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# A Service Life Analysis of Coast Guard C-130 Aircraft

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**A SERVICE LIFE ANALYSIS OF**

**U.S. COAST GUARD C-130 AIRCRAFT**

THESIS

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AFIT/GAQ/ENS/03-02

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# U.S. COAST GUARD C-130 AIRCRAFT

THESIS

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Jonathan B. Duff

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## Abstract

The U. S. Coast Guard, much like the rest of the Armed Services, is facing a dramatic transformation of its forces to meet current and future service requirements. The Coast Guard has responded to this transformation by initiating the Deepwater System, a complete review of the offshore mission requirements and the modernization of its infrastructure. In particular, Deepwater will review and modernize the Coast Guard's aviation assets, improving aircraft systems, airborne sensors, and communications and information management systems. However, these capability advancements will take time and money to implement, and will require careful management of the current resources to ensure a smooth transition.

One of the oldest and most versatile Coast Guard aircraft is the C-130, which the Coast Guard uses for Long Range Surveillance missions (LRS), as well as for logistics transport. Service life decisions regarding the C-130 are complicated by aging aircraft issues, and the forced introduction of a new generation C-130. It will be difficult for Coast Guard decision makers to select how program funding should be executed within the C-130 fleet. This study examines how long the current airframes can safely remain in service, how much the remaining service life will cost, and what level of availability can be realized for the rest of the service life. Once these questions can be reasonably answered, it will then be possible to perform an insightful and justifiable analysis of alternatives for modernizing, sustaining, and if necessary retiring the C-130s.

# A SERVICE LIFE ANALYSIS OF

# U.S. COAST GUARD C-130 AIRCRAFT

## Chapter 1. Introduction

The U. S. Coast Guard, much like the rest of the Armed Services, is facing a dramatic transformation of its forces to meet current and future service requirements. Emerging technologies, integrated information systems and improved operational methods present numerous opportunities for enhancing the U. S. Coast Guard's effectiveness and efficiency. However, these capability advancements will take time and money to implement, and will require careful management of the current resources to ensure a smooth transition. As Admiral Loy pointed out, while discussing the modernization and transformation of equipment in his State of the Coast Guard address on March 22, 2001,

> Our great challenge is to maintain our balance through the course of these two fundamental dynamics – phasing out the old platforms, systems, and processes while developing and phasing in the new – so that we continue to deliver results for America as we live through this transformation. (Loy, 2001)

For many years the Coast Guard has been considering how and when to replace much of its aging maritime fleet. In 1998, the Integrated Deepwater System Program (IDS) was formally recognized as the method for examining the current and future offshore mission requirements (Deepwater News, September 2001). Offshore requirements are defined as the Coast Guard's operational missions that require assets to operate more than 50 nautical miles from the shoreline. Under IDS, the Coast Guard solicited contractor teams to propose the future offshore requirements, and determine the appropriate systems that would fulfill these requirements. The goal of IDS was to select an industry team that would update and improve the current capabilities of the Coast Guard's ships, aircraft, and Command and Control infrastructure. This capability upgrade is required to combine the ships, aircraft, sensors, communications equipment and logistics infrastructure into a complete system. Fully integrating this system of assets, through enhanced interoperability, information connectivity and improved logistical support, will greatly improve the Coast Guard's ability to perform its mission. (Deepwater News, September 2001). On June 23rd, 2002 the Deepwater contract was awarded to Integrated Coast Guard Systems, a cooperative industry team captained by Lockheed Martin, and Northrop Grumman. (Deepwater News, July 2002)

There is no question that the Deepwater transformation will require a large investment of the Coast Guard's available funding, and will also place a great strain upon the funding for the support of its current assets. This presents a problem for Coast Guard decision makers, requiring them to select an optimal implementation method for this transformation. The legacy assets in the inventory must be judiciously utilized, and in some cases enhanced, so that they better integrate with the advanced systems that meet the new requirements.

Coast Guard aviation, in particular, will be an area of significant transformation. Improved aircraft systems, airborne sensors, and communications and information management systems will be prime areas for applying the very latest that technology has to offer, particularly as the oldest aviation resources are modernized. One of the oldest and most versatile Coast Guard aircraft is the C-130, which the Coast Guard uses for Long Range Surveillance missions (LRS), as well as for logistics transport. However, aging aircraft complications, and the forced introduction of a new generation C-130, will make it difficult for Coast Guard decision makers to select how program funding should be executed within the C-130 fleet.

With 27 C-130s currently being utilized, it is envisioned that they will remain in service for the foreseeable future. However, these aircraft are far from brand new, and may require significant modernization in order to continue their service at the current levels. With the 1500 series aircraft purchased in the early 1970s, and the 1700 series aircraft purchased in the mid to late 1980s, the average Coast Guard C-130 is approximately 20 years old. This is significant because many of the current aircraft systems are experiencing an increased failure rate. Flight instruments, radars, propeller assemblies, and many other system components are simply reaching the end of their anticipated service life, and their corresponding reliabilities are decreasing (Boubolis, 2001). Combining this reliability decrease with the issue of evolving technology, many systems become increasingly difficult to support. Manufacturers and repair facilities are often forced by economic pressure to eliminate, reduce, or charge much higher premiums for product support of older systems that contain dated technology (Boubolis, 2001). The end result for the Coast Guard is aircraft systems that fail more frequently and become more challenging to sustain.

The latest generation of C-130s, the "J" model, is a technological leap forward with its glass cockpit design, digital engine controls, automated systems and improved overall performance. However, the purchase price is somewhat restrictive for the Coast Guard, who cannot fund a complete fleet replacement at this time with their limited annual budget (Dwyer, 2001). Despite the fact that the Coast Guard did not originate this request, Congress has included the purchase of six C-130Js into the Coast Guard's FY 2002 budget (FDCH Press Release, 5/17/2000). The arrival of six C-130Js will create many difficulties within the current Logistics and Operational framework, as the aircraft is a significant departure from the previous C-130 variants. Maintaining and operating such a small number of nonconforming airframes will be a challenge for the men and women of the Coast Guard.

All of these issues must be dealt with, and informed decisions are required to determine where C-130 funding should be directed. Before this can happen, there needs to be a firm understanding of the status of the current airframes. For the 1500 and 1700 series C-130s, it is important to understand how long the airframes can safely remain in service, how much the remaining service life will cost, and what level of availability can be realized for the rest of the service life. Once these questions can be reasonably answered, an insightful and justifiable analysis of alternatives can be performed for modernizing, sustaining, and if necessary retiring the C-130s.

**Problem Statement**

The C-130 Program Managers are faced with selecting between many options for extending and improving the capabilities of the C-130 fleet in order to meet current and projected operational requirements. With the advanced age of the current Coast Guard C-130 fleet, and the assumption that C-130s will continue to be utilized, it will be highly beneficial to formulate predictions for the increased maintenance costs and Service Life Extension Programs (SLEP) throughout the remainder of its service life.

## Research Focus

This study examines the current status of the Coast Guard C-130s and provides a method for predicting the service life costs for the next 20 years. This research also establishes a prediction for the aircraft availability over the next 20 years. By establishing a reasonable assessment of cost and availability, it is assumed that program managers can make better decisions regarding modernization and retirement of C-130 airframes.

## Methodology

A spreadsheet model, incorporating historical data, cost estimates, and simulation, has been selected as the method for evaluating the cost and availability measures. Utilizing Monte Carlo simulation within Crystal Ball©, the uncertainty within the data will be represented as theoretical probability distributions, and an appropriate number of calculations will be performed to reveal an approximate distribution of the cost and availability measures (Crystal Ball, 1996). Based upon the statistical confidence of the resultant values, it will be possible to gain added insight into the expectations for how much the C-130s 20 year service life will cost, and what the aircraft availability will be during this period. It also provides the decision makers with information that increases their understanding of the interaction between service life cost and future aircraft availability.

## Review of Chapters

Chapter 2 presents the literature research conducted in the process of framing the identified problem. It covers the issues of aging aircraft, and how this relates to the Coast Guard's C-130 fleet. Chapter 2 also discusses the applicability of simulation techniques when costs and availability are uncertain. Chapter 3 explores the employment of spreadsheet models and simulation techniques for analyzing the various options presented to Coast Guard C-130 program managers. The spreadsheet model used in this study is also presented. Chapter 4 discusses the process that was followed to create the spreadsheet model as well as the results of the spreadsheet model. Chapter 5 discusses the conclusions of this research and provides recommendations for future study.

## Chapter 2. Literature Review

### Introduction

This chapter provides a brief examination of the background information that clarifies the scope of the problem as stated in Chapter 1. First it presents a summary of the more important aging aircraft issues, and how these may influence the cost and availability of an aircraft system. Next, the status of the Coast Guard C-130 fleet is examined with respect to age, where it will be apparent that aging aircraft issues are significant cost and availability considerations. From there, a brief overview of Life Cycle Costs is presented along with methods used for capturing these costs. This chapter also introduces key concepts for modeling aircraft availability. The chapter concludes with a discussion of Monte Carlo techniques for predicting outcomes under conditions of uncertainty.

### Aging Aircraft Issues

In every sector of aviation, aircraft fleets are being operated up to and beyond their designed service lives. In the U.S. Air Force alone, several aircraft are already operating beyond 35 years of service, and are expected to remain an active part of the inventory for at least another 25 years (NRC, 1997:23). The advanced age of these aircraft brings about new challenges for operators, maintainers and logisticians as they attempt to maintain the system's capabilities well beyond the original designer's specifications.

The strategy of retaining aircraft beyond their initial service life estimate reduces the costs of recurring procurement. This strategy is often employed within the DoD as an effort to control costs in a restrictive budget environment. However, it also results in higher support costs as the aircraft age (Pyles, 1999:1). Figure 1 presents the historical data on the KC-135, 727, 737, DC-9, and DC-10 heavy maintenance workload. It shows a workload increase from five to nine times over a 40 year period when compared to the first heavy maintenance inspection (Pyles, 1999:2). While increasing costs cannot be completely avoided, a thorough understanding of aging aircraft concerns will make it possible to at least minimize the growth of these costs (Pyles, 1999:6).

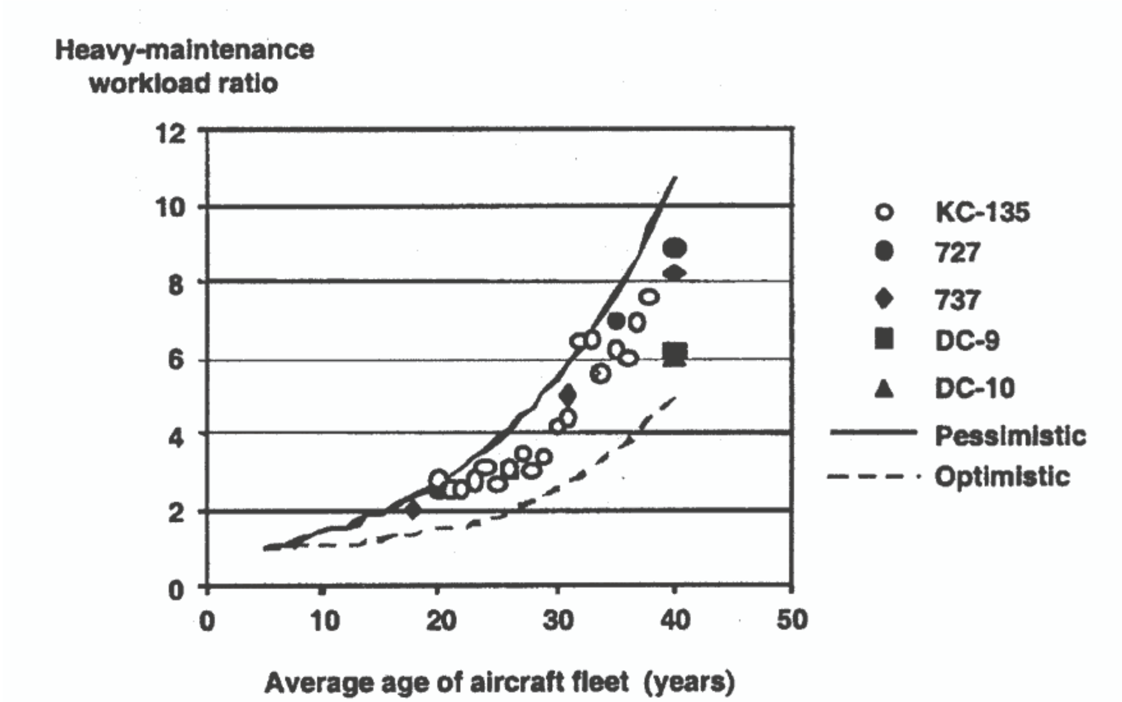



**Figure 1. Heavy-Maintenance Workload (Pyles, 1999)**

> The economic burden associated with the inspection and repair of fatigue cracks can be expected to increase with age until the task of maintaining aircraft safety could become so overwhelming and the aircraft availability so poor that the continued operation of the aircraft is no longer viable. In addition, corrosion detection, repair, and component replacement can add significantly to or, in some cases, dominate the total structural maintenance burden. (NRC, 1997)

The issue of aging aircraft must also examine the safety concerns of operating an aircraft with unknown or undetected damage, and ensuring that any damage is detected before it can lead to a catastrophic failure. The initial damage tolerance designed into an aircraft slowly deteriorates as the aircraft is operated, and can vastly complicate the failure modes of the various aircraft components (Swift, 1993:6). Utilizing various analysis techniques, structural modeling, and the most current inspection procedures, it is expected that any damage can be located and repaired well before it reaches a critical safety limit. There must also be a renewed emphasis on preventing damage. This can be accomplished through careful monitoring of the aircraft's systems, imposing operating limits, or initiating preventive maintenance practices at the appropriate times.

**Fatigue**

One of the most significant elements of aging aircraft is the influence of fatigue upon the aircraft structure, and the impact this has on the overall service life. Fatigue cracking is the appearance of cracks in the structural material as a result of repeated stress cycles. It is directly attributable to aircraft use, and therefore can only be avoided if the aircraft is removed from service. As an aircraft ages, fatigue cracking will become more prevalent in critical structural areas. This requires frequent inspections, repairs and possibly modifications. If this fatigue cracking is not corrected, or if it is not detected, it can lead to widespread fatigue damage. Widespread fatigue damage signals that the cumulative effect of the fatigue at each discrete location is serious enough to compromise the safety of the aircraft (NRC, 1997:29-30).

> It is difficult for the layman to appreciate the consequences of extremely small cracks of less than detectable size because aircraft have been able to sustain much larger cracks in the past. However, these extremely small cracks, which develop and become widespread with extended use of the aircraft, have the ability to drastically reduce this large crack residual strength capability which is expected to exist. (Swift, 1993:6)

The onset of widespread fatigue damage is typically difficult to predict, and therefore it is difficult to plan corrective maintenance actions (Swift, 1993:4). However, since it must be dealt with when it occurs, it will either require major structural repair, or retirement of the airframe. If it were possible to predict the occurrence of fatigue damage, there would be tremendous opportunity for maintenance cost savings. The corrective maintenance actions could be scheduled at the earliest onset of fatigue damage, while the repair costs are at their lowest, and the logistical support could be manipulated to anticipate the corrective measures. There are many innovative methods being developed for detecting fatigue cracks, even in inaccessible areas, that will facilitate repair at a very early stage. These Non-Destructive Inspection (NDI) techniques allow a detailed examination of the structural components, and many are being adapted for use on the aircraft. Performing this type of inspection on an aircraft, vice in a maintenance shop, eliminates the costly practice of removing and disassembling components for NDI analysis in a laboratory environment.

### Corrosion

A second area of great concern for aging aircraft is the impact of corrosion on an aircraft's service life. Corrosion is a very time-consuming and expensive maintenance problem for all of the military services, as well as civilian aircraft operators. The presence of contaminants or a corrosive operating environment can setup the corrosion process on any exposed metallic surface. If an electrolyte is present, corrosion can even occur at the grain boundaries within the metal itself (Intergranular corrosion). Much like fatigue cracks, corrosion can be difficult, or even impossible to detect by a visual inspection without significant component disassembly. It is present in some stage in all aircraft, and if left untreated, can require significant investment of man-hours to remove the corrosion and repair the affected areas. Severe corrosion damage can also significantly weaken the load bearing strength of a material, causing premature failure (NRC, 1997:27-28).

For many years NASA, DoD, commercial aircraft manufacturers and commercial aircraft operators have been extremely interested in preventing, and reducing, the impact corrosion has on aircraft maintenance costs. Some of the proven techniques for battling corrosion include: application of Corrosion Preventive Compounds (CPCs), improved protective coatings, dehumidifying storage aircraft, and corrosion mapping (NRC, 1997:27). A review of the documents presented at the Second Joint NASA/FAA/DoD Conference on Aging Aircraft indicates that corrosion detection techniques are also receiving a great deal of attention from researchers, and continue to make advances for improving early detection of corrosion damage (NASA, 1999). Early detection of corrosion, much like early detection of fatigue cracks, simplifies the corrective maintenance, and significantly reduces the maintenance costs (NRC, 1997:27-28). Some of the latest corrosion detection technologies include: thermography, magneto-optical imaging- eddy current, ultrasonics, and radiography (Hoppe, 3). Corrosion concerns should not ultimately limit the structural life of operational aircraft, but there will always be a cost for corrosion control, and it will generally increase as an aircraft ages (NRC, 1997:27).

Corrosion can also interact with residual tensile stresses from the material manufacturing process or operational fatigue stress, and can lead to stress corrosion cracks. Fortunately stress corrosion cracks are a well-documented phenomenon, and can be mediated, although not prevented by improved design, manufacturing and maintenance practices (NRC, 1997:29).

#### Wiring

A third aging aircraft concern is the status of an aircraft's wiring. Wiring is an often-overlooked component in an aircraft because when it is working, it requires very little maintenance. However, when wiring does fail, its complexity makes it difficult to troubleshoot because it can be hard to access, and many repairs do not return the system to 'like new' status (McMahon et al, 2002). Aircraft wiring is susceptible to aging through deterioration of the insulation, corrosion at the connectors, stress and fatigue, and also damage incurred from the wear and tear of maintenance (McMahon et al., 2002). Aromatic Polymide wiring insulation (DuPont trade name Kapton) is a particularly unsatisfactory wire type because a damaged wire can arc across an entire wire bundle, causing widespread system failure, and potentially starting an aircraft fire (McMahon et al., 2002). Aromatic Polymide wiring insulation can be found in approximately half of the commercial aircraft in service and has been a popular wiring type for the military due to its weight and performance characteristics (McMahon et al., 2002).

#### Modernization

The current pace of technology advancement gives a great advantage to organizations that can apply new technology quickly. However, for many DoD systems, this agility is not yet realized, and introduces the issue of technology lag. Aircraft avionics in particular suffer from not keeping pace with exponential technology growth as new systems are incorporated out of the necessity for improved component reliability, or in response to new requirements. By the time the avionics system is in full rate production, many of its subcomponents may already be one or two generations older than the latest technology (Connor et al., 1999:3). Therefore in this context, modernization issues can be described as the issues that affect a program's ability to incorporate the latest technologies into the aircraft system.

Within modernization, there is the further complication of system compatibility, because any component modernization upgrades can significantly affect the structure and integration of an aircraft's sub-systems. Once again, avionics provide a classic example. Modern electronics have very tight power requirements, specific cooling requirements, and incorporate high-speed data buses for sharing information. These technologically advanced components often do not react well when power surges are passed through the older power distribution systems, or when their cooling requirements are not met (Connor et al., 1999:4). If these issues are not resolved through testing and evaluation, the advanced systems will become a liability for the maintenance and logistical support systems.

### Obsolescence

Another concern for aging aircraft is the issue of system, or component obsolescence. For the purposes of this discussion, the term obsolete will be used to describe a component, part, or system that is no longer manufactured, or is approaching the end of its production. "Simply put, obsolescence occurs when you can no longer obtain piece parts to repair a system" (Eady & White, 2002). Typically aging aircraft are replete with these obsolete systems and technologies.

> Production obsolescence for uniquely military components may drive up costs even further. In general, the declining market for military aircraft and related materials has combined with the rapid technological advances of the past few decades to make production of many older military components unprofitable, thereby causing vendors to leave the marketplace entirely. Some older components simply cannot be manufactured any longer. Functionally equivalent replacement components must be designed, tested, and produced at considerably higher costs than the originals. (Pyles, 1999:5)

When resolving the dilemma of these obsolete items, there are several options: identifying alternative sources, substitution with a different version, making engineering changes to a substitute, a Life-of-type (LOT) buy to satisfy the remaining host systems life requirements, remanufacturing, emulation, or redesign of the item (Day and Lansdowne, 1993). Each of these strategies carries risks for success, and selecting among them will depend primarily upon the number of years the system is projected to remain in service, the quantity of items required, and the system performance requirements.

### Mission Requirements

As each airframe type is retained beyond the initial service life estimates, it will need to adapt to the latest mission requirements (Ostgaard et al., 2000:4-2). Examples would include the modification of the Navy's F-14s to carry ground attack ordinance, or the incorporation of defensive threat warning systems and countermeasures into various transport aircraft types. Since these requirements were not part of the original design, they must be tailored within the constraints of the aircraft using them (Ostgaard et al., 2000:2-4). However, if the original design applied open system architecture, then the modernization of the aircraft could be greatly simplified. Unfortunately, most of the aged aircraft in the U.S. military fleet were designed for specific purposes, responding to specific mission needs. Repeatedly adapting these aircraft to the current mission requirement will be costly and must address compatibility concerns with each upgrade (Ostgaard et al., 2000:4-3).

**Aging Aircraft Summary**

Aging aircraft will be expensive and will present numerous challenges to the operators, maintainers and logisticians who are tasked with supporting these assets. Therefore it would be highly advisable to establish a method for managing these assets. Enloe makes a good argument for applying systems engineering principles to aging aircraft issues. "The systems engineering approach, applied to the weapon system (including the support infrastructure), provides a method of determining and obtaining total system objectives." (Enloe, 1999:39). There will always be risks associated with unexpected and unplanned future events, but by systematically examining the aircraft's status, the current system requirements, and the projected requirements, it should be possible to enhance the value of these aged airframes and intervene before support costs become unmanageable (Enloe, 1999:44). Conversely, there needs to be contingency plans for circumstances that cannot be controlled. Finally, there is a need for an economic service life estimation model that incorporates the operating cost elements expected throughout the remaining service life, and clarifies the timetable for sustainment and ultimate retirement (NRC, 1997:45).

**Coast Guard C-130 status:**

Table 1 presents the status of U.S. Coast Guard C-130 aircraft with respect to age. The data is also presented in Figure 2 to better depict the ages of the current aircraft.

**Table 1 U.S. Coast Guard C-130 aircraft status (November 2002)**

| Tail Number | Aircraft Hours | Year Delivered | Tail Number | Aircraft Hours | Year Delivered |
|---|---|---|---|---|---|
| 1500 | 19818 | 1973 | 1709 | 15291 | 1984 |
| 1501 | 20368 | 1973 | 1710 | 12725 | 1984 |
| 1502 | 17757 | 1973 | 1711 | 12692 | 1984 |
| 1503 | 20864 | 1974 | 1712 | 12531 | 1985 |
| 1504 | 20907 | 1974 | 1713 | 12410 | 1985 |
| 1700 | 14798 | 1983 | 1714 | 13735 | 1985 |
| 1701 | 13220 | 1983 | 1715 | 13345 | 1985 |
| 1702 | 15191 | 1983 | 1716 | 12258 | 1985 |
| 1703 | 16633 | 1983 | 1790 | 15198 | 1985 |
| 1704 | 15189 | 1983 | 1717 | 12338 | 1987 |
| 1705 | 14551 | 1983 | 1718 | 11395 | 1987 |
| 1706 | 14321 | 1984 | 1719 | 12168 | 1988 |
| 1707 | 14576 | 1984 | 1720 | 11480 | 1988 |
| 1708 | 14202 | 1984 | | | |

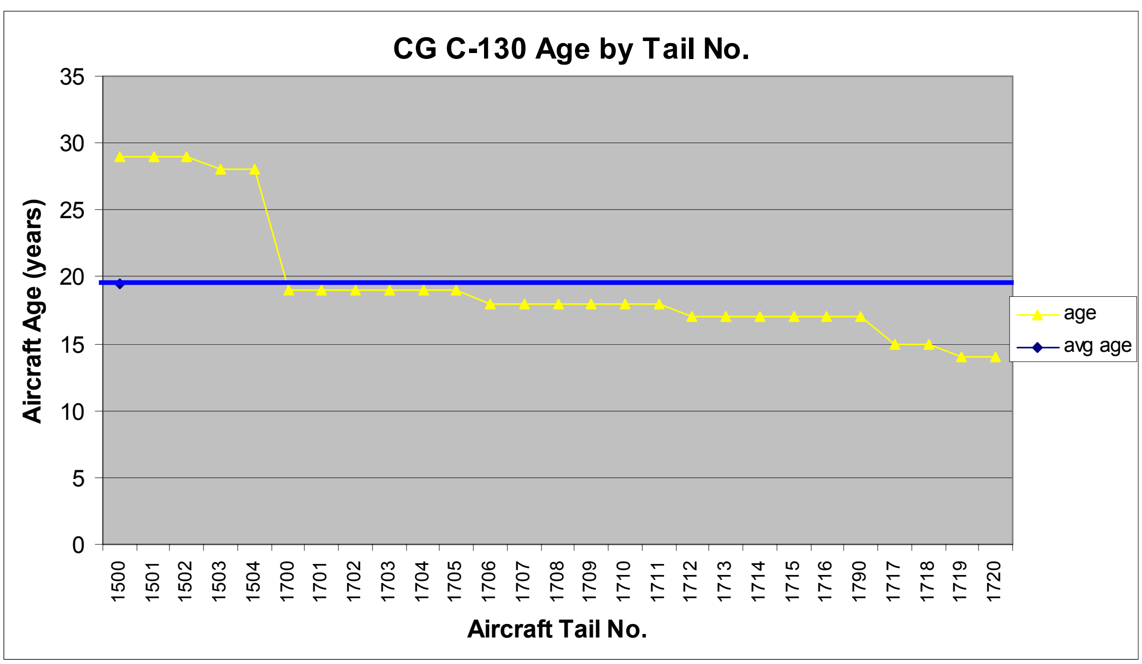



**Figure 2. Coast Guard C-130 aircraft age (2002)**

While the majority of the fleet is less than 20 years old, with a current average age of 19.4 years, as a whole the Coast Guard C-130 fleet will soon begin to experience significant age related difficulties. Examining Figure 2, it is readily apparent that a majority of the C-130 fleet will be reaching their 20-year design service life within the next 4 years. Since the aircraft were purchased in lots, in consecutive years, there is significant risk that any age related issues will become evident across the majority of the fleet, at approximately the same time. Responding to this type of universal fleet dilemma, while meeting aircraft availability requirements, will be very challenging for maintenance and program directors. Additionally, since the fleet size is relatively small, any age related events in just a few aircraft can have serious availability and cost consequences for the entire aircraft program. In light of this situation, it is imperative that all C-130 aircraft be properly monitored for any emerging trends that will affect availability, and Operations & Support (O & S) costs.

In 1996, an independent contractor, CAE, based out of Edmonton, Canada, was commissioned to perform a structural life extension engineering study of Coast Guard C-130 aircraft. This study first examined the methods for calculating the severity of Coast Guard operations. The calculated severity factors, which normalize aircraft with different basing and operational histories, allow the analysis of aggregated aircraft data. This is an important issue because no two aircraft have an identical history. The study then presented summaries from the inspection of three representative aircraft from various Air Stations. With this information, the analysis team was able to evaluate the effectiveness of the Programmed Depot Maintenance (PDM), and the corrosion control program.  The report also presented potential structural refurbishment program options, as well as recommendations that would allow the airframes to be operated up to a 40 year service life (CAE, 1997).

The preferred option presented within the recommendations section of the CAE study involved the implementation of limited structural upgrades, and an improvement of maintenance effectiveness.  This was to be accomplished through maintenance practices at the unit level that increased the level of detailed structural inspections, improved corrosion prevention practices, and updated maintenance data capture programs. Combining this with recommended improvements in the PDM process, and a structural refurbishment program, CAE estimated that the Coast Guard C-130 aircraft could be operated until reaching 40-50 years of service.  It was predicted that a failure to implement these recommendations, and continuing with the pre 1996 maintenance practices, would result in adverse consequences at the 10-year mark and beyond.  These consequences would include a rapid escalation of overall maintenance costs, and a corresponding decrease in aircraft operational availability (CAE, 1997).

**Life Cycle Cost Summary**

The life cycle of any system is defined as the entire sequence of activities that commence with the identification of a particular requirement, and continue until the system is retired and disposed (Blanchard, 1998: 10).  The Life Cycle Cost (LCC) of a system is essentially all of the costs incurred as a result of the system's life cycle.  These costs include Research and Development (R&D) costs, production and construction costs, Operation and Support (O&S) costs, and system retirement and phase-out costs (Blanchard, 1998:32-33).  "Life cycle costs may be categorized many different ways, depending on the type of system and the sensitivities desired in cost-effectiveness measurement. The objective is to provide *total cost visibility*" (Blanchard, 1998:33). This is Blanchard's preferred method for evaluating prospective system development because the total cost visibility clarifies the long-term economic benefits of competing systems. Previous cost evaluation techniques only examined the acquisition costs, and ignored the O&S costs (Blanchard, 1998:406). "…experience has indicated that a large segment of the life-cycle cost for a given system is attributed to operational and support activities (e.g., up to 75 percent of the total cost)" (Blanchard, 1998:4)

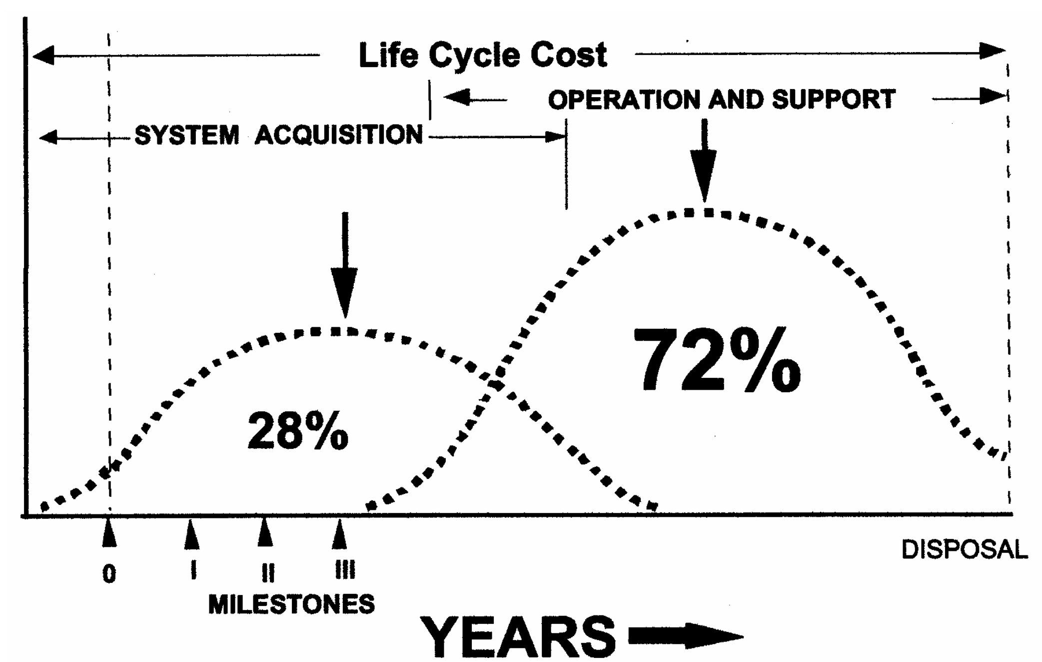



**Figure 3. Life Cycle Cost distribution for a 30 year system (Acquisition Logistics Guide, 1997)**

According to Seldon, Life Cycle Cost estimates have six primary uses:

1) Long range planning and budgeting.

2) Comparison of competing programs.

3) Comparison of logistics concepts.

4) Decisions about the replacement of aging equipment.

5) Control over an ongoing program.

6) Selection among competing contractors. (Seldon, 1979:11)

This study is interested in forecasting the long range planning and budgeting requirements for the C-130 over the next 20 years. Likewise this study provides important availability information that, when evaluated alongside the cost predictions will provide information necessary for the control of the C-130 program. Ultimately, this cost and availability information provides insight and facilitates the decision process for the eventual retirement of the C-130.

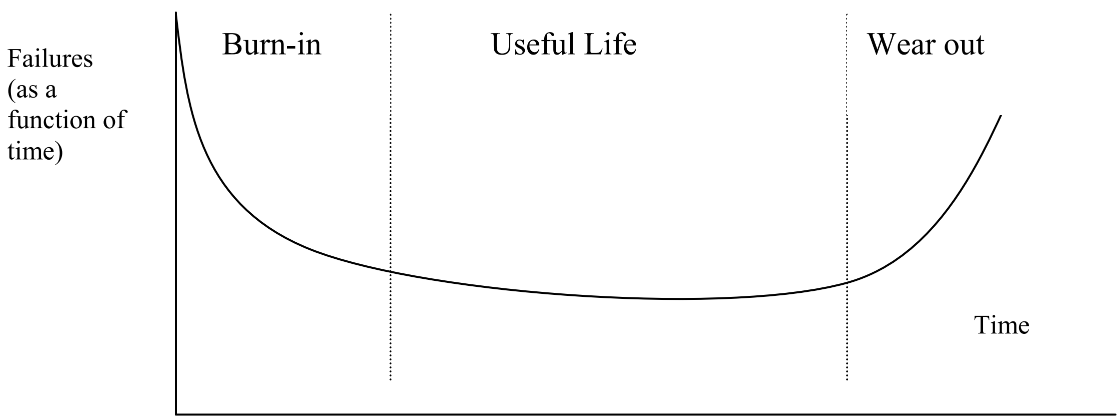
**LCC methods**

Blanchard's approach to LCC adopts a Cost Breakdown Structure (CBS). The CBS provides a detailed format for capturing costs associated with each phase of the life cycle, and is structured so that costs can be as detailed as necessary for the analysis (Blanchard, 1998:410).

Since Coast Guard C-130s are already fielded and in operational service, this study focuses on the O&S costs associated with continued use. Additionally, this study considers O&S costs as synonymous with Operation and Maintenance (O&M) costs. Blanchard defines O&M Cost as:

> the cost of system operation, and the sustaining maintenance and support of the system through its planned life cycle (e.g., manpower and personnel, spare/repair parts and related inventories, test and support equipment, transportation and handling, facilities, software, modifications, and technical data). (Blanchard, 1998:33)

From the literature of aging aircraft issues, it is evident that the Coast Guard's C-130s are approaching, or are already experiencing increased failure rates associated with a system that is nearing the end of its service life. Figure 4 depicts the assumed failure rate curve of a generic system throughout its service life. Initially, during burn-in, there are a large number of failures when the system is first introduced. The failure rate declines as the system matures and remains relatively low for the majority of its useful life. As the system ages, it enters a "wear-out" period, where failure rates experience an increasing trend (Blanchard, 1998:109). With higher failure rates, the system will experience increasing maintenance costs, and decreased system availability.




Source: Adapted from Blanchard, System Engineering Management

**Figure 4. Bathtub curve based on time-dependent failure rate**

Foster and Hunsaker propose that since an aircraft is a collection of components that each has their own bathtub curve. As the complexity of the aircraft systems and subsystems increase, there is a greater likelihood of the components failing at different times. These random failures result in an overall aircraft system that has component ages that range in age from old to new. As this cycle progresses, it is expected that the life of the entire aircraft system can be extended (Foster & Hunsaker, 1983:vii). This concept of renewal of the aircraft subsystems suggests that, barring any budgetary restrictions, thorough maintenance and orchestrated modifications will prolong an aircraft's service life (Foster & Hunsaker, 1983:vii).

**Cost estimating**

> Cost estimating is the process used to project the expected dollar cost. It is the estimating, evaluating, and documenting of program resource requirements from the conceptual phase through the operational phase. It involves the collection, evaluation, storage, and retrieval of cost-related data; the development of methods, factors, relationships, and automated cost models; and the validation and improvement of estimating methodologies. (HQ AFMC/FMR, 2002)

The uncertain nature of cost estimating prevents it from becoming an exact science. Therefore, the cost analyst must try to capture the probability distribution of the system cost, and base the estimate on available cost data and the probability of any uncertain costs. Establishing the probability distributions can be accomplished through past events, theoretical distributions, or subjective judgment (HQ AFMC/FMR, 2002).

There are many techniques for establishing a reasonable cost estimate, and they range from opinion based estimates at one extreme to highly detailed, mathematically rigorous methods at the other extreme (Fabrycky & Blanchard, 1991:144). Parametric cost estimates are derived from functional relationships between the cost being measured and certain parameters that influence the cost (Fabrycky & Blanchard, 1991:147). An example of this is Cost Estimating Relationships (CERs), where cost is estimated based upon the functional relationship to one or more independent variables.

Analogous cost estimates are made based upon the degree of similarity between the item of interest and an established item that has sufficient cost data. Analogous cost estimates unfortunately rely heavily on the judgment regarding the similarity between the two systems (Fabrycky & Blanchard, 1991:145). This could be demonstrated by selecting cost data of a large transport aircraft and declaring that it is sufficiently analogous to cost data for the C-130.

Another cost estimating method used is the Engineering procedures cost method. This method involves a thorough breakdown of costs assigned to each element of the system and then combines these costs to establish an overall estimate. This method is both time consuming and can promote the propagation of small errors into large errors as each cost is rolled into the total cost estimate (Fabrycky & Blanchard, 1991:145).

**Availability**

A general definition of availability is the probability that a system will function properly whenever it is required (Blanchard and Fabrycky, 1990:359). However, more specific availabilities are defined in a variety of ways, depending upon the need to capture the influence of the environment on the system availability. For instance, inherent availability is used to capture a system's availability without regard to the preventive maintenance, as well as any logistical, and administrative delay time (Blanchard and Fabrycky, 1990:359). Similarly, achieved availability is used to capture a system's availability based upon preventive and corrective maintenance, but disregards logistical and administrative delay time (Blanchard and Fabrycky, 1990:359). Perhaps the most useful measure for system availability is operational availability, which is defined as the probability that a system, under actual operating conditions, will function properly when it is required (Blanchard, 1998:128).

The Coast Guard uses availability as a Measure of Effectiveness (MOE), and defines aircraft availability as the percentage of time that aircraft assigned to Air Stations are available to perform Coast Guard missions (Coast Guard Headquarters, 2000). Conversely, Not Mission Capable Total (NMCT) time is the sum of Not Mission Capable times due to Unit-Level Maintenance, and Supply, and Depot-Level maintenance that is performed at a unit (Coast Guard Headquarters, 2000). It is significant to note that the Coast Guard definition of aircraft availability does not account for Depot or aircraft modification events.

**Availability models**

In 1972, the U.S. Air Force Logistics Command (AFLC) prototyped a version of the Aircraft Availability Model (AAM), developed by Logistics Management Institute (O'Malley, 1983:iv ). By 1977, LMI and AFLC began validating the AAM's ability to accurately forecast aircraft availability rates. The conclusion of the tests indicated that the AAM was a suitable method for computing aircraft availability rates and gave a "reasonable indication of actual Aircraft Availability" (O'Malley, 1983:vii ). The AAM has also been utilized as a means for preparing and justifying Program Objective Memorandums (POMs) and Budgets. It is well suited for this purpose because of its ability to relate reparable component expenditures and component sparing to aircraft availability rates (O'Malley, 1983:iv).

Within the AAM, an aircraft is considered available as long as there are no pending reparable component repairs, component replacements, or component shipments (O'Malley, 1983:iv). In theory, if enough reparable parts are stocked within the supply system, then the aircraft availability would approach 100 percent. The AAM does not take into account any aircraft maintenance, scheduled or unscheduled, nor does it account for consumable availability (O'Malley, 1983:1-1). It is primarily concerned with evaluating the supply system performance via the aircraft availability rate. The aircraft availability rate is defined as the percentage of aircraft available over a specified time period (O'Malley, 1983:1-1). This definition of availability is obviously more restrictive than the previously defined Operational Availability, as it completely ignores the effect of on-aircraft maintenance, as well as the effect that consumable stocking levels may have on aircraft availability (O'Malley, 1983:1-1). Based upon the research of aging aircraft issues, it seems apparent that aircraft maintenance is a significant issue for aircraft availability. The AAM overlooks this key availability driver and its usefulness is suspect when applied to aging aircraft.

**Monte Carlo simulation**

Any time that an estimate is created for some future event, there will always be an element of uncertainty in this estimate. It is therefore important to understand and describe the nature of the uncertainty, as well as its magnitude (Dienemann, 1966:1). If it is possible to represent the uncertainty for each element of an estimate as a probability distribution, it is then possible to draw random samples from these theoretical populations, and generate a probability distribution for the overall estimate. This technique for drawing random samples from probability distributions is often referred to as Monte Carlo simulation (Dienemann, 1966:7). With Monte Carlo simulation, the accuracy of the simulation output increases with the number of simulations. If the simulation is repeated enough times, a decision maker can develop a good understanding of the possible estimate results, based upon its simulated probability distribution (Clemen & Reilly, 2001:462). This increased understanding can be used to select among the decision maker's alternatives, direct areas for further analysis, or establish confidence in the analysis under study.

Monte Carlo simulation, like any kind of simulation, is an excellent tool for creating a model of uncertainty. It is both easy to use, and very flexible for performing an analysis that might otherwise overwhelm the decision maker (Clemen & Reilly, 2001:486). However, this does not mean that it will relieve the decision maker from a careful and detailed analysis of the problem (Clemen & Reilly, 2001:486). "The decision maker and the decision analyst are still required to think clearly about the problem at hand and to be sure that the decision model addresses the important issues appropriately" (Clemen & Reilly, 2001:487)

**Past Research**

There are numerous published studies that have examined either Operational & Support costs or system availability, but few that examine both. While it is not practical to review the entire collection of works that examine these topics, it is important to examine the basic questions that have been asked, and how the questions have been answered. A summary of selected works is provided in the next few paragraphs.

In 1977 Baker examined the existence of O&S data, specifically for aircraft engines. At the time there was no single repository within the Air Force for cost data and the collection of the data itself proved to be a challenge. The goal of the research was to compile historical cost data and use it to estimate future O&S costs. The Air Force has since made concerted efforts to provide greater visibility for cost data, e.g. the creation of the Air Force Total Ownership Cost (AFTOC) database maintained at Hill AFB (Baker, 1977).

Newhall conducted a study of LCC estimating for future generation F-16. Focusing on the acquisition and O&S costs, she intended to provide a model that could predict costs for future generation F-16's. However, she was ultimately only able to develop predictive models for the F-16 O&S costs. Her methodology employed three regression models, with each used independently based upon the level of information available and the need for the accuracy of the estimate. She concedes that even her most complex model is subject to increasing error as the prediction interval extends beyond two to three years (Newhall, 1991).

A 1994 Naval Postgraduate School study, conducted by Terry Redman, applied Monte Carlo simulation to estimate operating costs for two types of Military Sealift ships. Understanding that the operating cost elements could be approximated by selected distributions, Redman took random samples from these cost distributions to populate a total operating cost distribution. The output distribution was validated with an unused portion of the historical data, and the overall method was deemed suitable for predicting the ship's direct operating costs despite the inherent uncertainty (Redman, 1994). This study utilized historical direct costs, but did not apply expert opinion for estimating cost growth for any of the cost elements.

In 1983 Gardner examined the impact of Operational Availability on system Life Cycle Cost, where availability served as a surrogate for supportability. His research compared a pair of system options and evaluated the overall impact of availability on

LCC. Deterministic values of reliability, maintainability and cost were used in the model, which allowed a side by side comparison of system options (Gardner, 1983). A follow on study was conducted by Farnell which applied the same methodology, but with cost data from the Cost Oriented Resource Estimating (CORE) model. This follow on study intended to demonstrate that the CAIG approved cost element structures could be supported with the proven methodology (Farnell, 1984).

Merker applied multi-attribute value theory, in combination with aircraft readiness data and LCC information, to generate cost effectiveness curves for three different aircraft types. His 1985 study did not examine the effects of cost growth throughout the 20 year aircraft life, allowing the use of a constant O&S cost. Additionally, he used readiness data over a two year period, and calculated an average for this period. (Merker, 1985)

Additional aircraft availability research was conducted by Kapitzke in 1995. He examined the effects of component failures and depot repair times on aircraft availability. His methods utilized the Aircraft Availability Model (AAM) to establish predictions for aircraft availability; however, his approach did not include the affects of aircraft maintenance on aircraft availability (Kapitzke, 1995).

In February 2001, the KC-135 Economic Service Life Study Integrated Product Team (ESLS IPT) released their report on the anticipated cost and availability of the KC-135 fleet over a 40 year period. The study's primary purpose was to provide Air Force senior leadership with information that would facilitate informed decisions regarding the modernization and/or retirement of the KC-135 fleet (KC-135 ESLS, 2001). The ESLS

IPT accomplished this through the analysis of the sustainment costs, and availability drivers for the KC-135 through the year 2040 (KC-135 ESLS, 2001).

The KC-135 ESLS examined the overall KC-135 Service Life costs and availability by breaking each measure into discrete elements, and approximating how these elements might change during the 40 year period under investigation. The ESLS IPT utilized historical data, expert opinion, as well as anticipated modernization and sustainment initiatives as the basis for their trend predictions (KC-135 ESLS, 2001). The assumed trends were combined with bounded distributions for the engine and airframe PDM cost elements. These four cost elements were defined by minimum, maximum and most likely values. The remaining cost elements, which were assumed to be stationary, were developed through the Cost Oriented Resource Estimating (CORE) model.

The availability was generated through a similar process. The Not Mission Capable rate, Depot Possessed rate, and Aircraft Modification rate were sampled from distributions defined by minimum, maximum and most likely values. Subtracting these values from 100 percent resulted in the availability rate, which was then multiplied by the number of aircraft. Utilizing Monte Carlo simulation, the study developed distributions for the output values that were then plotted for the period of investigation. These output distributions permitted greater understanding of the cost and availability risk over the 40-year period.

