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Predicting the Cost per Flying Hour for the F-16 Using Programmatic and Operational Variables

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PREDICTING THE COST PER FLYING HOUR FOR THE F-16 USING PROGRAMMATIC AND OPERATIONAL VARIABLES

THESIS

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AFIT/GOR/ENC/05-01

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PREDICTING THE COST PER FLYING HOUR FOR THE F-16 USING PROGRAMMATIC AND OPERATIONAL VARIABLES

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Abstract

This research analyzes operational and programmatic data from all Air National Guard and 13 of 14 active duty F-16C/D Fighter Wings (FW) from 1998 to 2004 in search of explanatory variables that influence a wing's Cost Per Flying Hour (CPFH). Using data from both the Air Force Total Ownership Cost database and from the Air Force Knowledge Systems database, this research evaluates the predictive ability of the following nine explanatory variables: aircraft age, average sortie duration, MajCOM, base location, utilization rate, percent engine type, percent block, percent deployed, and previous year's CPFH, the last four of which were previously untested. Additionally, this research builds regression models that accurately predict the CPFH of an F-16C/D FW using these operational and programmatic variables. This research concludes that the following variables are highly predictive and quantifies the relative influence of each of these variables: utilization rate, base location, percent block, percent engine type, average age of aircraft, and the previous year's CPFH. Finally, this research identifies a lurking variable and proposes two possible explanations.

Dedication

It is with much love and gratitude that I dedicate this research effort to my loving wife.

Acknowledgments

First, and foremost, I acknowledge our Lord for bestowing upon me everything that I needed to accomplish this research effort. By far, the most important gift given to from above is a loving and understanding wife who fully supported me and sacrificed so much so that this final product is as much hers as it is mine. Second, I am deeply indebted to my advisor, Dr. Tony White, for his superior leadership throughout the twenty-one months we have worked together. He knew when to let me go, when to reel me in, and when to stick me in a pen. His love for regression has rubbed off on me and I continue to be awed by the science prediction and estimation of which he has mastered.

Additionally, there are several people whose contribution to this research effort is so substantial that without their assistance, there would be no thesis. To begin, my sponsors, Capt Chris McDaniels and Mr. Thomas Lies, who presented me this problem and guided me along the way. Additionally, I extend my appreciation to Mr. “Crash” William Lively, Mr. Ray Scheuring, Mrs. Deborah O’Neil, and Mrs. Brenda Smith for provided me with the data used in this analysis. Also, I want to thank my friend, Bob Carden, who selflessly contributed several weekends in order to teach me the ways of Microsoft Access. Finally, I want to thank all of my professors here at AFIT who ensured that I received the best possible education. In particular, I want to thank Lt Col Brigantic, Dr. Marcus Perry, Lt Col Tenney, and Dr. J.O Miller. I hope to make you proud as I use the skills you have imparted on me.

Eric M. Hawkes

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2. Air Force Knowledge System (AFKS)
3. Air Force Material Command (AFMC)
4. Air Force Total Ownership Cost (AFTOC)
5. Air National Guard (ANG)
6. Aviation Fuel (AVFUEL)
7. Congressional Budget Office (CBO)
8. Cost Per Flying Hour (CPFH)
9. Depot Level Repairable (DLR)
10. Fighter Wing (FW)
11. Major Command (MajCOM)
12. Mean Absolute Percent Error (MAPE)
13. Mission Design Series (MDS)
14. Operation Allied Force (OAF)
15. Operation Desert Storm (ODS)
16. Operations and Maintenance (O&M)
17. Operations Tempo (OPTEMPO)
18. Readiness Spares Packages (RSP)
19. Spares Requirement Review Board (SRRB)
20. Variance Inflation Factor (VIF)

21. Work Unit Code (WUC)

PREDICTING THE COST PER FLYING HOUR FOR THE F-16 USING PROGRAMMATIC AND OPERATIONAL VARIABLES

I. Introduction

Many military leaders and budget analysts believe that increases in the costs of operating and maintaining aging aircraft have created a budgetary crisis in the United States Air Force. The phrase “Death Spiral” has been coined to describe the phenomenon where funding is taken away from modernization programs in order to finance rapidly increasing operations and maintenance (O&M) expenses, which, in turn, take funding away from modernization programs. In the 2001 Air Force Posture Statement, Air Force Secretary James Roche stated, “Over the past five years, our flying hours have remained relatively constant, but the cost of executing our flying hour program has risen over 45% after inflation. Older aircraft are simply more difficult to maintain as mechanical failures become less predictable, repairs become more complicated, and parts become harder to come by and more expensive” (Roche, 2001). Furthermore, Defense Deputy Secretary Paul Wolfowitz echoed the Secretary’s sentiments when he told reporters in Aug 2001, “Aircraft, tanks, and other equipment are now beginning to become so old that operations and maintenance costs for those systems have begun to skyrocket” (Capaccio, 2001). The Air Force, along with the other services, claims that aging equipment is the root cause of the ever-increasing O&M costs.

The Congressional Budget Office (CBO), however, has taken issue with this claim. The director of the CBO, Dan Crippen, reported, “CBO’s findings are in conflict with the service's statements that spending on Operations and Maintenance for equipment is growing rapidly" and that the Air Force's position is "based on selective data" (Cappacio, 2001). The CBO report "finds no evidence to support the services' contention that spending on O&M for aging equipment has driven total O&M spending" (CBO paper, 2001). The report also stated that "the fraction of O&M funds spent operating and maintaining equipment appears to be declining" (CBO paper, 2001). Steven Kosiak, a defense budget analyst for the non-partisan Center for Strategic and Budgetary Assessments believes "focusing attention on the aging equipment issue has let the services avoid cutting costs related especially to headquarters, training, administration, communications, and base operations, where substantial cost growth has occurred over the past decade" (Cappacio, 2001).

Both sides acknowledge that in the past decade, budget estimates for the Air Force Flying Hour program have been inaccurate. For example, in both 1997 and 1998 the Air Force had ran out of funding for the Flying Hour program and how to request an additional $300M from Congress to make it through each fiscal year (GAO, 1999). What is missing in this discussion is the identification of factors that caused O&M costs to fluctuate. This research quantifies the influence operational and programmatic factors have on one facet of O&M costs, the Cost Per Flying Hour (CPFH), for the F-16C/D. This knowledge is then used to build a model that predicts the CPFH for any fighter wing in the United States Air Force.

Background

O&M costs are a broad category that covers everything from health care to communications. The portion concerned with operating and maintaining aircraft is called the Flying Hour program. The Air Force Cost Analysis Improvement Group (AFCAIG) develops CPFH factors for each aircraft type, also known as Mission Design Series (MDS), and for each Major Command (MajCOM). Budgets are prepared by multiplying each CPFH factor by the number of hours the MajCOM is authorized to fly (GAO, 1999). Figure 1 depicts the FY04 Flying Hour budget in comparison to the Air Force's total O&M budget.

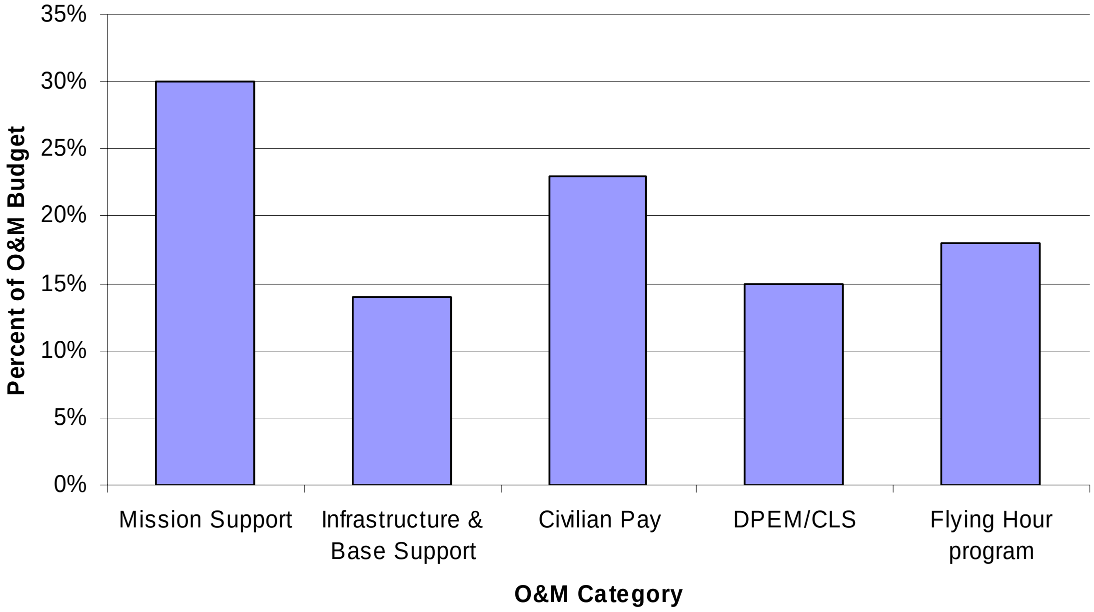


Figure 1: FY 04 O&M Budget

The CPFH is composed of three commodity groups: Consumable Supplies, Aviation Fuel, and Depot Level Repairables. A brief description of each of the groups is given next.

Consumable Supplies

Also known as General Support Division, this commodity consists of aircraft parts or supplies that are not economical to repair or have repair procedure and are discarded after use (Rose, 1997). These items are centrally procured by the Air Force through the Defense Logistics Agency. Examples of this type of commodity include screws, washers, wiring, and lights (Rose, 1997). Additionally, this commodity also includes purchases from the government purchase card. These purchases include other necessary items such as aircraft tools. Requirements for this commodity are determined by MajCOMs. In 2004, expenditures in this commodity accounted for 11% of the total $6.1B Air Force Flying Hour program (AFCAA Presentation, 2004).

Aviation Fuel (AVFUEL)

This commodity refers to the fuel expended during flight (Rose, 1997). Requirements for AVFUEL are also determined by MajCOMs. In 2004, expenditures for this commodity accounted for 24% of the total Air Force Flying Hour program.

Depot Level Repairables (DLRs)

Also known as the Material Support Division, this commodity refers to aircraft parts that when broken are removed and repaired (Rose, 1997). The Spares Requirement Review Board (SRRB) develops the requirements for these items. In Chapter 2, this process is more thoroughly discussed. In 2004, expenditures for the DLR commodity accounted for 65% of the total Air Force Flying Hour program (AFCAA Presentation, 2004).

Motivating the Problem

The Flying Hour program is a highly visibly portion of the President's budget that has historically been prone to inaccurate estimates. As noted earlier, inaccurate budget estimates require the Air Force to ask Congress for additional funding. Congress, then, typically takes funding away from modernization programs in order to ensure the solvency of the Flying Hour program. Since fuel costs and consumable supplies compose a small percentage of the total budget and are much more stable and predictable then DLRs, this research investigated variables that influenced the annual expenditures for DLRs only (GAO, 1999).

Research Questions

1. Does the CPFH of an F-16 fighter wing increase in a linearly fashion with increasing age of aircraft?
2. Does the CPFH of an F-16 fighter wing significantly change during contingencies?
3. Is the CPFH of an F-16 fighter wing dependent on the previous year's CPFH?
4. Does the Average Sortie Duration (ASD) of an F-16 fighter wing influence that wing's CPFH?
5. Does the utilization rate of an F-16 fighter wing influence that wing's CPFH?
6. Does the percent engine type of an F-16 fighter wing influence that wing's CPFH?
7. Do different aircraft blocks have a statistically significant influence on the CPFH for an F-16 fighter wing?

8. Does the MajCOMs influence the CPFH for F-16 fighter wings?
9. Does base location influence the CPFH of F-16 fighter wings?
10. What is the relative influence of each of these operational and programmatic variables?

Scope and Key Assumption

This research combines data from the Air Force Total Ownership Cost (AFTOC) database and the Air Force Knowledge System (AFKS) database into a single relational database spanning 1998 to 2004. This database contains operational, economic, and programmatic data for all F-16C/D's assigned to 40 fighter wings across five active duty MajCOM's and the Air National Guard (ANG). Data from 2004 is withheld in order to validate the models. Using hypothesis tests, each research question is answered. The answers from these investigative questions are used to develop a model to predict the CPFH for F-16C/D fighter wings.

The key assumption of this research is that the block number and engine type of each tail number remained the same across this timeframe. Since neither the AFKS nor the AFTOC database contained this specific historic data, it is necessary to make this assumption. Chapter 4 analyzes the validity of this assumption.

Preview

The next chapter expands upon the literature that was previously discussed as well as other studies relevant to O&M cost estimation. In Chapter 3, the specific steps taken to build the database and the model are outlined. Since the data comes from two different sources, the integrity of the database is verified by comparing a common field, hours. In

Chapter 4, the investigative questions are answered and a model is created to predict the CPFH for a F-16C/D fighter wing. Also, analysis on the key assumptions is performed. This research concludes with recommendations for action and areas of future research.

