance and Operational Data Access System.

Notes: MTBM(I) = mean time between maintenance inherent failure; MTBR = mean time between removals; FMC = Full mission capability; AC = aircraft.

TABLE C-2

C-5A RECURRING FLYAWAY COST

Lot	Units	Cost per lot ($ millions)		Cumulative	
		Then-year	FY90	Units	FY90
1	8	376.10	1,424.62	8	1,424.62
2	18	553.00	1,996.39	26	3,421.01
3	27	677.20	2,327.15	53	5,748.16
4	23	587.10	1,918.63	76	7,666.79

Source: Weapon System Budget Estimate, Air Force Form 1537.

TABLE C-3

C-5A INITIAL SPARES BASELINE

C-5A, 4 Bases, 69 PAA, 458 FH/PAA/year				
Requirement	Cost breakout by subsystem and requirement (FY90 $ millions)			
	Engine	Avionics	Other	Total[a]
Order and ship	7.095	5.781	6.357	19.232
Base repair	3.660	2.306	2.494	8.459
Insurance	0.000	1.884	9.123	11.007
Negotiated	6.908	6.239	17.521	30.669
O/I depot repair[b]	27.966	13.938	16.644	58.548
Non-job-routed depot repair	5.346	0.996	13.455	19.796
Condemnation	47.083	2.029	34.455	83.979
Safety level	50.390	34.219	80.821	165.433
Total[a]	148.448	67.392	181.282	397.123

Source: AAM & D041.

Notes: PAA = primary aircraft authorization; O/I = organizational/intermediate.

[a] Totals may not add because of rounding.

[b] Depot repair of items that failed at base level.

TABLE C-4

C-5B OPERATIONAL AND MAINTENANCE DATA

C-5B	February 1990 – July 1990	Desert Shield/Storm August 1990 – January 1991
	Maintenance data	
MTBM(I)	1.16 hours	4.33 hours
MTBR	1.64 hours	6.02 hours
FMC High	63.5%	66.11%
Low	51.3%	38.9%
	Operational data	
Flying hours (FH)	17,430	53,172
FH/AC/month	58.30	177.24
Sorties	4,854	9,354
Sortie length (hours)	3.6	5.7
Sorties/AC/month	16.2	31.1
Landings/sortie	3.5	1.4

Source: MODAS = Air Force Maintenance and Operational Data Access System.

Notes: MTBM(I) = mean time between maintenance inherent failure; MTBR = mean time between removals; FMC = Full mission capability; AC = aircraft.

TABLE C-5

C-5B RECURRING FLYAWAY COST

Lot	Units	Cost per lot ($ millions)		Cumulative	
		Then-year	FY90	Units	FY90
1	1	304.30	400.39	1	400.39
2	4	784.20	955.18	5	1,355.57
3	8	1,147.30	1,351.35	13	2,706.93
4	16	1,789.90	2,052.64	29	4,759.56
5	21	1,927.00	2,150.67	50	6,910.23

Source: Weapon System Budget Estimate, Air Force Form 1537.

TABLE C-6

C-5B INITIAL SPARES BASELINE

C-5B, 4 Bases, 46 PAA, 697 FH/PAA/year				
Requirement	Cost breakout by subsystem and requirement (FY90 $ millions)			
	Engine	Avionics	Other	Total[a]
Order and ship	2.915	2.518	3.519	8.950
Base repair	1.426	0.817	1.249	3.491
Insurance	0.000	1.373	7.985	9.358
Negotiated	6.932	5.076	17.688	29.695
O/I depot repair[b]	11.401	6.720	11.829	29.951
Non-job-routed depot repair	2.224	0.462	10.779	13.465
Condemnation	19.270	0.790	18.505	38.564
Safety level	29.516	19.129	56.509	105.158
Total[a]	73.684	36.885	128.063	238.632

Source: AAM & D041.

Notes: PAA = primary aircraft authorization; O/I = organizational/intermediate.

