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Calculation of the Actual Cost of Engine Maintenance

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THESIS

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Abstract

The cost of military operations has been difficult to determine, yet considered of high importance. The cost of an operation is largely dependant upon the answers to subordinate questions involving the discrete costs of military activities, like supporting individual items. While different cost estimates have received attention from the media, the question arises as to how accurate these figures are. There have been numerous studies performed by the Operations Research analysts to minimize costs while allocating scarce resources. However, the values of these studies are dependent upon whether or not the cost figures used are sufficiently "true" or accurate.

This research deals with the true representation of cost, in particular true cost of engine maintenance. In order to reach that goal, the thesis effort aimed to first look at the archival methods and models used to prepare cost estimations for a weapon system or a task performed in the Air Force. The engine maintenance is one and an important one of these tasks. Looking at those previous studies gained us insight on what the cost elements and factors might be. The research also looks at some of the current practices serving the same purpose. The characteristics of all of those models are also discussed briefly. Four analytical steps helped to come up with the cost elements that should go into the “actual” total cost of engine maintenance at the Base or Wing Level. The research provides detailed definitions of these consolidated elements and the relationships between them. The research also presents ways to gather the required data out of several databases whose functions and data types are also briefly discussed. A case study would not be possible due to the fact that the data was not accessible.

CALCULATION OF THE ACTUAL COST OF ENGINE MAINTENANCE

I. Introduction

1.1 Background

We live in an era when we constantly hear terms such as defense budget cuts, reduced military funding, demilitarization process, downsizing military forces, etc. One good example of this concept can be found in a recent press release by acting secretary of the Air Force Whit Peters (Peters: 1998):

"We (The Air Force) have finished downsizing.

- Personnel end strength has been reduced by more than 40 percent
- Major bases have been reduced by two-thirds overseas
- Purchases for aircraft replacement have been reduced by 77 percent
- Current existing aircraft inventories have been reduced by about 40 percent
- ICBMs have been reduced by 50 percent.

And we've realized savings quickly".

This is an indication that the concept of savings is prominent not only to individuals but also to governments. Savings are achieved by closely examining the expenses that individuals, governments, or companies make.

Politicians spend many hours in the congress determining the budget for the next year, and they have long arguments on which projects to fund or not to meet objectives.

The military budget, and its components, represents a large part of the total budget. The cost of aircraft jet engine maintenance is a significant part of a military budget. In very rough numbers, the cost of engine depot maintenance per flying hour is projected to increase 28 percent annually for the KC-135 and 21.7 percent annually for the F-16 (Peters: 1998). There is intense interest in knowing what the costs are of everything from equipment to services that the government purchases. In addition, we are not in the Cold War age anymore, so priorities have changed since the breakdown of the Berlin Wall in Germany in 1989 and collapse of the Soviet Union. Even the conflicts have changed; they have become "humanitarian operations." There are things that are more important than building the most lethal weapon. Scientists are now trying to find ways to promote human life. There are powerful non-governmental organizations which demand explanations for all government spending and action. The public is also more aware, and they want answers when things do not seem right. A free press will also shape our ideas as well as governments broadcasts.

Under these conditions, there is great interest in the process of finding the actual cost of military programs, including the cost of aircraft engine maintenance cost. For example, in the actual FY2001 budget, $284.7M was allocated for depot maintenance of 559 engines (Air Force, 2002:37). Every year the Air Force undertakes a budget formulation process for its flying hour program that considers the number of hours needed to attain and maintain combat readiness and capability for its aircrews, to test weapons systems and tactics and collateral requirements such as air shows, demonstration rides for VIPs, and ferrying aircraft (GAO, 1999:1). Funds are then calculated for and allocated to the budget based on the required hours. Therefore, there has always been an interest in predicting the life cycle cost of a weapon system, either to estimate budget requirements or to compare competing alternative systems. There have been quite a few accounting models and statistical models developed in the past to predict costs using different approaches. They each had their own advantages and disadvantages, which will be discussed later. There are a variety of models to predict the cost of engine maintenance per flying hour in use today, though they are not unified. On the other hand, the General Electric Company, which is one of the largest companies in the engine manufacturing industry, has a special program named Maintenance Cost Per Hour (MCPH) for their private sector users. This program calculates a predictable cost per engine flight hour; enabling airlines to accurately forecast operating costs, reduce cost of ownership, and improve asset utilization (General Electric: 2000). The company has started providing this sort of services for years now as a part of risk mitigation process and to be competitive in the market. Moreover, the Company has also provided cost per flying hour estimates for the Department of Defense (DoD) for the past 30 years though those estimates are hardly used during acquisition process (Longe: 2003). Speculation suggests that perhaps the DoD did not take that issue seriously in the past, when the most essential factors for a warfighter's engine were ruggedness, performance, and ease of maintenance rather than cost effectiveness. There are currently studies that are underway towards providing Organizational and/or Intermediate Level maintenance for the wing, the base, the Command, etc (Longe: 2003).

1.2 Problem Statement

There are currently several models to calculate the predicted the cost of actual engine maintenance per operating hour. Air Combat Command (ACC) and other units like United States Air Forces in Europe (USAFE), Air Force Material Command (AFMC), and the Air Force Total Ownership Cost (AFTOC) also have models serving the same purpose. This thesis will try to determine an improved model making use of the best aspects of the old models, and unify them to develop a proposed standard throughout the Air Force.

1.3 Research Questions

This research will seek answers to the following questions:

1. What uses are we going to get out of calculating the actual cost of engine maintenance per operating hour?
2. What are the current models in use?
3. How accurate and useful are the current models?
4. What are the characteristics and assumptions of the current models?
5. What are the primary causal factors in engine operating and support costs?
6. How should these factors be modeled?
7. Has there been a change in the major cost drivers of the previous models when compared to the new one?
8. What would the characteristics and structure of an improved, accurate total cost model be?

1.4 Scope

This research is going to focus on the engine maintenance performed at the Base/Wing level. For example, %88 percent of the maintenance activities performed on GE built F-16 engine (an F-110 family) belongs to the Base Level Maintenance (Longe:

2003). It is believed that once an appropriate cost model methodology is developed, it will be easier to apply the model to other units in the Air Force or the Air Force itself, since we will encounter similar cost parameters for most of the military purpose engines.

1.5 Limitations

First, data required for this research are not accessible to the researcher. Since the cost estimating relationships are far more important than the data used to come up with a total cost figure, the research was more concentrated on the accurateness of the relationships. If the user gets access to the database and pulls out the required data, the rest is just number crunching to find the true cost of engine maintenance. And the validation of these relationships is ascertained by having them reviewed by the experts on the area and the personnel who performed a similar type of calculation.

Secondly, although some general definitions or concepts are discussed in this research, the research draws its boundaries around the Base. Nonetheless, it is believed that the same cost elements and Cost Estimating Relationships (CER) may be applied to the Command and the whole Air Force with some adjustments to the CERs and definitions of some of the cost elements.

Third issue is the inclusion of every single cost factor that one way or another has a contribution to the engine maintenance. Examples include training expenses for the engine maintenance personnel as well as the aircraft maintenance personnel made in the Base training facility, payments to security personnel providing a secure environment for the engine maintenance personnel and payments doctors treating those personnel. We cannot deny that they all have a contribution in making the engine maintenance possible though they are not included in the model because of the reasons presented in the methodology and/or the gain coming out of that effort does not outweigh the time and resources that will be spent to reflect those costs on engine maintenance.

Another issue was to choose an appropriate relevant range through which the fixed costs will be same. Since the allocation of fixed costs is a key factor in calculating unit cost, users should pay adequate attention to the operating ranges over which the model is still valid. And, it is even advised in some texts to be careful while dealing with the unit cost figures because of the aforementioned predicament. Sometimes it is even more logical to work with the total cost figures, which we opted to do.

1.6 Summary

In this chapter, we introduced the importance of calculating the cost of military budgets, specifically on the cost of aircraft jet engine maintenance. The problem of developing an improved cost model from existing models was presented, along with the related research questions. Finally, the scope and limitations of the research were described. The next chapter will provide more insight about the problem and discuss the previous studies performed in this area.

II. Literature Review

2.1 Presentation of the Background

Like every biological organism on the earth, weapon systems have a certain period of lifetime. They are born; they lead, hopefully, a productive life; and then die. When we break down these periods into smaller sections, we shall see that process is much more complex than a short sentence. Weapon systems incur different types of costs during their lifetime. These costs can be summarized in the following categories: Research and Development, Investment, Operations and Support, Disposal all of which constitute the life cycle cost (Department Of Defense: 1992). The life cycle of a weapon system begins with the determination of a mission requirement and continues through the engineering and manufacturing development, production and deployment, and operations and support phases to the eventual disposal or demilitarization of the system by the government.

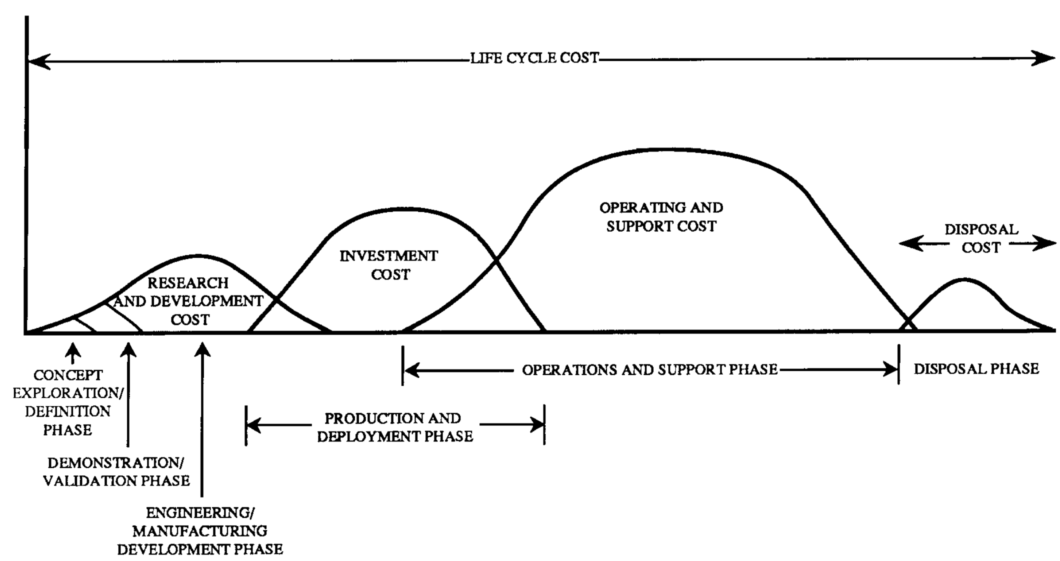

Figure 1: Life Cycle Program

Figure 1 plots a general picture of how various phases of a particular system's life cycle program relate to Life Cycle Costs (Department Of Defense, 1992: Ch2, 2).

Life Cycle Costs were further broken down under Engine Systems Cost that were recognized and addressed in the APSI (Aircraft Propulsion Subsystem Integration) program in the 1970s (Wagner: 1975). One of the cost categories was the Engine Specification Imposed Costs, since the engine model specification was a cost driver in requirements for design, development and qualification of an engine model. The other category was Development Costs, which consisted of all expenditures necessary to bring a design to a state of producibility. A third major category was Engine Acquisition Cost and Design-to-Cost (DTC). DTC was a costing procedure designed to provide the necessary details for accurate cost comparisons. The last two major categories were Operating and Support Costs, and Performance Costs that helped select the optimum engine/aircraft configuration.

2.2 Cost Estimating Tools

We have already mentioned how important it is to accurately estimate the costs of operating a weapon system. The primary objective is to create credible and dependable estimates to keep the weapon system running or the aircraft flying (Kammerer: 2002a). There are a variety of models used to achieve these estimates, including statistical and accounting models, both with weak and strong features. Accounting models were particularly useful in evaluating alternatives after the system matured during which actual cost data are available (Davidson & Griffiths, 1977:10). These models:

1. Were more accurate than the statistical models because the availability of the more information reduced uncertainty,

2. Could be applied to subsystems or components facilitating sensitivity analysis and trade-off decisions,
3. Could provide direct extrapolation of O&S costs with high reliability.

However, these accounting models have the following disadvantages. First, the relationship between future costs and the historical data may change for many reasons. For example, engine parts are undergoing several changes in design, material handling, and manufacturing processes. We can lose the information on improved reliability of the parts or engine itself. Second, evaluation may be tiring and time consuming due to vast amount of information. On the other hand, statistical models could be used early in the life cycle of a system and provided basis to construct confidence interval around the predicted cost.

There is much research on cost analysis of weapon systems, their operating and support costs, comparing these costs with a competing system and other issues. Popular cost estimating methods include the Catalog Method, Expert Opinion, Man-Loading Method, Parametric Method, Analogy Method, Engineering Build-Up, and their combinations (Sidey, 1992:2-16 to 2-18).

Catalog Method: The catalog method requires that you have a catalog or database where you basically check the price in the catalog and find the total cost of your system. Although the method seems to be quite easy, finding such catalog that contains the accurate cost is fairly difficult.

Expert Opinion: This method is logically used when the system is new and the required data is unavailable. In this method cost is found out asking experts and people who have experience on the matter. It seems the best way to just go up to an expert and ask for an opinion though the method has some particular disadvantages such that the data may be sided, optimistic or pessimistic since it is entirely based upon the past experiences and the knowledge of the person who is above all a human being. On the other hand, there is technique that we can partly avoid this disadvantage. It is called the Delphi Technique. In this technique, the data are acquired by asking experts independently and anonymously. In this way, we can get individual's opinion unaffected from the others'. This will also provide a degree of freedom to analyze the gathered data statistically. The experts who provided data very much differing from the others are asked to verify their answers. After several iterations, answers will naturally merge and reach a consensus. This method is obviously labor intensive, time consuming and expensive (Kosucu, 2001:29).

Man-Loading Method: This method is very similar to the expert opinion. The only difference is the people whose opinions are sought. In this method, the functional manager is responsible for both estimation and estimation (Sidey, 1992:Ch 2, 16).

Parametric Method: The Parametric Method establishes the functional relationships between one or more parameters that may be explanatory. These functional relationships may vary from simple equations to complex mathematical models. For example, we can find the total Depot Maintenance cost for engine overhaul using the following equation:

$$DMC = N * EO \tag{1}$$

where

DMC = Depot Maintenance Cost
N = Number of engines sent to Depot
EO = Amount the Depot charges for one Engine Overhaul

If we think that the Depot charge for Engine Overhaul is fixed over a Fiscal Year (FY), there is only one independent variable here in this equation, the number of engines sent to Depot.

Analogy Method: The Analogy Method utilizes the estimates previously made on a similar system. In this method, possible cost differences have to be computed and adjustments have to be made in order to find out an accurate cost estimate. Just like Expert Opinion Method, this method can also be effectively used when a new system is employed and the data is not readily available. For example, let's assume a Reserve Unit has recently renovated their unit with F-16s. They can calculate operating and maintenance cost of their unit by looking at the estimates of other units flying F-16.

Engineering Build-Up: This is a rather detailed yet more accurate method, because analyst has to specify each and every simple task that should be accomplished with regarding tools and equipment. After developing the complete cost breakdown structure, he has to assign costs to each of these elements to calculate the cost estimate. This method is not feasible for most of the complex systems since it is hard to find detailed data required. And, sometimes the gain is not worth the time and effort spent on such estimate.

These approaches are heavily dependent on the maturity of the program and the amount of information available. On the other hand, many models currently in use would fall into one of these three categories: Parametric models, accounting models and simulation models (Department Of Defense, 1992:Ch 3, 12).

> **Parametric Model**. A parametric model contains a set of equations each of which relates O&S costs to parameters that describe the design, performance or operating environment of a weapon system. These models are typically used in the early stages of a program when cost, technical and hardware data are limited.