II. Literature Review

Chapter Overview

This chapter is separated into two sections. The first section provides an overview of the financial processes by which the Air Force develops O&M budgets. In particular, this section describes how the Air Force develops CPFH factors. The second section reviews related research regarding variables that influence O&M costs. This latter section begins with research on the effect of aircraft aging and price instability on O&M costs and then summarizes research that explored the effect of other variables on O&M costs. It then ends with a presentation of the Logistics Management Institute's new physics based model which included operational variables such as time on the ground, number of landings, and numbers of sorties.

Financial Processes Overview

Currently, the Planning, Programming, and Budgeting System requires the operating commands to develop budgets for both fixed and variable expenditures to cover the costs of AFMC support services (Keating, 2002). The variable component is expressed as a CPFH. Once the CPFH factors are developed, they are used to fund programs in the Program Objective Memorandum, Budget Estimate Submission, and the President's Budget, as well as the initial distribution to the MajCOMs (Rose, 1997). Each MajCOM multiplies the approved command-specific factor for each weapon system by the number of programmed flying hours to price each year's flying hour program.

Factor Development Process

The CPFH factor development process is unique for each specific commodity being estimated. For example, consumable supplies are developed using historical obligations and actual flying hours over the previous eight quarters. They are adjusted to remove non-recurring costs in the baseline period and for known future changes, such as time compliance technical orders, phase inspections, modifications, and changes in operations tempo (OPTEMPO). The AVFUEL commodity uses historical gallons of fuel consumed and actual flying hours flown over a five year moving average.   Fuel is adjusted as well to account for reporting errors, anomalies and future OPTEMPO changes (Lies, 2005). The third commodity group, DLRs, is controlled by SRRB and is discussed next.

Spares Requirement Process

In the past, the spares requirement forecasting process was inefficient (Newsome, 2002). There was no central coordination between consummation estimates, spares pipeline requirements and readiness spares packages (RSP). Since the flying-hour factor did not cover non-sales based items (e.g. spares pipeline requirements, safety stock, and RSPs), they were not included in the MajCOM program objective memorandum submissions. This often resulted in unplanned year-of-execution bills to the Air Force (Newsome, 2002). To address this specific issue, along with a host of other financial management issues, the Air Force started the Spares Campaign in December of 2001. One of the stated goals of the Spares Campaign was to centralize the spares requirement process. This was accomplished by the creation of the SRRB. This board is solely responsible for forecasting spares requirements. Once developed, the fly spares portion of the SRRB is presented to the CPFH AFCAIG for review and approval of proposed fly spares CPFH factors and requirements (Lies, 2005).

Under this current system, “the SRRB computes spares requirement based upon the best analytical data available and consensus of relevant parties” (Newsome, 2002). The purpose of the SRRB is to integrate the supply chain, historical data, and relevant parties into one process that culminates in budget submission representing both MajCOMs and AFMC.

The Impact of Aircraft Age of O&M Costs

As aircraft age, many different processes take place that influence O&M costs. The Congressional Budget Office in their August 2001 report to Congress titled, “The Effects of Aging on the Costs of Operating and Maintaining Military Equipment”, listed three main factors: Corrosion, Fatigue, and Obsolete Parts.

Corrosion: Corrosion is defined as the “gradual destruction of a metal or alloy by a chemical action.” It is difficult to predict since it is heavily dependent upon the environment in which the aircraft is being operated. The Air Force Corrosion Prevention and Control Office (AFCPCO), addresses this specific issue. According to Major Dan Bullock, Chief of AFCPCO, "Up to 50% of the workload on some aircraft at Air Force depots is corrosion-related" (AFCPCO website, 2004). The workload Major Bullock is referring to is depot-level maintenance, which is different from spare parts, but still noteworthy.

Fatigue: If one takes a paper clip and bends it in half, it probably will not break. But, if one bends it in half thirty to fifty times, it probably will break. With each bend, small cracks form in the paperclip and given enough replications, the small cracks reach what engineers call the "critical crack length". At this point, the crack propagates throughout the structure. With each takeoff and landing, aircraft structural components are likewise stressed. "Fatigue refers to the weakening of material that results from prolonged stress" (CBO, 2001). As aircraft near the end of their useful life, the rate of fatigue failures increases dramatically.

Obsolete parts: "Many aging systems are expensive to maintain because the original manufacturer no longer makes the required parts" (CBO, 2001). As the life-span of aircraft is extended, the original supplier of the part has either gone out of business or they are no longer producing the part. This results in longer procurement times and increased costs (CBO, 2001).

Mr. Thomas Lies, chief of the Cost Factors Branch at Air Force Cost Analysis Agency, brought to my attention during a phone conversation another effect of age on spare parts. He calls it "reliability degradation". As parts from aircraft fail and are repaired by either base maintenance personnel or by the depots, they are then reinserted into supply system. As time passes, these parts presumably fail at greater rates since the parts continue to age. The effects of fatigue and corrosion degrade individual parts as well as whole aircrafts (Lies, 2005).

The Relationship between Aircraft Age and Cost

The Congressional Budget Office’s report presented seven additional studies that quantified the relationship between equipment age and O&M cost. These studies address all Department of Defense (DoD) equipment, not just Air Force aircraft. They are all significant in that they used empirical data to quantify this relationship. The reports are categorized in the manner in which the authors collected the data.

Studies Based on Data for Individual Aircraft

This first category captured the number of maintenance actions or costs associated with individual aircraft that are similar as possible to one another except for their age. This method of data collection should produce results that best isolate the effect of age on costs. Since data collection for this type of study can be difficult, there are only a small number of such studies. The results of these studies can be found in Table 1. Of particular importance is the result that all of these studies demonstrate that there is a positive relationship between aircraft age and O&M costs. Also take note of the results of the first study; the material cost increased 0.9 to 3.4 per year.

Table 1: Studies Based on Data for Individual Aircraft

Author/Date	Equipment Examined	Obervations	Estimated Effect of an Additional Year of Age
Center for Naval Analyses/March 1991	Five Navy aircraft (the F-14, E-2, A-6, P-3, and H-46) from 1984 to 1989	Multiple observations per aircraft type per year based on the number of aircraft entering depots	Maintenance man-hours increased by 0.8 percent to 1.4 percent. Materiel costs increased by 0.9 percent to 3.4 percent
Naval Air Systems Command/August 1993	Five Navy aircraft (the F-14, F/A-18, E-2, CH-53, and C-2) from 1977 to 1992	15 observations for the F-14, E-2, C-2; 10 observations for the F/A-18, CH-53	Depot maintenance manhours per flight hour increased by 2 percent to 8 percent. Rate of failures increased by 1 percent to 7 percent
Center for Naval Analyses/March 2000	(a) All F/A-18 aircraft by month from 1990 to 1999	(a) 27,000 observations	(a) Maintenance manhours increased by 6.5 percent to 8.9 percent
	(b) All F/A-18C aircraft by individual sortie for June 1996	(b) 3,595 observations	(b) Probability of unscheduled maintenance increased by 0.8 percent

Source: Congressional Budget Office

Studies Based on Average Ages and Aircraft Types over Time

This category of studies used aggregated data on the average age of a particular type of aircraft in a year and investigated the effect of average age on maintenance costs. Their results are similar to the results of the first group of study except that their estimates are less precise. This is due to the fact that the reports only have around 10 data points per aircraft type. Additionally, they did not account for other variables that may have contributed to the rise in maintenance cost. During the ten years that the data was collected, other factors such as changes in maintenance policy or changes in operating accounting practices may have confounded their results. Knowing these shortcomings allows the consumer to put the results in proper perspective. These studies are still important because they quantify the impact of age on O&M costs, but they do not produce results as clean as studies that use individual aircraft for analysis (CBO, 2001). A description of the study along with the results is summarized in Table 2.

Table 2: Studies Based on Average Ages and Aircraft Types Over Time

Author/Date	Equipment Examined	Obervations	Estimated Effect of an Additional Year of Age
Naval Air Systems Command/July 1993	10 Navy aircraft (P-3, S-3, CH-53, H-60, H-3, H-46, E-2, A-6, F-14, and F/A-18) from 1982 to 1992	A maximum of 10 observations per aircraft.	Maintenance man-hours increased by 2 percent to 6 percent. Aircraft overhaul costs ranged from -2 percent to 10 percent. DLR and engine overhaul costs increased by 5 percent to 6 percent
The RAND Corporation/October 1998	The KC-135 and commercial 727, 737, DC-9, and DC-10 aircraft	Not available	Programmed depot costs increased by 7 percent
Air Force Cost Analysis Agency/ March 1999	Air Force aircraft grouped by type (bomber, cargo/tanker, and fighter) using data from 1986 to 1996	11 observations per type of aircraft	Aircraft overhaul costs increased by 2.7 percent to 6.7 percent

Source: Congressional Budget Office

Similar to the previous set of studies, these studies show a positive correlation between aircraft age and O&M costs. Also take note that the ranges of the estimated effects are larger then that of the previous study. For examples, the first study observed that the aircraft overhaul cost ranged from -2 to 10 percent. This is a consequence of the small sample size.

Studies Based on Pooled Average Ages and Aircraft Types over Time

This category of studies combines, or pools, both different years and different types of aircraft before analyzing the effect of average age on cost. This approach increases the number of observations and enabled the researcher to quantify the effect of the equipment's age to be distinguished from other variables. The downside to this methodology is that it assumes each type of aircraft has the same age-related costs. For example, if technological advances made newer aircraft less maintenance intensive, then the studies using pooled data might overstate the effects of age on costs. This does not invalidate the results, but the consumer of this information should be aware of this shortcoming.

Table 3: Studies Based on Pooled Averages Ages and Aircraft Types Over Time

Author/Date	Equipment Examined	Obervations	Estimated Effect of an Additional Year of Age
The RAND Corporation/May 1990	Up to 74 types and versions of Air Force aircraft from 1981 to 1986	400 observations	Operation and support costs (O&M costs plus the costs of military personnel) increased by 1.7 percent, and O&M costs increased by 1.3 percent
Congressional Budget Office/February 2001	(a) 17 Air Force fighter, attack, bomber, cargo, and helicopter aircraft from 1996 to 1999	(a) 68 observations	(a) O&S and O&M costs increased by 1 percent
	(b) 13 Navy fighter, attack, cargo, and helicopter aircraft from 1986 to 1999	(b) 164 observations	(b) O&S costs increased by 2.4 percent, and O&M costs increased by 2.6 percent
	c) 20 Navy and Air Force fighter, attack, and bomber aircraft from 1976 to 1999	c) 327 observations	(c) O&M costs increased by 2.5 percent

Source: Congressional Budget Office

Aging Effect Summary

Empirical results suggest that each year O&M costs rise between 1.7 and 2.5 percent. This cost growth is presumably caused by fatigue, corrosion, and obsolete parts. Knowing this, this research models the aging effect by testing whether the previous CPFH is linearly related to the current year's CPFH and by testing whether the average age of aircraft is predictive of a fighter wing's CPFH. Chapter 4 details this analysis. Also noteworthy is the result that depot-level maintenance typically increased between 2 and 8 percent per year. The fact that depot-level maintenance is substantially more impacted by aging agrees with intuition since most depot-level repairs are caused by fatigue and corrosion. Now that the effect of age on O&M cost has been discussed, we shift to examining the impact of other variables on O&M costs starting with price instability.

Price Instability

Changes in prices in aircraft parts have contributed significantly to the variation of O&M costs. The General Accounting Office 1999 report titled, "Observations on the Air Force Flying Hour Program" stated, "Price instability has led to obligations exceeding funds provided for the flying hour program" (Gebicke, 1999). As example of the magnitude of these changes, Table 4 depicts FY 1999 price changes for specific repairable parts (Gebicke, 1999).

Table 4: Examples of Price Changes

Examples of the Magnitude of Fiscal Year 1999 Price Changes

Repairable part	Price in Sept 1998	Price in Oct 1998 (new fiscal year price)	Price Change	Price in Jan. 1999	Percent Change from Sept 1998
Core module	$1,557,348	$1,709,633	10	$1,592,204	2.24
Core module	380,493	671,099	76	625,003	64.26
Fan module	91,731	219,221	139	204,163	122.57
HPT module	87,109	148,031	70	137,863	58.26
Fan drive	58,339	155,164	166	144,507	147.7
Exciter	3,725,818	1,686	-99.95	1,433	-99.96
Comp rotor	55,694	152,593	173.98	14,660	-73.68
Fan rotor	15,096	105,730	600.38	131,726	772.59
Turbine rotor	52,695	96,913	83.91	10,018	-80.99

This extraordinary variation in the price of spare parts can be attributed to inefficiencies in the Air Force supply management activity group, the Air Force's primary purchaser of weapon system parts (Gebicke, 1999). The Air Force supply management activity group is part of the Air Force Working Capital Fund. This revolving fund relies on sales to fund future purchases rather than direct congressional appropriations. According to a June 1998 GAO report, titled, "Air Force Supply

Management: Analysis of activity's group financial report, prices, and cash management", the GAO report concludes that the activity group lacks the ability "to produce reliable information on its cost of goods sold and net operating results" (Brock, 1998). This has directly contributed to the activity group not generating enough cash and requiring the next year's prices to dramatically change. A different GAO report, titled, "Observations on the Air Force Flying Hour Program" cites this price instability as the culprit for the $300M budget shortfall during 1997 and 1998 (Brock, 1999).