# Chapter 3. Methodology

## Introduction

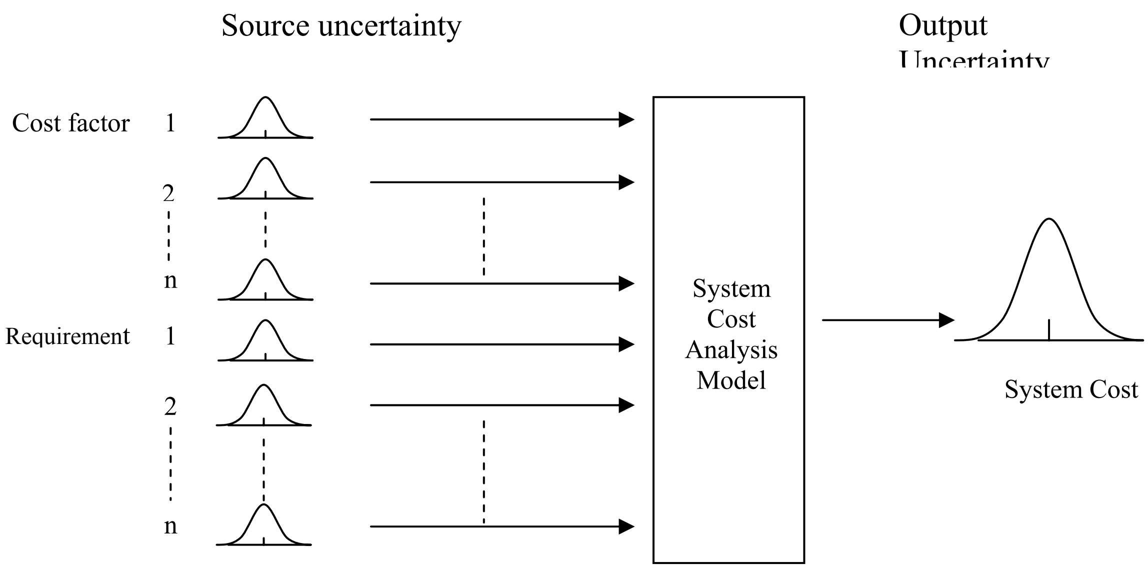
The primary goal of this study is to generate a method for predicting future service life costs and availability estimates for the Coast Guard C-130 fleet. In addition to the intrinsic value of these estimates, they will allow program managers to better grasp the decisions that must be made regarding C-130 sustainment, modernization, and potential replacement.

It is assumed that in order to adequately perform this estimate, it will be necessary to capture as much of the program's cost and availability uncertainty as possible. Existing historical data will be examined as a starting point. In areas where there is not sufficient data for the C-130, expert opinion and comparison to analogous systems will be used.

This chapter begins with a continuation of the discussion of Monte Carlo simulation, providing a more detailed description of the Monte Carlo process. The chapter then discusses the proven use of this simulation technique by the U.S. Air Force in its evaluation of the KC-135 aerial refuelers. The chapter concludes with a detailed description and definition of the various cost and availability factors used in this model.

## Monte Carlo Simulation

Understanding that there is significant uncertainty associated with estimates of future cost and availability, it is necessary to provide a method for capturing the probability for these values. As discussed in chapter 2, Monte Carlo simulation is an established method for picking random values from the distribution of uncertain input values and combining these to establish an output distribution. The process depicted in Figure 5 demonstrates how a random sample is taken from each input source of uncertainty. The system cost or availability model then combines these input samples to produce an output sample. As the process is repeated several times, the output samples produce a distribution that represents the uncertainty associated with the output of the model.




Source: Adapted from Dienemann; Estimating Cost Uncertainty Using Monte Carlo Techniques

**Figure 5. Relation of system output uncertainty to source uncertainty**

Applying this simulation process to a cost model, Garvey establishes the following procedural steps:

1) For each random variable defined in the system's Work Breakdown Structure (WBS), randomly select (sample) a value from its distribution function, which is known (or assumed).

2) Once a set of feasible values for each random variable has been established, combine these values according to the mathematical relationships specified across the WBS. This process produces a single value for the system's total cost.

3) Repeat the above two steps n-times (e.g. ten thousand times). This produces n-values each representing a possible (i.e. feasible) value for the system's total cost.
4) Develop a frequency distribution from these n-values. This distribution is the simulated (i.e. empirical) distribution of total system cost. (Garvey, 2000:298)

For cost uncertainty analysis purposes, a sample size of 10,000 simulations is generally sufficient (Garvey, 2000:303). Figure 6 depicts the 95 percent confidence curves as a function of sample size, where "k" is the upper bound and "i" is the lower bound of the interval. The true median for this demonstration is at 0.5. For a sample size of 100, the 95 percent confidence curves indicate that median lies between 0.4 and 0.6 with 95 percent confidence. As the sample size increases to 10,000 samples, the confidence curves indicate that the median lies between 0.49 and 0.51 with 95 percent confidence. It can be seen that there is only minimal improvement to the level of confidence as the sample size increases beyond 10,000 (Garvey, 2000, 303-4).

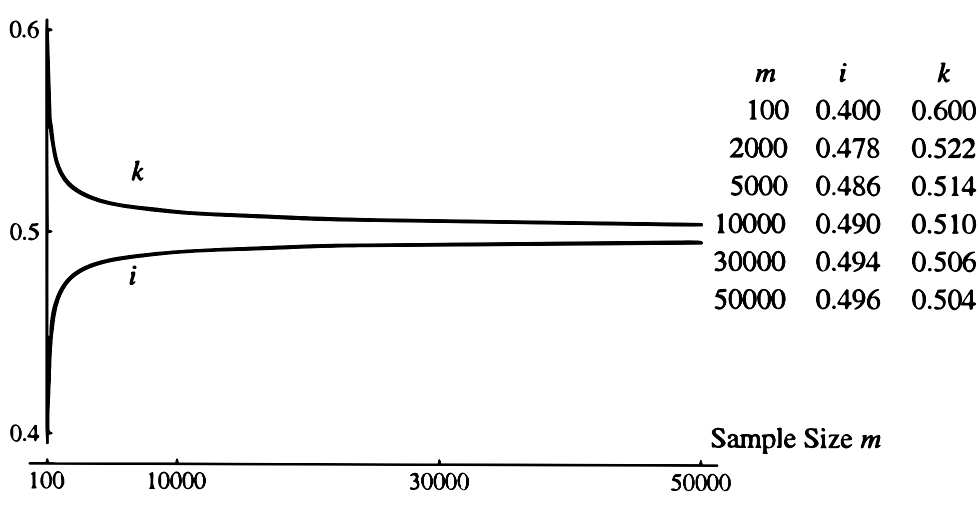



**Figure 6. Sample Size for Monte Carlo Simulations (Garvey, 2000)**

Crystal Ball®, a Decisioneering Inc product, has been selected as the software program for building the uncertainty in the model. Crystal Ball® is one of the Excel® add-in programs that incorporate Monte Carlo simulation. It utilizes the user's assumptions and inputs to forecast the range of possible outcomes for a spreadsheet model.

**Defining Distributions**

"Distributions are used to represent variables because rarely have we measured the entire parent population (i.e., we have rarely made all the measurements possible)" (Koller, 2000:270). It is also easy to represent an entire population of values as a distribution that is created from just a few point estimates (Koller, 2000:270).

Koller asserts that most subject matter experts are more comfortable defining random variable distributions based upon their knowledge and experience. By possessing a good understanding of the issue under investigation, an expert is quite adept at building a distribution that best represents the data. Koller believes that most professionals do not have the intimate familiarity with statistical distributions to select from the array of named statistical distributions. Koller proposes that the user should be allowed to select a combination of minimum, most likely, maximum and peakedness values to create the distributions (Koller, 2000:260).

Eliciting expert opinion raises the issue of bias. Kahneman, Slovic and Tversky discuss three important types of bias that can influence a subjective estimate: Representativeness, Availability, and Anchoring. Representativeness is the belief that a small sample of observations or events will be representative of the much larger population of possible observations, or events. For example, an expert may assume that the law of large numbers can be observed within a small sample of data. Availability is the bias that is manifested from an expert's use of past events to create an estimate. The expert's assessment for the likelihood for an event is influenced by what has been previously experienced. Anchoring is the bias that results from focusing on the first value that is estimated, such as a most likely value, and not sufficiently adjusting subsequently estimated values. The first value that is estimated proves influential to the remainder of the estimate (Kahneman, Slovic, and Tversky, 1982:3-20)

Vose discusses the methods for defining input distributions from observed data sources, as well as from expert opinion. In this study, the past is assumed to only explain a portion of the uncertainty. Since the forecast extends well into the future, it is important to consult with experts who can offer insight into the future behavior. Expert opinion is often elicited through non-parametric distributions, e.g., Uniform, General, Triangular, Cumulative and Discrete (Vose, 2000:272). The non-parametric distributions are typically easier to visualize and offer the desired flexibility for developing a distribution of a variable (Vose, 2000:272). However, depending upon the experience of the expert and the particular variable that is being modeled, it may be advantageous to use a parametric distribution (Vose, 2000:272-3).

The triangular distribution is commonly used as it is defined by a minimum, most likely and maximum value, each of which is relatively easy for an expert to estimate. It is a bounded distribution, so there is no possibility of selecting a value that is unreasonable, e.g., a negative cost. Additionally, it is not necessary to perform a detailed investigation of the distribution between these points because of the linear boundary of the distribution (Vose, 2000: 274). Figure 7 depicts several examples of triangular distributions.

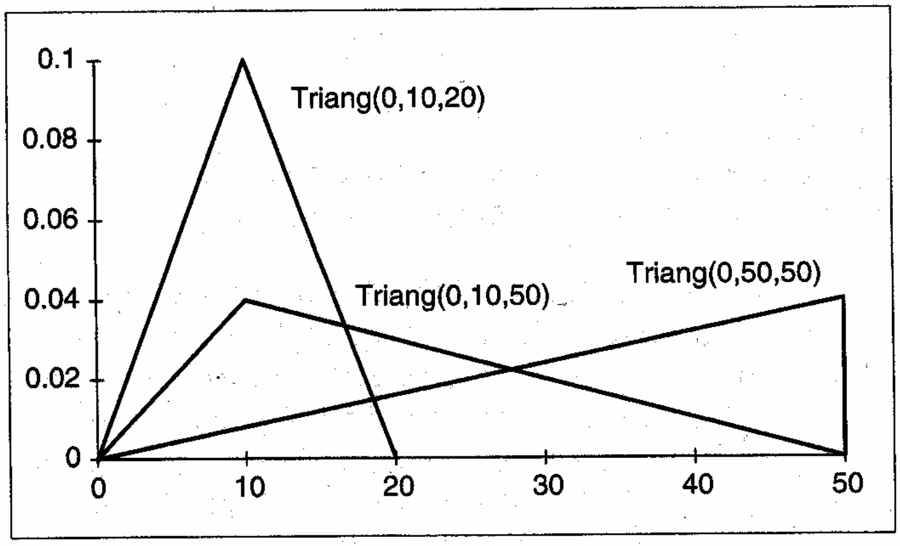



**Figure 7. Example Triangular Distributions (Vose, 2000)**

Finally, the triangular distribution can be developed without the minimum and maximum values if the expert can provide probabilities for the minimum and maximum being below or above the values provided (Vose, 2000:274). Figure 8 depicts the use of probabilities for the minimum and maximum values to reveal the complete distribution.

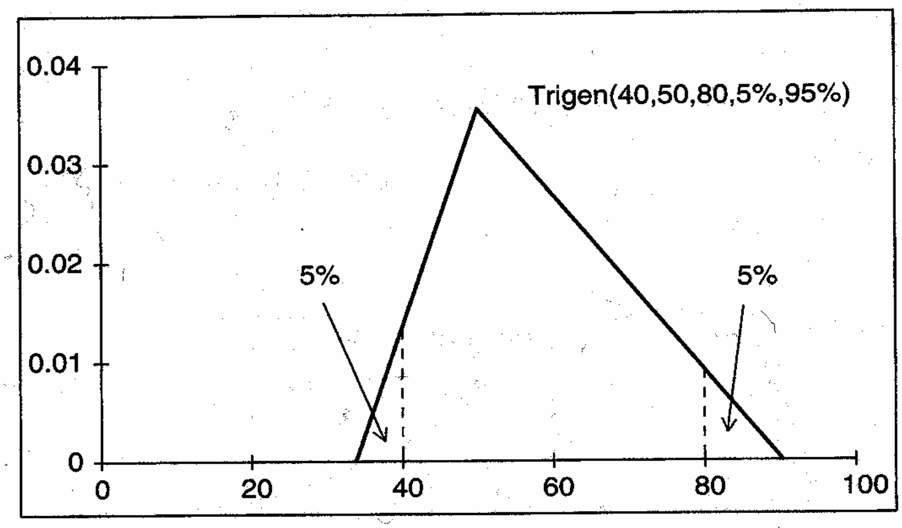



**Figure 8. Example of Trigen Distribution (Vose, 2000)**

The BetaPERT distribution, which is truly a parametric distribution, is also frequently used to capture expert opinion (Vose, 2000:273). The BetaPERT is related to the Beta distribution through the following equation (Vose, 2000:276):

$$BetaPERT(a,b,c) = Beta(\alpha 1, \alpha 2) * (c-a) + a$$

where:

$$\alpha 1 = [(\mu - a) * (2b - a - c)] / [(b - \mu) * (c - a)]$$

$$\alpha 2 = [\alpha 1 * (c - \mu)] / (\mu - a)$$

$$\mu = (a + 4 * b + c) / 6$$

Figure 9 depicts several examples of BetaPERT distributions. Like the triangular distribution, it is defined by the same three parameters, minimum, most likely and maximum; however, the mean has an increased sensitivity to the most likely parameter (Vose, 2000:276). This can potentially correct for some of the systematic bias that exists in a triangular distribution as it is less sensitive to the minimum and maximum value estimates (Vose, 2000:276).

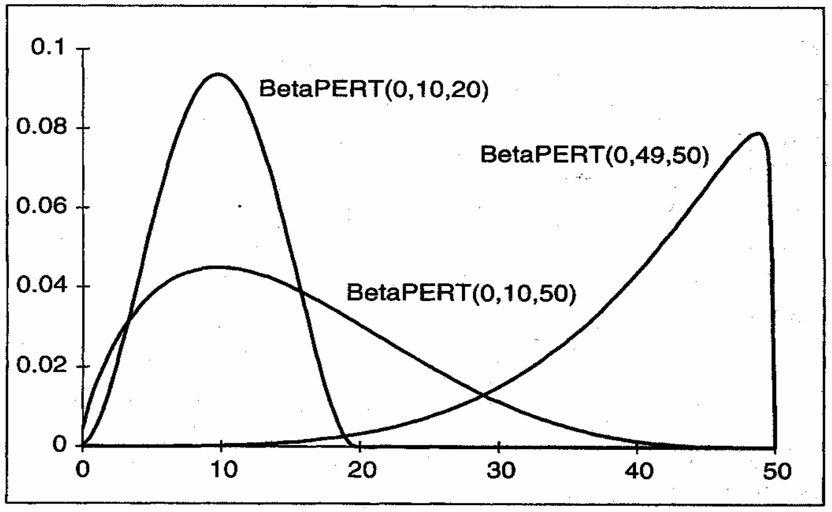



**Figure 9. Example PERT Distributions (Vose, 2000)**

Figure 10 demonstrates the advantage of utilizing the BetaPERT distribution versus a triangular distribution, particularly when the most likely values approach either the minimum or maximum value. Specifically a BetaPERT distribution's standard deviation is consistently lower than a triangular distribution with the same defining values. This lower standard deviation equates to a lower level of uncertainty within a model that uses BetaPERT distributions instead of triangular distributions (Vose, 2000:277).

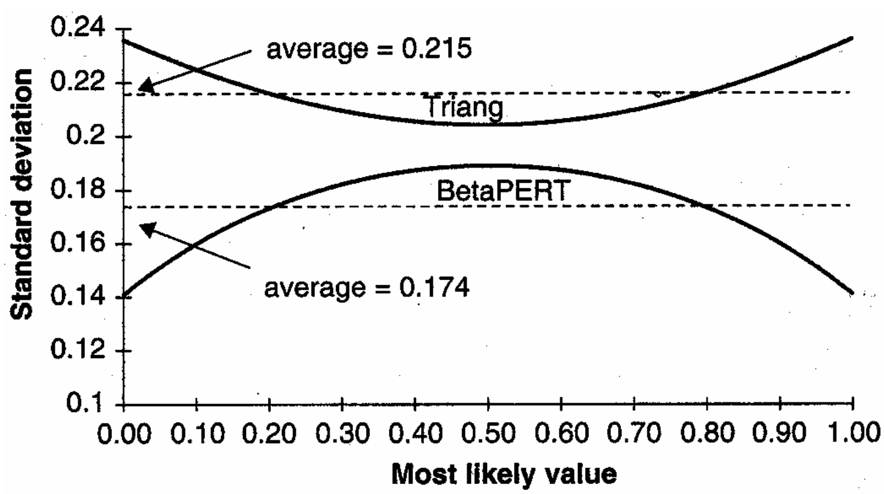



**Figure 10. Comparison of standard deviation of Triangular (0, most likely, 1) and BetaPERT (0, most likely, 1) distributions (Vose 2000)**

## Correlation

"Correlation is a necessary consideration in cost uncertainty analysis" (Garvey, 2000:339). It is a means of quantifying the relation between two or more variables or WBS elements (Coleman, 2002). When two or more cost elements are correlated, the relationship between these elements will influence the variance of the output distributions (Coleman, 2002). Positive correlation signifies that the elements increase or decrease together. Meanwhile, negative correlation signifies that as one element increases, the other decreases. The implication for cost analysis is that the output distribution can be significantly affected by the correlation between its cost elements (Coleman, 2002). A greater variance in the output distribution equates to a larger range of possible outcomes. Failing to account for correlation can result in a large underestimation, or overestimation of total cost (Book, 1999). Correlation was used to quantify the relationship among cost elements and the relationship among availability elements.

## C-130 Cost Analysis Methodology

The dynamic nature of modeling cost distributions generally requires the analyst to break the problem down into smaller elements. This logical disaggregating of the elements should continue until a point where each variable's uncertainty can be accurately represented (Vose, 2000:203). In 1992, the DoD Cost Analysis Improvement Group (CAIG) published the "Operating and Support Cost-Estimating Guide", which detailed the preferred cost element structure for generic weapons systems. Specifically for aircraft, the cost element structure is broken down as follows:

1.0 Mission Personnel
- 1.1 Operations
- 1.2 Maintenance
- 1.3 Other Mission Personnel

2.0 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

3.0 Intermediate Maintenance (External to unit)
- 3.1 Maintenance
- 3.2 Consumable Material/Repair Parts
- 3.3 Other

4.0 Depot Maintenance
- 4.1 Overhaul/Rework
- 4.2 Other

5.0 Contractor Support
- 5.1 Interim Contractor Support
- 5.2 Contractor Logistics Support
- 5.3 Other

6.0 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

7.0 Indirect Support
- 7.1 Personnel Support
- 7.2 Installation Support (OSD, 1992:4-2)

This cost element structure will provide the basis for how the C-130 costs are grouped and evaluated. The definitions for each of the above cost elements are included in the CAIG's report and are provided in Appendix A:

### Cost Analysis Assumptions

It is assumed that future C-130 mission requirements will remain unchanged throughout the 20-year period of the estimate. This assumes a constant inventory of airframes (27), and a constant rate of aircraft usage (800 programmed flight hours per year). It is also assumed that O&M personnel requirements remain unchanged throughout the period of investigation. Until sufficient Coast Guard C-130 data is available, it is assumed that Air Force C-130 historical data is suitable for establishing yearly trends in per airframe costs. Specifically, this study will examine Air Force C-130H data for indicators of trends relating airframe age with annual O&S costs.

This study will also include modernization costs within the 6.0 Sustainment cost element. This goes against the stated exclusion of costs associated with modifications that improve the operational capability of the C-130. Altering this definition will allow the inclusion of planned modifications that did not previously qualify as a sustainment cost element, e.g. Deepwater compatible communications upgrades.

### Cost Databases

Two primary databases were selected for use in this study: Air Force Total Ownership Cost (AFTOC) database and Coast Guard Aviation Logistics Management Information System (ALMIS). The AFTOC database is an extensive information system that contains data for all Air Force weapon systems. It was selected for the purposes of establishing cost trends from 1996 to 2002. Conveniently the AFTOC data was available in the CAIG cost element format. The ALMIS database contains exclusively Coast Guard data. Unfortunately, it has proven extremely difficult to extract many years worth of data necessary for establishing trends in C-130 cost elements. The data either does not exist, or it is aggregated with several other aircraft systems. These circumstances necessitated using the AFTOC database to establish trends, while the ALMIS database provides the anchoring point for the future estimates.

### Time Series Projections

Time series modeling can be based upon the observations of a variable collected over time, or if there is insufficient data, it can be based upon the opinion of experts who understand how a variable may change in the future (Vose, 2000:313). As the cost data is a collection of past costs observed over time, it will be necessary to examine the patterns they have exhibited. A widely accepted method for expressing a time series relationship is with the Additive Model. The Additive Model combines four components: Secular trend, Cyclical effect, Seasonal effect and Residual effect; to achieve the value of the response variable (McClave et al, 2001:771). The primary interest in this study is the Secular trend. However it must be recognized that there may be cyclical effects when examining a time interval as large as 20 years. Understanding the nature of the AFTOC data, plus the expert opinion, it will be possible to better predict the behavior of future costs.

For medium-term forecasting, when the patterns from the past will continue to occur, Vose proposes the use of regression to establish relationship betweens time and cost. "Regression analysis seeks to describe a logical relationship between a dependent variable and one or more independent variables" (Vose, 2000:324). Simple linear regression attempts to describe the relationship between the dependent variable and the independent variable as a straight line (Vose, 2000:324). In a similar fashion, curvilinear regression describes the relationship as a fit to a curved line (e.g. polynomial, log curve, exponential curve) (Vose, 2000:324).

Vose defines a long-term forecast as a forecast that looks beyond a two-year period. This particular study, which examines the O&S costs over a 20-year period, is clearly within this category. Vose further explains that while regression analysis of historical data will reveal existing trends, it will not supplant the use of experts for the estimate. He states that experts will undoubtedly possess critical knowledge of political, economic, technological and sociological factors that will have greater influence on the model than what would be achieved strictly through regression analysis (Vose, 2000:327).

**Availability methodology**

The structure of the aircraft availability model is much simpler than that of the cost model. Availability for the purposes of this study will be the percentage of entire C-130 fleet that is available for Coast Guard missions.

$$AvailabilityRate = 100\% - (NMCT + PDM + Mod)$$

Much like the cost model, each of the availability variables contains uncertainty. By once again disaggregating the elements and assigning trends and defined distributions, it will be possible to create an availability distribution that captures the range of possible outcomes.

**Availability Definitions**

The traditional Coast Guard definition for aircraft availability is the percentage of time that aircraft assigned to Air Stations are available to perform Coast Guard missions

(Coast Guard Headquarters, 2000). However, for this study, aircraft availability will be defined as the percentage of the entire aircraft fleet that is available to perform Coast Guard missions. This incorporates the occurrence of PDM and modification cycles into the availability measure.

NMCT – is the sum of Not Mission Capable percentages due to Maintenance (NMCM), Supply (NMCS), and Depot-Level maintenance which is performed at a unit (NMCD) (Coast Guard Headquarters, 2000). The Coast Guard maintains an NMCT target for mature aircraft systems of no more than 29 percent which equates to a unit aircraft availability of no less than 71 percent (Coast Guard Headquarters, 2000).

NMCM – is the percentage of time that an aircraft is Not Mission Capable because of unit-level scheduled or unscheduled maintenance work. This includes any time accrued while the aircraft is grounded awaiting maintenance action, and continues until all test flight items are satisfactorily completed. Pre-thru-post flight inspections or general aircraft servicing are not logged as NMCM time unless they would delay an aircraft launch beyond the mandated 30 minute departure criteria. (Coast Guard Headquarters, 2000)

NMCS – is the percentage of time that an aircraft is Not Mission Capable due to the lack of available parts or supplies. The NMCS accrues time when an aircraft is incapable of meeting mission readiness requirements because of the unavailability of required parts. The part in question should be preventing maintenance from proceeding, and consequently is the primary contributor to the NMC condition. The NMCS clock stops as soon as the part is available to maintenance personnel and time is now applied to the NMCM category (Coast Guard Headquarters, 2000). “NMCS should reflect cannibalization. For example, once a part is removed from an airframe (for installation on another airframe) it should be listed as NMCS. The status of the airframe receiving the cannibalized part should switch from NMCS to NMCM". (Coast Guard Headquarters, 2000)

NMCS Target – The Coast Guard has set a planning goal for NMCS of 5 percent, which equates to a parts availability rate of 95 percent). This target also serves as a justification for resources required to meet an NMCT rate of 29 percent. However, the Coast Guard balances achieving this goal against the goal of minimizing of total system costs. (Coast Guard Headquarters, 2000)

NMCD – is the percentage of time that aircraft are unavailable for operational use due to scheduled or unscheduled depot level maintenance. This type of maintenance is assumed to be beyond the capabilities of the assigned unit. When the Coast Guard makes a 'business decision' to perform depot level maintenance at Air Stations, these NMCD periods need to be reflected in the total NMCD time, and should not count against unit NMCM rates. (Coast Guard Headquarters, 2000)

PDM – is defined as the percentage of time that an aircraft is depot possessed. It will commence with the date that an aircraft is received at the depot facility and will continue until it is received by the next operational unit, or modification facility.

Mod – is defined as the percentage of time that an aircraft is undergoing an aircraft modification and where the time is not otherwise accounted for as PDM or under NMCT.

### Availability Assumptions

Much like the cost assumptions, it is assumed that the future C-130 mission requirements will remain unchanged throughout the 20-year period of the estimate. This assumes a constant inventory of airframes (27), and a constant rate of aircraft usage (800 programmed flight hours per year).

### Availability Databases

The Coast Guard ALMIS database is used exclusively for the generation of availability trends and as a means for establishing the input distributions. The Coast Guard has tracked NMCT data for many years and the data is easily extracted for any airframe or unit.

## Simulation Models

Table 2 demonstrates the construction of the Excel spreadsheet used to capture the cost model assumptions. The complete models are provided in Appendix B. Table 2 depicts a portion of the cost elements that were selected for simulation and the parameters that define the input distributions for each year under examination. The cost elements distributions were based upon per aircraft costs.

## Table 2. Sample Cost Model Assumptions with Triangular Distributions

| Year | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Pilot | 620648.6 | 749319.6 | 726613 | 681199.7 | 635786.3 | 620648.6 | 613079.7 |
| min | 595822.6 | 726840 | 688465.8 | 636921.7 | 586512.9 | 564790.2 | 550239 |
| most likely | 620648.6 | 749319.6 | 726613 | 681199.7 | 635786.3 | 620648.6 | 613079.7 |
| max | 657887.5 | 801772 | 784742 | 742507.6 | 699365 | 688919.9 | 686649.3 |
| Aircrew/Maint Technician | 639195.6 | 670124.5 | 690743.7 | 711362.9 | 670124.5 | 623731.2 | 597957.2 |
| min | 613627.8 | 650020.7 | 654479.6 | 665124.3 | 618189.8 | 567595.4 | 536666.6 |
| most likely | 639195.6 | 670124.5 | 690743.7 | 711362.9 | 670124.5 | 623731.2 | 597957.2 |
| max | 677547.4 | 717033.2 | 746003.2 | 775385.6 | 737136.9 | 692341.7 | 669712.1 |

| Year | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Fuel | 820373.9 | 836781.4 | 853188.9 | 863033.4 | 869596.3 | 876159.3 | 882722.3 |
| min | 799864.6 | 814748.9 | 829589.7 | 838014 | 843230.2 | 848428.9 | 853610.1 |
| most likely | 820373.9 | 836781.4 | 853188.9 | 863033.4 | 869596.3 | 876159.3 | 882722.3 |
| max | 840883.3 | 858813.8 | 876788.1 | 888052.7 | 895962.5 | 903889.8 | 911834.5 |
| Depot Level Reparables | 630231.4 | 829251.9 | 895592 | 961932.2 | 1011687 | 1028272 | 1028272 |
| min | 570359.4 | 605353.9 | 644826.3 | 678162.2 | 715262.9 | 719790.6 | 719790.6 |
| most likely | 630231.4 | 829251.9 | 895592 | 961932.2 | 1011687 | 1028272 | 1028272 |
| max | 701447.6 | 903884.5 | 1065755 | 1090831 | 1108809 | 1120817 | 1126986 |

| Year | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| PDM (basic + MSRs + O&A) | 581790.5 | 585274.3 | 592241.9 | 585274.3 | 557404.1 | 522566.4 | 480761 |
| min | 555028.2 | 544305.1 | 535386.6 | 526746.9 | 505008.1 | 480238.5 | 449992.3 |
| most likely | 581790.5 | 585274.3 | 592241.9 | 585274.3 | 557404.1 | 522566.4 | 480761 |
| max | 599942.4 | 601954.6 | 604975.1 | 604998.1 | 607013.1 | 614015.5 | 626912.4 |
| Engine Overhaul | 54329.64 | 54968.81 | 55607.99 | 55607.99 | 55607.99 | 55607.99 | 56247.16 |
| min | 51830.48 | 51121 | 50881.31 | 50881.31 | 50881.31 | 50881.31 | 50903.68 |
| most likely | 54329.64 | 54968.81 | 55607.99 | 55607.99 | 55607.99 | 55607.99 | 56247.16 |
| max | 57861.07 | 61180.29 | 63893.58 | 66173.5 | 67285.66 | 68286.61 | 69184.01 |

| Year | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Support Equipment Replacem | 37942.36 | 36483.04 | 34294.06 | 32105.07 | 29916.09 | 28456.77 | 27727.11 |
| min | 35703.76 | 33356.44 | 30350.24 | 27514.05 | 25009.85 | 24842.76 | 24510.77 |
| most likely | 37942.36 | 36483.04 | 34294.06 | 32105.07 | 29916.09 | 28456.77 | 27727.11 |
| max | 39194.46 | 38343.67 | 37517.7 | 37017.15 | 36677.13 | 36367.75 | 36183.88 |
| Sustaining Engineering Suppo | 133256.1 | 154577.1 | 165237.6 | 213209.8 | 266512.2 | 282502.9 | 277172.7 |
| min | 125277.4 | 134225.8 | 141682.8 | 153614 | 158088.2 | 161070.9 | 164053.7 |
| most likely | 133256.1 | 154577.1 | 165237.6 | 213209.8 | 266512.2 | 282502.9 | 277172.7 |
| max | 177476.3 | 187916.1 | 210287.1 | 247572 | 280382.8 | 301262.3 | 308719.3 |

Table 3 depicts a portion of the yearly forecasts. The yearly forecasts were generated through the summation of the cost elements that were simulated plus the stationary costs. The costs are presented as total system costs for the entire fleet of 27 aircraft.

**Table 3. Sample Cost Model Forecasts with Triangular Distributions**

| Year | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 |
|---|---|---|---|---|---|---|
| Mission Personnel | | | | | | |
| Pilot | 16757512 | 20231630 | 19618550 | 18392391 | 17166231 | 16757512 |
| Aircrew/Maint Technician | 17258282 | 18093360 | 18650079 | 19206798 | 18093360 | 16840743 |
| Unit Level Consumption | | | | | | |
| Fuel | 22150096 | 22593098 | 23036099 | 23301901 | 23479101 | 23656302 |
| Depot Level Reparables | 17016248 | 22389801 | 24180985 | 25972169 | 27315557 | 27763353 |
| Depot | | | | | | |
| PDM (basic + MSRs + O&A) | 15708345 | 15802406 | 15990530 | 15802406 | 15049911 | 14109291 |
| Engine Overhaul | 1466900.3 | 1484158 | 1501415.6 | 1501415.6 | 1501415.6 | 1501415.6 |
| Sustaining Support | | | | | | |
| Support Equip Replacement | 1024443.7 | 985042.06 | 925939.54 | 866837.01 | 807734.49 | 768332.81 |
| Sustaining Eng Support | 3597914.5 | 4173580.9 | 4461414 | 5756663.3 | 7195829.1 | 7627578.8 |
| Indirect Support | | | | | | |
| Base Operating Support | 3362092.7 | 3399449.2 | 3735658.5 | 4576181.7 | 5229921.9 | 5416704.8 |
| Disposal Costs | | | | | | |
| Stationary costs | 30005366 | 30005366 | 30005366 | 30005366 | 30005366 | 30005366 |
| Total Cost | 128347200 | 139157891 | 142106038 | 145382128 | 145844428 | 144446599 |

Table 4 depicts a portion of the Excel spreadsheet assumptions that defined the availability distributions. The availability parameters were formatted as percentages.

**Table 4. Sample Availability Model Assumptions with Triangular Distributions**

| Year | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|
| **NMCM** | 0.1648 | 0.1634 | 0.1626 | 0.1624 | 0.163 | 0.164 | 0.1642 |
| min | 0.158 | 0.153 | 0.151 | 0.15 | 0.149 | 0.148 | 0.147 |
| most likely | 0.1648 | 0.1634 | 0.1626 | 0.1624 | 0.163 | 0.164 | 0.1642 |
| max | 0.175 | 0.179 | 0.18 | 0.181 | 0.184 | 0.188 | 0.19 |
| **NMCS** | 0.0691 | 0.0586 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| min | 0.055 | 0.047 | 0.043 | 0.042 | 0.041 | 0.0405 | 0.04 |
| most likely | 0.0691 | 0.0586 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| max | 0.102 | 0.105 | 0.11 | 0.113 | 0.117 | 0.12 | 0.123 |
| **NMCD(u)** | 0.0236 | 0.0182 | 0.015 | 0.015 | 0.015 | 0.015 | 0.015 |
| min | 0.022 | 0.015 | 0.008 | 0 | 0 | 0 | 0 |
| most likely | 0.0236 | 0.0182 | 0.015 | 0.015 | 0.015 | 0.015 | 0.015 |
| max | 0.03 | 0.031 | 0.0335 | 0.0365 | 0.039 | 0.0422 | 0.0448 |

| No aircraft | 27 | | | | | | |
|---|---|---|---|---|---|---|---|
| **Year** | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
| PDM Possessed | 5.684211 | 6.113208 | 6.545455 | 6.821053 | 6.967742 | 6.967742 | 6.95279 |
| **PDM Interval** | 57 | 53 | 49.5 | 47.5 | 46.5 | 46.5 | 46.6 |
| min | 50 | 47 | 44 | 42 | 41 | 40.5 | 40 |
| most likely | 57 | 53 | 49.5 | 47.5 | 46.5 | 46.5 | 46.6 |
| max | 60 | 59.7 | 59.4 | 59.1 | 59 | 59 | 59 |
| **Flow Days** | 179 | 177 | 175 | 175 | 175 | 175 | 174 |
| min | 163 | 158 | 153 | 150 | 148 | 146 | 144 |
| most likely | 179 | 177 | 175 | 175 | 175 | 175 | 174 |
| max | 190 | 193 | 196 | 199 | 201 | 203 | 205 |
| equivalent aircraft | 2.787599 | 2.964487 | 3.138232 | 3.270368 | 3.340698 | 3.340698 | 3.314481 |
| **Percent PDM Possessed** | 0.103244 | 0.109796 | 0.116231 | 0.121125 | 0.12373 | 0.12373 | 0.122759 |
| **Percent Modification** | 0.074074 | 0.074074 | 0.088889 | 0.109259 | 0.111111 | 0.111111 | 0.111111 |
| min | 0.07037 | 0.07037 | 0.07037 | 0.055556 | 0.055556 | 0.055556 | 0.055556 |
| most likely | 0.074074 | 0.074074 | 0.088889 | 0.109259 | 0.111111 | 0.111111 | 0.111111 |
| max | 0.103704 | 0.12963 | 0.148148 | 0.148148 | 0.148148 | 0.148148 | 0.148148 |

Table 5 depicts a portion of the yearly forecasts for the calculation of the aircraft availability. The yearly forecasts were generated through the summation of the availability elements. Availability was simulated as a percentage and then translated to an equivalent number of aircraft.

**Table 5. Sample Availability Model Forecasts with Triangular Distributions**

| Year | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|---|---|---|---|---|
| NMCM | 0.1648 | 0.1634 | 0.1626 | 0.1624 | 0.163 | 0.164 | 0.1642 | 0.1648 | 0.1654 |
| NMCS | 0.0691 | 0.0586 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| NMCD(u) | 0.0236 | 0.0182 | 0.015 | 0.015 | 0.015 | 0.015 | 0.015 | 0.015 | 0.015 |
| PDM Possessed | 0.1032 | 0.1098 | 0.1162 | 0.1211 | 0.1237 | 0.1237 | 0.1228 | 0.1222 | 0.121 |
| Modification | 0.0741 | 0.0741 | 0.0889 | 0.1093 | 0.1111 | 0.1111 | 0.1111 | 0.1111 | 0.1111 |
| Availability | 0.5652 | 0.5759 | 0.5673 | 0.5422 | 0.5372 | 0.5362 | 0.5369 | 0.5369 | 0.5375 |
| Number of Aircraft | 15.26 | 15.55 | 15.317 | 14.64 | 14.503 | 14.476 | 14.497 | 14.495 | 14.512 |

# Chapter 4. Analysis

## Introduction

This chapter reviews the process for generating the cost and availability service life estimates. Ideally, this service life estimate would utilize both actual Coast Guard historical cost and availability data. Unfortunately much of the Coast Guard historical data is not maintained and accessibility to this data posed significant problems. Historical Coast Guard data was available for C-130 depot related costs for the last 15 years, as well as aircraft availability data for the last 6 years.

The Coast Guard data restrictions necessitated the cost estimates be formulated based on analogous Air Force aircraft. The Air Force Total Ownership Cost database (AFTOC) was utilized as the primary C-130 historical cost database. While the AFTOC data represents Air Force aircraft costs from 1996 to present, it was assumed that the annual trend in costs would be representative of the trends experienced by the Coast Guard.

## Review of AFTOC Data

The AFTOC database is a web enabled, and very extensive source of cost data for all U.S. Air Force aircraft across all Major Commands (MAJCOMs). The database lists cost data in the prescribed CAIG format from FY 1996 to present. It has the capability of displaying the cost data allocated to Level 1, Level 2 or Level 3 cost elements. This feature enables analysis at greater levels of detail for the distribution of costs.

Ideally, the data would have covered the entire life of the aircraft system. The Air Force does maintain aircraft system data prior to 1996 in the Weapons System Cost Retrieval System (WSCRS); however this data can only be accessed by written request.

Additionally, the WSCRS C-130 data prior to 1992 would not be compliant with the CAIG format, presenting cost translation problems. The AFTOC database was selected because of its currency and because of its compliance with the CAIG structure. Table 6 provides an example of the AFTOC data.

**Table 6. Sample of AFTOC C-130H Data (FY 2002)**

| CAIG | CAIG Description | Total | AFRC | AMC | ANG | F |
|---|---|---|---|---|---|---|
| 1.0 | Mission Personnel | $358,960,233.14 | $92,571,084.63 | $75,211,154.68 | $167,621,262.07 | |
| 1.1 | Operations | $104,428,654.05 | $22,375,504.15 | $37,944,471.84 | $34,057,135.12 | |
| 1.1.1 | Pilot | $46,802,475.10 | $7,112,288.08 | $17,905,716.92 | $17,143,287.57 | |
| 1.1.2 | Aircrew | $35,869,104.12 | $12,723,262.77 | $9,253,363.86 | $11,109,247.95 | |
| 1.1.3 | Crew Technician | $21,757,074.83 | $2,539,953.30 | $10,785,391.05 | $5,804,599.60 | |
| 1.2 | Maintenance | $168,100,024.73 | $45,019,540.44 | $34,398,864.06 | $75,653,654.15 | |
| 1.2.1 | Organizational | $53,429,972.47 | $11,511,216.01 | $22,133,403.21 | $11,747,988.99 | |
| 1.2.2 | Intermediate | $51,571,766.40 | $20,987,854.46 | $7,139,330.66 | $19,905,032.76 | |
| 1.2.3 | Ordnance Maintenance | $1,028,302.17 | $217,117.62 | $16,927.17 | $745,950.88 | |
| 1.2.4 | Other Maintenance Personnel | $62,069,983.68 | $12,303,352.34 | $5,109,203.01 | $43,254,681.52 | |
| 1.3 | Other Mission Personnel | $86,431,554.37 | $25,176,040.04 | $2,867,818.78 | $57,910,472.79 | |
| 1.3.1 | Unit Staff | $68,707,247.31 | $16,949,399.31 | $1,044,039.58 | $50,669,860.92 | |
| 1.3.2 | Security | $3,833,847.78 | $2,996,529.26 | | $676,218.51 | |
| 1.3.3 | Other Support | $13,890,459.28 | $5,230,111.47 | $1,823,779.21 | $6,564,393.36 | |
| 2.0 | Unit-Level Consumption | $223,723,718.45 | $38,803,891.53 | $64,483,478.73 | $104,775,992.05 | |
| 2.1 | POL/Energy Consumption | $67,440,606.24 | $16,478,091.76 | $13,529,067.40 | $31,783,947.66 | |
| 2.1.1 | AV Fuel | $66,305,826.93 | $16,197,183.26 | $13,446,042.98 | $31,000,696.49 | |
| 2.1.2 | POL | $1,105,363.93 | $280,908.50 | $53,609.03 | $783,251.17 | |
| 2.1.3 | Reserved | | | | | |
| 2.1.4 | Reserved | | | | | |
| 2.1.5 | Commercial Electricity | $29,415.38 | | $29,415.38 | | |
| 2.2 | Consumables | $46,514,032.96 | $8,769,526.61 | $11,221,000.11 | $23,027,703.42 | |
| 2.2.1 | General Support Division | $36,388,372.81 | $6,826,037.29 | $9,444,236.08 | $17,476,147.69 | |
| 2.2.2 | System Support Division | $30,250.00 | | | $11,000.00 | |
| 2.2.3 | Mission Support Supplies | $10,095,410.15 | $1,943,489.32 | $1,776,764.03 | $5,540,555.74 | |
| 2.3 | Depot Level Repairs (DLR) | $87,029,828.31 | $11,879,620.33 | $29,924,864.17 | $40,308,350.19 | |
| 2.3.1 | Flying DLR | $86,479,761.92 | $11,793,491.15 | $29,939,668.86 | $39,829,608.29 | |
| 2.3.2 | Non-Flying DLR | $550,066.39 | $86,129.18 | ($14,804.69) | $478,741.90 | |

The AFTOC data is presented as costs in dollars for the given year. In other words data from 1996 is presented in 1996 dollars. Leaving the data in this format influences the data and may camouflage trends that may exist. The data was adjusted for inflation and normalized to a constant year. The inflation indices were taken from the OSD inflation rate tables and are depicted in Table 7. The highlighted indices were used for data normalization. The AFTOC cost data was adjusted to constant fiscal year 2000 dollars (CY$2000) for consistency throughout the entire period being analyzed.

**Table 7. Raw Inflation Indices (www.saffm.hq.af.mil, Jan 2002)**

**USAF Raw Inflation Indices**
**Based on OSD Raw Inflation Rates**

| Convert From | | Fiscal Year | Military Compensation Pay Base (3500) | Military Compensation Other Expenses (3500) | Military Compensation Total (3500) | Retirement (3500) | Operations & Maint. Non-Pay, Non-POL (3400) | Research, Develop., Testing, Evaluation (3600) | Military Construct. (3300) | Fuel |
|---|---|---|---|---|---|---|---|---|---|---|
| 1996 | to | 2000 | 1.143 | 1.126 | 1.142 | 1.105 | 1.051 | 1.051 | 1.051 | 0.826 |
| 1997 | to | 2000 | 1.111 | 1.098 | 1.110 | 1.084 | 1.029 | 1.029 | 1.029 | 0.815 |
| 1998 | to | 2000 | 1.081 | 1.073 | 1.080 | 1.127 | 1.022 | 1.022 | 1.022 | 0.681 |
| 1999 | to | 2000 | 1.045 | 1.041 | 1.045 | 1.100 | 1.014 | 1.014 | 1.014 | 0.747 |
| 2000 | to | 2000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 2001 | to | 2000 | 0.962 | 0.970 | 0.962 | 1.033 | 0.982 | 0.982 | 0.982 | 0.614 |
| 2002 | to | 2000 | 0.906 | 0.916 | 0.907 | 0.951 | 0.966 | 0.966 | 0.966 | 0.620 |

Additional data reduction occurred through the elimination of cost elements that did not translate to the Coast Guard cost structure. For instance, the Coast Guard does not utilize intermediate maintenance facilities for the C-130. Any traditional intermediate maintenance functions are either performed at Coast Guard operational units with unit or contract maintenance personnel, or at the depot or repair facility.

Another key cost element difference is that the Coast Guard utilizes the same personnel for operational aircrew as well as aircraft maintenance, whereas the Air Force uses separate personnel. This inconsistency was resolved by examining the sum of the Air Force costs for the aircrew, crew technician and all the maintenance elements, with the exception of the intermediate maintenance costs. This allowed the assessment of the trend for the combination of these functions, which best reflects the reality of the Coast Guard.

The data was further reduced to those elements that tended to dominate the cost of the system. The idea being that the most expensive cost elements were the primary concern and deserving of the bulk of the analysis. The Air Force C-130 cost structure in Figure 11 shows that the O&M costs are dominated by the Personnel and Unit Level Consumption cost elements.