[a] Totals may not add because of rounding.

[b] Depot repair of times that failed at base level.

TABLE C-7

C-141B OPERATIONAL AND MAINTENANCE DATA

C-141B	February 1990 – July 1990	Desert Shield/Storm August 1990 – January 1991
	Maintenance data	
MTBM(I)	1.46 hours	3.70 hours
MTBR	1.93 hours	4.76 hours
FMC High	37.8%	28.52%
Low	17.7%	10.6%
	Operational data	
Flying hours (FH)	130,081	235,563
FH/AC/month	93.31	147.32
Sorties	41,150	46,700
Sortie length (hours)	3.16	5.04
Sorties/AC/month	29.5	29.2
Landings/sortie	2.2	1.5

Source: MODAS = Air Force Maintenance and Operational Data Access System.

Notes: MTBM(I) = mean time between maintenance inherent failure; MTBR = mean time between removals; FMC = Full mission capability; AC = aircraft.

TABLE C-8

C-141B RECURRING FLYAWAY COST

Lot	Units	Cost per lot[a] ($ millions)		Cumulative	
		Then-year	FY90	Units	FY90
1	16	104.01	445.05	16	445.05
2	45	284.03	1,193.14	61	1,638.19
3	84	475.22	1,934.45	145	3,572.63
4	100	512.18	2,022.26	245	5,594.89
5	34	198.46	751.34	279	6,346.23

Source: Weapon System Budget Estimate, Air Force Form 1537.

[a] Without stretch modification.

TABLE C-9

C-141B INITIAL SPARES BASELINE

C-141B, 4 Bases, 247 PAA, 1,049 FH/PAA/year				
Requirement	Cost breakout by subsystem and requirement (FY90 $ millions)			
	Engine	Avionics	Other	Total[a]
Order and ship	7.296	28.457	9.936	45.690
Base repair	0.241	5.719	2.579	8.539
Insurance	0.000	0.306	0.649	0.955
Negotiated	0.276	6.365	4.394	11.036
O/I depot repair[b]	17.462	64.272	19.552	101.286
Non-job-routed depot repair	5.520	1.264	6.553	13.338
Condemnation	84.134	6.279	32.732	123.144
Safety level	47.217	49.846	42.247	139.308
Total[a]	162.146	162.508	118.642	443.296

Source: AAM & D041.

Notes: PAA = primary aircraft authorization; O/I = organizational/intermediate.

[a] Totals may not add because of rounding.

[b] Depot repair of times that failed at base level.

TABLE C-10

B-1B OPERATIONAL AND MAINTENANCE DATA

B-1B	February 1990 – July 1990	Desert Shield/Storm August 1990 – January 1991
	Maintenance data	
MTBM(I)	1.23 hours	1.14 hours
MTBR	1.51 hours	1.45 hours
FMC High	20.28%	48.39%[a]
Low	0.77%	14.3%
	Operational data	
Flying hours (FH)	13,749	9,300
FH/AC/month	28.41	16.15
Sorties	3,123	2,100
Sortie length (hours)	4.4	4.4
Sorties/AC/month	6.5	3.7
Landings/sortie	3.9	4.7

Source: MODAS = Air Force Maintenance and Operational Data Access System.

Notes: MTBM(I) = mean time between maintenance inherent failure; MTBR = mean ti e between removals; FMC = Full mission capability; AC = aircraft.

[a] During this period, the B-1B fleet was grounded.

TABLE C-11

B-1B RECURRING FLYAWAY COST

Lot	Units	Cost per lot ($ in millions)		Cumulative	
		Then-year	FY90	Units	FY90
1	1	669.5	857.2	1	857.2
2	7	1,885.0	2,276.6	8	3,133.8
3	10	2,089.9	2,429.3	18	5,563.1
4	34	4,824.3	5,415.0	52	10,978.1
5	48	5,826.3	6,312.4	100	17,290.5

Source: Weapon System Budget Estimate, Air Force Form 1537.

