# NAVAL POSTGRADUATE SCHOOL
# MONTEREY, CALIFORNIA



# THESIS

**ANALYSIS OF F/A-18 ENGINE MAINTENANCE COSTS USING THE BOEING DEPENDABILITY COST MODEL**

by

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December, 1994

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# REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188



| | | |
|---|---|---|
| 1. AGENCY USE ONLY *(Leave blank)* | 2. REPORT DATE December 1994 | 3. REPORT TYPE AND DATES COVERED Master's Thesis |

| | |
|---|---|
| 4. TITLE AND SUBTITLE ANALYSIS OF F/A-18 ENGINE MAINTENANCE COSTS USING THE BOEING DEPENDABILITY COST MODEL | 5. FUNDING NUMBERS |
| 6. AUTHOR(S) Thomas A. Meadows | |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey CA 93943-5000 | 8. PERFORMING ORGANIZATION REPORT NUMBER |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) | 10. SPONSORING/MONITORING AGENCY REPORT NUMBER |

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

| | |
|---|---|
| 12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited. | 12b. DISTRIBUTION CODE |

13. ABSTRACT *(maximum 200 words)*

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This research concluded that the Dependability Cost Model is a powerful management tool in the analysis of aircraft maintenance system costs. However, its use as a budget estimation tool in a rapidly changing cost environment presented a number of difficulties and yielded marginal results.

| | |
|---|---|
| 14. SUBJECT TERMS Engine Maintenance Costs, Computer Modeling, GE-F404 Engine | 15. NUMBER OF PAGES 128 |
| | 16. PRICE CODE |

| | | | |
|---|---|---|---|
| 17. SECURITY CLASSIFICATION OF REPORT Unclassified | 18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified | 19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified | 20. LIMITATION OF ABSTRACT UL |

NSN 7540-01-280-5500 Standard Form 298 (Rev. 2-89)

Prescribed by ANSI Std. 239-18 298-102

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# ANALYSIS OF F/A-18 ENGINE MAINTENANCE COSTS USING THE BOEING DEPENDABILITY COST MODEL

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Submitted in partial fulfillment
of the requirements for the degree of

**MASTER OF SCIENCE IN MANAGEMENT**

from the

**NAVAL POSTGRADUATE SCHOOL**
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## ABSTRACT

This thesis explores the use of a computerized aircraft maintenance system cost model to analyze the F/A-18 engine maintenance system. The Dependability Cost Model is a Paradox Data Base model, developed by the Boeing Corporation, and is currently used in the airline industry to estimate costs associated with maintaining aircraft or the implementation of service bulletin changes to the aircraft. Research was conducted to determine the feasibility of adapting this model to the F/A-18 using existing maintenance information systems, and the possibility of forecasting future funding requirements driven by engine component service life changes.

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# I. INTRODUCTION

The U. S. Navy is evolving into a more streamlined organization due to an ever-changing fiscal climate and tightening financial constraints. Optimizing the use of our financial resources is one of many key factors essential to maintaining the desired operational readiness in light of the current budgetary environment. Naval aviation must seek opportunities to increase the effectiveness and efficiency of every dollar spent. Through the use of the latest decision support technology available to highlight areas of high maintenance costs, the Navy can maximize the benefit derived from each and every maintenance dollar.

## A. BACKGROUND

Budgeting for maintenance costs within the F/A-18 aircraft system has been a dynamic problem in recent history due, in part, to changing service life requirements within the engine components. Many of the changes within the system have occurred so rapidly that our budgeting system has not had sufficient time to react and, at times, this problem has severely strained current funding levels. Predicting the impact of the short term adjustments on available funds as well as forecasting the future funding required in light of a major component service life change is a difficult task. This thesis proposes to examine the feasibility of using a computerized decision support model, developed by the Boeing Company, to estimate the funding requirements driven by changes in service life, failure rates, prices and other factors.

Currently, the McDonnell Douglas F/A-18 maintenance program uses the NALCOMIS system to record and analyze data. The information collected by this system is periodically downloaded into the NALDA data base. It contains an enormous volume of historical information that could be a valuable resource providing input data for the Boeing model. Application of a computer model to the available data could provide a valuable insight to potential cost savings within the F/A-18 system or predictions of future funding requirements driven by changes in component service life.

Boeing began to investigate a new perspective on aircraft maintenance cost in 1990. This focus was directed toward the dependability of their aircraft. Through this effort, a computerized methodology was developed and was called the Dependability Cost Model (DCM). A major advantage to this approach was the identification of relatively few items that absorbed a large portion of the overall dollars. Boeing found, from over 3000 items included in the data base, approximately 300 were responsible for over 80 percent of the costs. Once identified, these items can be upgraded or redesigned to reduce future maintenance cost. Additionally, use of this model allows the airline industry to evaluate the economic benefits of a system change through a comparison of the existing system with a proposed system over the entire life of that system.

The DCM has the capability to analyze the cost of maintaining an aircraft system to a level of detail limited only by available information and computer hardware. A similar spreadsheet model (Customer Cost Benefit Model) developed within Boeing performs a similar calculation, but is limited to 35 component inputs. By using a data base model built with Paradox software, user flexibility is greatly improved and input data is limited only by available computer memory. This thesis applies the DCM to the engine system of the F/A-18, but the method could be expanded and applied on a much broader scale, encompassing other systems or the entire aircraft. Output from the model could provide information for potential reduction of costs through modification of an existing system or show the cost impact of a service life change on the existing system.

As our financial resources are constricted, the efficient use of available funding becomes imperative. A detailed analysis of the cost drivers for a maintenance system will provide a better understanding of the overall process and place the decision maker in a better position to allocate these resources in the most effective manner.

## B. OBJECTIVES

The purpose of this thesis is to assess the practicality of using a computerized aircraft maintenance cost model with the existing maintenance information systems used by the U. S. Navy. Information collected by the NALCOMIS system and compiled in the Navy's maintenance information systems will be used to provide inputs for the model. Output from the model can give decision makers insight into the areas of high costs, and these areas can be targeted for reduction efforts. In addition to an analysis of historical cost drivers the model can provide predictions of future costs due to changes within the maintenance system. This information could be used as a budgeting tool to assess the impact of a change on current funding levels or aid in the determination of future funding levels.

## C. RESEARCH QUESTIONS

The primary focus of this research is to investigate whether a computerized maintenance cost model used in the airline industry has potential applicability to Naval Aviation. Recently, the U. S. Navy has begun to use the NALCOMIS system to record and track F/A-18 maintenance data. If the data can be manipulated to provide reasonable inputs, computer models could be valuable decision making tools for both redesign and/or budgetary decisions. Thus, the secondary question of this thesis is, Can the information contained in the NALDA data base be applied to the Boeing Dependability Cost Model?

## D. SCOPE OF THESIS

The model was designed for analysis of the entire maintenance system of a commercial aircraft fleet, but calculations can be restricted to specific aircraft systems. This research effort has been limited to the organizational and intermediate maintenance levels and the engine system of the F/A-18 (F404-GE-400).

## E. THESIS PREVIEW

The following chapter will present the Dependability Cost Model. It contains information concerning the data required and the manipulation of that data into cost outputs. Chapter III discusses the construction of a data base containing F/A-18 data taken from Navy's maintenance information systems. Also, simplifying assumptions and further scope limitations driven by the access to existing data are discussed. Chapter IV presents the output derived from the data base constructed during this research effort. It breaks down the costs incurred to the engine modules driving the costs and gives an additional example of a detailed analysis on the afterburner module. Chapter V will discuss issues concerning the adaptation of the model to the Navy's maintenance organization and the F/A-18. The final chapter will summarize the research results, discuss the implications of this research to the U. S. Navy and provide recommendations on further research in this area.

## II. DEPENDABILITY COST MODEL

Boeing defines dependability as the ability of an aircraft to meet schedules, have low maintenance costs, be easily repaired and quickly restored to flying condition [Ref. 1]. Dependability costs are a portion of the ownership costs and incorporate some elements of operating costs. These costs are summarized in Table 2.1 and include maintaining the aircraft, having spare parts available and the cost of schedule interruptions.

| Ownership Costs | Dependability Costs |
|---|---|
| Acquisition Costs | Operating Costs<br>Line Maintenance<br>Shop Maintenance<br>Scheduled Maintenance<br>Spares Costs<br>Schedule Interruptions |
| Administrative Costs | |
| Installation Costs | |
| Training Costs | |
| Operating Costs<br>Line Maintenance<br>Shop Maintenance<br>Scheduled Maintenance<br>Spares Costs<br>Fuel Costs<br>Schedule Interruptions | |

Table 2.1 Ownership Costs Versus Dependability Costs

The company began investigating the possibility of measuring aircraft performance by more than schedule reliability, the traditional method, and research led to the concept of dependability dollars per flight hour. Boeing developed the Dependability Cost Model (DCM) to calculate and analyze the costs associated with this concept and through this model created a broader understanding of the complex cost drivers within their aircraft maintenance systems.

## A. INTRODUCTION

The concept of dependability costs for aircraft is an economic indicator containing all the elements mentioned in the above definition. Specifically, these elements are line maintenance, shop maintenance, scheduled maintenance, cost of holding spare parts and schedule interruptions. These dependability cost elements are used to determine the cost drivers within the maintenance system, and the DCM allows the user to compare various system modifications, highlighting the high cost areas of an operational or proposed system.

Cost outputs from the DCM are generated from three data bases, each containing information simulating a portion of the maintenance system. Flexibility exists within the model to examine one aircraft, a mixed fleet of aircraft, compare an existing system with a proposed system, or calculate costs using as few or as many component inputs as desired. The outputs can be expressed in annual cost per airplane, annual cost per component, annual cost per fleet or a present value of the fleet for a specified number of years. This allows the user a method of cost analysis which detects areas of high costs. Through a greater understanding of the associated cost drivers, the user can exercise options to reduce the overall cost of operations.

Boeing was able to identify a relatively small number of components responsible for a high percentage of the overall costs [Ref. 2]. For example, the exterior lighting system of the 737 aircraft was found to absorb a much larger portion of cost than expected. Conventional thinking would have never suspected the light bulbs of a multi-million dollar aircraft to contribute a significant amount to the total operating costs. However, once the high removal rates, labor costs and aircraft downtime associated with the bulb failure are factored into the overall picture, this system was found to be quite costly. Through redesign of the exterior lighting covers for quick access, the labor involved was substantially reduced, thereby reducing the overall aircraft maintenance costs. This example illustrates the potential embodied within the model for analysis of an operating maintenance system.

A key feature of the model allows the user to compare two systems by assessing the economic impact resulting from a service bulletin change or other possible maintenance modifications. This lends itself to use as a cost/benefit analysis tool for the airlines or for military usage, perhaps a budgeting tool. If a system change is required, the costs can be predicted with reasonable accuracy for adjustments in current funding or for future requirements.

## B. COST ELEMENTS

The DCM uses five primary cost elements [Ref. 3]. These are line maintenance costs, shop maintenance costs, spares costs, scheduled maintenance costs, and schedule interruption costs. Each of these elements will vary in relative importance as the component reliability, price and other factors of the maintenance system interact.

### 1. Line Maintenance Costs

Line maintenance costs are defined as the costs to perform unscheduled labor on a component that occurs on the line. It encompasses the frequency of unscheduled maintenance actions, time to perform those actions and any other actions required to restore the aircraft to a flying condition. Total line maintenance costs are further divided into removal activities and non-removal activities. Line removal activity costs are calculated from the product of aircraft flights, average flight hours, number of aircraft, quantity per aircraft, labor rates, overhead burden factor and average maintenance hours per each removal. This product is then divided by the mean time between unscheduled removal, yielding a cost for line removal activities as shown in Equation (1) below.

$$LLABREM=\frac{Flts*NA*Qty*Aveflthr*Mnthrrem*Dirlab*(1+Bf)}{MTBUR} \quad (1)$$

where:

LLABREM = Line labor costs for removal activities;
Flts = Flights per year per airplane;
NA = Number of airplanes in the fleet;
Qty = Component quantity per airplane;
Aveflthr = Average flight hours per flight;
Mnthrrem = Average maintenance hours per removal;
Dirlab = Direct labor hour rate;
Bf = Burden factor;
MTBUR = Mean time between unscheduled removal.

Non-removal activity costs are calculated in a similar fashion with the primary difference being that the number of maintenance actions for non-removal per 1000 flight hours is used instead of the average maintenance hours per removal and 1000 hours is used in the denominator. The formula shown in Equation (2) represents line labor maintenance costs for non-removal activities.

$$LLABMA = \frac{Flthr * Qty * Mntnorem * Mnthrnorem * Dirlab * (1+Bf)}{1000} \quad (2)$$

where:

LLABMA = Line maintenance costs for non-removals;

Flthr = FLTS*NA*AVEFLTHR;

Mntnorem = Non-removal maintenance actions/1000 hours;

Mnthrnorem = Non-removal maintenance action hours.

Total line maintenance costs are derived from the sum of the removal and non-removal line maintenance costs.

**2. Shop Maintenance Costs**

Shop maintenance costs include both the labor and material costs associated with any maintenance action performed in the shop to restore the component to an operating state [Ref. 4]. These costs are sub-divided into labor and materials for unscheduled removals, labor and materials for scheduled removals and outside maintenance costs. Boeing found specific data on individual components was much harder to collect with the desired precision; in some cases the total shop labor hours and total shop material were divided by the number of components passing through the shop to derive an average used in the calculation. However, a provision was built into the model to allow for the case of actual material cost for a specific component that could be separated from the whole. A material cost basis field in the component data base allows the model to determine the proper algorithm to be used for shop material costs.

Shop labor costs for unscheduled removals are calculated by the product of annual flights, number of aircraft, average flight time, quantity of the component per aircraft, shop labor average time, labor rate and the burden factor. This number divided by the mean time between unscheduled removal yields the shop labor costs for unscheduled removals. Equation (3) presents the details.

$$SHOPLAB=\frac{Flts*NA*Aveflthr*Qty*Slabhr*Dirlab*(1+Bf)}{MTBUR} \quad (3)$$

where:

SHOPLAB = Shop labor for unscheduled removals;
Slabhr = Shop labor average time to repair.

Shop labor costs for a scheduled removal is a similar calculation but uses overhaul labor average time instead of shop labor average time in the numerator and mean time between overhauls as the denominator. This is shown in Equation (4).

$$OVRLAB=\frac{Flts*Aveflthr*NA*Qty*Ovrlabhr*Dirlab*(1+Bf)}{MTBO} \quad (4)$$

where:

OVRLAB = Shop labor for scheduled removals;
Ovrlabhr = Overhaul shop labor average time;
MTBO = Mean time between overhaul.

Shop material costs for an unscheduled removal are determined by using one of two methods depending on the material cost basis field mentioned in the opening paragraph of this section. If it is necessary to use the average data, the denominator of the algorithm is the mean time between unscheduled removals as shown in Equation (5).

$$SHOPMAT=\frac{Flts*Aveflthr*NA*Qty*Smatfail}{MTBUR} \quad (5)$$

where:

SHOPMAT = Shop material for unscheduled removals;

Smatfail = Shop material average costs.

If more precise shop material data is available for the specified component, the mean time between failures is used in the denominator, as shown in Equation (6).

$$SHOPMAT=\frac{Flts*Aveflthr*NA*Qty*Smatfail}{MTBF} \quad (6)$$

where:

SHOPMAT = Shop material for unscheduled removals;

Smatfail = Shop material average costs;

MTBF = Mean time between failures.

For calculation of shop material costs for scheduled removals, the value for shop material average costs is replaced with the overhaul material costs in the numerator and mean time between overhaul in the denominator. This is shown in Equation (7).

$$TOVERMAT = \frac{Flts*Aveflthr*Qty*NA*Ovramat}{MTBO} \quad (7)$$

where:

TOVERMAT = Shop material costs for scheduled removals;

Overmat = Overhaul shop material average per removal.

The remaining portion of the total shop cost is the outside maintenance costs. This captures the miscellaneous costs such as shipping and any maintenance performed by an outside source and is calculated via Equation (8).

$$TOUTCOSTS = \frac{Flts*Aveflthr*NA*Qty*Outcost}{MTBUR} \quad (8)$$

where:

TOUTCOSTS = Outside maintenance costs;

Outcost = Cost of outside maintenance, shipping, etc.

Total shop maintenance costs for a component are then calculated from the sum of the above mentioned labor costs, the appropriate material costs and the outside maintenance costs.

### 3. Spares Costs

Spares costs comprise the next element of dependability costs. The model provides the user a calculated number of spares, given a probability of having a spare on hand at the time of failure, or allows the user to set the desired number of spares. A field in the component data base contains the desired number of spares to be held, but if this field is left blank, the model calculates the required number of spares based on a Poisson distribution. Data on component reliability and shop turnaround time are used in this calculation as well. Equations (9) and (10) build up the components of the spares calculation shown in Equation (11).

$$RR=\frac{1}{MTBO}+\frac{1}{MTBUR} \tag{9}$$

where:

RR = Removal Rate; and

$$N=Qty*Flthrs*Turndays*\frac{RR}{365} \tag{10}$$

where:

N = Mean of the Poisson Distribution;

Flthrs = Flight hours into a particular airport;

Turndays = Days for a component to cycle through a shop.

The final formula used in the spares calculation is an iterative formula used to determine the number of spares required to ensure a required availability. Equation (11), the Poisson distribution formula, drives the model into a programming loop until the cumulative sum is greater than the desired probability of having a spare on hand. Boeing has labeled this desired probability as the fill rate.

$$PROB = \sum_{r=0}^{PROB > FILLRATE} \frac{\exp^{-N} * N^{r}}{r!} \qquad (11)$$

where:

PROB = Probability of having a spare available;

r+1 = Spares required;

FILL RATE = Desired probability of a spare available.

Once the number of required spares is determined, the cost of a spare is applied to this quantity for a total spares costs.

#### 4. Scheduled Maintenance Costs

Scheduled maintenance costs are defined as those costs associated with the labor to inspect, labor for corrective action and the material for that corrective action performed during a regularly scheduled check [Ref. 5]. The corrective action is further defined as the labor expended after the component has been found to be faulty during a scheduled check. Once the component is removed and sent to the shop for repair, the remaining portion of the labor required for repair is counted as shop maintenance. Data for each of the scheduled maintenance labor categories is collected in units of labor hours per 1000 flight hours and the material costs data is collected in units of material costs per 1000 flight hours. These values are used in conjunction with the number of flights, average flight hours, component quantity per aircraft and number of aircraft to yield the total scheduled maintenance costs for labor and materials as shown in Equations (12), (13) and (14).

$$SCHIN = \frac{Flts*NA*Qty*Aveflthr*Schmntinsmh*Didlab*(1+Bf)}{1000} \quad (12)$$

where:

SCHIN = Scheduled inspection costs;

Schmntinsmh = Scheduled inspection labor per 1000 hours.

$$SCHCAL = \frac{Flts*NA*Qty*Aveflthr*Recmhrs*Dirlab*(1+Bf)}{1000} \quad (13)$$

where:

SCHCAL = Scheduled corrective action labor costs;

Recmhrs = Rectification man hours per 1000 flight hours.

$$SCHEDCAMAT = \frac{Flts*NA*Quant*Aveflthr*Schcamat}{1000} \quad (14)$$

where:

SCHEDCAMAT = Scheduled corrective action material costs;

Schcamat = Scheduled corrective action material costs per 1000 flight hours.

Total schedule maintenance costs are the sum of the scheduled inspection costs, scheduled corrective action labor costs and the scheduled corrective action material costs.

### 5. Schedule Interruption Costs

Costs associated with schedule interruptions are divided into the four categories of delay, cancellation, air-turnback and diversion. Each record in the component data base contains information on the frequency which each category of interruption occurs for that specific component. This information is entered into the model as occurrences per 100 flights, and cost per occurrence is entered through the airplane and economic data base.