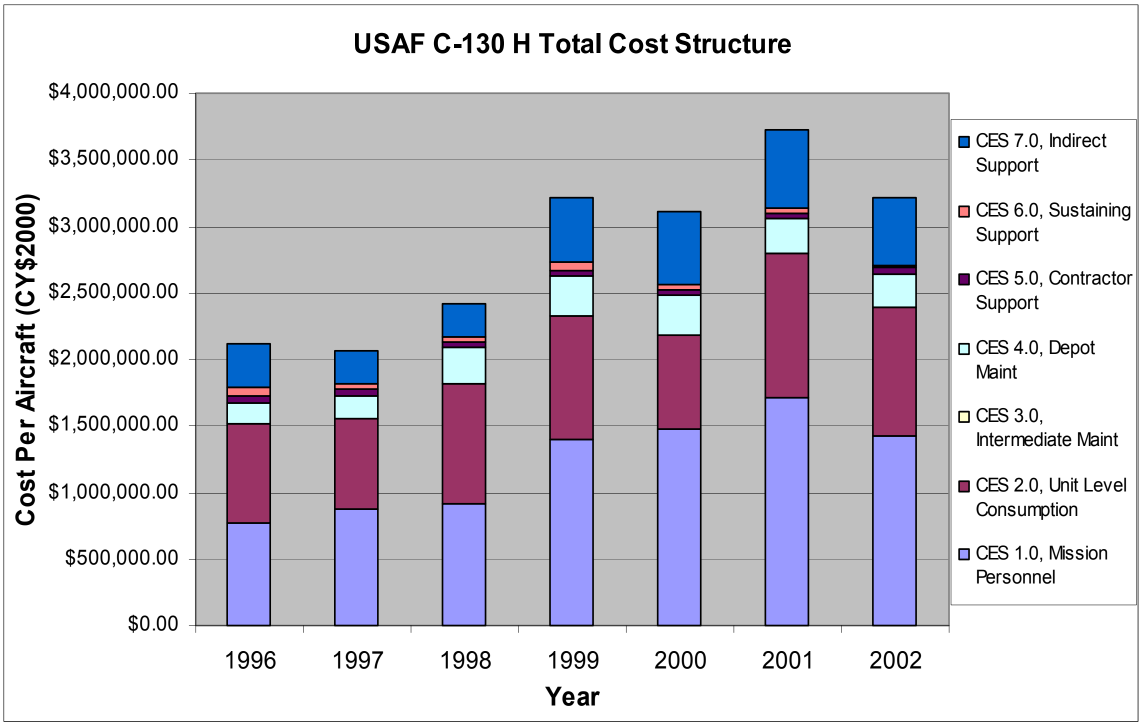



**Figure 11. AFTOC C-130H cost breakdown**

The Indirect Support and Depot cost elements contribute approximately 20 to 30 percent of the total O&M costs and were included in the analysis. As noted in Chapter 2, the Depot costs will become more influential as the airframes age. The Contractor Support and Sustaining Support elements were the smallest contributors to the overall cost and could be excluded from further analysis because of their minor contributions.

Contractor Support was eliminated, however, Sustaining Support was not because it includes costs associated with upgrades and modifications.

The Level 1 cost elements have been reduced to Mission Personnel, Unit Level Consumption, Depot Maintenance, Sustaining Support, and Indirect Support. These were representative of Coast Guard cost sources and exhibited the greatest influence for the analogous Air Force C-130s. Next, it was necessary to examine the cost elements at their lower levels. Examining each cost element allocation at Level 3, any trend could be visualized with respect to time. For example, Figure 12 depicts the Level 3 cost allocation for Unit Level Consumption adjusted to constant year 2000 dollars (CY$2000). Examining this data, it appears that two elements dominate the cost structure, Fuel and Flying Depot Level Reparables. These two elements also exhibited an increasing trend with respect to time. The remaining Level 3 elements appear relatively stationary, or contribute only a minor percentage of the total cost for this Level 1 cost element. These relatively stationary elements will only be included as constant annual costs. Additionally, it was discovered that many of these smaller sub-elements are not accounted for as independent cost sources within Coast Guard data sources. They were typically aggregated with similar costs, or aggregated across many different platforms (i.e. C--130, HH-65, HH-60, or HU-25 aircraft).

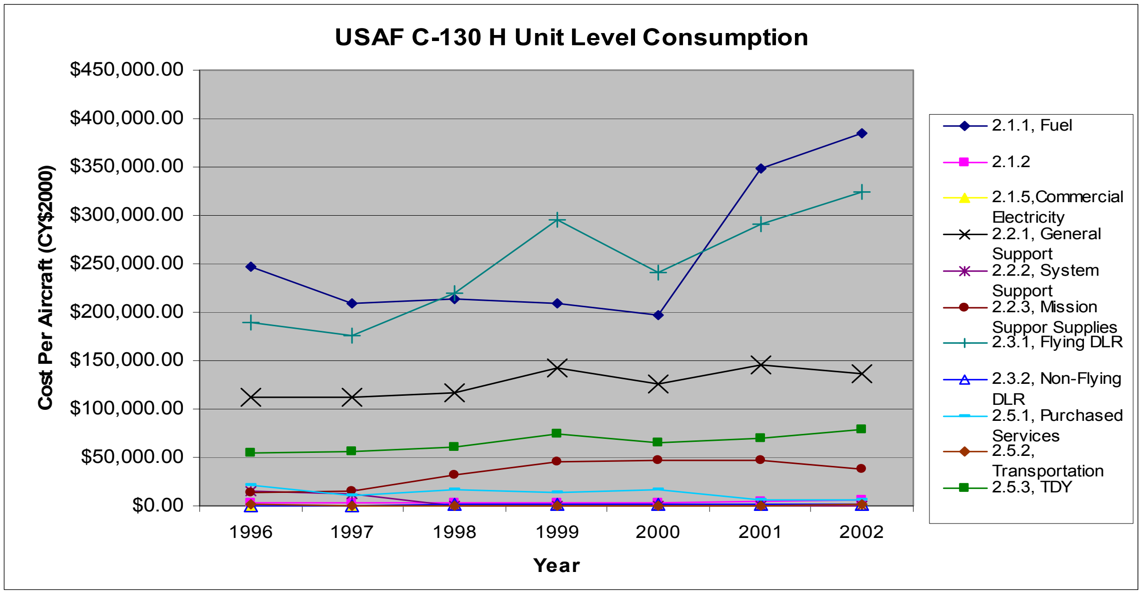



**Figure 12. USAF C-130H Unit Level Consumption, Level 3**

The determination was made to model the Coast Guard Fuel and Flying Depot Level Reparables costs as trends with respect to time. Figure 13 depicts the Level 3 elements that were retained within this cost element for further forecasting purposes. The other Level 3 elements were included in the total cost as constant cost sources.

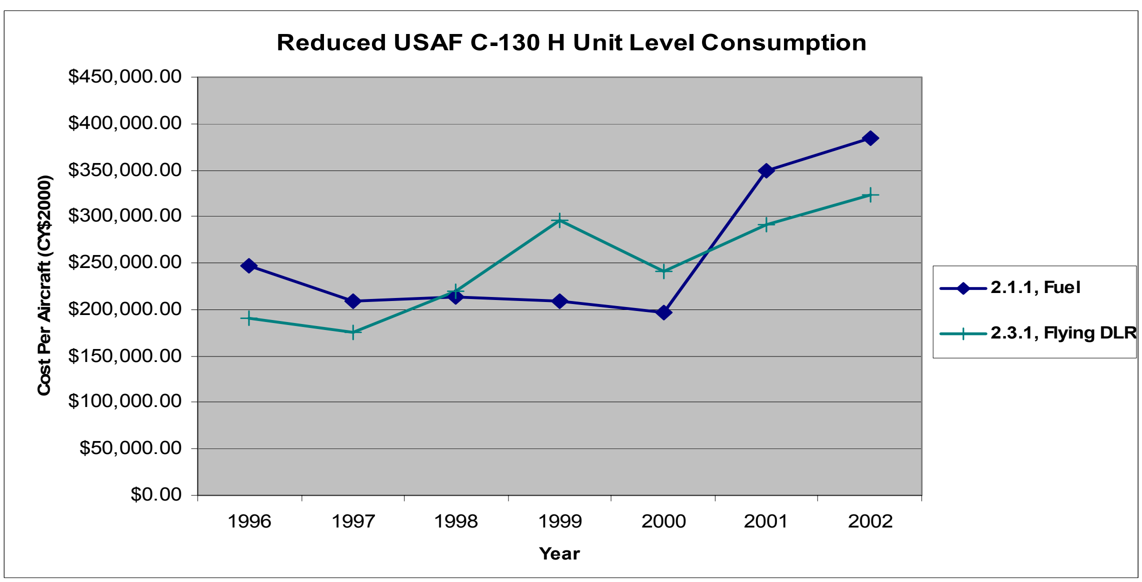



**Figure 13. Reduced USAF C-130H Unit Level Consumption, Level 3**

In the case of certain cost elements, the historical data was only allocated to Level 2 sub-elements, for instance, Depot Maintenance (Figure 14). In this situation, a similar evaluation was performed which resulted in the elimination of the Depot Maintenance - Other cost sources. See Figure 15.

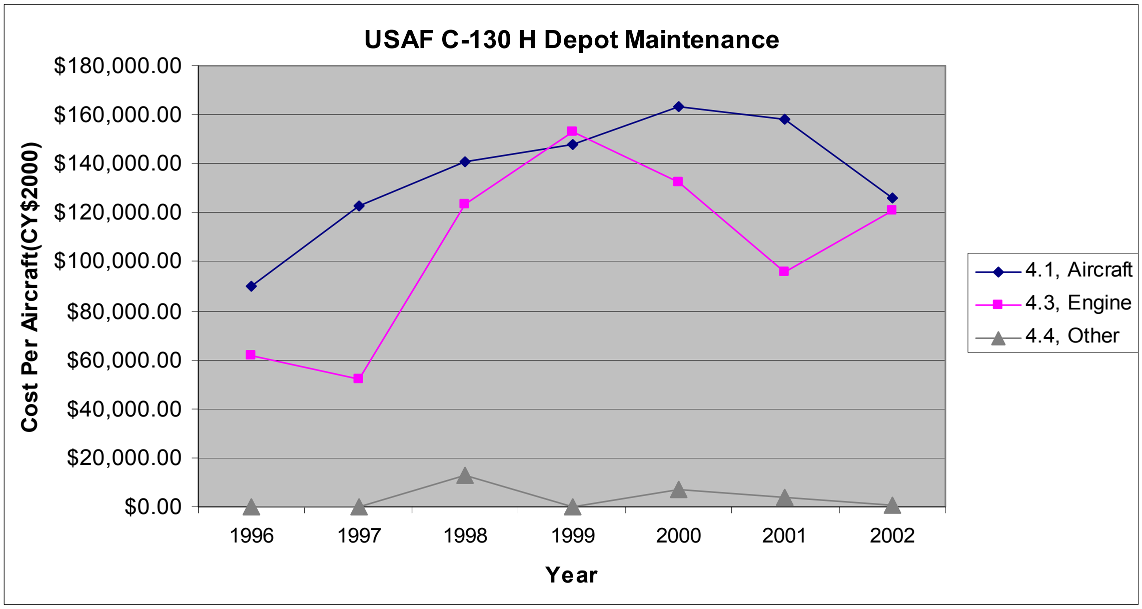



**Figure 14. USAF C-130H Depot Maintenance, Level 2**

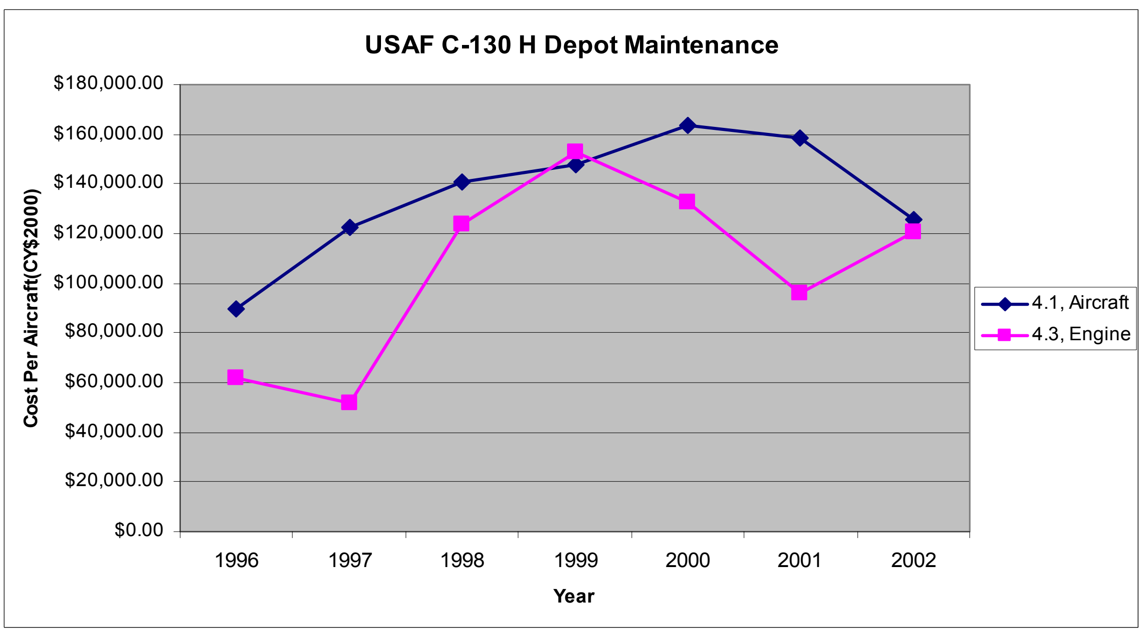



**Figure 15. Reduced USAF C-130H Depot Maintenance, Level 2**

This process of examining the lower level cost elements continued until all cost elements that represented the cost sources relevant to Coast Guard aircraft were identified. A subset of these cost elements were evaluated as unchanging with respect to time and were treated as stationary costs. These stationary costs were not forwarded to the subject matter experts, and were modeled as constant cost sources for the entire period of evaluation. The identified cost elements that did exhibit a trend with respect to time were forwarded to selected experts, and examined for an assessment of each element's uncertainty. Appendix C contains graphical representations of the Air Force historical data for the five Level 1 cost elements that were utilized for the analysis of this study.

**Review of Coast Guard Availability Data**

Gathering unit availability data was significantly easier than collecting cost data since the Coast Guard has been using this information as a Measure of Effectiveness for many years. Likewise, there was an abundance of Depot Maintenance information. This information, combined with expert opinion for future airframe modification efforts provides a sound basis for future fleet availability estimates.

Figure 16 depicts the historical unit availability over the last six years. As previously mentioned, the Coast Guard maintains an availability goal of 71 percent. Aircraft systems that are not achieving this availability objective often receive increased resources to elevate the fleet-wide unit availability (Boubolis, 2002). This is likely a significant cause and effect relationship at the program level and could easily explain any tendency to return to a value approaching 71 percent.

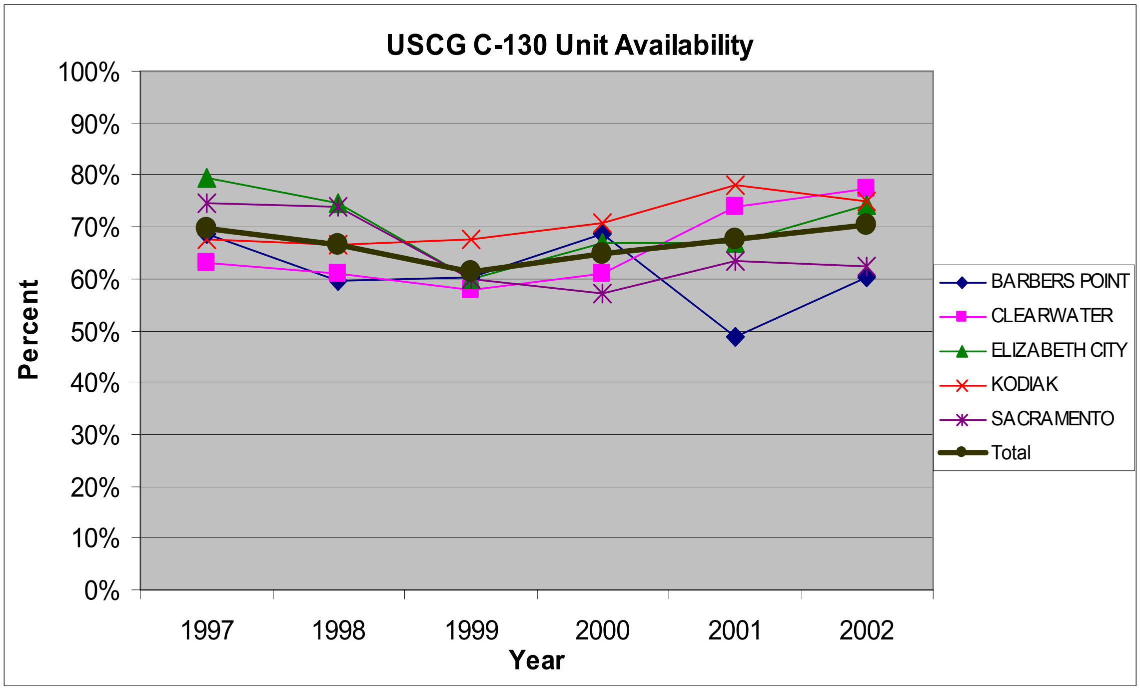



**Figure 16. Coast Guard C-130 Unit Availability**

As previously mentioned, this study is interested in overall aircraft availability, to include those airframes that are undergoing PDM or Modifications. The incorporation of these additional elements will help to describe the anticipated fleet availability in an unconstrained environment and provide indications of future aircraft readiness challenges.

There are many PDM metrics that can be utilized to predict the PDM possession rate, and the Coast Guard is fortunate that managing a small number of aircraft allows for more customized analysis of the historical data. For example, the Coast Guard is currently tracking PDM corrosion maintenance hours by tail number. The Coast Guard is also attempting to develop an environmental severity index that will illuminate any relationships between aircraft basing and corrosion maintenance requirements. For the purposes of this study, it was sufficient to examine the historical PDM flow days and the

PDM interval, as this data can generate a PDM possession rate. Figure 17 depicts the Coast Guard historical PDM flow days and Figure 18 depicts the historical PDM interval.

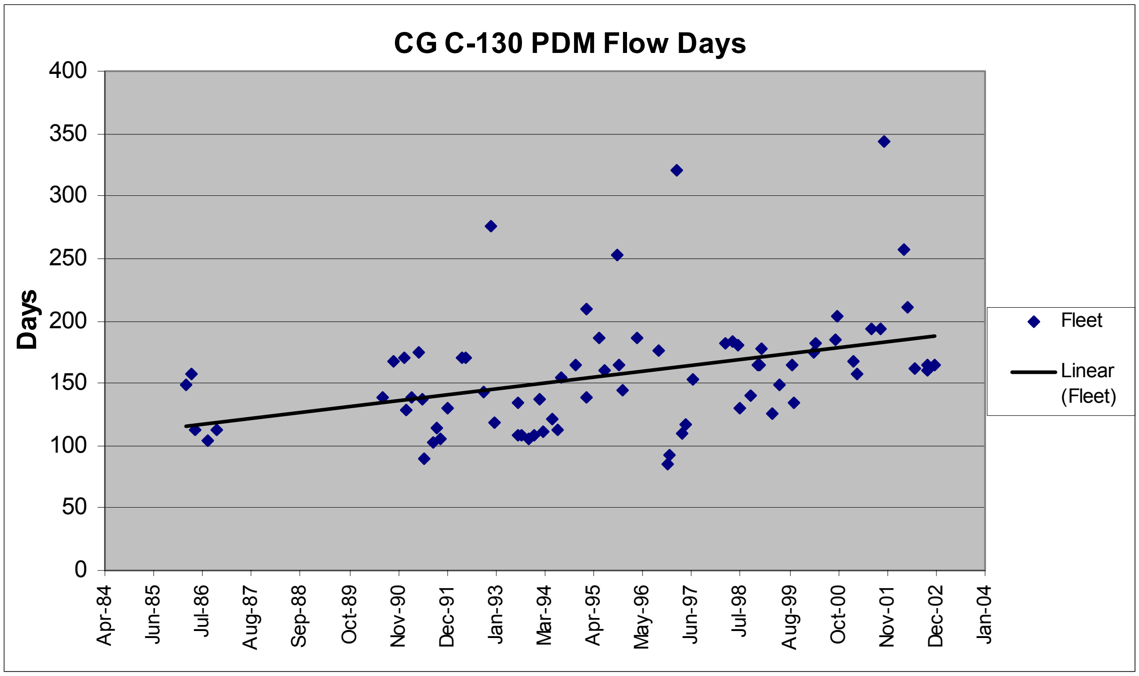



Figure 17. Coast Guard C-130 PDM Flow Days

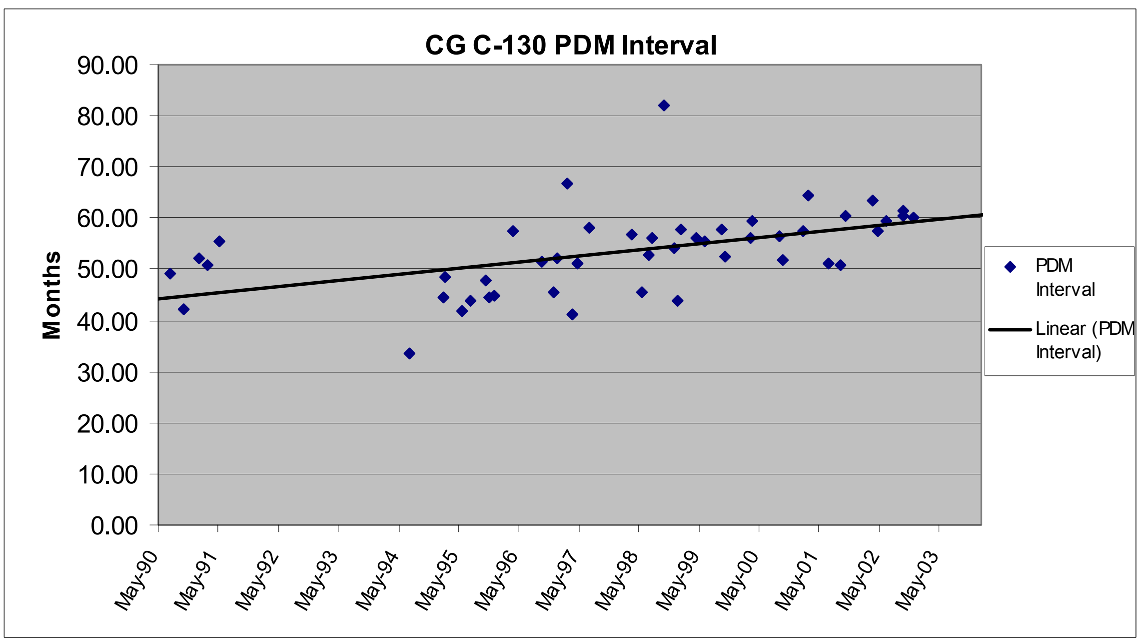



Figure 18. Coast Guard C-130 PDM Interval

The final measure used to calculate fleet availability was the aircraft modification possession rate. Unfortunately, historical data on this measure is not specifically tracked. It is feasible that this data could be backed out of the availability and PDM data, but ultimately it would represent a wide variety of modifications. These modification programs are typically supported through short term budget appropriations, and are executed within the operational and PDM constraints. For these reasons, experts within the Product Line were used to predict modification possession rates that captured the range of possibilities.

**Solicitation of Expert Opinion**

Due to the limited amount of historical data, the lack of Coast Guard Cost Estimating Relationships and the relative uncertainty for the future, it was important to solicit the opinion of system experts. While not as rigorous or consistent as Parametric cost estimating, expert opinion does provide insight into the uncertainty for occurrence of future events.

The reduced Air Force and Coast Guard data was presented to two Coast Guard C-130 program experts. These experts were asked to assess the validity of using Air Force cost data for estimating Coast Guard costs. Specifically, the experts were asked to consider the following questions while examining the data.

1) Is it appropriate to formulate an estimate for Coast Guard costs based upon this data set?
2) Is the Air Force data sufficient to create a trend estimate?
3) Will the estimated trend change with respect to time?

They were then asked to draw or explain their estimate for each of the cost elements over a 20-year period. The experts were encouraged to discuss their thoughts, but it was requested that they provide individual estimates.

To assist in their evaluation, the experts were presented with the following comparison of Air Force and Coast Guard C-130 Flight hour usage. Figure 19 illustrates the consistent higher usage of the Coast Guard's C-130s when compared to Air Force C-130s.

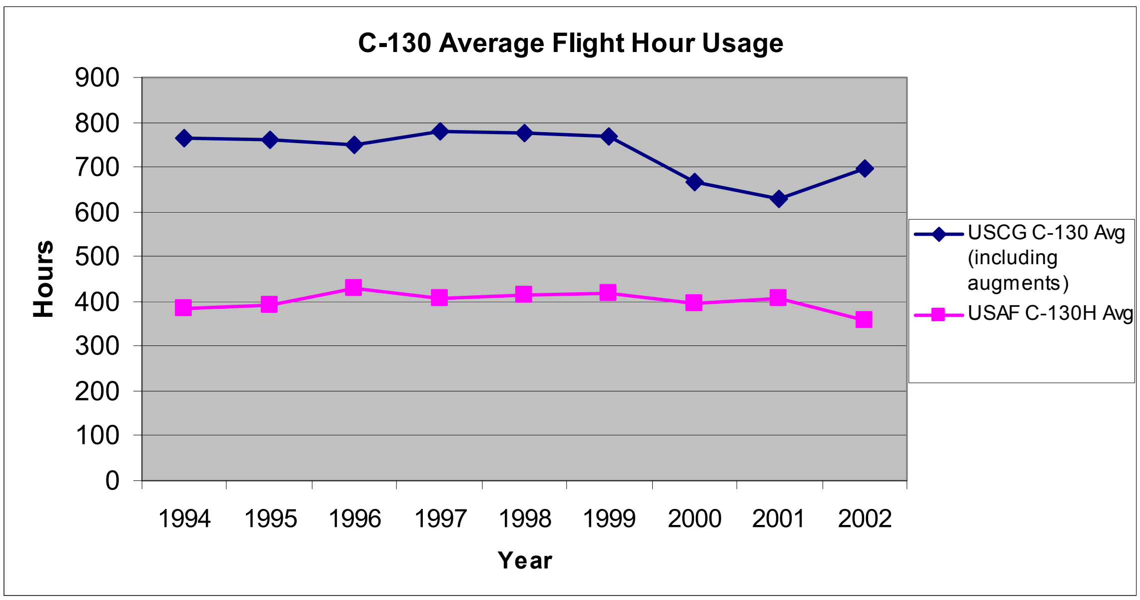



**Figure 19. C-130 Flight Hour Comparison, USAF vs Coast Guard**

Figure 20 was included as an example of the type of the estimate information that was requested from the experts. The Contractor Support element was not included as a cost element of uncertainty. The complete initial solicitation document is included as Appendix D.

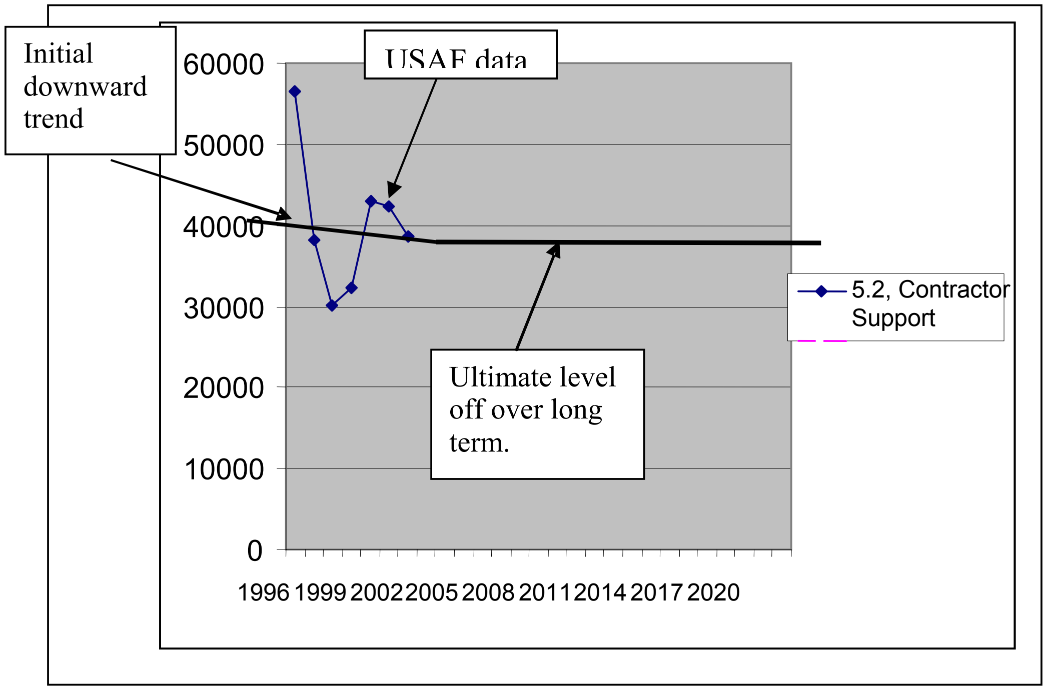



**Figure 20. Initial Solicitation Example Utilizing eliminated Cost Element**

Only one of the selected experts was able to return his initial solicitation within the requested timeline. The returned document's trend estimates were anchored to actual Coast Guard FY2002 data, with the trend estimate scaled as a percentage deviation. The trend estimates, now anchored and scaled to the Coast Guard actual cost data, were returned to both original experts for further evaluation. This iterative solicitation allowed the experts to seek clarification of unclear items, and an opportunity for clarification of the expert's submission. As an example, Figure 21 represents the 20-year estimate for PDM costs anchored to the actual Coast Guard costs. The expert's response identified that Coast Guard PDM costs had been steadily increasing. In the expert's opinion, the costs will increase slightly between 2003 and 2005, but eventually decrease in years 2005 to 2011, as the Coast Guard reaps the benefits of the recent fundamental shift away from a PDM to a Progressive Structural Inspection (PSI) approach. Long term PDM costs were expected to gradually increase for the last 10 years of the estimate.

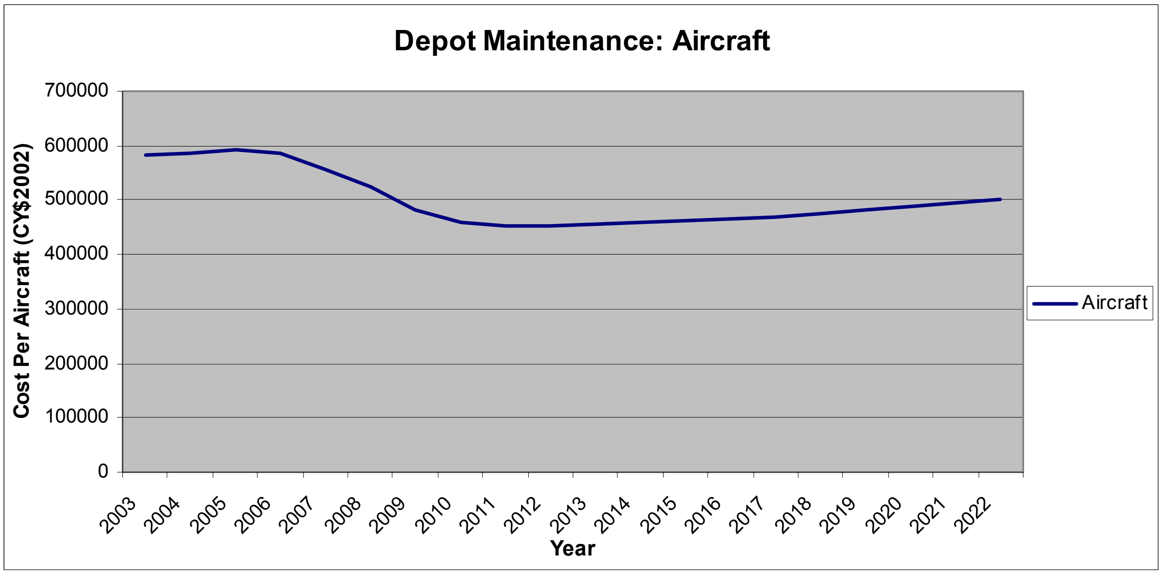



**Figure 21. Coast Guard Depot Maintenance Trend Estimate**

The remaining cost elements were evaluated in a similar fashion, and the Coast Guard adjusted estimates were returned to the experts for evaluation of the best and worst case estimates. This second solicitation allowed both experts to reassess the previous input and once again, discussions between experts and with the researcher helped to clarify issues within the estimate, and the estimating process.

The second solicitation document is included as Appendix C and its primary purpose was to quantify estimates for the minimum and maximum values for the each cost element. Additionally, this document requested that the experts provide estimates for the minimum, most likely and maximum values for C-130 NMCM, NMCS, NMCD, PDM Flow days, PDM interval, and equivalent modification possessed aircraft.

Figure 22 depicts the expert response for Depot Maintenance costs and now forms the basis for both the triangular and beta distributions used in the simulation model. The final cost and availability estimates are included in Appendix F. The only remaining aspect was the assessment of correlation between the cost and availability variables.

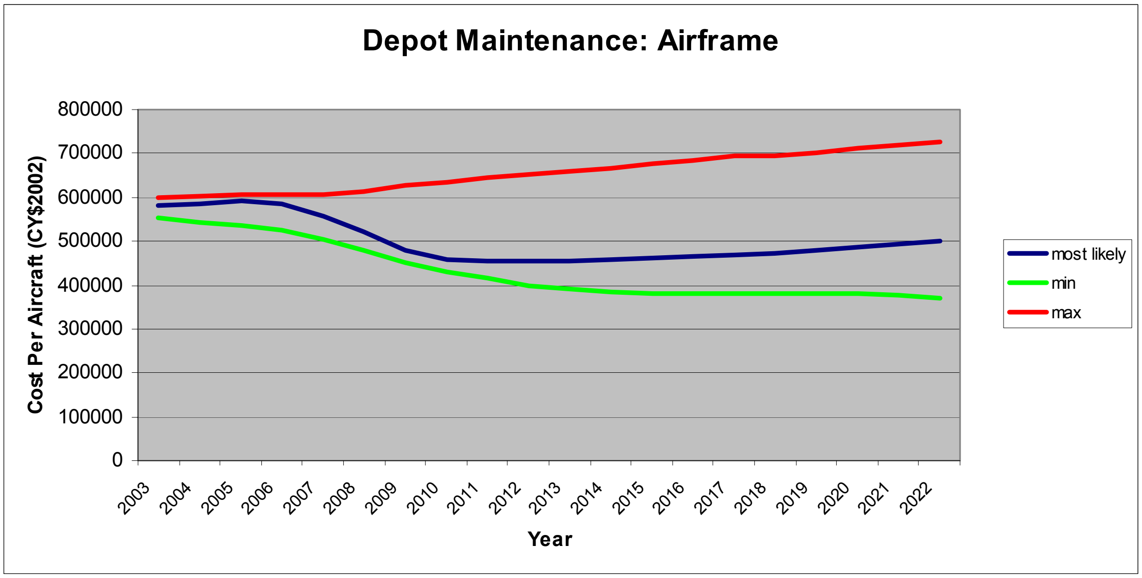



**Figure 22. Coast Guard Depot Maintenance Minimum, Most Likely and Maximum Estimate**

Due to a lack of historical cost data, a calculation of correlation between the cost elements was not performed. Once again expert opinion was used as a means of approximating the degree of correlation between cost elements and availability measures. The final correlation coefficients are presented in Table 8.

**Table 8. Cost and Availability Correlation Matrices**

**C-130 Cost and Availability Correlation**

Please enter values from correlation scale in uncolored empty cells

| | Pilot | Aircrew/Technician | Fuel/POL | DLR | Depot - Airframe | Depot - Engine | Support Equip | Sustaining Eng Support | Base Operating Costs |
|---|---|---|---|---|---|---|---|---|---|
| Pilot | 1 | | | | | | | | |
| Aircrew/Technician | 0.3 | 1 | | | | | | | |
| Fuel/POL | 0.3 | 0.2 | 1 | | | | | | |
| DLR | 0.3 | 0.2 | 0.3 | 1 | | | | | |
| Depot - Airframe | 0.3 | 0.2 | 0.5 | 0.2 | 1 | | | | |
| Depot - Engine | 0.3 | 0.2 | 0.6 | 0.2 | 0.3 | 1 | | | |
| Support Equip | 0 | 0.1 | 0.3 | 0.2 | 0.2 | 0.1 | 1 | | |
| Sustaining Eng Support | 0 | 0.1 | 0.2 | 0.3 | 0.3 | 0.1 | 0.1 | 1 | |
| Base Operating Costs | 0 | 0 | 0.1 | 0 | 0.1 | 0.1 | 0.1 | 0.1 | 1 |

| | NMCM% | NMCS % | NMCD % | Flow Days | PDM Interval | Modification Days |
|---|---|---|---|---|---|---|
| NMCM% | 1 | | | | | |
| NMCS % | -0.3 | 1 | | | | |
| NMCD % | -0.2 | -0.1 | 1 | | | |
| PDM Flow Days | 0.3 | 0.2 | 0.2 | 1 | | |
| PDM Interval | 0.2 | 0.3 | 0.3 | 0.5 | 1 | |
| Modification Days | 0.2 | 0.2 | 0.2 | -0.2 | 0.3 | 1 |

Correlation Scale

| | Negative | Positive |
|---|---|---|
| Zero | 0 | 0 |
| Slight | -0.1 to -0.3 | 0.1 to 0.3 |
| Moderate | -0.4 to -0.6 | 0.4 to 0.6 |
| Strong | -0.7 to -0.9 | 0.7 to 0.9 |
| Perfect | -1.0 | 1.0 |

## Simulation Results

The cost and availability simulations were performed utilizing Crystal Ball® as an add-in to Microsoft Excel®. Ten thousand trials were performed, based upon the recommendation from Garvey (2000), with an initial random number seed of 999. For the purposes of comparison, the models were executed first with triangular distributions and then with BetaPERT distributions. Figure 23 depicts a typical Crystal Ball® Frequency Chart for the cost per C-130.

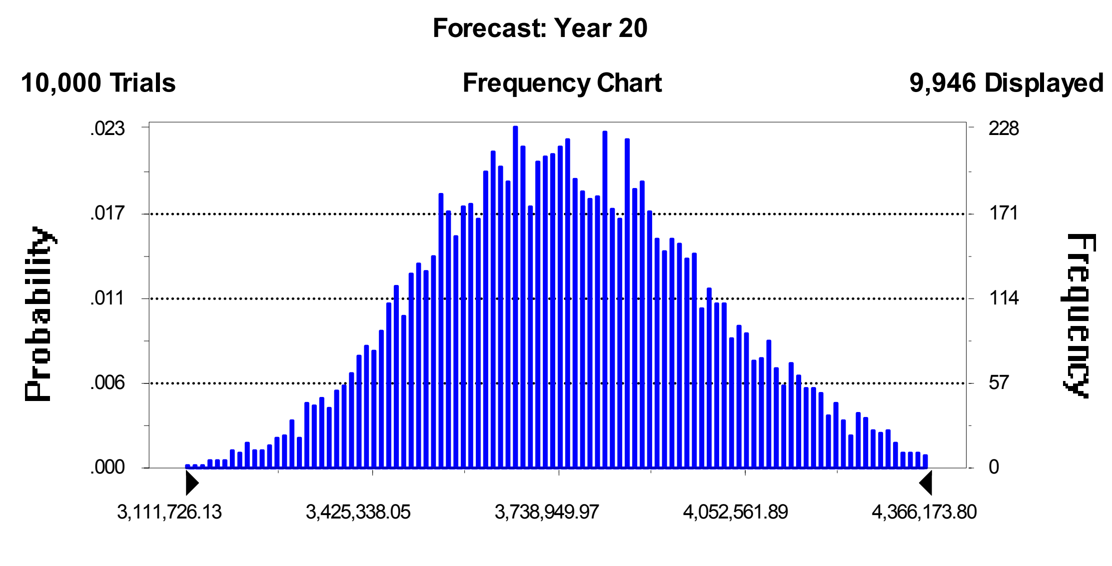



**Figure 23. Sample of Crystal Ball Frequency Chart**

This histogram represents the sampling distribution of potential costs based upon the input parameters. In this particular example the output is the cost per C-130 not including the stationary costs. This information makes it possible to establish predictions for costs being less than, or more than a specific value. Crystal Ball® provides the option of displaying this information graphically, or as a list of statistical measures (Table 9).

**Table 9. Statistical Results, 2022 Cost Per C-130 estimate, Triangular Distribution Assumption**

| Statistics: | Value |
|---|---|
| Trials | 10000 |
| Mean | 3,662,959.52 |
| Median | 3,661,521.98 |
| Mode | --- |
| Standard Deviation | 53,336.95 |
| Variance | 2,844,830,506.34 |
| Skewness | 0.12 |
| Kurtosis | 2.72 |
| Coeff. of Variability | 0.01 |
| Range Minimum | 3,504,781.81 |
| Range Maximum | 3,838,479.03 |
| Range Width | 333,697.22 |
| Mean Std. Error | 533.37 |

Often it is preferred to represent this same information as a cumulative density function to more easily assess the probability associated with the system cost being less than, or more than a specific dollar amount (Figure 24). The probability is obtained by proceeding vertically from a specific cost until reaching the top of the cumulative density function, and then proceeding horizontally to read the corresponding probability.

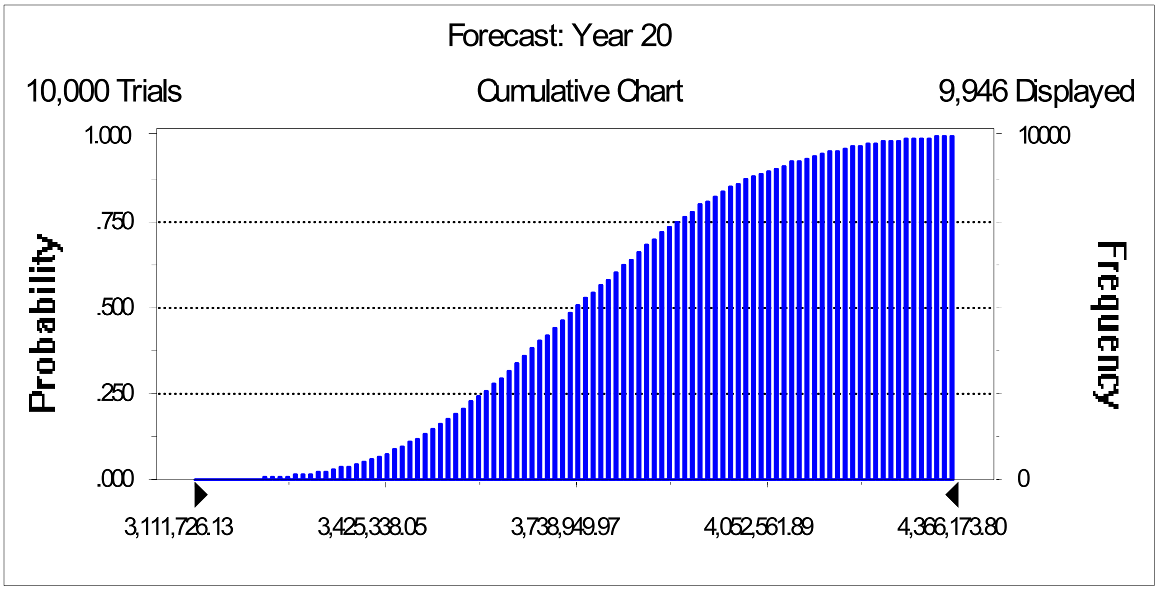



**Figure 24. Sample of Crystal Ball Cumulative Chart**

A similar sampling distribution was generated for each year of the estimate and is used to generate the trend estimate. Trend estimates, that include the stationary costs, were created for the cost per aircraft and also for the total system. Figure 25 depicts the Total System cost based upon the Triangular distribution assumption. Figure 26 depicts the Total System cost based upon the BetaPERT distribution assumptions.