TABLE C-12

B-1B INITIAL SPARES BASELINE

B-1B, D041 Bases, baseline				
Requirement	Cost breakout by subsystem and requirement (FY90 $ millions)			
	Engine	Avionics	Other	Total[a]
Order and ship	14.627	41.531	18.712	74.868
Base repair	0.210	38.523	2.800	41.534
Insurance	4.834	2.204	7.226	14.265
Negotiated	6.026	35.460	17.273	58.760
O/I depot repair[b]	34.304	149.065	55.900	239.269
Non-job-routed depot repair	2.045	14.078	1.229	17.351
Condemnation	71.644	21.172	38.262	131.076
Safety level	82.561	271.720	132.323	486.605
Total[a]	216.251	573.753	273.725	1,063.728

Source: AAM & D041.

Notes: O/I = organizational/intermediate.

[a] Totals may not add because of rounding.

[b] Depot repair of times that failed at base level.

TABLE C-13

F-16A/B OPERATIONAL AND MAINTENANCE DATA

F-16A/B		February 1990 – July 1990	Desert Shield/Storm August 1990 – January 1991
		Maintenance data	
MTBM(I)		2.57 hours	2.93 hours
MTBR		2.50 hours	2.84 hours
FMC	High	74.55%	81.13%
	Low	60.54%	69.59%
		Operational data	
Flying hours (FH)		84,314	76,899
FH/AC/month		25.94	18.04
Sorties		61,336	55,884
Sortie length (hours)		1.4	1.4
Sorties/AC/month		23.6	16.4
Landings/sortie		1.1	1.1

Source: MODAS = Air Force Maintenance and Operational Data Access System.

Notes: MTBM(I) = mean time between maintenance inherent failure; MTBR = mean time between removals; FMC = Full mission capability; AC = aircraft.

TABLE C-14

F-16A/B RECURRING FLYAWAY COST

Lot	Units	Cost per lot ($ millions)		Cumulative	
		Then-year	FY90	Units	FY90
1	105	815.6	1,488.3	105	1,488.3
2	145	925.6	1,519.9	250	3,008.2
3	175	1,274.2	1,868.3	425	4,876.5
4	180	1,445.7	1,948.4	605	6,824.9
5	120	1,054.6	1,350.3	725	8,175.2
6	60	520.4	628.5	785	8,803.7

Source: Weapon System Budget Estimate, Air Force Form 1537.

TABLE C-15

F-16A/B INITIAL SPARES BASELINE

F-16A and F-16B, D041 Bases, baseline				
Requirement	Cost breakout by subsystem and requirement (FY90 $ millions)			
	Engine	Avionics	Other	Total[a]
Order and ship	6.301	19.974	4.928	31.203
Base repair	0.201	13.993	1.271	15.466
Insurance	0.000	1.102	4.553	5.657
Negotiated	2.022	51.626	84.284	137.932
O/I depot repair[b]	21.196	49.589	12.932	83.717
Non-job-routed depot repair	8.704	12.313	38.787	59.804
Condemnation	96.878	15.112	84.858	196.848
Safety level	57.875	111.463	34.116	203.451
Total[a]	193.177	275.173	265.729	734.079

Source: AAM & D041.

Notes: O/I = organizational/intermediate.

[a] Totals may not add because of rounding.

[b] Depot repair of times that failed at base level.

TABLE C-16

F-16C/D OPERATIONAL AND MAINTENANCE DATA

F-16C/D	February 1990 – July 1990	Desert Shield/Storm August 1990 – January 1991
	Maintenance data	
MTBM(I)	3.54 hours	4.88 hours
MTBR	3.65 hours	5.32 hours
FMC High	90.14%	90.61%
Low	85.69%	87.63%
	Operational data	
Flying hours (FH)	130,525	134,581
FH/AC/month	42.16	24.19
Sorties	94,754	89,432
Sortie length (hours)	1.4	1.5
Sorties/AC/month	30.1	16.1
Landings/sortie	1.0	1.0

Source: MODAS = Air Force Maintenance and Operational Data Access System.