A delay is defined as a schedule slippage, and this category requires the historical delay rate as well as an additional value for an average delay time. This average delay time is required only for this category because cost data is entered as delay costs per hour. Equation (15) is used for the delay cost calculation:

$$DELCOSTS=\frac{Flts*NA*Qty*Numdel*Delcost*Avedeltm}{100} \qquad (15)$$

where:

DELCOSTS = Total delay costs;
Numdel = Delay rate per one hundred departures;
Delcost = Cost of one hour of delay;
Avedeltm = Average delay length in hours.

Cancellation is the term used for a schedule interruption that results in the scheduled flight never leaving the airport. A cancellation rate is taken from historical data and entered in the form of cancellations caused by the component for every 100 departures. Cancellation costs are entered as the costs per cancelled event. This formula is shown in Equation (16).

$$CANCOST=\frac{Flts*NA*Qty*Numcancels*Cancelcost}{100} \qquad (16)$$

where:

CANCOST = Total costs of cancellation;
Numcancels = Number of cancellations per 100 departures;
Cancelcost = Costs incurred from a cancelled event.

Air-turnback is a schedule interruption resulting from an aircraft aborting a mission after departure and returning to the point of origin for repair. The rate of occurrence per 100 departures is taken from historical data and used in a manner similar to cancellations. Equation (17) provides the definition.

$$ATBCOST=\frac{Flts*NA*Qty*Numatbks*Airtbkcost}{100} \qquad (17)$$

where:

ATBCOST = Total costs of air-turnbacks;
Numatbks = Air-turnbacks per 100 departures;
Airtbkcost = Costs of each air-turnback;

The final interruption category is aircraft diversion. This is defined as an in-flight abort resulting in the aircraft landing at a field other than the point of origin or the intended destination. It also is taken from historical data and used in Equation (18) as a rate of occurrence per 100 departures.

$$DIVCOST=\frac{Flts*NA*Qty*Numdivs*Divercost}{100} \quad (18)$$

where:

DIVCOST = Total diversion costs;

Numdivs = Number of diversions per 100 departures;

Divercost = Costs of a single diverted aircraft.

Total schedule interruption costs are determined through the sum of the four interruption cost categories discussed above.

## C. COST DRIVERS

Two primary cost drivers account for the majority of dependability costs within a typical airline maintenance system. These are the removal rate of the component and the schedule interruption rate caused by the component [Ref. 6]. Numerous secondary cost drivers are present such as labor rate, overhead rate, and maintenance action rate to name a few, but the two primary cost drivers normally account for the majority of dependability costs.

Removal rate affects three of the five cost elements found within the model, giving this driver a greater potential impact on total operating costs. Most of the secondary cost drivers affect the cost elements through routine maintenance checks, without the component being removed, but removal of the component normally incurs a larger percentage of the maintenance and material costs.

Schedule interruption rate is a major concern within the airline industry due to excessive tangible costs involved. However, the intangible costs resulting from an impact on the airlines' customers make this an extremely difficult cost to quantify. Boeing recommends airline companies collect cost data for these interruptions through their marketing research facilities. This cost driver affects only one of the five cost elements, but the high cost of one interruption has placed this cost driver very high on the airline industry's priority list. In contrast, military tactical aviation does not incur such tangible costs as a result of an interrupted schedule nor is customer good will a major concern. There is concern with lost training opportunities or mission sorties, but seldom, if ever, are these losses expressed as a monetary value. This cost driver, and the entire cost element, may decrease substantially in relative importance for military aviation.

### 1. Removal Rate

Simply put, the removal rate is how often the part must be removed from the aircraft. However, the tremendous number of factors involved in this rate make it very complex. A component will not contribute significant costs other than acquisition, installation and scheduled maintenance if it performs flawlessly for an indefinite period. The rate at which the component is removed and/or replaced drives the associated labor and material costs.

Many components have a designated service life and are removed at the end of that life to be overhauled. This aspect of the removal rate within the DCM is captured by the mean time between overhaul. Another aspect of this value includes unscheduled removals in which the part has failed and the failure results in the premature overhaul of the component. Shop maintenance costs are heavily dependent on this value for both the labor and material costs incurred during overhaul.

Another important element of the removal rate is the mean time between unscheduled removals. This number, expressed in flight hours, represents the actual removal rate of the component. It can capture all the unscheduled removals of a component or only the remainder of unscheduled removals not already captured by the mean time between overhaul. Overlapping definitions of these two could result in the double counting of unscheduled removals resulting in a component overhaul. Care must be taken to consistently apply those removals resulting in overhaul to the desired value.

Both of the above values contribute to the removal rate of the component, and their relative importance is dependent on the individual component characteristics. Only one or the other is typically used for a specific calculation of line, shop or unscheduled maintenance costs. During the calculation of spares required the model combines the two factors and uses the overall removal rate as an input for the Poisson distribution.

**2. Schedule Interruption Rate**

This rate has four inputs to determine the overall interruption rate caused by the component. These inputs are delays, cancellations, air-turnbacks and diverts. Each of these interruption events are measured in occurrences per 100 flights caused by a specific component. An overall interruption rate is never calculated by the model. Instead, the costs incurred from each event are derived and the four cost values are summed to arrive at the total interruption costs. The high cost per occurrence involved with the airline industry is the primary reason interruption rate is so significant.

**3. Secondary Cost Drivers**

There are many secondary cost drivers within the model that have an indirect effect on the total operating costs. These have little effect when acting alone, but acting through the removal rate, can result in a significant contribution to the overall costs.

Most significant of these secondary cost drivers is the labor rate. This value represents the average hourly wage rate paid to maintenance personnel but does not include fringe benefits. It acts through the removal rate in all three of the five cost elements dependent on removals, but has an additional impact through a fourth element. This fourth element is the scheduled maintenance cost element, which is heavily influenced by the maintenance action rate, but may be overshadowed as the primary driver. These scheduled maintenance costs are determined from the maintenance actions per 1000 flight hours and the average time required to perform routine checks as discussed earlier.

Burden factor is similar to the labor rate in its effect on the cost elements but its relative impact on the cost elements is much less. Expressed as a percentage of direct labor hourly wage rate, it compensates for the fringe benefits received by maintenance personnel.

Component price can have a substantial impact on the operating cost, especially with a high quantity per aircraft. However, price has only an indirect effect on the cost elements. Removal rate influences the relationship of component price to operating costs through the spares required and whether the component is expendable or repairable. A high priced component with exceptional reliability will have little or no impact on operating costs.

## D. MODEL STRUCTURE

The basic structure of the model incorporates three data bases used for inputs and, through the manipulation of this data, generates the cost information simulating the operation of an aircraft maintenance system. Information contained in the first data base represents the economic factors of the specific aircraft and the economy in general. The second contains information dealing with the aircraft components or line replaceable units (LRUs). Route information is compiled in the third data base helping to simulate operating conditions more precisely.

From the initial input data the model calculates dependability costs and uses this information to compare any changes due to system modifications made by the user. Output data is presented in three columns showing the baseline data, the data calculated from any modifications and a final column highlighting the differences between the original system and the modified system. Also, a wide range of cost information broken down by specific component or different aspects of the aircraft maintenance system is available.

### 1. Aircraft and Economic Inputs

All variables concerning the aircraft fleet and economic conditions are contained in this data base. Table 2.2 shows these inputs and their respective definitions. Variables designated to reflect operational activity include the fleet size, number of flights per year and the average time for each flight. Fleet size consists of the current number of aircraft existing in the fleet, but proposed additions can be included. Also, a data field is present to drive the model into the use of a particular route structure, if desired. This route structure will be discussed later in the section dealing with the route structure data base.

The economic factors input through this data base are used to calculate annual dependability costs or the computations can be presented for any number of years entered into the study length field. If the present value analysis is chosen, the model uses the minimum attractive rate of return and the general rate of inflation to determine the economic benefit derived from a proposed change.

A spares factor is included in this data base representing inventory costs expressed as a percentage of the part price. It is required for the calculation of the spares holding costs and used in addition to the expend field. The expend field is an abbreviation of expendable material provisionary days and reflects the days required to replenish the spares inventory. Both fields are essential to the derivation of spares holding costs.

Costs for a single occurrence of each type of interruption event are also given through this data base. These costs are an average dollar amount the airline expends either through rescheduling or loss of future business resulting from an impact on the customers.

**2. Component Inputs**

The component data base contains all values associated with individual aircraft components. Each record of the data base holds information pertaining to a unique aircraft part. These component records are organized by aircraft system/sub-system, an organizational system used by the Air Transportation Association (ATA). It is used by Boeing to breakdown the aircraft into its basic components. The first field of the data base contains a ten digit assigned number (ASN) divided into four sets of digits. The initial set of digits represents the major aircraft system and each subsequent set of digits is used to further specify any sub-system association. This allows the data to be sorted by aircraft system/sub-system and can be used to narrow the scope of the analysis to a particular aircraft system.

Subsequent fields within this data base contain the information required to perform the calculations discussed earlier. Only the primary inputs affecting dependability costs are shown in Table 2.3. Other fields exist in the data base for administrative purposes. These fields are used to record the sources of information, the engineer responsible for a particular project, and other administrative functions.

| Input Variable | Definition |
|---|---|
| AVEFLTHRS | Average flight hours for one flight |
| FHPY | Average annual flight hours for one aircraft |
| NA | Total number of aircraft in the fleet |
| NAM | Number of aircraft currently in the fleet |
| EAM | Proposed number of aircraft in the fleet |
| DIRLABOR | Direct labor hourly rate |
| BF | Burden factor accounting for employee fringe benefits |
| DELAYCOSTS | Average hourly cost of a schedule delay |
| CXNCOSTS | Average cost of a schedule cancellation |
| ATBCOSTS | Average cost of an air-turnback |
| DIVCOST | Average cost of a diverted aircraft |
| SPAREFAC | Spares factor: inventory costs of holding spare parts (% of part price) |
| EXPEND | Expendable material provisionary days |
| MARR | Minimum attractive rate of return |
| INFLATION | General inflation rate |
| STDYLEN | Study length in years |
| MEL CODE | Minimum equipment list code |
| ENGINE | Engine type |
| ROUTE | Specifies use of model route structure |
| MODEL | Aircraft model |
| SERIES | Aircraft series |

Table 2.2 Aircraft and Economic Inputs

| INPUT VARIABLES | DEFINITIONS |
|---|---|
| ASN | Assigned Number: (Example 01-23-456-789) |
| NOMENCLATURE | Name of part or system |
| QPA | Quantity per airplane |
| DELAY | Number of delays per 100 departures |
| CAN | Number of cancellations per 100 departures |
| ATB | Number of airborne turnbacks per 100 departures |
| DIV | Number of diverts per 100 departures |
| DELAY TIME | Average length of schedule delays |
| MTBF | Mean time between failures in flight hours |
| MTBUR | Mean time between unscheduled removals |
| ATFR | Average time for repair (removals) |
| MA/1000 | Maintenance actions per 1000 flight hours |
| ATFMA | Average time for maintenance actions (Non-removals) |
| SHOP LABOR HOURS | Average shop labor hours per removal |
| SHOP MATERIAL | Average shop material costs per removal |
| MTBO | Mean time between overhauls |
| OVERHAUL LABOR HOURS | Average shop labor hours per overhaul |
| OVERHAUL MATERIAL | Average material cost per overhaul |
| PRICE | Part price |
| EXPENDABLE | Is the part a consumable? Yes or No |
| SHOP LENGTH | Shop turnaround time in days |
| MEL CODE | Minimum equipment list code |
| SCHED MAINT/1000 HRS | Scheduled maintenance actions per 1000 flight hours |
| NO. OF SPARES | Number of spares required |
| FILL RATE | Desired probability of having a spare on hand |
| MATERIAL COST BASIS | Material costs based on average or actual |
| SCA LABOR | Scheduled corrective action labor per 1000 flight hours |
| SCA MATERIAL | Scheduled corrective action material per 1000 flight hours |

Table 2.3 Component Data Base Inputs

### 3. Route Inputs

Route structures within the model are contained in the third data base and contribute a significant level of complexity to the model. This structure is instrumental in the calculation of spares required, expanding the spares inventory costs to several locations. Input fields are shown in Table 2.4 and include identification codes for the various stations, a minimum equipment list (MEL) code, extra turn-around days, location of the spares, and flight hours into the station. Most of the above are self explanatory, with the exception of the MEL code and extra turn-around days.

| INPUT VARIABLES | DEFINITIONS |
|---|---|
| STATION | Three letter code for airport identification |
| MEL CODE | Minimum equipment list code applicable to the station |
| TURNDAYS | Extra turn-around days required for a station |
| SPARES STATION | Three letter code designating the location of spares inventory |
| FLIGHT HOURS | Flight hours of the fleet into the station |

Table 2.4 Route Data Base Inputs

MEL codes provide a means of determining the urgency of having a spare on hand in the event of a failure and determines whether the aircraft is operational if a specific component failed. It is compared to a MEL code in the component data base record, and the more restrictive of the two is used. Through this comparison the maintenance facilities of the distant station can be simulated and contrasted with the aircraft's home base, showing that a failure in a remote location will be more costly. Thus, an effect on the spares inventory will be taken into account for both locations, increasing the total spares costs.

If the extra turn-around days field contains a value for the station it reflects a difference in the station's ability to perform the required maintenance in a timely manner. The route's extra turn-around days are added to the component's turn-around time from the component data base. This extra time to receive and repair a component at the station will drive the spares required to a higher value, incurring a steeper cost.

A route structure in the model allows the user to tailor the model to a more precise simulation of the actual operating conditions. When the route field of the airplane and economic data base is left blank the route structure is not used simulating the operations from a single location. Tactical military aircraft in peacetime typically operate from a single base and the complexity of the route structure will not apply to this analysis.

### 4. Outputs

After the required data base information is compiled and stored in the appropriate data base files, the user has a number of options for both inputs and outputs. If the user wishes to edit model inputs prior to calculation, this option is available. Also, the user can choose between running the model using only the original information for calculations, or editing the original data for a comparison to any proposed changes. Calculations can be performed for the present year or a present value analysis over a specified period.

Once the calculations are completed the model presents an output menu containing the options of LRU inputs, LRU outputs, output totals or spares totals. Selection of LRU inputs will provide a list of individual components used in the calculations and all the information contained in the data base files for that component. The LRU output will present the calculated costs of the individual components used in the calculation. A total system cost broken down by cost elements is given under the output totals option and, if a comparison of systems was chosen, the cost data is presented in three columns showing the original, proposed and a column highlighting the differences between the two systems. Spares totals will give spare availability, totals for each station and total cost of spares inventory.

## E. SUMMARY

Boeing has shifted the emphasis on operating costs away from the traditional airline approach, which focused primarily on reliability. The shift to dependability dollars and their attempt to highlight the cost drivers has had a significant impact on understanding the complexity of aircraft maintenance systems. A focus on the root causes, or drivers, of these costs will aid the attempt to control and reduce them in the future. Economic conditions within the airline industry have forced aircraft manufacturers to concentrate on developing a competitive edge, and the control of operating costs is one method Boeing uses to provide that edge to their customers. This model provides flexibility to the user by tailoring inputs to simulate operating conditions and the capability to analyze the benefits of a proposed change prior to implementation. Understanding the cost drivers within a maintenance system can have applications to any company or military unit seeking to maximize efficiency of the funds expended.

# III. DATA BASE CONSTRUCTION

This chapter presents the information sources, assumptions and methods used to construct the data bases required for Boeing's Dependability Cost Model (DCM). Data was collected from various sources for the engine of the F/A-18, the F404-GE-400, and manipulated into the desired format. The author found the U. S. Navy's current maintenance information systems contained the necessary data, but time constraints of this research effort required simplifying assumptions to be made in certain areas. These assumptions are discussed in detail throughout this chapter. Information was collected in the form of printed reports and computer text files, then imported and/or typed into spreadsheets for analysis and ease of manipulation. After the data base was constructed in a spreadsheet file, this file was imported into the Paradox data base program for use with the DCM.

## A. MODEL'S ORGANIZATIONAL STRUCTURE ALTERED

The DCM was built for a maintenance system designed and operated by the airline industry. The airline maintenance organization designed into the model differs tremendously from the one used by the U. S. Navy. Naval aircraft maintenance is performed at the three levels of organizational, intermediate and depot. These levels are commonly referred to as "O" level, "I" level and depot level. Labor and material costs are incurred at each level, but the model highlights labor costs for two levels and material costs for only one of these. The model's distinction between line and shop maintenance does not completely correlate to any of the three levels used in the Naval service. This led the author to specifically define the maintenance levels addressed by this research effort and gather information pertaining to those levels. The resulting output from the model will not capture all the costs of the

F/A-18's engine maintenance, but only those within the variable definitions chosen by the author.

Line maintenance, as implied by the model's construction, corresponds closely with the "O" level maintenance. For this level of maintenance, the model calculates only the associated labor costs and neglects any material costs incurred. Labor costs are based on the maintenance actions performed and the time required to perform those actions. A detailed discussion of the actual data gathered and the manipulation of that data will be presented in a subsequent section.

Costs incurred due to shop maintenance are calculated for both the labor and materials expended while performing aircraft maintenance at this level. Shop maintenance was used to simulate the "I" level of the Navy's aircraft maintenance system. The information gathered by the author concerning material costs was taken from the Aviation Intermediate Maintenance Department, located at Naval Air Station Lemoore, CA. The availability of information was decisive in limiting the definition of shop maintenance to this level.

Depot level maintenance costs are beyond the scope of this research effort. However, the model does contain a provision for outside maintenance costs that could be used to capture this expense. A detailed analysis of both labor and material costs incurred from an outside source is not available through this model. Outside maintenance costs are entered as a single variable and any distinction between labor and material components would not be relevant to an airline's internal cost analysis.

Another element of dependability cost is the scheduled maintenance costs. During this calculation the model does not distinguish between line or shop maintenance. These costs are based solely on the data base fields of scheduled maintenance per 1000 flight hours, scheduled corrective action labor and scheduled corrective action material usage. Information gathered by the author did not yield the detail necessary to accurately distinguish scheduled maintenance activity from overall maintenance activity. An alternative use of these data fields was to calculate cannibalization costs.

Cannibalization is the removal of a working component from one aircraft for replacement in a second aircraft in order to restore the second to an operating condition. During this research effort, the author developed the impression that cannibalization was a major problem within the Navy's aircraft maintenance system. This practice increases the down time of the aircraft being cannibalized, adversely affecting the overall readiness of the aircraft fleet. Often short term operational requirements are met through cannibalization at the expense of long term fleet readiness.

A possible solution is increased funding for spare parts inventory, but there is a trade-off between increased inventory costs and reduced cannibalization costs. An economically efficient balance of the two can only be established if decision makers are aware of both costs, and their relationship to each other.

This led to an attempt to highlight the costs associated with cannibalization. The Engine Component Improvement Feedback Reports (ECIFRs) gave data on cannibalization man hours and the number of actions at both the "O" level and "I" level as a combined total. Providing this data, without regard to a particular level, allowed the author to use the scheduled maintenance portion of the model as a cannibalization costs calculation. Unfortunately, only the labor hours and maintenance actions associated with cannibalization were contained in the ECIFRs, and material costs were not available. Therefore, only the labor costs due to cannibalization will be calculated by the model. This leaves the material costs of cannibalization as an unknown. Therefore, the economically efficient balance between increased spare parts inventory costs and decreased cannibalization costs, discussed above is beyond the scope of this thesis.

Other components of dependability costs to be calculated by the model, spares holding costs and schedule interruption costs, were not redefined by the author. Assumptions dealing with the variables driving these costs will be discussed in a subsequent section.

Through these modifications to the organizational definitions, the author was able to build a data base from information contained in the Navy's maintenance information sources. Table 3.1 summarizes the changes from the original definitions to those of the author.

| Dependability Costs | Revised Definition |
|---|---|
| Line Maintenance Costs | "O" Level Labor Costs |
| Shop Labor Costs | "I" Level Labor Costs |
| Shop Material Costs | "I" Level Material Costs |
| Scheduled Maintenance Costs | Cannibalization Costs |
| Spares Holding Costs | Spares Holding Costs |
| Schedule Interruption Costs | Schedule Interruption Costs |

Table 3.1 Revised Definitions of Dependability Costs

## B. REVISION OF VARIABLE DEFINITIONS

As the redefinition of the model's organizational structure took shape, a requirement to align variables with this new structure evolved. The primary information sources presented actions and man hours requiring manipulation into rates, and the use of a spreadsheet program greatly simplified this task. After careful study of the model's structure and determining possible alternatives, the author contacted Boeing [Ref. 7] to discuss various methods to rearrange the accounting for removals and maintenance actions without disrupting the accuracy of the output. The author was cautioned to prevent double counting any maintenance actions, but exact definitions of the variables could be altered by the user. This led to the redefinition of the model's variables as discussed below.