Accounting Model. An accounting model is a set of equations used to aggregate elements of O&S costs such as manpower, materials, spares, fuel, transportation, modifications and support equipment from simple relationships or direct inputs. Some elements are computed on the basis of unit cost and procurement quantity. Others are estimated using separate models or methodologies and are provided as throughput in order to arrive at an aggregate estimate of O&S costs.

Simulation Model. This type of model uses computer simulations to determine the effect on O&S costs of a system's characteristics, operational constraints, basing concept, maintenance plan, and spare and support requirement. Over time, statistical simulations generate probability density functions that describe the impact of system characteristics, operations, and maintenance concepts. However, the large amount of data required normally limits the use of such models to the later program phases, when sufficient amount of data are available.

It is obvious that there is more than one tool to estimate the costs. And, it is the analyst's decision together with the decision maker to implement one or a combination of these tools that will help them reach the objective. Here, it is important to know what fidelity level is required to decide on tools that should be used in addition to finding a useful model.

2.3 Previous Studies

In the late 1970s the Air Force Aero Propulsion Laboratory (AFAPL) had the responsibility for estimating the life cycle cost of Air Force turbojet engines during the design phase (Davidson & Griffiths, 1977:1). AFAPL had problems with the models they were using. They could only estimate portions of jet engine LCC, and they were not sure which model to use in the design phase. The latter is especially important since selecting the model is as crucial as deciding on which phase of the system it should be used. Davidson and Griffiths conducted research on several models to determine the best type, use, application technique and decomposition. These models/techniques were used for variety of estimating purposes pertinent to engine life cycle costs. For example, the DO24K was a database used to estimate Actuarial Removal Interval by quarter for the succeeding five fiscal years, and the GO72A database accumulated the cost of resources consumed in item repair within the ALC's Directorate of Maintenance. Now, we will introduce some of the models that have previously been in use.

2.3.1 Simulation Models

At the beginning of 1980s, a discrete event simulation was used to simulate engine operations and support for a peacetime scenario at five bases. That simulation is designed to assess and accumulate the cost for engine inspections at the base level and the cost for engine repair at the flight line, base intermediate shop and depot levels (Hellesto & Oliverson, 1982:41). Two relevant versions of model output were developed. The first version provided a breakout of cost information. The simulation kept track of each engine component in the O&S system; the accounting process accumulated and provided a monthly breakout of unit failure and repair costs. In the second version, the output of monthly data is suppressed and accumulated to provide only the year and total cost over a 20-year simulation period since the life cycle of a weapon system was considered to be 20 years. As the authors noted, the model had three major limitations: First, the actual repair process at each level was not modeled. Instead, a probability of repair and average repair times were used to represent the repair of individual parts. Second, the simulation did not include the actual procurement process for the purchase of spare engines, Line Replaceable Units (LRU) and Shop Replaceable Units (SRU) or the initial procurement of aircraft and engines. When they were needed, they were identified and procured outside the system. Lastly, the operations process did not simulate the actual flying of aircraft to generate engine failures. The number of engine failures was a function of the number of aircraft assigned and hours flown at each base (Hellesto & Oliverson, 1982:42). In addition, the model allowed aircraft to enter the system on a predetermined monthly schedule and deployed engine support equipment when necessary. These assumptions are hard to accept now, since we know that the Air Force has a limited number of ground support equipment and there is no longer a practice of regular delivery of aircraft to the bases anymore.

Super Operating and Support Cost Model (SOSCM) is built in the mid 1980s. Cost Estimating Relationships and algorithms were developed through discussions with industry analysts and reviewed by the Air Force cost estimating community. The computer code was written in Basic Computer Language to facilitate the calculations in the algorithms. The model was directed to estimate operation and maintenance cost of aircraft engine. This particular model has actually been used in several engine source selection processes of different aircraft programs including F-15, F-16, and F-22. This model will be examined in more detail later in the research.

2.3.2 Statistical Models

A good example of a statistical model was completed in 1985. The purpose of the study was to develop a cost estimating equation which predicted jet engine annual Operating and Support costs using multivariate linear regression techniques (Cox: 1985). The author came up with a statistically significant regression model including only these four variables selected from 13 independent variables: TIT (Turbine Inlet Temperature), SFC (Specific Fuel Consumption), WT (Weight), and EFHRS (Engine Annual Flying hours). The data for these 13 variables are collected from various sources such as Weapon System Cost Retrieval System (WSCRS) still in use, Maintenance Data

Collection System (MDCS), Component Support Cost System (CSCS), etc. Equation for the model was (Cox, 1985:58).

$$ADJC = \beta 0 + \beta 1 * TIT + \beta 2 * SFC + \beta 3 * WT + \beta 4 * EFHRS \qquad (2)$$

where

ADJC = Adjusted Cost
$\beta 0 = -415350$
$\beta 1 = 184.307$
$\beta 2 = 93565.729$
$\beta 3 = 18.962133$
$\beta 4 = 0.049260$

The model was statistically significant with a p-value of 0.0001, and the R-square was 0.8775. The model represents the fixed costs by the intercept term which is actually the mean response of the data used; that is a strong but invalid assumption. Because one may have negative beta coefficients to predict the response in a regression model or in this case a positive coefficient. Our total cost cannot be lower than our already incurred fixed cost which may take place in a typical regression model. Another concern is that, these selected factors may not be explanatory for fixed portion of the total cost. For example, it is hard to consider TIT and/or SFC to explain the changes in the fixed costs. Similar models could be developed with different data for other applications that will surely have different cost figure.

As a weapon system matures, it is believed that technology changes alter the cost estimating relationships (CER), by either changing the functional relationship between the dependent variable (cost) and the independent variables which are considered cost drivers (Simpson & Sims: 1984). Simpson and Sims tried to develop a technological index in their research, based on selected characteristics of new products, which measures the state-of-the-art at the point of time when each product was being developed. This is a difficult task, because they were trying to quantify intangible concept of technology. In addition, “there has been a marked lack of reference in the cost estimating literature…Gordon and Munson’s model is one technology forecasting technique that provides an explicit technology measure.” They used weights, K, to reflect the influence of each parameter in determining the overall state-of-the-art (SOA) index. These weights are derived by either soliciting the opinions of experts on the system as to the relative importance of each parameter, or by allowing the analyst to make an explicit assumption about the growth pattern of the particular technology. The technique proposed by Gordon and Munson for quantifying technology can be represented by two models (Simpson & Sims, 1984:21-23). The arithmetic model was:

$$SOA = K1 * (P1 / P1') + K2 * (P2 / P2') + \ldots + Kn * (Pn / Pn')] \tag{3}$$

where

SOA	= State of the art index
K	= The relative weight assigned to each parameter
P	= The value of the parameters determined to be meaningful in describing the state of the art
P′	= A reference value for that particular parameter
n	= The number of parameters

The second model was the multiplicative form that was appropriate for the cases in which one parameter had to be present to some degree or the state of the art of technology was zero. This model was similar to the first one.

$$SOA = P1 / P1' * [K2 * (P2 / P2') + K3 * (P3 / P3') + \ldots + Kn * (Pn / Pn')] \tag{4}$$

If the reference values were selected in such fashion that P < P′ for all n parameters and the weights sum to unity, the index values would fall between zero and one which then would have some physical significance to the analyst. The result of these decisions and manipulations was a technology index for that specific system. They applied those indices to Baseline CERs that were used to estimate development cost to Model Qualification Test (MQTCOST), cumulative average unit production cost at 1000 units (PROCOST), and total development cost (TDEVCOST). The baseline CERs were already established by the Rand Corporation in 1974. They were then updated by Birkler in 1982. Birkler had limited the number of explanatory variables leaving those three in each CER: Thrust (THR), Mach Number (MACH), and Turbine Inlet Temperature (TIT). Researchers incorporated technology indices into the models as independent variables to evaluate the impact of SOA on the value and significance of the coefficients. Their research concluded that the state-of-the-art index was significant and a valid cost driver, but they also noted that the multicollinearity between the SOA and the Turbine Inlet Temperature (TIT) precluded SOA from joining the original independent variables in the equation to improve the estimating accuracy of the Baseline CERs (Simpson & Sims, 1984:63).

Birkler's explanatory variables are still in use even today. The Aircraft Turbine Engine Cost Model provided in the National Aeronautics and Space Administration (NASA) website uses equations for estimating development and production costs and time of arrival for U.S. military turbojet and turbofan engines (NASA: 2000). Another regression analysis is applied to the expanded database with the same explanatory variables. Besides MQTCOST, PROCOST, TDEVCOST, it also calculates Time Of Arrival (TOA) using certain engine performance characteristics based on 29 U.S. military turbojet and turbofan engines developed and produced during the past 30 years (NASA: 2000). It is also noted in the site that cost estimates will reflect military technology and the manner in which programs were conducted during the 1950s, 1960s, and 1970s. If an engine is developed that is not in the mainstream trend, such as a variable cycle or lift engine, the estimating relationship described may not apply.

As it was stated before statistical models had also strong and weak features as did all other models. They are particularly useful to construct a confidence interval around the estimated cost and to demonstrate results using visual aids like charts. On the other hand, selection of parameters is particularly important to reduce bias. And, an analyst should not be too complacent of the model since the relationships are bound to change.

2.4 Recent Developments

In the early 1990s, as a result of the Defense Management Review and downsizing of budgets, two changes to maintenance budgeting and costing were made. First, the "Reparable Support Division" was created and the cost element for spares was moved from a procurement appropriation into the O&M category, and became known as Depot Level Reparables (DLR). Second, funding for AVPOL was decentralized to the MAJCOMs (Rose: 1997). Hence, MAJCOMs were forced to play a more active role in cost estimating and factor development, since these changes meant that MAJCOMs would fund their own flying hour program. Since they were to fund their flying hour program, they had to estimate how much that would cost. The MAJCOMs developed several programs to accomplish this task while looking at cost estimating programs already developed by civilians and other forces. This development drew increased attention to the need for estimating cost per engine flying hour although the Air Force's interest to calculate engine costs dated back to the second half of the 1970s.

There are several software packages in the market used to estimate different types of costs in every field. The Automated Cost Estimating Integrated Tools (ACEIT) helps analysts store, retrieve, and analyze data; build cost models; analyze risk; time phase budgets; and document cost estimates (Tecolote Research Inc: 2003). Cost Analysis Strategy Assessment (CASA) is a Life Cycle Cost (LCC) decision support tool. CASA can present the total cost of ownership depending on user selections; including RDT&E costs, production costs, and operating/support costs (USAMC: 2003). CASA covers the entire life of the system, from its initial research costs to those associated with yearly maintenance, as well as spares, training costs, and other expenses. The Systematic Approach to Better Long-Range Estimating (SABLE) is an interactive database model which calculates aircraft peacetime operations and support (O&S) costs for typical or specific Air Force flying squadrons (Active/Guard/Reserve) by Model/Design/Series (MDS) and MAJCOM (AFCAA: 2002). In addition, the Navy has another cost model named Affordable Readiness Cost Model. The Affordable Readiness Cost Model is a comprehensive tool designed to assist in the preparation of an Affordable Readiness Initiative proposal. The model provides a means to compare a ten-year cost of a Baseline situation with an Alternative initiative (Navy: 2003). There are five modules that can be selected from the main menu. Each module has different cost factors with respect to their objective. Each module provides the Affordable Readiness Initiative Profile report and a series of backup reports showing the results of the calculations, a comparison of the Baseline with the Alternative, and a listing of the inputs provided by the user. This model is easy to use; however, it is heavily dependent upon data that is not always easily available and accurate. For example, O-level average material cost per removal or mean flight hour between removals is one of the metrics required to calculate Operating and Support cost, but that data is not readily available in current cost systems.

Another cost model was developed and currently being used by U.S. Air Forces in Europe (USAFE) originated as the 8th Air Force in 1942 and flew heavy bombardment missions over the European continent during World War II. In August 1945, the command was given its current name, U.S. Air Forces in Europe. It is headquartered at Ramstein Air Base, Germany, and a major command of the U.S. Air Force. It is also the air component of the U.S. European Command, a Department of Defense unified command and the U.S. component of the North Atlantic Treaty Organization (NATO). In fulfilling its NATO responsibilities, USAFE maintains combat-ready wings dispersed from Great Britain to Turkey. The Command supports U.S. military plans and operations in Europe, the Mediterranean, the Middle East and parts of Africa with about 35,000 active-duty, reserve and civilian employees and equipment assets including about 225 fighter, attack, tanker and transport aircraft, and a full complement of conventional weapons. As Chapter 1 also pointed out, since the end of the Cold War, DoD had to go over priorities and mission statements of some of its components. As a corollary to this change, USAFE's role in Europe and Africa has expanded from warfighting to a mission that includes supporting humanitarian and peacekeeping operations, as well as other non-traditional contingencies throughout its area of responsibility. USAFE has participated in several major humanitarian efforts, including Provide Hope I and II, which airlifted food and medical supplies to the people of the former Soviet Union, and Provide Promise, the airlifting of supplies into a war-torn Yugoslavia from July 1992 until December 1995, providing air protection over the skies of Bosnia-Herzegovina in Operation Deny Flight.

The command also plays a major role in furthering democracy in the former Eastern Bloc, as USAFE people take part in Partnership for Peace exercises and Military-to-Military contact programs.

As the Command was required to do, they prepared a spreadsheet that they could input the cost factors they developed and were approved by Air Force Cost Analysis Improvement Group (AFCAIG; discussed later). The Logistics Cost Factors were General Support Division (GSD), Material Support Division (MSD) and Aviation Fuel (AVFUEL). The model sums up expenditures made in these Logistic Cost Factors and comes up with the total cost, and divides this amount by the flying hours to find cost per flying hour. With this model, they also keep track of other metrics including the portion of the flying program funded by the USAFE itself in order to crosscheck the budgeted amount. Figure 2 shows a section of the spreadsheet.

MDS	FY02 TOTAL PROGRAM HOURS	FY02 FLOWN	HOURS LEFT	% FLOWN
F-15E	15,400	12,119	3,281	79%
F-15C/D	7,163	5,866.30	1,296.70	82%
TOTAL	22,563	17,985	4,578	80%

COMMODITY	FY02 USAFE FUNDED	FY02 RAFL OBLIG	%OF USAFE FUNDED	FUNDED RATE PER HOUR	CPFH	DELTA
GSD	2,980,000	2,524,198	85%	416	430	14
MSD	40,027,000	36,093,462	90%	5,588	6,153	565
AVPOL	12,198,000	9,996,474	82%	1,703	1,704	1
TOTAL COSTS	55,205,000	48,614,135	88%	7,707	8,287	580

Figure 2: USAFE Cost Model Spreadsheet

The expenditures made to each commodity which are Logistics Cost Factors approved by AFCAIG are included in the following figure. It can be observed in the figure that expenses made to General Support Division (GSD), Material Support Division (MSD), and the Fuel are summed to find the total costs. The figure also demonstrates what percentage of the flying hour program is accomplished and currently funded by the USAFE in addition to cost per flying hour (CPFH) and the difference (Delta) from the funded rate.