Notes: MTBM(I) = mean time between maintenance inherent failure; MTBR = mean time between removals; FMC = Full mission capability; AC = aircraft.

TABLE C-17

F-16C/D RECURRING FLYAWAY COST

Lot	Units	Cost per lot ($ millions)		Cumulative	
		Then-year	FY90	Units	FY90
1	60	972.6	1,174.7	60	1,174.7
2	144	1,538.1	1,780.2	204	2,954.9
3	150	1,713.7	1,923.3	354	4,878.2
4	180	1,900.7	2,059.3	534	6,937.5
5	180	2,017.9	2,099.8	714	9,037.3
6	180	2,106.2	2,087.4	894	11,124.7
7	180	2,306.8	2,197.0	1,074	13,321.7
8	150	1,996.8	1,828.6	1,224	15,150.3
9	108	1,852.0	1,634.6	1,332	16,784.9
10	48	963.6	820.8	1,380	17,605.7
11	24	625.1	514.5	1,404	18,120.2

Source: Weapon System Budget Estimate, Air Force Form 1537.

TABLE C-18

F-16C/D INITIAL SPARES BASELINE

F-16C and F-16D, D041 Bases, baseline				
Requirement	Cost breakout by subsystem and requirement (FY90 $ millions)			
	Engine	Avionics	Other	Total[a]
Order and ship	30.839	89.267	12.105	132.212
Base repair	2.196	26.599	5.014	33.810
Insurance	0.087	2.567	2.096	4.749
Negotiated	82.328	448.663	108.616	639.608
O/I depot repair[b]	145.339	338.384	30.708	514.431
Non-job-routed depot repair	11.438	12.028	11.973	35.437
Condemnation	206.460	32.025	111.246	349.730
Safety level	88.940	94.801	47.505	231.250
Total[a]	567.627	1,044.334	329.263	1,941.227

Source: AAM & D041.

Notes: O/I = organizational/intermediate.

[a] Totals may not add because of rounding.

[b] Depot repair of times that failed at base level.

TABLE C-19

F-15A/B OPERATIONAL AND MAINTENANCE DATA

F-15A/B		February 1990 – July 1990	Desert Shield/Storm August 1990 – January 1991
		Maintenance data	
MTBM(I)		1.70 hours	1.79 hours
MTBR		1.72 hours	1.86 hours
FMC	High	79.85%	85.22%
	Low	64.3%	72.44%
		Operational data	
Flying hours (FH)		40,103	38,011
FH/AC/month		28.02	17.61
Sorties		31,180	30,460
Sortie length (hours)		1.3	1.2
Sorties/AC/month		25.5	16.0
Landings/sortie		1.1	1.1

Source: MODAS = Air Force Maintenance and Operational Data Access System.

Notes: MTBM(I) = mean time between maintenance inherent failure; MTBR = mean time between removals; FMC = Full mission capability; AC = aircraft.

TABLE C-20

F-15A/B RECURRING FLYAWAY COST

Lot	Units	Cost per lot ($ millions)		Cumulative	
		Then-year	FY90	Units	FY90
1	30	374.2	1,019.6	30	1,019.6
2	62	668.4	1,646.3	92	2,665.9
3	72	742.9	1,684.6	164	4,350.5
4	108	1,193.6	2,578.0	272	6,928.5
5	132	1,495.9	2,991.8	404	9,920.3

Source: Weapon System Budget Estimate, Air Force Form 1537.