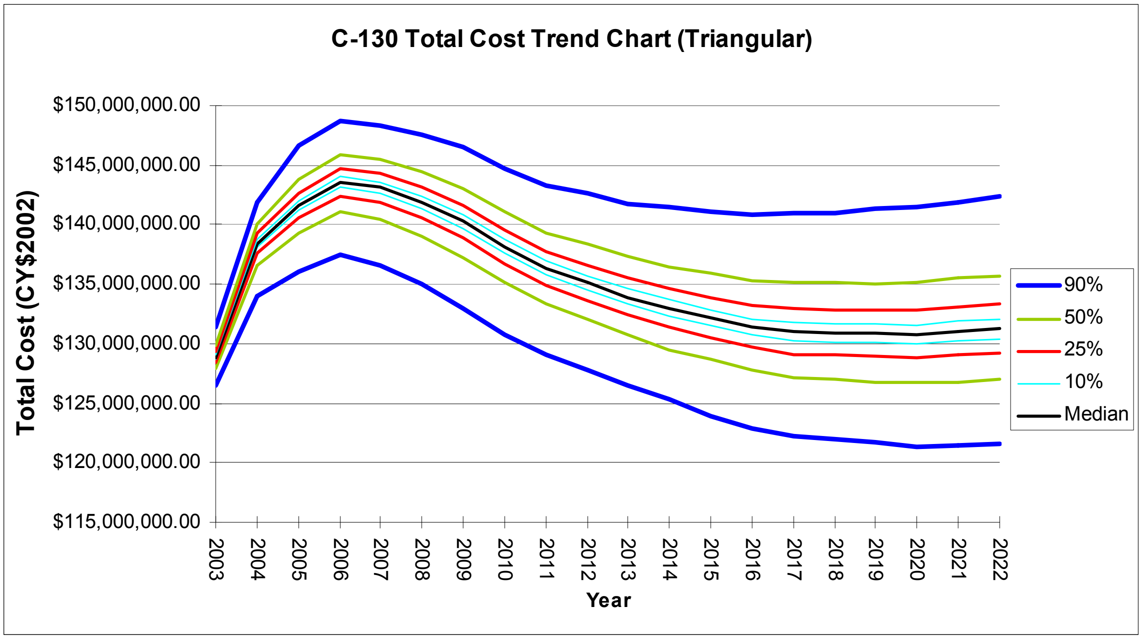



**Figure 25. C-130 Total Cost Trend based upon Triangular distributions**

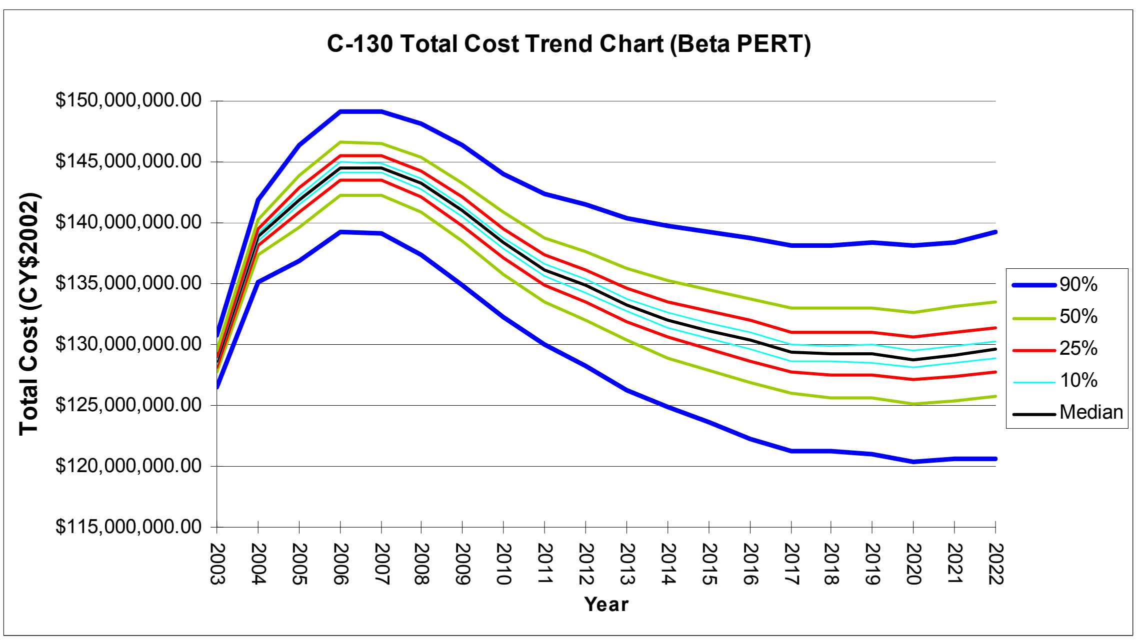



**Figure 26. C-130 Total Cost Trend based upon BetaPERT distributions**

Comparing these simulations side by side, it is apparent that they both exhibit the same general shape and tendency. There is an initial increase in the total cost under both assumptions, until approximately FY 2006 when the Total System cost decreases. This is followed by a decrease in total cost until approximately 2016 when the trend appears to remain relatively constant, or display a slight increase, depending on the level of certainty that is being examined.

The primary difference between the two trend estimates is that the variance is slightly smaller for the BetaPERT estimate. As described in Chapter 3, this is the result of greater emphasis on the most likely value of the estimates. It can also be observed that the BetaPERT distributions resulted in a trend estimate that was slightly lower, beyond approximately 2010, when compared to the same distribution curve with the triangular trend estimate.

The overall trend output provides a quantitative representation of the cost risk associated with the range of possible outcomes. It is now possible to visualize the extremes of the total costs, in addition to the median value for the total cost of the system. Since the median total cost value has an equal probability for being exceeded or not exceeded, it would seem prudent to pursue a funding level that represents a greater probability of covering all expenditures. For instance, it might be prudent to seek funding that provides a confidence level of 75 percent for the costs not exceeding this value. This provides an added assurance that the program will not fall short of the required operating funds for a given year. Obviously the selection of the funding target would be subject to the discretion of the Program Manager, but it is clear that this can now be supported with a desired confidence level.

A similar process was followed for the generation of the availability trend estimate. The trend generated for C-130 availability with Triangular distributions is depicted in

Figure 27 and with BetaPERT distributions is depicted in Figure 28. For simplicity and clarity purposes, the availability is represented as equivalent aircraft.

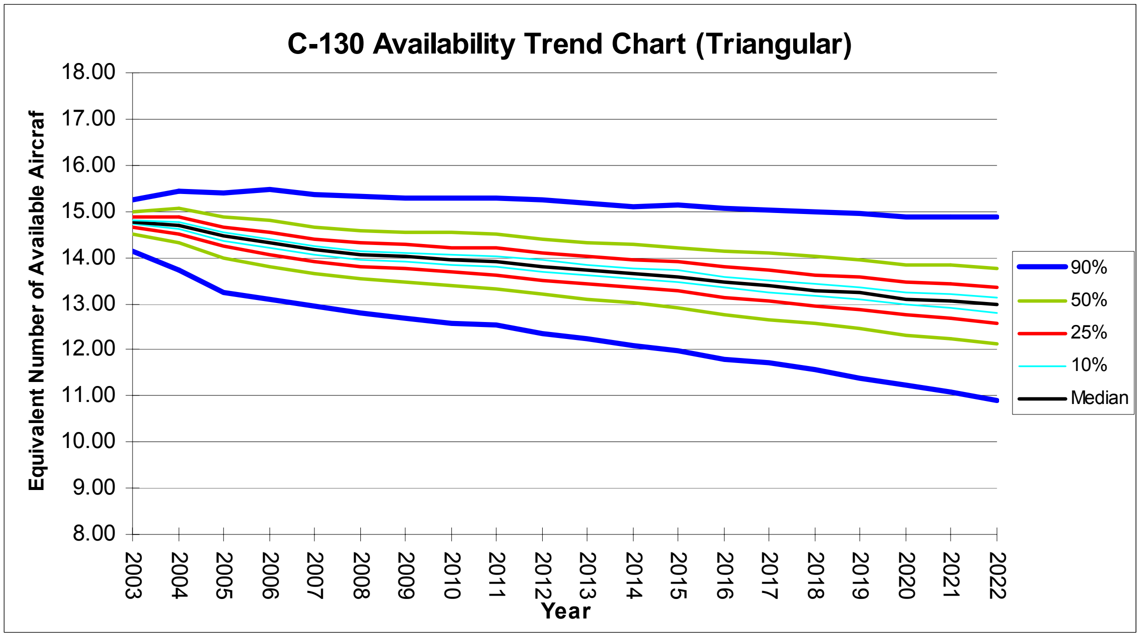



**Figure 27. C-130 Availability Trend based upon Triangular distributions**

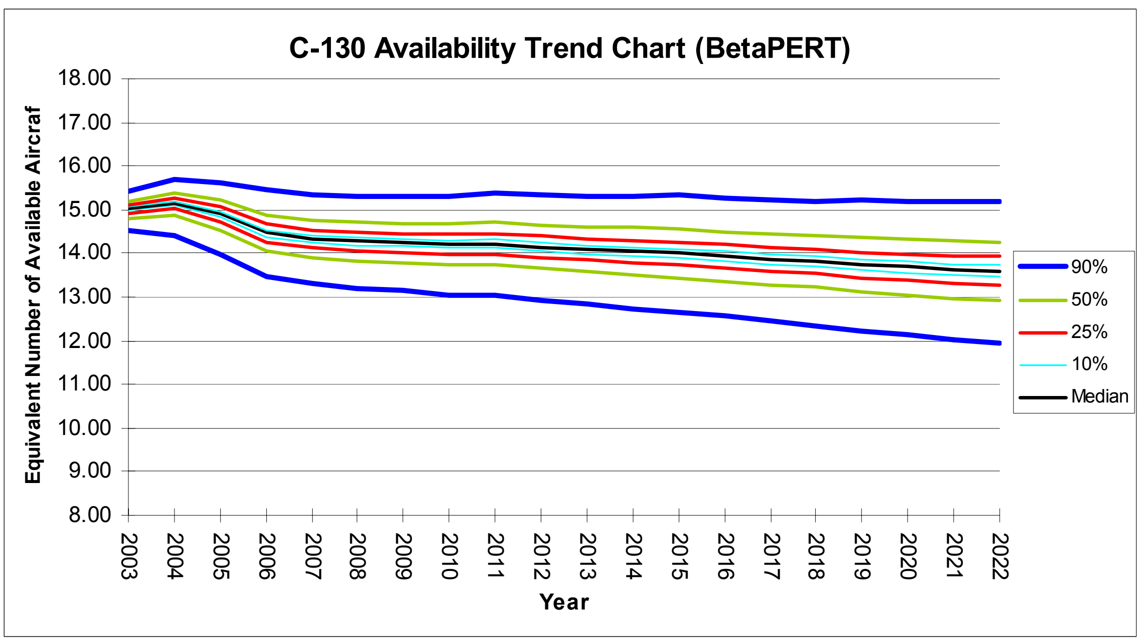



**Figure 28. C-130 Availability Trend based upon BetaPERT distributions**

Both of these trends show a decline in aircraft availability for the 20 year period. Depending on which distribution was used, the median value for availability decreases by 1.5 to 2 aircraft over the period of study. Once again, the Triangular distributions resulted in slightly larger variance than the BetaPERT distributions. This variance difference results in a prediction of 11 aircraft available versus 12 in the year 2022 at the lower 90 percent boundary ($5^{th}$ percentile). This difference at the lower 90 percent boundary describes the model's sensitivity to the use of triangular versus BetaPERT distributions. If the expert or program manager is comfortable with providing four times the emphasis on the most likely value, then the BetaPERT prediction interval is suitable for availability risk analysis, creating a smaller variance. However, if the expert or program manager favors equal emphasis for the defining parameters, then the more conservative triangular estimate is suitable for availability risk analysis.

The availability trend estimate quantifies the availability risk associated with each year. Depending upon the desired level of confidence, the Program Managers can visualize the availability impact of the current maintenance and logistics practices. Much like the discussion of total cost, it would now be up to the Program Managers to decide what level of confidence they wish to base decisions on.

Comparing the cost and availability estimates side by side, it is possible to examine the critical years where a cost increase or availability decrease might exceed program constraints. For example, in the year 2010, it is predicted that the median of the aircraft availability will be approximately 14 equivalent aircraft. Comparing this to the total cost trend estimate, it is apparent that this occurs at a time when total costs are estimated to be decreasing (Figure 29). This type of information should inspire management decisions that would adjust one resource to influence the other. In this notional example, continued funding at the 2008 level prior to 2010 could preclude or postpone further reduction in availability. Figure 29 depicts this notional adjustment to the total cost and a notional response in the aircraft availability.

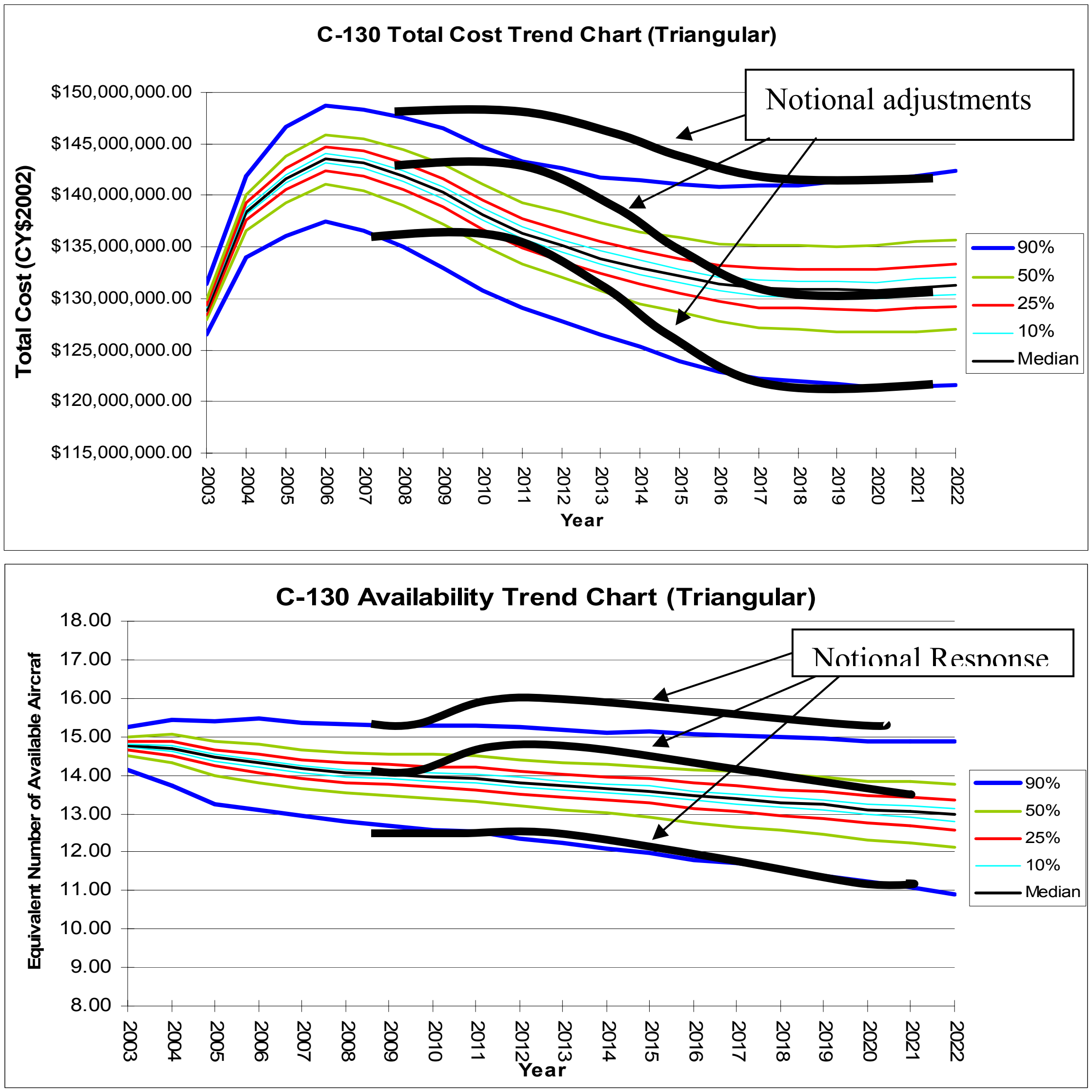



**Figure 29. Comparison of Total Cost to Aircraft Availability**

This application of applying adjustments in the cost profile and observing the response in the availability profile could be quite powerful for decision makers.

Implementing these adjustments could be pursued with the same methodology used for the initial estimate of cost and availability.  Each availability improvement initiative could be modeled as having a minimum, most likely and maximum availability parameter.  Likewise, the availability improvement initiative could be modeled as an associated minimum, most likely and maximum cost.

## Chapter 5. Conclusions and Recommendations

### Introduction

This chapter is presented for the purpose of summarizing the results of the study. It presents the limitations of the study, as experienced by the researcher, and the areas identified for further study.

### Background

The Coast Guard is facing a dramatic transformation of its entire structure over the next several years. The implementation of the Integrated Deepwater System is breaking new ground for the Coast Guard as it strives to meet the mission requirements for the 21$^{st}$ Century. However, there is now an additional organizational transformation taking place. Since this research was commenced, it has been determined that the Coast Guard will be transferred intact to the new Department of Homeland Security. This migration is clearly based upon compelling shared aims between the mission of the Coast Guard and the tenets of the Department of Homeland Security. However, it brings significant challenges to the men and women of the Coast Guard.

Personnel, equipment and organizational elements will be exercised to the limit of their abilities. The seriousness of these challenges and the enormity of the tasks ahead require the maximum effort from every individual and resource. With this in mind, it will be vital that each resource is properly managed to ensure that the required level of service is maintained at a reasonable cost.

## Research Focus

This study examined the current status of the Coast Guard C-130s and provided a method for predicting the service life costs for the next 20 years. This research also established a prediction for the aircraft availability over the next 20 years. By establishing a reasonable assessment of cost and availability, it was demonstrated that program managers can make better decisions regarding modernization and retirement of C-130 airframes.

## Summary of Results

Based upon the simulation results, the Coast Guard can expect the Total Cost of the C-130 aircraft to increase in the years 2002 to 2006, and also be higher in the long term (2007 – 2022) than they are today. This near term increase in cost is a considerable concern because it would coincide with the execution of the Integrated Deepwater System. Likewise the C-130 availability will continue to decline as PDM flow days continue to increase, maintenance requirements expand and modification efforts remain a necessity for the long term.

This study provides an improved method of examining potential cost and availability predictions versus simply examining the most likely estimate. The decision maker can now witness the range of potential outcomes, and engage risk management techniques in a more focused manner. Critical periods can be identified and potentially averted through advanced planning and recurring analysis. This study also creates opportunities for evaluating an adjustment in the funding profile, and observing the corresponding response to availability.

A key discussion point for this study is the validation of the results. Regarding an estimate of future events, validation of risk models is generally only possible over time (Koller, 2000:3).

> Attempting to validate the model relative to some other path that might have been taken or another model that might have been used is folly. You rarely, if ever, have the opportunity to know the result(s) of the "road not taken". In the case of many of the scenarios described in this book, the only validation possible is to deem whether the decisions made using model output were, in the end, good decisions for the company. (Koller, 2000:3)

**Recommendations**

The status of the Coast Guard accounting system cannot be adequately evaluated based on the limited exposure gained from this research. However, after examining just a fraction of the structure and processes in use by the Air Force and DoD, it seems likely that the Coast Guard could reap tremendous benefits from similar practices. First and foremost would be the benefits that could come from a historical cost database that is accessible from all management levels. While it would take several years before any satisfactory results could be gathered from the data, eventually, it would be possible to create purely objective cost estimating relationships for any system represented in the database. The current acquisition of six new C-130Js presents an excellent opportunity for creating this type of database and would allow full analysis of the future system costs.

Proceeding hand-in-hand with the creation of a cost database, the Coast Guard should ensure that there is a sufficient number of educated analysts on staff. Certainly the Coast Guard has a pool of these individuals, but this staffing level must increase if the Coast Guard expects to elevate its cost analysis capabilities beyond the current level. This enhanced cadre of cost analysis professionals should be afforded opportunities for professional exchanges with DoD services, as well as interaction with private sector enterprises, to include participation in professional conferences and symposiums.

An additional area of interest for the Coast Guard would be the investigation of an accounting system that provides direct traceability for costs to the appropriate system or program office. Successfully accomplishing this, could produce an accounting system that enables a more dynamic analysis of costs as the Coast Guard seeks to continuously balance the mix of assets to meet the current and future mission objectives. In the case of the C-130, it might be feasible to examine scenarios involving a full range of retirement, modification, or acquisition options. Program managers could then conduct sensitivity analysis to identify critical breakpoints that have significant influence on the system cost.

**Future research**

Providing cost and availability estimates will assist Coast Guard decision makers in their selection of program choices. The logical next step would be the consideration of C-130 mission effectiveness, with the ultimate goal to bring all three elements together into one decision tool. Simultaneously evaluating Cost, Availability, and Mission Effectiveness, the program managers could uncover the areas of interaction between these measures. On a broader level, it may be possible to apply Value Focused Thinking, or a comparable decision analysis technique to assess and select between alternative operational systems.

The future of the Coast Guard is undoubtedly very dynamic as the service adjusts to cope with its changing environment. Having the means of modeling cost, availability, and mission effectiveness provides insight into how limited assets can be best applied to a changing operational environment. .Furthermore, this modeling approach provides the robust capability to adjust the number of aircraft in the inventory. Applying mission and resource constraints to a specific aircraft system, or across mission areas, would be a feasible method to predict optimal aircraft usage profiles, or an optimal number of operational aircraft.

## Appendix A – CAIG Cost Element Definitions

1.0 Mission Personnel. Includes the cost of pay and allowances of officer, enlisted, and civilian personnel required to operate, maintain, and support a discrete operational system, or deployable unit. This includes the personnel necessary to meet combat readiness, unit training, and administrative requirements.

- 1.1 Operations. The pay and allowances for full complement of aircrew personnel required to operate a system. Aircrew composition includes the officers and enlisted personnel (pilot, non-pilot, and crew technicians) required to operate the aircraft of a deployable unit.
- 1.2 Maintenance. 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. Depending on the maintenance concept and organizational structure, this element will include maintenance personnel at the organizational level and possibly the intermediate level.
- 1.3 Other Mission Personnel. The pay and allowances of military and civilian personnel who perform unit staff, security, and other mission support activities. The number and type of personnel in this category will vary depending on the requirements of the particular system. These billets exist only to support the system whose costs are being estimated.

2.0 Unit-Level Consumption. Includes the cost of fuel and energy resources; operations, maintenance, and support materials consumed at the unit level; stock fund reimbursements for depot-level reparables; operational munitions expended in training; transportation in support of deployed unit training; temporary additional duty/temporary duty (TAD/TDY) pay; and other unit-level consumption costs, such as purchased services for equipment leases and service contracts

- 2.1 POL/Energy Consumption. The unit-level cost of petroleum, oil, and lubricants (POL), propulsion fuel, and fuel additives required for peacetime flight operations. Includes in-flight and ground consumption, and an allowance for POL distribution, storage, evaporation, and spillage. May also include field-generated electricity and commercial electricity if necessary to support the operation of the system
- 2.2 Consumable Material/Repair Parts. The costs of material consumed in the operation, maintenance, and support of an aircraft system and associated support equipment at the unit level. Depending on the maintenance concept or organizational structure, consumption at the intermediate level should be reported either in this element or in element 3.0, Intermediate Maintenance (External to Unit). Costs need to be identified at the level of detail shown below; the descriptions are intended

merely to illustrate the various types of materials encompassed in this element:

- Maintenance Material. The cost of material expended during maintenance. Examples include consumables and repair parts such as transistors, capacitors, gaskets, fuses, etc.
- Operational Material. The cost of non-maintenance material consumed in operating a system and support equipment. Examples include coolants, deicing fluid, tires, filters, batteries, paper, diskettes, ribbons, charts and maps.
- Mission Support Supplies. The cost of supplies and equipment expended in support of mission personnel. Examples include items relating to administration, housekeeping, health and safety.

2.3 Depot-Level Reparables. The unit-level cost of reimbursing the stock fund for purchases of depot-level reparable (DLR) spares (also referred to as exchangeables) used to replace initial stocks. DLRs may include repairable individual parts, assemblies, or subassemblies that are required on a recurring basis for the repair of major end items of equipment.

2.4 Training Munitions/Expendable Stores. The cost of expendable stores consumed in unit-level training. Includes the cost of live and inert ammunition, bombs, rockets, training missiles, sonobouys, and pyrotechnics expended in noncombat operations and training exercises.

2.5 Other. Include in this element any significant unit-level consumption costs not otherwise accounted for. Examples include purchased services, transportation, TAD/TDY

3.0 Intermediate Maintenance (External to Unit). Intermediate maintenance performed external to a unit includes the cost of labor and material and other costs expended by designated activities/units in support of an aircraft system and associated support equipment. Intermediate maintenance activities include calibration, repair, and replacement of parts, components, or assemblies, and technical assistance.

3.1 Maintenance. The pay and allowances of military and civilian personnel who perform intermediate maintenance on an aircraft system, associated support equipment, and unit-level training devices.

3.2 Consumable Material/Repair Parts. The costs of repair parts, assemblies, subassemblies, and material consumed in the maintenance and repair of aircraft, associated support equipment, and unit-level training devices.

3.3 Other. Include in this element any significant intermediate maintenance costs not otherwise accounted for. For example, this could include the cost of transporting subsystems or major end items to a base or depot facility.

4.0 Depot Maintenance. Depot maintenance includes the cost of labor, material, and overhead incurred in performing major overhauls or maintenance on aircraft, their components, and associated support equipment at centralized repair depots, contractor repair facilities, or on site by depot teams. Some depot maintenance activities occur at intervals ranging from several months to several years. As a result, the most useful method of portraying these costs is on an annual basis or an operating-hour basis.

4.1 Overhaul/Rework. The labor, material, and overhead costs for overhaul or rework of aircraft returned to a centralized depot facility. Includes programmed depot maintenance, analytic condition inspections, and unscheduled depot maintenance. Cost of major aircraft subsystems that have different overhaul cycles (i.e., airframe, engine, avionics, armament, and support equipment) should be identified separately within this element.

4.2 Other. Include in this element any significant depot maintenance activities not otherwise accounted for. For example, this could include component repair costs for reparables not managed by the DBOF, second-destination transportation costs for weapons systems requiring major overhaul or rework, or contracted unit-level support.

5.0 Contractor Support. Contractor support includes the cost of contractor labor, materials, and overhead incurred in providing all or part of the logistics support required by an aircraft system, subsystem, or associated support equipment. Contract maintenance is performed by commercial organizations using contractor personnel, material, equipment, and facilities or government-furnished material, equipment and facilities. Contractor support may be dedicated to one or multiple levels of maintenance and may take the form of interim contractor support (ICS) if the services are provided on a temporary basis or contractor logistics support (CLS) if the support extends over the operational life of a system.

5.1 Interim Contractor Support. Interim contractor support (ICS) includes the burdened cost of contract labor, material, and assets used in providing temporary logistics support to a weapon system, sub system, and associated support equipment. The purpose of ICS is to provide total or partial logistics support until a government maintenance capability is developed.

5.2 Contractor Logistics Support. Contractor logistics support includes the burdened cost of contract labor, material, and assets used in providing support to an aircraft system, subsystem, and associated support equipment. CLS funding covers depot maintenance and, as negotiated with the operating command, necessary organizational and intermediate maintenance activities. If CLS is selected as the primary means of support, all functional areas included in the CLS cost should be identified.

5.3 Other. Include in this element any contractor support costs not otherwise accounted for. For example, if significant, the burdened cost of contract labor for contractor engineering and technical services should be reported here.

6.0 Sustaining Support. Sustaining support includes the cost of replacement support equipment, modification kits, sustaining engineering, software maintenance support, and simulator operations provided for an aircraft system.

- 6.1 Support Equipment Replacement. The costs incurred to replace equipment that is needed to operate or support an aircraft, aircraft subsystem, training systems, and other associated support equipment. The support equipment being replaced (e.g., tools and test sets) may be unique to the aircraft or it may be common to a number of aircraft systems, in which case the costs must be allocated among the respective systems.
- 6.2 Modification Kit Procurement/Installation. The costs of procuring and installing modification kits and modification kit initial spares (after production and development) required for an aircraft and associated support and training equipment. Includes only those modification kits needed to achieve acceptable safety levels, overcome mission capability deficiencies, improve reliability, or reduce maintenance costs. Excludes modifications undertaken to provide additional operational capability not called for in the original design or performance specifications.
- 6.3 Other Recurring Investment. Include in this element any significant recurring investment costs not otherwise accounted for.
- 6.4 Sustaining Engineering Support. The labor, material, and overhead costs incurred in providing continued systems engineering and program management oversight to determine the integrity of a system, to maintain operational reliability, to approve design changes, and to ensure system conformance with established specifications and standards. Costs in this category may include government and/or contract engineering services, technical advice, and training for component or system installation, operation, maintenance, and support.
- 6.5 Software Maintenance Support. The labor, material, and overhead costs incurred after development by depot-level maintenance activities, government software centers, laboratories, or contractors for supporting the update, maintenance and modification, integration, and configuration management of software.
- 6.6 Simulator Operations. The costs incurred to provide, operate, and maintain onsite or centralized simulator training devices for an aircraft system, subsystem, or related equipment.
- 6.7 Other. Include in this element any significant sustaining support costs not otherwise accounted for. Examples might include the costs of follow-on operational tests and evaluation, such as range costs, test support, data reduction, and test reporting.

7.0 Indirect Support. Indirect support includes the costs of personnel support for specialty training, permanent changes of station, and medical care. Indirect support also includes the costs of relevant host installation services, such as base operating support and real property maintenance.

7.1 Personnel Support. Includes the cost of system-specific and related specialty training for military personnel who are replacing individuals lost through attrition. Examples include specialty training, permanent change of station, or medical support costs.

7.2 Installation Support. Consists of personnel normally assigned to the host installation who are required for the unit to perform its mission in peacetime. Include only those personnel and costs that are directly affected by a change in the number of aircraft and associated mission personnel. Examples include base operating support, and real property maintenance costs. (OSD, 1992:C2-C10)

# Appendix B – Excel Spreadsheet Models

## Cost Model Assumptions

### Mission Personnel

| Year | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pilot | 620648.6 | 749319.6 | 726613 | 681199.7 | 635786.3 | 620648.6 | 613079.7 | 605510.8 | 605510.8 | 605510.8 | 605510.8 | 605510.8 | 605510.8 | 607024.6 | 608538.4 | 610052.1 | 611565.9 | 613079.7 | 614593.5 | 616107.2 |
| min | 595822.6 | 726840 | 688465.8 | 636921.7 | 586512.9 | 564790.2 | 550239 | 535877.1 | 528308.2 | 520739.3 | 513170.4 | 505601.5 | 498032.6 | 491689.9 | 485309.3 | 478890.9 | 472434.7 | 465940.6 | 459408.6 | 452838.8 |
| most likely | 620648.6 | 749319.6 | 726613 | 681199.7 | 635786.3 | 620648.6 | 613079.7 | 605510.8 | 605510.8 | 605510.8 | 605510.8 | 605510.8 | 605510.8 | 607024.6 | 608538.4 | 610052.1 | 611565.9 | 613079.7 | 614593.5 | 616107.2 |
| max | 657887.5 | 801772 | 784742 | 742507.6 | 699365 | 688919.9 | 686649.3 | 684227.2 | 690282.3 | 696337.4 | 702392.5 | 708447.6 | 714502.8 | 722359.3 | 730246 | 738163.1 | 746110.4 | 754088 | 762095.9 | 770134.1 |
| Aircrew/Maint Technician | 639195.6 | 670124.5 | 690743.7 | 711362.9 | 670124.5 | 623731.2 | 597957.2 | 567028.4 | 536099.6 | 520635.2 | 510325.6 | 510325.6 | 510325.6 | 510325.6 | 511356.5 | 512387.5 | 513418.4 | 514449.4 | 515480.4 | 516511.3 |
| min | 613627.8 | 650020.7 | 654479.6 | 665124.3 | 618189.8 | 567595.4 | 536666.6 | 501820.1 | 467746.9 | 447746.2 | 432500.9 | 426121.8 | 419742.8 | 413363.7 | 407806.8 | 402224.2 | 396615.7 | 390981.5 | 385321.6 | 379635.8 |
| most likely | 639195.6 | 670124.5 | 690743.7 | 711362.9 | 670124.5 | 623731.2 | 597957.2 | 567028.4 | 536099.6 | 520635.2 | 510325.6 | 510325.6 | 510325.6 | 510325.6 | 511356.5 | 512387.5 | 513418.4 | 514449.4 | 515480.4 | 516511.3 |
| max | 677547.4 | 717033.2 | 746003.2 | 775385.6 | 737136.9 | 692341.7 | 669712.1 | 640742.1 | 611153.5 | 598730.4 | 591977.6 | 597080.9 | 602184.2 | 607287.4 | 613627.8 | 619988.8 | 626370.5 | 632772.8 | 639195.6 | 645639.1 |

### Unit Level Consumption

| Year | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fuel | 820373.9 | 836781.4 | 853188.9 | 863033.4 | 869596.3 | 876159.3 | 882722.3 | 886003.8 | 889285.3 | 892566.8 | 895848.3 | 899129.8 | 902411.3 | 902411.3 | 902411.3 | 902411.3 | 902411.3 | 902411.3 | 902411.3 | 902411.3 |
| min | 799864.6 | 814748.9 | 829589.7 | 838014 | 843230.2 | 848428.9 | 853610.1 | 855605 | 857591.2 | 859568.6 | 861537.3 | 863497.3 | 865448.5 | 864248.3 | 863048.1 | 861847.9 | 860647.7 | 859447.5 | 858247.3 | 857047.1 |
| most likely | 820373.9 | 836781.4 | 853188.9 | 863033.4 | 869596.3 | 876159.3 | 882722.3 | 886003.8 | 889285.3 | 892566.8 | 895848.3 | 899129.8 | 902411.3 | 902411.3 | 902411.3 | 902411.3 | 902411.3 | 902411.3 | 902411.3 | 902411.3 |
| max | 840883.3 | 858813.8 | 876788.1 | 888052.7 | 895962.5 | 903889.8 | 911834.5 | 916402.6 | 920979.5 | 925565 | 930159.3 | 934762.3 | 939374.1 | 940574.3 | 941774.5 | 942974.7 | 944174.9 | 945375.1 | 946575.3 | 947775.5 |
| Depot Level Reparables | 630231.4 | 829251.9 | 895592 | 961932.2 | 1011687 | 1028272 | 1028272 | 1011687 | 961932.2 | 928762.1 | 879007 | 829251.9 | 796081.8 | 746326.7 | 696571.6 | 679986.5 | 663401.5 | 630231.4 | 630231.4 | 630231.4 |
| min | 570359.4 | 605353.9 | 644826.3 | 678162.2 | 715262.9 | 719790.6 | 719790.6 | 715262.9 | 715677.5 | 697500.3 | 674198.4 | 638523.9 | 589100.5 | 556759.7 | 543325.8 | 543989.2 | 537355.2 | 538847.9 | 538847.9 | 538847.9 |
| most likely | 630231.4 | 829251.9 | 895592 | 961932.2 | 1011687 | 1028272 | 1028272 | 1011687 | 961932.2 | 928762.1 | 879007 | 829251.9 | 796081.8 | 746326.7 | 696571.6 | 679986.5 | 663401.5 | 630231.4 | 630231.4 | 630231.4 |
| max | 701447.6 | 903884.5 | 1065755 | 1090831 | 1108809 | 1120817 | 1126986 | 1108809 | 1094679 | 1082008 | 1067993 | 1060613 | 1034906 | 1022468 | 1022567 | 1019980 | 1015004 | 1008370 | 1008370 | 1008370 |

### Depot

| Year | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PDM (basic + MSRs + O&A) | 581790.5 | 585274.3 | 592241.9 | 585274.3 | 557404.1 | 522566.4 | 480761 | 459858.4 | 452890.8 | 452890.8 | 456374.6 | 459858.4 | 463342.2 | 466825.9 | 470309.7 | 473793.5 | 480761 | 487728.6 | 494696.1 | 501663.7 |
| min | 555028.2 | 544305.1 | 535386.6 | 526746.9 | 505008.1 | 480238.5 | 449992.3 | 429967.6 | 415300.9 | 399902.6 | 392938.5 | 384901.5 | 379940.6 | 379996.3 | 380010.3 | 379982.4 | 379801.2 | 379940.6 | 375969.1 | 370227.8 |
| most likely | 581790.5 | 585274.3 | 592241.9 | 585274.3 | 557404.1 | 522566.4 | 480761 | 459858.4 | 452890.8 | 452890.8 | 456374.6 | 459858.4 | 463342.2 | 466825.9 | 470309.7 | 473793.5 | 480761 | 487728.6 | 494696.1 | 501663.7 |
| max | 599942.4 | 601954.6 | 604975.1 | 604998.1 | 607013.1 | 614015.5 | 626912.4 | 634604.6 | 644916.6 | 652162.8 | 659917.7 | 664955.2 | 675089.5 | 684833.7 | 695117.8 | 695055.1 | 699988.1 | 710132.8 | 717804.1 | 724904 |
| Engine Overhaul | 54329.64 | 54968.81 | 55607.99 | 55607.99 | 55607.99 | 55607.99 | 56247.16 | 56247.16 | 56247.16 | 56886.33 | 56886.33 | 57525.5 | 58164.68 | 58803.85 | 59443.02 | 61360.54 | 62638.88 | 63917.23 | 65834.74 | 68391.43 |
| min | 51830.48 | 51121 | 50881.31 | 50881.31 | 50881.31 | 50881.31 | 50903.68 | 50903.68 | 50903.68 | 50913.27 | 50913.27 | 51025.12 | 51184.91 | 50865.33 | 50823.78 | 50929.25 | 50737.49 | 50494.61 | 50692.75 | 50951.62 |
| most likely | 54329.64 | 54968.81 | 55607.99 | 55607.99 | 55607.99 | 55607.99 | 56247.16 | 56247.16 | 56247.16 | 56886.33 | 56886.33 | 57525.5 | 58164.68 | 58803.85 | 59443.02 | 61360.54 | 62638.88 | 63917.23 | 65834.74 | 68391.43 |
| max | 57861.07 | 61180.29 | 63893.58 | 66173.5 | 67285.66 | 68286.61 | 69184.01 | 69352.75 | 69746.48 | 70254.62 | 70254.62 | 73345.02 | 75614.08 | 77621.08 | 79356.43 | 81486.79 | 83936.1 | 85649.08 | 87560.21 | 89729.56 |

### Sustaining Support

| Year | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Support Equipment Replacem | 37942.36 | 36483.04 | 34294.06 | 32105.07 | 29916.09 | 28456.77 | 27727.11 | 27727.11 | 27873.04 | 28018.97 | 28164.91 | 28310.84 | 28456.77 | 28602.7 | 28748.63 | 28894.57 | 29040.5 | 29186.43 | 29332.36 | 29478.3 |
| min | 35703.76 | 33356.44 | 30350.24 | 27514.05 | 25009.85 | 24842.76 | 24510.77 | 24178.04 | 23859.32 | 23535.94 | 23179.72 | 22846.85 | 22480.85 | 22195.7 | 22021.45 | 21873.19 | 21693.25 | 21510.4 | 21353.96 | 21194.89 |
| most likely | 37942.36 | 36483.04 | 34294.06 | 32105.07 | 29916.09 | 28456.77 | 27727.11 | 27727.11 | 27873.04 | 28018.97 | 28164.91 | 28310.84 | 28456.77 | 28602.7 | 28748.63 | 28894.57 | 29040.5 | 29186.43 | 29332.36 | 29478.3 |
| max | 39194.46 | 38343.67 | 37517.7 | 37017.15 | 36677.13 | 36367.75 | 36183.88 | 36017.52 | 36151.34 | 36536.74 | 37036.85 | 37370.31 | 37534.48 | 37841.38 | 38350.68 | 39007.67 | 39698.36 | 40189.72 | 40595.99 | 41004.31 |
| Sustaining Engineering Suppo | 133256.1 | 154577.1 | 165237.6 | 213209.8 | 266512.2 | 282502.9 | 277172.7 | 271842.4 | 266512.2 | 255851.7 | 239861 | 229200.5 | 223870.2 | 223870.2 | 223870.2 | 223870.2 | 224936.3 | 228134.4 | 231332.6 | 234530.7 |
| min | 125277.4 | 134225.8 | 141682.8 | 153614 | 158088.2 | 161070.9 | 164053.7 | 167036.5 | 162562.3 | 159579.5 | 156596.8 | 153614 | 149139.8 | 146157 | 143174.2 | 140191.4 | 137208.6 | 134225.8 | 131243 | 128260.2 |
| most likely | 133256.1 | 154577.1 | 165237.6 | 213209.8 | 266512.2 | 282502.9 | 277172.7 | 271842.4 | 266512.2 | 255851.7 | 239861 | 229200.5 | 223870.2 | 223870.2 | 223870.2 | 223870.2 | 224936.3 | 228134.4 | 231332.6 | 234530.7 |
| max | 177476.3 | 187916.1 | 210287.1 | 247572 | 280382.8 | 301262.3 | 308719.3 | 313193.5 | 316176.3 | 320650.5 | 325124.7 | 327212.6 | 332880 | 335266.2 | 337652.4 | 340038.7 | 343021.5 | 346004.3 | 348987.1 | 351969.8 |

### Indirect Support

| Year | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Base Operating Support | 124522 | 125905.5 | 138357.7 | 169488.2 | 193700.8 | 200618.7 | 166029.3 | 133515.2 | 124522 | 124522 | 124522 | 124522 | 124522 | 124522 | 124522 | 124522 | 124522 | 124522 | 124522 | 124522 |
| min | 112848 | 112848 | 112848 | 112848 | 112848 | 112848 | 108956.7 | 95337.12 | 79771.87 | 66152.29 | 60315.32 | 56424.01 | 52532.7 | 50587.04 | 48641.39 | 48641.39 | 48641.39 | 48641.39 | 48641.39 | 46695.73 |
| most likely | 124522 | 125905.5 | 138357.7 | 169488.2 | 193700.8 | 200618.7 | 166029.3 | 133515.2 | 124522 | 124522 | 124522 | 124522 | 124522 | 124522 | 124522 | 124522 | 124522 | 124522 | 124522 | 124522 |
| max | 134250.2 | 142032.8 | 159543.7 | 188728.6 | 202348.2 | 206239.5 | 208185.1 | 208185.1 | 208185.1 | 208185.1 | 208185.1 | 210130.8 | 210130.8 | 212076.4 | 212076.4 | 214022.1 | 215967.8 | 215967.8 | 217913.4 | 221804.7 |

# Cost Model Forecasts

| Year | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mission Personnel | | | | | | | | | | | | | | | | | | | | |
| Pilot | 16757511.6 | 20231629.9 | 19618550.2 | 18392390.8 | 17166231.4 | 16757511.6 | 16553151.7 | 16348791.8 | 16348791.8 | 16348791.8 | 16348791.8 | 16348791.8 | 16348791.8 | 16389663.8 | 16430535.8 | 16471407.7 | 16512279.7 | 16553151.7 | 16594023.7 | 16634895.7 |
| Aircrew/Maint Technician | 17258282.3 | 18093360.5 | 18650079.3 | 19206798.1 | 18093360.5 | 16840743.2 | 16144844.7 | 15309766.6 | 14474688.4 | 14057149.3 | 13778789.9 | 13778789.9 | 13778789.9 | 13778789.9 | 13806625.8 | 13834461.8 | 13862297.7 | 13890133.7 | 13917969.6 | 13945805.5 |
| Unit Level Consumption | | | | | | | | | | | | | | | | | | | | |
| Fuel | 22150095.7 | 22593097.6 | 23036099.5 | 23301900.6 | 23479101.4 | 23656302.2 | 23833502.9 | 23922103.3 | 24010703.7 | 24099304.1 | 24187904.5 | 24276504.8 | 24365105.2 | 24365105.2 | 24365105.2 | 24365105.2 | 24365105.2 | 24365105.2 | 24365105.2 | 24365105.2 |
| Depot Level Reparables | 17016248.4 | 22389800.5 | 24180984.6 | 25972168.6 | 27315556.6 | 27763352.6 | 27763352.6 | 27315556.6 | 25972168.6 | 25076576.6 | 23733188.5 | 22389800.5 | 21494208.5 | 20150820.5 | 18807432.4 | 18359636.4 | 17911840.4 | 17016248.4 | 17016248.4 | 17016248.4 |
| Depot | | | | | | | | | | | | | | | | | | | | |
| PDM (basic + MSRs + O&A) | 15708344.5 | 15802406.5 | 15990530.4 | 15802406.5 | 15049910.9 | 14109291.5 | 12980548.2 | 12416176.5 | 12228052.6 | 12228052.6 | 12322114.6 | 12416176.5 | 12510238.5 | 12604300.4 | 12698362.3 | 12792424.3 | 12980548.2 | 13168672.1 | 13356795.9 | 13544919.8 |
| Engine Overhaul | 1466900.33 | 1484157.98 | 1501415.63 | 1501415.63 | 1501415.63 | 1501415.63 | 1518673.28 | 1518673.28 | 1518673.28 | 1535930.93 | 1535930.93 | 1553188.58 | 1570446.24 | 1587703.89 | 1604961.54 | 1656734.49 | 1691249.79 | 1725765.09 | 1777538.05 | 1846568.65 |
| Sustaining Support | | | | | | | | | | | | | | | | | | | | |
| Support Equip Replacement | 1024443.74 | 985042.061 | 925939.538 | 866837.014 | 807734.49 | 768332.808 | 748631.967 | 748631.967 | 752572.135 | 756512.303 | 760452.471 | 764392.64 | 768332.808 | 772272.976 | 776213.144 | 780153.313 | 784093.481 | 788033.649 | 791973.817 | 795913.986 |
| Sustaining Eng Support | 3597914.54 | 4173580.86 | 4461414.03 | 5756663.26 | 7195829.08 | 7627578.82 | 7483662.24 | 7339745.66 | 7195829.08 | 6907995.91 | 6476246.17 | 6188413.01 | 6044496.42 | 6044496.42 | 6044496.42 | 6044496.42 | 6073279.74 | 6159629.69 | 6245979.64 | 6332329.59 |
| Indirect Support | | | | | | | | | | | | | | | | | | | | |
| Base Operating Support | 3362092.65 | 3399449.24 | 3735658.5 | 4576181.66 | 5229921.9 | 5416704.83 | 4482790.2 | 3604910.45 | 3362092.65 | 3362092.65 | 3362092.65 | 3362092.65 | 3362092.65 | 3362092.65 | 3362092.65 | 3362092.65 | 3362092.65 | 3362092.65 | 3362092.65 | 3362092.65 |
| Disposal Costs | | | | | | | | | | | | | | | | | | | | |
| Stationary costs | 30005366.3 | 30005366.3 | 30005366.3 | 30005366.3 | 30005366.3 | 30005366.3 | 30005366.3 | 30005366.3 | 30005366.3 | 30005366.3 | 30005366.3 | 30005366.3 | 30005366.3 | 30005366.3 | 30005366.3 | 30005366.3 | 30005366.3 | 30005366.3 | 30005366.3 | 30005366.3 |
| Total Cost | 128347200 | 139157891 | 142106038 | 145382128 | 145844428 | 144446599 | 141514524 | 138529722 | 135868939 | 134377772 | 132510878 | 131083517 | 130247868 | 129060612 | 127901192 | 127671879 | 127548153 | 127034198 | 127433093 | 127849246 |