### 1. Removal Variables Redefined

The most significant alteration of variable definitions occurred in rearranging the removals of aircraft components. Variables are defined in the DCM to distinguish between scheduled or unscheduled component removals. Data, taken from the FY93 ECIFRs for the F/A-18, contained information on the removal of aircraft engine components, but the presentation of the data did not fully specify whether the removal was scheduled or unscheduled. Only a limited number of total removals were listed as scheduled maintenance, and a full accounting of scheduled versus unscheduled was not possible. For this reason, the author was driven to redefine the mean time between unscheduled removals (MTBURs) to include all component removals, with the exception of cannibalization removals. (Cannibalization removals and non-removal actions will be included in other variables to be discussed later.)

Removals for a specific component were totaled from a list of actions taken by both "O" level and "I" level maintenance activities [Ref. 8]. This provided a total number of non-cannibalization removals for the derivation of a mean time between removal actions, and the variable MTBUR was used in this research effort to include all non-cannibalization removals at the "O" and "I" levels.

### 2. Overhaul Variable Redefined

Boeing uses the mean time between overhaul (MTBO) to account for scheduled removals at the shop level [Ref. 9]. This variable is used to calculate shop labor and shop materials costs for the scheduled removal of a component. In the previous section, the MTBUR was used to account for all non-cannibalization removals. This change of definition left no removal actions for the MTBO. The author chose to use this variable for all non-removal maintenance actions at the "I" level. Model calculations incorporate both labor and material costs for actions accumulated within this variable, and the model adds these costs to the respective shop maintenance category. The combination of MTBUR and MTBO accounts for all non-cannibalization maintenance actions at the "I" level.

### 3. Cannibalization Maintenance Actions

Removals due to the cannibalization of aircraft parts are the only removals not counted in the above MTBUR definition. Cannibalizations normally occur due to the non-availability of replacement parts and account for approximately 7 percent of total man hours expended for FY93 maintenance actions [Ref. 10]. The ECIFR contained detailed information on the number of cannibalization actions taken and man hours expended for these actions. This data was used to derive an overall cannibalization rate per 1000 flight hours and an average time for a cannibalization action for each component.

The variables used to calculate costs for the cannibalization maintenance actions were the scheduled maintenance variables. Information in the ECIFR cannibalization summary did not distinguish between "O" level and "I" level maintenance and the model does not separate scheduled maintenance costs at the line and shop levels. Calculations are based on the scheduled maintenance rates and average times to perform the work, and the average cannibalization rates and average times to perform cannibalization actions were derived from the ECIFR cannibalization summary. The mixture of costs between the line and shop levels gave the author flexibility to use this cost element as a cannibalization cost calculation vice a scheduled maintenance cost calculation. The scheduled maintenance cost element is capable of calculating the associated material costs, but the author did not possess data to estimate the material costs incurred as a result of cannibalization actions.

**4. Line Non-Removal Maintenance Actions**

Only the line maintenance actions involving the non-cannibalization removal of a component were counted as a part of the MTBUR and cannibalization actions have been included as a part of the scheduled maintenance variables. Any other line maintenance actions performed must be included in the model to provide an accurate "O" level labor cost estimate. The only portion of aircraft maintenance actions which remain to be included are the line non-removal maintenance actions. Capturing the costs associated with "O" level non-removal maintenance actions required collecting data on the rate of occurrence and the average time for each of these actions. This data was derived from two sources, a section of the ECIFR titled "Major Causes for Maintenance on the High Maintenance Action Work Unit Codes" and reports received from the Naval Aviation Logistics Data Analysis (NALDA) users group. A cost element of the model was built expressly for these costs and required no redefinition by the author.

By redefining the DCM variables as discussed above, all maintenance actions at the "O" level and "I" level have been counted in the calculation of dependability costs for the F/A-18 engine system. Figures 3.1 and 3.2 on the following pages give a summary of differences between model design and the author's definition of the model variables.

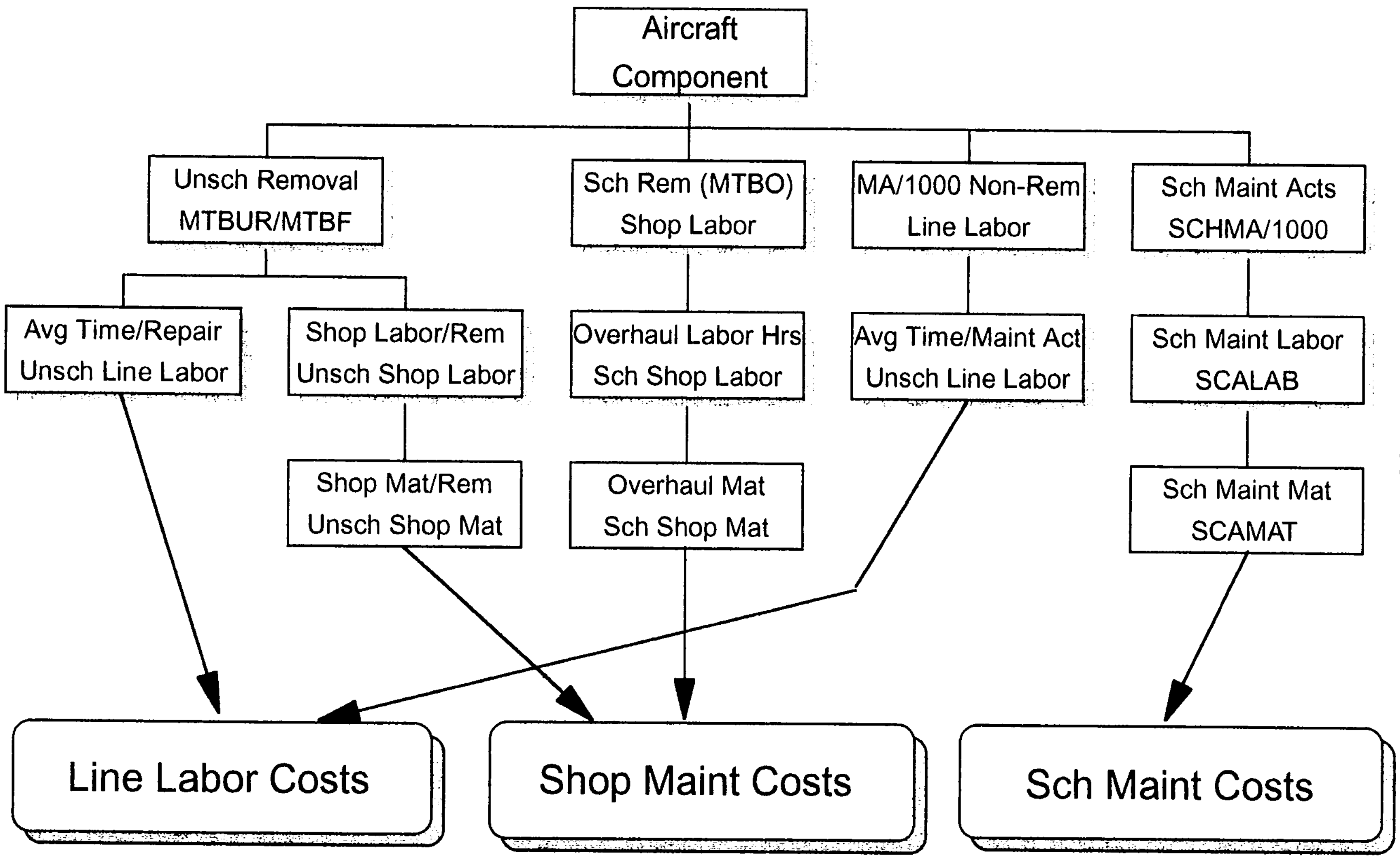


Figure 3.1 Originally Designed Structure of the DCM

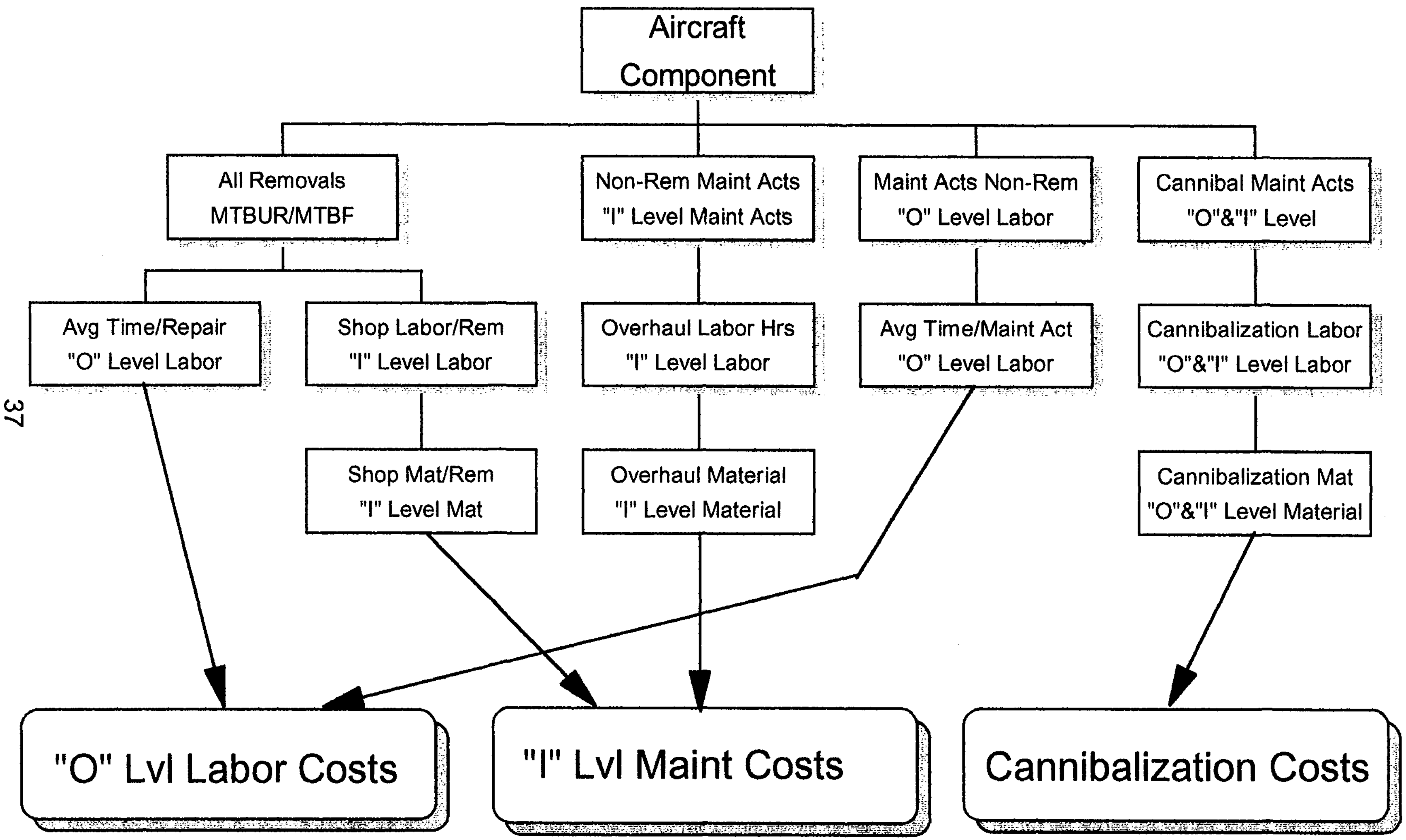


Figure 3.2 DCM Structure Redefined for Naval Use

## C. INFORMATION SOURCES

One of the more challenging aspects of this research effort was the collection of data. The author found numerous sources available, but timely access to this information was a major constraint. All F/A-18 maintenance information used in this report originated from the following three sources: Naval Aviation Logistics Data Analysis (NALDA) data base, Engine Component Improvement Feedback Reports (ECIFR) for FY93 and Aviation Intermediate Maintenance Department (AIMD), Naval Air Station Lemoore, CA.

The author used the ECIFR as the primary source in the derivation of the required maintenance action rates. This report gave a more detailed separation of "O" level from "I" level maintenance actions in most areas of interest. A significant weakness, in some cases, was the coverage of only the aircraft components absorbing the upper 80 percent of maintenance actions and man hours, while components in the lower 20 percent of maintenance actions and man hours were left unidentified. Maintenance actions and man hours associated with unidentified components were not added to the rates nor totals, leaving the final cost calculations short of the actual dependability costs to support the F/A-18.

Boeing recommended building the data base using components believed to absorb the higher percentage of maintenance resources and, from this foundation, building to a desired level of detail [Ref. 11]. The author felt the usage of components listed in the upper 80 percent was consistent with Boeing's recommendation, hence the costs incurred from components listed in the lower 20 percent will not be calculated nor included in overall cost estimation.

A valuable secondary source proved to be the reports generated from the NALDA data base. At the request of the author, reports were generated for calendar years 1992 and

1993 containing information on F/A-18 flight hour activity, maintenance actions taken and man hours expended. The component breakdown within these reports demonstrated the level of detail available through the NALDA data base, but reports originally requested did not specify any separation of maintenance actions based on the different maintenance levels. After receipt of these initial reports and the final model definitions were determined, time constraints did not allow the collection of additional NALDA reports.

Maintenance action rates and average time for maintenance actions derived from the NALDA reports contained a mix of "O" level and "I" level information. For this reason, NALDA information was only used in the areas needed to supplement ECIFR data. Typically, this was used for lower level components and the author found in many instances that the man hours attributed to lower level components were exclusively from a particular organizational level. The greatest mixing of the two levels occurred at the major component level, and this level was in most cases, adequately covered by the ECIFR information. Overall, the use of the NALDA data for some components in the lower levels should not significantly degrade the output of the model.

Material cost data was the most difficult to acquire and the only information gathered concerned the major engine modules for the "I" level. A single information source containing all "O" level and "I" level material usage data was never discovered by the author. Material cost data gathered from AIMD NAS Lemoore, CA., was via an internal document [Ref. 12] averaging the material consumption incurred by that department on major engine module maintenance over a five month period. This sample is too small to establish an adequate statistical sample, but it was used by the author in the absence of more accurate information. Other data gathered at NAS Lemoore included pricing information for engine parts from the Aviation Supply Division and shop turnaround time for engine components from the AIMD Repair Cycle Data Reports. Material costs output from the model will be slightly degraded. This results from the small sample size and the usage of only upper level engine component material costs.

## D. DATA BASE LAYOUT

During data base construction, the author attempted to use any existing data structure within the Naval maintenance organization. This was for both consistency and ease of output interpretation. The data base constructed during this research effort contained 258 component records. Many records in the data base are not complete, but consideration was given to any detrimental effects on the final output. Records containing partial information were left in the final data base only if accuracy of the final calculations would not be adversely affected. This will serve to capture as many costs allowed by the data but will not contain 100 percent of the actual maintenance system costs.

### 1. Work Unit Codes and Assigned Numbers

Organization of the data base requires a structure similar to that used by the ATA and discussed in Chapter II. This structure divides the aircraft into systems and sub-systems, identifying the relationship of each part to the system in which it functions. The DCM uses the assigned number (ASN) as the numerical identification for each aircraft part in the data base and the grouping of like numbers identifies a particular system or ATA. A hypothetical example of an aircraft system breakdown is illustrated in Table 3.2.

| ASN | 32-45-598-011 |
|---|---|
| 32 | Aircraft Landing Gear System |
| 45 | Right Main Landing Gear Assembly |
| 598 | Right Main Landing Gear Strut |
| 011 | Main Landing Gear Wheel |

Table 3.2 ASN Example

A similar structure of aircraft system breakdown is used by the Navy's maintenance organizations. Aircraft systems are organized by work unit codes (WUCs) serving the same function as the ATA system for the airline industry. The WUC is a seven digit number, with the first two digits identifying the major aircraft system and subsequent digits specifying components and parts in greater detail. For construction of the F/A-18 data base, these WUCs were formatted as required by the model and used for the ASN data base field. This research effort concentrated on aircraft engines which are identified in the Naval data structure by WUCs beginning with 27. The F/A-18 engine is identified by WUCs 274XXXX and the data base was constructed using WUCs from 2740000 through 2747912. Table 3.3, on the following page, provides an example WUC used with the F/A-18 engine.

The engine data used in this research was collected from the F404-GE-400, one of two engines currently in service with the F/A-18. There are six major modules of the engine, each designated by the fourth digit of the WUC. Other engine components not related to the individual modules are grouped into a separate category designated by a 7 as the fourth digit. The format change of the WUC consisted only of adding the hyphenation between the appropriate digits, separating the groups of digits as shown in the ASN example of Table 3.2.

This format change resulted in the example WUC of Table 3.3 appearing as 27-41-240-000 in the data base. This allowed the author to use the WUCs in the data base and prevented the use of an ad hoc numbering system for this function.

| WUC | 2741240 |
|---|---|
| 27 | Turbo Fan Engine |
| 4 | F/A-18 F404-GE-(SERIES) |
| 1 | Fan Module |
| 2 | Fan Rotor Assembly |
| 40 | Stage 1 Fan Blade Pair |

Table 3.3 Work Unit Code Example

### 2. Mean Time Between Failures

The first rate determined for the data base was the mean time between failures (MTBF) and was taken from both the ECIFR and NALDA reports. A section of the ECIFR titled "Maintenance Actions and Man Hours by Work Unit Code" [Ref. 13] ranked the WUCs, in descending order, by both maintenance actions and maintenance man hours expended. This section gave a list of the highest ranking WUCs in each category, detailing the top 80 percent of the total maintenance effort. A column of data contained in the maintenance action ranking provided an "expected flight hour per failure" for each of the WUCs listed. The author compiled this data (for the F/A-18A, F/A-18B, F/A-18C and F/A-18D) into a spreadsheet and took an average of "expected flight hours per failure" weighted by total flight hours flown by each type of F/A-18. Flight hour information was given for each report in a separate ECIFR section [Ref. 14]. For any WUC not listed in the top

80 percent, the weighted average consisted only of the data available, and a zero from any of the four reports was not figured into the final MTBF. The procedure described above provided an MTBF for 55 of the 258 WUCs contained in the data base.

For the WUCs not covered by the ECIFR data, NALDA Equipment Condition Analysis reports were used. The Reliability/Maintainability Analysis Report [Ref. 15] detailed the number of failures occurring for each WUC. Also, the Flight Activity and Inventory Utilization Report [Ref. 16] gave the flight hour information necessary to derive failure rates. These reports contained all 27XXXXX WUCs in the Navy's maintenance system, including many the author could not identify as F/A-18 WUCs. Reports from NALDA were received in DOS text files and imported into spreadsheets for analysis and manipulation. The number of total failures for each WUC was divided by total flight hours during the period to derive the MTBF. Information on another 125 WUCs was taken from this procedure, leaving 78 WUCs of the 258 in the data base without a failure rate. A missing failure rate for a component will not degrade the final output as long as adequate data is contained in other fields to calculate a removal rate. Also, due to the critical nature of engine components, few are intentionally flown to failure before removal.

### 3. Mean Time Between Unscheduled Removals

The MTBUR variable was redefined by the author to include all non-cannibalization removals of the component. The derivation of removal rates is explained below. Two sections of the ECIFRs, titled "Work Unit Code by Organizational Level Action Taken Code" [Ref. 17] and "Work Unit Code by Intermediate Level Action Taken Code," [Ref. 18] provided this data. These reports gave a detailed breakout of the maintenance actions performed at both levels and gave the associated action taken code. Action taken codes are descriptions of the maintenance action performed, allowing the author to distinguish removals from cannibalization and non-removal maintenance actions. Total non-cannibalization removals for each F/A-18 variant were added together giving a total number of non-cannibalization removals for each WUC. The total flight hours divided by the total non-cannibalization removals yielded a mean flight hour between removals. From the list of 258 WUCs used in the data base, the author was able to determine a mean time between non-cannibalization removal for 134.