TABLE C-21

F-15A/B INITIAL SPARES BASELINE

F-15A and F-15B, D041 Bases, baseline				
Requirement	Cost breakout by subsystem and requirement (FY90 $ millions)			
	Engine	Avionics	Other	Total[a]
Order and ship	8.131	12.540	4.927	25.597
Base repair	0.910	16.278	1.478	18.665
Insurance	0.000	2.551	5.246	7.798
Negotiated	5.046	21.597	6.487	33.131
O/I depot repair[b]	23.975	23.456	13.123	60.553
Non-job-routed depot repair	7.644	8.331	1.052	17.025
Condemnation	61.226	11.565	29.832	102.623
Safety level	64.644	107.655	50.908	223.210
Total[a]	171.576	203.973	113.053	488.602

Source: AAM & D041.

Notes: O/I = organizational/intermediate.

[a] Totals may not add because of rounding.

[b] Depot repair of times that failed at base level.

TABLE C-22

F-15C/D OPERATIONAL AND MAINTENANCE DATA

F-15C/D	February 1990 – July 1990	Desert Shield/Storm August 1990 – January 1991
	Maintenance data	
MTBM(I)	2.07 hours	4.13 hours
MTBR	2.11 hours	4.36 hours
FMC High	85.84%	85.43%
Low	77.31%	72.43%
	Operational data	
Flying hours (FH)	63,203	74,480
FH/AC/month	38.59	28.94
Sorties	46,606	41,299
Sortie length (hours)	1.4	1.8
Sorties/AC/month	27.6	16.1
Landings/sortie	1.0	1.0

Source: MODAS = Air Force Maintenance and Operational Data Access System.

Notes: MTBM(I) = mean time between maintenance inherent failure; MTBR = mean time between removals; FMC = Full mission capability; AC = aircraft.

TABLE C-23

F-15C/D RECURRING FLYAWAY COST

Lot	Units	Cost per lot ($ millions)		Cumulative	
		Then-year	FY90	Units	FY90
1	97	1,275.6	2,327.7	97	2,327.7
2	78	1,124.6	1,846.6	175	4,174.3
3	60	956.9	1,403.1	235	5,577.4
4	42	824.5	1,111.2	277	6,688.6
5	36	863.3	1,105.4	313	7,794.0
6	39	944.2	1,140.3	352	8,934.3
7	36	1,008.1	1,166.8	388	10,101.1
8	42	1,252.5	1,405.7	430	11,506.8
9	40	1,060.6	1,149.1	470	12,655.9

Source: Weapon System Budget Estimate, Air Force Form 1537.

TABLE C-24

F-15C/D INITIAL SPARES BASELINE

F-15C and F-15D, D041 Bases, baseline				
Requirement	Cost breakout by subsystem and requirement (FY90 $ millions)			
	Engine	Avionics	Other	Total[a]
Order and ship	10.965	24.953	7.078	42.997
Base repair	1.349	27.583	2.245	31.178
Insurance	0.000	2.887	1.623	4.510
Negotiated	10.321	27.245	6.821	44.387
O/I depot repair[b]	31.451	63.089	17.759	112.298
Non-job-routed depot repair	10.306	13.384	1.594	25.286
Condemnation	88.873	22.267	44.555	155.694
Safety level	84.215	166.271	72.292	322.777
Total[a]	237.480	347.680	153.967	739.128

Source: AAM & D041.

Notes: O/I = organizational/intermediate.

[a] Totals may not add because of rounding.

[b] Depot repair of items that failed at base level.

TABLE C-25

F-15E OPERATIONAL AND MAINTENANCE DATA

F-15E		February 1990 – July 1990	Desert Shield/Storm August 1990 – January 1991
		Maintenance data	
MTBM(I)		2.73 hours	3.67 hours
MTBR		2.99 hours	4.79 hours
FMC	High	78.04%	82.94%
	Low	0.31%	74.9%
		Operational data	
Flying hours (FH)		11,764	15,639
FH/AC/month		72.62	24.21
Sorties		7,293	8,213
Sortie length (hours)		1.6	1.9
Sorties/AC/month		45.4	12.7
Landings/sortie		1.2	1.2

Source: MODAS = Air Force Maintenance and Operational Data Access System.