The Air Combat Command (ACC) was activated on 1 June 1992 in the middle of historic changes within the Air Force and the Department of Defense after the collapse of the former Soviet Union and the end of the Cold War that led senior defense planners to conclude that the structure of the military establishment which had evolved during the Cold War years was not suited to the new world situation. This restructuring of forces consolidated airlift and most refueling assets under a single umbrella, the new Air Mobility Command (AMC). This command represented the "global reach" facet of the Air Force mission, while the new ACC provided the Air Force's "global power" which has then become the command's motto: "Global Power for America." Upon activation, ACC assumed control of all fighter resources based in the continental United States, all bombers, reconnaissance platforms, battle management resources, and intercontinental ballistic missiles (ICBMs). Furthermore, ACC had some tankers and C-130s in its composite, reconnaissance, and certain other combat wings. Then, the Command underwent several organizational and mission changes while on the one hand losing its ICBMs, nearly all its tankers, and a part of its training mission, ACC has gained the combat rescue and theater airlift missions. As it is also discussed in Chapter 1, participation in humanitarian operations has always been a recurring theme. The command participated in many relief operations such as Provide Promise and Deny Flight in Eastern Europe and Operation Provide Comfort out of Incirlik AB, Turkey, Operation Safe Haven in Cuba, and Operation Restore Hope in Somalia. Despite its brief history, ACC has already been an important component of the Air Force in providing combat-ready forces to the challenging missions of the new world in and out of the nation.

The ACC is currently using a similar methodology like USAFE is to calculate the CPEFH rate for engine maintenance, too. But, unlike USAFE, ACC does not include fuel costs. They just pull the consumption data pertinent to engine parts from Air Force Total Ownership Cost (AFTOC) database at Hill AFB and divide the totaled amount by the flight hours to find CPEFH. Figure 3 is a portion of that spreadsheet used in calculations. In the AFTOC conference, which was held in June 2002, it was suggested by one of the attendants that the denominator be multiplied by two for the aircraft equipped with two engines. Although that seems logical at first, it is obvious that the metric will not reflect a correct estimate for CPEFH on second thought. As it was mentioned before, MSD and GSD expenses are summed to find total cost and the total cost is divided by the flying hours of that period. If the procedure were performed as proposed, denominator would have been multiplied by two representing a unit flying twin-engine aircraft. Two engines generate MSD and GSD expenses but that does not necessarily mean that the current CPEFH is actually half of the other. Proposed approach will surely lead analysts into believing that the CPEFH is lower than it is. Of course having a second engine requires extra resources and personnel to maintain both engines but they should be accounted for in a different way not by multiplying the denominator by two. For the purposes of the study, this issue will not be addressed here. Major Commands are doing what they are supposed to do. They actually do not calculate the Operating and Support cost of engine maintenance. On the other hand, these are some of the current practices that keep track of engine specific cost data.

MDS	TMS	FY99 Hours	FY99 GSD Costs	FY99 MSD Costs	Total FY99 Costs	FY99 CPEFH
F-15E	F100-PW-229	237	$192,785	$5,695,542	$5,888,327	$24,805
F-16C/D	F100-PW-229	9,755	$118,158	$14,436,432	$14,554,591	$1,492
Totals	**F100-PW-229**	**9,993**	**$310,943**	**$20,131,975**	**$20,442,917**	**$2,046**
F-16C/D	**F110-GE-100**	**41,414**	**$2,506,163**	**$41,478,367**	**$43,984,531**	**$1,062**
F-16C/D	**F110-GE-129**	**29,639**	**$866,120**	**$10,555,024**	**$11,421,145**	**$385**

Figure 3: ACC Cost Model Spreadsheet

2.5 Current Procedures

It is mentioned several times that the shrinking DoD budget has surfaced the importance of cost estimating procedure. Many deficiencies have been observed when the previous cost estimation studies are examined. These were (Department Of Defense, 1992:Ch 3, 3):

- Insufficient Documentation: The estimate was hard to replicate by another user since the data sources, methodologies, calculations, and assumptions were not clearly described in the documentation.

- Omitted or Incomplete Cost Elements: Cost Element Structure was not complete or some applicable costs were disregarded.

- Programmatic Information Missing: The basic program description or the operating, maintenance, and deployment concepts established in the program documentation were not presented with the O&S estimate.

- Inconsistency with Previous Estimates: There were some differences between the estimates but reasons or the possible reasons were not discussed. Had there been a policy change in manning? Or, had there been a change in operating concepts?

- Presentation of Results: There was not a standard format to present the results. That was leading to insufficient level of detail which was differing from one estimate to another.

All of these reasons pioneered in preparing an authoritative source document. Such document was prepared by the Office of the Secretary of Defense (OSD) Cost Analysis Improvement Group (CAIG) for use by DoD components in developing cost estimates of weapon Operating and Support Costs. The Air Force Cost Analysis Improvement Group (AF CAIG) was established at the direction of the Secretary of the Air force and is chaired by the Deputy Assistant Secretary of the Air Force (Cost and Economics). The AF CAIG's primary responsibility is explained in the AFI 65-608 as to review cost estimates and provide a recommended Service Cost Position (SCP) to the Air Force Integrated Process Team (AF IPT) and the Overarching Integrated Product Team, as necessary, for all All Acquisition Category (ACAT) I programs involved in a major milestone decision. The AF CAIG process consists of three phases (Air Force: 1997)

1. The Cost Integrated Process Team (CIPT) kick-off phase entails the formation of a CIPT consisting of representatives from the Air Force Cost Analysis Agency

(AFCAA), the System Program Office (SPO), the Acquisition Executive SAF/AQ, and the Program Executive Office (PEO). The team determines and recommends to the AF CAIG, the scope of cost analysis in support of the milestone review.

2. The CIPT SCP Development Phase involves the development of SCP which is an iterative process that produces a single Air Force estimate.

3. The last phase is the briefing the SCP to the AF CAIG.

As for the Cost Per Flying Hour costs, SAF/FMC distributed a document named AFCAIG FY03 Amended Program Objective Memorandum (APOM) Data Call and Guidance in September 2000 to ensure that all costs contributing to the cost per flying hour factor are mission related and represent items consumed in the actual repair of the aircraft. It included a schedule of events, cost factors to be used, adjustments and how they should be made, etc. They also provided a Microsoft Access CPFH Tool urging the MAJCOMs to use this application developed by AFCAA/FMFF in preparing submissions. This application would also serve as a repository for MAJCOM-specific weapon system historical data such as funding obligations, fuel consumption, flying hours, National Item Identification Number (NIIN), prices, etc. This application is distributed via SAF/FMC website and the data files are distributed via CD-ROM.

2.6 Engine Flying Hours or Total Accumulated Cycles?

There are costs conspicuously related to an activity, a process or a product. There are also some other costs that seem illogical to attribute because the cost object is not the only one that benefits from the service; however, they cannot be avoided. Often when several goods or services are produced by a common process or organization some estimate of the per-unit costs of these goods or services is required (Billera and Heath: 1982). Examples include engine maintenance performed by an Air Force Base, Engine Overhauls performed by the Depot. In some of these cases a common denominator is required to allocate those costs accordingly. For example, if we wanted to calculate unit cost or average cost per unit, we would have to find a unit to divide the total costs by that amount to come up with the unit cost (average cost) or in our case the cost of engine maintenance per "unit". It is as crucial that we choose the unit appropriately as it is used with caution (Horngren & Foster & Datar, 2000:33). The majority of the literature reviewed used the flying hour of the aircraft (the next higher assembly from the engine). For example, a research performed in 1987 sought to test practicality of allocating depot maintenance costs based on Flight Hours (FH) and Primary Authorized Aircraft (PAA). The study used three modeling techniques: regression analysis, goal programming, and linear programming. And, FH dominated in all three approaches used in the research (Kalish, 1987:82).

Actually, aircraft flying hours and engine flying hours are two different things such that engine-flying hours are up to 45 minutes more than the aircraft flying hours. Because the engine starts running 30 minutes before take-off and shuts down 15 minutes after landing. These two measures can be tracked separately and found in several databases. Although the literature searched does not indicate the use of Total Accumulated Cycles (TAC), it has potential to be a good measure, since it reflects the wear-out of the today's jet aircraft engine that is flying variety of missions in a more hostile and different environments. One cycle is counted each time one of the following transitions occurs: engine is started and shut down, after burner becomes OFF-ON-OFF, and Power Level Angle (PLA) exceeding 85 degrees to less than 22 degrees to over 58 degrees and back to exceeding 85 degrees. Because of this, number of engine cycles is collected and recorded as “Significant Historical Data” for the indicated engine on the aircraft (Air Force, 2001:A1-34). On the other hand, we perform most of the scheduled maintenance based on flying hours; we replace time change items on the basis of flying hours. Only engine overhauls are performed based on the number of TAC, and the number of flight hours needed to reach that specific number of TAC is unknown in advance. Consequently, it will be sound to use flying hours as a common denominator when needed.

2.7 Resolution of the Key Issues

While talking about the previous efforts to build a cost-estimating model, we have discussed some common approaches and cost elements. These cost elements represent the consumption of items, parts, or things needed to operate weapon system. They have dollar values associated with them that remind us the money spent on them or in other terms “the cost”. Cost is defined as a resource sacrificed or forgone to achieve a specific objective which is in our case the safe operation of the weapon system. Costs behave according to two major categories: Fixed and Variable (Horngren & Foster & Datar, 2000:30). “Fixed Costs” remain unchanged in total for a given period of time or during a specific level of activity or volume, and “Variable Costs” change directly in response to the related level of activity or volume. Those can also be called as “strictly variable” or “proportionately variable” if the cost per unit of a variable cost remains the same. In general, there are also key activities or factors which have a significant causal effect on total costs. These factors are called “Cost Drivers”.

Besides variable and fixed costs, there are also other type of costs such as Sunk Cost, Direct Cost and Indirect Cost. Now, we will provide a brief explanation of these cost types whose identifications are prominent in any cost estimating study.

Sunk Cost is the cost of resources already acquired and will remain unchanged by any choice between the alternatives (Edwards & Black: 1979). This type of cost is actually related to the concept of Relevant Cost which is important during the decision making process between alternatives. This is because every decision deals with selecting courses of action in the future. Therefore, only relevant costs should be considered while comparing alternatives. And, nothing can be done to alter the past and the past costs which are unavoidable (Horngren & Foster & Datar, 2000:378-379). For example, the buildings and hangars in a Base are built when the Base is set up for operation. It was paid in the past and unrecoverable. Another example can be the Research and Development costs which are also treated as Period Costs that are the expenses of the period in which they are incurred.

Direct Cost is the cost that can be traced back to the cost object. This is the most perceived cost while operating a system or manufacturing. Several examples from different areas can be given to direct costs such as the cost of meat in Mac Donald’s restaurant chain, cost of fuel in the operation of the American Airlines, wages paid to the personnel doing the repairs in a maintenance facility. It is important to note that it should be economically feasible to attribute these costs to the cost object.

Indirect Costs are also related to the cost object though it is not economically feasible to attribute these costs to the cost object. In the private sector these costs are deemed as a burden on production activities although they encompass many functions such as production planning, financial and information technology services, equipment and facility maintenance, and depreciation of capital assets (Steans and Applegate, 2002:Ch 5, 4). The cost of Quality and Assurance personnel is a good example for indirect costs. They definitely perform a crucial job in any type of business as in engine maintenance but it is hard to trace this cost back to engine maintenance. Because it is not cost effective to attribute these costs to cost objects, evaluation of these costs is not a challenging task. It generally requires allocation, which we will discuss later. The following graph is helpful in understanding the preceding discussion.

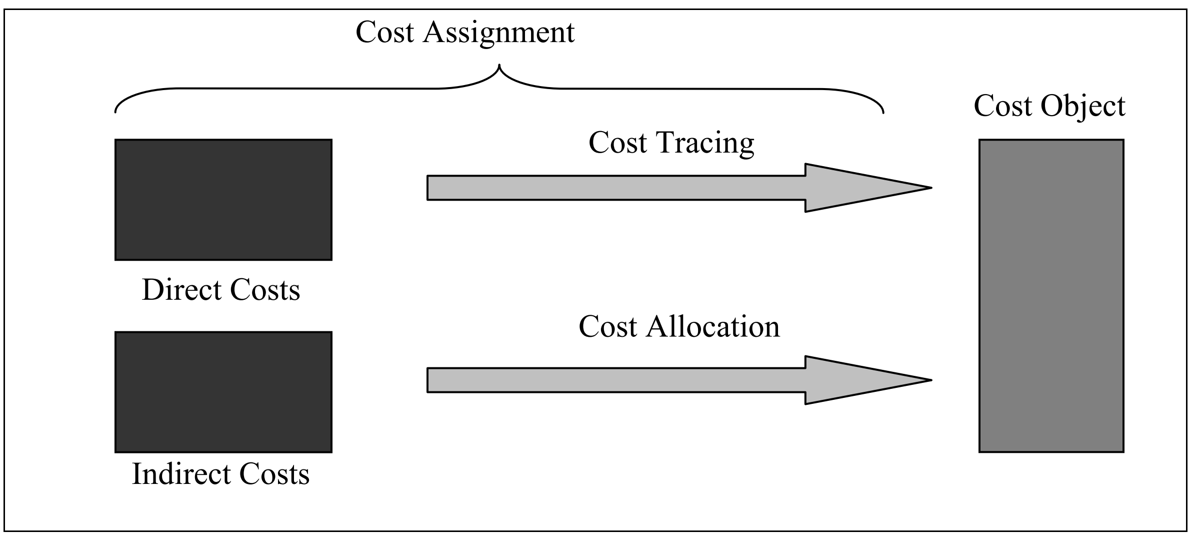

Figure 4: Cost Assignment Procedure

The importance of identification types of cost and their behaviors, and make clear distinction between them is stressed before. The following example will help clear this issue a little bit more. For example, some companies classify payroll fringe costs as manufacturing overhead. In other companies, however, the fringe benefits related to direct manufacturing labor are treated as an additional direct manufacturing labor cost. Let's consider a direct laborer such as a lathe operator or an auto mechanic whose gross wages are computed on the basis of a nominal or stated wage rate of $20 an hour, may enjoy fringe benefits totaling, say, $5 per hour. Some companies classify the $20 as direct manufacturing labor cost and the $5 as manufacturing overhead. Other companies classify the entire $25 as direct manufacturing labor cost. The latter approach is preferable because these costs are a fundamental part of acquiring direct manufacturing labor services (Horngren & Foster & Datar, 2000:43). There are also several benefits and allowances which may be considered overhead provided to the military personnel in addition to the basic salary. This research will treat these costs all together as Direct Labor Cost considering that they are required to have and keep direct labor in its body. As for the example, how does the procedure would impinge on the company's ledger? First, that might result in not taking advantage of a tax cut for companies that would have some certain percentage of direct labor cost and/or secondly, it might lead to miscalculating the cost-to-benefit rate. On the other hand, what if we had a similar issue in our case? Well, that might lead us not to represent that portion properly in the true cost of engine maintenance that will subsequently result in taxpayer's money be accounted for poorly. Cost allocation is an integral part of the "true" cost estimating process. There are several options from intricate set of math functions to a simple equation that are suggested for use according to the type and size of the problem. For example, Bronisz, et al. used game theory, which is a useful tool for making decisions in cases where two or more decision makers have conflicting interests (Winston, 1993:824). They assumed that the cost allocation not only dealt with sharing the costs among the players, but also with allocation of the cost among the different goods. The problem was modeled by a family of so-called multi-items cooperative games. Those were cost games with side payments in which they explicitly introduced vector of goods as well as a cost allocation procedure based on pricing (Brunisz and Krus: 2000). Billera, et al. introduced a mathematics function that gives the marginal cost of the good at some certain production level. They actually formulate the problem as follows: the problem is allocating the shared production costs of a group of goods or services. There are *n* different goods or services (or different grades of the same good or service). It is known that the total cost of producing x_i units of good *i* is $f(x_1, \ldots, x_n)$. If the quantity *i* required is α_i, $i = 1, \ldots, n$, what portion of the total cost $f(\alpha_i, \ldots, \alpha_n)$ should be allocated to the *i*th good in the form of a per unit cost. The function is (Billera and Heath: 1982):

$$c_i(f,\alpha) = \int_0^1 \frac{\partial f}{\partial x_i}(t\alpha)dt. \tag{5}$$

Where, $c_i(f,\alpha)$ represents the marginal cost of the *i*th good at production level α averaged over consumption levels $(t\alpha_1, \ldots, t\alpha_n)$ with *t* being between zero and one.