**NMC**

| Year | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **NMCM** | 0.1648 | 0.1634 | 0.1626 | 0.1624 | 0.163 | 0.164 | 0.1642 | 0.1648 | 0.1654 | 0.1666 | 0.1682 | 0.1694 | 0.1714 | 0.1734 | 0.176 | 0.178 | 0.1794 | 0.1814 | 0.182 | 0.1832 |
| min | 0.158 | 0.153 | 0.151 | 0.15 | 0.149 | 0.148 | 0.147 | 0.146 | 0.145 | 0.144 | 0.143 | 0.142 | 0.142 | 0.142 | 0.142 | 0.142 | 0.141 | 0.141 | 0.14 | 0.14 |
| most likely | 0.1648 | 0.1634 | 0.1626 | 0.1624 | 0.163 | 0.164 | 0.1642 | 0.1648 | 0.1654 | 0.1666 | 0.1682 | 0.1694 | 0.1714 | 0.1734 | 0.176 | 0.178 | 0.1794 | 0.1814 | 0.182 | 0.1832 |
| max | 0.175 | 0.179 | 0.18 | 0.181 | 0.184 | 0.188 | 0.19 | 0.193 | 0.196 | 0.2005 | 0.206 | 0.2105 | 0.2155 | 0.2205 | 0.227 | 0.232 | 0.237 | 0.242 | 0.245 | 0.248 |
| **NMCS** | 0.0691 | 0.0586 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| min | 0.055 | 0.047 | 0.043 | 0.042 | 0.041 | 0.0405 | 0.04 | 0.039 | 0.0385 | 0.038 | 0.0375 | 0.037 | 0.036 | 0.036 | 0.036 | 0.036 | 0.036 | 0.036 | 0.036 | 0.036 |
| most likely | 0.0691 | 0.0586 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| max | 0.102 | 0.105 | 0.11 | 0.113 | 0.117 | 0.12 | 0.123 | 0.127 | 0.13 | 0.133 | 0.136 | 0.139 | 0.142 | 0.145 | 0.148 | 0.151 | 0.156 | 0.1605 | 0.168 | 0.175 |
| **NMCD(u)** | 0.0236 | 0.0182 | 0.015 | 0.015 | 0.015 | 0.015 | 0.015 | 0.015 | 0.015 | 0.015 | 0.015 | 0.015 | 0.015 | 0.015 | 0.015 | 0.015 | 0.015 | 0.015 | 0.015 | 0.015 |
| min | 0.022 | 0.015 | 0.008 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| most likely | 0.0236 | 0.0182 | 0.015 | 0.015 | 0.015 | 0.015 | 0.015 | 0.015 | 0.015 | 0.015 | 0.015 | 0.015 | 0.015 | 0.015 | 0.015 | 0.015 | 0.015 | 0.015 | 0.015 | 0.015 |
| max | 0.03 | 0.031 | 0.0335 | 0.0365 | 0.039 | 0.0422 | 0.0448 | 0.0467 | 0.0488 | 0.0508 | 0.0525 | 0.0548 | 0.0567 | 0.0584 | 0.0602 | 0.0615 | 0.0635 | 0.0645 | 0.0655 | 0.0667 |

**PDM & Mod**

| No aircraft | 27 | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Year** | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 |
| PDM Possessed | 5.684211 | 6.113208 | 6.545455 | 6.821053 | 6.967742 | 6.967742 | 6.95279 | 6.923077 | 6.893617 | 6.864407 | 6.835443 | 6.806723 | 6.778243 | 6.75 | 6.721992 | 6.694215 | 6.666667 | 6.639344 | 6.612245 | 6.585366 |
| **PDM Interval** | 57 | 53 | 49.5 | 47.5 | 46.5 | 46.5 | 46.6 | 46.8 | 47 | 47.2 | 47.4 | 47.6 | 47.8 | 48 | 48.2 | 48.4 | 48.6 | 48.8 | 49 | 49.2 |
| min | 50 | 47 | 44 | 42 | 41 | 40.5 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40.2 | 40.4 | 40.6 | 40.8 |
| most likely | 57 | 53 | 49.5 | 47.5 | 46.5 | 46.5 | 46.6 | 46.8 | 47 | 47.2 | 47.4 | 47.6 | 47.8 | 48 | 48.2 | 48.4 | 48.6 | 48.8 | 49 | 49.2 |
| max | 60 | 59.7 | 59.4 | 59.1 | 59 | 59 | 59 | 59 | 59 | 59 | 59 | 59 | 59 | 59 | 59 | 59 | 59 | 59 | 59 | 59 |
| **Flow Days** | 179 | 177 | 175 | 175 | 175 | 175 | 174 | 174 | 173 | 173 | 173 | 172 | 172 | 172 | 171 | 171 | 171 | 170 | 170 | 170 |
| min | 163 | 158 | 153 | 150 | 148 | 146 | 144 | 142 | 140 | 138 | 136 | 134 | 132 | 130 | 128 | 126 | 124 | 122 | 120 | 118 |
| most likely | 179 | 177 | 175 | 175 | 175 | 175 | 174 | 174 | 173 | 173 | 173 | 172 | 172 | 172 | 171 | 171 | 171 | 170 | 170 | 170 |
| max | 190 | 193 | 196 | 199 | 201 | 203 | 205 | 207 | 209 | 211 | 213 | 214 | 214 | 215 | 215 | 215 | 215 | 216 | 216 | 216 |
| equivalent aircraft | 2.787599 | 2.964487 | 3.138232 | 3.270368 | 3.340698 | 3.340698 | 3.314481 | 3.300316 | 3.267386 | 3.253541 | 3.239813 | 3.207552 | 3.194131 | 3.180822 | 3.149207 | 3.136194 | 3.123288 | 3.092297 | 3.079676 | 3.067157 |
| **Percent PDM Possessed** | 0.103244 | 0.109796 | 0.116231 | 0.121125 | 0.12373 | 0.12373 | 0.122759 | 0.122234 | 0.121014 | 0.120502 | 0.119993 | 0.118798 | 0.118301 | 0.117808 | 0.116637 | 0.116155 | 0.115677 | 0.11453 | 0.114062 | 0.113598 |
| **Percent Modification** | 0.074074 | 0.074074 | 0.088889 | 0.109259 | 0.111111 | 0.111111 | 0.111111 | 0.111111 | 0.111111 | 0.111111 | 0.111111 | 0.111111 | 0.111111 | 0.111111 | 0.111111 | 0.111111 | 0.111111 | 0.111111 | 0.111111 | 0.111111 |
| min | 0.07037 | 0.07037 | 0.07037 | 0.055556 | 0.055556 | 0.055556 | 0.055556 | 0.055556 | 0.055556 | 0.055556 | 0.055556 | 0.055556 | 0.055556 | 0.055556 | 0.055556 | 0.055556 | 0.055556 | 0.055556 | 0.055556 | 0.055556 |
| most likely | 0.074074 | 0.074074 | 0.088889 | 0.109259 | 0.111111 | 0.111111 | 0.111111 | 0.111111 | 0.111111 | 0.111111 | 0.111111 | 0.111111 | 0.111111 | 0.111111 | 0.111111 | 0.111111 | 0.111111 | 0.111111 | 0.111111 | 0.111111 |
| max | 0.103704 | 0.12963 | 0.148148 | 0.148148 | 0.148148 | 0.148148 | 0.148148 | 0.148148 | 0.148148 | 0.148148 | 0.148148 | 0.148148 | 0.148148 | 0.148148 | 0.148148 | 0.148148 | 0.148148 | 0.148148 | 0.148148 | 0.148148 |

# Availability Model Forecasts

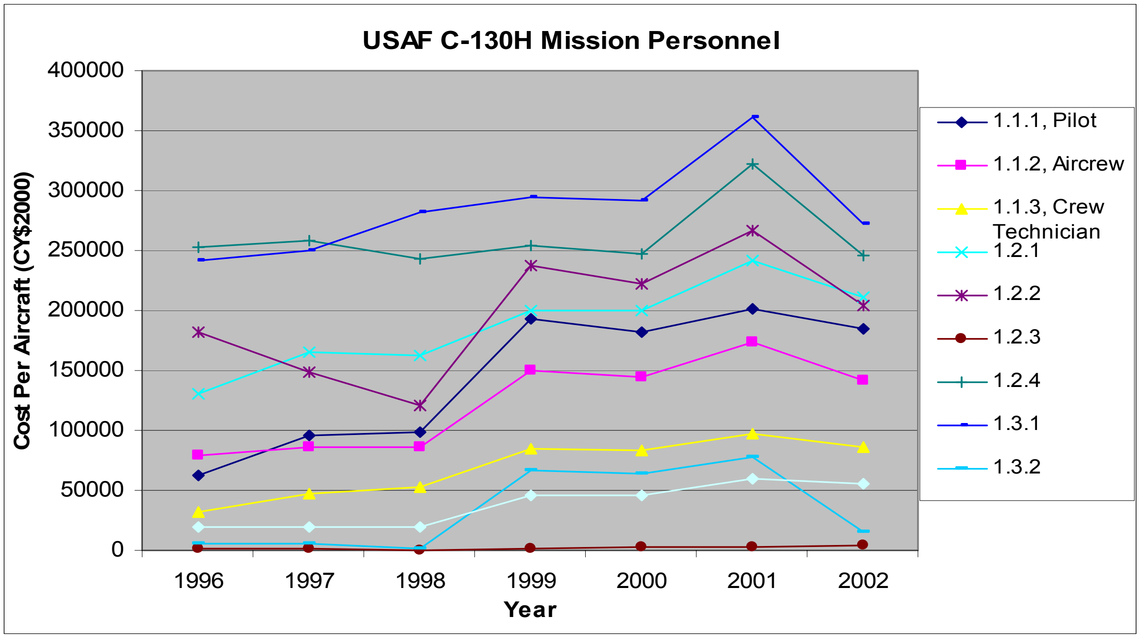
## C-130 Availability Model

| Year | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NMCM | 0.1648 | 0.1634 | 0.1626 | 0.1624 | 0.163 | 0.164 | 0.1642 | 0.1648 | 0.1654 | 0.1666 | 0.1682 | 0.1694 | 0.1714 | 0.1734 | 0.176 | 0.178 | 0.1794 | 0.1814 | 0.182 | 0.1832 |
| NMCS | 0.0691 | 0.0586 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| NMCD(u) | 0.0236 | 0.0182 | 0.015 | 0.015 | 0.015 | 0.015 | 0.015 | 0.015 | 0.015 | 0.015 | 0.015 | 0.015 | 0.015 | 0.015 | 0.015 | 0.015 | 0.015 | 0.015 | 0.015 | 0.015 |
| PDM Possessed | 0.1032 | 0.1098 | 0.1162 | 0.1211 | 0.1237 | 0.1237 | 0.1228 | 0.1222 | 0.121 | 0.1205 | 0.12 | 0.1188 | 0.1183 | 0.1178 | 0.1166 | 0.1162 | 0.1157 | 0.1145 | 0.1141 | 0.1136 |
| Modification | 0.0741 | 0.0741 | 0.0889 | 0.1093 | 0.1111 | 0.1111 | 0.1111 | 0.1111 | 0.1111 | 0.1111 | 0.1111 | 0.1111 | 0.1111 | 0.1111 | 0.1111 | 0.1111 | 0.1111 | 0.1111 | 0.1111 | 0.1111 |
| Availability | 0.5652 | 0.5759 | 0.5673 | 0.5422 | 0.5372 | 0.5362 | 0.5369 | 0.5369 | 0.5375 | 0.5368 | 0.5357 | 0.5357 | 0.5342 | 0.5327 | 0.5313 | 0.5297 | 0.5288 | 0.528 | 0.5278 | 0.5271 |
| Number of Aircraft Available | 15.26 | 15.55 | 15.317 | 14.64 | 14.503 | 14.476 | 14.497 | 14.495 | 14.512 | 14.493 | 14.464 | 14.464 | 14.423 | 14.382 | 14.344 | 14.303 | 14.278 | 14.255 | 14.251 | 14.231 |

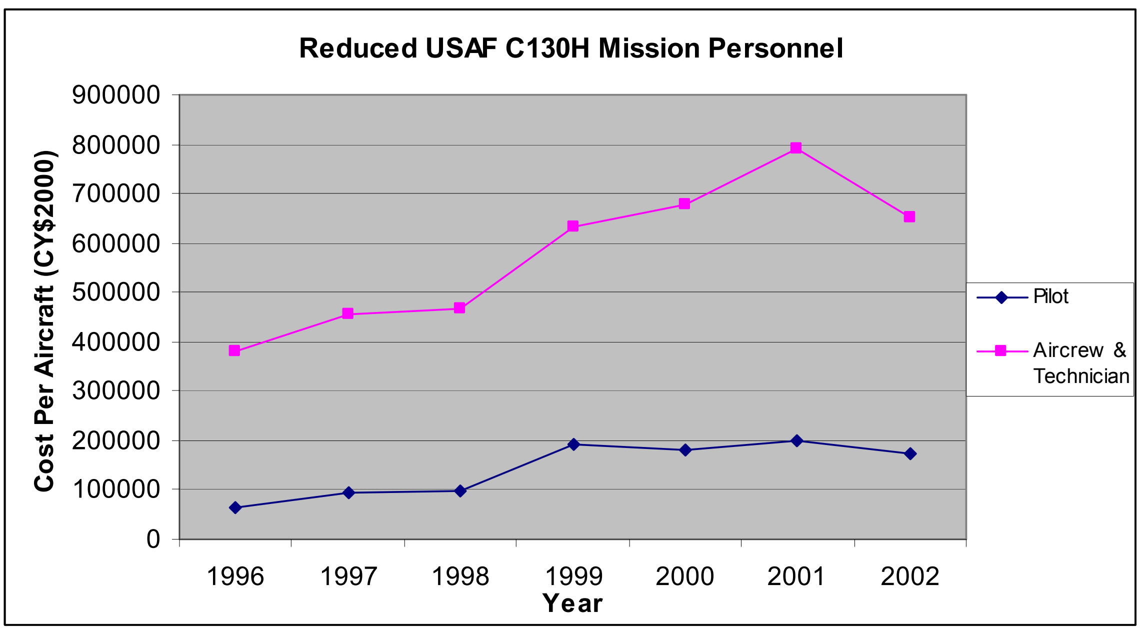
## Appendix C – USAF Historical Cost Element Reduction

Air Force Historical Cost Elements

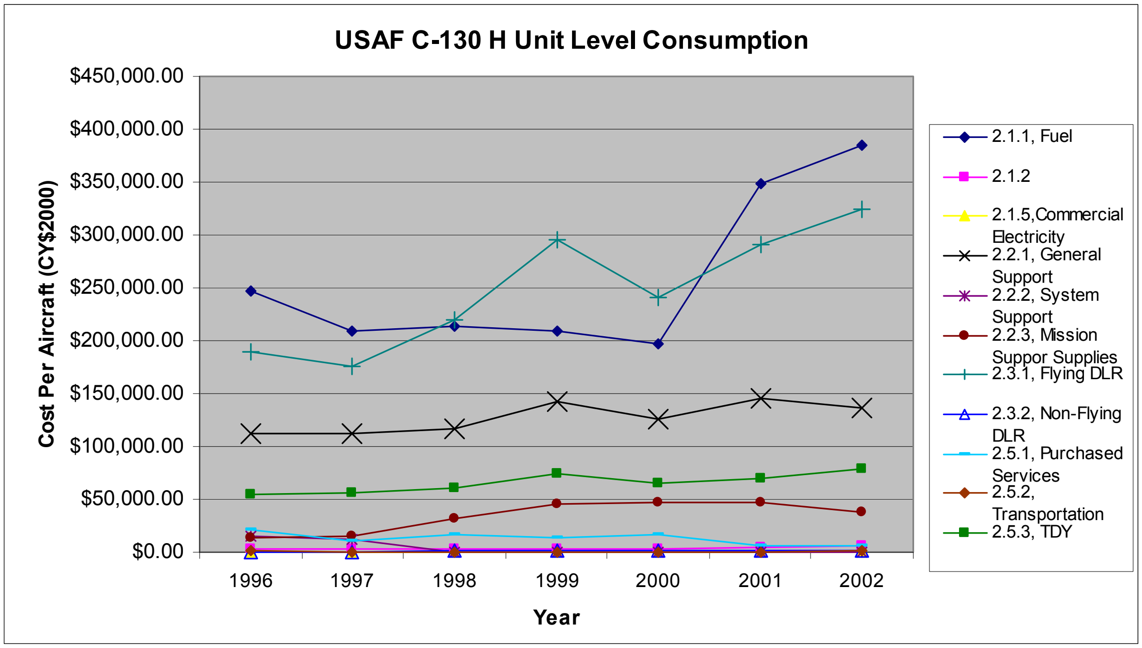
Mission Personnel



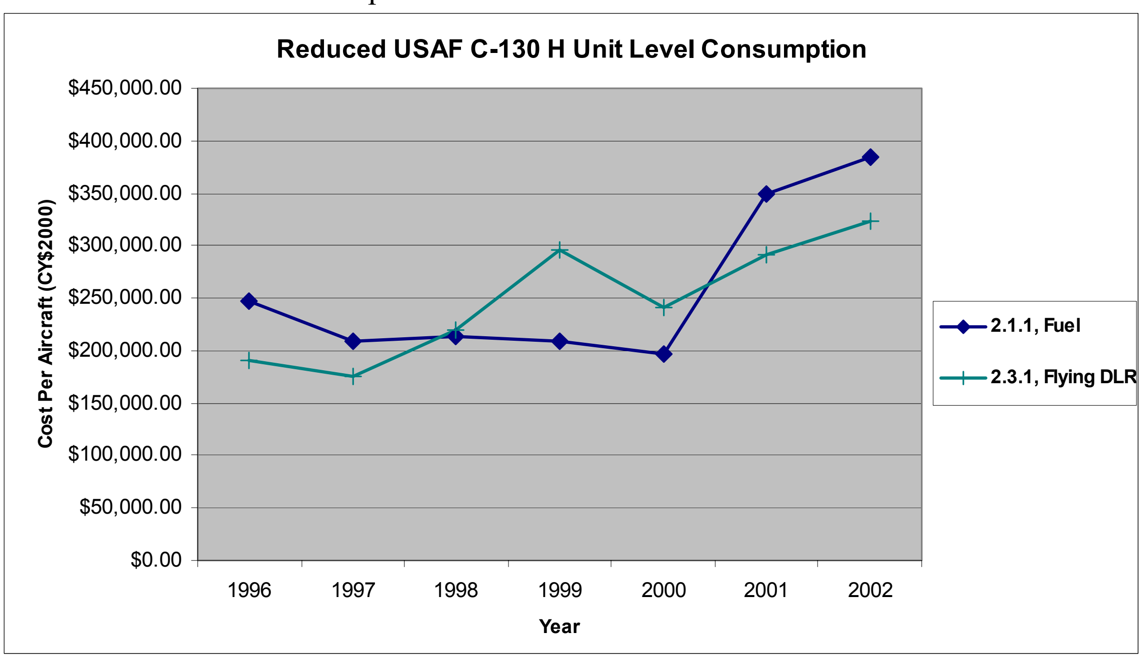

Reduced Mission Personnel



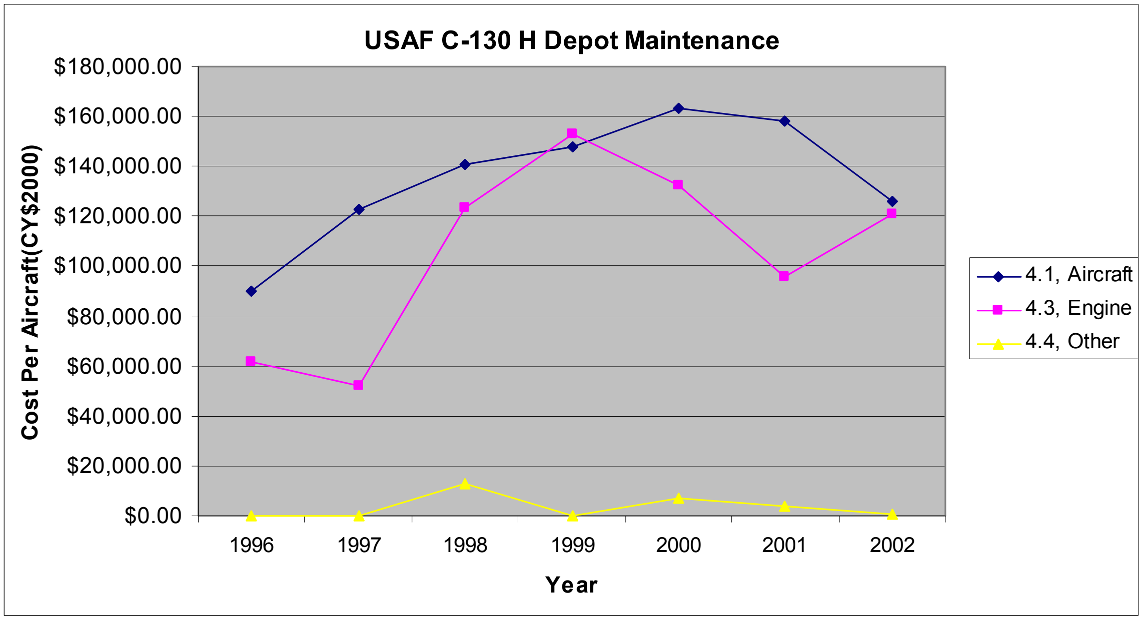
Unit Level Consumption



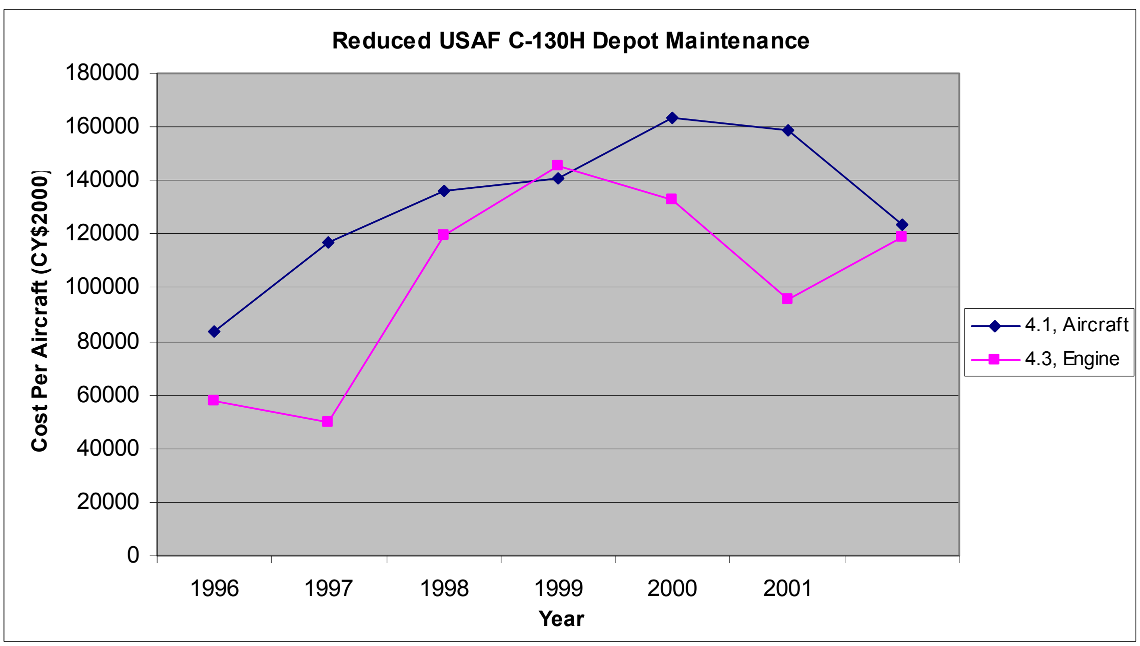

Reduced Unit Level Consumption



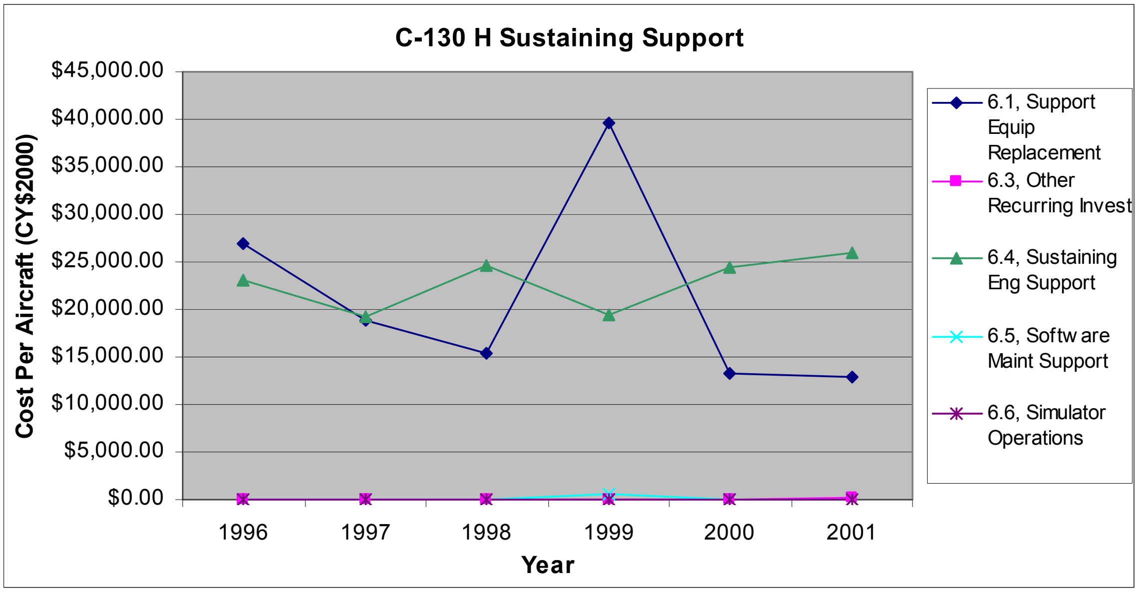
Depot Maintenance



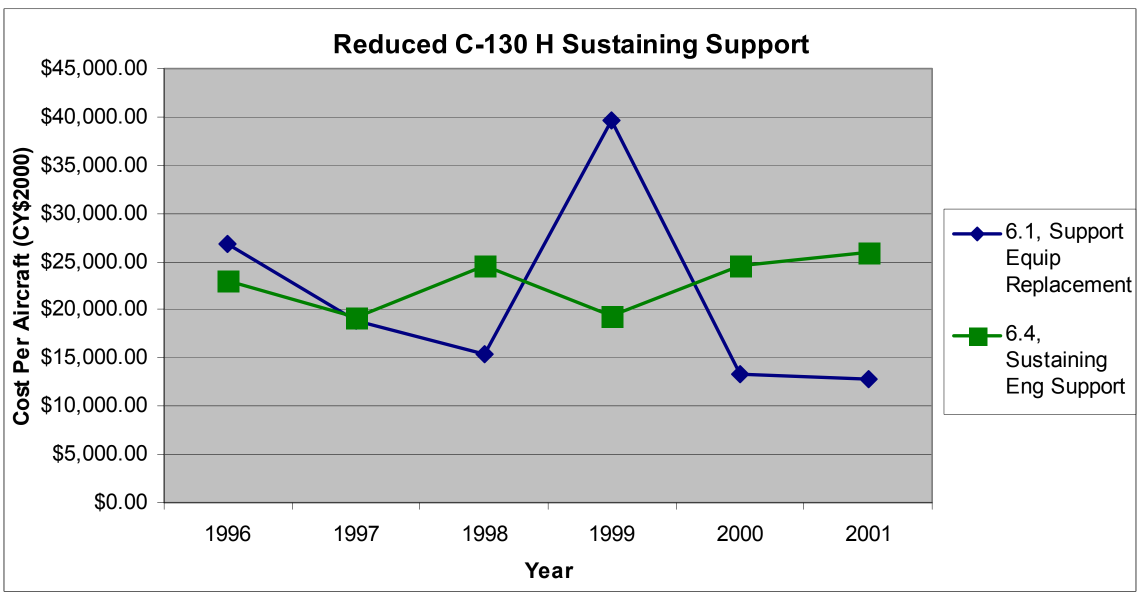

Reduced Depot Maintenance



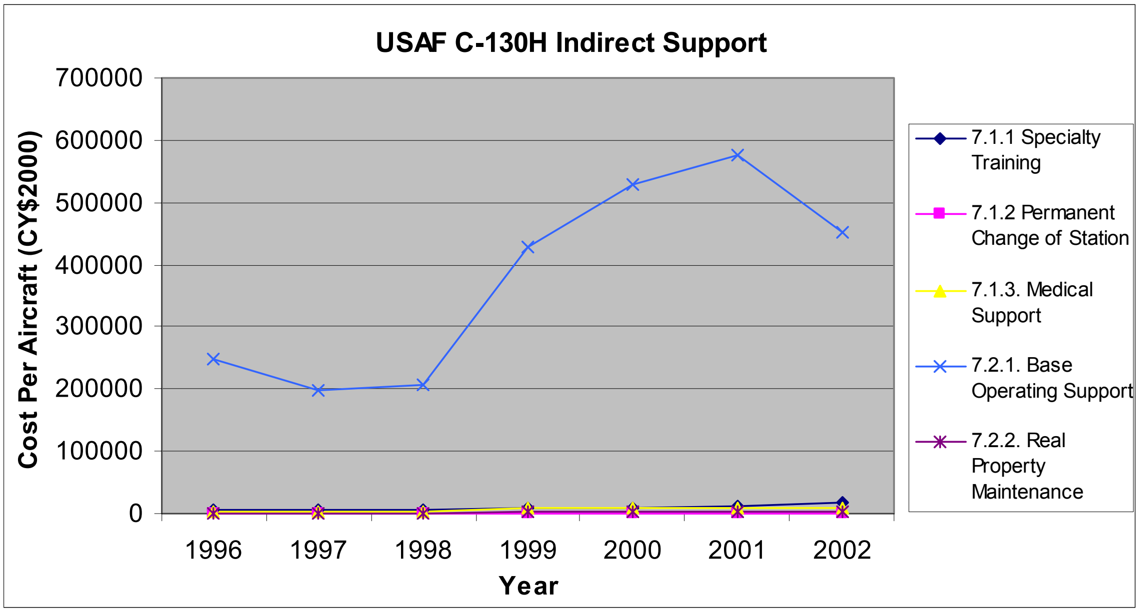
Sustaining Support



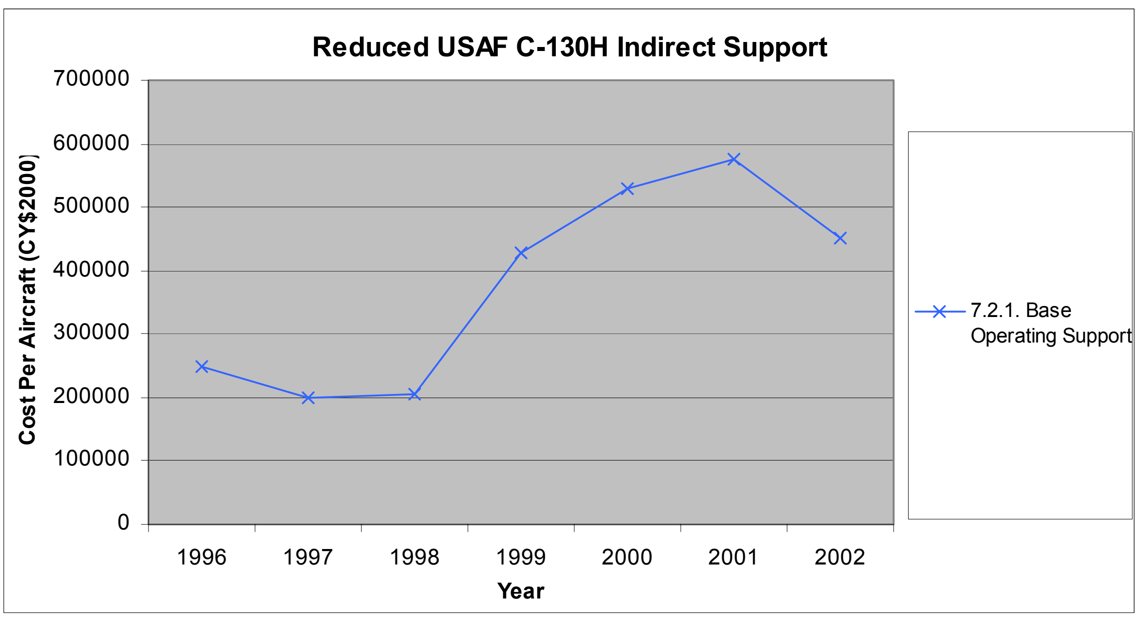

Reduced Sustaining Support



Indirect Support




Reduced Indirect Support



## Appendix D – Initial Expert Solicitation

Coast Guard C-130 20 year projections

Gentlemen,

Thank you for participating in this study. Currently I am in need of some expert opinion that can help me establish trends for various Coast Guard C-130 costs and overall availability. It is my hope that with your knowledge of the Operation and Support of our current C-130s, you will be able to make educated predictions for the future C-130 costs and availability measures.

In the next few pages you will find graphical representations of Air Force C-130 cost elements and Coast Guard availability measures. The cost elements span the years 1996 to 2002. The Air Force cost data was utilized because of the limited availability of similar Coast Guard cost data. I am including a graphical representation of the Air Force average flight hours so that you can keep this in mind as you assess the trends of the Air Force data. Additionally, it is important to note that the Air Force data includes all active, Guard and Reserve aircraft in the cost structure. All of the plots depict cost per aircraft data that has been adjusted to Constant Year 2000 dollars. This eliminates any variability associated with varied aircraft inventory and inflation.

Although the total system Operational & Support costs are made up of many cost elements, I am only including the 5 most significant elements to simplify your assessments. The cost elements excluded from this solicitation are Intermediate Maintenance, and Contractor Support. Similarly I have combined some of the lower level cost elements and excluded others so that they better represent the Coast Guard's typical C-130 structure. For example, in the Mission Personnel cost element, I have rolled the aircrew, crew technician and maintenance costs into one cost element. This results in Mission Personnel costs being the sum of the Pilot costs, the Aircrew/Technician costs, and the Support Personnel costs.

When examining the cost structures I would like you to ponder the following questions:

1) Is it appropriate to formulate an estimate for Coast Guard costs based upon this data set?
2) Is the Air Force data sufficient to create a trend estimate?
3) Will the estimated trend change with respect to time?

Your feedback can be provided in any format, but I would like to suggest a few options. As the graphs are in a Word document, it should be possible to draw a line using the tools on the drawing tool bar. If you feel more comfortable with estimating at points, you could also use AutoShapes to identify your estimate at a particular year. If you prefer to estimate based upon a percentage increase or decrease, you can provide this as a text based estimate by any means you choose. Obviously there is no right or wrong answer for the information I am requesting. If I can borrow a quote from a famous statistician, "all models are wrong, some models are useful". Just so you know, the second iteration of this process will solicit your input for the ranges you feel appropriately bound the estimate you provide in this process.

Some important assumptions for my study:

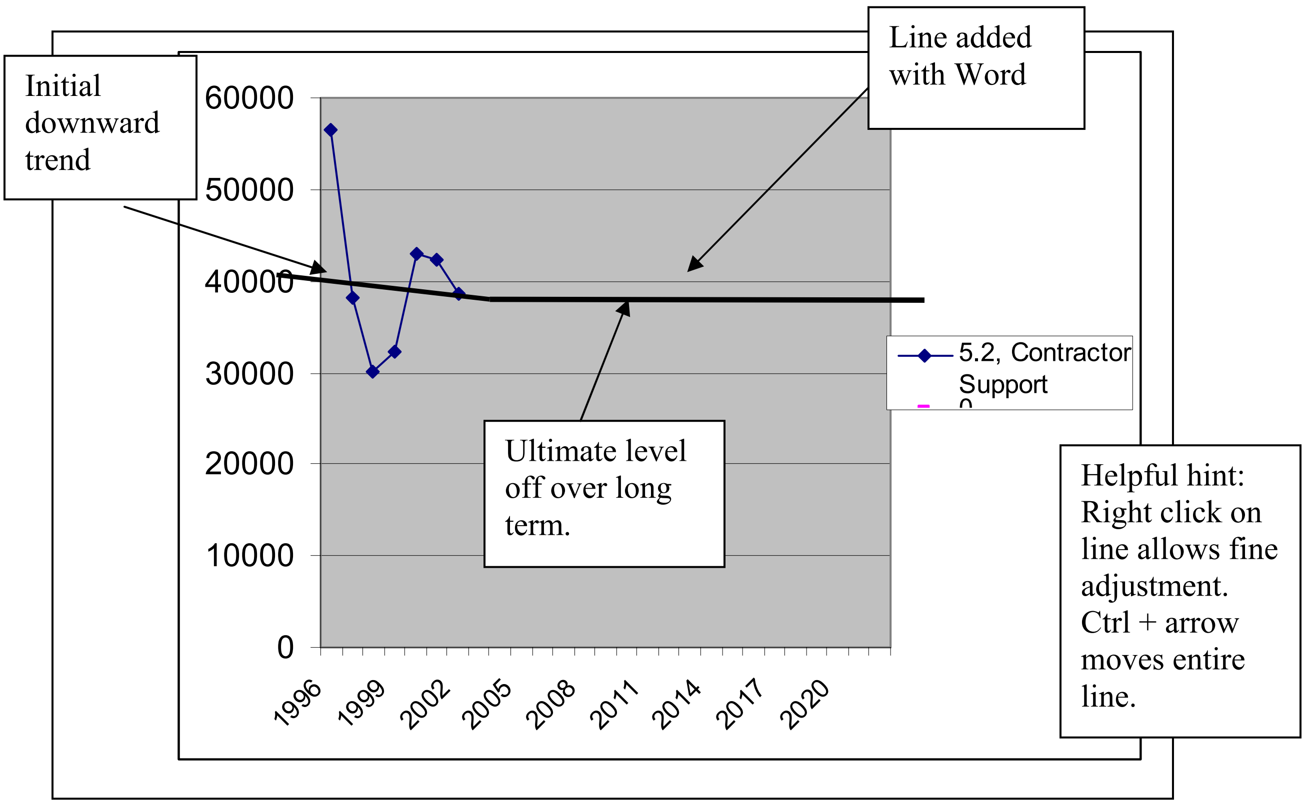
1) The C-130 inventory remains constant at 27 airframes.
2) The annual operating tempo remains constant.
3) The C-130 mission profile remains constant.
4) There are no increases in personnel.
5) The current aircraft sites are constant throughout the study.

Prior to viewing the categories, I would like you to review three typical biases that can occur when developing a subjective estimate. These biases are typically associated with the generation of the range of possible values, i.e., the min, max and most likely values, but I would like to introduce them now so that you can keep them in mind. The first type of bias is Overconfidence, which can be summarized as the bias associated with expressing an estimate with greater certainty than it should have. The second bias, Anchoring, is the selection of a single value that becomes the basis for estimating other values, or the distribution of the minimum and maximum values. The third bias is

Availability, which is the bias that results from the expert's direct knowledge of past events, or the expert's ability to imagine the outcomes that may occur.

The following is an example of how I might evaluate a cost element, and should clarify what I'm hoping you can do.

Category: Contractor Support

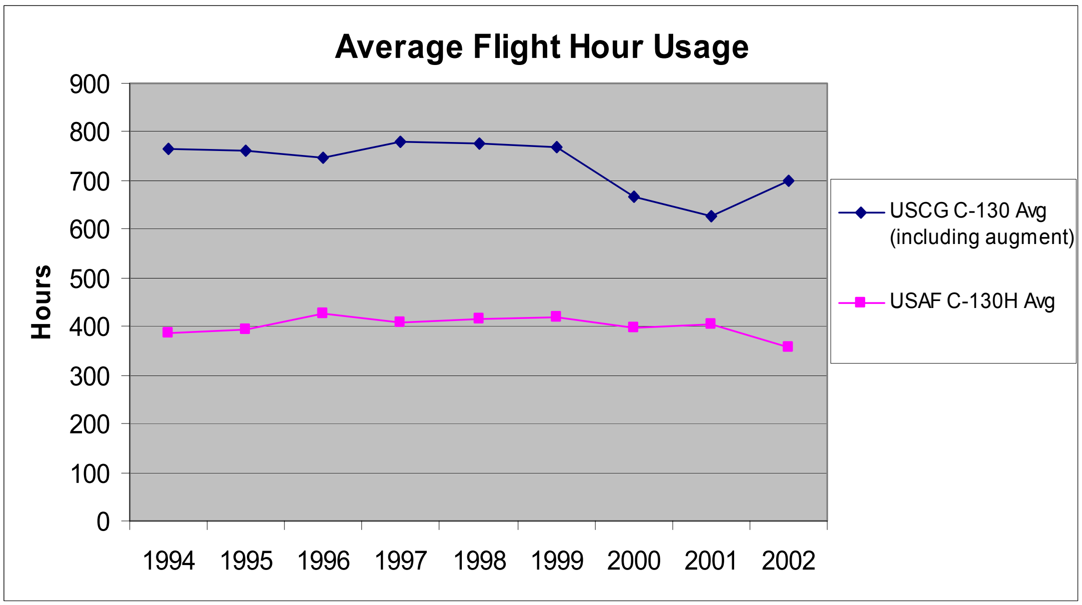



Looking at the category, I am doubtful that the Coast Guard spends as much as the Air Force on Contractor Support per aircraft. Therefore answering question 1) I would say there is limited applicability to estimating Coast Guard costs, but may have applicability for the trend. Assessing the trend, I would say that there is a current downward correlation between time and cost, however it is very gradual. Answering question 2) there seems to be enough information for a short term trend estimate, but it doesn't seem likely that the trend will always be negative. Answering question 3) I would predict that the trend would level off over a 20 year interval, with a relatively constant trend from 2006 onward.

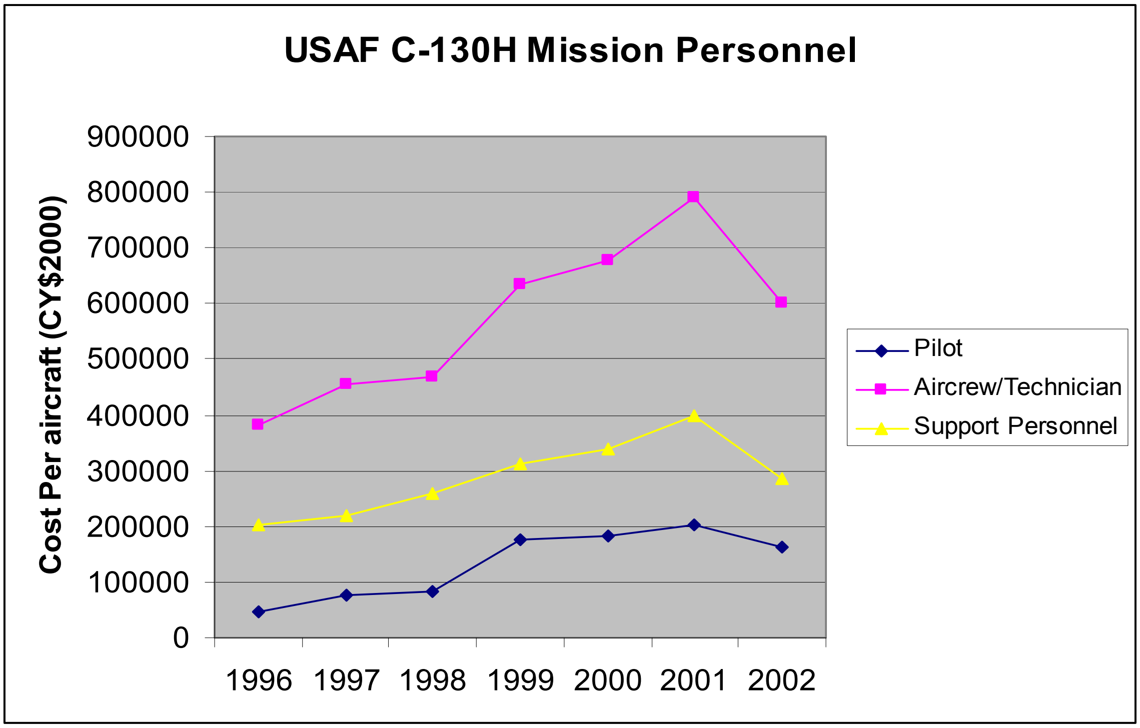
For each of the following cost categories I will present one graph that shows the data for the Air Force C-130H. I will then provide a graph with a larger timeline for your estimating use. If you desire to examine other data, e.g., C-130E, please let me know.

So that you can grasp the key difference between C-130 operations in the Air Force vs Coast Guard, the following graph is provided. The Coast Guard average does not include any augment flight hours. During this period the Air Force had approximately 275 C-130H in the inventory.