On behalf of the Air Force Studies and Analysis (AFSAA), Mr. Clifton Nees contributed to the discussion on the impact of price instability in a briefing he presented to Air Force senior leaders in May 2002. He characterized the variability of DLR expenditures for F-16's by National Stock Number (NSN) across three different fiscal years, 1998, 1999, and 2000. He defined expenditures as the cost of a part times the number of parts consumed. Using transactional data from the AFTOC database, he computed the total expenditure change for each individual part across this timeframe. Figure 2 displays a histogram of his results and Figure 3 magnifies on the central portion of the histogram.

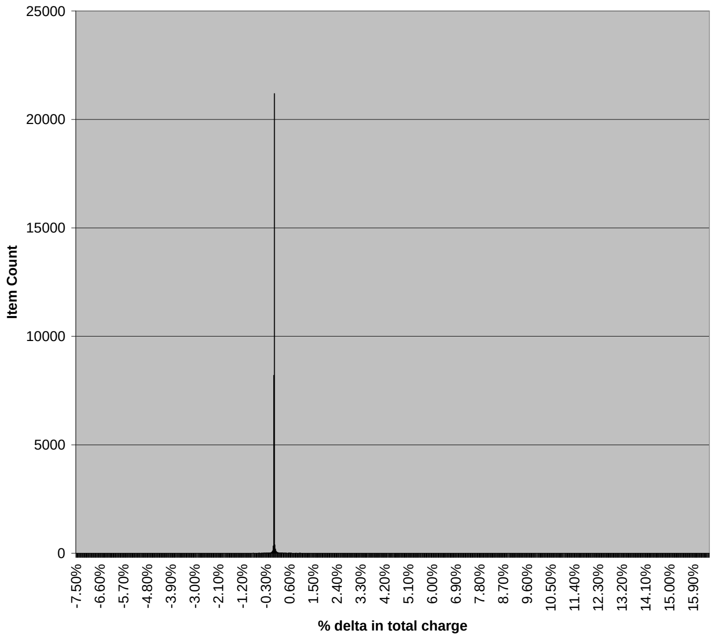


Figure 2: Change in Expenditure by Part (FY 98 – 00)

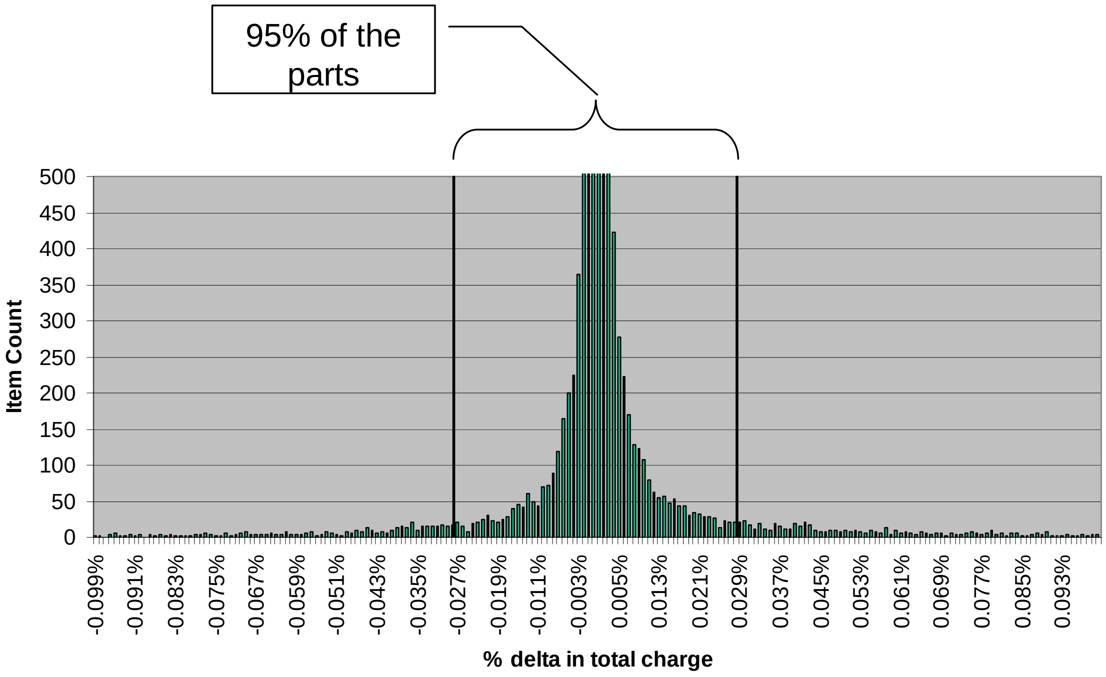


Figure 3: Change in Expenditure by Part (Magnified)

From Figures 2 and 3, Mr. Nees concluded that the vast majority of parts did not see any changes in expenditure from year to year. In fact, over 95% of the expenditures for a given DLR over these years went up or down less than 0.029 percent. Mr. Nees also noted that there were some substantial outliers. Presumably, the parts listed in the GAO report in Table 4 belong to this group of extreme outliers. He then investigated whether those outliers drove the overall change in expenditures for the F-16. His results are shown in Figure 4.

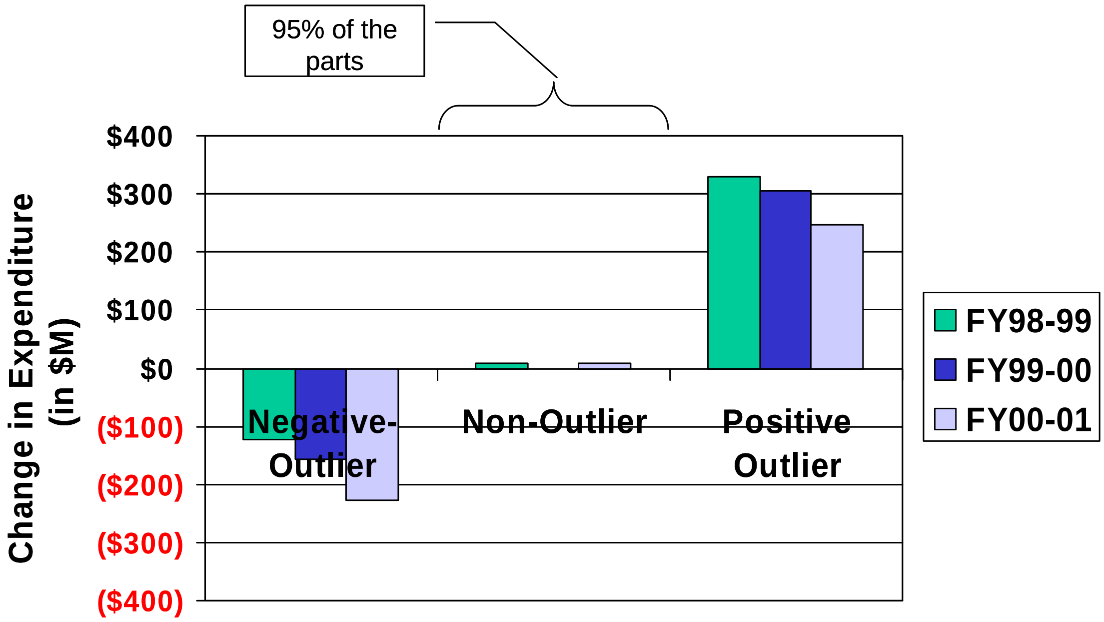


Figure 4: Outlier Impact on Variation in Expenditures

Mr. Nees concluded that less than 5% of the parts were driving almost all of the variation in expenditure. This can be seen by observing how small the three middle bars are relative to the outliers. He then asked the question, “Are the 5% of DLRs driving the variation always the same?"   To answer this question, he presented the chart seen in Figure 5.

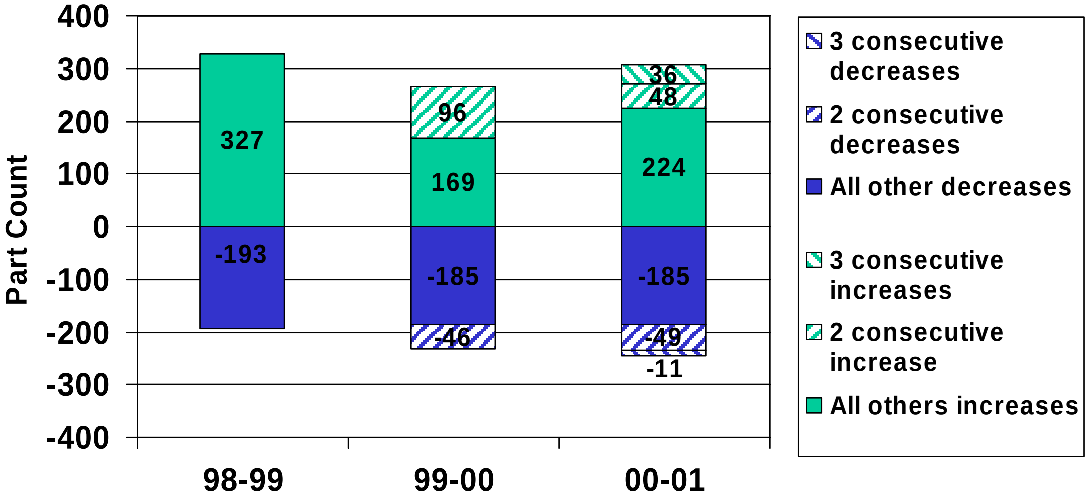


Figure 5: Consistency of Outliers

The left column displays the number of positive, 327, and the number of negative, 193, outliers sample points from the expenditure change from FY 1998 to FY 1999. Since this column displays only those sample points using expenditure change year 1998-1999, each point represents a distinct DLR item.

The middle column displays the number of positive, 265, and the number of negative, 231, outliers sample points. The right diagonal section of the column displays those DLR items which were also positive outliers in 1998-1999, hence the designation "2 consecutive increases". The 169 DLR items shown in the solid bar represent positive outliers for the first time in 1999-2000, hence the designation "All other increases". An analogous breakdown was performed for the negative outliers.

And finally, the right column displays the number of positive, 308, and the number of negative, 245, outliers sample points. The left diagonal section of the column displays those DLR items which were also positive outliers in 1998-1999 and 1999-2000 hence the designation “3 consecutive increases”. The right diagonal section of the column displays those DLR items which were also positive outliers in 1999-2000 hence the designation “2 consecutive increases”. The solid section displays those DLR items which were positive outliers for the first time in 2000-2001, hence the designation “All other increases”. An analogous breakdown was performed for the negative outliers.

As you can see, each year a significant number of new DLR items are identified as expenditure change outliers. That is, the set of DLR items that experience large expenditure changes from year to year was not consistent between the years 1998 and 2001 (Nees, 2002).

Other Variables that Influence O&M Costs

Most of the research on this topic has focused on the effect of age on O&M costs. Recently, there have been several key studies completed by Logistic Management Institute and the RAND corporation that analyzed the effect of other variables besides age and price instability on O&M costs. Some of the variables in their analysis include: Mission Profile, Sortie Duration, OPTEMPO, Landings per Sortie, Location, and Modifications. Related research on each variable is provided along with author and year of the study. Included in the list are studies that analyzed responses other than O&M cost (e.g. maintenance man-hour or maintenance removals per sortie). These studies are included because O&M costs are inherently connected to these other responses.

Mission Profile

Mission Profile refers to the objective of the sortie. During training sorties, it is common for pilots to practice high “G” maneuvers. These sorties place extra stress on the aircraft and its components. Likewise, during recent contingencies, fighter aircraft have spent more time patrolling airspace. This difference is believed to influence O&M costs.

1) The mission profile of F-4 sorties had a direct impact on the number of maintenance discrepancies identified by maintainers for certain work unit codes (WUC). Additionally, specific WUC codes are more sensitive to certain types of missions then other WUCs. As an example, the results of the fire control system, WUC 74B, for different Mission Symbols are shown in Appendix A along with statistical tests (Hunsaker, 1977).
2) In an unpublished study that was cited in Sherbrook’s literature review, Sweetland determined that amount of maintenance performed per sortie was significantly higher for training sorties (Donanaldson and Sweetland, 1968).
3) Using data from 1993 to 1996, Sherbrooke linked data from the supply database with the core automated maintenance database and determined short training missions where the pilots pull have as many as eight G’s had three times as many demands per sortie as long cross-country sorties (Sherbrooke, 1997).