Notes: MTBM(I) = mean time between maintenance inherent failure; MTBR = mean time between removals; FMC = Full mission capability; AC = aircraft.

TABLE C-26

F-15E RECURRING FLYAWAY COST

Lot	Units	Cost per lot ($ millions)		Cumulative	
		Then-year	FY90	Units	FY90
1	8	237.6	257.4	8	257.4
2	42	1,235.5	1,285.6	50	1,543.0
3	42	1,171.6	1,161.1	92	2,704.1
4	36	1,238.6	1,179.6	128	3,883.7
5	36	1,197.8	1,096.9	164	4,980.6
6	36	1,202.5	1,061.3	200	6,041.9

Source: Weapon System Budget Estimate, Air Force Form 1537.

TABLE C-27

F-15E INITIAL SPARES BASELINE

F-15E, D041 Bases, baseline				
Requirement	Cost breakout by subsystem and requirement (FY90 $ millions)			
	Engine	Avionics	Other	Total[a]
Order and ship	2.593	46.147	4.943	53.683
Base repair	0.493	25.814	5.633	31.939
Insurance	0.000	1.387	0.911	2.298
Negotiated	10.564	60.903	10.188	81.655
O/I depot repair[b]	5.878	125.284	13.977	145.140
Non-job-routed depot repair	5.063	5.922	0.299	11.283
Condemnation	39.427	6.134	12.840	58.400
Safety level	34.433	111.637	38.054	184.126
Total[a]	98.451	383.228	86.845	568.524

Source: AAM & D041.

Notes: O/I = organizational/intermediate.

[a] Totals may not add because of rounding.

[b] Depot repair of times that failed at base level.

APPENDIX D

AN ESTIMATE PREPARED USING SUGGESTED REVISIONS TO THE FACTOR-BASED MACRO METHODOLOGY

AN ESTIMATE PREPARED USING SUGGESTED REVISIONS TO THE FACTOR-BASED MACRO METHODOLOGY

Our study found that factor-based, macro estimating methods for Initial Spares must be sensitive to the major cost drivers. Traditional Initial Spares factors are seldom adjusted for differences in operating tempo (OPTEMPO), reliability, or flyaway cost equipment distribution between the historical weapon system and the new aircraft. This appendix illustrates how Initial Spares estimates can be prepared that are explicitly adjusted for the important cost drivers. For this illustration, we choose to adjust C-5B data to reflect characteristics of the C-17A aircraft and compare this macro estimate with the Initial Spares estimate developed for the annual update to the C-17A program office cost estimate.

Since Logistics Management Institute (LMI) did not have access to shipset data for the C-17A, this example will be based on flyaway cost. The C-5B aircraft was chosen not because it is the best analog to the C-17A, but rather, because it is the only airlift aircraft for which flyaway costs may still be assumed to reflect the same configuration as represented by the D041 spares baseline.

STEP 1

We used the Aircraft Availability Model (AAM) to develop a C-5B Initial Spares baseline.[1]

STEP 2

This baseline was then recalculated for the following C-17A operating conditions used in the Air Force estimate [all but mean time between removal (MTBR) are direct inputs to the AAM].

- Annual flying hours: 1,432 per previous aircraft authorization
- Basing concept: 4 active CONUS bases
- Availability target: 82.5 percent
- MTBR: 2.8 hours

[1]See Appendix C for the results.

STEP 3

For the C-17A reliability, we assumed that fielded on-equipment removal data for a mature C-17A weapon system would equal the C-17A MTBR goal of 2.8 hours. Field-reported MTBR data include on-equipment[2] removals for both investment and expense[3] items. Because the AAM data base contains only investment items, field-reported MTBR data cannot be used directly for this analysis. Instead, MTBR data were first used to identify the relative improvement between the C-5B and the C-17AA and then this improvement factor was used to adjust the demand data in the AAM. (Implied in this adjustment is that both investment and expense items will experience the same change.) If the ratio of $MTBR_{C\text{-}17AA}/MTBR_{C\text{-}5B} = 1.5$, the C-5B mean time between demand data are multiplied by 1.5.