### 4. Mean Time Between Overhaul and Maintenance Actions per 1000 Flight Hours

The remaining maintenance actions, less cannibalization actions taken from the procedure described above, were used to determine MTBO and MA/1000. Both variables were redefined by the author, with MTBO relating to "I" level non-removals and MA/1000 referring to "O" level non-removals. The total non-removal actions performed at the differing levels of maintenance organization were not added to produce an overall maintenance action rate. These variables require the separation of actions performed at each particular level. At this point, all actions taken, excluding cannibalization, are counted in the maintenance action rates. For the 258 WUCs contained in the data base, MTBO was determined for 114 and MA/1000 was determined for 152.

### 5. Scheduled Maintenance per 1000 Flight Hours

From the redefinitions discussed earlier, the scheduled maintenance action rates were used to calculate the costs of cannibalization maintenance actions. A cannibalization summary is located at the end of each ECIFR and gives a breakdown of total cannibalization maintenance actions as well as the man hours expended on those actions for each WUC. This information was used in the derivation of both the maintenance actions per 1000 flight hours and the associated labor expended per 1000 flight hours. Cannibalization actions were added from each of the four aircraft variants, multiplied by 1000 and divided by total flight hours. Man hours associated with the cannibalization actions were converted into a rate per 1000 flight hours in the same manner. The author calculated cannibalization rates and man hour expenditure rates for 73 WUCs listed in the data base.

#### 6. Maintenance Action Times

The model requires four separate average maintenance action times for the calculation of dependability costs. During calculation of line maintenance costs ("O" level labor costs), the model uses average time for repair and average time for maintenance actions. Average time for repair relating to non-cannibalization removal actions and average time for maintenance actions represent the average for non-removal actions. In the calculation of shop labor ("I" level labor costs), the model needs the average shop labor hours and average overhaul labor hours for non-cannibalization removals and non-removals, respectively. Data gathered with respect to these averages was insufficient from either source. This led to the assumption the average time to perform a task on a WUC was the same regardless of whether that work was a removal or non-removal maintenance action.

NALDA's Reliability/Maintainability Analysis Report presented the total maintenance action for each WUC, without regard to the level at which it was performed, but the man hour data given in the NALDA reports was separated by the maintenance level performing the task. An inability to separate the maintenance actions by the organizational level performing the task led the author to use total "O" level man hours over total maintenance actions for each of the two average times required by the model for line maintenance calculations. Then a similar computation of total "I" level man hours over total maintenance actions was used for the shop labor average times required.

The author felt this would not be grossly inaccurate after a careful examination of the data contained in the NALDA report. Over 65 percent of 400 WUCs listed showed the total man hours expended on that WUC to be weighted at least 90 percent/10 percent toward one of the two levels. This led the author to conclude that the labor expended on most WUCs is predominately expended at a particular level. Thus, any average would contain man hours predominately from a particular level of maintenance, and would be only slightly affected by man hours from the other level. This makes the method used to calculate WUC average maintenance times a reasonable estimate. However, those WUCs containing a more equitable distribution of man hours could contain inaccuracies affecting the final output.

The NALDA reports were the sole source for the average maintenance times used in the data base. ECIFR information was not used due to the inability to separate either the man hours or the number of maintenance actions by the organizational level performing those actions.

### 7. Schedule Interruption Rates

Costs due to schedule interruptions are calculated from the cost of a single interruption event and the number of interruptions per 100 departures. Military aircraft do not incur additional costs from this cost element in the same manner as the airline industry. Many of the airline's costs are associated with the negative impact on customer relations caused by the schedule interruption and its adverse effect on future business. A potential impact felt by the military from an excessively high interruption rate would be decreased operational effectiveness or mission capability. Consequently, the author chose to use this cost element to calculate a total number of interruptions vice the actual costs of those interruptions. Placing the cost of a single interruption event at one dollar will drive the dollar amount associated with the schedule interruptions to be equal to the number of interruptions experienced. This will highlight a total number of interruptions during the annual interruption cost calculations vice the actual costs incurred due to these interruptions.

As discussed in Chapter II, there are four types of interruption events. These are delays, cancellations, air-turnbacks and diverts. Only the cancellations and air-turnbacks were used in this research effort. Delay and divert information was not available through the information sources used, but the ECIFR did contain information on aircraft mission aborts. Aborts were listed by WUC in the categories of pre-flight and in-flight aborts and these terms were assumed to be synonymous with cancellation and air-turn back, respectively. A minor weakness in this assumption would be an in-flight abort does not always result in a air-turnback. It could lead to an air-turnback or a divert, but in the absence of specific divert data this assumption was made. The author used the number of pre-flight aborts and flight sortie information [Ref. 19] to calculate the number of cancellations per 100 departures. Also, the in-flight aborts were used with the flight sortie information to derive the number of air-turnbacks per 100 departures.

**8. Spares Required and Spares Holding Costs**

Spares calculations are the most complex aspect of the model. They depend on a number of variables and are sensitive to any incomplete records contained in the data base. A major problem experienced during the collection of data was that the WUC structure does not directly relate to a specific part of the engine. A WUC relates to the job performed and does not necessarily relate to a specific part. Therefore, it is not always possible to find a particular part number directly related to a unique WUC. Part prices collected by the author were placed in the data base only when no ambiguity existed between the WUC and part number. The result was only 88 of the 258 data base records contain pricing information.

The Navy supply system uses both unit prices and net prices. A unit price is the cost of purchasing a new unit, and this was the price used by the author. The net price refers to the price charged to a Navy command if the item is repairable and a replacement part is returned to the supply system for repair. The new purchase (or unit) price of a component more accurately reflects the intent of the model structure in the spares holding costs calculation. A net price could be used in the model as a part of the shop material costs to be incurred for the replacement of an aircraft part, but was not used in this research effort. Data collected covered all major engine module material costs and incorporated the net prices of individual parts within each module. Using net prices in this manner would have double counted the costs of replacing lower level components.

Another major input for the spares calculation is the expendability of the part. Any part that is consumed during use can be listed as expendable in the data base and the spares calculation will compensate on the basis of days required to resupply. The data base field labeling parts as expendable or repairable was not used in this research effort due to the lack of removal data available at the lower aircraft system levels. An attempt was made to label all lower level parts known to be expendable, but insufficient removal data caused an undefined solution, a division by zero, during the removal rate calculation of Equation 9. As mentioned in Chapter II, the spares calculation is the only event requiring the use of an overall removal rate, and the model is sensitive to a lack of data in this area.

After redefining the MTBO variable as non-removal shop maintenance actions, Equation 9 was edited to delete the MTBO portion. As written in the model, removal rate was calculated from the inverse of both MTBUR and MTBO which accounted for all removals in the original structure. Since MTBO was used in this research to account for non-removal shop maintenance actions, the removal rate would be exaggerated if not altered. After the equation was edited, the removal rate equals the inverse of the MTBUR variable, and use of the expendable field with a blank or zero for MTBUR creates the undefined solution. This implies the part is never removed from the aircraft; however, all engine components are eventually removed as the aircraft engine is periodically replaced.

Shop turnaround time also affects the spares costs calculation, and data was gathered from the Repair Cycle Data Reports [Ref. 20] of AIMD, NAS Lemoore, CA. Reports from the past seven months were examined and average days, weighted on the monthly number of repairs, were determined for WUCs listed in these reports. Only 69 of the 258 WUCs were found in the reports, and of those found, the author concluded the sample size was too small to provide a valid statistical sample.

Overall, the data collected for the calculation of spares required and spares holding costs was insufficient to provide any relevance to this analysis. The subsequent analysis of cost calculations presented in the following chapter will focus on the drivers of the line and shop maintenance costs calculated by the model.

**E. AIRCRAFT AND ECONOMIC DATA BASE INPUTS**

The second data base required for operation of the model contains information dealing with aircraft flight hour activity and economic assumptions. The following discussion will describe information sources used by the author in the collection of data for flight activity, labor rates, spares holding factors, inflation rates and minimum attractive rate of return.

### 1. Flight Hour Averages

Flight activity data was available through both primary sources used by the author. The Equipment Condition Analysis report generated by the NALDA users group detailed all monthly flight hours, flight sorties and numbers of aircraft reported in the inventory for 1992 and 1993 [Ref. 21]. The average number of aircraft in the inventory was the only figure used from this report due to an inconsistency in the total flight hours and sorties when compared to the ECIFR data. Comparison of the two sources showed a difference of over 8,600 flight hours and 6,600 sorties, or approximately 4 percent of the totals. ECIFR data had been used as the primary source in most calculations but did not contain an inventory number. For this reason, the aircraft inventory from the NALDA report was used, while the ECIFR data was used for the flight hour and sortie totals. From these totals the author calculated average annual flight hours and the average flight time per aircraft sortie.

### 2. Employee Compensation

Labor rate information is input through the direct labor hourly rate and the burden factor fields of the data base. A significant weakness of this model in relation to Naval aircraft maintenance is the use of a single rate for all labor costs. Labor rates differ significantly for each level of maintenance in the military maintenance organization while the model only accepts a single rate. Information collected from the Visibility and Management of Operating Support Costs for Aviation Systems (VAMOSC) gave an hourly wage rate for both "O" level ($17.08) and "I" level ($20.51). This figure includes all fringe benefits with the exception of retirement, with a factor of 30 percent used to reflect retirement [Ref. 22]. The direct labor rate of the DCM does not include fringe benefits, but the added burden factor compensates for all fringe benefit costs, including retirement. A combination of the direct labor hourly rate and burden factor accounts for all expenses incurred due to employee compensation. Using the rates received from VAMOSC would slightly alter the source of non-retirement fringe benefits for military labor, but total compensation would be calculated.

The actual rate used as input was $19.55. This was a compromise between the two given rates. As presented, the model calculations cover both the "O" level and "I" level maintenance actions and the use of either would over or under estimate the total labor costs. For a single rate, the author chose to average the two, weighted on the man hours expended at each level of maintenance. The percentages of total man hours expended from the "O" level and "I" level were 28 percent and 72 percent, respectively. The above labor rate resulted from a weighted average and the retirement percentage of 30 was used as the burden factor.

**3. Spares Inventory Factor**

Spares holding costs are partially dependant on the spares factor entered from this data base. This factor is a percentage of new part price used to reflect inventory costs. Although data collected for spares calculations will be inadequate to estimate the actual costs, a rate was determined for this field. Taken from Naval Supply System Publication, NAVSUP 553, the Navy uses 23 percent for consumable materials and 21 percent for repairables [Ref. 23]. These percentages were averaged for entry into this data base field and 22 percent was used.

**4. Inflation and Discount Percentages**

The final economic inputs for this data base are the minimum attractive rate of return (MARR) and the inflation rate. A discount factor of 7 percent is recommended by the

Office of Management and Budget for evaluation of government investments [Ref. 24] and this rate was used as the MARR. An inflation rate of 2.4 percent was taken from the estimates made by the Navy Comptroller's office in a notice discussing budget preparation and submission [Ref. 25]. These rates are required for the present value calculations performed by the model during analysis of costs over several years. Typically, the federal government uses inflation rates varying over the life of a budget submission, but this model restricts the user to a single rate for the entire period. Due to the inherent inaccuracies of predicting these rates far into the future, this was not viewed as a significant weakness of the model.

## F. SUMMARY

This chapter began by discussing the differences between the aircraft maintenance organization designed into the model and that used in the U. S. Navy. After highlighting the fundamental differences, the author was required to redefine many of the variables to fit the Navy's maintenance organization and the data collected. This redefinition included limiting the analysis to "O" level and "I" level maintenance, excluding "O" level material costs and all depot level costs. Methods and procedures used in deriving the maintenance action rates and the sources of information were discussed in detail. Deficiencies in the data were covered, including the use of material costs for major engine modules only, and simplifying assumptions were made in the average times to perform maintenance actions. Additional difficulties in the identification of specific parts to match WUCs forced the author to exclude the spares holding costs from further analysis.

Overall, the constructed data base should provide a reasonable estimate of the dependability costs associated with the maintenance of the F/A-18's F404-GE-400 engine. From the original list of 258 F/A-18 WUCs, the data collected produced 145 records with sufficient information to allow the cost calculations. A data base of this size for a single aircraft system should be more than adequate for a detailed analysis. The following chapter will attempt to identify the cost drivers within the "O" level labor costs and the "I" level labor and materials costs of the F/A-18 engine system.

## IV. OUTPUTS FROM THE DEPENDABILITY COST MODEL

This chapter will present and discuss the final output derived from the DCM. Primary emphasis will be given to identifying the high cost areas of "O" level and "I" level F/A-18 engine maintenance and demonstrating the level of detail possible with this model. After a brief description of the engine modules, the discussion will turn to the analysis of the engine maintenance costs. The author will first identify high cost areas of the engine maintenance system by the cost components of labor and material. Then the emphasis will shift to the engine modules for an analysis of the labor and material resources required for the maintenance of each module. A final analysis will take a very close look at the afterburner module. This will be an example showing the level of detail this model can provide. The afterburner module was chosen because of the high cost of labor involved, and the data allows for a detailed analysis of "O" level, "I" level and cannibalization labor cost components.

During the cost calculations the author ran the model numerous times. The initial run calculated the overall costs of the engine maintenance system, and subsequent runs calculated the costs for each module. From the output of the individual modules, a portion of the overall costs incurred from each was established, and in the case of the afterburner module, printouts were produced to detail the labor costs associated with each WUC of the module.

### A. DESCRIPTION OF THE ENGINE MODULES

The F/A-18 engine is designed around a modular engine concept. Each module can be removed and replaced as needed to quickly restore the engine to an operational condition. This design provides an ease of maintenance and increased maintainability over older engine designs. The WUC structure contained in the Navy's information resources distinguished the data of each module under its own unique WUC, greatly simplifying the task of organizing data to provide model inputs. As discussed in Chapter III, the WUCs were used as an assigned number allowing the model to sort and analyze the data for each module. All six major modules and two other categories of engine components are listed in Table 4.1 with their respective WUCs. Information listed under the general engine WUC of 2740000 was placed in a separate category, not attributable to any specific module. Also, the final category of 2747000 deals with the accessories attached to the engine, such as the accessory gearbox, and is not a part of an engine module. The following sections will present the overall engine maintenance system cost, the modules primarily responsible for those costs and the components of these costs.

| WUC | ENGINE MODULE |
|---|---|
| 2740000 | F404-GE-(SERIES) ENGINE |
| 2741000 | FAN MODULE |
| 2742000 | HIGH PRESSURE COMPRESSOR MODULE |
| 2743000 | COMBUSTION MODULE |
| 2744000 | HIGH PRESSURE TURBINE MODULE |
| 2745000 | LOW PRESSURE TURBINE MODULE |
| 2746000 | AFTERBURNER MODULE |
| 2747000 | ENGINE ACCESSORIES |

Table 4.1 F/A-18 Engine Modules and Associated WUC

## B. OVERALL ENGINE MAINTENANCE COSTS

Costs are analyzed from two perspectives. The total costs are separated, first, into the components of labor and materials and, second, a cost distinction among the individual modules. This will provide an overall view of the relationship between the cost components and a magnitude of the difference between the labor and material costs. A benefit of the second view will be identification of the high cost modules, showing the relationship of each module to the total cost picture. Also, the cost breakdown by module will serve as the beginning of a detailed analysis of a single module.

During the first phase of this analysis, cost components are compared to establish which component, labor or material, contributes more to the overall costs. Following this determination, the labor costs associated with the overall engine system are segregated along their components of "O" level, "I" level and cannibalization labor. A further analysis of the material costs incurred by the different organizational levels is not possible because the material cost data collected involved only "I" level material consumption.

### 1. Labor and Material Components of Overall Costs

The first run of the DCM provided a macro-level view of the total cost picture for the entire aircraft fleet. A total engine maintenance system cost of $238,655,618 was calculated for the 595 aircraft fleet. Figure 4.1 shows a breakdown of the labor and material components. Material costs are by far the most significant portion of the overall cost, absorbing 92.4 percent or $220,574,741 of the total. The labor costs portion of overall costs calculated by the model accounts for only 7.6 percent or $18,080,876 of the total costs.

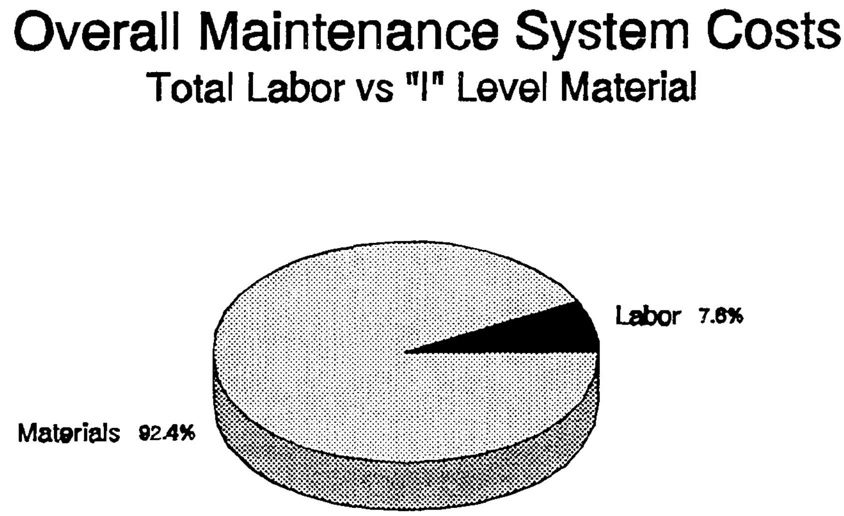


Figure 4.1 Total Labor Costs versus "I" Level Materials

Material costs were expected to be the larger portion of total costs, but the author was surprised that the ratio was weighted this heavily towards materials. Also, recall from the Chapter III discussion that this data base was built with only the "I" level material costs of major engine modules. The addition of "O" level material costs would increase the material portion of this cost, pushing the percentage even higher than shown by the data used.

Unfortunately, a further analysis of material costs was not possible with the data collected during this research effort, but the data does allow further analysis of the labor costs. Figure 4.2 gives an illustration of the labor costs separated into the components of "O" level, "I" level and cannibalization labor. The dollar amounts of these components were $4,826,333,41, $11,682,231 and $1,572,330, respectively.

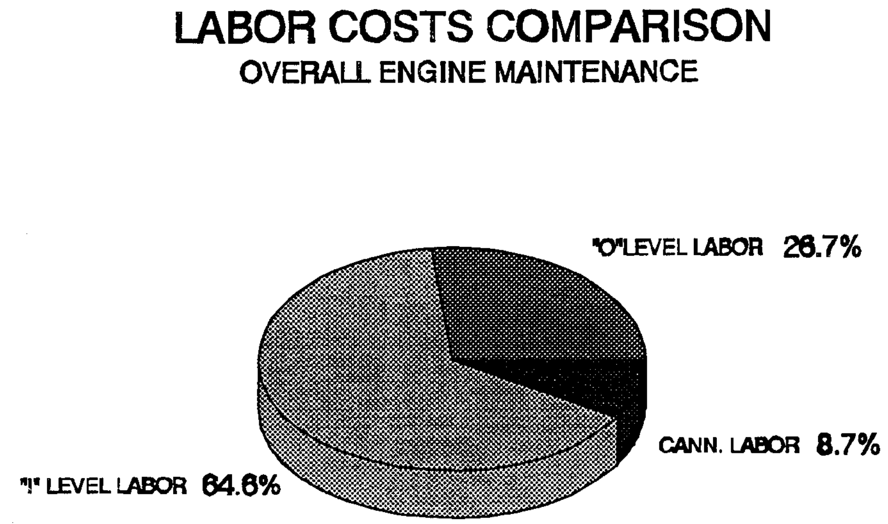


Figure 4.2 Maintenance Level Labor Costs Comparison

The cost percentages resulting from the model's calculations were slightly different from the ratios of man hours taken from the 1992 and 1993 NALDA reports. For example, the percentage of "O" level man hours was 27.6 percent in the NALDA reports, while the costs calculations show the labor costs percentage of 26.7 percent. Likewise, the "I" level labor percentage decreased slightly from 72.4 percent of total man hours, to 64.6 percent of total labor costs. These decreases are due to the separation of cannibalization labor from the whole and the lack of precision inherent in the use of average maintenance action rates for any system that is not completely static.