Average Sortie Duration (ASD)

1) For the B-52, F-100, F-102, F-4C, and F-5A, unscheduled flight-line man-hours are only slightly related to sortie length (Donaldson and Sweetland, 1968).
2) For the B-52, the percentage of components removed to facilitate other maintenance increased with decreasing sortie length (Boeing, 1970).
3) Sortie length appears to have no effect on maintenance man-hours for the C-5 (Little, 1972).
4) The F-4 sortie length had little effect on equipment failure rate per sortie (Hunsaker, 1977).
5) Regardless of sortie length, the C-5 tends to have the same number of maintenance write-ups (Casey, 1977).
6) There is no evidence of a one-to-one relationship between sortie duration and spare part demand. At best, there is only a 7 to 10 percent increase in demand for every additional hour of flying for most aircraft (Sherbrooke, 1997).
7) Contrary to the previous studies, Howell concluded for the C-141A, C-130E, and Boeing 727, maintenance removals per sortie depends on sortie length (Howell, 1978).

Utilization rate

The Air Force defines utilization rate as the number of flight hours per month per aircraft. For the purposes of this research, utilization rate is defined as the number of hours per year per aircraft.

1) Total B-52 maintenance man-hours per flight hour decreased as utilization rates increased while sortie length was held constant (Boeing, 1970).
2) Higher utilization rates tend to require less maintenance (Sherbrooke, 1997).

Location

1) A base-by-base comparison of 3 different pieces of avionics equipment on fighter aircraft operating from 9 different bases revealed variations in mean time between failures as large as 5 to 1. On an average basis, there was a 2 to 1 difference in reported failure rate between the two best and two worst bases (Drnas, 1976).
2) Hydraulic leaks tend to be likely in cold climates. Also, avionic systems tend to fail more in wet climates (Tetmeyer, 1982).
3) The demand rate for A-10's at Nellis AFM was five times larger than that of other A-10 bases (Sherbrooke, 1997).

Modifications

This variable refers to effect of modernizing an aircraft on O&M costs. In a 2003 report titled, "Aging Aircraft: USAF Workload and Material Consumption Life Cycle Patterns", Raymond Pyles of the RAND Corp. noted,

> "To our knowledge, there have been no previous studies of growth in age-related modification cost. In the past, it may have been irrelevant, because only a few aircraft platforms were retained long enough to require upgrading to meet more-modern operating requirements. As likely, the data for such analyses have been difficult to obtain."

In conclusion, there are many other variables that influence O&M costs beyond age. There has not been a single overarching study that has quantified the impact of each of these variables relative to one another. Additionally, most of the variables analyzed have been operational factors such as ASD, Mission Type, and Utilization Rate. As we shall see next, the search for the operational factors that best explained variation in O&M costs has culminated in the work performed by Logistic Management Institute.

Logistic Management Institute's Physics-Based Model

In August of 2000, Mr. David Lee and Mr. John Wallace of the Logistics Management Institute developed a physics-based model that used other parameters besides hours to predict consumption costs (Lee, 2000). Their analysis came as a result of poor forecasting for spare part during Operation Desert Storm (ODS). During that contingency, the number of flying hours dramatically increased, but the consumption of parts did not. Figure 6 displays the actual consumption versus predicted during this timeframe.

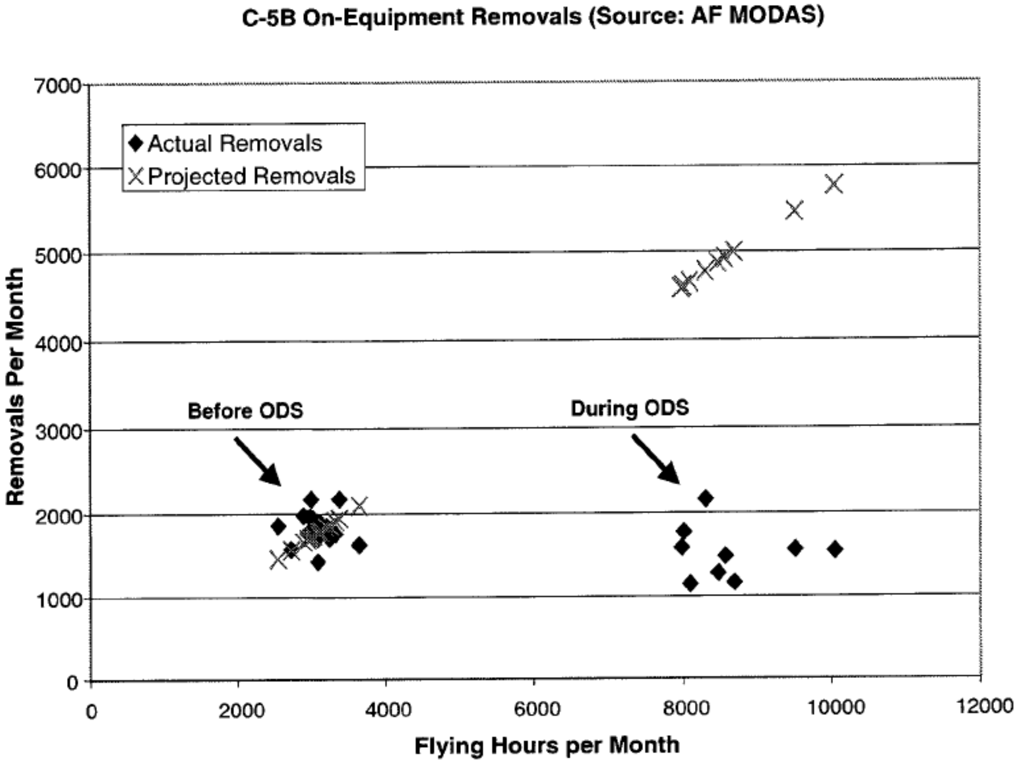


Figure 6: Projected and Actual C-5B Removals Before and During ODS

In this instance, the proportional model terribly over-estimated the number of removals. In their analysis, they stated, “to be consistently accurate, a material consumption model must consider more parameters than just flying hours” (Lee, 2000). They then choose to include the following variables in their model: time on the ground, sorties, and landings. They then tested their model on F-16C, KC-10, and C-17 data from Operation Allied Force (OAF) in Kosovo. The results of this analysis can be found in Table 5.

Table 5: Comparison of Proportional Model to Physics-Based Model during OAF
(F-16C bolded to emphasis system relevant to this thesis)

		Proportional Model		Physics-based Model	
	Calibration Set	Relative Error	RMS Error	Relative error	RMS error
C-5B	1	203	212	-15.3	22.1
	2	42.4	51.6	1	18.6
	3	65.9	73.7	14.6	25.2
	4	94.4	102.3	-4.24	18.38
C-17	1	24	25.5	-2.1	4.5
	2	38.5	39.4	8.5	9.3
	3	16.6	17.8	0.02	0.03
	4	22.6	23.7	-2.4	3.1
KC-10	1	72.9	73.1	13.6	17.6
	2	62	62.1	11.1	15.5
	3	62.7	62.9	15.8	19.5
	4	62.5	62.8	14.4	18.6
F-16C	**1**	**23.5**	**29.7**	**-24**	**24.7**
	2	**25.4**	**31.5**	**-1.8**	**10.3**
	3	**14.2**	**22.1**	**-1.2**	**9.8**
	4	**18.8**	**25.7**	**3.1**	**12**

Their analysis used several different calibration sets, and therefore, produced different results. Table 5 convincingly shows how proportional models are not useful when the flying profile dramatically changes. In their own words, "Our investigation shows that this physics-based model is at least as accurate as the CPFH-based model in the general case, is far more accurate during wartime surges, and is generally more robust than the CPFH-based model" (LMI, 2000).

Chapter Summary

This chapter began with an overview of the financial processes that create O&M budgets and then presented analysis by AFSAA that characterized the variability in annual expenditures for DLRs. Their work showed that from 1998 to 2001 the variation in annual O&M expenditures was driven by a small number of different parts each year. Next, this chapter reviewed seven studies that quantified the relationship between aircraft age and cost. These studies revealed that O&M costs typically increase 1.7 to 2.5 percent each year presumably due to the aging effect. This research models the aging effect by both testing the previous year's CPFH and by testing whether the average age of a fighter wing is predictive of a fighter wing's CPFH.

This chapter then followed with a summary of research that explored the impact of other variables on O&M costs. This section revealed that there are many other variables besides the number of flight hours that influence O&M costs. This section also showed that most of the previous research in this area has dealt with operational factors such as Mission Type, Utilization Rate, and ASD. This chapter culminated in Logistic Management Institute's physics based model that predicted O&M costs by using different operational factors (i.e. time on the ground, sorties, and landing). Using this literature as a backdrop, this research identifies new, programmatic variables that are useful in predicting O&M costs. Chapter 3 presents how this is accomplished. Then in Chapter 4, these programmatic variables are combined with operational variables to create a model that predicts the CPFH for an F-16C/D fighter wing.

III. Methodology

Chapter Overview

This chapter describes the process used to create the database and presents an overview of multiple linear regression. Since there is not one database that contains operational, programmatic, and economic data, this research creates a database by combining data from two different sources, the Air Force Knowledge System (AFKS) database and the Air Force Total Ownership Cost (AFTOC) database. Both the AFKS and the AFTOC database contain the number of hours flown and this is used to check the validity of each data point. After database creation is discussed, the removal of two data points is explained and the correlation among explanatory variables is presented. This chapter then concludes with an overview of multiple linear regression, which is used in Chapter 4 during the model building portion of this research effort.

Description of AFKS and AFTOC Databases

Both the AFTOC and AFKS databases take data from a variety of sources and combine it into a central repository. In fact, the AFKS database takes data from 26 different databases and information systems and according to Gary Ahrens, Vice President of Bearing-Point Inc, is, “one of the larger government enterprise warehouses that we’re aware of” (Jackson, 2005). Of the 26 databases, the data in AFKS mainly comes from the Reliability and Maintainability Information System (Jackson, 2005). This research uses historical, operational data from the AFKS database to test whether deployments influence the CPFH for F-16’s.

Similar to the AFKS database, the AFTOC database does not create any new data, but feeds data in from a variety sources, mainly the Air Force Core Automated Maintenance System and the Standard Base Supply System. The purpose of the AFTOC database is to capture all the life cycle costs associated with a particular weapon system (Schmidt, 1999). For this reason, the data in the AFTOC database is ideal for performing CPFH analysis. The next section presents exactly what data is retrieved from the database for this research effort.

Data Collected from the AFTOC Database

The lead manager of the AFTOC database supplied three data sets, two of them are Microsoft Excel™ spreadsheets and the other is a Microsoft Access™ database. All of this data originated from the AFTOC database. Data set 1 contains the amount each fighter wing spent on DLR's by year, by wing, and by MDS. Included in this spreadsheet are the fields: number of aircraft assigned to that fighter wing and the number of hours flown. Since current accounting system does not distinguish between dollars spent on F-16C's and F-16D's, all of the F-16C/D's fields are summed together. Therefore, one row in this spreadsheet contained the fields: year, MajCOM, location of the base, Then-Year (TY) obligations for DLRs, flying hours, number of aircraft in inventory, fighter wing, and MDS. This spreadsheet contains data from 1996 to 2004. Table 6 displays an example of this data set 1.

Table 6: An Example of Data Set 1

Year	CMD	Base	Obligations	Flying Hours	Inventory	Fighter Wing	MDS
1996	ANG	ANDREWS AFB (MD)	$1,545,105.30	3884.100098	17.5	113th FW	F-16C
1996	ANG	ATLANTIC CITY ANG STN (NJ)	$1,532,314.84	3734.199951	16.5	177th FW	F-16C
1996	USAFE	AVIANO AIR BASE (ITALY)	$15,688,833.68	11523.2998	37.5	31st FW	F-16C

The second data includes a spreadsheet that lists every F-16 tail number along with the corresponding engine, engine manufacturer, and block number. Since the first two digits in the tail number represent the year made (i.e. tail number 7800001 was made in 1978), this research adds the field, “Year Made”, to the spreadsheet. An example of this data set is shown in Table 7.

Table 7: An Example of Data Set 2

TailNumber	BlockNumber	Engine	Manufacturer	Year Made	MDS
85001450	30	F0110100	GE	1985	F-16C
85001452	25	F0100220	PW	1985	F-16C
85001453	30	F0110100	GE	1985	F-16C

The third data set is an Access database and contains the fields: tail number, MDS, year, MajCOM, fighter wing, location of base, flying hours, and sorties. Unlike data set 1 where one row represents the activities of one fighter wing, by MDS, by year, one row in this database represents the activities of a particular tail number. Using the relational capabilities of Access, this data set contributes the following explanatory variables to the research effort: average age of fighter wing, percent of each block in fighter wing, percent of each engine in fighter wing, and ASD. This database contains data from 1998 to 2004 and is shown in Table 8.