Because of the different spares requirements by equipment category, improvement ratios were calculated for each equipment category used in Chapter 4 (i.e., engine, avionics, and airframe).[4] Table D-1 summarizes the calculations.

TABLE D-1

MTBR IMPROVEMENT CALCULATIONS

Equipment category	C-5B MTBR (hours)	C-17A MTBR (hours)	Improvement ratio
Engine components	22.8	44.7	1.96
Avionics components	6.6	9.9	1.51
Airframe components	2.3	4.3	1.85
Total	1.59	2.8	1.76

Source: Air Force Maintenance and Operational Data Access System, March – July 1990 and ASD/PA&E.

Note: Standard report extracts give data in 6-month increments. In August, airlift activities of Desert Shield started. Flying activities jumped to three times normal levels. Inclusion of August 1990 data changed MTBR by 37 percent over the average encountered in the 5 previous months.

[2]On-equipment removals only include those items removed from the aircraft itself. They do not include removal of an item to facilitate maintenance of another item nor, do they include items removed from the component at the base or depot repair facility.

[3]Expense items are bought with Operations and Maintenance appropriations. These are sometimes referred to as throwaway items. While descriptive, the term is not accurate because some investment items are also throwaway items.

[4]MTBR data were grouped into these three categories based on the two-digit work unit code (WUC).

STEP 4

With these changes to the C-5B data base, outputs from the AAM were used to construct Initial Spares factors for the three equipment groups (Engine, Avionics, and Airframe) reported in the Air Force Form 1537. Air Force Form 1537 data were used to calculate the C-5B flyaway costs for each equipment group. Table D-2 summarizes these calculations.

TABLE D-2

C-5B INITIAL SPARES FACTORS
Using C-17 OPTEMPO and MTBR = 2.8

(FY90 dollars)

	Engines	Avionics	Airframe	Total
Spares inventory value	$76.7	$45.2	$138.6	$260.4
C-5B flyaway cost	$829.2	$138.1	$5,942.9	$6,910.2
C-5B IS factor	9.2%	32.7%	2.3%	3.8%

STEP 5

The next step is to take the C-5B Initial Spares (IS) factors by equipment category and weight them for the distribution of C-17A flyaway cost. These calculations are summarized in Table D-3. The C-5B factor adjusted for C-17 OPTEMPOs, reliability, basing concepts, and equipment density is 4.8 percent of recurring flyaway.

STEP 6

Apply the adjusted Initial Spares factor to the C-17A recurring flyaway cost. The C-17A recurring flyaway cost is $23,595.5 (then-year dollars in millions). Using the adjusted Initial Spares factor of 4.8 percent of recurring flyaway cost, produces a funding requirement of $1,132.8 million.

STEP 7

The results of Step 6 will not yield an estimate of the total Initial Spares that can be compared with the Air Force estimate. To this must be added (1) whole engines and modules not included in the D041 database, (2) forward support spares

TABLE D-3

C-5B INITIAL SPARES FACTOR

(Weighted for C-17 flyaway cost)

Equipment Category	C-5B IS factor (% of equipment category flyaway)		C-17[2] flyaway cost distribution		Adjusted C-5B IS factor (% of total flyaway)
Engine	9.2	X	.129	=	1.2
Avionics	32.7	X	.054	=	1.8
Airframe	2.3	X	.817	=	1.9
Total					4.8

Source: Table D-2 and Weapon System Budget Estimate, Air Force Form 1537.

needed to support worldwide airlift missions, (3) spares for support equipment and training equipment, and (4) provisioning data.