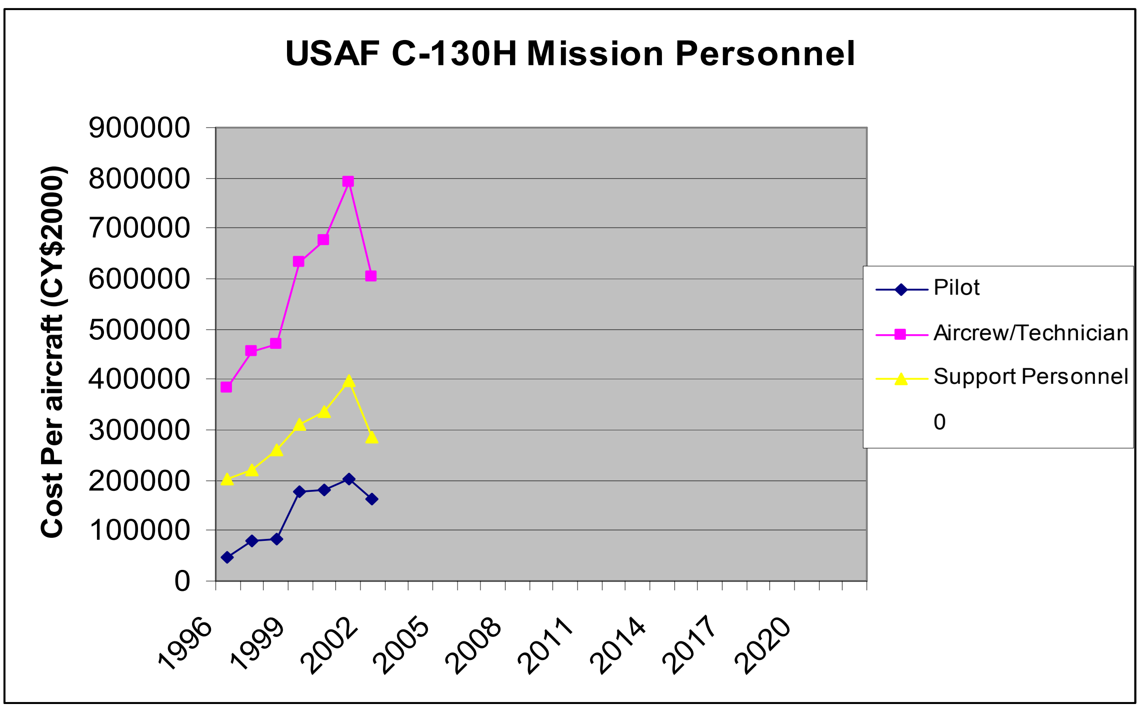
USAF C-130H Average Flight Hour Utilization



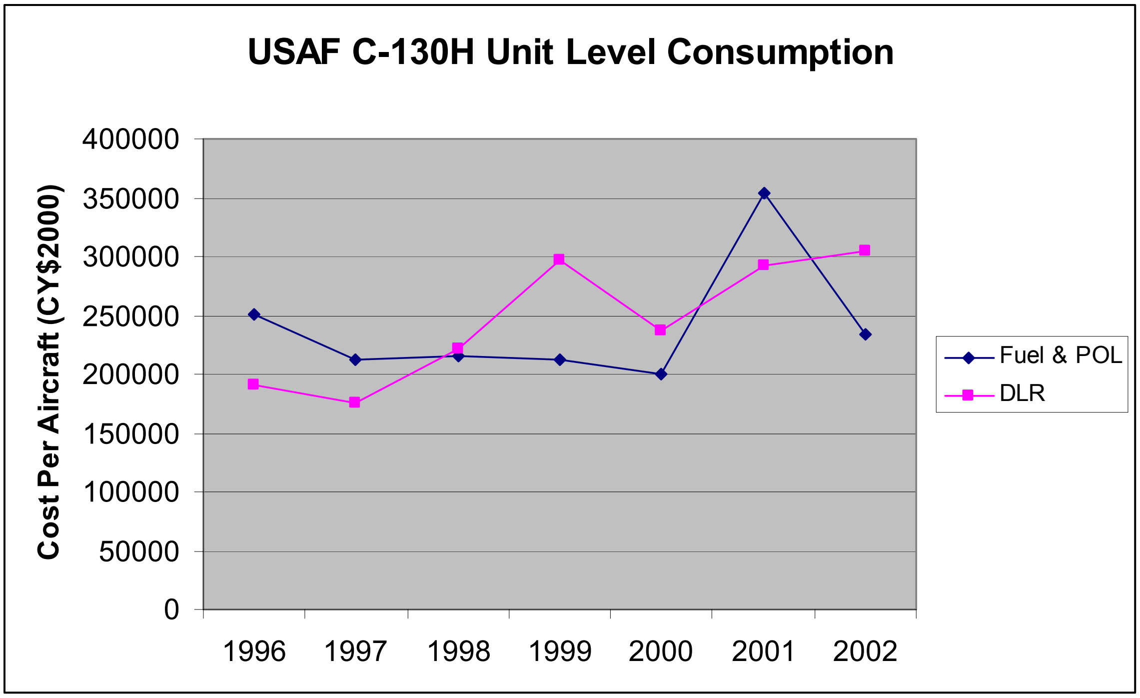
Category: Mission Personnel



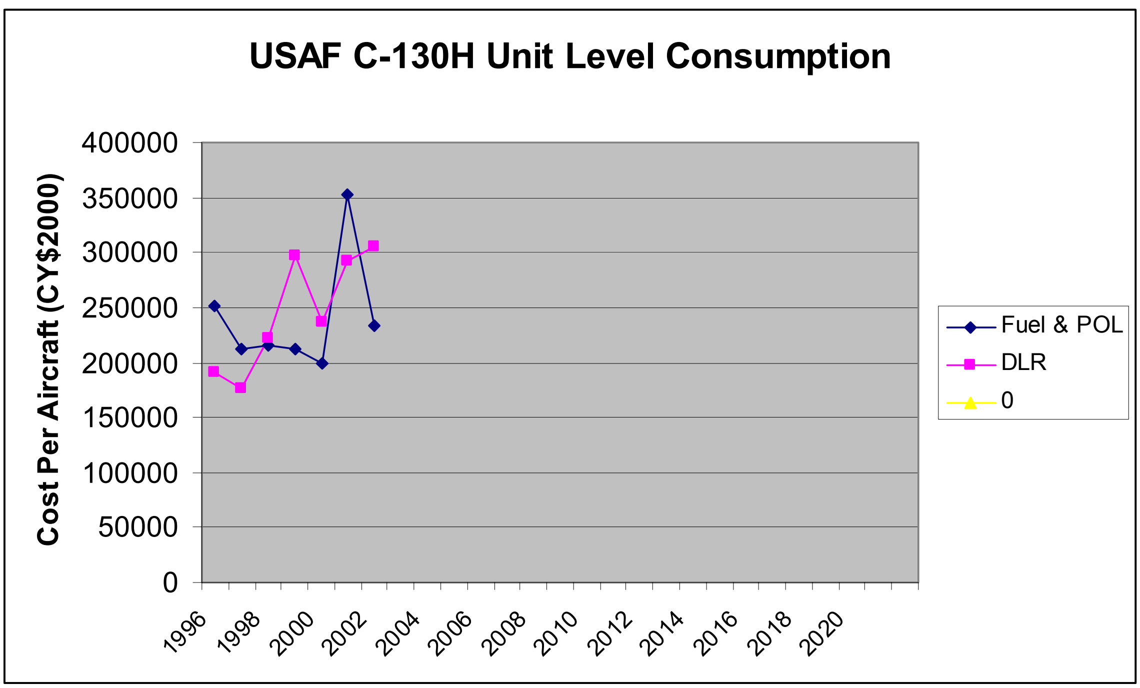

Please estimate trends for Pilot, Aircrew/Technician and Support Personnel costs.



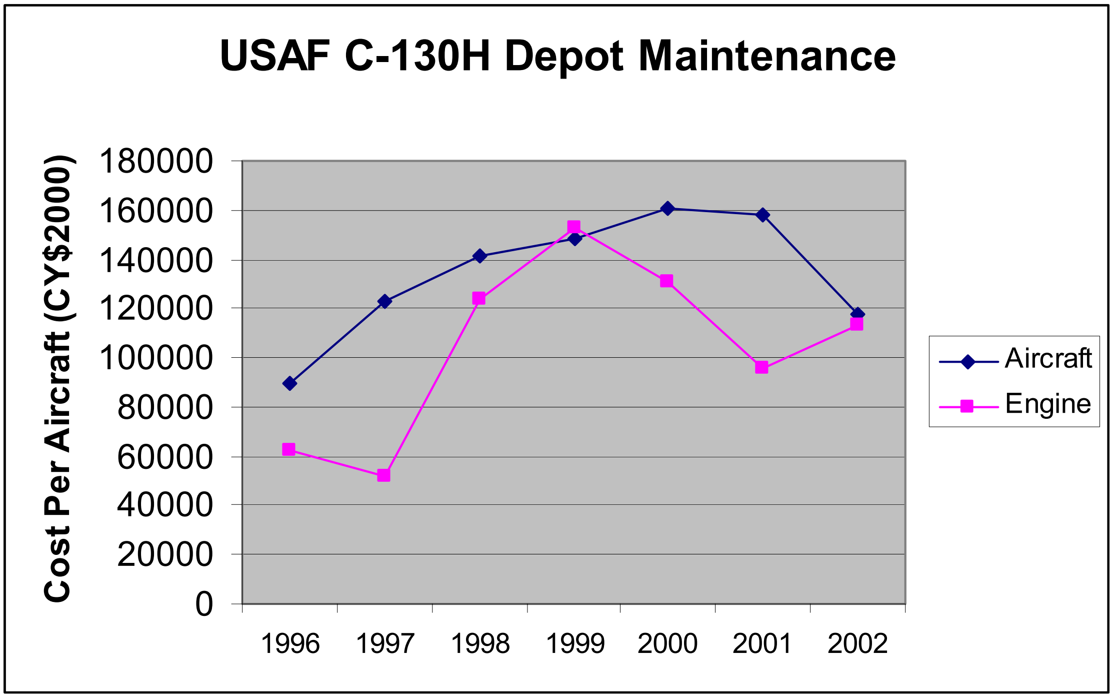
Category:  Unit Level Consumption



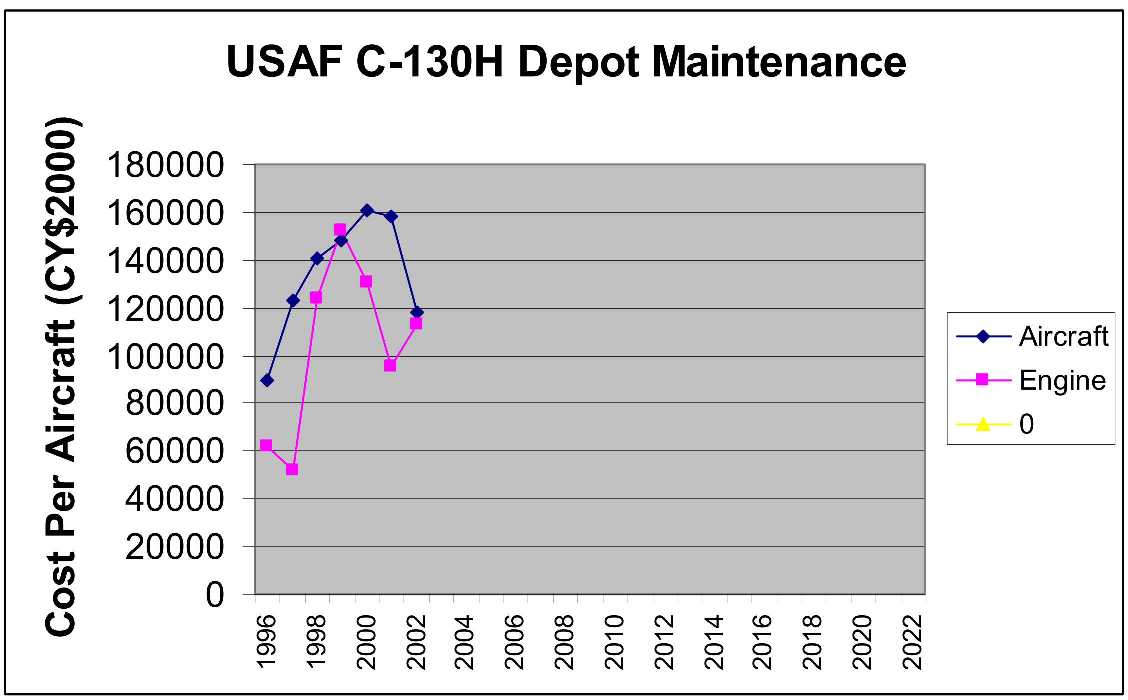

Please estimate trends for Fuel & POL, and Depot Level Reparables (DLR)



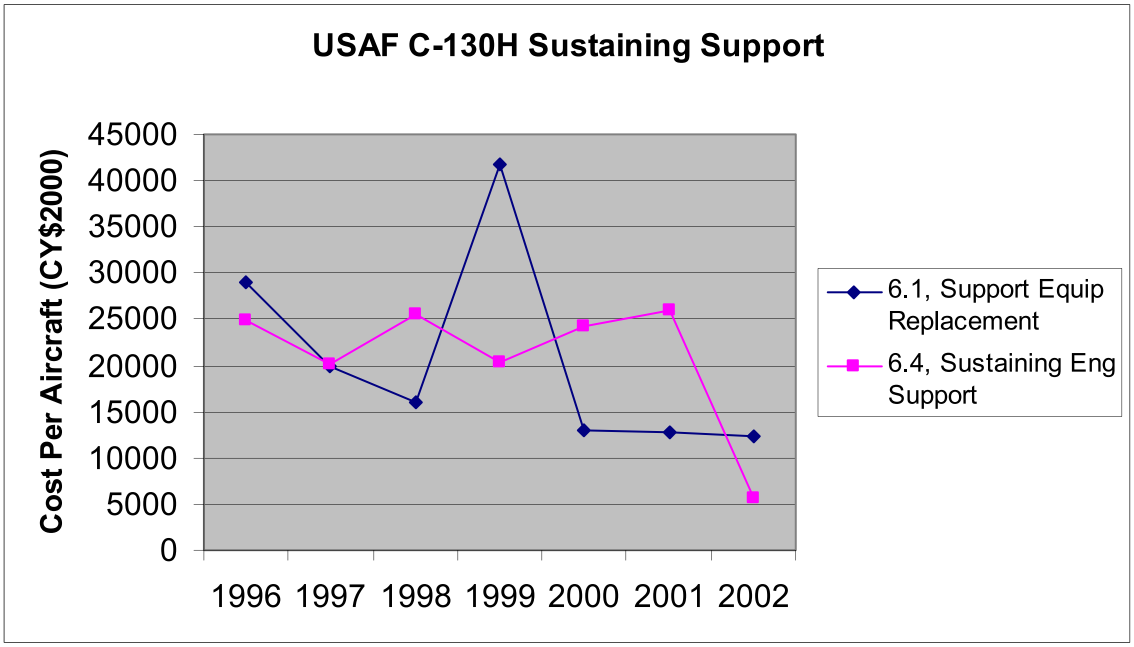
Category:  Depot Maintenance



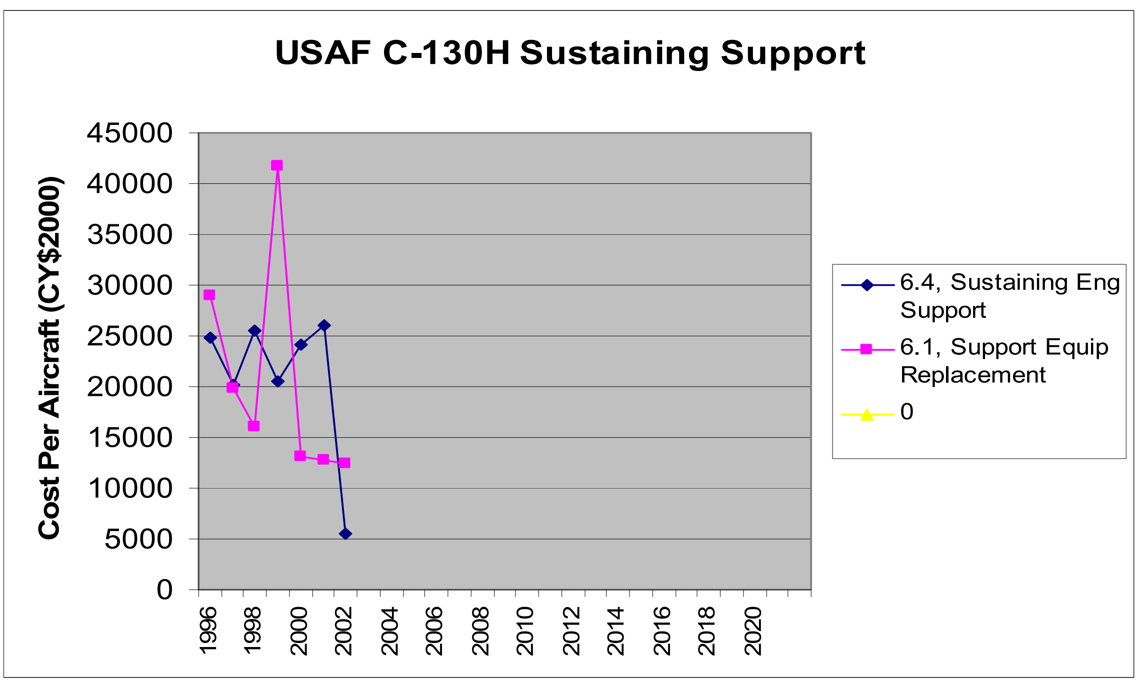

Please estimate trends for Aircraft and Engine Depot Maintenance.



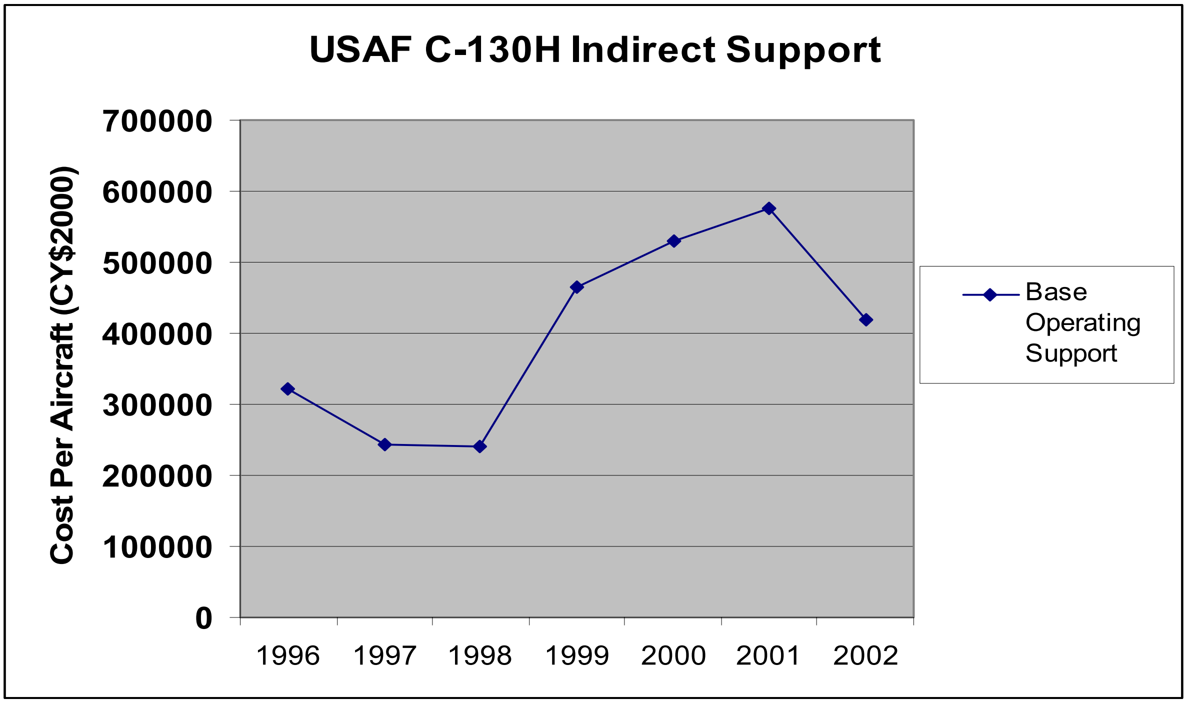
Category: Sustaining Support



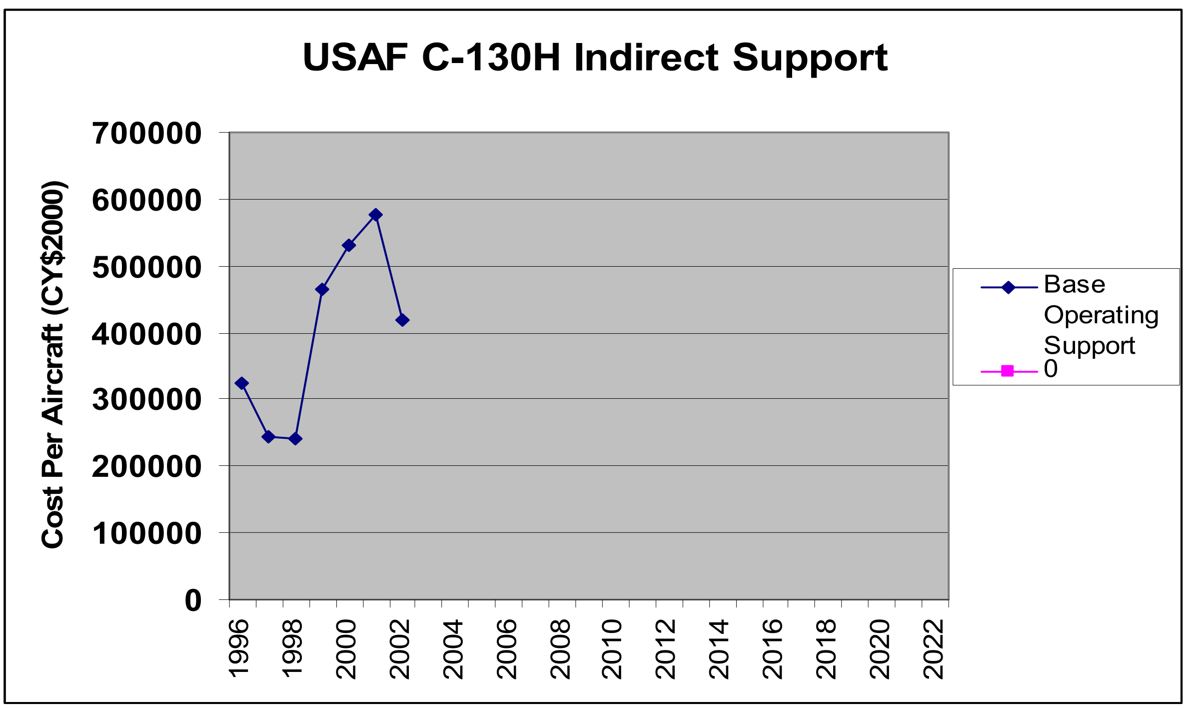

Please estimate the trend for Support Equipment Replacement and Sustaining Engineering Support. This category will include recurring modifications and system upgrades. Anticipated aircraft modifications should be projected under Sustaining Engineering Support.



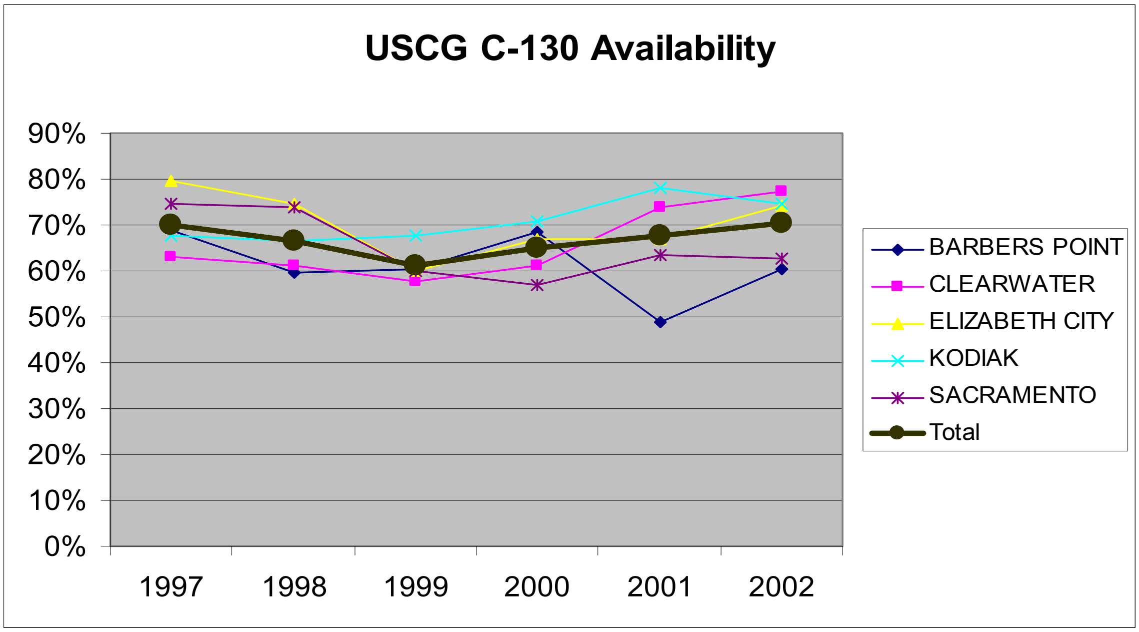
Category: Indirect Support



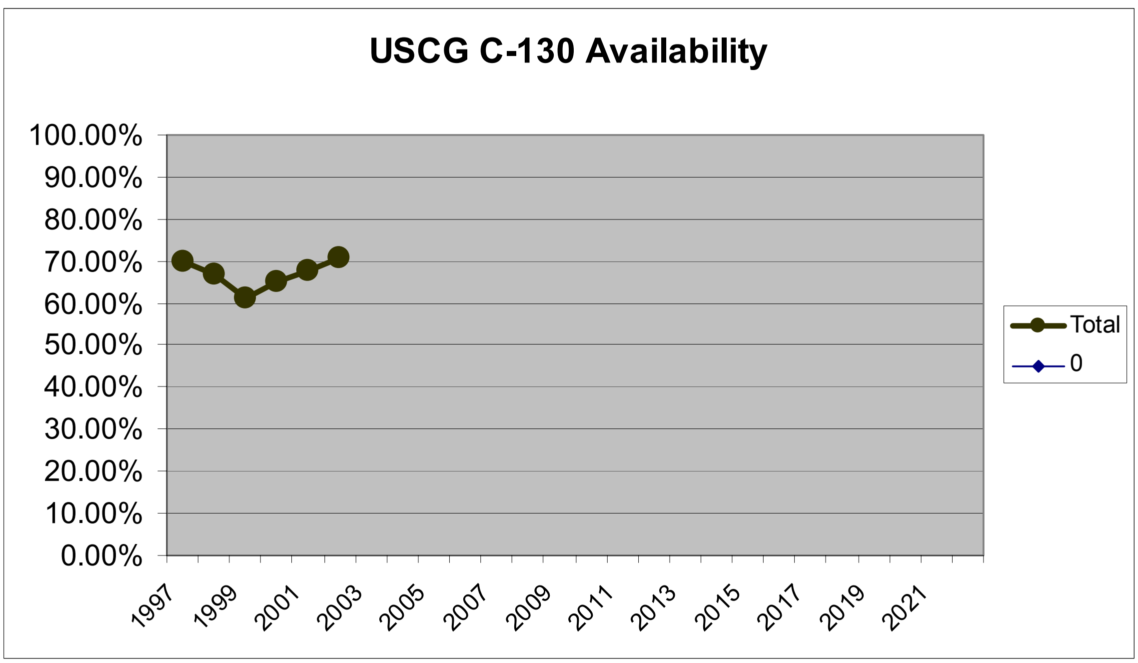

Please estimate trends for Base Operating Support



Coast Guard C-130 Availability




Please estimate the trend for fleet-wide availability. In addition, please estimate the number of PDM and Modification possessed aircraft through the period.




Thank you again for your time. Please e-mail, or fax this document back to me at your earliest convenience. Happy Holidays.

## Appendix E – Second Expert Solicitation

Coast Guard C-130 20 year projections
Round 2

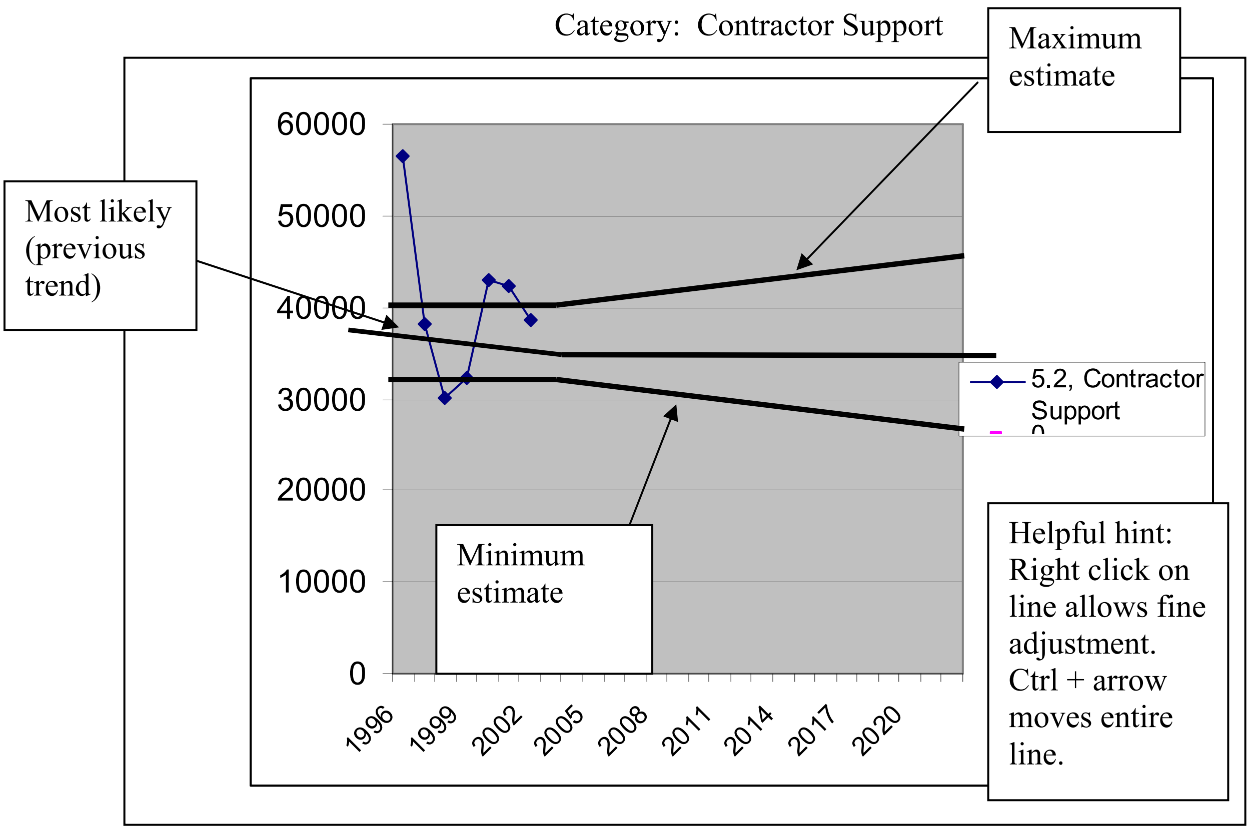
Gentlemen,

I have examined the input from LCDR Boubolis, extracted the trends that he provided, and anchored them to the best Coast Guard cost figures I could find. The trends were applied to the Coast Guard cost figures as percentages so that any changes are scaled to the initial anchoring point. I would like you both to examine the trend estimates to ensure that they are satisfactory. If you would like to change them, I only ask that you provide your reasoning for the change.

Once you are satisfied with the estimates for the trends, I would like you to estimate minimum and maximum boundaries for each of the elements. I have provided an example on the next page. Your feedback can be provided in any format, but I would like to suggest a few options. As the graphs are in a Word document, it should be possible to draw a line using the tools on the drawing tool bar. If you feel more comfortable with estimating at points, you could also use AutoShapes to identify your estimate at a particular year. If you prefer to estimate based upon a percentage increase or decrease, you can provide this as a text based estimate by any means you choose. Obviously there is no right or wrong answer for the information I am requesting.

Prior to viewing the categories, I would like you to review three typical biases that can occur when developing a subjective estimate. These biases are typically associated with the generation of the range of possible values, i.e., the min, max and most likely values, but I would like to refresh them now so that you can keep them in mind. The first type of bias is Overconfidence, which can be summarized as the bias associated with expressing an estimate with greater certainty than it should have. The second bias, Anchoring, is the selection of a single value that becomes the basis for estimating other values, or the distribution of the minimum and maximum values. The third bias is Availability, which is the bias that results from the expert's direct knowledge of past events, or the expert's ability to imagine the outcomes that may occur. I cannot remove any of these biases from your estimates, and perhaps you cannot either. I only mention them for the sake of your awareness.

The following is an example of how I might evaluate a cost element, and should clarify what I'm hoping you can do.

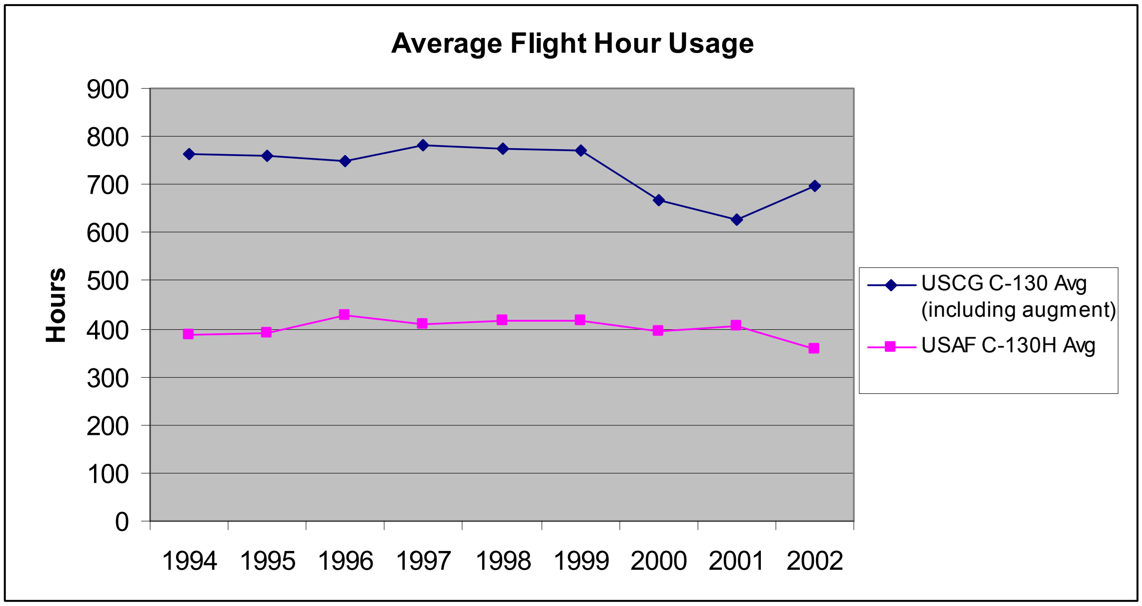



I might justify my estimate boundaries as having specific constant maximum and minimum values initially, but beyond 2004 I estimate that the maximum and minimum possible values become harder to quantify. This creates a widening of the estimate as the values become less certain.

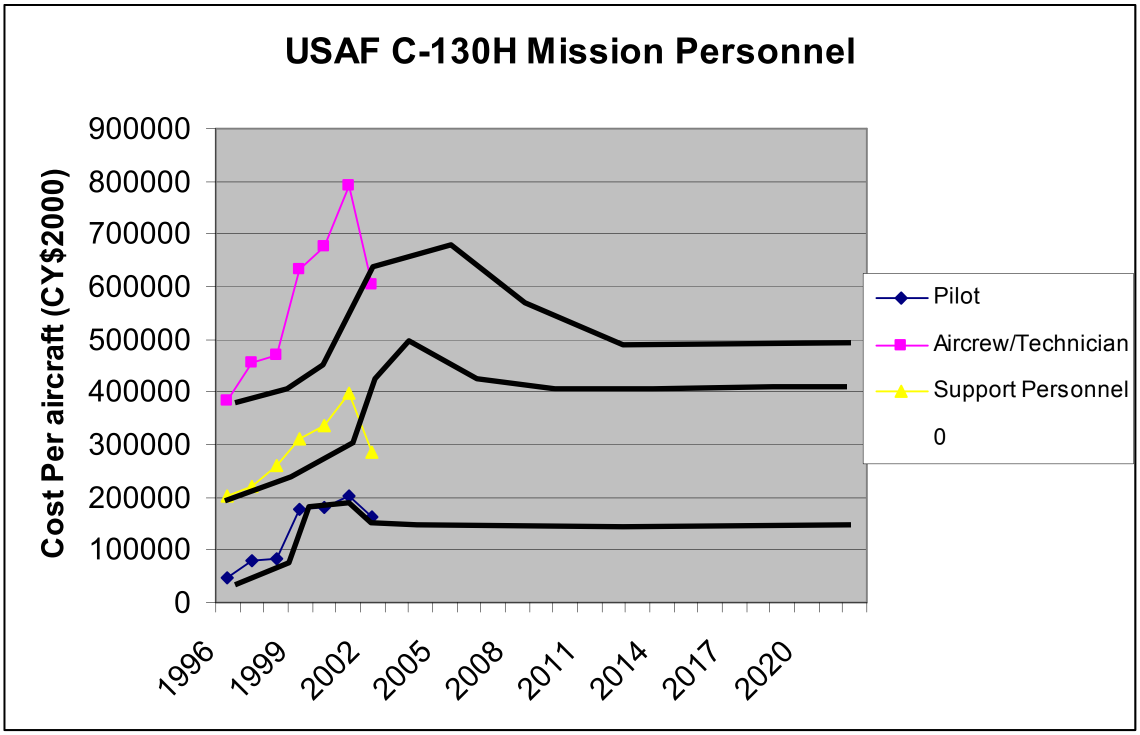
For each of the following cost categories I will present one graph that shows the trend estimate for the Air Force C-130H. I will then provide a graph that shows the trend anchored with the most current Coast Guard cost figures.

I have updated the flight hour comparison chart for your use. The Coast Guard average does now include augments. During this period the Air Force had approximately 275 C-130Hs in the inventory.

USAF C-130H Average Flight Hour Utilization



Category: Mission Personnel




Expert Comments were:

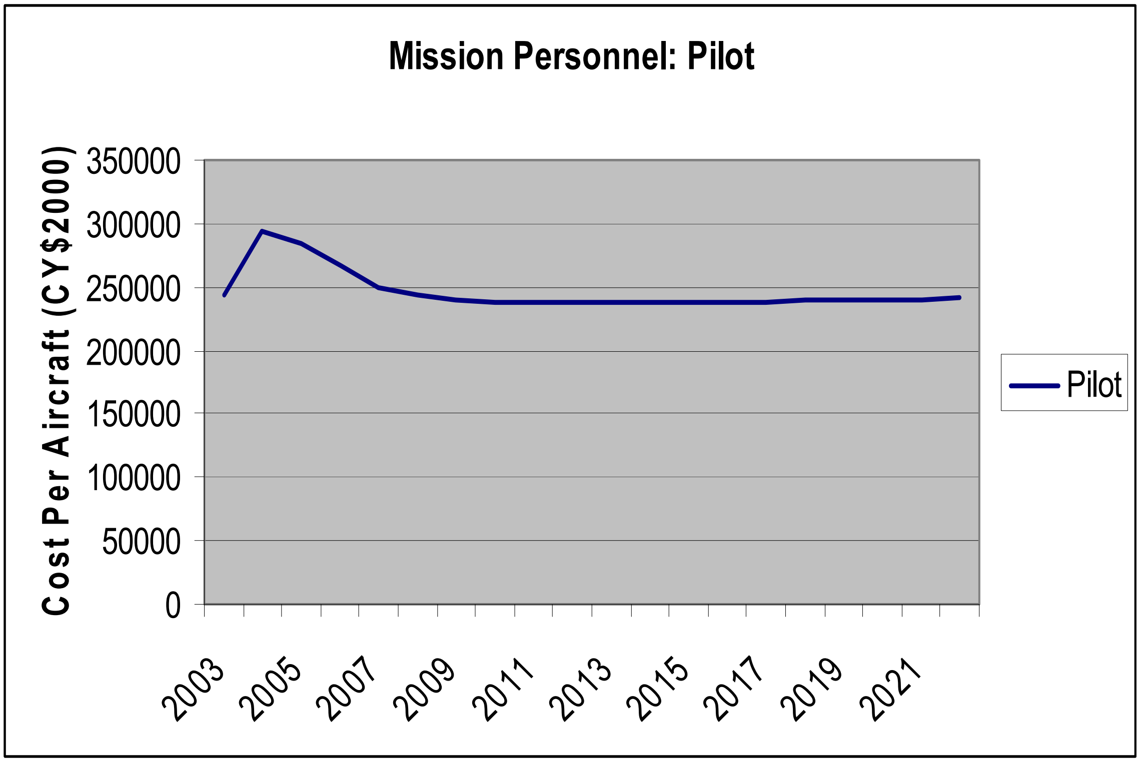
1) Is it appropriate to formulate an estimate for Coast Guard costs based upon this data set? Limited applicability. If upward trend is due to pay increases, then its appropriate to estimate on this data. However, would this not show an initial downward trend (96-99) due to 2002 dollars remaining yet pay increases did not keep up with inflation or consumer cost index? Not sure what the down turn in 2002 is due to. I can see pilot pay increases due to retention bonuses.

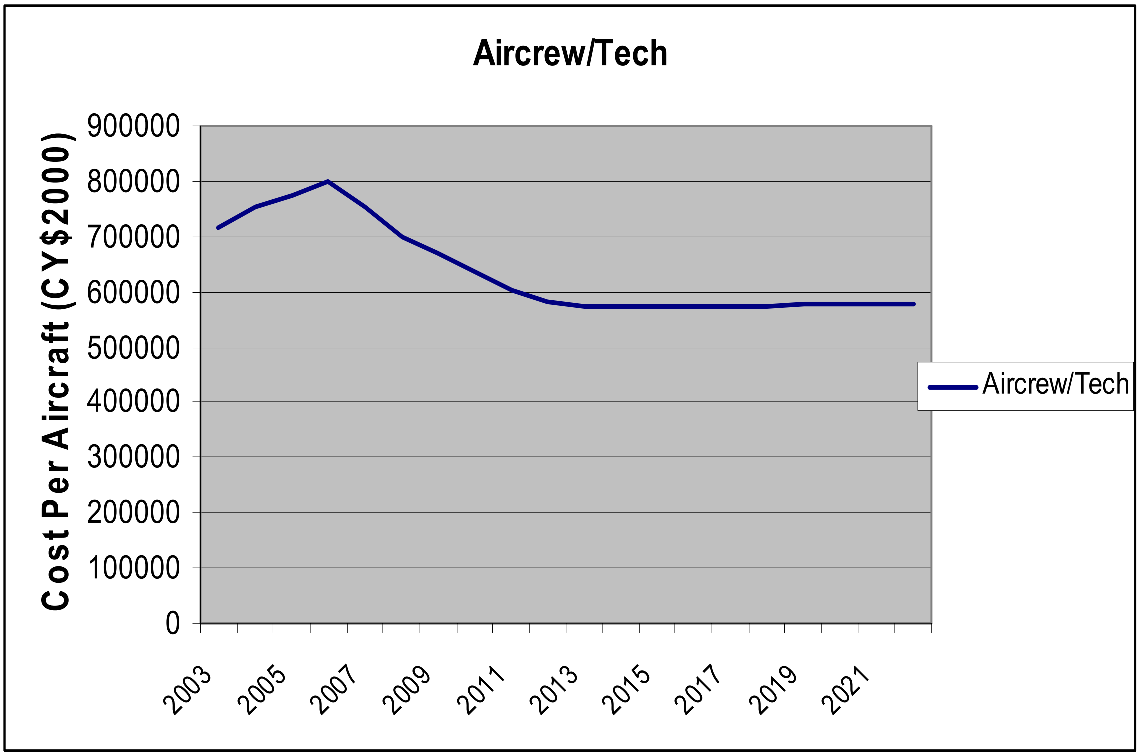
2) Is the Air Force data sufficient to create a trend estimate? I would assume that if personnel numbers are fixed (civil service and active duty folks) then the only mission personnel cost increases would be due to increased pay/benefits above inflation and/or increases in contractor support (CFT, TAMSCO folks) "support personnel."

3) Will the estimated trend change with respect to time? See my trend lines. I have shown increases due to Deepwater support personnel

costs which will eventually decrease and level off. Just my estimates. Also I expect aircrew to increase in number and cost …we are adding 5 billets per CASPER pallet to the field.

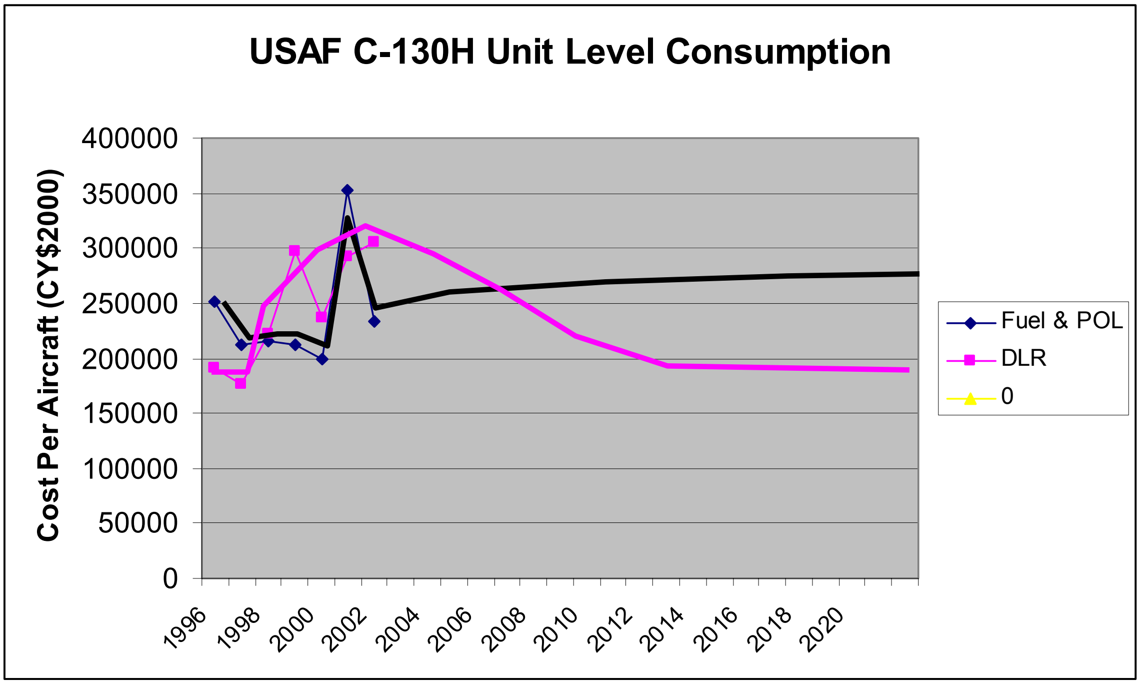
Please estimate trends for max and min Pilot and Aircrew/Technician costs.