Table 8: An Example of Data Set 3

TailNumber	MDS	Year	CMD	Fighter Wing	Possessing_Base	Flying_Hours	Sorties
83001157	F-16C	1999	ANG	174th FW	SYRACUSE (NY)	1.1	1
83001157	F-16C	2000	ANG	174th FW	SYRACUSE (NY)	0.9	1
83001157	F-16C	2001	ANG	174th FW	SYRACUSE (NY)	1.1	1

Data Collected from the AFKS Database

The office, AF/XOOT, supplied this research with operational data from the AFKS database, denoted data set 4. One row of this data contains the activities of a particular tail number and includes the fields: tail number, MDS, year, MajCOM, fighter wing, mission symbol, and hours. AF/XOOT also sent a list of all the designated contingency mission symbols along with their description, denoted data set 5. This data is in Appendix B. From the AFKS data, this research obtains the percent each fighter wing was deployed from 1998 to 2004. An example of data set 4 is shown in Table 9.

Table 9: An Example of Data Set 4

TailNumber	MDS	Year	CMD	Fighter Wing	Mission Symbol	Hours
80000581	F-16A	2000	ang	120th FW	t3mt	197.5
80000581	F-16A	2000	ang	120th FW	t3ex	16.9
80000581	F-16A	2001	ang	120th FW	t3mt	14.4

Description of Explanatory Variables and Response

This next section elaborates on the different variables used in the analysis.

Response: Cost Per Flying Hour

This is the amount of dollars expended by a wing on DLR’s divided by the number of hours flown by that fighter wing. It is computed directly from data set 1. All costs in this analysis are converted to CY04$ using MajCOM specific conversion factors listed in Appendix C.

Average Sortie Duration

This is the total number of sorties a wing performed divided by the total number of hours flown. This explanatory variable is computed from data set 3.

Average Age

This is the average age of all the F-16's in the fighter wing. It is computed by connecting the tail number information in data set 2 with the wing information in data set 3.

Percent Deployed

This is the total amount of combat hours a wing has flown divided by the total number of hours flown. It is computed by connecting the tail number information in data set 2 with data set 4. Only hours whose mission symbols is on the list of designated contingency mission symbols are counted as combat hours.

Percent Engine Type

The F-16 has five different engines: F0100229, F0100220, F0100200, F0110129, and F0110100.   Unfortunately, data set 2 does not distinguish between the engines F0100200 and F0100220, and therefore, aircraft with either of those engines are counted together. The grouping of these two engines reduces the inferential power of this variable. This research uses four explanatory variables to describe this category. For example, one explanatory variable is the percent of the wing that has engine F0100200 or

F0100220. Another explanatory variable is the percent of the wing that has engine F0100229, and so on. Each of these explanatory variables are computed by connecting data set 2 with data set 3.

Percent Block

As the F-16 has matured, the Air Force has maintained its status as a premier tactical fighter by making block upgrades. The United States Air Force currently has seven F-16C/D blocks in service: 25, 30, 32, 40, 42, 50 and 52. Each block represents a significant technological improvement from the previous block. For detailed information regarding what improvements were made by block number, visit the website http://www.faqs.org/docs/air/avf162.html. Similar to the coding scheme used in the previous explanatory variable, this research uses seven different variables to capture the block effect. This data is computed by connecting data set 2 with data set 3.

MajCOM

This is simply the MajCOM the wing is assigned to. This research analyzes Air Education and Training Command, Air Combat Command, United States Air Force in Europe, Pacific Air Forces, and the Air National Guard. Air Force Material Command is was removed from the analysis because of the accounting system used is fundamentally different than the other commands.

Location

This explanatory variable describes the location the wing is assigned to. This research analyzes forty different base locations.

Utilization Rate

This explanatory variable is defined as the numbers of hours flown divided by the number of aircraft. It is computed directly from data set 1.

Lag 1 CPFH

This explanatory variable is the previous year's DLR obligations divided by the previous year's hours flown. It is computed from data set 1.

Database Summary

Table 10 displays all of the variables this research analyzes and the data set from which they came from. Variables connected by multiple data sets are computed by using the relational capability of Access.

Table 10: Relationship Between Explanatory Variable and Data Source

	Data Set				
Variable	1	2	3	4	5
DLR Expenditures	X				
CPFH	X				
Hours	X		X	X	
Average Sortie Duration			X		
Average Aircraft Age		X	X		
Percent Deployed				X	X
Percent Engine Manufacture		X	X		
Percent Engine Type		X	X		
Percent Block		X	X		
MajCOM	X				
Location	X				
Utilization Rate	X				
Lag 1 CPFH	X				
	AFTOC			AFKS	
	Data Source				

Most impressively, this database has all of this data for 40 of 44 Air Force fighter wings from 1998 to 2004. Air Force Material Command's three fighter wings are not included because of differences in accounting system and data set 1 did not include the 53d fighter wing out of Eglin AFB. The main limitation of this database is that the explanatory variables, percent engine type and percent block, are computed with the assumption that the current configuration of these aircraft has not changed significantly from 2004. More analysis on this limitation is presented in Chapter 4.

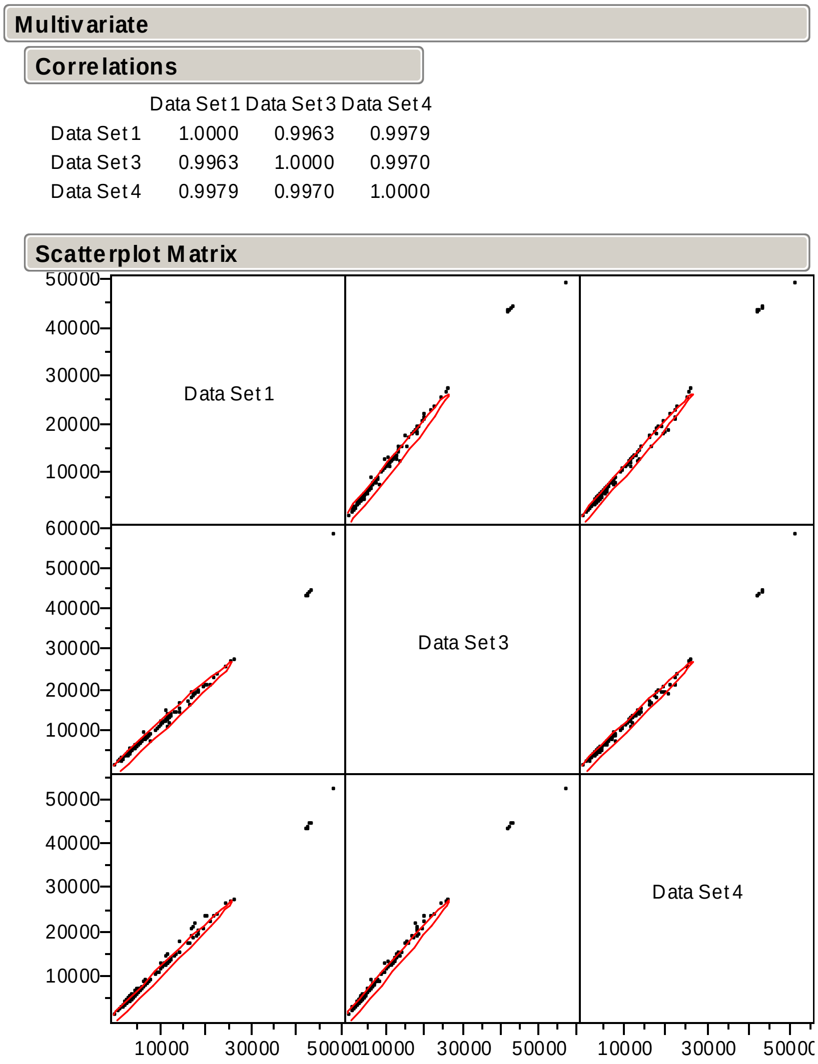
Categorical Coding Scheme

The variables MajCOM and Base are categorical variables with levels 5 and 40, respectively. To isolate the effects of each individual level, a "0" or "1" coding scheme is adopted. This research creates a dummy variable for each level of the categorical variable minus one. The effect of the level that does not have an assigned dummy variable is captured in the intercept. Therefore, each dummy variable is assigned a "1" if that data point includes that level or a "0" if it does not. In this way, the effect of each level is ascertained.

Validation of Database

Since the AFTOC and AFKS database contained a common field, hours flown, this analysis investigated whether or not this field matches between data sources and data sets by plotting the hours field from the three main data sets. This is shown in Figure 7.

The match between these two databases is not entirely exact. There is some unaccounted for variation between the two. However, this variation is less than seven tenths of one percent of the total variation. For the purposes of this research, the variation is within acceptable limits.

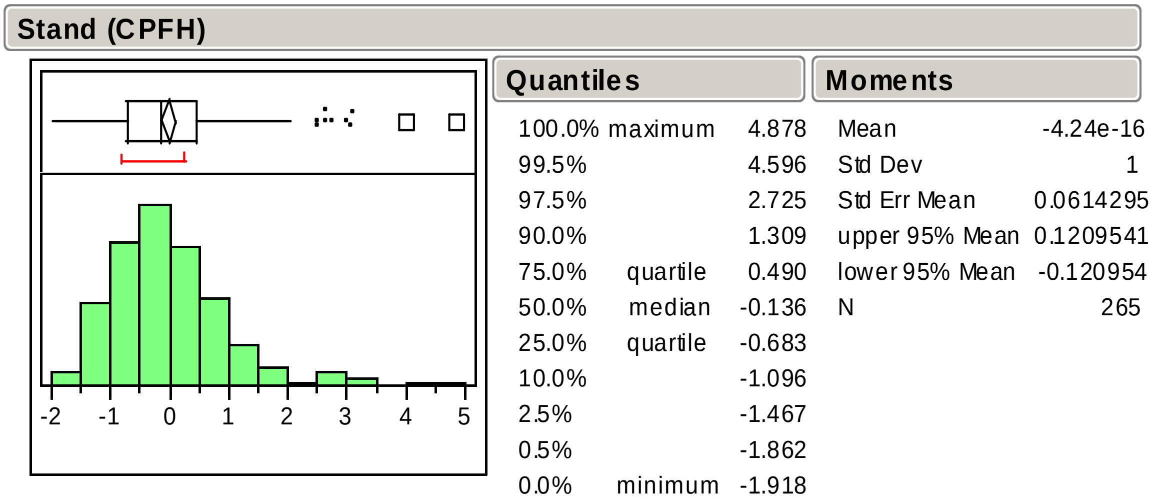


	Data Set 1	Data Set 3	Data Set 4
Data Set 1	1.0000	0.9963	0.9979
Data Set 3	0.9963	1.0000	0.9970
Data Set 4	0.9979	0.9970	1.0000

Figure 7: Scatterplot and Correlation Matrix of AFKS and AFTOC Hours

Removal of Two of Mountain Home's of Data Points

This research noticed that two data points, both from Mountain Home AFB, were extremely dissimilar then the rest of the data. Figure 8 displays a histogram of the standardized CPFH (i.e the distribution of the CPFH is transformed such that the mean is zero and the variance is one). One would expect ninety-nine percent of the observations to fall within three standard deviations of the mean. As one can see, these data point's CPFH are 4.6 and 4.87 standard deviations away from the mean. For a sample size of 265, this is a statistical aberration.



Stand (CPFH)

Quantiles

100.0%	maximum	4.878
99.5%		4.596
97.5%		2.725
90.0%		1.309
75.0%	quartile	0.490
50.0%	median	-0.136
25.0%	quartile	-0.683
10.0%		-1.096
2.5%		-1.467
0.5%		-1.862
0.0%	minimum	-1.918

Moments

Mean	-4.24e-16
Std Dev	1
Std Err Mean	0.0614295
upper 95% Mean	0.1209541
lower 95% Mean	-0.120954
N	265

Figure 8: Histogram of the Standardized CPFH
(Squared data points reflect two extreme outliers)

Another way to compare these data points to other data points is to plot CPFH by fighter wing. This is plotted in Figure 9 along with the quartiles. Notice the spike from these two data points.

This research cannot explain why the two of Mt. Home AFB data points are abnormally large. Henceforward, the two points squared in Figure 9 are removed from the analysis for being a major outliers. In Chapter 4, this research concludes that all of the Mt. Home's data is suspect.