We prepared a separate estimate for forward support speres, throughput Air Force estimates for whole engine and engine modules, support and training equipment spares, and provisioning data. A spreadsheet was developed to convert Air Force C-17A estimates into FY90 dollars, to combine the factor estimates and the throughput from the C-17A estimate, and to convert the time-phased funding requirements into then-year dollars. Adding these throughputs to the results of Step 6 yields an estimate of $1.979 billion (in then-year dollars).

Table D-4 presents a comparison of the two estimates. On the surface, these two estimates appear to be very close (within 4 percent). However, when the assumptions underlying these estimates are compared, the two estimates are too close to be reasonable. The Air Force estimate is based on an MTBR of 4.4 hours, the adjusted factor estimate is based on an MTBR of 2.8 hours. Based on the elasticity ratio for MTBR, we would expect the two estimates to be much further apart.

A presentation given to personnel from Assistant Secretary of Defense (Program Analysis and Evaluation) [ASD(PA&E)] by the C-17A Independent Technical Assessment (ITA) team provides a possible explanation. According to the C-17A ITA team, the MTBR used in the Air Force C-17A estimate is calculated using the C-17A MTBR contract specification and does not include removals for throwaway items. Therefore, these MTBRs cannot be compared with data from the Air Force

TABLE D-4

C-17 INITIAL SPARES ESTIMATES

Air Force C-17 Initial Spares	$2.054 billion
Adjusted factor methodology	$1.979 billion

Maintenance Data Collection System (D056). The ITA team claims that to be comparable with D056 data, the C-17A MTBR would have to be derated by 0.6. Thus, the C-17A MTBR of 4.4 hours would equate to a D056 MTBR of 2.66 hours. The adjusted cost factor estimate was made by adjusting C-5B data for reparable items by the ratio of C-5B D056 MTBR data to the contractually guaranteed MTBR of 2.8. When the difference in definitions is accounted for, both estimates are based on nearly the same MTBR (2.66 for the Air Force estimate and 2.8 for the adjusted factor). Putting these estimates on the same MTBR, 2.66 hours, would increase the adjusted factor estimate by approximately $.04 billion. This change makes the comparison between the two estimates even closer ($2.054 billion versus $2.019 billion). Had the C-5B actuals been used without adjustment, the estimate for the C-17A would be $1.622 billion or 21 percent lower than the Air Force estimate.

APPENDIX E

GLOSSARY

GLOSSARY

AAM	=	aircraft availability model
ASD(PA&E)	=	Assistant Secretary of Defense (Program Analysis and Evaluation
AFLC	=	Air Force Logistics Command
AFLCR	=	Air Force Logistics Command Regulation
BPC	=	base processing factor
BRCT	=	base repair cycle time
CAIG	=	Cost Analysis Improvement Group
CER	=	cost estimating relationships
CONUS	=	Continental United States
DAB	=	Defense Acquisition Board
DRCT	=	depot repair cycle time
DS/DS	=	Desert Shield/Desert Storm
ECO	=	engineering change order
FH	=	flying hours
ICA	=	independent cost analysis
ICS	=	interim contractor support
IS	=	Initial Spares
ISB	=	initial spares baseline
LMI	=	Logistics Management Institute
LRU	=	line replaceable unit
LSC	=	logistics support cost
MC&R	=	Management Consulting & Research, Inc.
MTBM(I)	=	mean time between maintenance inherent failures

MTBR	=	mean time between removals
OPTEMPO	=	operating tempo
O&S	=	operating and support
PAA	=	primary aircraft authorization
PLT	=	procurement lead time
POM	=	program objective memorandum
POS	=	peacetime operating stocks
PPBS	=	programming, planning, and budgeting system
PSE/ATE	=	peculiar support equipment/automatic test equipment
R&M	=	reliability and maintainability
RS	=	Replenishment Spares
SAR	=	selected acquisition reporting
SRU	=	shop replaceable unit
WUC	=	work unit code