**2. Engine Module Costs**

The next breakdown of engine maintenance system costs will deal with the individual modules and their associated cost components. From this view the relative size of the total cost incurred from each module will be highlighted, showing the module that drives the majority of the engine maintenance costs. The portion of total costs associated with each of the modules presented in Figure 4.3 is a combination of the total labor and "I" level materials required to maintain each.

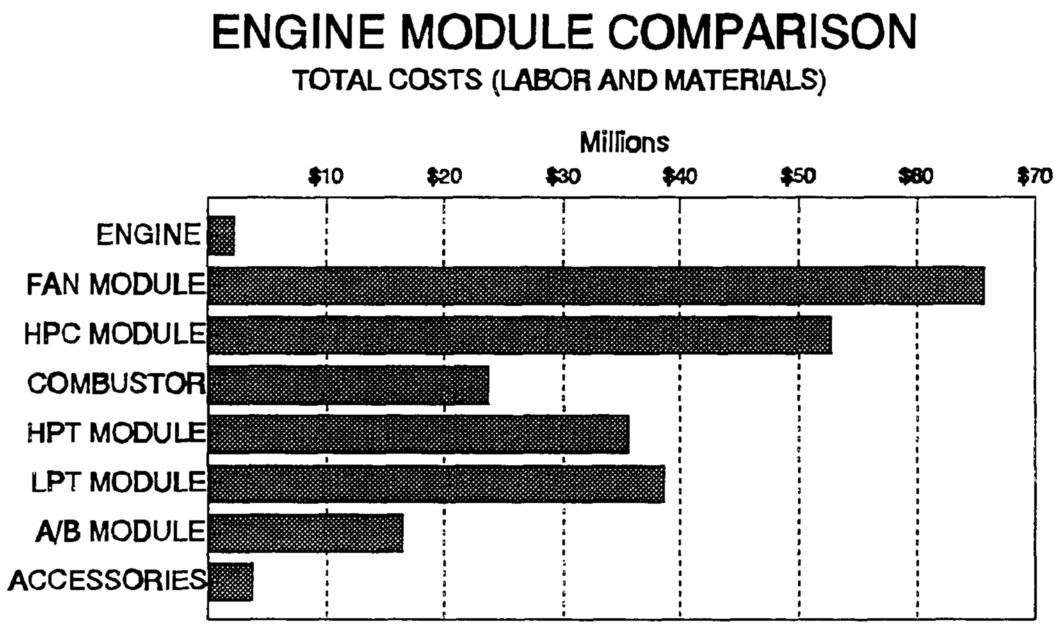


Figure 4.3 Total Costs of Engine Modules Compared

As shown in Figure 4.3 the fan module consumes the highest percentage of the total costs. Labor and materials required to maintain the fan module totaled $65,698,313, or 27.5 percent of the total engine maintenance costs. Notice that the afterburner module represents a relatively small portion of the total maintenance costs. The dollar amount associated with the afterburner was calculated to be $16,430,077, or 6.8 percent of total costs. This figure will be broken down in great detail in a subsequent section. Further information on the total costs of all modules and their percentage of the total engine maintenance costs are contained in Appendix A.

#### *a. Material Costs by Engine Module*

Total costs of the individual modules were separated into the components of labor and materials. A breakdown of the "I" level materials associated with each module is shown in Figure 4.4. Material costs were calculated from the average material usage on major engine modules reported by the AIMD, located at NAS Lemoore [Ref. 26]. Using the overall average costs for the major modules prevents any analysis from proceeding beyond that level of detail. Any greater detail requires knowledge of the exact composition of those averages.

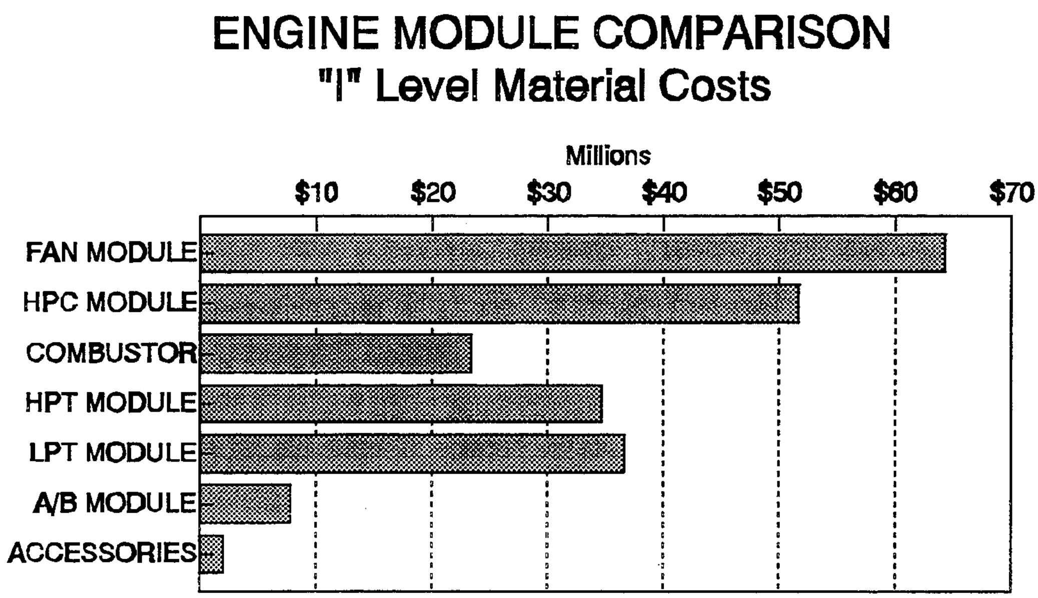


Figure 4.4 "I" Level Material Costs by Module

Once again the major contributor to the maintenance costs is the fan module. Total "I" level material costs for the fan module were calculated to be $64,357,638, or 29.2 percent of the total. The afterburner module consumes a small portion of the "I" level material costs, only $7,834,457, or 3.6 percent of the total. Further detail on other modules is presented in Appendix B.

*b. Labor Costs by Engine Module*

The next portion of the analysis turns to the labor costs associated with each module. Total labor costs contain components of "O" level, "I" level and cannibalization labor. Individual components of the labor costs will be analyzed in detail for the afterburner module in a subsequent section. A graphic comparison of the total labor costs associated with each module is contained in Figure 4.5. From this perspective the man hour intensive module can be seen. Even though the fan module was the primary contributor to overall costs, it is not the major contributor to total labor costs. The module requiring the overwhelming majority of maintenance man hours is the afterburner module. Total labor costs for the afterburner module were calculated to be $8,595,620, or 47.5 percent of the total engine system labor costs. Additional data on the labor costs associated with each individual module is contained in Appendix C.

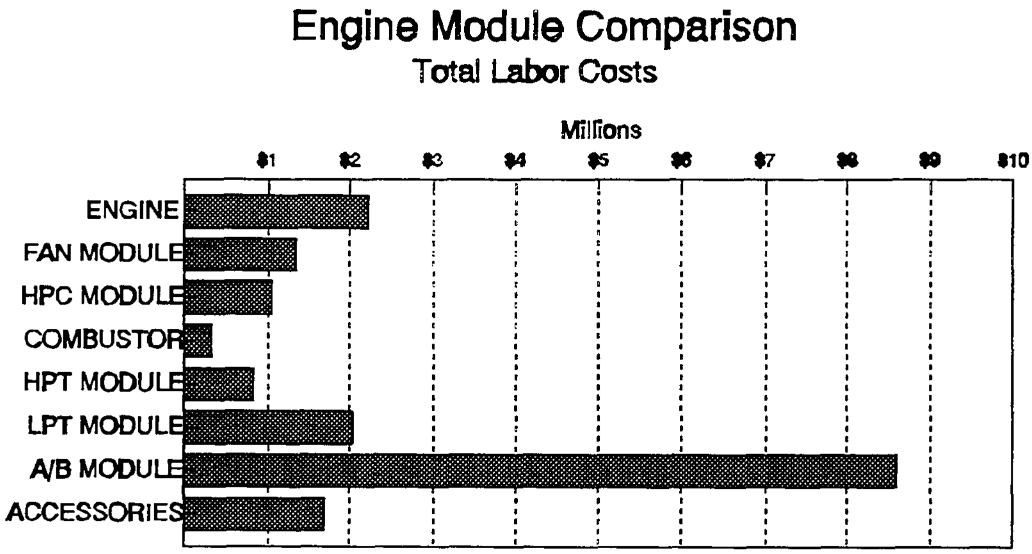


Figure 4.5 Total Labor Costs Comparison by Module

From a total cost perspective, the fan module was determined to be the most costly module in the areas of total costs and "I" level material costs. Separation of the labor component from the total cost picture revealed the afterburner module as the primary contributor to the total labor costs. The following section will break down the labor costs of the afterburner module, showing the level of detail possible from this model.

## C. DETAILED ANALYSIS OF THE AFTERBURNER MODULE COSTS

This section will review the major cost components of labor and materials for the afterburner section. Then the labor costs will be divided into its components of "O" level, "I" level and cannibalization labor. A final analysis of the afterburner section will trace the source of the labor costs down to the specific WUC on which the labor was expended. This will demonstrate the level of detail available through computer modeling of a maintenance system. The level of detail is more limited by the data collected and the organization of that data than by the model.

### 1. Labor and Material Components

The afterburner is a low cost module relative to the overall costs and those of the other modules. The average "I" level material replacement costs of an engine module range from a high of $127,307 (fan module) to a low of $10,588 (afterburner module) [Ref. 27]. Ranking the modules by total maintenance costs, the afterburner module ranks last of the major modules, followed only by the accessories and the general engine category. However, in terms of labor costs, the afterburner module is by far the most expensive. As pointed out in the previous section, the model's calculations show that 47.5 percent of all engine labor costs result from the maintenance performed on this module. Also, data collected during this research effort was much more detailed in the area of maintenance actions and led the author to focus more on this aspect of maintenance costs. For these reasons, the afterburner module was chosen for the detailed analysis.

The components of engine maintenance costs, total labor and "I" level materials are shown in Figure 4.6. Total module costs are comprised of 52.3 percent labor and 47.7 percent materials, equating to dollar amounts of $8,595,620 and $7,834,457, respectively.

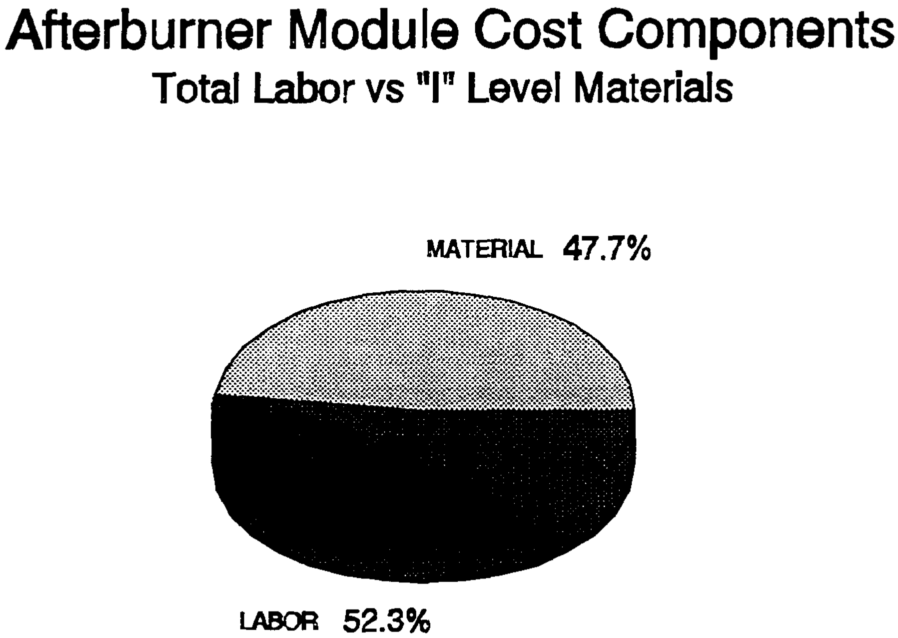


Figure 4.6 Afterburner Labor versus Material Costs

**2. Afterburner Module Labor Costs Analysis**

This section will break the labor costs associated with the afterburner module into components of "O" level, "I" level and cannibalization labor. Information concerning the separation of labor costs at the differing levels of maintenance was taken from a printout produced by the model. This printout gives all the inputs used during the cost calculations, listed by ASN. It contains multiple columns of data showing an average annual cost incurred per aircraft in each cost element. Data from this printout is graphically presented below in Figure 4.7, using the three cost elements of "O" level, "I" level and cannibalization labor. This figure indicates that the major contributor of labor costs is the "I" level, possessing 62.2 percent of the total labor costs for maintenance on the afterburner module.

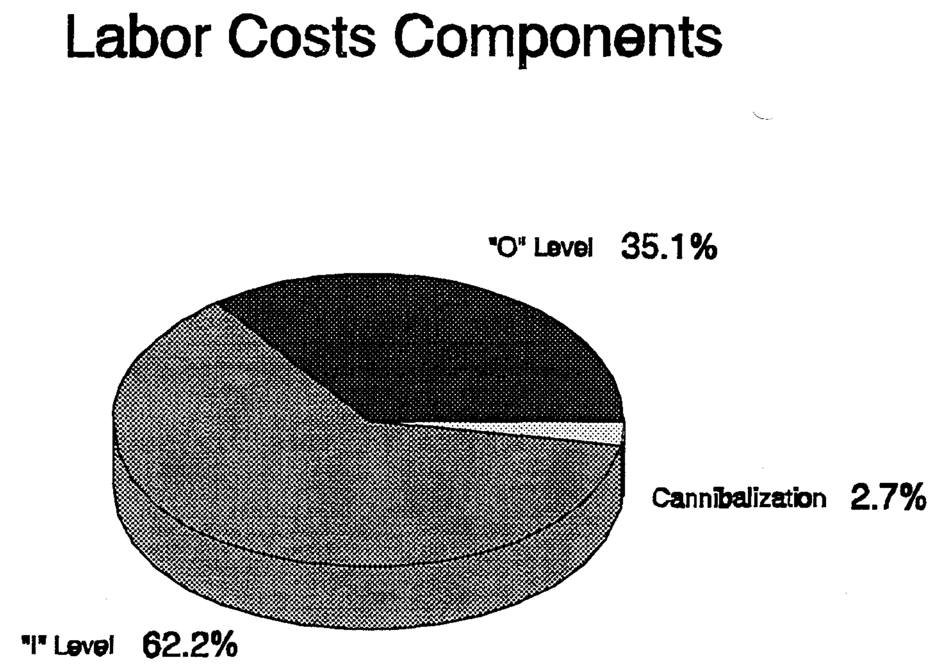


Figure 4.7 Afterburner Labor Cost Components

### 3. Afterburner Labor Costs by WUC

A further breakdown of these costs will consist of identifying the specific WUC responsible for the labor expended. Information of this nature could potentially be useful in the identification of a single part incurring an abnormally high percentage of the overall labor. Once identified the part can be redesigned for greater maintainability, reducing overall maintenance system costs.

The initial presentation of this data will detail the total average annual labor costs incurred per aircraft by WUC. This information is presented in Figure 4.8. Figures 4.9

through 4.11 show the average annual labor costs per aircraft for the separate labor components of "O" level, "I" level and cannibalization labor, also presented by WUC. Data collected by the author contained information on 27 WUCs within the afterburner module that were used in the cost calculations. Only the WUCs containing the highest percentages of the labor from each component are presented in the following figures. Each figure shows the WUCs that comprise the top 90 percent of the labor costs from their respective labor component.

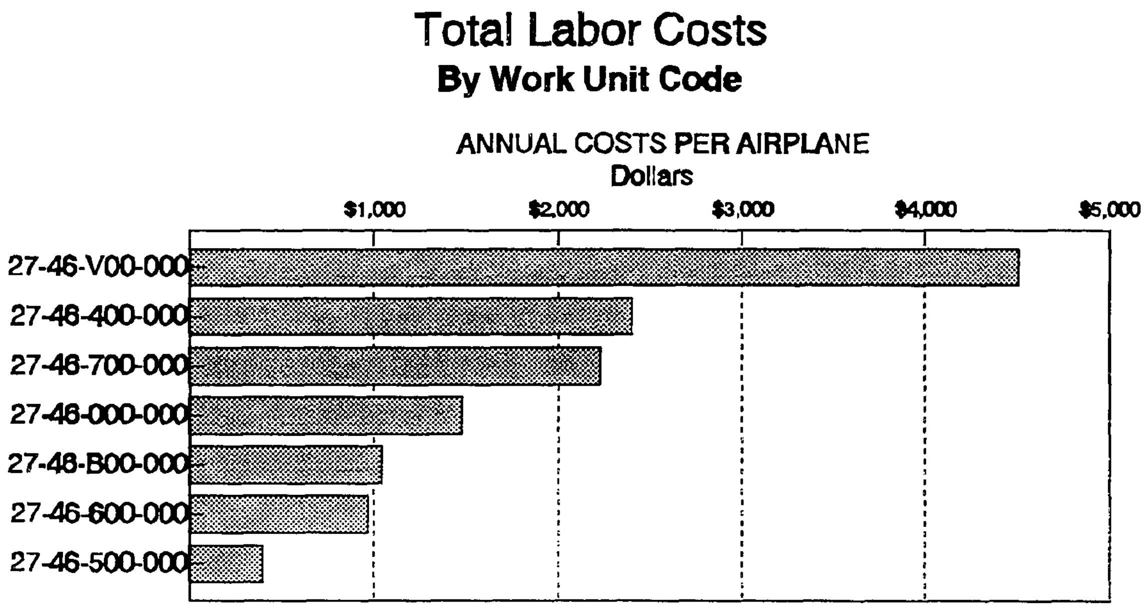


Figure 4.8 Upper 90 Percent of Total Labor Costs by WUC

Figure 4.8 indicates that ASN 27-46-V00-000 requires the major portion of the labor required for maintenance of the afterburner module. This ASN (or WUC of 2746V00) is the afterburner main spray bar. During the author's visit to AIMD NAS Lemoore it was mentioned as being particularly troublesome [Ref. 28] with respect to "I" level maintenance. Model calculations show this particular part accounts for 31.2 percent of the total labor incurred due to afterburner module maintenance.

Figures 4.9 through 4.11 give the labor component breakdown of each WUC, showing only the top 90 percent in each labor component.