I eliminated the Support Personnel category since it did not change.

Category: Unit Level Consumption



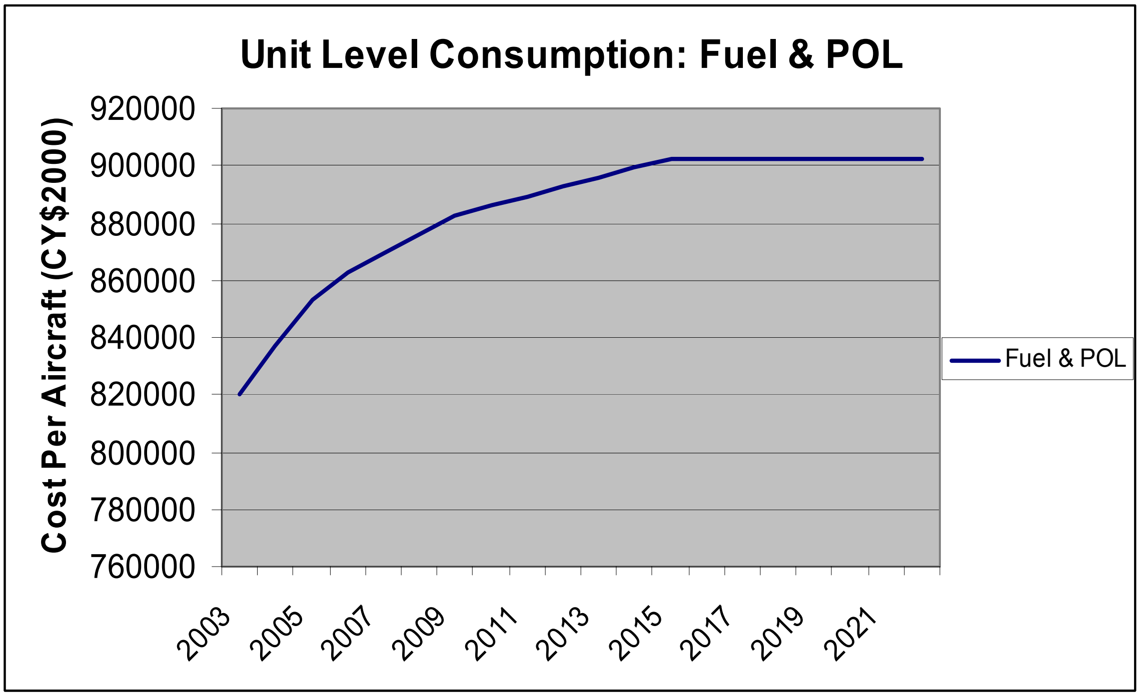

Expert comments were:

1) Is it appropriate to formulate an estimate for Coast Guard costs based upon this data set? Yes appropriate and applicable

2) Is the Air Force data sufficient to create a trend estimate? Yes, fuel & POL should mirror Air Force. DLR as show will increase more quickly than Air Force as we have smaller supply pipelines and high usage (Programmed flight hours) leads to great material consumption.

3) Will the estimated trend change with respect to time? Continue to increase until costs justify component replacements/upgrades or airframes replaced. Fuel & POL will reflect economic trends.

Please estimate the minimum and maximum values for Fuel & POL



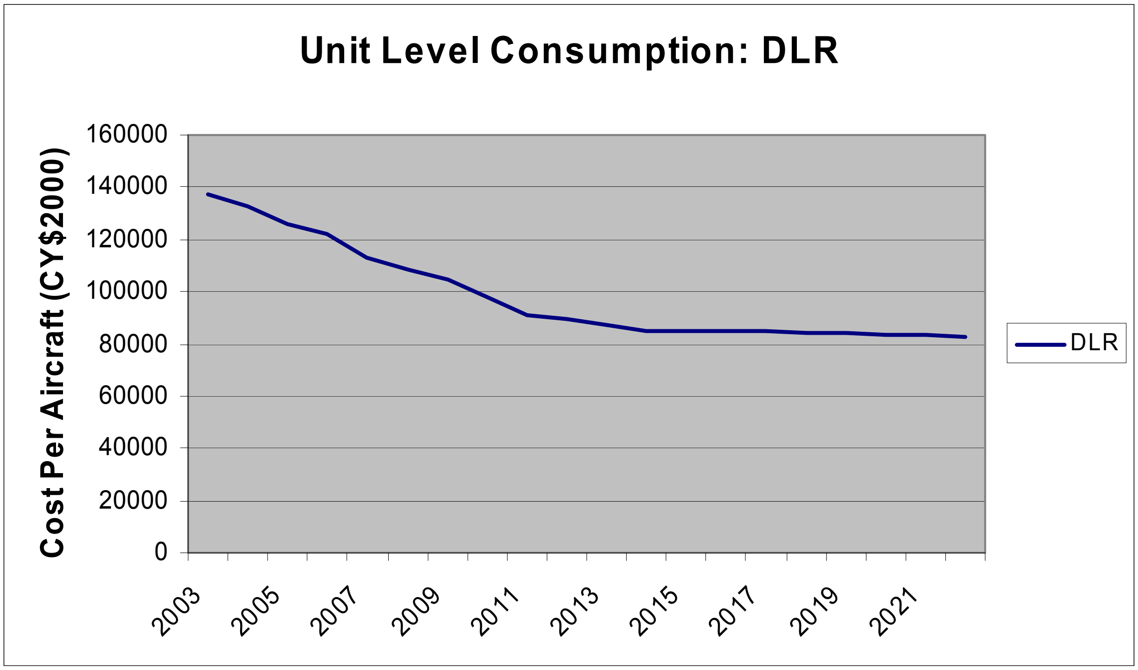

Please examine the trend estimate for Depot Level Reparables once more. I suspect that there might be some reduction in cost per aircraft, but I don't believe that it would occur immediately. This was contrary to the comments.

I have used the following AFC-41 cost accounts to build the Depot Level Reparable category:

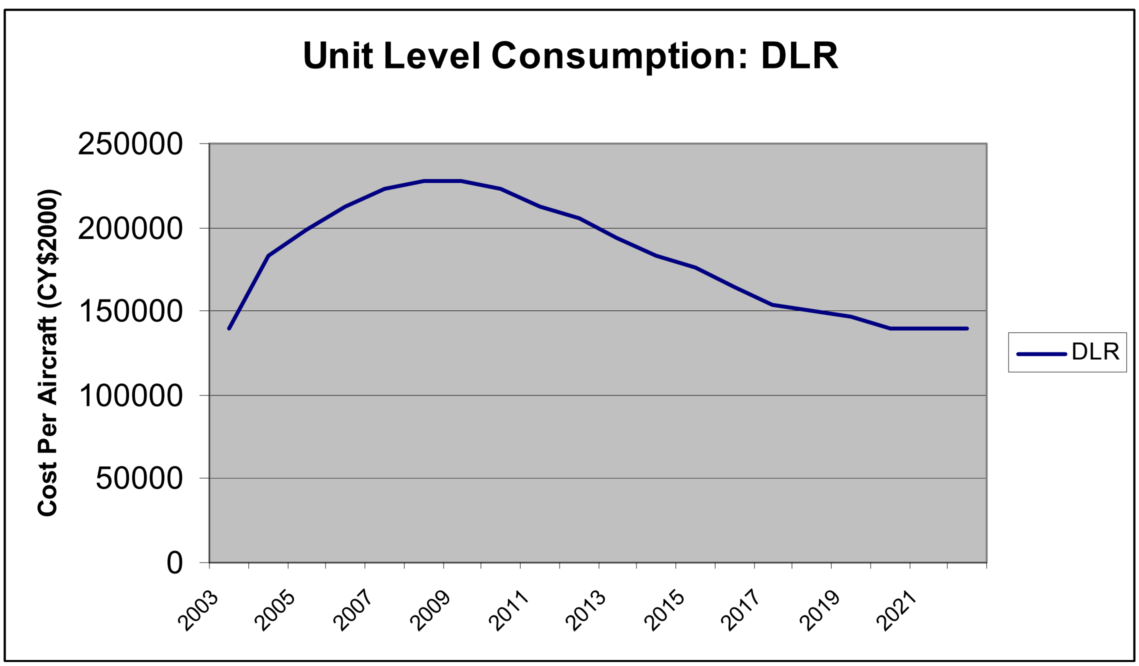
| | |
|---|---|
| Component Repair Division | 1,224,760 |
| Aviation Logistics Division | 601,009 |
| Materials Branch | 1,933,081 |
| Total | 3,758,850 |

I was a bit concerned that the values were so much lower than what the Air Force values were. My only attempt at an explanation would be that we have a management advantage because of our lower number of spares.

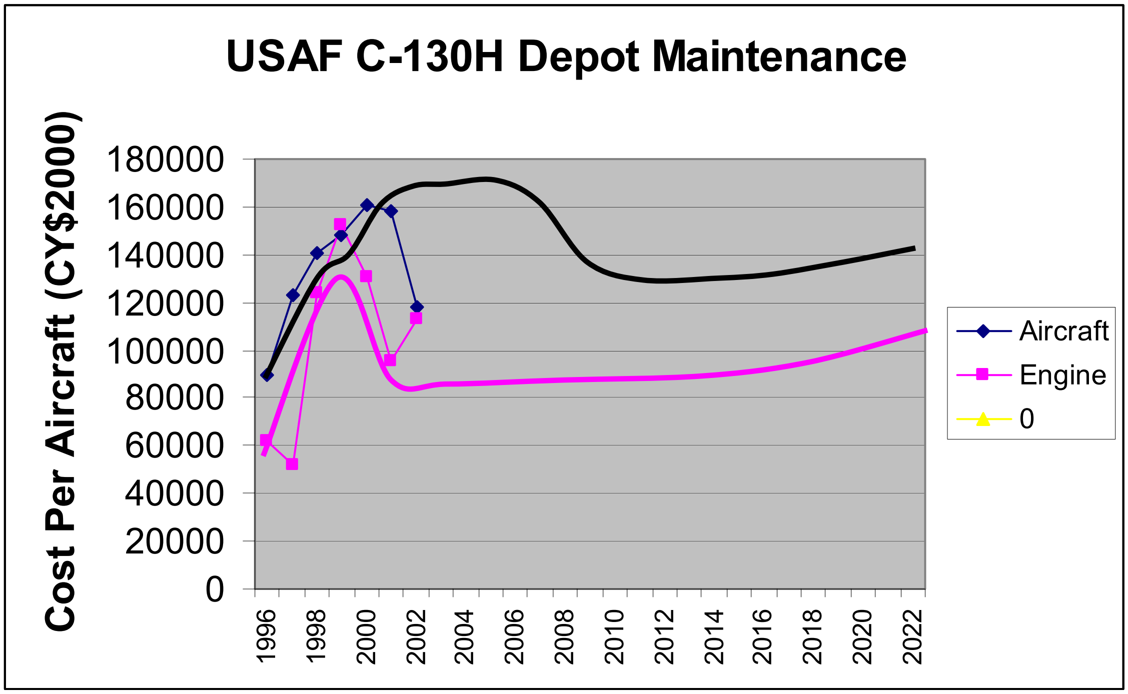
Please estimate the minimum and maximum values for Depot Level Reparables.




Based upon the comments I developed the following chart. Please feel free to use it if you feel it satisfies the comments you provided.



Category: Depot Maintenance



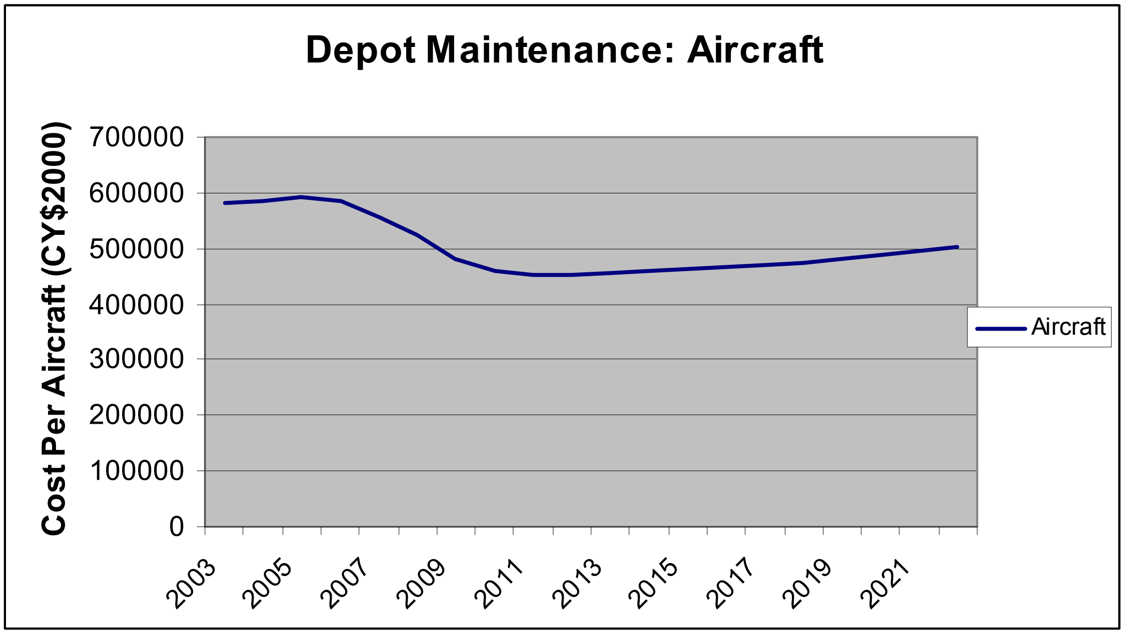

Expert comments were:

1) Is it appropriate to formulate an estimate for Coast Guard costs based upon this data set? Somewhat until 2000 when we departed from the traditional Air Force PDM support concept to develop our own Coast Guard depot work specification ( PSI – Progressive Structural Inspect). We saw an increase in our PDM/PSI funding from $12M to $19M per year. We anticipate the cost to level then decrease as we move towards Coast Guard PSI work.

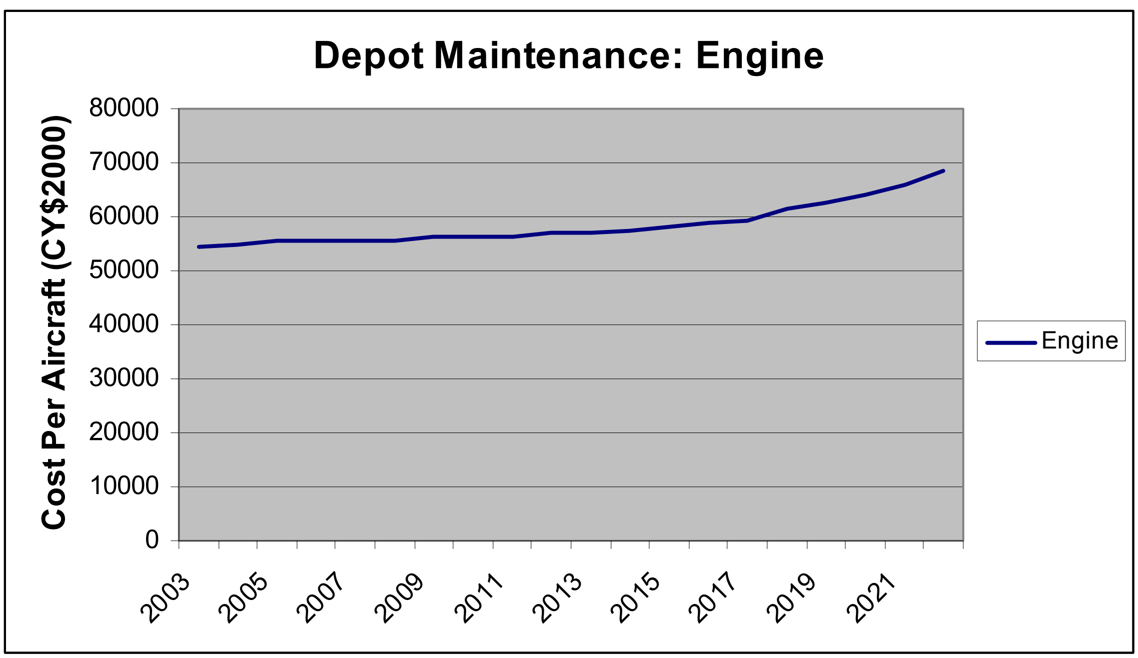
2) Is the Air Force data sufficient to create a trend estimate? Somewhat anticipated Coast Guard trends with given depot support program improvements as shown.

3) Will the estimated trend change with respect to time? Yes as noted

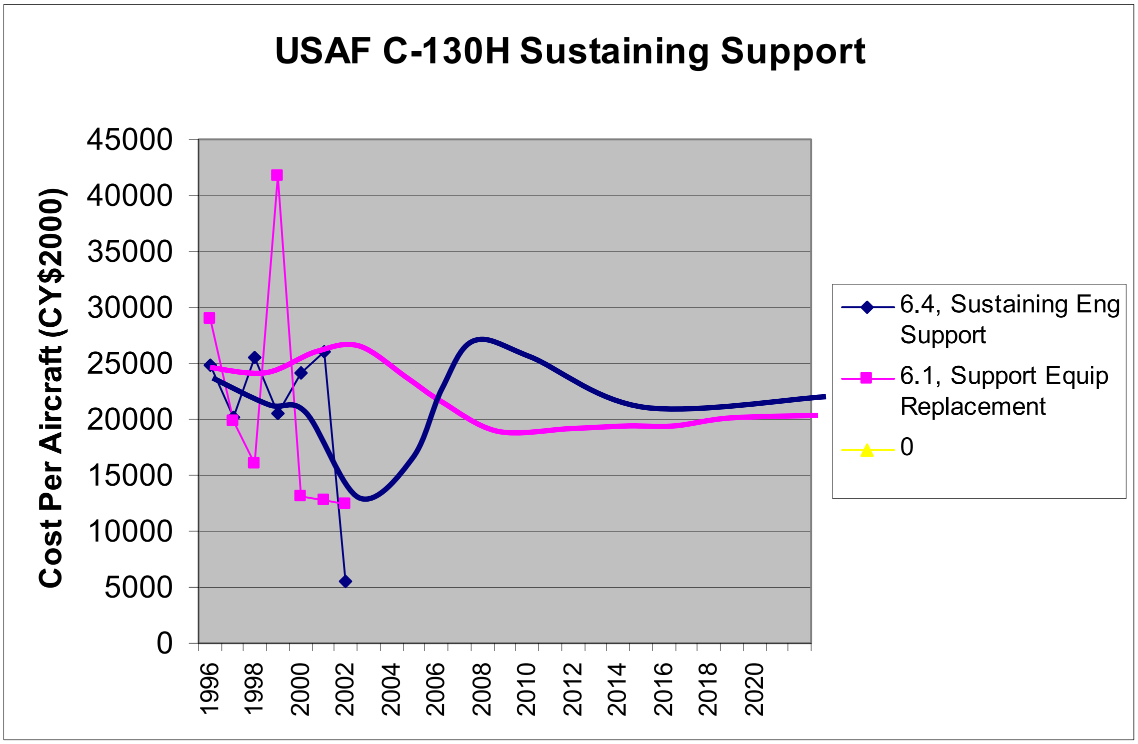
Please estimate trends for Aircraft and Engine Depot Maintenance.




I used FY02 engine overhaul data, which was the first full year under the new process. I am a bit concerned that the engine maintenance costs were lower than the Air Force when you consider that our airplanes fly significantly more hours. However, I cannot dispute the data that was provided. Perhaps this is simply a testament to the savings we are now seeing.



Category: Sustaining Support



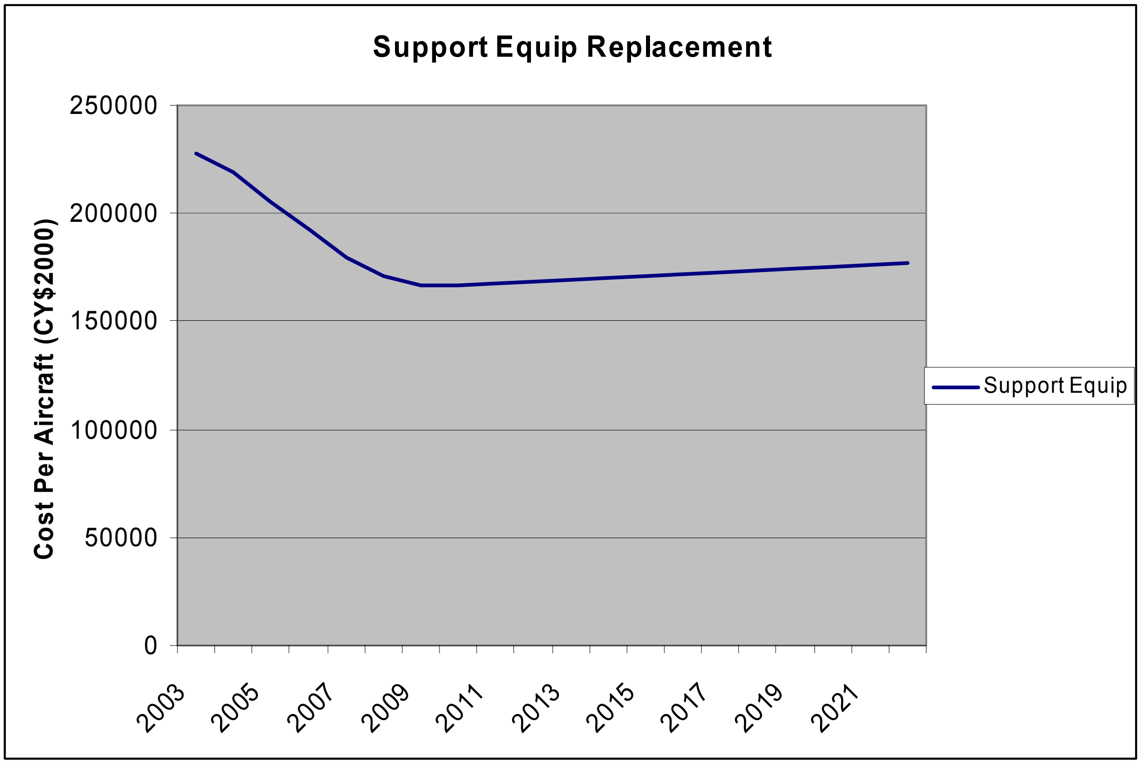

Expert comments were:

1) Is it appropriate to formulate an estimate for Coast Guard costs based upon this data set? Looks like you transposed the line colors … Somewhat, with Deepwater, DW, we expect a short-lived increase in upgrade/modification costs followed by asset recapitalization but I've tried to show this as a steady increasing trend … with out the asset recapitalization, we would continue modifications & upgrades.

2) Is the Air Force data sufficient to create a trend estimate? Somewhat but not directly.

3) Will the estimated trend change with respect to time? As shown

I used the AR&SC GSE cost account data for this cost element. Please estimate the trends for max and min Support Equipment Replacement costs.




I am using the following definition for Sustaining Engineering Support.

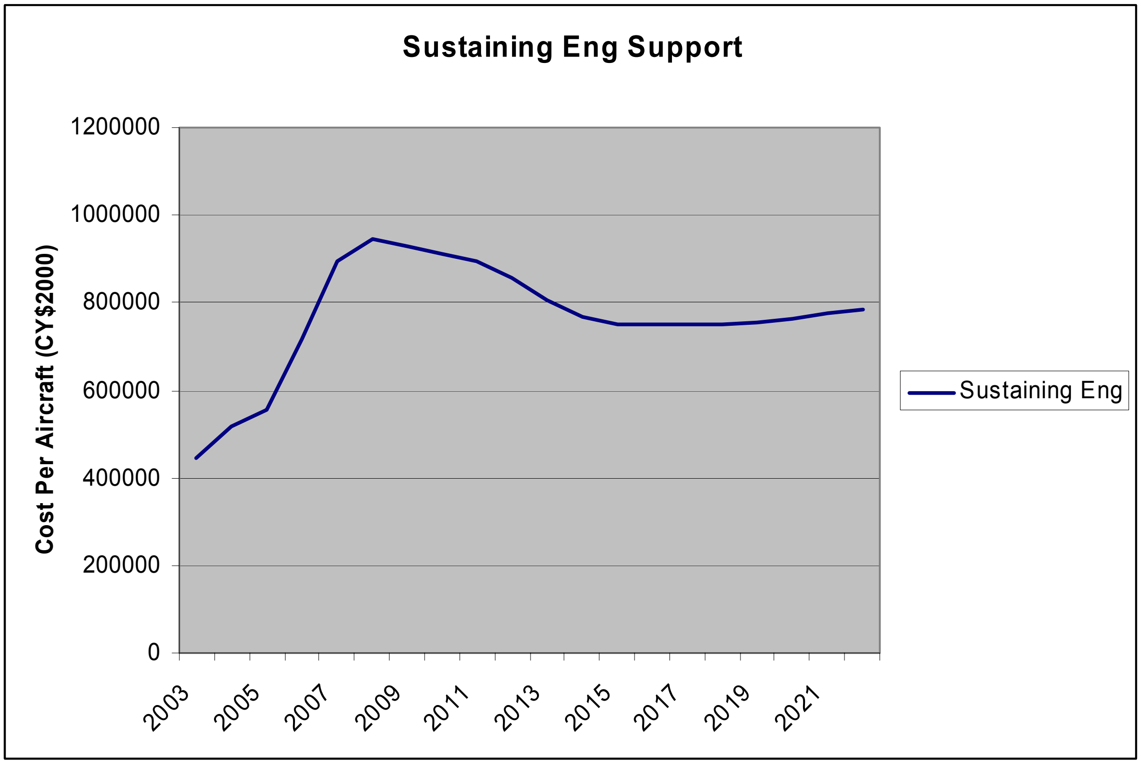
*Sustaining Engineering Support.* *The labor, material, and overhead costs incurred in providing continued systems engineering and program management oversight to determine the integrity of a system, to maintain operational reliability, to approve design changes, and to ensure system conformance with established specifications and standards. Costs in this category may include government and/or contract engineering services, technical advice, and training for component or system installation, operation, maintenance, and support*

Based on this definition I have allocated the following AR&SC costs to this category:

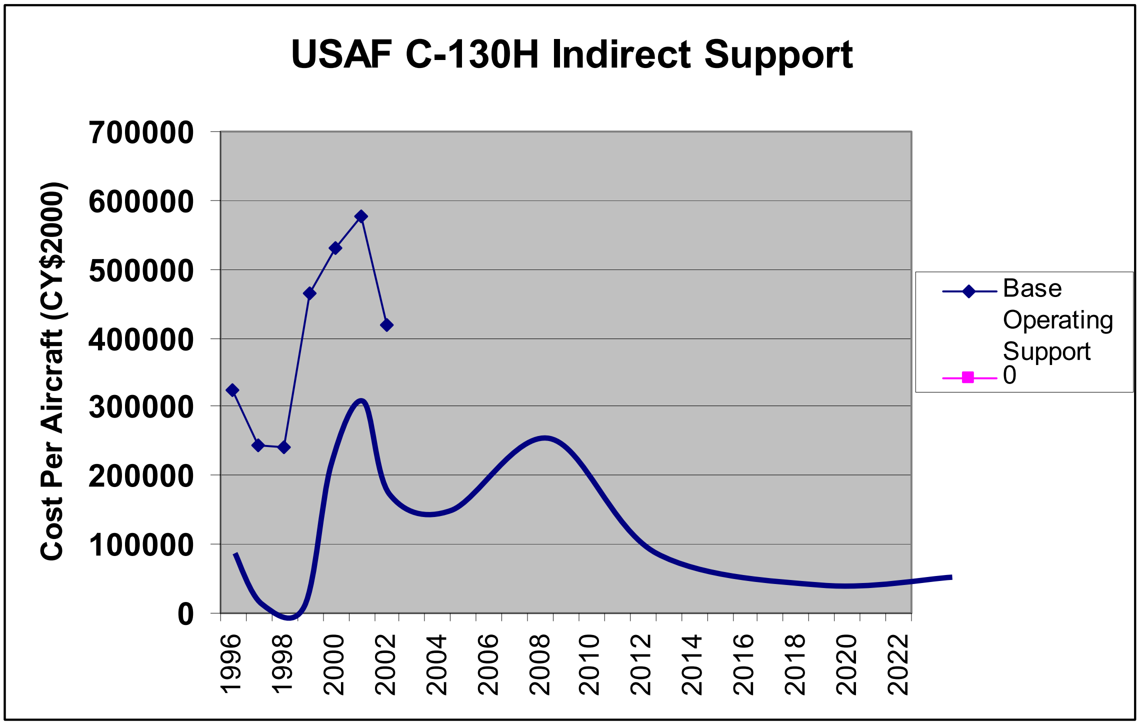
| | |
|---|---|
| Engineering Industrial Support Division | 2,394,610 |
| Information Services Division | 4,198,331 |
| Technical Representatives Allocated | 1,394,409 |
| ACMS | 1,919,027 |
| HC-130 Admin Support | 222,766 |
| HC-130 Engineering Support | 1,933,081 |
| Total | 12,062,224 |

If any of these costs do not belong in this category, please bring them to my attention.

Please estimate the trends for max and min Sustaining Engineering Support costs.


Sustaining Eng Support
Cost Per Aircraft (CY$2000)
1200000
1000000
800000
600000
400000
200000
0
2003
2005
2007
2009
2011
2013
2015
2017
2019
2021
Sustaining Eng

Category: Indirect Support




Expert comments were:

1) Is it appropriate to formulate an estimate for Coast Guard costs based upon this data set? Yes with the exception that the Coast Guard doesn't maintain a golf course on every base :~) just joking … actually, I believe the trends will be similar but our costs are shifted down from what the Air Force realizes.

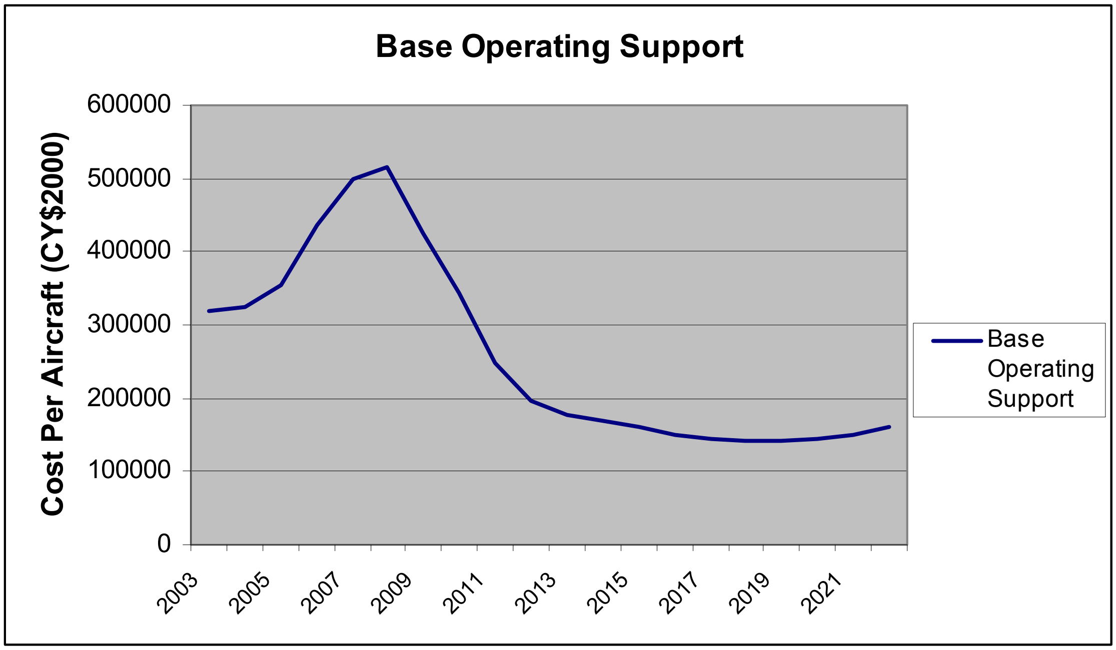
2) Is the Air Force data sufficient to create a trend estimate? As noted above.

3) Will the estimated trend change with respect to time? See trends

At this time I do not have a good FY02 value for C-130 base operating costs. I am attempting to locate this information and will provide it as soon as possible. I have *estimated* that the FY'02 Operating Support costs per Coast Guard C-130 aircraft were

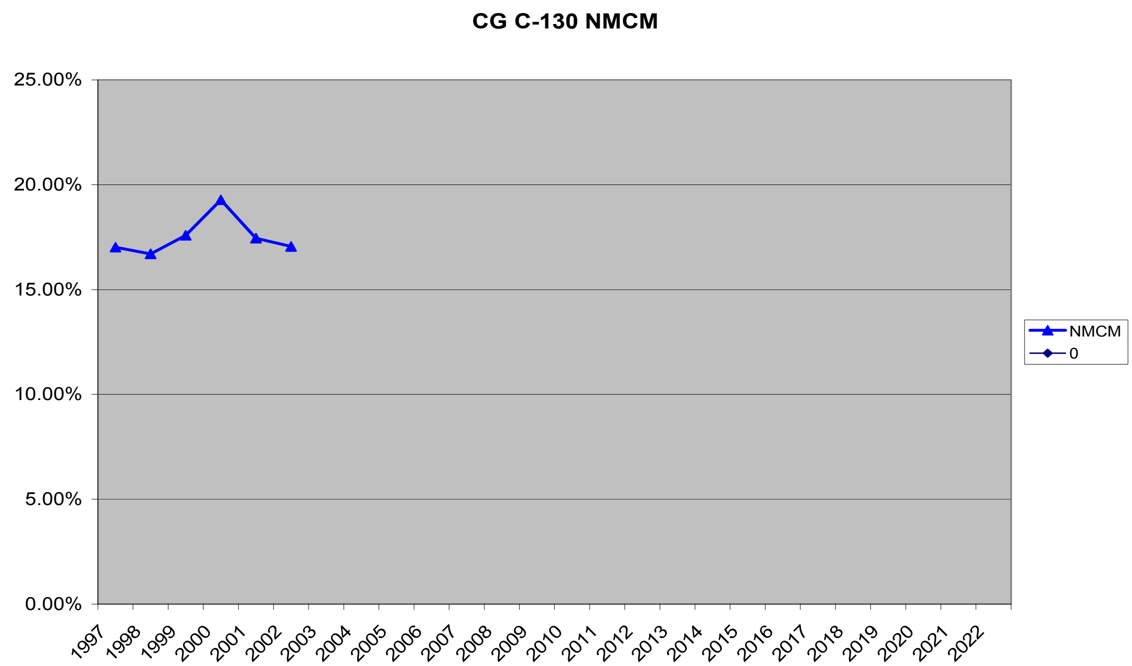
$320,000.00 (approximately 5 percent of the total Operating Expense). I will update this number as soon as I can.

Please estimate trends for Base Operating Support.

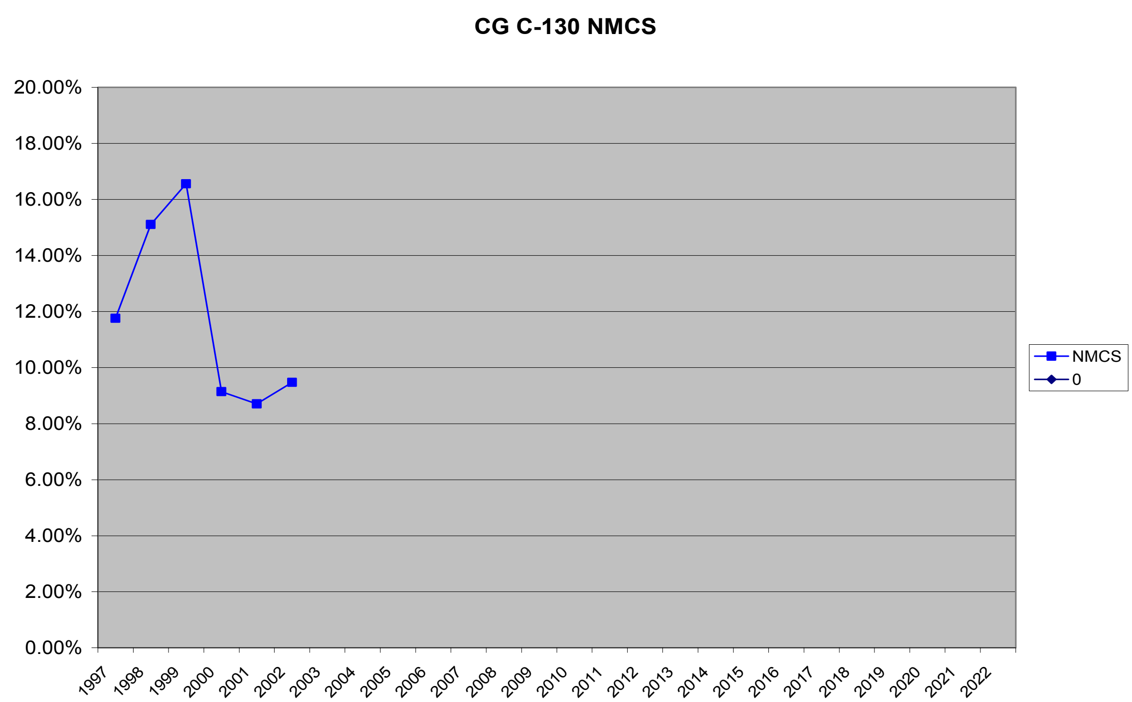


Coast Guard C-130 Availability

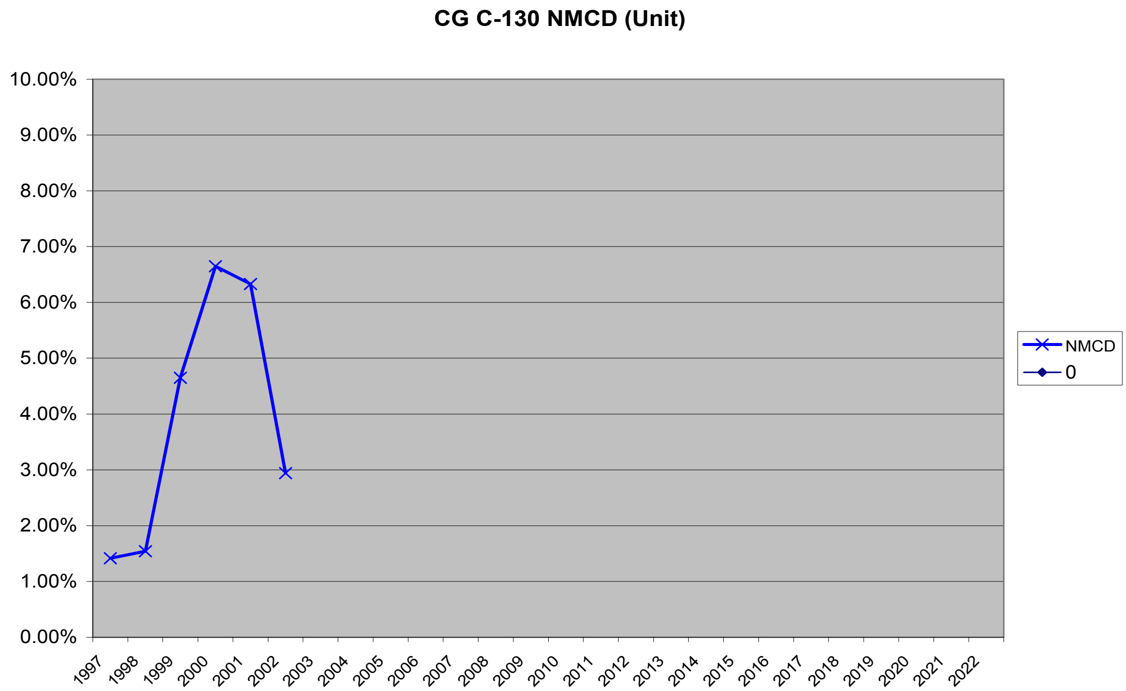
Please estimate the trend for the minimum, most likely and maximum unit NMCM



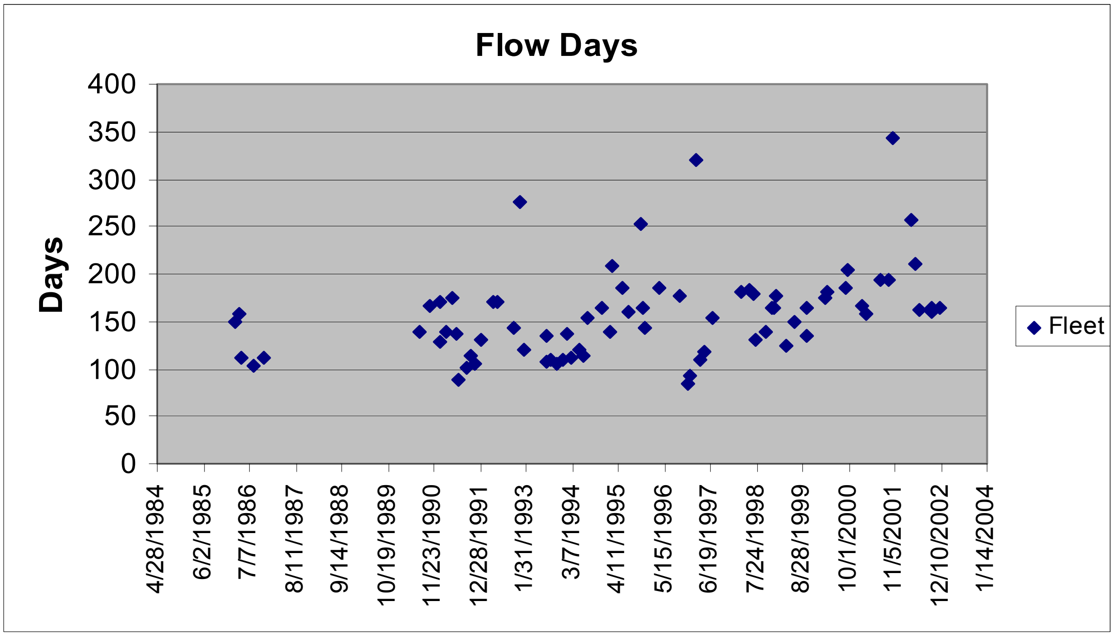

Please estimate the trend for the minimum, most likely and maximum unit NMCS



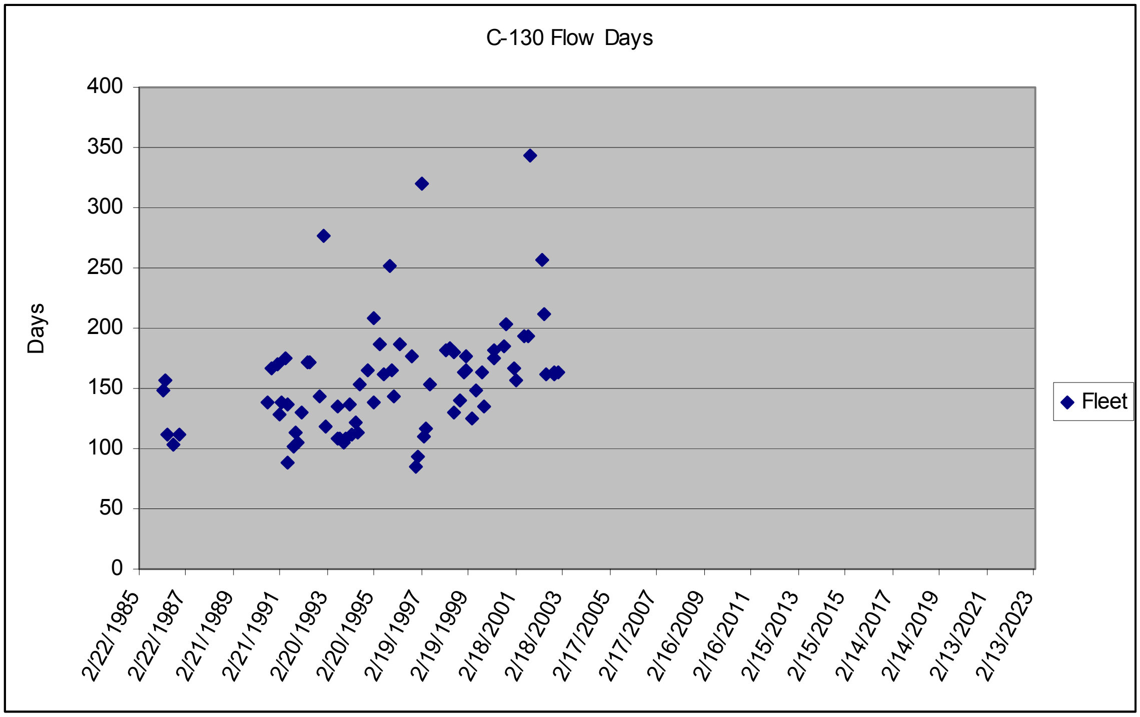
Please estimate the trend for the minimum, most likely and maximum unit NMCD



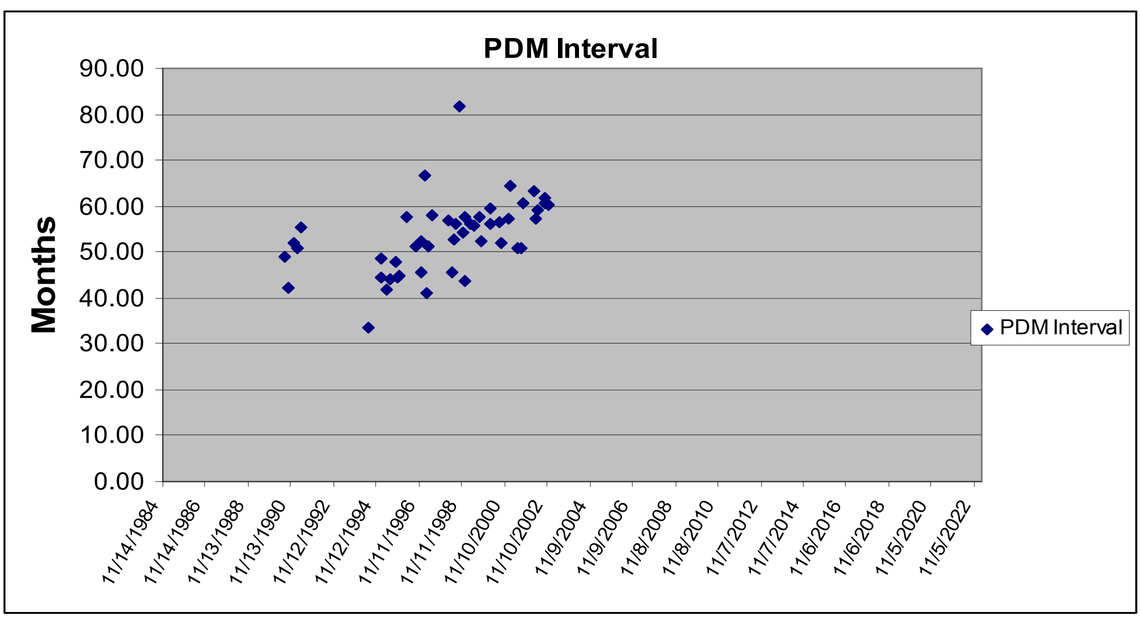
The following chart represents the PDM flow days for the 1500 and 1700 series aircraft. Please estimate the trend for fleet-wide PDM Flow days. Once you are satisfied with your estimate for the trend, please select boundaries for the minimum and maximum number of flow days through FY 2022.