The other issue is as important as identifying cost types and their behaviors. It is the process of defining where to draw cost boundaries and how they should be allocated. This is sort of the field on which the analyst performs its play. For example, this research has chosen to build a cost model around the Base. Since the boundaries are set around the Base, Depot Costs as an example will reflect the costs Depot charges for the services or repairs provided to the Base and it will be a variable cost changing with the number of items sent to Depot. The costs incurred within the Depot will not be a concern to the research. On the other hand, if the diameter of the study were supposed to be expanded, Depot Costs would then behave differently and would also be a big concern to the study.

In this case, these costs should be taken into consideration internally rather than looking at them externally.

Within the cost estimating community in the Air Force there is a discussion as to what consumes fuel. Some say engine burns all fuel and others say aircraft consumes fuel and have nothing to do with engine maintenance cost. This research agrees with the latter thought. Fuel consumed during engine maintenance should be distinguished from the fuel aircraft consume to accomplish their mission.

We previously discussed the flying hour program, which is currently used along with the main cost factors approved by AFCAIG to prepare budget estimates. Each major command develops a cost per flying hour rate for each of the aircraft types in its inventory. These rates include three major program expense elements: depot level reparable parts, consumable supplies and aviation fuel (GAO, 1999:8). It is assumed that these three elements (cost drivers) capture the majority of Direct expenses to operate and support a weapon system. For example, consumable supplies are aircraft parts or supplies that have no authorized repair procedures and are discarded after use. These items fall into two subcategories of System Support Division (SSD) and General Support Division (GSD). Those items are centrally procured by the Air Force, and include items such as disposable aircraft parts, antennas, lights, wiring and windshields are in the SSD. The GSD includes all other expendable items such as common bench stock items, administrative supplies, tools, etc. (Rose: 1997). Depot-level reparable (DLR) items are parts that can be repaired at a facility and are used in direct support of aircraft maintenance. Aviation fuel is the cost of the fuel purchased to operate aircraft (GAO, 1999:8). Under the working capital fund concept, what was SSD and DLR have been combined into a new category called Material Support Division (MSD) (AFI 65-503). These Direct expenses are certainly not all the costs factors that should be considered when calculating the total maintenance cost of a weapon system. For example, the pay and allowances of military and civilian personnel who perform maintenance on and provide ordnance support to assigned aircraft, associated support equipment and unit level training devices. AFI 65-503, USAF Cost and Planning Factors, contains a complete list of the cost factors that the MAJCOM FMs and LGs use while developing their CPFH cost factors. A complete list of USAF Cost and Planning Factors is provided in Appendix A.

2.8 Costing Scope and Bases

Cost estimates differ greatly within the cost estimating community. For example, Deputy Assistant Secretary, Cost & Economics Mr. Joseph T. Kammerer indicates: "for the eight program case histories reviewed, the CAIG estimates were higher than the service estimates in all cases-anywhere from 6% to 53%" (Kammerer: 2002b). Further investigation revealed that the cost estimating methods were not the issue, the real problem was the assumptions made in the technical, schedule, and other programmatic areas (Kammerer: 2002b). For this reason, the focus of this research is going to be on the existing or previously used models, and identify any assumptions made. The appropriate allocation of the indirect costs associated with engine maintenance will be the most arduous task. There are basically two types of costing systems that are used to assign costs to the cost object (Horngren & Foster & Datar, 2000:97). A brief discussion of these costing systems will be presented later in this chapter.

LCC has always been an important factor in the acquisition process of any weapon system in the United States Air Force (USAF). During this acquisition decision, the first thing that comes to mind is obviously the Research and Development costs. This requirement was the primary reason that led to the development of a number of LCC models. On the other hand, Operation and Maintenance of the weapon system was a much bigger issue and had significantly long-term effects on the total cost over the economic life of a weapon system, which can easily be viewed in Figure 1.

This research effort tried to review as many models pertinent to engine costs as possible. That was because the cost elements and the cost factors that drive costs and Cost Estimating Relationships (CER) in each model would shed light on our understanding of what type of costs the Air Force incurs while performing this job and how these costs behave. The interest towards the estimating of Operating and Support costs had led to preparing a valuable document by Cost Analysis Improvement Group (CAIG) in 1992. They summarized a generic Operating and Support Cost Element Structure, and defined the terms related to O&S costs. The basic cost elements were mission personnel, unit-level consumption, intermediate maintenance, depot maintenance, and contractor support, sustaining support, indirect support. The complete cost element structure (CAIG's) will be given in Appendix B.

Cost-Allocation Base

The cost allocation base is a factor that is the common denominator for systematically linking an indirect cost or group of indirect costs to a cost object. If the cost object is a job, product, or customer, the cost-allocation base can also be called a cost-application base. A cost-allocation base can be financial (such as direct labor costs) or non financial (such as the number of miles traveled). Companies often seek to use the cost driver of the indirect costs as the cost-allocation base. For example, the number of miles traveled may be used as the base for allocating automobile operating costs among different sales districts (Horngren & Foster & Datar: 2000). A more specific example may be the following. The direct man-hours on the aircraft maintenance can be used as a cost allocation or application base, to allocate indirect or General and Administrative (G&A) costs to engine or avionics system maintenance. Or, the proportion of direct man-hours on the engine maintenance or another system to the whole direct man-hours on the aircraft maintenance might be another way to allocate indirect costs.

2.9 Costing Systems

Two basic type of costing systems are used to assign costs to products and services. They are job-costing system and process costing system. Cost benefit analysis, which the management has to accomplish whenever a resource allocation is required, is crucial in determining which costing system to use. Another key point is to know how the operations in the system are carried out.

2.9.1 Job-Costing System

In this system, the cost object is an individual unit, batch, or lot of a *distinct* product or service called a **job**. The product or service is often custom-made, such as specialized machinery made at Hitachi, construction projects managed by Bechtel Corporation, repair jobs done at Sears Automotive Stores, and advertisements produced by Saatchi and Saatchi. Each special machine made by Hitachi is unique and distinct. Similarly, an advertising campaign for one client at Saatchi and Saatchi differs greatly from advertising campaigns for other clients. Because the products and services are distinct, job-costing systems can accumulate costs by each individual product, service, or job (Horngren & Foster & Datar, 2000:97). Many maintenance tasks handled in the Air Force Bases are distinct in nature. Examples include periodic inspection of an aircraft and Air Ground Equipment (AGE) shop activities.

2.9.2 Process-Costing System

The cost object in the process-costing system is masses of identical or similar units of a product or service (Horngren & Foster & Datar, 2000:97). For example a bank follows the same procedures to all its customers when they wish to deposit checks, open an account or make a payment. The bank basically provides exactly the same service to the customers. In this system, total costs of producing a unit or providing a service in each period are divided by the number of products manufactured or services provided to obtain unit cost. And, this unit cost applies to all of the identical units produced. For example TAC rebuilds performed on the engine at the Depot facilities are identical or similar. Each time an engine comes to Depot for a TAC rebuild, Depot provides the same service. Because they have to follow the same type of procedures and replace the predetermined parts each time.

2.10 Data Sources

The majority of the existing models were actually built to estimate the Operating and Support cost of aircraft and engine was, of course, a big part of them. There were just a few models aimed at engine and most of these were dealing with Life Cycle Cost (LCC) of an engine that includes all the phases from Research and Development to Disposal which we briefly touched upon in the previous chapter. And, there are several databases, which contain the cost information of numerous items pertaining to aircraft, and aircraft operation and support costs in a variety of different forms to help cost analysts and contractors utilize the information in their cost calculations and estimation processes. Some of them are Weapon System Cost Retrieval System (WSCRS), Air Force Total Ownership Cost (AFTOC), Depot Maintenance Cost System (DMCS), Comprehensive Engine Management System (CEMS), Core Automated Maintenance System (CAMS) and Reliability and Maintainability Information System (REMIS) that retrieves data from several CAMS.

For example, WSCRS collects and assembles the historic depot level repairable costs, depot maintenance costs, and the base level depot level condemnation costs for the major USAF aircraft and engines (approximately 150 aircraft 100 engines). WSCRS also keeps track of a weapon system's programmed vs. actual flying hours and inventories, and a weapon system's installed engines, engine changes/upgrades, and replacements.

And, AFTOC, whose motto is "making access and analysis of your data easier", is still developing into becoming a Management Information System that will provide detailed cost information on all major weapon systems. It's one of the many objectives is to provide routine and timely visibility into all Air Force costs, and to satisfy congressional O&S reporting requirements. It now serves as a single data repository from different data sources within the Air Force.

CAMS is an automated information system (AIS), which supports the Operations Group/Logistics Group Commanders (Chief of Maintenance for Communications Electronic (C-E)) functional areas. This AIS consists of computer programs that provide automated inventory control and management information systems for base-level maintenance managers allowing for effective utilization of their resources in mission accomplishment (Air Force: 2001). The several CAMS from the Bases feed the REMIS database but it does not contain all of the data types CAMS has.

Depot Maintenance Cost System (DMCS) has existed since 1960s as the source for comprehensive production and cost information on DoD depot maintenance to answer depot maintenance questions-who, what, when, where, and how much (Steans & Applegate, 2002:Ch 1, 3).

2.11 Summary

This chapter provided some of the terms and definitions about a weapon system's life cycle cost and discussed how it breaks down. Some of the techniques and the cost models used to estimate different costs in a weapon system's life cycle and cost estimating relationships were presented. Some of the advantages and disadvantages of the statistical and accounting models used in the past were also discussed. The definitions and usages of the three types of models mentioned in the CAIG report, and some of the models and previous research performed in this area were presented. A brief description of some of the existing models used by different units of the DoD was presented. This chapter also provided a background information on these units and their force structures in addition to their role in the United States Air Force. After that, the use of flying hours as a basis cost measure to keep track of the engine performance was discussed and unit cost and the implications behind it were also described. Definitions of cost, cost driver, direct cost, sunk cost, and indirect cost were provided. Then, a discussion on cost categories and their evolution was presented in addition to what falls under these categories. Some approaches to cost allocation problem are also presented in this chapter. The allocation base is described and some of the possible cost bases are then given as examples. Chapter continued with a discussion of the costing systems used to assign costs to cost objects. The data sources, which are currently in use, are presented concisely along with the type of data they contain.

Next chapter will provide a detailed description of the methodology that should be followed to answer the research questions. The analytical steps of implementing the methodology will also be explained. A discussion of why it is important to look at the previous models will be discussed. And, some examples from the cost calculation and allocation processes will conclude the next chapter.

III. Methodology

3.1 Introduction

The intent of this research was to come up with a model which would reflect the actual Operation and Maintenance (O&M) cost of a jet aircraft engine, primarily the F-16 engine built by General Electric (GE). There have been numerous studies performed by the Operations Research analysts to minimize costs in order to allocate scarce resources. But, the value of these studies is questionable unless the costs represented are true or actual. Therefore, after having explained why we need to find out the "actual" or "true" cost of engine maintenance in Chapter 1, we looked at some of the research and studies performed in this area, and presented various models performing similar type of cost calculations and estimations in Chapter 2. These models were of various types. Some of them were statistical models, some of them were accounting models and some of them were computer models. Although chapter 2 provided insight into the different models, studies and their purposes, this research is concerned with the ones that are closely related to jet engine costs. This chapter will present detailed description of the methodology followed to answer the research questions as well as to build a credible model.

3.2 Description of Methodology

A basic yet effective methodology is chosen to meet the objective of the research. The research is going to assess the existing models in order to come up with a true cost of engine maintenance. The following analytical steps are used to achieve this goal.

- Finding the cost factors
- Determining the effects of each factor
- Cost element trend evaluation
- Cost feasibility

Finding the factors was actually performed in the literature review by examining the existing models, previous models and studies done in this particular area, and military and civilian documents prepared for this issue. By looking at all those models provided insight into what should be included in an operating and support cost model.

The other point is to determine the effects of each factor on engine maintenance cost. What factors drove the engine maintenance cost historically? Are those still the cost drivers? Examining the previous studies and comparing them to some of the current practices used to keep track of engine maintenance costs also served us to accomplish this step.

Another point is to assess how these costs behave; they may be variable, semi-variable, fixed, etc. Determining the trend of these cost elements with respect to a metric is a challenging task. At this point interviewing with the experts in the cost estimation world and people actually working on engine maintenance proved useful while explaining the cost element behavior.

Finally, a determination must be made if costs are reasonable. Are they actual costs? Are they budgeted costs? Are they actually the money leaving the system to buy goods and/or services? Here, interviews again played an important part to determine their feasibility according to a unit.

The research performed all of these steps together. For example, the literature review revealed that engine overhaul cost is one of the factors constituting total engine maintenance cost. It is a variable cost factor with respect to the number of engines a unit sends in a period. On the other hand, it is a semi-variable cost with respect to engine flying hours in a period. If the base hypothetically flies so many hours in a period, there will be a fixed portion resulting from high flying hours (scheduled maintenance) and a variable portion resulting from unscheduled events such as Foreign Object Damage (FOD) intake.

3.3 Summary

It is always important to adopt a sound methodology in answering research questions and reaching the objective of the research. In this chapter, a detailed description of the methodology is presented after a brief introduction. Each analytical step of the methodology is discussed separately. Next chapter will provide the detailed discussion of the models that shed light on the research. A thorough explanation of the cost elements used in the model will also be provided along with conclusions.

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IV. Findings and Analysis

4.1 Introduction

Some cost estimating models were presented in the literature review. All of these models helped analysts in their reports to decision-makers and/or on the studies regarding cost analysis, cost reduction, cost effectiveness, etc. Each of those models has been useful in some way. There is also agreement that there is still work to be done in finding "actual" costs associated with a weapon system that will have assumptions accepted by the whole cost estimating community.

This chapter will present discussions on the findings and analysis. An in depth discussion of the selected models from past and present will be provided first. After that, the cost elements that should be included in the model will be provided. Definitions of these cost elements and why they are chosen are also presented in the chapter.

4.2 Models In General

The literature review revealed that most of the models would fall into these three categories: accounting, simulation and parametric models. The research presented several examples of statistical models and simulation models in Chapter 2. Statistical models generally used some of the engine characteristics to estimate costs. Examples include the Turbine Inlet Temperature, Thrust-to-Weight Ration, and Specific Fuel Consumption. Even today, the National Aeronautics and Space Administration (NASA) prescribes a cost model on their website for estimating development and production costs and time of arrival for U.S. military turbojet and turbofan engines using these characteristics (NASA: 2002) and a few more discussed in Chapter 2. They have some advantages and disadvantages discussed earlier; but they are now easier to implement using tools like Jump, SAS, etc. Simulation models, on the other hand, used different parameters and metrics to estimate costs. And, they are widely dependent upon the probability that the cost-incurring event will occur. In the military environment, these probabilities have a large confidence interval around them.

4.2.1 Air Combat Command Engine Cost Model

The Air Combat Command assumed control of all fighter resources based in the continental United States upon activation on 1 June 1992. The ACC is one of the Major Commands of the Air Force and it constitutes the "Global Power" facet of the Air Force mission with its force structure. Some of the responsibilities assigned to Major Commands in engine management as indicated in the AFI F21-104 are (Air Force: 1998):

- Recommend improved logistic concepts, policies, and procedures for engines to HQ USAF/ILM.
- Redistribute command owned engines (as required).
- Oversee Stock Record Account Number (SRAN) engine operations and appoint a command engine manager (EM).
- Compute wartime engine removal rates in accordance with engine managers when wartime operating conditions (actual or anticipated) differ significantly from peacetime operating conditions.
- Compute MAJCOM base stock-level requirements.
- Forecast engine depot repair requirements prior to periodic negotiations.
- Make all required Program Objective Memorandum (POM) inputs for DPEM funds, AFCAIG adjustments, and approved engine modifications.
- Responsible for budgeting and allocating O&M funds used to purchase depot-level reparable items through MSD.