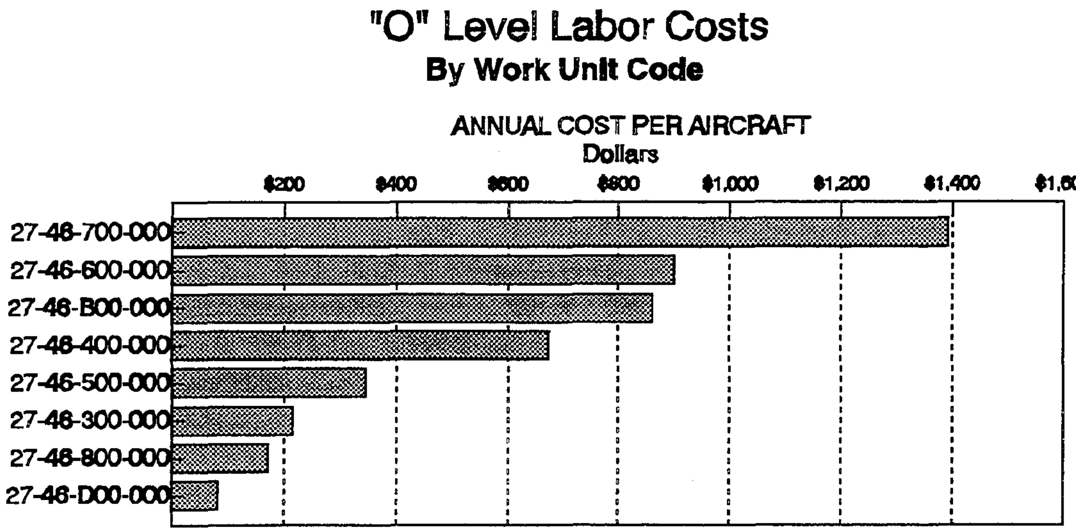


Figure 4.9 Top 90 Percent of "O" Level Labor Costs by WUC

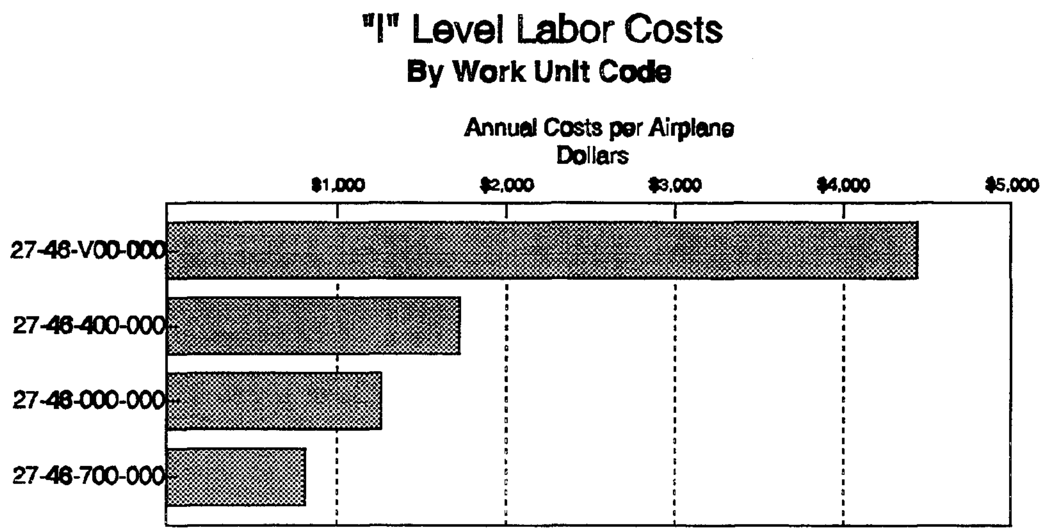


Figure 4.10 Top 90 Percent of "I" Level Labor Costs by WUC

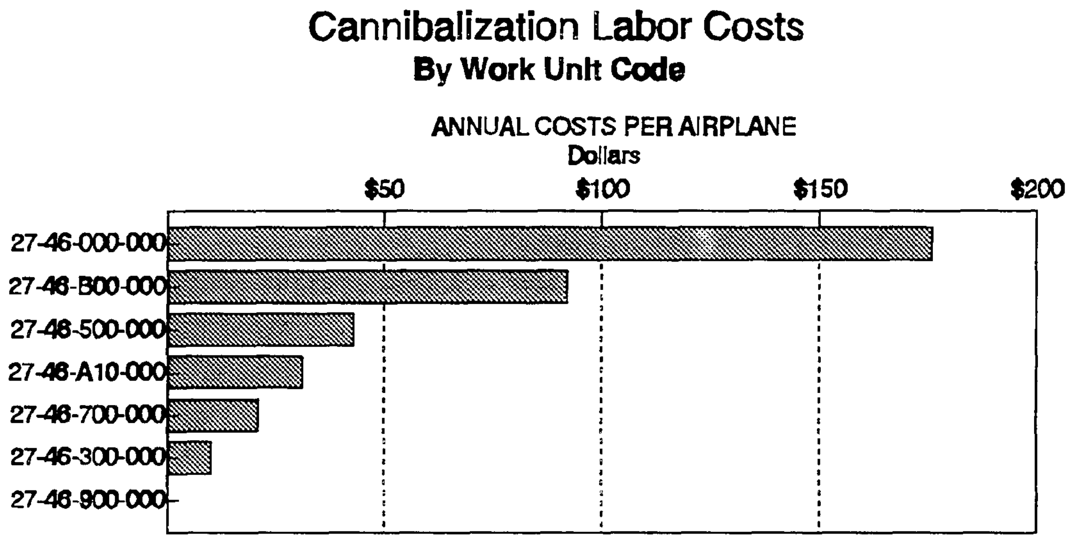


Figure 4.11 Top 90 Percent Cannibalization Labor Costs by WUC

From the figures presented above, the detail possible through computer modeling is apparent. The calculations performed correlated with the impression gathered by the author during field visits as in the case of the afterburner spray bar. As seen in Figure 4.10, the majority of the labor expended for afterburner maintenance at the "I" level is on this part, and this is the most significant portion of the total labor expended in afterburner maintenance.

**D. SUMMARY**

The preceding chapter examined the cost outputs derived from the DCM. Initially, total system maintenance costs were separated into the components of labor and materials. Material costs were determined to be the major contributor to the total maintenance system costs, accounting for 92.4 percent of the total. Due to the level of detail available within the material cost data, a further analysis of the material costs was not possible.

Labor costs were presented as the remaining 7.6 percent of the total maintenance system costs. Data collected with respect to the labor costs contained a greater level of detail, allowing the author to separate total labor costs into its components. Viewing the "O" level, "I" level and cannibalization labor components gave a picture of which maintenance level performs the majority of maintenance actions on the F/A-18 engine system. Results showed the "O" level, "I" level and cannibalization labor components to be 26.7 percent, 64.6 percent and 8.7 percent of the total labor costs, respectively.

Total maintenance system costs were then divided among the major engine modules, accessories and the general engine WUC. This highlights the high cost areas of the engine by the module responsible for the expenditure. A similar breakdown of labor costs and "I" level material costs was performed by module. Results showed that the fan module was the highest cost area of the engine for both total system costs and the "I" level material consumption. The labor costs analysis showed the afterburner module to be responsible for almost one half (47.5 percent) of the total labor costs incurred.

A final portion of the analysis dealt specifically with the afterburner module. It began with the separation of labor and material components and continued into the segregation of labor costs by the maintenance level performing the action. An additional level of detail was demonstrated, further breaking down the labor costs to the individual WUC responsible for the labor expenditure. This highlighted the afterburner engine parts requiring the highest labor expense within the overall engine maintenance system.

This type of analysis can be useful in efforts to reduce overall aircraft maintenance system cost, but does have limitations. Accuracy of the data can greatly affect the outcome of a computer simulation. A model can provide a level of detail that goes beyond the point of usefulness and even beyond the level of detail prescribed by the data collected.

Efforts to collect data can place a manpower burden on the administration of a maintenance system, incurring costs beyond any benefit received by the increased detail of the data.

For example, the final breakdown of labor costs to the specific WUC in this chapter has exceeded the precision of the data collected. Assumptions concerning the average maintenance action times made in Chapter III were too broad to realistically consider the model output valid to this level of detail. The cost information presented in this research effort is merely an estimate and is not intended to be precise. The final portion of the analysis was presented for demonstration purposes and gave a general idea of the actual distribution of the maintenance resources, but is not accurate enough to relate precisely to the reality of everyday maintenance actions.

The next chapter of this thesis will discuss the model outputs from a real world perspective and give the author's overall impression of its usefulness. A major topic of the discussion will be the applicability of this model to Naval tactical aviation and some problems associated with its adaptation to the F/A-18. Also, alternative uses and possible modifications will be presented.

## V. DCM APPLICATION TO THE F/A-18

This chapter will discuss the problems associated with adaptation of the DCM to the F/A-18 engine maintenance system. After this discussion, the model is used to calculate the FY94 "I" level material cost of AIMD, NAS Lemoore and compare this estimate to the cost forecasted in their mid-year budget call. A final use of the model will be to forecast the annual "I" level material cost for FY95 based on service life adjustments to major engine components.

The cost estimations below have been limited to the material costs for a number of reasons. First, the data used while constructing the data base consisted of maintenance actions and man hours of high maintenance action WUCs taken from the ECIFRs. High maintenance action items were defined in the ECIFR as the top 80 percent of total actions and man hours. Therefore, any estimation of actual labor costs would be significantly underestimated. This level of detail allows for the analysis of high maintenance action components, but a full accounting of all actions is not possible.

Second, the material costs used for this analysis were average module costs for all "I" level material expenses incurred. The use of total "I" level material costs divided by total engine modules pushed through the system fully captures all material costs, allowing a solid base for further estimation without losing a percentage of the total material costs.

Third, funding for total engine maintenance originates from two appropriation accounts. All material costs are funded through the operation and maintenance appropriation, but labor expenses are paid through a combination of military personnel appropriation and the operations and maintenance appropriation. Labor performed by military personnel originates from the military personnel appropriation, which would include "O" level labor and a portion of "I" level labor. The remaining "I" level labor performed by civilian personnel would be funded through the operations and maintenance appropriation. This mixture of appropriations for labor costs obscures the issue of reducing appropriated funds in this area. Any analysis focusing on the reduction of appropriated funds would require knowing the relationship of military versus civilian labor. Data used in this project does not distinguish between military and civilian labor nor does the model contain any provision for this distinction.

Maintenance costs originating from the operations and maintenance appropriations have been an area of concern in the recent past. The rapid and unexpected growth of maintenance costs have strained the funding resources appropriated through this account. Engine component service life reductions have driven these cost increases and adversely impacted fleet readiness by absorbing funds intended for the other items within this appropriation. Material costs make up the majority of this increase, but a small percentage can be attributed to the increased labor costs.

Because of the nature of the data, complexity of appropriation accounts and the relative size of labor and material cost components, the focus here will be on the material cost portion of this issue.

### A. DCM ADAPTATION TO THE U.S. NAVY

The DCM was not designed for the organizational structure used by the Navy. This forced the author to limit the scope of this research effort and redefine many of the variables. The original purpose of the model was to identify the high cost drivers of an entire aircraft maintenance system. This research applied the model only to the engine system of one aircraft. The multiple levels of maintenance in the Navy's organization precluded the analysis of the entire engine maintenance system costs, and as discussed in Chapter III, depot level costs and "O" level material costs were excluded from this analysis. The model's design allows for only two levels of maintenance and the material costs associated with one of those levels. Constrained by the model's design and in some cases data collected, the author attempted to capture as much of the engine maintenance system costs as practical. The resulting analysis presented in the previous chapter showed only the costs associated with "O" and "I" level labor and "I" level materials. The total Navy maintenance organization exceeded the capacity of the model's design, but analysis of the areas within the scope of this research effort provide some insight into the maintenance system costs. Additional problems encountered with the F/A-18 will be addressed below.

### B. DCM ADAPTATION TO THE F/A-18

A significant problem with the use of this model for the F/A-18 engine is the use of flight time averages to predict engine module removals. The F/A-18 uses an onboard engine monitoring system to track and record engine data through various sensors. This system records engine thermal cycles, rotor speeds and many other factors to determine the service life remaining on engine components. Service lives are given as engine life cycle fatigue, effective full thermal cycles, equipment operating time, etc. and tracked continuously on a computerized maintenance information system. Any part within an engine module reaching its life limit will result in the module's removal from the engine. All scheduled removals of the engine components are based on these criteria which are better suited for tracking engine wear than flight time.

Any correlation to flight time is purely coincidental. The number of flight hours between engine component removals depends on how aggressively the aircraft is flown. For example, a typical flight transporting the aircraft from one base to another could require full power only once, on take off, while a flight consisting of air combat maneuvering could require a pilot to modulate the throttle between idle and full power several times during each training engagement. Each throttle movement creates temperature and rotor speed changes, increasing wear on the engine components. Total component wear on the engine for the two flights would be drastically different.

The cross country transportation may involve only a few "effective full thermal cycles" in a two hour flight, but the air combat mission may involve more than a dozen in a one hour flight. Thus, an engine component removal would occur in relatively few flight hours for an aggressive training mission, but the less demanding missions would require engine component replacements after a relatively high number of flight hours had been flown.

To compensate for this problem, any flight hour average would need to be taken over a long period. A period of two years, as used in this project, is a sufficient length to cover the full work-up and deployment cycle of a squadron. It could possibly average out the differing intensities of the operations. But the negative side of the long period average is an inherent inability to capture any system changes.

This presents problems of some magnitude for the maintenance funding of the F/A-18. Changes in the service life of engine components have occurred frequently in the recent past, creating a major problem in the prediction of required funding. The following sections discuss this problem in detail and attempt to use the DCM as a cost estimation tool by adjusting the model inputs for engine component service life reductions.

## C. MODEL FORECAST OF FY94 "I" LEVEL MATERIAL COSTS

After the initial cost data was generated for the entire fleet of 595 aircraft, another run of the model was performed utilizing the actual number of aircraft supported by AIMD NAS Lemoore, 218 [Ref. 29]. Cost data from this run was compared to the forecasted annual material costs taken from the AIMD NAS Lemoore mid-year budget call [Ref. 30]. Their estimate was $84,844,490 and the model estimated the annual "I" level material costs to be $80,815,619. The model's cost estimate differs by roughly 4.7 percent, which is a significant error. However, the historical data used during data base construction does not contain the latest revisions to engine component service lives nor does this data fully reflect changes occurring in 1992 and 1993. These changes would cause the model to underestimate the material expenses. Table 5.1 shows the engine life cycle fatigue (ELCF) changes that occurred during the period covered by the data [Ref. 31].

The timing of these changes degrades the accuracy of historical data used in the data base. An average removal rate taken over the entire period of 1992 and 1993 would not fully represent the impact of a change occurring during the period. The later a change occurred in the period, the less influence it would have on the average. Only changes occurring before, and fully implemented throughout the period would be fully represented by the average.

Additional changes to component service lives have occurred since the end of the data collection period. These changes are not reflected in the averages used in model calculations and further exacerbate the underestimation problem. Table 5.2 gives a list of changes occurring from January 1994 through July 1994.

| COMPONENT | ORIGINAL ELCF | CHANGED ELCF | DATE OF CHANGE |
|---|---|---|---|
| FAN MODULE | | | |
| Stage 1 Disk | 5850 | 2700 | 6/92 |
| | | 2400 | 10/92 |
| | | 2200 | 4/93 |
| Stage 2 Disk | 8770 | 3800 | 3/92 |
| | | 3300 | 10/92 |
| | | 3100 | 4/93 |
| Stage 3 Disk | 4380 | 2100 | 3/92 |
| | | 1800 | 10/92 |
| | | 1700 | 4/93 |
| HP COMPRESSOR MODULE | | | |
| Stage 1-2 Comp. Spool | 2240 | 1850 | 7/93 |
| Stage 3 Comp. Spool | 7480 | 3470 | 7/93 |
| Stage 4-7 Comp. Spool | 14560 | 12500 | 7/93 |
| HP TURBINE MODULE | | | |
| Fwd Cooling Plate | 2100 | 1600 | 6/92 |

Table 5.1 ELCF Changes 1992 Through 1993

| COMPONENT | ORIGINAL ELCF | CHANGED ELCF | DATE OF CHANGE |
|---|---|---|---|
| FAN MODULE | | | |
| Fan Aft Shaft | 9030 | 4600 | 1/94 |
| HP COMPRESSOR MODULE | | | |
| Stage 1-2 Comp. Spool | 2240 | 1700 | 1/94 |
| | | 1500 | 7/94 |
| Forward Shaft | 4910 | 4000 | 7/94 |
| HP TURBINE MODULE | | | |
| HP Turbine Disk | 10500 | 7200 | 7/94 |
| LP TURBINE MODULE | | | |
| LP Turbine Disk | 10520 | 6240 | 1/94 |
| Forward Seal | 22030 | 18000 | 1/94 |
| Conical Shaft | 12370 | 6700 | 1/94 |

Table 5.2 ELCF Changes January 1994 Through July 1994

These changes highlight the problem associated with using historical averages in a changing cost environment. Averages will always lag behind actual changes to some degree. The severity of the lag will depend on the length of time the average covers and the magnitude of the change. This will create a situation of over or underestimation depending on the direction of movement in the value being averaged. If the period of data collection is too long, the average will not respond rapidly enough, or if too short, could be adversely affected by short term spikes. In the case of the model's estimate for annual "I" level material costs, the author believes the underestimation was due to the reduction of component service lives both during and after the data collection period. The lag in the data with respect to the 1992 and 1993 changes and the exclusion of the 1994 changes resulted in the low estimation.

**D. BUDGET FORECAST FROM THE DCM**

A feature of the model discussed in Chapter II would allow the user to manually edit the component inputs to compensate for service life reductions on engine components. This would allow a budgetary planner to view the cost differential between the existing system and any proposed change to the system. Use of this feature would allow decision makers to forecast the additional costs incurred due to the change, leading to funding adjustments or the development of alternate plans if additional funding was not possible. However, this method only allows a planner to compensate for known changes while much of the problem has been the recurring unexpected changes.

The author adjusted the mean flight hours between removals on the components listed in Table 5.2 in an attempt to estimate an annual "I" level material cost based on the most recent service life changes. These adjustments were performed by equating the ratio of new ELCF over original ELCF, to the adjusted mean flight hours between removal over the original mean flight hours between removal, and then solving for the adjusted mean flight hours between removals. Original mean flight hours between removals and the adjusted values are compared in Table 5.3.

| MODULE | ORIGINAL MEAN FLIGHT HOURS BETWEEN REMOVAL | ADJUSTED MEAN FLIGHT HOURS BETWEEN REMOVAL |
|---|---|---|
| FAN MODULE | 899 | 458 |
| HP COMPRESSOR MODULE | 978 | 655 |
| HP TURBINE MODULE | 982 | 673 |
| LP TURBINE MODULE | 779 | 421 |

Table 5.3 Removal Rates Adjusted for ELCF Changes

These adjusted values were then used in the model to forecast an annual funding requirement for the F/A-18 engine based on the recent service life changes. The resulting estimate for the annual "I" level material cost incurred by AIMD NAS Lemoore, CA. was $130,149,966. This estimate inherently assumes the system will operate on the adjusted mean flight hour between removals for an entire year.

Also, as mentioned earlier the original mean flight hours between removals do not fully compensate for the changes shown in Table 5.1. Those changes would further reduce the mean flight time between removals, but the degree to which the original data captured the 1992 and 1993 changes is unknown. Additional information on the number of removals occurring before and after the change would be required for this clarification. Both of the above factors will cause the forecasted annual "I" level material cost to be underestimated.

Another possible distortion of this forecast is a large portion of the "I" level material costs are incurred from the replacement of parts found to be defective after the module is removed. If the flight time between removals decrease, this could also lead to a decrease in the number of additional parts found to be defective. A reduction in the additional part defects found during module removals would decrease the average costs per module, implying that the $130,149,966 annual "I" level material cost forecast could be overestimated.

Whether the model's estimate is too high or too low can not be determined from the information contained in this project. A final validity check can be performed only after next year's funds are expended, and further changes would influence the accuracy of a historical comparison. This particular use of the model goes beyond the designer's intentions. Also, the ratio method used to adjust the mean flight hour values was a crude estimate and assumes a constant intensity of the missions flown. In the author's opinion, the model has potential as a budget estimating tool for a stable system. For a dynamic system such as the F/A-18 engine system it could be used with caution, but simplifying assumptions and adjustments would affect the accuracy of the estimates.

## E. SUMMARY

This chapter has attempted to check the accuracy of the model as compared to current cost estimates and explain any inaccuracies. It has also discussed some issues associated with the use of this model with the F/A-18 engine system, and forecasted the resulting "I" level material costs based on recent service life changes. This alternative use of the model is beyond the designer's original intentions, but recent funding problems in the engine maintenance system are severe enough to warrant a search for a solution. Inability to forecast funding levels adversely impacts fleet readiness and reduces the operations and maintenance funds available for other programs.

Also, the model was built to highlight high cost areas of an entire aircraft maintenance system and was not specifically designed for an engine system. As shown in Chapter IV, the analysis of high cost areas provides a valuable insight, but use as a cost estimation tool is of questionable reliability. The author's attempt to forecast a future funding level was a marginal success. Input data was altered and a forecast produced, but this forecast cannot be validated. Construction of the data base gives reason to suspect an underestimation, but material cost factors could cause an overestimation. A relative strength of the two factors cannot be inferred from the available data.