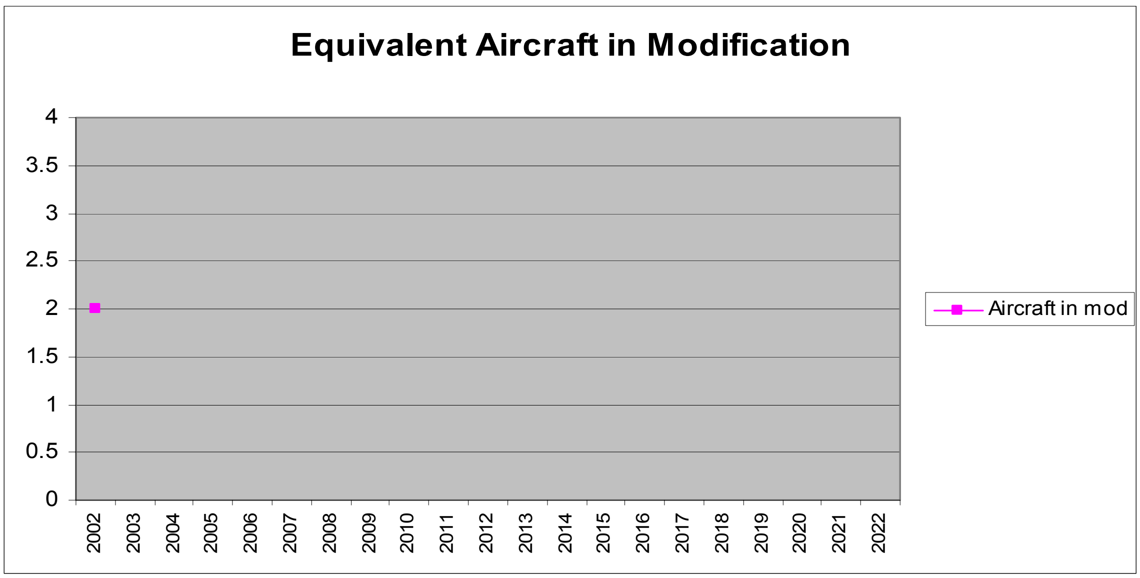

Please use the following chart for creating your trend, minimum and maximum estimates.




The following chart represents the Intervals between PDMs. Obviously there is a data gap between 1991 and 1994. Please estimate the trend for the PDM Interval. Once you are satisfied with your estimate for the trend, please select boundaries for the minimum and maximum number of months between PDMs through FY 2022.

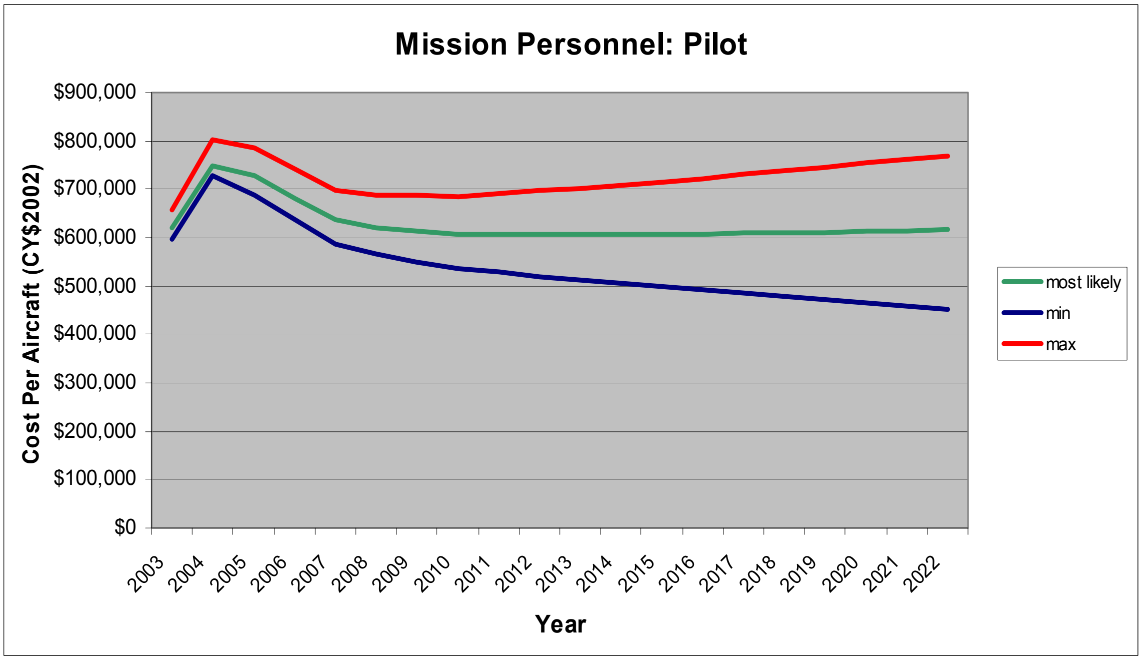


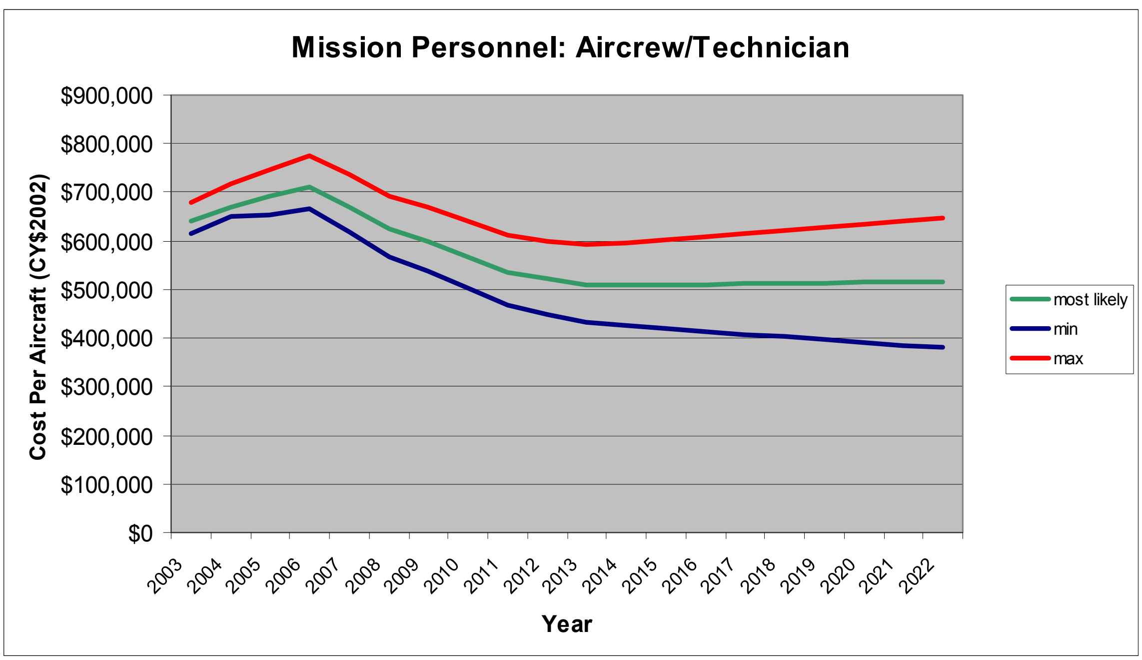
The final uncertainty I would like to capture with this survey is the number of equivalent aircraft undergoing modifications each year. For example, if 2 aircraft are in modification for 240 days each, the equivalent aircraft in modification would be 1.32 (2*240/365). Unfortunately I do not have any historical data on C-130 modifications. Please use the following graph for estimating the minimum, most likely and maximum number of equivalent aircraft that are expected to be modified each year.

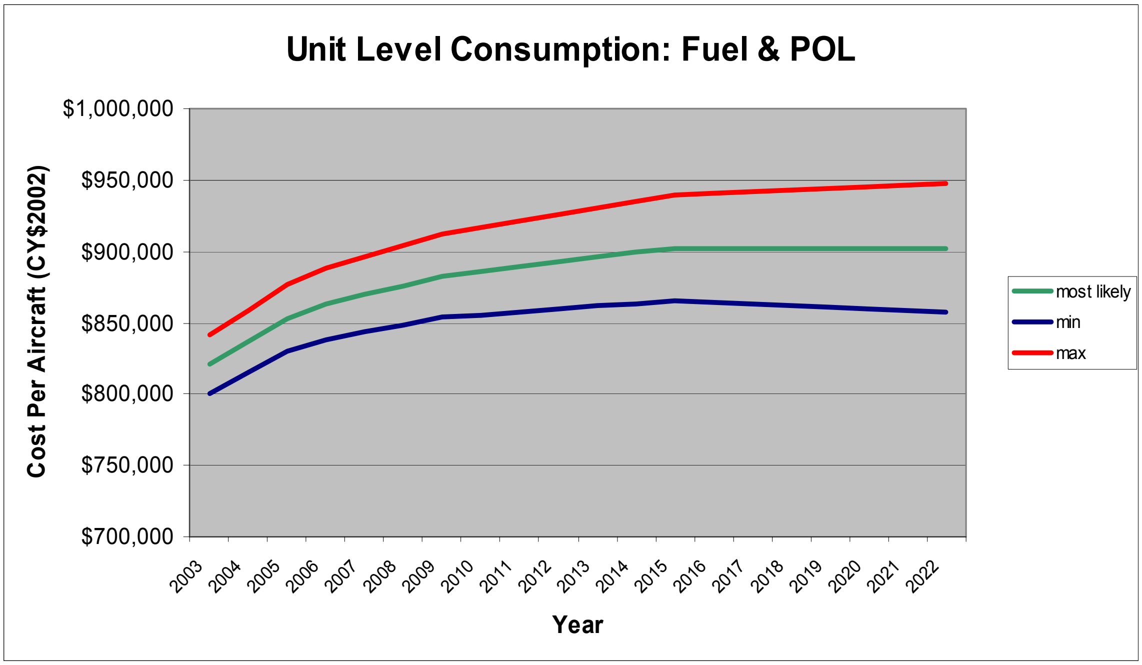


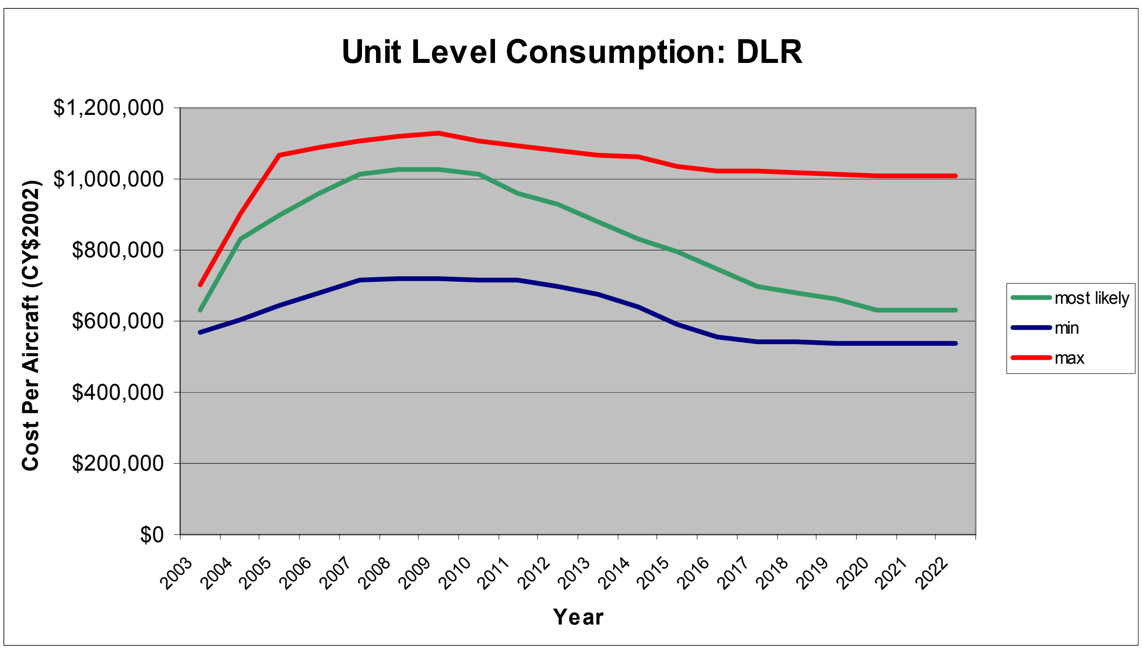

Thank you again for your time. Please e-mail, or fax this document back to me at your earliest convenience.

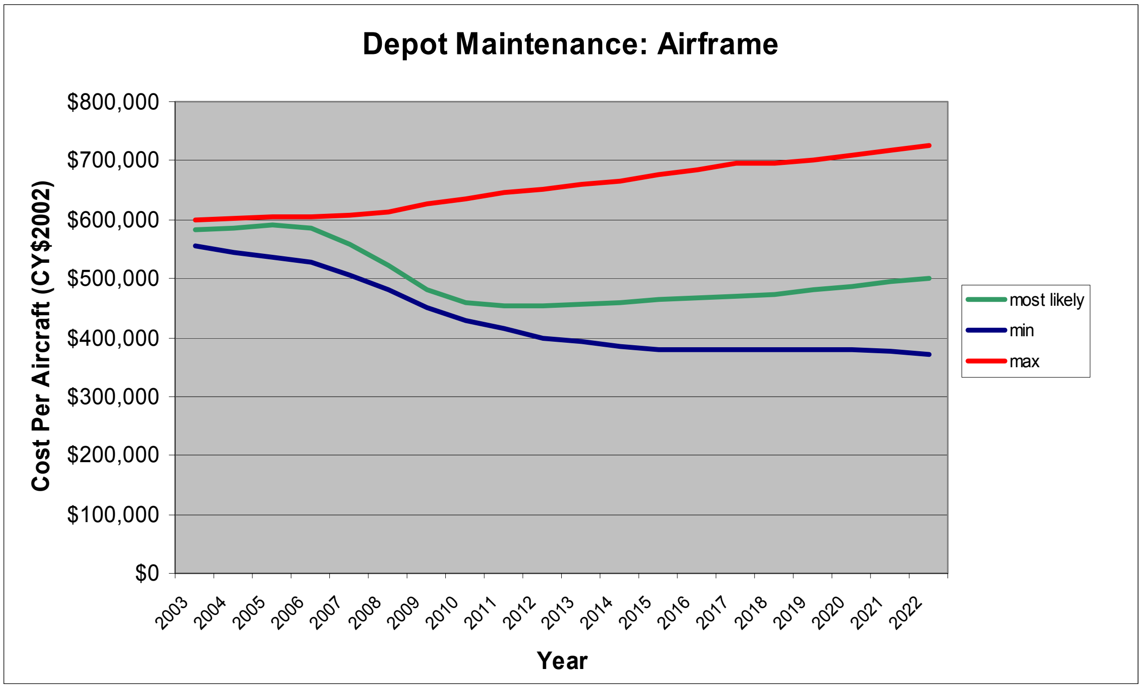
## Appendix F – Final Cost and Availability Estimates

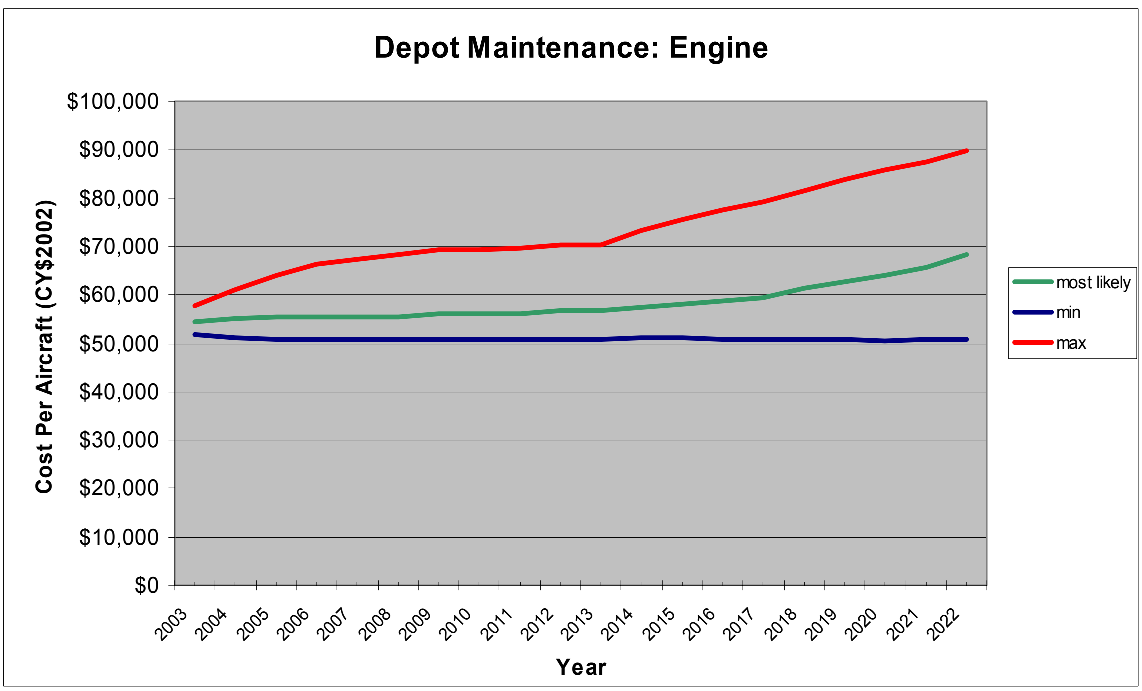


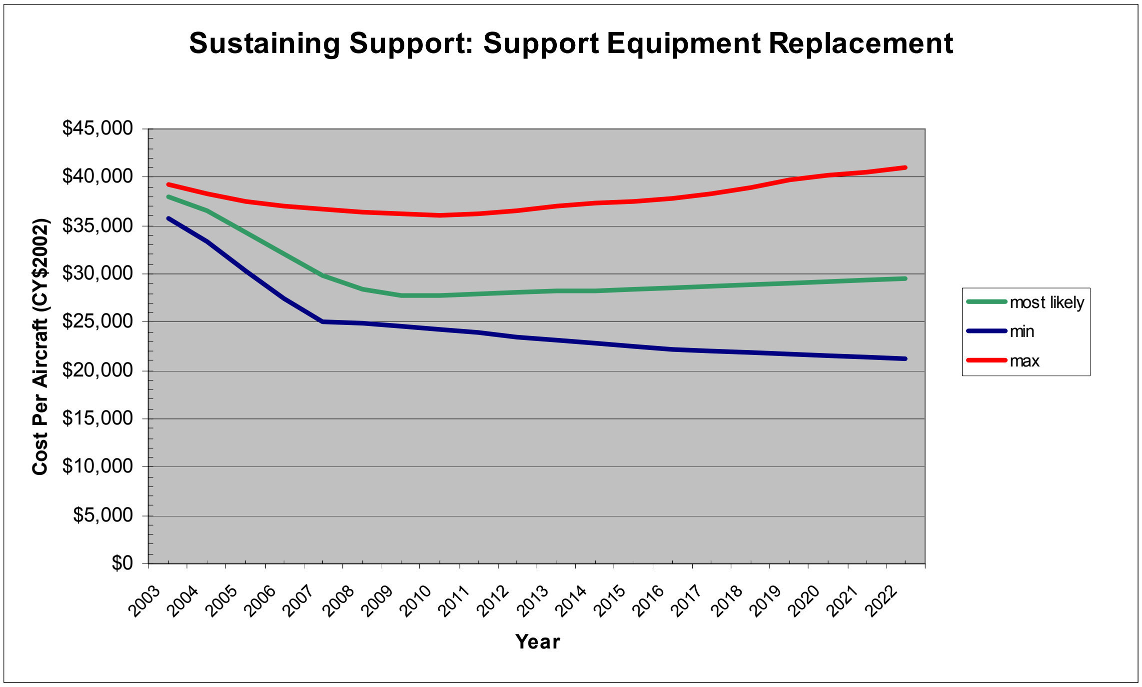




Unit Level Consumption: Fuel & POL
$1,000,000
$950,000
$900,000
$850,000
$800,000
$750,000
$700,000
Cost Per Aircraft (CY$2002)
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
Year
most likely
min
max

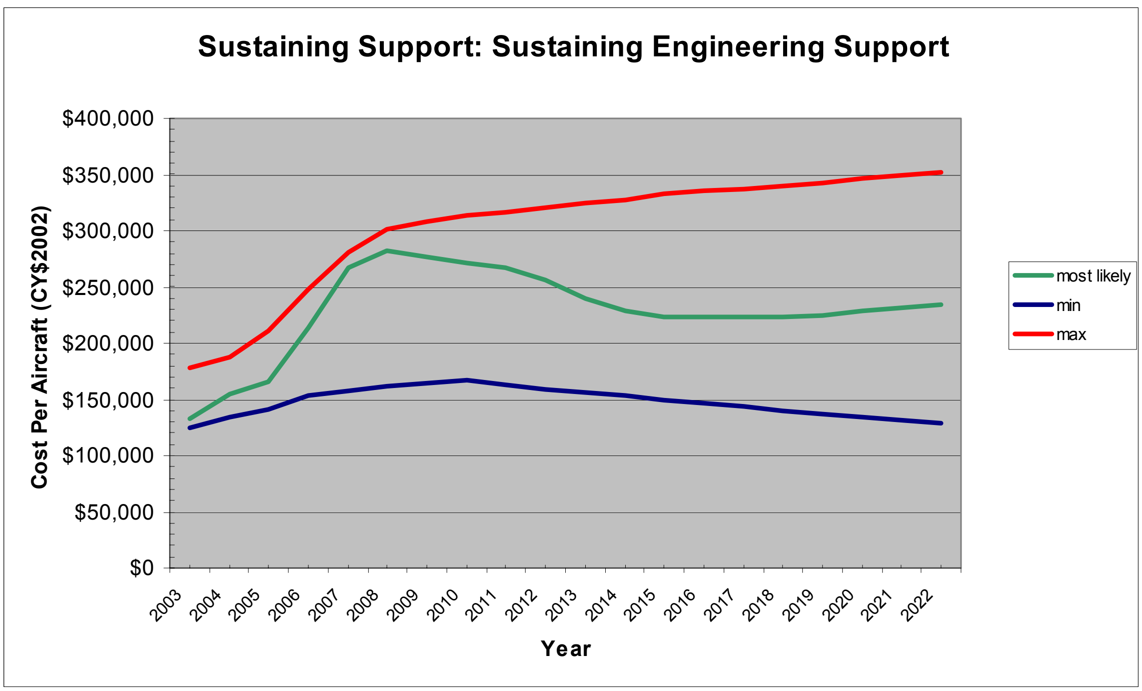

Unit Level Consumption: DLR
$1,200,000
$1,000,000
$800,000
$600,000
$400,000
$200,000
$0
Cost Per Aircraft (CY$2002)
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
Year
most likely
min
max


Depot Maintenance: Airframe
Cost Per Aircraft (CY$2002)
$800,000
$700,000
$600,000
$500,000
$400,000
$300,000
$200,000
$100,000
$0
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
Year
most likely
min
max

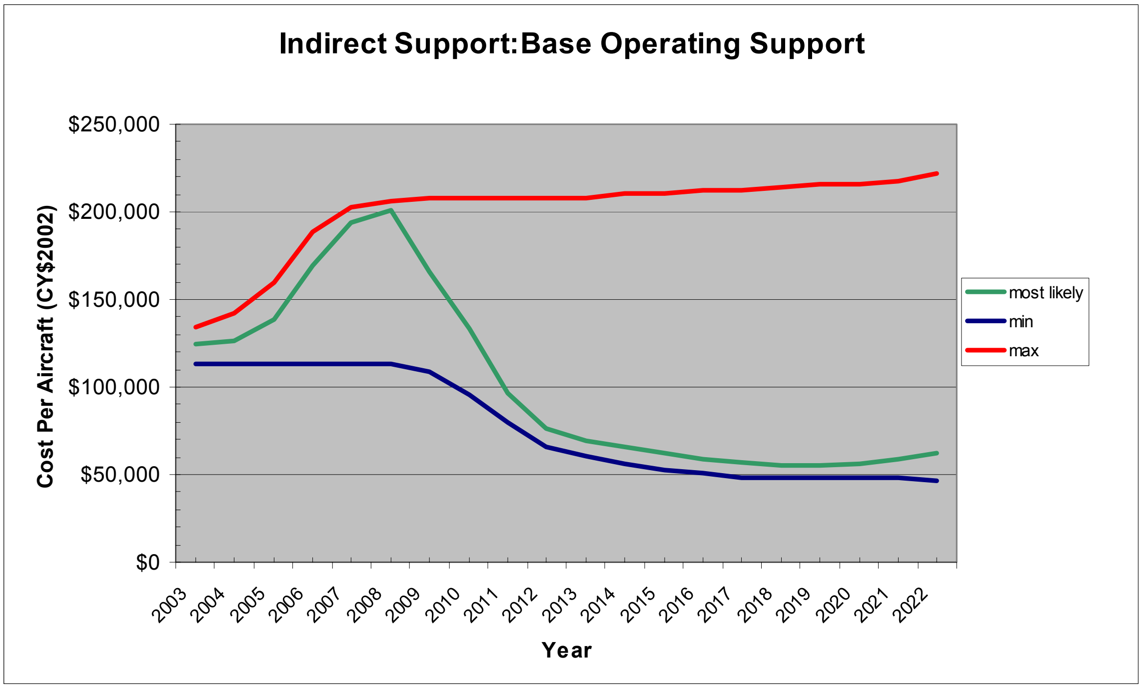

Depot Maintenance: Engine
Cost Per Aircraft (CY$2002)
$100,000
$90,000
$80,000
$70,000
$60,000
$50,000
$40,000
$30,000
$20,000
$10,000
$0
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
Year
most likely
min
max

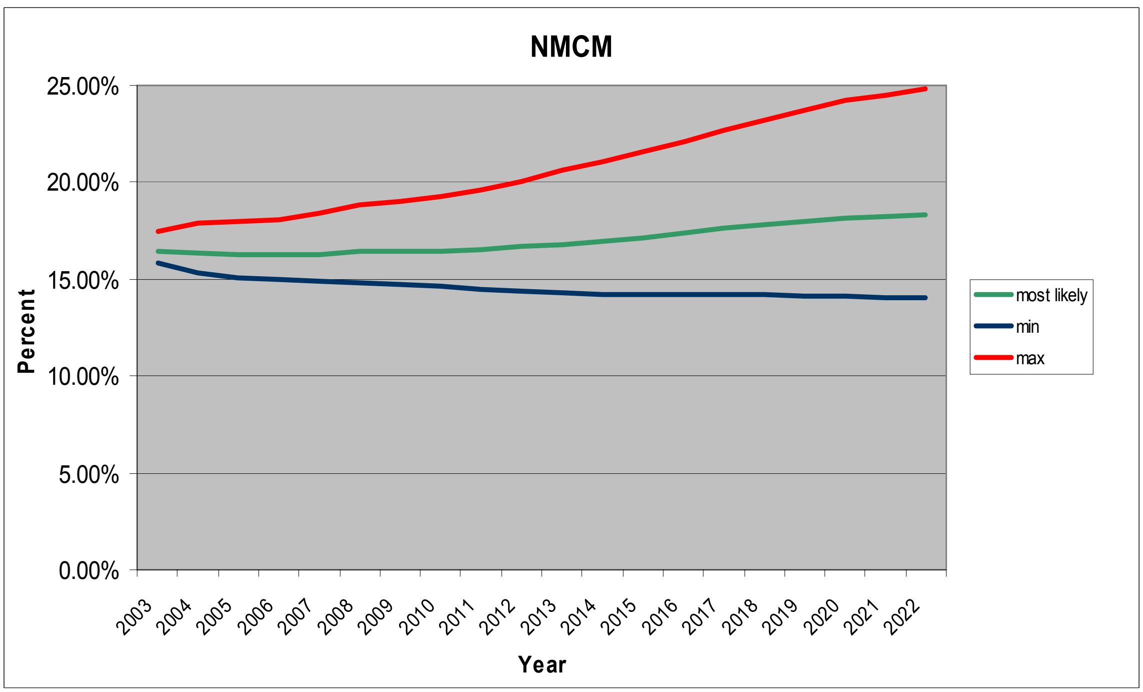


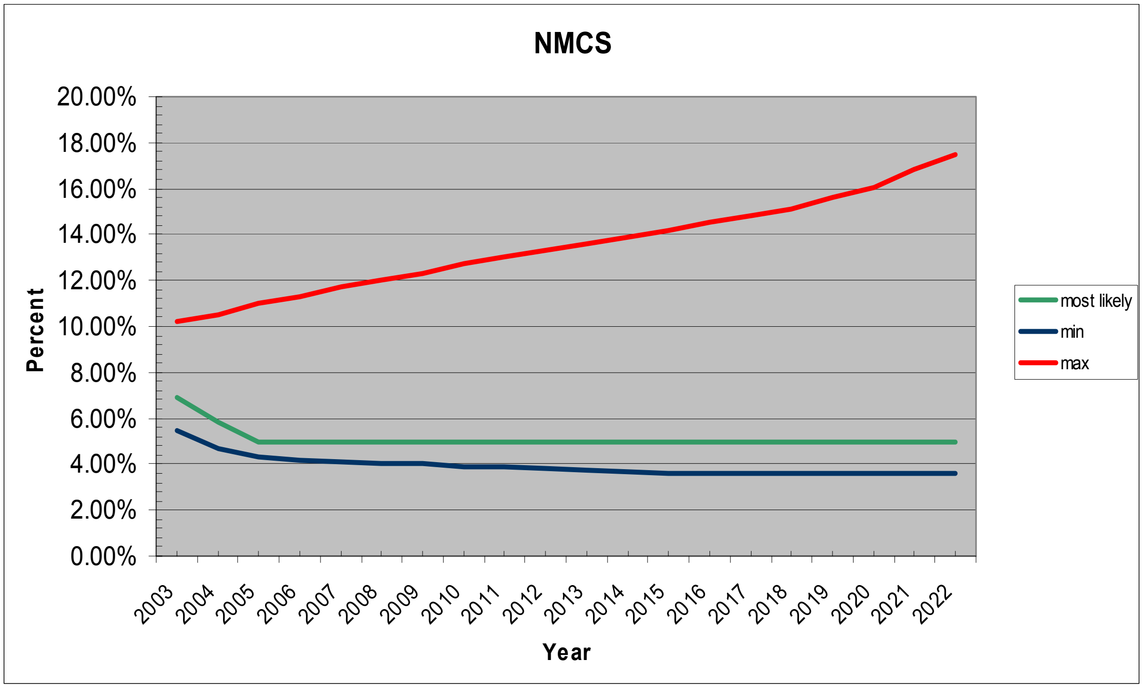
Sustaining Support: Support Equipment Replacement
$45,000
$40,000
$35,000
$30,000
$25,000
$20,000
$15,000
$10,000
$5,000
$0
Cost Per Aircraft (CY$2002)
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
Year
most likely
min
max

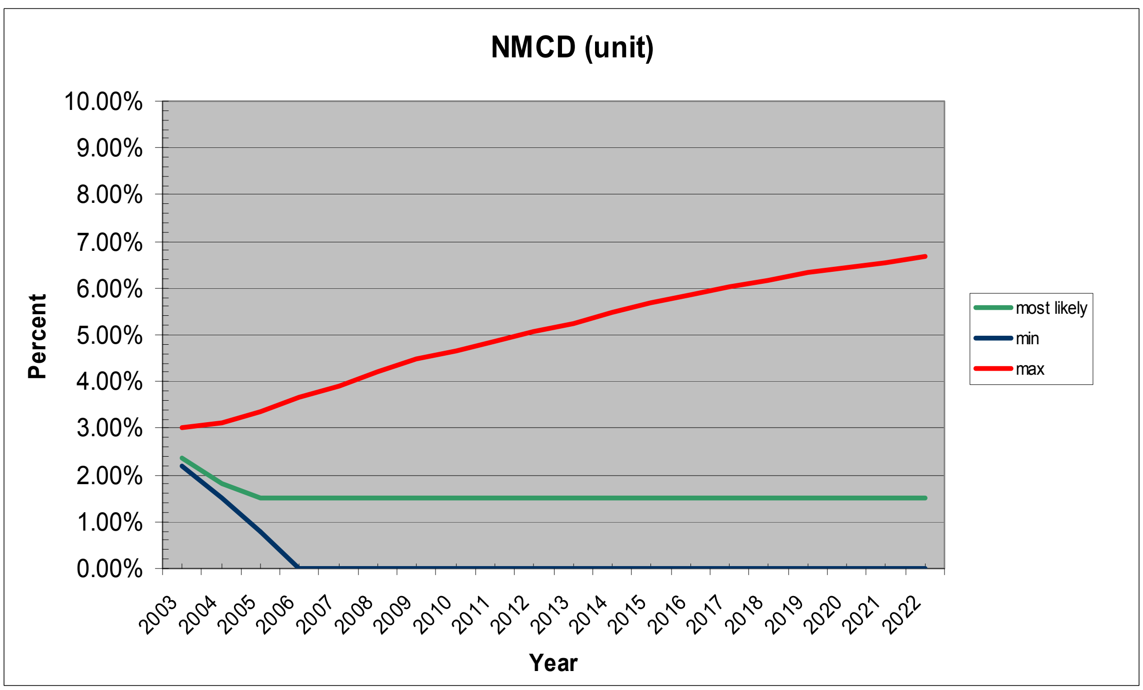



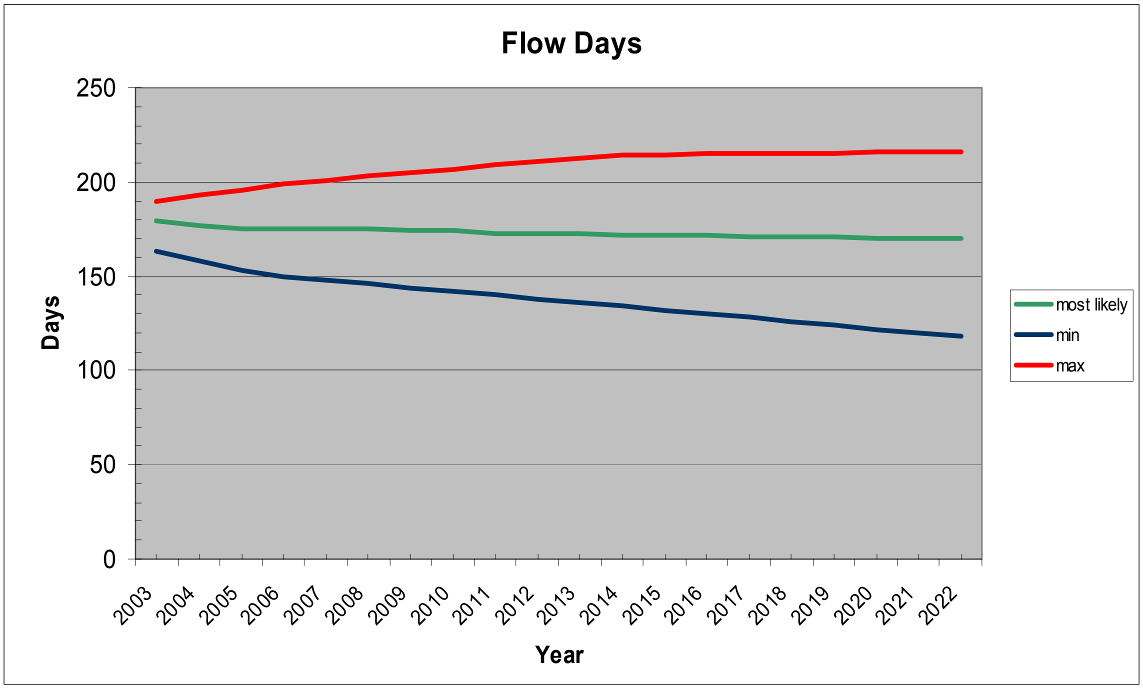
Sustaining Support: Sustaining Engineering Support
$400,000
$350,000
$300,000
$250,000
$200,000
$150,000
$100,000
$50,000
$0
Cost Per Aircraft (CY$2002)
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
Year
most likely
min
max

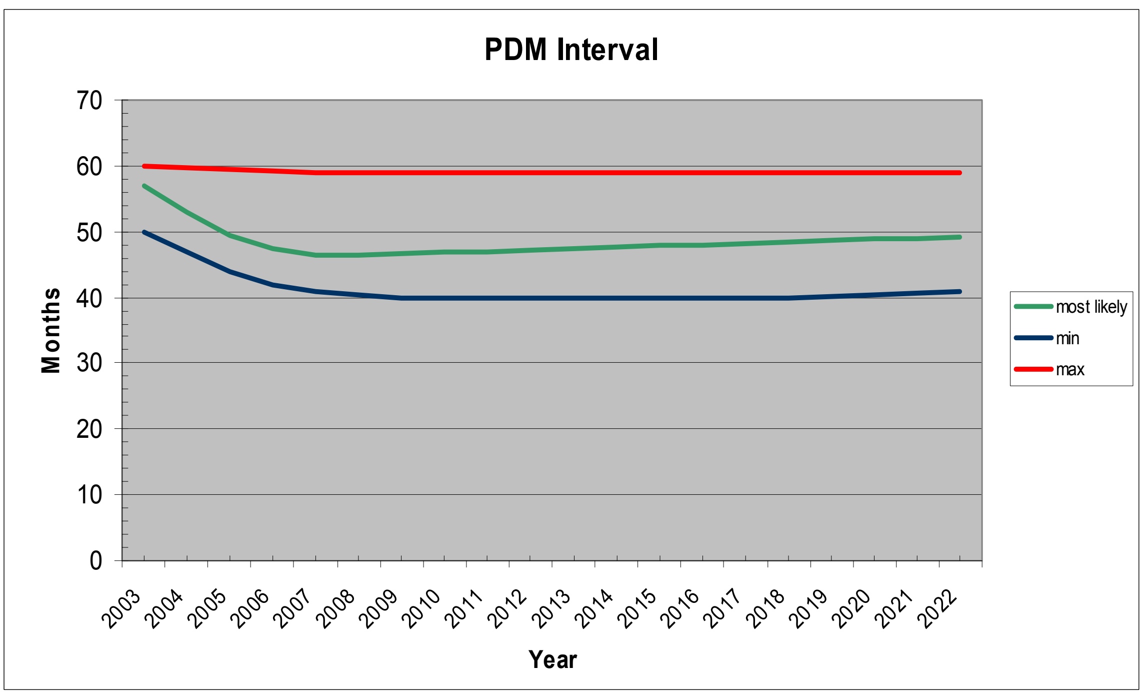

Indirect Support:Base Operating Support
Cost Per Aircraft (CY$2002)
$250,000
$200,000
$150,000
$100,000
$50,000
$0
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
Year
most likely
min
max

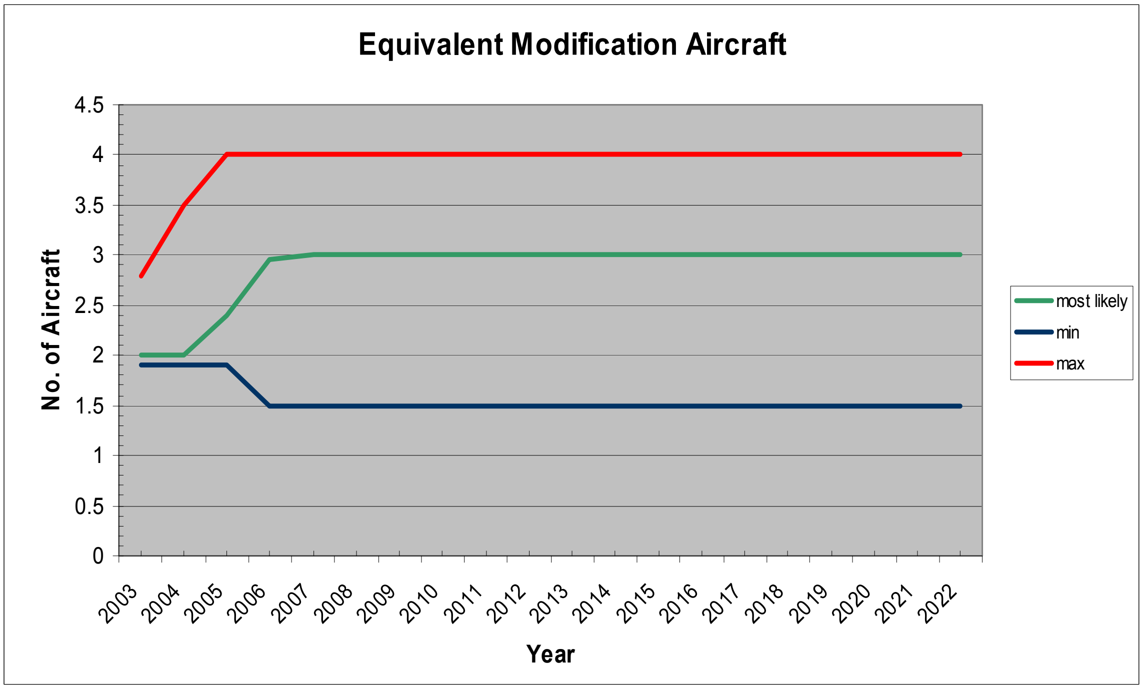

NMCM
Percent
25.00%
20.00%
15.00%
10.00%
5.00%
0.00%
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
Year
most likely
min
max


NMCS
20.00%
18.00%
16.00%
14.00%
12.00%
10.00%
8.00%
6.00%
4.00%
2.00%
0.00%
Percent
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
Year
most likely
min
max


NMCD (unit)
10.00%
9.00%
8.00%
7.00%
6.00%
5.00%
4.00%
3.00%
2.00%
1.00%
0.00%
Percent
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
Year
most likely
min
max


Flow Days
250
200
150
100
50
0
Days
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
Year
most likely
min
max


PDM Interval
70
60
50
40
30
20
10
0
Months
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
Year
most likely
min
max


Equivalent Modification Aircraft
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
No. of Aircraft
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
Year
most likely
min
max

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## Vita

Lieutenant Commander Duff graduated from Jay County High School in Portland, Indiana in 1983. He enrolled at Purdue University, West Lafayette, Indiana and graduated in 1987, with a Bachelor of Science degree in Aeronautical and Astronautical Engineering. In 1989, he enlisted in the United States Coast Guard, and in early 1990 he attended U.S. Coast Guard Officer Candidate School located in Yorktown, Virginia. He received his commission as an Ensign in May 1990.

His first assignment was at Naval Flight Training, Pensacola, Florida, where he graduated on the Commodore's list in 1991. After completing his transition training with the Coast Guard, he was then stationed at U.S. Coast Guard Air Station Astoria, Oregon, where he flew the HH-65A Dolphin, and HH-60J Jayhawk helicopters. While in Astoria, he completed his training as a designated Maintenance Officer.

In 1996, he was re-assigned to Polar Operations Division, Aviation Training Center Mobile, Mobile, Alabama. During this assignment he completed deployments in support of Deep Freeze '97 and Arctic West Summer '98. In 1998, he completed his qualification in the HC-130H Hercules, and was transferred to U.S. Coast Guard Air Station Barbers Point, Hawaii, where he served as the Fixed Wing Engineering Officer. In August 2001, he entered the Graduate School of Engineering and Management, Air Force Institute of Technology. Upon graduation, he will be assigned to U.S. Coast Guard Aircraft Repair and Support Center, Elizabeth City, North Carolina.

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**14. ABSTRACT**

The U.S. Coast Guard is facing a dramatic transformation of its forces to meet current and future service requirements. Responding to this transformation, the Coast Guard has initiated the Deepwater System, a complete review of the offshore mission requirements and the modernization of its infrastructure. Deepwater will review and modernize the Coast Guard's aviation assets, improving aircraft systems, airborne sensors, and communications and information management systems. However, these capability advancements will take time and money to implement, and will require careful management of the current resources. One of the oldest and most versatile Coast Guard aircraft is the C-130. Service life decisions regarding the C-130 are complicated by aging aircraft issues, and the introduction of the C-130J. It will be difficult for Coast Guard decision makers to select how program funding should be executed within the C-130 fleet. This study examines how long the current airframes can safely remain in service, how much the remaining service life will cost, and what level of availability can be realized for the rest of the service life. Answering these questions, it will then be possible to perform an insightful analysis of alternatives for modernizing, sustaining, and if necessary retiring the C-130s.

**15. SUBJECT TERMS**

Service Life Cost, Cost Analysis, Cost Estimating, Availability, Monte Carlo Simulation, Aging Aircraft, Risk Analysis, C-130 Aircraft, Coast Guard

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