In order to accomplish those tasks, the ACC keeps track of data coming from its subordinate Air Force Bases. Since the research is interested in the cost of engine maintenance, it will focus on that portion of the data monitoring system per se. The command felt that they should look into engine costs more closely for analysis purposes (Sullivan: 2003b). The responsible office tracks expenses only from Base level. Those expenses or costs are directly related to aircraft itself. The office includes the parts and fuel consumed at the base level. That consumption data is extracted from the AFTOC database that was previously discussed in Chapter 3. When the data is pulled out for each base under ACC's command, the office breaks it down by the particular type of engine each base has on inventory. Then, the costs from GSD (consumable parts) and MSD (reparable parts) are summed to get overall costs per engine type and these are input into separate spreadsheets. Figure 5 shows an excerpt from one of the spreadsheets used.

Base	FY99 Hours	FY99 GSD Costs	FY99 MSD Costs	Total FY99 Costs	FY99 CPEFH
Cannon	15917.1	1172609.59	16494786.62	17667396.21	1109.96326
Hill	13999.3	863003.29	14647850.32	15510853.61	1107.973514
Moody	7342.6	470550.34	10241023.12	10711573.46	1458.825683
TOTALS	41413.7	2506163.22	41478367.35	43984530.57	1062.076814
Base	FY01 Hours	FY01 GSD Costs	FY01 MSD Costs	Total FY01 Costs	FY01 CPEFH
Cannon	17008.4	2639829.56	14996726.2	17636555.76	1036.93209
Hill	18996	2803508.96	18286113.75	21089622.71	1110.213872
Moody	2376.9	385057.02	2781426.54	3166483.56	1332.190483
TOTALS	39266.4	5828395.54	36527138.18	42355533.72	1078.671172

Figure 5: Part of the Spreadsheet

Depot costs are not included in that total cost. To narrow down the costs to the engine excluding the rest of the aircraft, specific Federal Stock Class (FSC) are pulled under MSD. As for GSD, engine supply shop codes are used to pull out the data. For this part of the calculation, fuel cost is not included (Sullivan: 2003a). All this data are entered into the spreadsheet by fiscal year and several analyses are then performed. For example, Figure 6 show a cost per flying hour comparison of several engines operated under ACC.

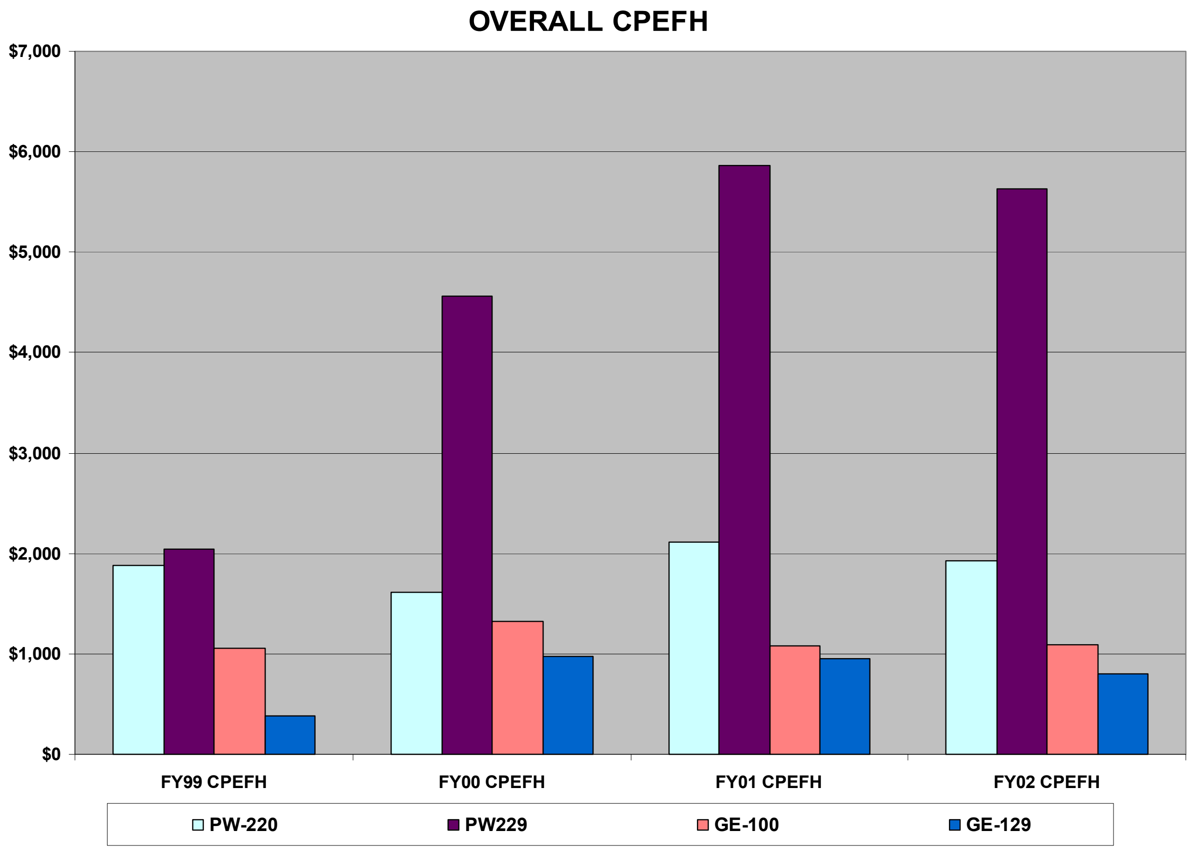

Figure 6: Cost Comparison of Engines

4.2.2 United States Air Force in Europe (USAFE) Cost Model

The USAFE's model is similar to the ACC's. The USAFE is also a Major Command of the Air Force; it is also an air component of the U.S. European Command. Like the ACC, USAFE gathers data from wings and bases and enters that data into an spreadsheet to keep track of monthly expenses. USAFE has the same responsibilities-discussed in the previous section-as other Major Commands. For several years in USAFE they have been attempting to track the amount of money they spent repairing their fighter engines on a monthly basis (Mackey: 2002). Figure 7 shows a small part of this big spreadsheet.

F-15 E LAKENHEATH						
SUMMARY DATA		CUM	CUM	CUM	CUM	CUM
	CUM	COST	COST	COST	COST	%
	FUNDING	AVFUEL	GSD	MSD	TOTAL	SPENT
Oct-01	$ 119,226,000	$2,303,196	$840,015	$6,222,208	$9,365,419	8%
Nov-01	$ 119,226,000	$4,226,003	$1,535,361	$11,219,420	$16,980,784	14%
Dec-01	$ 119,226,000	$5,400,910	$2,080,440	$18,438,118	$25,919,468	22%
Jan-02	$ 119,226,000	$7,300,636	$3,009,753	$21,382,521	$31,692,910	27%
Feb-02	$ 119,226,000	$9,182,748	$3,949,048	$24,208,766	$37,340,562	31%
Mar-02	$ 119,226,000	$13,327,138	$4,693,709	$32,565,438	$50,586,285	42%
Apr-02	$ 119,226,000	$15,788,067	$5,284,352	$36,796,364	$57,868,783	49%
May-02	$ 119,226,000	$18,383,040	$5,993,983	$45,341,307	$69,718,330	58%
Jun-02	$ 119,226,000	$19,830,596	$6,508,398	$50,942,363	$77,281,358	65%
Jul-02	$ 119,226,000	$21,855,286	$7,406,005	$58,734,481	$87,995,772	74%
Aug-02		$0	$0	$0		#VALUE!
Sep-02		$0	$0	$0		#VALUE!

Figure 7: Part of the Spreadsheet

While doing this they encountered several problems. First, they do not include engine repair costs from the flight line because those are much more difficult to track and determine. So, they base their CPEFH on JEIM. The JEIM expenses are determined by the USAFE fighter wings and sent to the command engine manager who uses a four-quarter rolling average to prepare reports (Mackey: 2002). The JEIM expenses are determined by the USAFE fighter wings and sent to the command engine manager who uses a four-quarter rolling average to prepare reports (Mackey: 2002). Secondly, they cannot determine whether the cost increase or decrease is due to the price changes in the cost of parts or not, because sometimes the cost of parts increases 30% or more each year and they have no control over the prices they pay, as they are established Air Force Material Command (AFMC) and they must pay the bill to receive the goods.

4.2.3 Super Operating and Support Cost Model (SOSCM)

Back in the early 1980s, The Aeronautical Systems Division, Deputy for Propulsion supported aircraft acquisition programs and also acquired engines for the Air Force. When a new weapon system was fielded the program was commonly assigned to an already existing office or a special program office was formed. This group chose one of the existing LCC cost estimating models and modified it for the specific necessities of the new system if required. Using the model chosen, cost analyses were performed and inputs were provided to the decision makers. After the acquisition program was completed, personnel started to work on another program or the special program office transferred responsibility to a logistics or support office. The need to analyze life cycle costs on the acquisition decisions identified the need to have an Operating and Support Cost model designed only for aircraft engines. Even though the Director of Acquisition Logistics was interested in the total life cycle cost of an engine, his primary concern was for the Operating and Support cost which had the long term effects and required quick response consisting of the approximate costs rather than a detailed study (Meitzler: 1986). The SOSCM was developed to meet this need. The analysts working for the Deputy for Propulsion through discussions with the industry analysts developed equations for the model in 1985. These equations were then reviewed by some of the cost estimating community and applied to an engine program. Upon having satisfactory results, SOSCM Version 1.0 was created to provide easy-to-use, menu driven O&S Cost Model. The code was written in Basic by an Operations Research Analyst at that time. The model structure was deterministic in nature and enabled user to make O&S cost comparisons among engines.

The model had various uses in applications such as O&S cost estimates, trade-off analyses, repair level analyses, spares provisioning, and cost driver sensitivity analyses (Meitzler: 1986). But, the model had mostly been used in a source selection environment to estimate O&S costs. It was also possible to look at some of the impacts of maintenance decisions-two or three level-by changing the number of intermediate maintenance facilities and/or the condemnation information.

The data were input in two ways: internal and external. The internal group of data consisted of variables had built-in default values but those may be changed by the user. These were the standard logistics and cost factors as well as the operational scenario parameters. Some of these data could be found in the AFMC Cost and Planning Factors AFLCP 173-10, such as Base Labor Rate (BLR) and Depot Repair Cycle Time (DRCT). Figure 8 shows internal input data parameters.

PROGRAM DEFINITION FACTORS

Number of Production Years
Number of Steady State Years
Total PAA Engines

STANDARD COST FACTORS

Fiscal Year Dollars
Base Labor Rate ($/hr)
Base Material Rate ($/hr)
Depot Labor Rate ($/hr)
Depot Material Rate ($/hr)
Fuel Cost ($/Gal)
Packaging Rate ($/lb)
Shipping Rate CONUS ($/lb)
Shipping Rate OS ($/lb)

OPERATIONAL CONCEPT FACTORS

Number of Bases
Number of JEIMs
Utilization Rate (Hrs/Mo)
Percent of Fleet in CONUS
Fuel Utilization (Gal/EFH)

LOGISTICS SUPPORT FACTORS

Base Repair Cycle Time (d)
Depot Repair Cycle Time CONUS (d)
Depot Repair Cycle Time OS (d)
Order and Ship Time CONUS (d)
Order and Ship Time OS (d)
Spares Confidence Factor (Z)
Packaged Weight Ratio
Recurring SE Cost Factor

Figure 8: Internal Input Data Parameters

The second type of data was external. This group of data included engine specific data for which there were no default values. Those data might be gathered from the contractors. Maintenance Event Rates (MER) and Engine Removal Rate (ERR) can be given as examples to this type of data. Although this data might be entered during the execution of SOSCM, an external editor or a spreadsheet was used to construct the data file. But this data had to be in American Standard Code for Information Interchange (ASCII) format. During the execution process, two other type of data had to be entered; one of which was whole engine spares and the other one was the cost of common and peculiar support equipment. Figure 9 shows us the external input data parameters.

ENGINE INPUT DATA MATRIX FACTORS

Code (E-Engine, L-LRU, S-SRU, 0-Inspect)
Item/Event Name
Maintenance Event Rate (per 1000 EFH)
Engine Removal Rate (per 1000 EFH)
LRU Removal Rate (per 1000 EFH)
Not Reparable This Station Rate
Base Maintenance Man Hours/Event
Depot Maintenance Man Hours/Event
% Unit Cost Consumable/Event, Base
% Unit Cost Consumable/Event, Depot
% Unit Cost Condemned/Event, Base
% Unit Cost Condemned/Event, Depot
Unit Price
Weight
Quantity per Engine

Figure 9: External Input Data Parameters

The problem is now to gather this type of information. Unfortunately this data is not contained in handy regulation book. Many things have changed since then as to the way Air Force operates. For example, you can transport engines via civilian contractors such as FedEx, UPS, DHL. That will definitely affect the shipping cost used in the model which was originally pre-determined and could be found in an Air Force publication.

Another example could be labor rates; depots as well as bases have a variety of employees that have different payrolls and it is not easy to gather the data on how much a depot is paying their employers. Besides that, there were some factors such as Recurring Support Equipment Cost Factor whose determination was sort of up to the analyst who was not necessarily knowledgeable about support equipment. And, you get some of the data from the contractors as to how many maintenance actions you should expect in a Fiscal Year. Operations in the Base are very dynamic in nature and it is really hard to "prophesy" when or how many you will get a malfunction, a discrepancy. Sometimes you can reach the expected number in a month for any reason which is part of the nature of aviation. Think of a major assembly whose NRTS rate is given as 1 that you as a Base have to send that item to Depot. But before sending the item to Depot you should remove the item which means that you will incur some material, consumables cost. This cost turns out to be zero in the model in the wake of the way equation is built. It is not very common across model but sometimes happening. Other than that, second part of the pipeline spares cost does still not make much sense mathematically although we are told that the model itself sorts it out internally because of the way code is written.

As discussed in Chapter 2, the SOSCM model was used in the source selection processes of several aircraft programs including the F-22 which is considered to ensure air dominance in future conflicts. During this process, contractors, which were generally Pratt Whitney and General Electric, were supposed to provide the metrics used in the model for the Air Force to calculate Life Cycle Costs of competing engines that would power the aircraft. This procedure was one of the factors that helped decision makers throughout the acquisition process.

The model has recently been considered for revision in 2000. The objective was to translate the code written in Basic into a user-friendly Excel tool. The office that took on the job ran into some programming problems and never completed the job. They actually came up with a model that worked for a set of data, though it was not as generic as they wanted it to be.