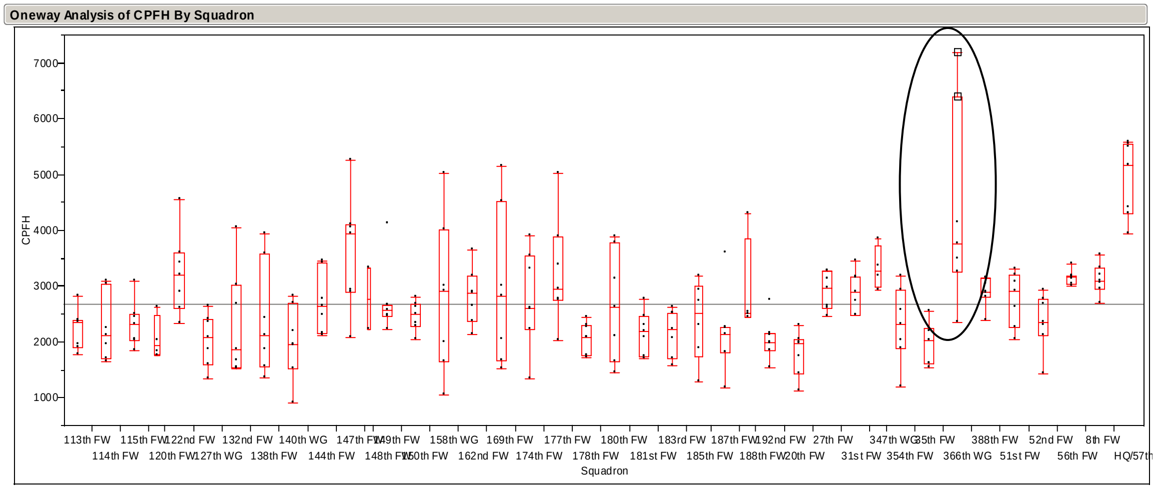
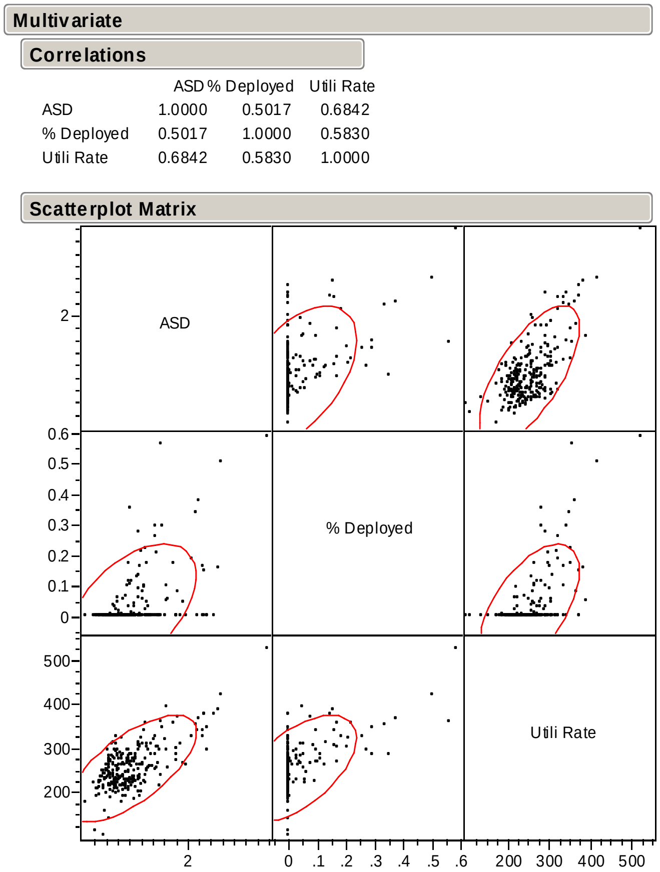


Figure 9: CPFH by Fighter Wing
(Data points from Mt. Home AFB are circled and the two outliers are squared for effect)

Correlation between Explanatory Variables

This research also notes that the explanatory variables ASD, utilization rate, and percent deployed are correlated. This is observed in Figure 10. When explanatory variables are correlated, determining which variable belongs in the model and which variable does not becomes more difficult. For example, ice cream consumption and temperature are correlated. When the weather warms up, people tend to eat more ice cream. Temperature and crime rates are also correlated. The colder months tend to keep people inside whereas the warmer months give individuals the opportunity to vandalize. If one develops a model to predict crime rates and includes ice cream consumption as an explanatory variable, he or she may erroneous conclude that it is predictive when in fact, there is only a mathematical association, not a causal relationship. This faulty conclusion came about because the analyst failed to identify the lurking variable, temperature. Further analysis of which of these three correlated variables, utilization rate, ASD, and percent deployed, belong in the model is accomplished in Chapter 4.



Multivariate

Correlations

	ASD	% Deployed	Utili Rate
ASD	1.0000	0.5017	0.6842
% Deployed	0.5017	1.0000	0.5830
Utili Rate	0.6842	0.5830	1.0000

Scatterplot Matrix

Figure 10: Correlations Among Three Explanatory Variables

An Overview of Multiple Linear Regression

According to Montgomery (2001), regression models are useful for data description, parameter estimation, and prediction. In general, multiple linear regression determines the functional form of a response, *y*, to a series of *k* explanatory variables as seen in (1) (Montgomery, 2001).

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \ldots + \beta_k x_k + \varepsilon \qquad (1)$$

Regression, then, estimates each of the beta's coefficients, denoted β_i. These estimates represent the expected change in the response for a unit change in X_i given all other variables are held constant. There are several techniques by which these parameters are estimated. This research uses the method of least squares where the sum of the residuals squared is minimized. That is,

$$SSE = \sum_{i=1}^{n} (y_i - \hat{y}_i)^2$$

is minimized where

$$\hat{y}_i = \hat{\beta}_0 + \hat{\beta}_1 x_1 + \hat{\beta}_2 x_2 + \hat{\beta}_3 x_3 + \ldots + \hat{\beta}_k x_k$$

In matrix form, the estimate for the $\hat{\beta}$ vector is given by:

$$\hat{\beta} = (X'X)^{-1} X'y$$

where y is a column vector with each entry is the observed CPFH for a fighter wing and X is a matrix with each column corresponding to the explanatory variable.

Chapter Summary

This chapter began by discussing the two data sources where the five sets of data originated. Then this chapter described how the five sets of data were used to develop the various explanatory variables in the database. Following that discussion, this chapter verified the data by comparing a common field, hours. Further investigation of the data revealed two data points that were extremely dissimilar then the rest and they were subsequently removed. Following their removal, this chapter identified three explanatory variables that were correlated: ASD, utilization rate, and percent deployed. This chapter’s closing discussion on multiple linear regression leads the way to the next chapter, Results and Analysis. The next chapter uses the database developed in this chapter to answer the investigative questions and to develop a model to predict the CPFH for a F-16C/D fighter wing using programmatic and operational variables.

IV. Results and Analysis

Chapter Overview

In this chapter, this research uses the database created in Chapter 3 in combination with the information from the literature review in Chapter 2 to solve the investigation questions presented in Chapter 1. These questions are answered in the following manner. First, the results of one-way analysis of variance are given. These results do not consider the synergistic or antagonistic effects, also known as interaction effects, between the other explanatory variables. The results of this analysis are then used to develop a model to predict the CPFH of an F-16C/D fighter wing. Unlike the one-way analysis, this model does take into account synergistic and antagonistic effects between explanatory variables. The 2004 data is withheld during the model building process and used to validate the model. Once the model is validated, the 2004 data is reinserted into the database. Then, all the explanatory variables that were not found to be significant during the initial model building portion are one at a time tested again to see if the 2004 data changes their significance. After that investigation is complete, a final model is determined and the relative influence of each explanatory variable is computed by comparing the standardized beta coefficients. This chapter closes with an analysis of the key assumption that states that the configuration of each fighter wing has not significantly changed since 1998.

One-Way Analysis of Variance

Table 11 presents the analytical results of the one-way analysis variance using single linear regression. These results do not consider the influence of other variables on the response, the CPFH, but they do shed light on the first nine investigative questions. Question 10 requires the use of multiple linear regression and is addressed following the model building portion of this research. For each of the hypothesis tests performed in Table 11, the null hypothesis is that the beta coefficient corresponding to that explanatory variable is equal to zero, while the alternative is that it is not equal to zero.

Although this analysis does not consider the influence of other explanatory variables, it is insightful and is the first step in answering the investigative questions. The explanatory variables that appear to be significant are: lag 1 CPFH, ASD, engine type, block, MajCOM, and base. The direction and magnitude of their influence can be determined by the sign and absolute value of the beta coefficient. To account for the synergistic and antagonistic effects between explanatory variables, this research uses multiple linear regression to develop a predictive model of the CPFH. The steps taken to build this model are presented next.

Table 11: One-Way Analysis of Variance For All Explanatory Variables

(Shaded variables indicate significance at 0.05 confidence level. Bases not included are not significant)

Explanatory Variable	Beta Coefficent	Std Error	p-value
Average Age	-3.12	16.95	0.854
Percent Deployed	-1115.54	615.65	0.0711
Lag 1 CPFH	0.403	0.0522	< 0.0001
ASD	-956.57	223.93	< 0.0001
Utilization Rate	-3.3641	1.04	0.0015
Percent Engine F0100200/F0100220	576.82	109.38	< 0.0001
Percent Engine F0100229	853.81	244.49	0.0006
Percent Engine F0110129	-632.05	191.73	0.0011
Percent Engine F0110100	-467.52	103.18	< 0.0001
Percent Block 25	588.91	141.86	< 0.0001
Percent Block 30	-621.43	106.43	< 0.0001
Percent Block 32	1457.04	382.33	0.0002
Percent Block 40	189.42	155.25	0.2235
Percent Block 42	212.96	176.9	0.2297
Percent Block 50	-630.07	190.91	0.0011
Percent Block 52	853.81	244.49	0.0006
MajCOM = ANG	-355.41	110.4	0.0014
MajCOM = ACC	630.69	146.77	< 0.0001
MajCOM = AETC	524.54	326.48	0.1093
MajCOM = PACAF	-115.65	171.06	0.499
MajCOM = USAFE	-12.26	235.23	0.958
Base = SELFRIDGE ANG BASE (MI)	-622.31	325.82	0.0572
Base = BUCKLEY ANG BASE (CO)	-662.06	325.52	0.043
Base = ELLINGTON (TX)	985.74	322.36	0.0025
Base = ATLANTIC CITY ANG STN (NJ)	623.93	325.81	0.0566
Base = SHAW AFB (SC)	-872.6	323.61	0.0075
Base = MISAWA AIR BASE (JAPAN)	-695.13	325.25	0.0335
Base = MOUNTAIN HOME AFB (ID)	767.49	383.76	0.0465
Base = NELLIS AFB (NV)	2334.68	294.55	< 0.0001
* Base = EIELSON AFB (AK)	-355.57	327.35	0.2784

* = Not Significant in One-Way Analysis but Significant in Final Model

Model Building Process

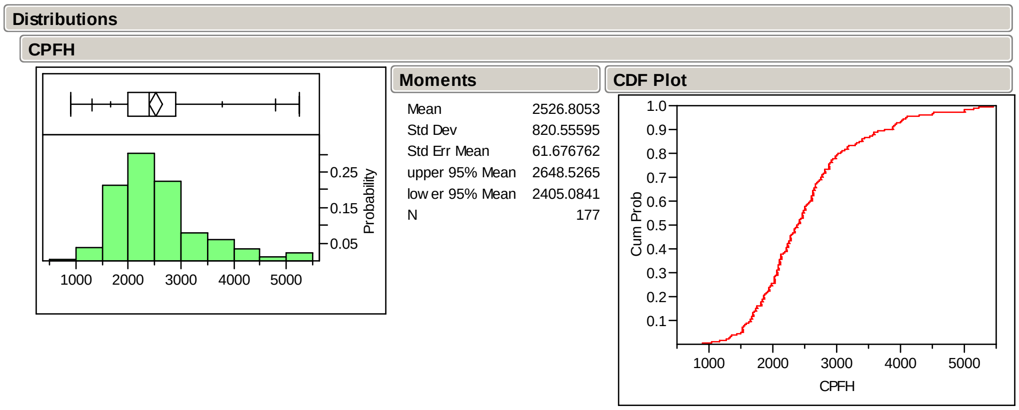
The process that determines the best possible functional form between the CPFH and the explanatory variables is not accomplished using a straight-forward, turn-the-crank procedure. Black-box programs, such as Stepwise and best subsets regression, fail to properly handle correlations between explanatory variables and fail to communicate to the analyst key differences between competing models. They rely on a single measure of effectiveness, R^2, that can be artificially inflated by adding more explanatory variables. Even worse, these black-box programs completely ignore the standard regression assumptions of normality, constant variance, and independence. Singer and Willet (2003) best summarize the danger of using black-box algorithms for variable selection:

> "Never let a computer select predictors mechanically. The computer does not know your research questions nor the literature upon which they rest. It cannot distinguish predictors of direct substantive interest from those whose effects you want to control."

For these reasons, this research did not use Stepwise and chose instead to analyze the data by carefully examining individual leverage plots and by plotting the residuals of various models against each explanatory variable. This approach revealed how the different explanatory variables interact and identifies which explanatory variables are essential to the model and which are not.

An examination of the data using these techniques reveals that the ANG fighter wings behave much differently then the active duty fighter wings. Not only is the dummy variable ANG significant, but even more importantly, the beta coefficients for the other variables change considerably when the ANG units are excluded from the model. Some descriptive statistics help explain why the ANG fighter wings behave fundamentally different then the other active duty fighter wings.