# VI. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

This chapter summarizes the entire research effort, discusses the author's concluding thoughts and offers suggestions for further research. Areas of discussion will include the Dependability Cost Model's applicability to the Navy's F/A-18 and Naval Aviation in general. The possibility of designing future models specifically tailored for military aviation and their use in the reduction of aircraft maintenance system costs is also addressed. In closing, recommendations will be made on further research in the area of aircraft maintenance system cost reductions.

## A. SUMMARY

After a brief mention of the funding problems associated with F/A-18 engine maintenance system, the author proposed to examine an aircraft maintenance system cost model developed by the Boeing Corporation and determine its applicability to Naval aviation maintenance. Benefits derived from the successful use of this model could be increased economic efficiency of the aircraft maintenance system or possibly a tool for estimating future funding requirements. A secondary goal of this research was to determine whether the Navy can use this type of model with the existing maintenance information resources.

Chapter II provided a detailed look at the model, explaining the required inputs and methods of manipulation used by the model. The complexity of this model was shown during this chapter and much of its potential was not used in this research effort, specifically, the route structure showing the cost impacts due to multiple maintenance locations and the spares holding cost element estimating the inventory costs associated with the maintenance system. The route structure is not viewed as a significant loss of value to this research because the operations of the F/A-18 normally involve a single location. However, the lack of data forcing the author to exclude spares holding costs from the scope of this research is a severe deficiency.

The construction of the data base for the F/A-18 and the information sources used are described in Chapter III. Information within the Navy's maintenance system was more than adequate with respect to component reliability and labor expended, but material cost data was not obtained for the entire fleet. Gathering reliability data was constrained by time rather than the availability of information. Material cost data was difficult to find, and the data used by this project was narrowly focused on one AIMD facility. Appendix D contains a portion of the data base constructed. This data base sample contains information on the six major modules of the engine and other sample WUCs with each module.

A demonstration of the model's output was given in Chapter IV. The first calculation was a dependability cost estimate for the entire fleet of aircraft. This cost estimate contained "O" and "I" level labor and "I" level materials for a fleet of 595 F/A-18 aircraft and was estimated to be $238,655,618.

Initially total engine maintenance system costs were separated into components of total ("O" and "I" level) labor and "I" level materials. This showed the "I" level material costs to be the most significant contributor to the total cost picture. According to the data used, 92.4 percent of the total costs were incurred from "I" level material consumption.

Total labor accounted for 7.6 percent of the total costs. A further breakdown of the labor costs separated labor into the components of "O" level, "I" level and cannibalization labor. The resulting percentages were 26.7 percent, 64.6 percent and 8.7 percent, respectively.

The cost analysis then turned to the six major engine modules. Total costs were determined for each module, and the fan module proved to be the highest cost item. Separating the costs of each module into labor and material components showed the fan module responsible for 29.2 percent of total "I" level material costs and the afterburner module absorbing 47.5 percent of the "O" and "I" level labor costs.

A final portion of Chapter IV demonstrated a detailed analysis of maintenance costs associated with the afterburner module. Examination of labor and material components of the total costs showed 52.3 percent resulting from the labor expended on this module. Labor costs were then broken down by WUC into the annual costs per airplane. This showed the afterburner main spray bar accounting for 31.2 percent of the total labor costs incurred by this module. Information such as this indicates how a particular part can absorb an abnormally high percentage of the total costs, but does not necessarily indicate a problem. A part may require such maintenance for reliable operation, but this information could allow a decision maker to target specific areas for cost reduction efforts.

Chapter V discussed issues adversely affecting the use of this model with both the Navy's maintenance organization and the F/A-18. A fundamental problem of the differing organizational structures prevents this model from being applied to the total Naval maintenance organization. As designed, the DCM has enormous potential to highlight a piece of the Navy's maintenance organization, but three maintenance levels exceed the capability of a model designed for only two maintenance levels.

Problems associated with the use of this model on the engine system of the F/A-18 were also addressed. Rapidly changing services lives and the use of flight time averages are the most severe restrictions in this area. Module service lives based on engine fatigue criteria do not relate to a constant flight time between removals. Varying intensities of the missions flown can cause a large error in an average taken over a short period, but service life changes prevent long term averages from being precise. Any distortion of the input data will affect the final output.

An alternative use of the model as a budget forecasting tool was demonstrated in the final portion of Chapter V. The author attempted to validate the model's output through a comparison with AIMD NAS Lemoore's FY94 budget estimate. Model inputs were altered to conform with the actual number of aircraft supported by AIMD NAS Lemoore. The model's estimate differed from the FY94 mid-year budget estimate by 4.7 percent. This inaccuracy can be partially explained by the service life reductions that occurred during and after the period represented by data collection. After altering the input data for service life changes that have occurred in 1994, a final estimate was made for FY95 "I" level material costs. An estimate of $130,149,966 was calculated, but a validation of this estimate is not possible with the data contained in this research effort.

## B. CONCLUSIONS

Through examination of the data actually collected, it is apparent that current maintenance information systems used by the Navy hold the component reliability data to build a data base without altering the variable definitions. However, the material cost data would be difficult to obtain on a broad scale. Specific data on a particular maintenance entity, such as that used from the AIMD NAS Lemoore, was not difficult to obtain, but may not apply to all AIMD facilities. Therefore, the use of this model to forecast the funding requirements for the Navy as a whole would be grossly inaccurate. However, the highlighting of costs for a particular maintenance entity could provide valuable information.

The structure of this model is not well-suited for the entire Naval maintenance system, because the complexity of the Navy's maintenance organization exceeds the model's structure. However, this structure could be useful to highlight the costs of a specific "O" level or "I" level maintenance entity. Combining the two levels of maintenance created the need to redefine input variables and exclude portions of the total maintenance system from the cost analysis.

An alternative use for the model was explored by the author. This was an attempt to use this model as a budget forecasting tool. The increases in annual funding requirements driven by recent service life changes have created a severe problem for budgetary planners, maintenance personnel and operators of the F/A-18. Accurately forecasting the annual funding requirements could ease the burden on the operations and maintenance appropriation, allowing funding resources to be applied where originally intended.

However, forecasting funding requirements for known service life changes only addresses one half of the issue. Long lead times required for budget submissions force planners to estimate maintenance funding based on today's knowledge of component service lives. Any service life reduction occurring between budget submission and the end of the budget execution will cause actual expenses to exceed the budgeted amount. While this model can forecast additional funds required to finance a known change, it cannot be used to foresee future service life changes. Thus, the more difficult portion of this problem, predicting a service life change, will continue to plague the F/A-18 community.

## C. RECOMMENDATIONS

On several occasions the author has discussed the differences between the Navy's maintenance organization and the maintenance structure designed into Boeing's DCM. The two are drastically different and the DCM is not capable of calculating the total maintenance system costs for the Navy's maintenance organization. Despite this limitation there are pieces of the Navy's maintenance organization that could benefit from the use of this model.

An application of this model to a single "O" level activity could provide valuable information to that activity. The model's structure of line and shop maintenance could be related directly to the line division and other work centers of a single squadron. Information taken from the use of this model could be used to highlight areas of potential cost reduction, increasing the economic efficiency of maintenance practices.

Another possible use of the DCM would be tracking the practices of a single "I" level facility. This research effort focused on a single "I" level maintenance activity for the cost estimation example, and the estimate derived from model calculations was close enough to be encouraging. The data base was constructed from fleet-wide averages, and the use of local averages for a particular activity could provide accurate cost estimates as well as highlight areas of potential savings.

Originally the model was designed for application to the entire aircraft maintenance system. The scope of this project was limited to a portion of the Navy's maintenance system and the engine system of one aircraft. Further research applying the model to the entire F/A-18 or other Naval aircraft could highlight maintenance system costs from a broader perspective. Results of this effort showed the fan module as the primary driver of engine material costs and the afterburner module driving the engine labor costs. Expanding the picture to the entire aircraft may highlight additional points of interest for redesign or a needed change of current maintenance practices.

Several deficiencies of the DCM as related to Navy maintenance were mentioned throughout the text of this project. The author feels it would be possible to construct a model correcting these deficiencies. Some additions would be incorporation of another level of maintenance activity, material costs for all maintenance levels, additional labor rates peculiar to each maintenance level and eliminating the schedule interruption cost element. This would provide a more realistic simulation of the Navy's maintenance organization, but the added complexity could render a larger model practically useless. The DCM is well designed and the author found it relatively easy to use despite the lack of any prior knowledge of Paradox programs. Preserving the user-friendly aspect of a model should be a primary consideration in the construction of any similar models.

The greatest deficiency in this research effort was the inability to use the spares holding cost element of the model. Data collection, constrained by the time allowed for this project prevented the author from analyzing the relationship between spares inventory costs and cannibalization maintenance costs. Cannibalization is a volatile issue in Navy maintenance due to its impact on readiness, but what is the true cost of cannibalization? The analysis in Chapter IV showed cannibalization labor costs to be 8.7 percent of the total "O" and "I" level labor costs, but can this expenditure be avoided through an increased spare parts inventory? Also, would it be economically efficient to increase inventories to preclude all occurrences of cannibalization? The addition of material costs of cannibalization could substantially increase the total cannibalization costs, but data was not available to calculate these material costs. In Chapter III the author theorized that an increase in spares inventory could reduce cannibalization, but at what point do added inventory costs exceed the benefits derived from decreased cannibalization?

This model can be used to calculate cannibalization maintenance costs and the spares holding costs. Through manipulation of the data inputs, the number of spares on hand can be set to levels actually held in the Navy's supply system. Thus, an estimate of the actual spares inventory costs could be compared to the cannibalization maintenance costs. Adjustments can then be made to the inventory values showing the additional costs of each unit added to the inventory. The model will not reduce the cannibalization rate based on an increasing spares inventory, but the necessary reduction in the cannibalization rate to economically compensate for the increased inventory costs could be calculated. The addition of a statistical model predicting a behavior of the cannibalization rate could then provide a point of minimum total costs to the system, achieving an economically efficient balance between the increased inventory costs and decreased cannibalization maintenance costs.

Another difficulty would be establishing the cost of all potential benefits of decreased cannibalization. If increased readiness is considered as part of the benefit derived from decreased cannibalization, the total economic benefit would be difficult to calculate. This would require placing a dollar value on readiness and this could be very difficult. Defining an exact unit of readiness as well as a cost per unit of readiness would be required. At best, this value would contain some subjectivity and the higher the monetary value of readiness, the greater its impact on the above analysis.

## APPENDIX A. TOTAL ENGINE MODULE COSTS

The Table below contains cost data as calculated by Boeing's Dependability Cost Model. These costs include "O" level labor, "I" level labor and "I" level material replacement costs. Costs are given for each major engine module and the percentage of overall engine costs it represents. Calculations were based on a fleet of 595 F/A-18 aircraft.

| ENGINE MODULE | TOTAL MODULE MAINTENANCE COSTS | % OF OVERALL MAINTENANCE |
|---|---|---|
| Gen. Engine WUC | $2,226,323 | 0.9% |
| Fan Module | $65,698,314 | 27.5% |
| HPC Module | $52,794,628 | 22.1% |
| Combustion Module | $23,675,461 | 9.9% |
| HPT Module | $35,489,429 | 14.9% |
| LPT Module | $38,626,881 | 16.2% |
| A/B Module | $16,430,077 | 6.9% |
| Accessories | $3,714,503 | 1.6% |
| TOTALS | **$238,655,616** | **100.0%** |

## APPENDIX B. ENGINE MODULE "I" LEVEL MATERIAL COSTS

The Table below contains cost data as calculated by Boeing's Dependability Cost Model. These costs include "I" level material replacement costs. Costs are given for each major engine module and the percentage of overall "I" level material costs it represents. Calculations were based on a fleet of 595 F/A-18 aircraft.

| ENGINE MODULE | "I" LEVEL MATERIAL COSTS | % OF OVERALL "I" LEVEL MATERIAL COSTS |
|---|---|---|
| Gen. Engine WUC | $00 | 0.0% |
| Fan Module | $64,357,638 | 29.1% |
| HPC Module | $51,745,932 | 23.5% |
| Combustion Module | $23,347,172 | 10.6% |
| HPT Module | $34,666,044 | 15.7% |
| LPT Module | $36,603,718 | 16.6% |
| A/B Module | $7,834,457 | 3.6% |
| Accessories | $2,019,781 | 0.9% |
| **TOTALS** | **$220,564,741** | **100.0%** |

## APPENDIX C. ENGINE MODULE LABOR COSTS

The Table below contains cost data as calculated by Boeing's Dependability Cost Model. These costs include "O" level and "I" level labor costs. Costs are given for each major engine module and the percentage of overall labor costs it represents. Calculations were based on a fleet of 595 F/A-18 aircraft.

| ENGINE MODULE | TOTAL LABOR COSTS | % OF OVERALL LABOR COSTS |
|---|---|---|
| Gen. Engine WUC | $2,226,323 | 12.3% |
| Fan Module | $1,340,676 | 7.4% |
| HPC Module | $1,048,697 | 5.8% |
| Combustion Module | $328,289 | 1.8% |
| HPT Module | $823,386 | 4.6% |
| LPT Module | $2,023,164 | 11.2% |
| A/B Module | $8,595,620 | 47.5% |
| Accessories | $1,694,722 | 9.4% |
| **TOTALS** | **$18,080,877** | **100.0%** |

## APPENDIX D. DATA BASE EXCERPT

| ASN | NOMENCLATURE |
|---|---|
| 27-41-000-000 | FAN MODULE |
| 27-41-100-000 | FRONT FRAME ASSEMBLY |
| 27-41-200-000 | FAN ROTOR ASSEMBLY |
| 27-42-000-000 | HIGH PRESSURE COMPRESSOR MODULE |
| 27-42-100-000 | COMPRESSOR MIDFRAME ASSEMBLY |
| 27-42-200-000 | COMPRESSOR ROTOR ASSEMBLY |
| 27-43-000-000 | COMBUSTOR MODULE |
| 27-43-100-000 | COMBUSTION LINER |
| 27-43-200-000 | NOZZLE SUPPORT AND SEAL |
| 27-44-000-000 | HIGH PRESSURE TURBINE MODULE |
| 27-44-100-000 | HIGH PRESSURE TURBINE ROTOR ASSEMBLY |
| 27-44-200-000 | FAN DRIVE SHAFT ASSEMBLY |
| 27-45-000-000 | LOW PRESSURE TURBINE MODULE |
| 27-45-100-000 | LOW PRESSURE TURBINE ROTOR ASSEMBLY |
| 27-45-200-000 | LOW PRESSURE TURBINE CASE |
| 27-46-000-000 | AFTERBURNER MODULE |
| 27-46-100-000 | AFTERBURNER CASE |
| 27-46-200-000 | AFTERBURNER LINER |
| 27-46-V00-000 | AFTERBURNER MAIN SPRAY BAR |
| 27-47-000-000 | ENGINE LEVEL COMPONENTS |
| 27-47-100-000 | ACCESSORY GEARBOX ASSEMBLY |
| 27-47-200-000 | EXHAUST CENTERBODY |

## APPENDIX D. DATA BASE EXCERPT

| ASN | QUANTITY PER AIRCRAFT | DELAYS PER 100 DEPARTURES | CANCELS PER 100 DEPARTURES |
|---|---|---|---|
| 27-41-000-000 | 2 | | 0.001264 |
| 27-41-100-000 | 2 | | 0.000632 |
| 27-41-200-000 | 2 | | |
| 27-42-000-000 | 2 | | 0.001264 |
| 27-42-100-000 | 2 | | |
| 27-42-200-000 | 2 | | |
| 27-43-000-000 | 2 | | |
| 27-43-100-000 | 2 | | |
| 27-43-200-000 | 2 | | |
| 27-44-000-000 | 2 | | |
| 27-44-100-000 | 2 | | |
| 27-44-200-000 | 2 | | |
| 27-45-000-000 | 2 | | |
| 27-45-100-000 | 2 | | |
| 27-45-200-000 | 2 | | |
| 27-46-000-000 | 2 | | 0.003159 |
| 27-46-100-000 | 2 | | |
| 27-46-200-000 | 2 | | |
| 27-46-V00-000 | 2 | | 0.000632 |
| 27-47-000-000 | 2 | | 0.004422 |
| 27-47-100-000 | 2 | | 0.000632 |
| 27-47-200-000 | 2 | | |

## APPENDIX D. DATA BASE EXCERPT

| ASN | AIR TURNBACKS PER 100 DEPARTURES | DIVERTS PER 100 DEPARTURES | AVERAGE DELAY TIME |
|---|---|---|---|
| 27-41-000-000 | 0.001264 | | |
| 27-41-100-000 | | | |
| 27-41-200-000 | | | |
| 27-42-000-000 | 0.000632 | | |
| 27-42-100-000 | | | |
| 27-42-200-000 | | | |
| 27-43-000-000 | | | |
| 27-43-100-000 | 0.000632 | | |
| 27-43-200-000 | | | |
| 27-44-000-000 | | | |
| 27-44-100-000 | | | |
| 27-44-200-000 | | | |
| 27-45-000-000 | | | |
| 27-45-100-000 | | | |
| 27-45-200-000 | | | |
| 27-46-000-000 | 0.004422 | | |
| 27-46-100-000 | | | |
| 27-46-200-000 | | | |
| 27-46-V00-000 | | | |
| 27-47-000-000 | 0.013267 | | |
| 27-47-100-000 | | | |
| 27-47-200-000 | | | |

## APPENDIX D. DATA BASE EXCERPT

| ASN | MEAN TIME BETWEEN FAILURE | MEAN TIME BETWEEN FAILURE SOURCE |
|---|---|---|
| 27-41-000-000 | 4098.455 | ECIFR |
| 27-41-100-000 | 1821.000 | ECIFR |
| 27-41-200-000 | 3949.014 | ECIFR |
| 27-42-000-000 | 2224.086 | ECIFR |
| 27-42-100-000 | 3929.000 | ECIFR |
| 27-42-200-000 | 233640.300 | NALDA |
| 27-43-000-000 | 5987.023 | ECIFR |
| 27-43-100-000 | 31152.030 | NALDA |
| 27-43-200-000 | 35944.65 | NALDA |
| 27-44-000-000 | 21176.940 | ECIFR |
| 27-44-100-000 | 467280.500 | NALDA |
| 27-44-200-000 | | |
| 27-45-000-000 | 39842.980 | ECIFR |
| 27-45-100-000 | | |
| 27-45-200-000 | 51920.060 | NALDA |
| 27-46-000-000 | 3731.89 | ECIFR |
| 27-46-100-000 | 52708.000 | ECIFR |
| 27-46-200-000 | 51920.060 | NALDA |
| 27-46-V00-000 | 30119.000 | ECIFR |
| 27-47-000-000 | 3883.208 | ECIFR |
| 27-47-100-000 | 9166.000 | ECIFR |
| 27-47-200-000 | 24593.710 | NALDA |

## APPENDIX D. DATA BASE EXCERPT

| ASN | MEAN TIME BETWEEN REMOVALS | MEAN TIME BETWEEN REMOVAL SOURCE |
|---|---|---|
| 27-41-000-000 | 899.214 | ECIFR |
| 27-41-100-000 | 18583.75 | ECIFR |
| 27-41-200-000 | 5718.077 | ECIFR |
| 27-42-000-000 | 978.092 | ECIFR |
| 27-42-100-000 | 55751.250 | ECIFR |
| 27-42-200-000 | 8577.115 | ECIFR |
| 27-43-000-000 | 1103.985 | ECIFR |
| 27-43-100-000 | 22300.500 | ECIFR |
| 27-43-200-000 | 31857.860 | ECIFR |
| 27-44-000-000 | 982.401 | ECIFR |
| 27-44-100-000 | 5868.553 | ECIFR |
| 27-44-200-000 | 223005.000 | ECIFR |
| 27-45-000-000 | 779.738 | ECIFR |
| 27-45-100-000 | 13117.940 | ECIFR |
| 27-45-200-000 | 223005.000 | ECIFR |
| 27-46-000-000 | 614.339 | ECIFR |
| 27-46-100-000 | 22300.500 | ECIFR |
| 27-46-200-000 | 13117.940 | ECIFR |
| 27-46-V00-000 | 774.323 | ECIFR |
| 27-47-000-000 | 3539.762 | ECIFR |
| 27-47-100-000 | 18583.750 | ECIFR |
| 27-47-200-000 | 44601.000 | ECIFR |