When we look at how the model performs calculations, we see that most of the algorithms are unique and independent of one another. There are common terms used such as the expected number of maintenance actions per thousand hours. Here we present the equations pertaining to Operating and Support Costs. The following equations are based on the expected number of Maintenance Actions (MA) and Removal Actions (RA):

$$MAij = QPEj * MERij * (EFHi / 1000) \tag{7}$$

where

MA_{ij} = Maintenance actions in year "i" on item "j"
QPE_j = Quantity of the item "j" in the engine
MER_{ij} = Maintenance event rate in year "i" on item "j"
EFH_i = Engine flying hours in year "i"

The maintenance event rate is basically the expected number of maintenance actions for whatever reason in a thousand engine flying hours. Another common term was Removal Actions whose equation is quite similar to Maintenance Actions.

$$RAij = QPEj * [(ERRij) or (LRRij)] * (EFHi / 1000) \tag{8}$$

where

RA_{ij} = Removal Actions in year "i" on item "j"
ERR_{ij}= Engine/Major assembly removal rate in year "i" on item "j"
LRR_{ij}= Line Replaceable Unit removal rate in year "i" on item "j"

Base Labor

The Base Labor Cost is the cost to perform engine maintenance tasks at the field level, both on the flight line and in the intermediate level maintenance shop. The base labor rate should include direct labor and overhead.

$$BLC = \sum_{i=1}^{n} \sum_{j=1}^{m} MAij * (1 - NRTSij) * BMMHij * BLR \tag{9}$$

where

BLC = Base Labor Cost
$NRTS_{ij}$ = Not Repairable This Station rate in year "i" for item "j"
$BMMH_{ij}$ = Base maintenance man-hours per event in year "i" to repair item "j"
BLR = Base Labor Rate
n = number of years "i" in life
m = number of items "j"

Base Material

The base material cost is the cost of consumable material used during the engine maintenance process other than condemnations and pipeline. For example, engine removal, major assembly separation, component or part removal.

$$BMC = \sum_{i=1}^{n} \sum_{j=1}^{m} MAij * (1 - NRTSij) * (1 - BCONDij) * BCONij * UPij \tag{10}$$

where

BMC = Base Material Cost
$BCOND_{ij}$ = Percent of unit price condemned per event in year "i" for item "j"
$BCON_{ij}$ = Percent of unit price consumed per event in year "i" for item "j"
UP_{ij} = Unit Price in year "i" for item "j"

Depot Labor

The Depot Labor Cost covers the cost to perform engine maintenance tasks at the depot. And, the Depot Labor Rate should include direct labor and overhead just like the Base Labor Rate.

$$DLC = \sum_{i=1}^{n} \sum_{j=1}^{m} MAij * NRTSij * DMMHij * DLR \qquad (11)$$

where

DLC	= Depot Labor Cost
$DMMH_{ij}$	= Depot maintenance man hours per event in year "i" to repair item "j"
DLR	= Depot Labor Rate

Depot Material

The Depot Material Cost is the cost of consumable material, other than condemnations and pipeline, used during the maintenance process at the Depot. As in the Base Material, these costs include the material consumed during engine removal, major assembly separation, and component or part removal.

$$DMC = \sum_{i=1}^{n} \sum_{j=1}^{m} MAij * NRTSij * (1 - DCONDij) * DCONij * UPij \qquad (12)$$

where

DMC	= Depot Material Cost
DCONDij	= Percent of unit price condemned per event in year "i" for item "j"
DCONij	= Percent of unit price consumed per event in year "i" for item "j"
UPij	= Unit Price in year "i" for item "j"

Condemnation Spares

The condemnation spares cost is the cost to replace discarded reparable items. It includes damaged items whose repair is neither feasible nor economical as well as items intended for condemnation. It also includes the costs for replacement, obsolescence, and modifications. You will notice that the number of years start with three because the condemnation costs for the first two years are excluded from the Condemnation Spares

Cost element. They are computed with a similar algorithm and included in the Initial Spares Costs.

$$CONDC = \sum_{i=3}^{n} \sum_{j=1}^{m} MAij * [NRTSij * DCONDij + (1 - NRTSij) * BCONDij] * UPij \quad (13)$$

Second Destination Transportation

The Second Destination Transportation costs account for the packaging and the shipping of engines and reparable assemblies and parts between the maintenance facilities. Original equation is changed to a more feasible equation since the costs resulted in unrealistic. They separated packaging cost from the shipping cost and applied to the equation.

$$TRANC = \sum_{i=1}^{n} \sum_{j=1}^{m} 2 * RAij * NRTSij * (WTij * PCKCST + WTij * PWTRATIO * SHPCST) \quad (14)$$

where

TRANC	= Second Destination Transportation Cost
WT_{ij}	= Bare weight of item "j" in pounds
SHPCST	= Shipping cost per pound
PCKCST	= Packaging cost per pound
PWTRATIO	= Packaged weight to bare weight ratio

Recurring Support Equipment

The Recurring Support Equipment cost is an approximation of the maintenance and other recurring costs associated with the support equipment. The following cost estimating relationship is used to calculate this cost.

$$RSEC = \sum_{i=1}^{n} RSEFACT * SEi \quad (15)$$

where

RSEC = Recurring support equipment cost

RSEFACT = Recurring SE cost factor

SE_i = Cumulative cost of SE in the inventory in year "i"

Spare Engines

The Spare Engines cost is the cost of whole spare engines required to support the aircraft. This amount is determined and entered the model externally as a common practice. A simple equation is used to calculate this cost.

$$SEC = \sum_{i=1}^{n} QTYi * EUPi \tag{16}$$

where

SEC = Whole spare engines cost

QTY_i = Whole spare engines purchased in year "i"

EUP_i = Engine unit price in year "i"

Initial Spares

The Initial Spares consists primarily of the costs to fill the maintenance and supply pipelines with adequate number of parts and assemblies. This is by far the most complex equation of the model. Air Force Logistics Command defines the Initial Spares as all the spares required to fill the pipelines plus the condemnation spares for years 1 and 2 of the program life.

$$ISC = PSPC + \sum_{i=1}^{2} CONDCi \tag{17}$$

where

PSPC = Pipeline spares cost

CONDC = Condemnation spares cost for the year "i"

Since we have already looked at how to calculate the condemnation spares cost previously, we will now explain the calculation of pipeline spares cost. The cost estimating relationship is conspired of two parts. The first part of the equation accounts for the stock of parts and assemblies for the Base and Intermediate shop pipeline. And, the second part accounts for the depot repair cycle pipeline.

$$PSPC = NBASE * \sum_{j=1}^{m} STKij * UPij + \sum_{j=1}^{m} RAij * NRTSij * DRCT * UPij \tag{18}$$

where

NBASE = Number of Bases

DRCT = Depot repair cycle time

STK_{ij} = Base stock quantity for item "j"

i = initial steady-state year

The second part of the equation is straightforward; however, the first part calls for some additional explanation. The stock at Base consists of pipeline and safety stock items as defined below:

$$\begin{aligned} &STKij = \delta ij * Tij + v * \sqrt{(\delta ij * Tij)} \ldots Where \\ &\delta ij = RAij \,/\, NBASE \end{aligned} \tag{19}$$

and

T_{ij} = Weighted Base pipeline time for the repair of item "j"

v = Safety stock confidence level factor

The weighted Base pipeline time includes the Base Repair Cycle Time (BRCT) and the Order and Ship Time (OST). And, the safety stock confidence level factor represents a desired spares availability value and approximates the standard Z-scores of a normal distribution. The common values used are 1.65 for line replaceable units and 0.85

for major assemblies and whole engines. These represent 95% and 80% confidence levels respectively.

$$Tij = [(1 - NRTSij) * BRCTj + NRTSij * OSTj] \qquad (20)$$

4.3 Cost Elements and Behaviors

This section will provide descriptions and explanations about the cost elements that are incorporated into the suggested model. These cost elements are chosen primarily due to the following reasons: they are already included in an existing model currently in use, and there is an obvious factual relationship cited in the literature review or judgment based on experience between the cost element and a true or total cost.

4.3.1 Labor Cost

Labor Cost is the cost to perform engine maintenance in an Air Force Base. Literature review revealed that majority of the LCC and O&S cost models contain labor cost as one of the elements. It is also advised by CAIG that the mission personnel or labor should be included in the cost element structure (Department Of Defense, 1992: Ch 4, 2). This element will be comprised of direct and indirect labor costs.

Direct labor cost is the cost which is attributable or traceable to engine maintenance activities. Direct labor is also described as the "hands-on" labor performed by a Resource Control Center (RCC) of a maintenance production branch or laboratory and four conditions are stated to warrant a direct labor classification (AFMC, 2000:170):

1. It should increase the value or utility of a product by altering the composition, condition, conformation, or construction of the product or which provides a service directly to the customer rather than in support of other direct labor in the Directorate of Maintenance
2. It should be accurately, consistently, and economically identified to a product, group of products, or customer.

3. It should be supported by official work requests and authorized by prescribed work authorization documents (WAD) indicating the specific nature of the work to be done.
4. It should be applied to the product or group of products of a customer outside the Directorate of Maintenance.

In the model, direct labor basically consists of the basic pay and allowances made to the maintenance personnel working in the flight line, Jet Engine Intermediate Maintenance (JEIM) shop, and engine maintenance personnel in the periodic inspection shop. This payment includes basic pay, retired pay accrual, incentive pay, special pay, basic allowance for quarters, variable housing allowance, basic allowance for subsistence, hazardous duty pay, reenlistment bonuses, clothing allowances, overseas station allowances, uniform allowances, family separation allowances, separation payments, and social security contributions where applicable (Department Of Defense, 1992:B-2). As discussed in Chapter 2, those allowances could also be viewed as indirect labor costs. This research opted to consider these allowances as a part of the direct labor costs.

There are also some maintenance personnel who work on engines besides the ones working in engine shops. For example, the crew-chief has a contribution to engine maintenance by taking the engine oil sample for Joint Oil Analysis Program (JOAP) and servicing the engine with the right amount of engine oil which is critical to engine operation. We will not include their payments into that sum since they devote a lot more time to aircraft maintenance than do they to engine maintenance. The research believes that the effort to find out their contribution to engine maintenance will not outweigh the time spent on getting that data.

Indirect labor cost is the cost related to engine maintenance but cannot be traced to it in an economically feasible (cost-effective) way. For example, quality assurance personnel who perform random and scheduled inspections, such as an engine bay inspection each time an engine is rolled back or replaced, on engine maintenance activities. So, indirect labor cost will constitute the apportioned payments of the officers working in the flight line and the JEIM, the personnel working in the Quality and Assurance (Q&A), Maintenance Operation Center (MOC), etc. From the base-level perspective, labor cost is not an "actual" cost because they do not have to pay the salary and allowances on their budget. This is not the money coming out of their budget, because a higher level agency makes the payments.

Straight Line Assumptions

Labor cost is a fixed cost element with respect to any measure such as engine flight hours, number of engines changed, number of parts replaced or number of inspections done on the engines for a certain period of time. However as flying hours increase to a high level, the base will eventually need more manpower to support the increased flying hours. Therefore, labor costs follow a step function. On the other hand, the need for indirect labor will exist after a longer period of time. The following illustrations will help visualize the labor cost. In Figure 10, solid lines represent the direct labor cost and dashed lines represent indirect labor cost.

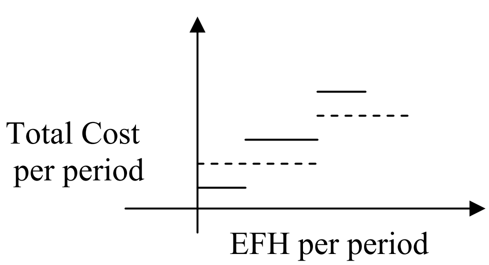

Figure 10: Labor Cost

Existing models have calculated the labor costs as straight-line approximations to the "true" step function:

$$DLC = DMHRS * BLRE \tag{21}$$

where

DLC = Direct Labor Cost
DMHRS = Direct Man-Hours Spent on Engine Maintenance
BLRE = Base Labor Rate for Enlisted

$$InLC = (TInLC \div DMHRS) * MHRSI \tag{22}$$
$$TInLC = TMHRS * (BLRO + BLRE) \tag{23}$$

where

InLC = Indirect Labor Cost
TInLC = Total Indirect Labor Cost
MHRSI = Indirect Labor Hours Spent on Engine Maintenance
TMHRS = Total Indirect Labor Hours
BLRO = Base Labor Rate for Officers

$$TDLC = DLC + InLC \tag{24}$$

where

TDLC = Total Direct Labor Cost

There is a risk involved calculating costs this way. Above, the cost is being calculated based on rates like many of the simulation models have been doing. In this case, response will be different because the cost will not be fixed as mentioned before. And, we will face the problem which is defined by scholars as the allocation problem. This problem has been an interest to many researchers and several approaches were briefly discussed in the literature review.

The new response can be observed in Figure 11. When these figures are put together as in Figure 12, it can be concluded that the cost is sometimes being estimated higher or lower than it really is. Here, the analyst has to make a choice between these options. If we underestimate the costs related to a specific cost element and prepare the budget taking this data into consideration, there may not be sufficient funds to allocate for the system at the end of the fiscal year. On the other hand, if the costs are overestimated with a great deal, management may want to take some measures to curb those costs resulting in deficient operation of the system. This research chose to treat labor cost as fixed up to a certain number of flying hours that will follow a step function. One should also keep in mind that if the segments in such a step function were smaller or shorter enough, then the cost element behavior could be approximated by a linear function.

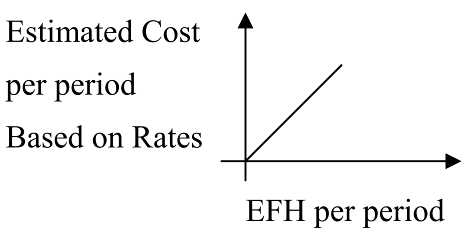

Figure 11: Labor Cost Based on Rate

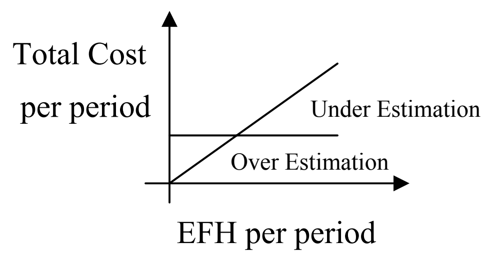

Figure 12: Cost Function Comparison

4.3.2 Spares Cost

Spares Cost is the cost incurred to replace the failed Line Replaceable Units (LRU) and Shop Replaceable Units (SRU). The need for these removals may occur during scheduled maintenance such as preflight, thru-flight and post-flight inspections. The removals may also be due to a sortie-generated discrepancy and scheduled or unscheduled inspections done by Q&A personnel. And, there are also time change items which would presumably not break down before the estimated operation time. The flight line personnel would never want to wait for the item being fixed, instead they almost always replace the items from pipelines. And, the supply system feed the pipelines. In this scenario maintenance and supply personnel have three options:

1. The LRU may be repaired at the Base,
2. The LRU may require to be sent to depot for repair, and
3. The LRU may unfortunately be condemned and discarded.

This cost element will include the cost of LRUs repaired on the base, the cost of Depot Level Reparables and the spares condemned by the Base. The LRUs that become Not Repairable This Station (NRTS) and require sending to depot will also be incorporated into the Spares Cost. If the Back Shop, the JEIM, replaces a Shop Replaceable Unit (SRU) to fix the LRU, maintenance and supply personnel will again face choosing one of the three options mentioned above for those SRUs as well.

The Spares Cost element will follow a step function because total cost is not affected until an LRU fails due to the reasons mentioned before. On the other hand, there are time change items that will increase the total cost as the flying hour increases. In other words they will have a linear relationship. So, they will constitute the variable portion of this cost factor. This cost may never be zero even if there is no flying hours because there may be breakdowns due to scheduled maintenance activities, during inspections by Quality and Assurance (Q&A) personnel, during periodic inspection, Time Compliance Technical Order (TCTO), etc.

As discussed in Chapter 2, the TAC has the potential to drive these costs since it reflects what the aircraft underwent through the flight better than the flying hours. An aircraft can have so many flight hours with a small number of TAC if it is not flown aggressively. It should also be noted that there is definitely a positive relationship between TAC and flying hours because if one of them increases the other will, too (given a relatively constant sortie mix and durations). Time change items are often replaced by engine flying hours because of this assumption. Engine overhauls, however are performed based on the number of TAC; so, the effect of TAC shall be observed in the Depot Maintenance Cost. Increased flying hours will give rise to the frequency of scheduled maintenance that might require replacing more parts in a specific period. If failure rates remain constant, the failures will occur with increasing frequency as the flying hours increase. Time change items will also be replaced more often in the same period, with higher hours. Figures 13 and 14 represent the behaviors of these costs.