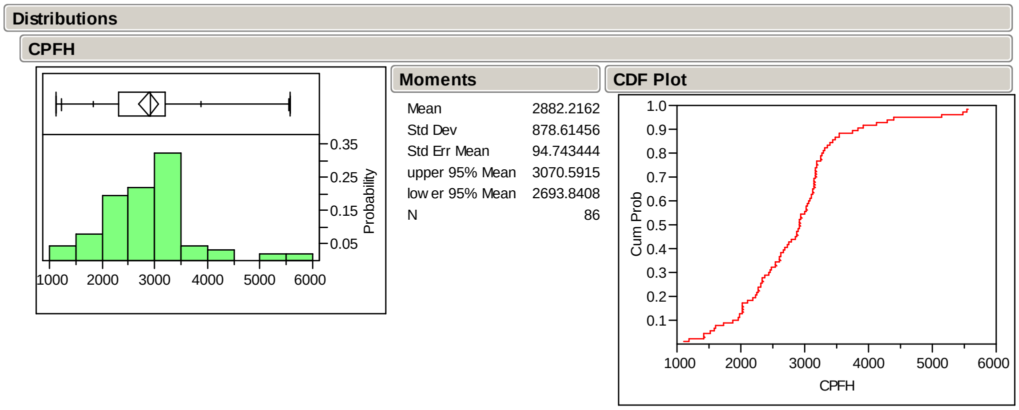
Figures 11 and 12 display the distribution of the response, CPFH, for ANG fighter wings and for active duty fighter wings. As Figure 11 and Figure 12 show, there is considerable difference between the distribution of the ANG and active duty FW's CPFH. Additionally, the mean of the two distributions are significantly different as noted by the 95% confidence interval listed. Further contributing to the differences is the average number of hours each of these fighter wings fly a year. This is presented in Figure 13 and Figure 14.



Moments

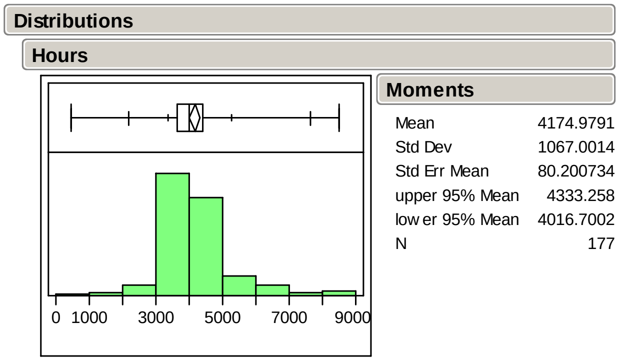
Mean	2526.8053
Std Dev	820.55595
Std Err Mean	61.676762
upper 95% Mean	2648.5265
low er 95% Mean	2405.0841
N	177

Figure 11: Histogram and CDF Plot of ANG FW's CPFH



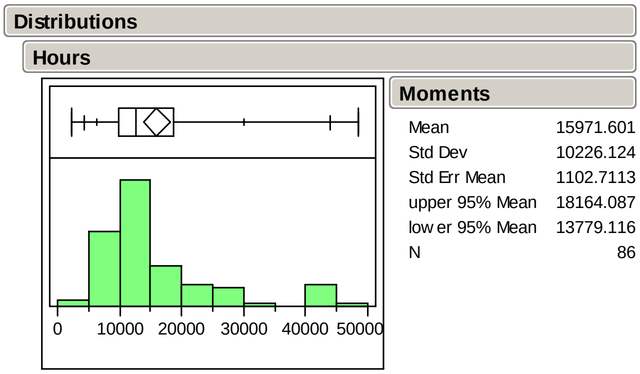
```
Mean             2882.2162
Std Dev          878.61456
Std Err Mean     94.743444
upper 95% Mean   3070.5915
low er 95% Mean  2693.8408
N                       86
```

Figure 12: **Histogram and CDF Plot of Active Duty FW's CPFH**



```
Mean             4174.9791
Std Dev          1067.0014
Std Err Mean     80.200734
upper 95% Mean    4333.258
low er 95% Mean  4016.7002
N                      177
```

Figure 13: Histogram of Hours Flown for ANG FWs

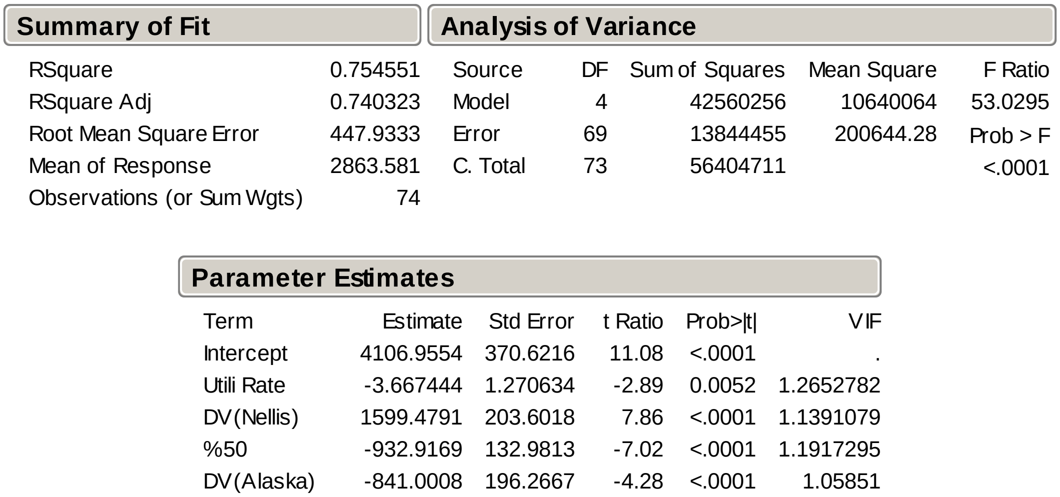


```
Mean             15971.601
Std Dev          10226.124
Std Err Mean     1102.7113
upper 95% Mean   18164.087
low er 95% Mean  13779.116
N                       86
```

Figure 14: Histogram of Hours Flown for Active Duty FWs

Figures 13 and 14 reinforce the claim that there are inherent differences between ANG and active duty fighter wings. Active duty fighter wings fly almost four times as many hours as ANG fighter wings and have a standard deviation that is nearly 10 times as large. Due to these major differences, two models are built, one for ANG fighter wings and one for active duty fighter wings.

The first model, named Model A, relates the CPFH of active duty fighter wings to four explanatory variables, utilization rate, DV(Nellis), DV(Alaska), and percent block 50. The second model, named Model B, relates the CPFH of ANG fighter wings to four explanatory variables: utilization rate, DV(NJ), DV(Ellington), and percent block 30. For each model, this research chose these variables with great care and after considerable time testing various combinations of explanatory variables. Additionally, both of these models were built without the 2004 data. Figures 15 and 16 display the results for Model A and B, respectively.



Summary of Fit

RSquare	0.754551
RSquare Adj	0.740323
Root Mean Square Error	447.9333
Mean of Response	2863.581
Observations (or Sum Wgts)	74

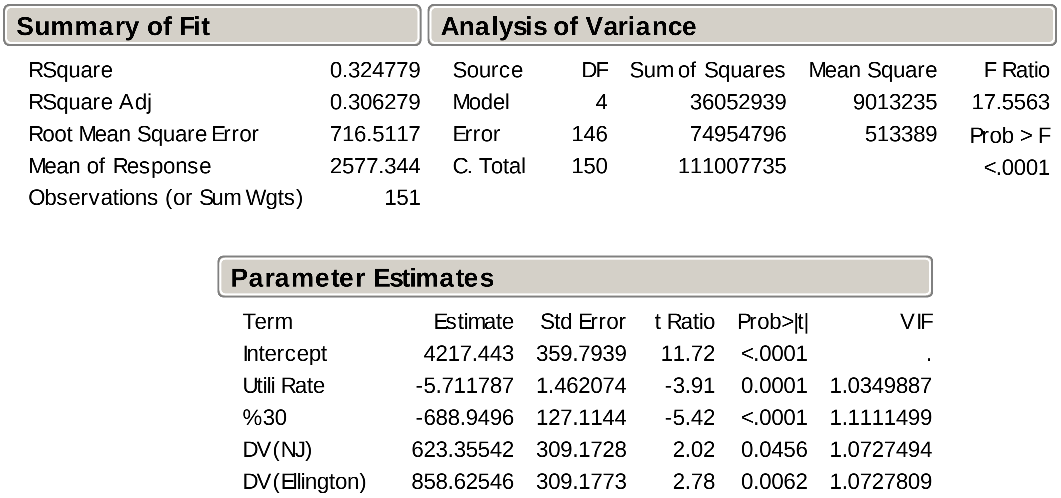
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	4	42560256	10640064	53.0295
Error	69	13844455	200644.28	Prob > F
C. Total	73	56404711		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|	VIF
Intercept	4106.9554	370.6216	11.08	<.0001	.
Utili Rate	-3.667444	1.270634	-2.89	0.0052	1.2652782
DV(Nellis)	1599.4791	203.6018	7.86	<.0001	1.1391079
%50	-932.9169	132.9813	-7.02	<.0001	1.1917295
DV(Alaska)	-841.0008	196.2667	-4.28	<.0001	1.05851

Figure 15: Model A, Active Duty FW Model



Summary of Fit

RSquare	0.324779
RSquare Adj	0.306279
Root Mean Square Error	716.5117
Mean of Response	2577.344
Observations (or Sum Wgts)	151

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	4	36052939	9013235	17.5563
Error	146	74954796	513389	Prob > F
C. Total	150	111007735		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|	VIF
Intercept	4217.443	359.7939	11.72	<.0001	.
Utili Rate	-5.711787	1.462074	-3.91	0.0001	1.0349887
%30	-688.9496	127.1144	-5.42	<.0001	1.1111499
DV(NJ)	623.35542	309.1728	2.02	0.0456	1.0727494
DV(Ellington)	858.62546	309.1773	2.78	0.0062	1.0727809

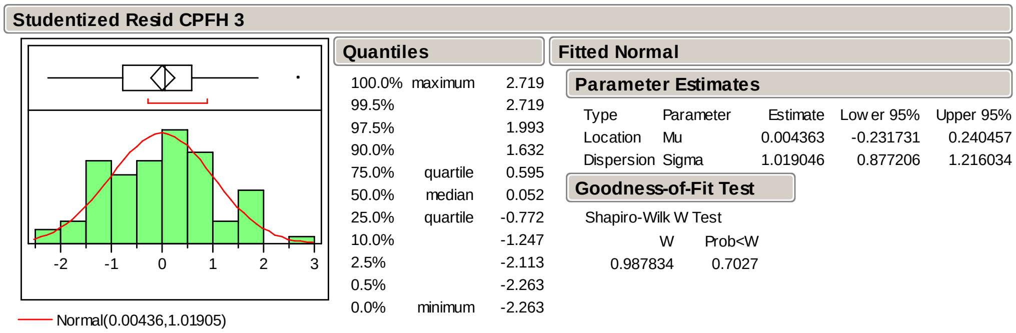
Figure 16: Model B, ANG FW Model

There are three important differences between these two models. First, the change in the beta coefficient that corresponds to the utilization rate changes from -3.66 in Model A to -5.71 in Model B. This difference signals that the ANG's CPFH cannot be modeled by simply adjusting it up or down my fixed rate. The rate at which changes in utilization rate affect the CPFH are different between ANG and active duty fighter wings. Second, the explanatory variables that best describe the functional form of the response also change. The explanatory variable "percent block 50" in Model A is replaced by the explanatory variable "percent block 30" in Model B. This change is due to the higher number of block 50's in active duty fighter wings and the higher number of block 30's in an ANG fighter wing. Using the database created in Chapter 3, the average ANG fighter wing has 52% Block 30s and no Block 50s where as the average active duty fighter wing has 25% Block 50s and 10% Block 30s. Appendix D lists the percent of each block by both ANG and active duty fighter wings. Finally, the last key difference between these two models is the large difference in the adj R^2 between the two models, 0.74 in Model A as compared to 0.306 in Model B. This difference describes how well the model fits the data and is further supported by the difference in F-Ratios, 52 in Model A and only 17.55 in Model B. In short, operational and programmatic variables appear to be better at predicting the CPFH for active duty fighter wings then for ANG fighter wings. Next, the residuals are checked to ensure the three assumptions, normality, constant variance, and independence, are not violated and any overly influential data points along with any extreme outliers are identified.

Residual Diagnostics

Normality Assumption

The objective test for the assumption of normality is accomplished by fitting a standard normal distribution to the standardized residuals and performing a Shapiro-Wilk Goodness of Fit test. The null hypothesis for this test is that the distribution is normally distributed. As Figures 17 and 18 show, Model A passes the objective test, but Model B does not. This is determined by recalling the null hypothesis for the Shapiro-Wilk test is that the distribution is normally distributed. Therefore, a *p*-value below 0.05 for this hypothesis test tells the reader to reject the null hypothesis in favor of the alternate hypothesis. Also recall that Model A has 74 observations while Model B has 151 observations. The larger sample size of Model B makes it more difficult to pass this test since even slight deviations from normality will be detected.