## APPENDIX D. DATA BASE EXCERPT

| ASN | AVERAGE TIME FOR REPAIR | AVERAGE TIME FOR REPAIR SOURCE |
|---|---|---|
| 27-41-000-000 | 0.344795 | NALDA |
| 27-41-100-000 | 0.841115 | NALDA |
| 27-41-200-000 | 0.204462 | NALDA |
| 27-42-000-000 | 1.111471 | NALDA |
| 27-42-100-000 | 2.384884 | NALDA |
| 27-42-200-000 | 0.024645 | NALDA |
| 27-43-000-000 | 0.281416 | NALDA |
| 27-43-100-000 | 1.086131 | NALDA |
| 27-43-200-000 | 0.845122 | NALDA |
| 27-44-000-000 | 0.097681 | NALDA |
| 27-44-100-000 | 0.031596 | NALDA |
| 27-44-200-000 | | |
| 27-45-000-000 | 0.047021 | NALDA |
| 27-45-100-000 | 0.032258 | NALDA |
| 27-45-200-000 | 1.576923 | NALDA |
| 27-46-000-000 | 0.755100 | NALDA |
| 27-46-100-000 | 1.726236 | NALDA |
| 27-46-200-000 | 0.300980 | NALDA |
| 27-46-V00-000 | 1.992272 | NALDA |
| 27-47-000-000 | 4.879457 | NALDA |
| 27-47-100-000 | 1.014542 | NALDA |
| 27-47-200-000 | 4.914286 | NALDA |

## APPENDIX D. DATA BASE EXCERPT

| ASN | MAINTENANCE ACTIONS PER 1000 FLIGHT HOURS | MAINTENANCE ACTIONS PER 1000 FLIGHT HOURS SOURCE |
|---|---|---|
| 27-41-000-000 | 0.493262 | ECIFR |
| 27-41-100-000 | 0.130042 | ECIFR |
| 27-41-200-000 | 0.686083 | ECIFR |
| 27-42-000-000 | 1.313872 | ECIFR |
| 27-42-100-000 | 0.143495 | ECIFR |
| 27-42-200-000 | 0.008968 | ECIFR |
| 27-43-000-000 | 0.417031 | ECIFR |
| 27-43-100-000 | 0.251115 | ECIFR |
| 27-43-200-000 | 0.067263 | ECIFR |
| 27-44-000-000 | 0.098652 | ECIFR |
| 27-44-100-000 | | |
| 27-44-200-000 | | |
| 27-45-000-000 | 0.031389 | ECIFR |
| 27-45-100-000 | 0.004484 | ECIFR |
| 27-45-200-000 | 0.017937 | ECIFR |
| 27-46-000-000 | 1.138988 | ECIFR |
| 27-46-100-000 | 0.417031 | ECIFR |
| 27-46-200-000 | 0.017937 | ECIFR |
| 27-46-V00-000 | 0.484294 | ECIFR |
| 27-47-000-000 | 0.748862 | ECIFR |
| 27-47-100-000 | 0.242147 | ECIFR |
| 27-47-200-000 | 0.035874 | ECIFR |

# APPENDIX D. DATA BASE EXCERPT

| ASN | AVERAGE TIME FOR MAINTENANCE ACTION | AVERAGE TIME FOR MAINTENANCE ACTION SOURCE |
|---|---|---|
| 27-41-000-000 | 0.344795 | NALDA |
| 27-41-100-000 | 0.841115 | NALDA |
| 27-41-200-000 | 0.204462 | NALDA |
| 27-42-000-000 | 1.111471 | NALDA |
| 27-42-100-000 | 2.384884 | NALDA |
| 27-42-200-000 | 0.024645 | ECIFR |
| 27-43-000-000 | 0.281416 | NALDA |
| 27-43-100-000 | 1.086131 | NALDA |
| 27-43-200-000 | 0.845122 | NALDA |
| 27-44-000-000 | 0.097681 | NALDA |
| 27-44-100-000 | 0.031596 | NALDA |
| 27-44-200-000 | | |
| 27-45-000-000 | 0.047021 | NALDA |
| 27-45-100-000 | 0.032258 | NALDA |
| 27-45-200-000 | 1.576923 | NALDA |
| 27-46-000-000 | 0.755100 | NALDA |
| 27-46-100-000 | 1.726236 | NALDA |
| 27-46-200-000 | 0.300980 | NALDA |
| 27-46-V00-000 | 1.992272 | NALDA |
| 27-47-000-000 | 4.879457 | NALDA |
| 27-47-100-000 | 1.014542 | NALDA |
| 27-47-200-000 | 4.914286 | NALDA |

## APPENDIX D. DATA BASE EXCERPT

| ASN | SHOP LABOR HOURS | SHOP LABOR HOURS SOURCE |
|---|---|---|
| 27-41-000-000 | 14.90301 | NALDA |
| 27-41-100-000 | 6.748432 | NALDA |
| 27-41-200-000 | 6.526769 | NALDA |
| 27-42-000-000 | 18.17415 | NALDA |
| 27-42-100-000 | 6.701163 | NALDA |
| 27-42-200-000 | 26.46825 | NALDA |
| 27-43-000-000 | 11.16350 | NALDA |
| 27-43-100-000 | 6.924574 | NALDA |
| 27-43-200-000 | 9.307317 | NALDA |
| 27-44-000-000 | 15.04860 | NALDA |
| 27-44-100-000 | 12.62528 | NALDA |
| 27-44-200-000 | 13.78966 | NALDA |
| 27-45-000-000 | 16.21912 | NALDA |
| 27-45-100-000 | 14.48710 | NALDA |
| 27-45-200-000 | 3.676923 | NALDA |
| 27-46-000-000 | 15.47913 | NALDA |
| 27-46-100-000 | 6.604183 | NALDA |
| 27-46-200-000 | 13.61078 | NALDA |
| 27-46-V00-000 | 73.71077 | NALDA |
| 27-47-000-000 | 1.298302 | NALDA |
| 27-47-100-000 | 18.45943 | NALDA |
| 27-47-200-000 | 0.832143 | NALDA |

## APPENDIX D. DATA BASE EXCERPT

| ASN | SHOP MATERIAL | SHOP MATERIAL SOURCE |
|---|---|---|
| 27-41-000-000 | 127307.10 | AIMD LEMOORE |
| 27-41-100-000 | | |
| 27-41-200-000 | | |
| 27-42-000-000 | 111338.60 | AIMD LEMOORE |
| 27-42-100-000 | | |
| 27-42-200-000 | | |
| 27-43-000-000 | 56700.54 | AIMD LEMOORE |
| 27-43-100-000 | | |
| 27-43-200-000 | | |
| 27-44-000-000 | 74917.40 | AIMD LEMOORE |
| 27-44-100-000 | | |
| 27-44-200-000 | | |
| 27-45-000-000 | 62786.09 | AIMD LEMOORE |
| 27-45-100-000 | | |
| 27-45-200-000 | | |
| 27-46-000-000 | 10587.82 | AIMD LEMOORE |
| 27-46-100-000 | | |
| 27-46-200-000 | | |
| 27-46-V00-000 | | |
| 27-47-000-000 | 15727.80 | AIMD LEMOORE |
| 27-47-100-000 | | |
| 27-47-200-000 | | |

## APPENDIX D. DATA BASE EXCERPT

| ASN | MEAN TIME BETWEEN OVERHAUL | MEAN TIME BETWEEN OVERHAUL SOURCE |
|---|---|---|
| 27-41-000-000 | 471.469 | ECIFR |
| 27-41-100-000 | 5068.295 | ECIFR |
| 27-41-200-000 | 14867.000 | ECIFR |
| 27-42-000-000 | 640.819 | ECIFR |
| 27-42-100-000 | 17154.230 | ECIFR |
| 27-42-200-000 | 12389.170 | ECIFR |
| 27-43-000-000 | 861.023 | ECIFR |
| 27-43-100-000 | 27875.630 | ECIFR |
| 27-43-200-000 | 37167.500 | ECIFR |
| 27-44-000-000 | 441.594 | ECIFR |
| 27-44-100-000 | 27875.630 | ECIFR |
| 27-44-200-000 | 44601.000 | ECIFR |
| 27-45-000-000 | 567.443 | ECIFR |
| 27-45-100-000 | 223005.000 | ECIFR |
| 27-45-200-000 | | |
| 27-46-000-000 | 388.511 | ECIFR |
| 27-46-100-000 | 20273.180 | ECIFR |
| 27-46-200-000 | 8920.200 | ECIFR |
| 27-46-V00-000 | 551.993 | ECIFR |
| 27-47-000-000 | 11150.250 | ECIFR |
| 27-47-100-000 | 3185.786 | ECIFR |
| 27-47-200-000 | | |

## APPENDIX D. DATA BASE EXCERPT

| ASN | OVERHAUL LABOR HOURS | OVERHAUL LABOR HOURS SOURCE |
|---|---|---|
| 27-41-000-000 | 14.903 | NALDA |
| 27-41-100-000 | 6.748 | NALDA |
| 27-41-200-000 | 6.527 | NALDA |
| 27-42-000-000 | 18.174 | NALDA |
| 27-42-100-000 | 6.701 | NALDA |
| 27-42-200-000 | 26.468 | NALDA |
| 27-43-000-000 | 11.163 | NALDA |
| 27-43-100-000 | 6.925 | NALDA |
| 27-43-200-000 | 9.307 | NALDA |
| 27-44-000-000 | 15.049 | NALDA |
| 27-44-100-000 | 12.625 | NALDA |
| 27-44-200-000 | 13.790 | NALDA |
| 27-45-000-000 | 16.219 | NALDA |
| 27-45-100-000 | 14.487 | NALDA |
| 27-45-200-000 | 3.677 | NALDA |
| 27-46-000-000 | 15.480 | NALDA |
| 27-46-100-000 | 6.604 | NALDA |
| 27-46-200-000 | 13.611 | NALDA |
| 27-46-V00-000 | 73.711 | NALDA |
| 27-47-000-000 | 1.298 | NALDA |
| 27-47-100-000 | 18.460 | NALDA |
| 27-47-200-000 | 0.832 | NALDA |

## APPENDIX D. DATA BASE EXCERPT

| ASN | PRICE | PRICE SOURCE | SHOP LENGTH |
|---|---|---|---|
| 27-41-000-000 | 230548.30 | G.E. | 77.0 |
| 27-41-100-000 | 54110.00 | NAVAL SUPPLY | 13.7 |
| 27-41-200-000 | 123410.00 | NAVAL SUPPLY | 0.8 |
| 27-42-000-000 | 478178.01 | G.E. | 111.4 |
| 27-42-100-000 | 45240.00 | NAVAL SUPPLY | |
| 27-42-200-000 | 124620.00 | NAVAL SUPPLY | |
| 27-43-000-000 | 1019507.70 | G.E. | 68.9 |
| 27-43-100-000 | 38190.00 | NAVAL SUPPLY | 3.9 |
| 27-43-200-000 | 23590.00 | NAVAL SUPPLY | 4.3 |
| 27-44-000-000 | 208428.00 | G.E. | 63.0 |
| 27-44-100-000 | 160820.00 | NAVAL SUPPLY | 2.5 |
| 27-44-200-000 | 23010.00 | NAVAL SUPPLY | 4.0 |
| 27-45-000-000 | 282374.80 | G.E. | 91.0 |
| 27-45-100-000 | 97760.00 | NAVAL SUPPLY | 2.5 |
| 27-45-200-000 | | | |
| 27-46-000-000 | 2300395.10 | G.E. | 39.1 |
| 27-46-100-000 | 37660.00 | NAVAL SUPPLY | |
| 27-46-200-000 | 20590.00 | NAVAL SUPPLY | 1.6 |
| 27-46-V00-000 | 893.00 | NAVAL SUPPLY | 2.6 |
| 27-47-000-000 | | | |
| 27-47-100-000 | 52220.00 | NAVAL SUPPLY | 7.7 |
| 27-47-200-000 | | | |

## APPENDIX D. DATA BASE EXCERPT

| ASN | EXPENDABLE | MEL CODE | HC | OPTION | A |
|---|---|---|---|---|---|
| 27-41-000-000 | NOT USED | 1 | | 1 | A |
| 27-41-100-000 | NOT USED | 1 | | 1 | A |
| 27-41-200-000 | NOT USED | 1 | | 1 | A |
| 27-42-000-000 | NOT USED | 1 | | 1 | A |
| 27-42-100-000 | NOT USED | 1 | | 1 | A |
| 27-42-200-000 | NOT USED | 1 | | 1 | A |
| 27-43-000-000 | NOT USED | 1 | | 1 | A |
| 27-43-100-000 | NOT USED | 1 | | 1 | A |
| 27-43-200-000 | NOT USED | 1 | | 1 | A |
| 27-44-000-000 | NOT USED | 1 | | 1 | A |
| 27-44-100-000 | NOT USED | 1 | | 1 | A |
| 27-44-200-000 | NOT USED | 1 | | 1 | A |
| 27-45-000-000 | NOT USED | 1 | | 1 | A |
| 27-45-100-000 | NOT USED | 1 | | 1 | A |
| 27-45-200-000 | NOT USED | 1 | | 1 | A |
| 27-46-000-000 | NOT USED | 1 | | 1 | A |
| 27-46-100-000 | NOT USED | 1 | | 1 | A |
| 27-46-200-000 | NOT USED | 1 | | 1 | A |
| 27-46-V00-000 | NOT USED | 1 | | 1 | A |
| 27-47-000-000 | NOT USED | 1 | | 1 | A |
| 27-47-100-000 | NOT USED | 1 | | 1 | A |
| 27-47-200-000 | NOT USED | 1 | | 1 | A |

## APPENDIX D. DATA BASE EXCERPT

| ASN | SCHEDULED MAINTENANCE PER 1000 FLIGHT HOURS | MODEL | SERIES | ENGINE |
|---|---|---|---|---|
| 27-41-000-000 | 0.48878 | F/A-18 | 400 | F404 |
| 27-41-100-000 | 0.00448 | F/A-18 | 400 | F404 |
| 27-41-200-000 | 0.00897 | F/A-18 | 400 | F404 |
| 27-42-000-000 | 0.06726 | F/A-18 | 400 | F404 |
| 27-42-100-000 | | F/A-18 | 400 | F404 |
| 27-42-200-000 | | F/A-18 | 400 | F404 |
| 27-43-000-000 | 0.24215 | F/A-18 | 400 | F404 |
| 27-43-100-000 | | F/A-18 | 400 | F404 |
| 27-43-200-000 | | F/A-18 | 400 | F404 |
| 27-44-000-000 | 0.21076 | F/A-18 | 400 | F404 |
| 27-44-100-000 | | F/A-18 | 400 | F404 |
| 27-44-200-000 | | F/A-18 | 400 | F404 |
| 27-45-000-000 | 0.61882 | F/A-18 | 400 | F404 |
| 27-45-100-000 | | F/A-18 | 400 | F404 |
| 27-45-200-000 | | F/A-18 | 400 | F404 |
| 27-46-000-000 | 0.76680 | F/A-18 | 400 | F404 |
| 27-46-100-000 | | F/A-18 | 400 | F404 |
| 27-46-200-000 | | F/A-18 | 400 | F404 |
| 27-46-V00-000 | | F/A-18 | 400 | F404 |
| 27-47-000-000 | 0.08072 | F/A-18 | 400 | F404 |
| 27-47-100-000 | 0.03139 | F/A-18 | 400 | F404 |
| 27-47-200-000 | 0.00897 | F/A-18 | 400 | F404 |

## APPENDIX D. DATA BASE EXCERPT

| ASN | MULTI-USE | NO. OF SPARES | MB FILL | MATERIAL COST BASIS |
|---|---|---|---|---|
| 27-41-000-000 | | | 0.95 | |
| 27-41-100-000 | | | 0.95 | |
| 27-41-200-000 | | | 0.95 | |
| 27-42-000-000 | | | 0.95 | |
| 27-42-100-000 | | | 0.95 | |
| 27-42-200-000 | | | 0.95 | |
| 27-43-000-000 | | | 0.95 | |
| 27-43-100-000 | | | 0.95 | |
| 27-43-200-000 | | | 0.95 | |
| 27-44-000-000 | | | 0.95 | |
| 27-44-100-000 | | | 0.95 | |
| 27-44-200-000 | | | 0.95 | |
| 27-45-000-000 | | | 0.95 | |
| 27-45-100-000 | | | 0.95 | |
| 27-45-200-000 | | | 0.95 | |
| 27-46-000-000 | | | 0.95 | |
| 27-46-100-000 | | | 0.95 | |
| 27-46-200-000 | | | 0.95 | |
| 27-46-V00-000 | | | 0.95 | |
| 27-47-000-000 | | | 0.95 | |
| 27-47-100-000 | | | 0.95 | |
| 27-47-200-000 | | | 0.95 | |

## APPENDIX D. DATA BASE EXCERPT

| ASN | INTERCHANGE | SCHEDULED CORRECTIVE ACTION LABOR | SCHEDULED CORRECTIVE ACTION MATERIALS |
|---|---|---|---|
| 27-41-000-000 | NO | 6.07341 | |
| 27-41-100-000 | NO | 0.05381 | |
| 27-41-200-000 | NO | 0.03587 | |
| 27-42-000-000 | NO | 0.83406 | |
| 27-42-100-000 | NO | | |
| 27-42-200-000 | NO | | |
| 27-43-000-000 | NO | 2.20533 | |
| 27-43-100-000 | NO | | |
| 27-43-200-000 | NO | | |
| 27-44-000-000 | NO | 2.98244 | |
| 27-44-100-000 | NO | | |
| 27-44-200-000 | NO | | |
| 27-45-000-000 | NO | 6.53707 | |
| 27-45-100-000 | NO | | |
| 27-45-200-000 | NO | | |
| 27-46-000-000 | NO | 8.27381 | |
| 27-46-100-000 | NO | | |
| 27-46-200-000 | NO | | |
| 27-46-V00-000 | NO | | |
| 27-47-000-000 | NO | 0.36546 | |
| 27-47-100-000 | NO | 0.24349 | |
| 27-47-200-000 | NO | 0.01973 | |

## APPENDIX D. DATA BASE EXCERPT

Additional data base fields contained in the data base structure, but were not listed above are as follows:

- Overhaul Materials
- Overhaul Materials Source
- Freight Costs
- Project Number
- Engineer Responsible
- Part Number
- Administrative Comments

These fields were not used during this research and do not contain any additional information.

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22. Telephone conversation between the author and Mr. Alan Doermann from the Naval Center for Cost Analysis (NCA-61), August 24, 1994.

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26. Memorandum from AIMD Officer, NAS Lemoore to Command Naval Air Forces Pacific (N421), Subject: F404-GE-400 Engine Module Cost Data Call, February 17, 1994.

27. Ibid., p. 1.

28. Conversation with ADC Bowers, Aviation Intermediate Maintenance Department, Naval Air Station Lemoore, CA., August 26, 1994.

29. Telephone conversation between the author and LCDR Martin Jones, Aviation Intermediate Maintenance Department, Naval Air Station Lemoore, CA., September 19,1994.

30. Naval Message from Naval Air Station Lemoore, CA., Date Time Group 021830Z FEB 94, to Commander Naval Air Forces Pacific, Subject: 94 Flight Hour Program Aviation Operations and Maintenance Funding Midyear Call Data, February 2, 1994, p. 2.

31. Facsimile Transmission from Aviation Intermediate Maintenance Department, Naval Air Station Cecil Field, FL., to Aviation Intermediate Maintenance Department, Naval Air Station Lemoore, CA., Subject: F404 Engine Program Shortfalls, January 27, 1994, p. 2.

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