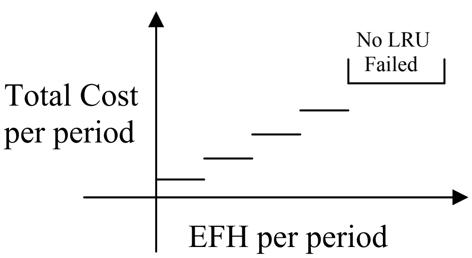

Figure 13: Base Repair, Depot and Condemnation

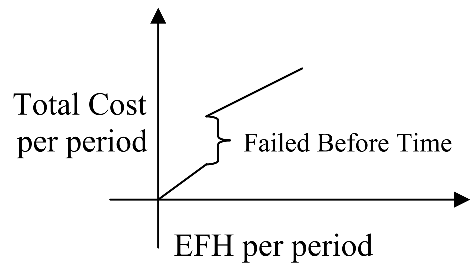

Figure 14: Time Change Items

Bases pay different prices to purchase spares. For example, exchange price is the price charged to exchange a Depot-level repairable item (DLR) for a serviceable item. If they don't have the item to return, then they are charged with the standard price, which is exchange price plus the carcass price. In order to calculate the spares cost, the following equation can be used:

$$SPRCST = \sum_i (DLR_i * EXCH_i) + (CONDM_i * STD_i) + (NRTS_i * EXCH_i) \quad (25)$$

where

SPRCST = Spares Cost
DLR = Depot-level Repairable Item
CONDM = Condemned Item
NRTS = Not Repairable This Station Item
EXCH = Exchange Price
STD = Standard Price
i = All of the items which are DLRs, Condemned, or NRTS in the period.

Some of this cost data are included in the Material Support Division (MSD) of the Defense Working Capital Fund (DWCF) and extracted from several databases.

4.3.3 Depot Maintenance Cost

Depot Maintenance is described as the maintenance which is the responsibility of and performed by designated maintenance activities, to augment stocks of serviceable material, and to support Organizational Maintenance and Intermediate Maintenance activities by the use of more extensive shop facilities, equipment, and personnel of higher technical skill than are available at the lower levels of maintenance (AFMC, 2000:170). From the definition, it is understood that the depot maintenance cost should be in the model because depot maintenance supports I-level and O-level maintenance performed in the Base. Literature review also confirmed this fact. In addition, depot maintenance work is widely varied (Steans & Applegate, 2002:Ch 1, 2):

- Depot level maintenance is performed on the full spectrum of DoD end items and components, ranging from complete weapon systems to equipment to depot-level repairable components (DLRs) to software packages.
- Maintenance output encompasses a wide range of services, including complete overhauls, repairs, condition inspections, installation of modifications, and the manufacture of replacement parts.
- The tasks performed in individual job orders change continuously, depending upon the configuration of the end items and components inducted, the nature and pace of military operations, the threat to be confronted, new technologies, and the effect of aging weapon systems and equipment on failure rates.
- Depot maintenance activities also accomplish intermediate or organizational-level work to meet operational requirements and for cost effectiveness.

There is a near linear relationship, similar to that for spares, between total cost and the engine flight hours since in a certain number of flight hours we are supposed to send certain engine accessories (such as the gearbox) for overhaul. As for the engine itself, engine overhaul is accomplished every certain number of Total Accumulated

Cycles (TAC) and as it was noted earlier the number of flying hours to reach that specific number of TAC would not be known in advance. The third item is the maintenance of the support equipment whose maintenance is not dependent upon none of the measures above. Their maintenance is mostly performed time-based and on Base Air Ground Equipment (AGE) shop; but, there may be times that they need depot maintenance work.

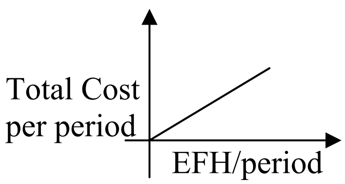

Figure 15: Engine Accessories

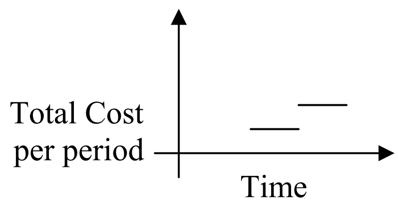

Figure 16: Support Equipment

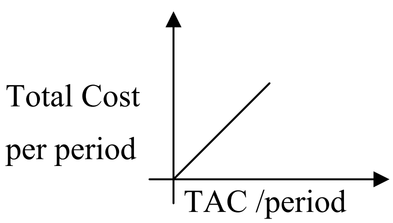

Figure 17: Engine

The Base is not responsible for the cost of repairs performed at the depot. These costs are funded by the Command (Sullivan: 2003b). Depot Cost may be found by multiplying the number of items sent to depot by the rate depot charges to repair those items in that period and summing for all the items needed depot maintenance as follows.

$$DMC = \sum_i ITNM_i * DCHG_i \qquad (26)$$

where

DMC = Depot Maintenance Cost
ITNM = Item i that required depot maintenance in the period
DCHG = Depot Charge for the item

Performing depots also keep track of these costs for their own analysis. For example, Depot Maintenance Cost System (DMCS) has existed since 1960s as the source for comprehensive production and cost information on DoD depot maintenance to answer depot maintenance questions-who, what, when, where, and how much (Steans & Applegate, 2002:Ch 1, 3).

4.3.4 Consumables Cost

This factor is basically the cost of consumable material used during the engine maintenance. This cost may also be examined in two groups: direct material cost such as nuts, bolts, washers and gaskets that you have to discard per Technical Order (T.O.) and indirect material cost like office supplies in the O-level and I-level engine shops. Direct materials are attributable to engine maintenance whereas the indirect materials are related to engine maintenance but not economically feasible to attribute to engine maintenance. Shops are going to consume direct materials only when they replace an item or perform a maintenance activity on engine; in other words, we cannot perform engine maintenance without having to use consumables. Therefore, consumables cost will have to be included into the model.

As it was discussed earlier in the chapter, as the flying hours increase, the base is more likely to have more sortie-generated failures and more time-change items both of which mean more replacements resulting in more use of consumables. Since the government already furnished the offices when the base was opened, those costs will be deemed as sunk cost. Therefore, the research will only include bits and pieces shops use as indirect material cost. Although these costs are not traceable to engine maintenance, they will be pooled into the consumables cost since they are consumed in the course of engine maintenance. Direct material cost will respond as will the Spares Cost. On the other hand, indirect material cost will be fixed across the engine flight hours until it increases so much. Due to the reasons discussed before, it may not necessarily start at zero because the replacements may be required even if there is no flight. These costs are currently tracked under General Support Division (GSD) of the Defense Working Capital Fund (DWCF) and can be extracted from several databases. On the other hand, relevant literature revealed that the cost of consumables discarded while replacing an item could be function of the unit price of that item. The rate and unit price could be gained from the contractors (OEM). As shown in Figure 18, these costs are represented in solid and dashed lines. Solid line represents direct material costs whereas the dashed lines represent indirect material cost behavior.

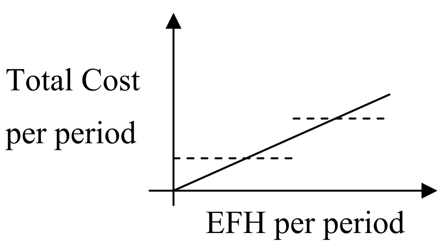

Figure 18: Consumables Cost

The can also be calculated as follows:

$$CONCST = INMAT + \sum_i (UP_i * CONRT_i) \tag{27}$$

where

CONCST	= Consumables Cost
INMAT	= Indirect Material Cost incurred in a period
UP	= Unit Price of item i
CONRT	= Consumables Rate for item i.

4.3.5 Support Equipment Maintenance Cost

Since majority of the support equipment used during engine maintenance is amortized over the years, this cost factor will constitute the cost to maintain common and peculiar support equipment. Common support equipment is the equipment that can also be used by the other specialists and peculiar support equipment is the one used only by engine maintenance personnel. This cost element constitutes the maintenance performed on support equipment, their alignment and calibration if required, and the expenses to replace parts on the support equipment.

The literature review revealed that some models only include the cost of replacing equipment; some others capture the procurement and maintenance of the support equipment as well under different cost elements' name. This research chooses to have only maintenance of the support equipment.

This maintenance cost is not actually driven by the number of flying hours, but if the flying hours increase radically, the base may have to purchase extra equipment to support the missions or AGE shop may have to perform increased maintenance, which would result in more expenses, due to the excessive usage resulting from increased failures. On the other hand, support equipment maintenance is based on days or a specific time. So, support equipment cost will respond to time differently.

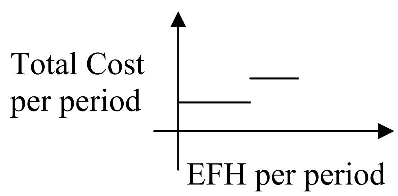

Figure 19: Support Equipment Cost Based on EFH

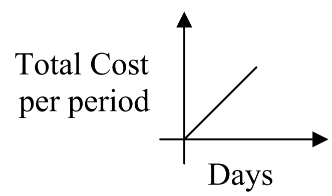

Figure 20: Support Equipment Cost Based on Time

The cost can be calculated as follows:

$$ASCST = [(TCSTSE \div TOpHRS) \times OpEM] + PMC \tag{28}$$

where

ASCST = The assigned portion of the cost of maintaining GSE

TCSTSE = Total cost of maintaining common support equipment in a period

TOpHRS = Total operating hours of GSE in a period

OpEM = Number of operating hours used on engine maintenance

PMC = Peculiar support equipment maintenance cost.

The allocation problem discussed in the Labor Cost will arise here, too. The research again chose to treat this cost element as fixed cost up to a certain number of flying hours. It is hard to keep track of operating hours of most of the support equipment, because they don't have a gauge on them.

4.3.6 Transportation Cost

This cost element is probably the most intriguing and complicated of all, because there are many uncontrollable factors that come into play while estimating the transportation cost. The literature review indicates that only a small portion of the models examined includes this cost factor. But this a true cost incurred by the Bases.

For example, a base has to send engines, DLRs, etc. for depot maintenance work. Therefore, transportation cost is an important factor in the Operation and Maintenance of aircraft engines. In order to send an item to anywhere, it should first be properly packaged in accordance with the properties of the item and management should have to decide on the means to transport the item and urgency of the delivery. So, an Air Force Base does incur packaging and shipping cost anytime an item calls for a trip to another maintenance facility. And, when the Base requires a part, there are several factors that should be considered. If it is a brand new item then transportation cost is included in the unit price as long as special delivery is not requested. Other than that, priority, Required Delivery Date (RDD), weight, destination, and availability are some of them. Property of the material is also very important. For example, hazardous materials and/or exceptionally heavy and big parts such as a propeller shaft cannot be shipped via commercial contractors. Because, they often require special means of handling and there are military regulations regarding those items.

There are several commercial contractors that provide transportation for DoD as well as Air Lift Command (ALC). Federal Express (FedEx), United Parcel Service (UPS), and DHL are some of those providing the service under Blanket Purchase Agreement, Guarantee Traffic contracts.

Basically bases must keep in mind these three questions while dealing with transportation cost: how fast do they want it? Which carrier they have contract with? And, what item is being carried? If they always use first priority shipment, their transportation cost will surely soar up. Although contractors have special rates for DoD there may be price differences between the contractors that will affect the cost.

This research follows the precedent that the cost will rise as the flying hours increase. More flying hours may result in increased number of sortie-generated failures that will cause more parts being sent to depot maintenance work. As stated earlier in the chapter, the frequency of the scheduled maintenance in a period will increase in addition to the number of time change items.

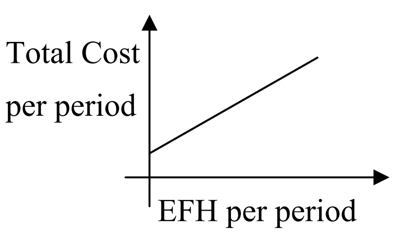

Figure 21: Transportation Cost

Transportation cost can be calculated as follows:

$$TRANCST = \sum_i (DISRATE * DIST)_i + (WTRATE * WT)_i + SCRG_i \qquad (29)$$

where

TRANCST = Transportation Cost.
DISRATE = Rate that the carrier charges per mile applied to priority.
WTRATE = Rate that the carrier charges per pound applied to priority.

DIST = Distance the part i carried.
WT = Weight of the part i.
SCRG = Any applicable special charge due to the property of the part i. (this may be a function of weight, unit price, distance)

4.3.7 Aviation Petroleum, Oil, Lubricants (AVPOL)

This cost element is comprised of the cost of fuel consumed during engine maintenance and the cost of engine oil consumed. For engine maintenance purposes we consume fuel during ground test runs to diagnose the discrepancy and to check if it is fixed later. There is also fuel consumed in the engine test cell, which is mostly used by JEIM personnel for various inspections performed on the engine, for example, a receiving check run whenever an engine enters the base's inventory. There will be fixed portion of this cost representing the fuel consumed during scheduled maintenance, test cell runs, etc. even if there is no flight. Increasing the number of flight hours in a period will probably cause more engine-related failures that subsequently require maintenance at least a ground check run to observe the failure on the ground. Engine also consumes a small amount of oil every flying hour. Therefore increasing flying hours will definitely increase the consumption of engine oil.

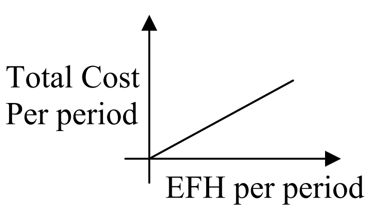

Figure 22: AVPOL Cost

The cost can be calculated as follows:

$$POLCST = \sum_i FCR * MHRS_i + OCR * EFH_i \tag{30}$$

where

POLCST = AVPOL Cost
FCR = Fuel Consumption Rate of the engine

OCR = Oil Consumption Rate in a flying hour (including JOAP sample)
EFH = Engine Flying Hour on period i
MHRS = Number of hours engine run for maintenance purposes on period i

4.3.8 Modification Cost

This cost element is generally used in the models estimating Operating and Support Cost of aircraft. Although the F-16's engine is matured over the years there may still be modifications needed in time. Modifications come in the form of Time Change Technical Orders (TCTOs). Some of these TCTOs can be applied using the resources such as manpower and supplies in the inventory, bases already have. But, others may require special kits or even skilled manpower to apply. This cost factor will be fixed until a TCTO arrives and such kits, if needed, are procured in a period. Therefore, it will follow a step function with regards to flying hours. Following the convention of existing models, this step function will be approximated by a linear function.

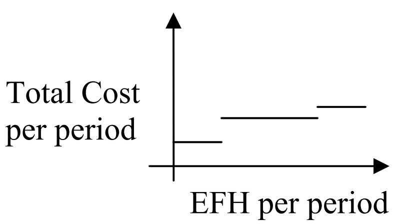

Figure 23: Modification Costs

And, the cost can be calculated as follows:

$$TMODCST = \sum_i ANUM_i * MODCST_i \qquad (31)$$

where

TMODCST = Total Modification Cost.
ANUM = Total Number of Aircraft that the modification i is applied in the period.
MODCST = The cost applying modification i.

4.3.9 Contractor Support Cost

This cost element is also not widely used in the models the research examined. But sometimes bases do need contract maintenance performed by commercial organizations using their personnel, material, equipment, facilities or government-furnished material, equipment, and facilities. In the Operating and Support Cost Estimating guide prepared by CAIG, two types of contractor support cost maintenance are discussed. First, Interim Contractor Support (ICS) cost which is the cost of labor, material, and assets used to provide temporary logistics support until government maintenance capability is developed. Second, Contractor Logistics Support (CLS) cost which is the cost of labor, material, and assets used to provide support to a weapon system (Department of Defense: 1992). CLS also covers Depot Maintenance and necessary O-level and I-level maintenance activities as negotiated between the parties. The maintenance of engine test cell, "Hush-House" exemplifies this cost element at Base level. Hush-House must be up and running all the time to support engine maintenance and when it breaks down Base calls for contractor support per agreement. The cost will be fixed until the facility breaks down.

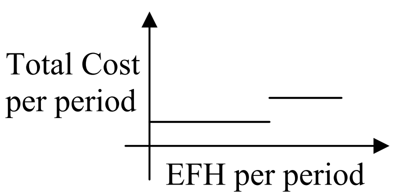

Figure 24: Contractor Support Cost

The cost can simply be calculated as follows:

$$TCSC = \sum_i CSC_i \tag{32}$$

where

TCSC = Total Contractor Support Cost.
CSC = The cost contractor charged per visit i.

4.4 Summary

In this chapter models in general are discussed first. Then, the three models used to deduce the cost elements and cost estimating relationships are described in detail.

Those three models were ACC Cost Model, USAFE Cost Model and Super Operating and Support Cost Model (SOSCM). SOSCM used linear approximation in the cost calculations whose strong and weak sides were also discussed in the chapter. We also benefited from the linear approximation in some of the cost calculations. And lastly, a list of the cost elements that are proposed to include into the model is provided in Appendix C.

V. Conclusions and Recommendations

5.1 Introduction

This chapter will present the results of the research. It will provide the answers to the research questions. Some recommendations for further study are also presented in this chapter. In the earlier chapters, it is first presented how the research observed the system by looking at the existing and previous models built in this area. Secondly, it formulated a mathematical model of the system and verified the model using expert opinion due to lack of sufficient data. Lastly, it presents recommendations. These are some of the important steps of operations research procedures.

5.2 Research Answers

1. <u>What uses are we going to get out of calculating the actual cost of engine maintenance per operating hour?</u>

As indicated several times in the research, shrinking Air Force budget in parallel with the DoD budget forced every unit to look at their expenses once again and see if they can operate and/or accomplish their missions at a lesser cost. In the wake of these developments, many cost reduction programs have emerged. If one of these cost reduction programs was applied to a weapon system that was perceived to have high operation and maintenance cost, which indeed have not, operation of the system might be handicapped because of the precautions resulted from the program. It is obvious that a good number of cost reduction precautions may cause serious safety deficiencies in the operation that in turn result in undesired accidents which may cause loss of system or personnel. Consequently, it is almost a life-and-death matter to know the true/actual operation and maintenance cost of a weapon system. Another gain may arise during the decision making process of whether or not the I-level and O-level maintenance should be contracted out to the Original Engine Manufacturer (OEM) by comparing the costs of these two alternatives.

2. <u>What are the current models in use?</u>

There are currently models in use to keep track of the engine maintenance expenses. Some major commands have models to perform this task plus to find a cost per engine flying hour metric. Examples include ACC Cost Model and USAFE Cost Model.

3. <u>How accurate and useful are the current models?</u>

The models mentioned above do not actually cover all of the costs associated with engine maintenance. However, they include most of the direct maintenance costs such as the parts and the fuel consumed. Cost estimating community does not seem to have reached a unanimous decision as to which cost factors to use for the calculation of cost per engine flying hour.

4. <u>What are the characteristics and assumptions of the current models?</u>

Current practices generally take into account some of the factors included in the Logistics Factors under USAF Cost and Planning Factors (AFI 65-503). These factors are primarily developed for use in the programming and budgeting process to increment and decrement the baseline program as a result of force structure changes (Air Force, 1994: A-2). Linear approximation assumption is also discussed in chapter 4.

5. <u>What are the primary causal factors in engine operating and support costs?</u>

The research indicated that the primary causal factors in engine operating and support costs are Labor, Spares, Depot Maintenance, and Transportation.

6. How should these factors be modeled?

Some of these costs are directly traceable to engine maintenance and easy to calculate whereas the cost allocation is required for the shared costs with aircraft the next higher assembly of the engine. There are many approaches to cost allocation. It is up to the analyst, and the needs and time determined for the study to choose on of these approaches. A recommended approach is described in chapter 4 with an explanation of each cost element.

7. Has there been a change in the major cost drivers of the previous models when compared to the new one?

Generically, cost factors have not changed for deterministic models. This phenomenon is also observed with the statistical models used to estimate cost. For example, cost factors developed by Birkler in 1982 are still used in a NASA cost model to estimate turbine engine cost. The only change is the use of JAVA and expanded database used for the model that increased degrees of freedom and thus fidelity of the model.

8. What would the characteristics and structure of an improved, accurate total cost model be?

First, such model should encompass all the cost elements associated with engine maintenance. Second, it should clearly distinguish the costs assigned engine maintenance from the costs assigned to the next higher assembly. In other words, shared costs must be allocated justly. Third, it should also differentiate the actual and budgeted costs. Last and the foremost is the assumptions made. They must be documented clearly for the future users. The operating and support guide prepared by CAIG explains the characteristics of a “good” model in detail (see Department Of Defense, 1992:Ch3, 13).

5.3 Recommendations for Future Study

There are several databases with overlapping data. The time and money spent to collect data for several databases and maintain them can be directed to building a unified database. Such database may have several sections or departments dedicated to special purposes and its access can be limited to that data’s users. For example, Depot Maintenance Costs may be covered under another section. Everyone should have access to the database in accordance with his or her job position. And, if you are an analyst or an auditor working for the Air Force, one should be able to roam freely in the database for analysis or inspection of the data. There is study started within the Air Force towards a unified database, but the research could not gather information on this study or its current situation.

The Air Staff is currently trying to find out the cost of engine maintenance throughout the Air Force. With a few adjustments to the cost estimating relationships and the unified database, this can be achieved. Since it is known that there is no such database yet, serious data mining can be required to gather the data for all the Air Force units.

If the data was accessible, a predictive model could have been developed. So, an analyst with the clearance to access data can develop such a model.

It is indicated in the research that some of the expenses are not paid out of the base’s budget. If it is aimed to find the physical money per se spent to maintain base owned engines, this can easily be achieved by eliminating the expenses made by the

Command, Air Force, DoD, or Government. At any rate, these are the costs incurred to maintain engines at all.

Maintainers tend to avoid entering data into the computer system. They spend lots of hours on the job though it seems harder to enter data into the computer in ten minutes. And, the management always reprimands them for doing so. Because they have to enter How Malfunctioned Codes, When Discovered Codes, etc., which they believe, are not used for anything. Then it becomes difficult to trust in the data collected this way. If the number of entries per maintenance action is reduced and the personnel entering the data are convinced that the data is used for some serious analysis towards effectiveness of the system, they can be more willing to cooperate and care to enter the true data.

Cost allocation, as discussed throughout the research, is playing an essential part in cost estimation of any sort. If the assigning of indirect costs to cost objects becomes a growing necessity for the Air Force, the techniques discussed briefly in the literature review can be applied in a future study in the allocation of such costs. A study must be conducted to determine the effect of the straight-line model assumption with respect to the true cost (step) functions.

5.4 Summary

This research attempted to build an engine cost model that could accomplish true cost estimation. It also examined the current practices. This archival study gained us the necessary insight into the issue. The objective was to estimate the cost of engine maintenance performed on Base/Wing level. Determining the scope of the subject to a specific level is particularly important since the concepts of direct and indirect costs, variable and fixed costs may vary in accordance with this selection of the level maintenance is being performed. Therefore, this research scopes the issue at the beginning to Base/Wing level. After that, the cost elements and their in depth explanations are provided with a way to calculate them and a way to gather the this data as much as possible. The research concluded with a number of recommendations and observations for the possible future studies.

The cost estimation processes has become a crucial part of any institution trying to survive in our competitive global economy. The DoD faces this dilemma: because of spending so much on personnel, operations, and support costs, they cannot buy new weapon systems. On the other hand, it is impossible to operate those new weapon systems without the trained personnel and the maintenance support. The issues such as cost estimation, cost reduction programs, cost of personnel, cost comparison and cost effectiveness of a weapon system will always be in the agenda of the Air Force as well as the DoD from now on through the 21st. century.

Appendix A: AFI 65-503 US Air Force Cost and Planning Factors

1. **LOGISTICS FACTORS**
   - 1.1 LOGISTICS COST FACTORS
   - 1.2 CONTRACTOR LOGISTICS SUPPORT
   - 1.3 UNIT FLYAWAY COSTS
   - 1.4 MUNITIONS ACQUISITION COSTS
   - 1.5 MUNITIONS TRAINING COSTS
   - 1.6 AVIATION FUEL FACTORS AND PRICES
   - 1.7 GROUND VEHICLE O&M COSTS
   - 1.8 AIRCRAFT REIMBURSEMENT RATES
   - 1.9 TUITION RATE FACTORS

2. **PERSONNEL FACTORS**
   - 2.1 TYPICAL ACQUISITION AND TRAINING COSTS
   - 2.2 ENLISTED/OFFICER PERSONNEL ACQUISITION COST PER GRADUATE BY AIR FORCE SPECIALTY CODE
   - 2.3 STANDARD COMPOSITE RATES BY GRADE
   - 2.4 MILITARY PAY RATES PER UNIT OF TIME
   - 2.5 MILITARY PAY RATES BY FLYING STATUS/LOCATION
   - 2.6 ANG/AGR COMPOSITE PAY FACTORS/TURNOVER RATES
   - 2.7 AFRES COMPOSITE PAY FACTORS/TURNOVER RATES
   - 2.8 PCS COST PER MOVE
   - 2.9 PCS COST PER WORK-YEAR
   - 2.10 CIVILIAN STANDARD COMPOSITE PAY RATES, BY GRADE
   - 2.11 CIVILIAN STANDARD COMPOSITE PAY RATES, MAJOR CATEGORIES
   - 2.12 CIVILIAN STANDARD COMPOSITE PAY RATES, BY MAJCOM/FOA
   - 2.13 DEPENDENTS PER MILITARY SPONSOR
   - 2.14 RETIREMENT AND OTHER PERSONNEL BENEFITS ACCELERATION FACTORS
   - 2.15 APPLICATION OF CIVILIAN BASE PAY ACCELERATION FACTORS
   - 2.16 APPLICATION OF MILITARY STANDARD COMPOSITE RATE ACCELERATION FACTORS
   - 2.17 FASCAP MILITARY PAY AND BENEFIT FACTORS
   - 2.18 REPRESENTATIVE OFFICER AIRCREW TRAINING COSTS
   - 2.19 REPRESENTATIVE ENLISTED AIRCREW TRAINING COSTS

Appendix A1: AFI 65-503 US Air Force Cost and Planning Factors

3. **PROGRAMMING FACTORS**
   - 3.1 AUTHORIZED AIRCREW COMPOSITION (ACTIVE/GUARD/RESERVE)
   - 3.2 AIRCRAFT/MISSILE FACTORS- ACTIVE
   - 3.3 AIRCRAFT PROGRAM FACTORS- (GUARD/RESERVE)
   - 3.4 TYPICAL AIRCRAFT SQUADRON STRENGTHS (ACTIVE/GUARD/RESERVE)

4. **INFLATION FACTORS**
   - 4.1 USAF RAW INFLATION INDICES
   - 4.2 USAF WEIGHTED INFLATION INDICES
   - 4.3 OSD OUTLAY RATES
   - 4.4 HISTORICAL AIRCRAFT INFLATION INDICES

5. **ATTRITION FACTORS**
   - 5.1 ATTRITION DATA/ESTIMATED AIRCRAFT LOSSES
   - 5.2 AIR PEACE ATTRITION LOSS FLYING HOUR LEVELS
   - 5.3 AVERAGE ATTRITION RATES USAF/GUARD/RESERVE

Appendix B: CAIG's Generic O&S Cost Element Structure

1. **MISSION PERSONNEL**
    - 1.1 OPERATIONS
    - 1.2 MAINTENANCE
    - 1.3 OTHER MISSION PERSONNEL

2. **UNIT-LEVEL CONSUMPTION**
    - 2.1 POL/ENERGY CONSUMPTION
    - 2.2 CONSUMABLE MATERIAL/REPAIR PARTS
    - 2.3 DEPOT-LEVEL REPARABLES
    - 2.4 TRAINING MUNITIONS/EXPENDABLE STORES
    - 2.5 OTHER

3. **INTERMEDIATE MAINTENANCE (EXTERNAL TO UNIT)**
    - 3.1 MAINTENANCE
    - 3.2 CONSUMABLE MATERIAL/REPAIR PARTS
    - 3.3 OTHER

4. **DEPOT MAINTENANCE**
    - 4.1 OVERHAUL/REWORK
    - 4.2 OTHER

5. **CONTRACTOR SUPPORT**
    - 5.1 INTERIM CONTRACTOR SUPPORT
    - 5.2 CONTRACTOR LOGISTICS SUPPORT
    - 5.3 OTHER

6. **SUSTAINING SUPPORT**
    - 6.1 SUPPORT EQUIPMENT REPLACEMENT
    - 6.2 MODIFICATION KIT PROCUREMENT/INSTALLATION
    - 6.3 OTHER RECURRING INVESTMENT
    - 6.4 SUSTAINING ENGINEERING SUPPORT
    - 6.5 SOFTWARE MAINTENANCE SUPPORT
    - 6.6 SIMULATOR OPERATIONS
    - 6.7 OTHER

7. **INDIRECT SUPPORT**
    - 7.1 PERSONNEL SUPPORT
    - 7.2 INSTALLATION SUPPORT

Appendix C: Summary of Cost Elements for a Base Level Model

1. **LABOR COST**
   1.1 Direct Labor Cost
   1.2 Indirect Labor Cost

2. **SPARES COST**
   2.1 Cost of LRUs, SRUs Repaired on Base
   2.2 Cost of LRUs, SRUs Condemned

3. **DEPOT MAINTENANCE COST**
   3.1 Cost of Engine Overhaul
   3.2 Cost of Engine Accessories Overhaul
   3.3 Cost of Support Equipment Overhaul
   3.4 Cost of Repair DLRs
   3.5 Cost of Repair NRTSed items

4. **CONSUMABLES (MATERIAL) COST**
   4.1 Direct Material Cost
   4.2 Indirect Material Cost

5. **SUPPORT EQUIPMENT COST**
   5.1 Maintenance "upkeep" Cost of SE

6. **TRANSPORTATION COST**
   6.1 Packaging and Shipment Cost of Engine
   6.2 Packaging and Shipment Cost of Spares

7. **AVPOL**
   7.1 Cost of Fuel
   7.2 Cost of Engine Oil

8. **MODIFICATION COST**

9. **CONTRACTOR SUPPORT COST**

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Vita

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14. ABSTRACT

The cost of military operations has been difficult to determine, yet considered of high importance. The cost of an operation is largely dependant upon the answers to subordinate questions involving the discrete costs of military activities, like supporting individual items. While different cost estimates for various programs have received attention from the media, the question arises as to how accurate these figures are. This research deals with the true representation of cost, in particular true cost of engine maintenance. In order to reach that goal, the thesis effort aimed to first look at the archival methods and models used to prepare cost estimations for a weapon system or a task performed in the Air Force. Four analytical steps helped to come up with the cost elements that should go into the "actual" total cost of engine maintenance at the Base or Wing Level. The research provides detailed definitions of these consolidated elements and the relationships between them.

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