Studentized Resid CPFH 3

Quantiles

100.0%	maximum	2.719
99.5%		2.719
97.5%		1.993
90.0%		1.632
75.0%	quartile	0.595
50.0%	median	0.052
25.0%	quartile	-0.772
10.0%		-1.247
2.5%		-2.113
0.5%		-2.263
0.0%	minimum	-2.263

Fitted Normal

Parameter Estimates

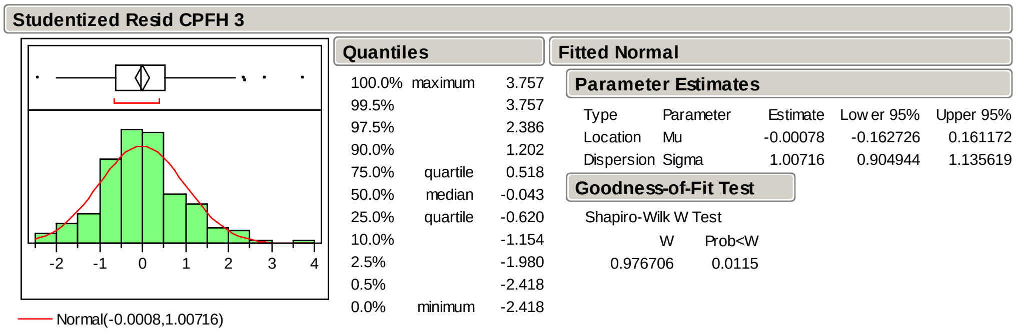
Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	Mu	0.004363	-0.231731	0.240457
Dispersion	Sigma	1.019046	0.877206	1.216034

Goodness-of-Fit Test

Shapiro-Wilk W Test

W	Prob<W
0.987834	0.7027

Figure 17: Shapiro-Wilk Goodness of Fit Test for Model A



Studentized Resid CPFH 3

Quantiles

100.0%	maximum	3.757
99.5%		3.757
97.5%		2.386
90.0%		1.202
75.0%	quartile	0.518
50.0%	median	-0.043
25.0%	quartile	-0.620
10.0%		-1.154
2.5%		-1.980
0.5%		-2.418
0.0%	minimum	-2.418

Fitted Normal

Parameter Estimates

Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	Mu	-0.00078	-0.162726	0.161172
Dispersion	Sigma	1.00716	0.904944	1.135619

Goodness-of-Fit Test

Shapiro-Wilk W Test

W	Prob<W
0.976706	0.0115

Figure 18: Shapiro-Wilk Goodness of Fit Test for Model B

Both model’s residuals are mound shaped, and therefore, pass the subjective test for normality. Model B contains one moderate outlier which is causing the minor deviation from the assumption of normality. With this data point excluded, the model passes the assumption (*p*-value = 0.181). Regression is robust to deviations in normality such as these.

Constant Variance Assumption

The objective test for the constant variance assumption is accomplished using the Breusch-Pagan test. This is accomplished and the results are listed in Table 12. Figures 19 and 20 follow and add to the discussion by plotting the residuals by predicted for both models.

Table 12: Breusch-Pagan Constant Variance Test for Models A and B
(Shaded row indicates failure of Constant Variance Test)

	Breusch-Pagan Test for Constant Variance					
	SSE (Full)	**SSR (Reduced)**	**Predictors**	**Sample Size**	**Test Statistic**	**p-value**
Model A	13844455	6.97E+11	5	74	9.96	0.0764
Model B	74954796	8.69E+12	5	151	17.63	0.00344

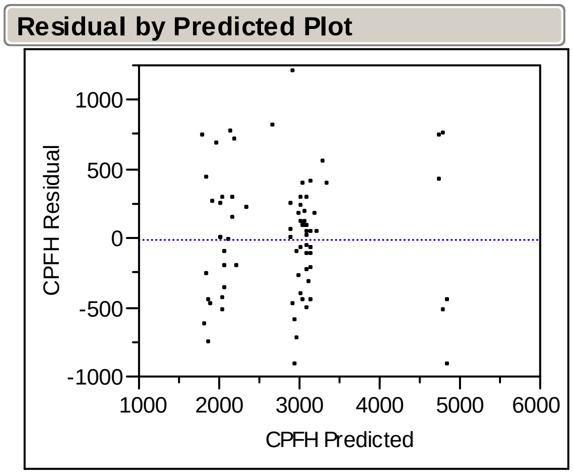


Figure 19: Model's A Plot of Residuals by Predicted

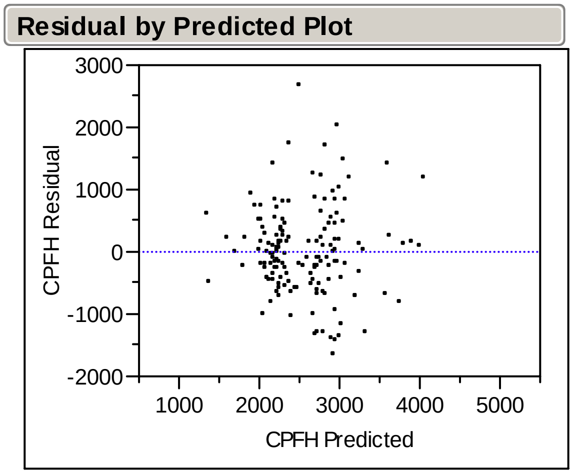
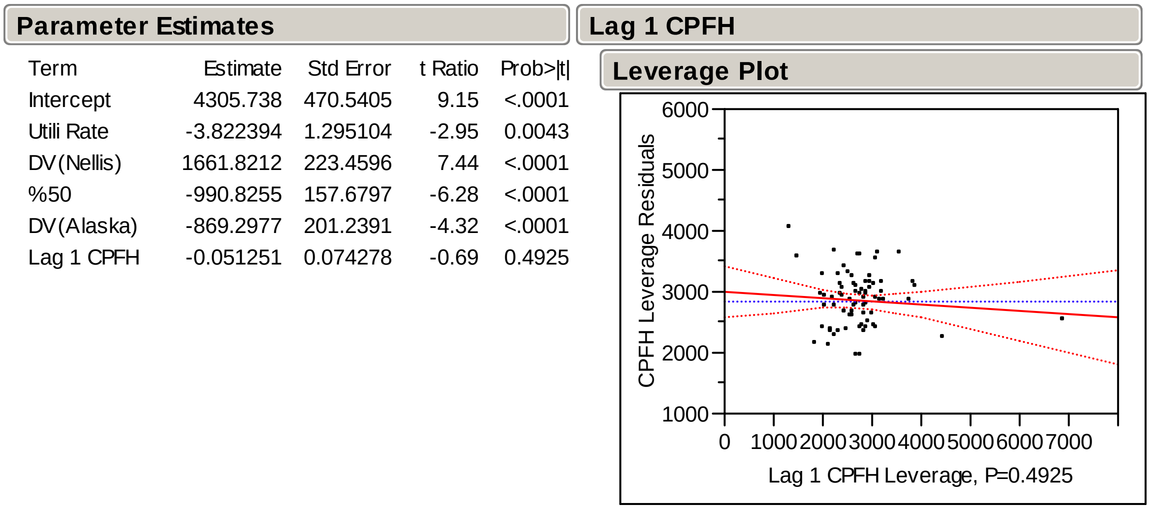


Figure 20: Model's B Plot of Residuals by Predicted

As seen in Table 12, Model B fails the objective test for constant variance since the alternate hypothesis of the Breusch-Pagan test is that the model does not pass the assumption of constant variance. There appears to be a slight diamond shape in the residuals and the Breusch-Pagan test is detecting it. Since regression is robust to minor deviations from this assumption, Model B is still a usable model. The impact of this deviation is that the actual p-values may be slightly different then stated

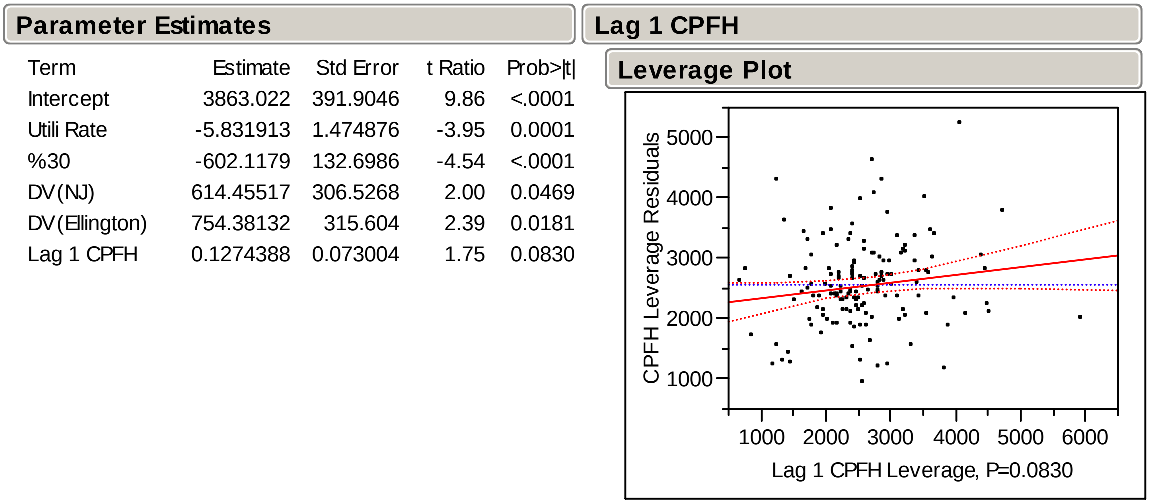
Independence Assumption

Unlike the assumption of normality and constant variance, regression is not robust to deviations in the assumption of independence. Without additionally modeling, the *p*-values could be much larger or much smaller then calculated. The Durbin-Watson test is typically used to detect a lag 1 autocorrelation. This test can not be implemented on either model since there are only six data points per fighter wing and it would be nonsensical to compute the autocorrelation between the different fighter wings. This research opts to validate this assumption by inserting the lag 1 CPFH explanatory variable and testing whether the corresponding beta coefficient is equal to zero or not. This test is not equivalent to the Durbin-Watson test, but it does give insights to whether the models pass this assumption or not. The results of this test are shown in Figures 21 and 22.



Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	4305.738	470.5405	9.15	<.0001
Utili Rate	-3.822394	1.295104	-2.95	0.0043
DV(Nellis)	1661.8212	223.4596	7.44	<.0001
%50	-990.8255	157.6797	-6.28	<.0001
DV(Alaska)	-869.2977	201.2391	-4.32	<.0001
Lag 1 CPFH	-0.051251	0.074278	-0.69	0.4925

Figure 21: Model A's Test for Independence



Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	3863.022	391.9046	9.86	<.0001
Utili Rate	-5.831913	1.474876	-3.95	0.0001
%30	-602.1179	132.6986	-4.54	<.0001
DV(NJ)	614.45517	306.5268	2.00	0.0469
DV(Ellington)	754.38132	315.604	2.39	0.0181
Lag 1 CPFH	0.1274388	0.073004	1.75	0.0830

Figure 22: Model B's Test for Independence

From this analysis, both of these models pass this critical assumption, though the *p*-value for Model B is borderline (*p* –value = 0.083). To complete the residual diagnostics, overly influential data points and extreme outliers are identified. Figures 23 and 24 display Cook's Distance for both models.

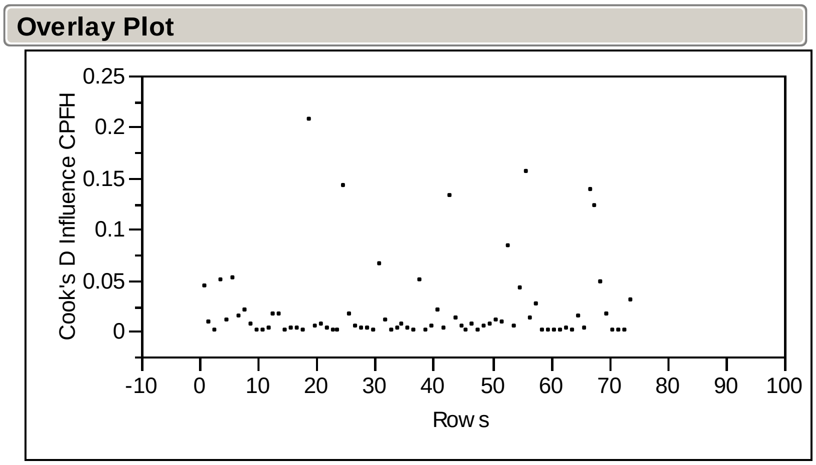


Figure 23: Cook's Distance Overlay Plot for Model A

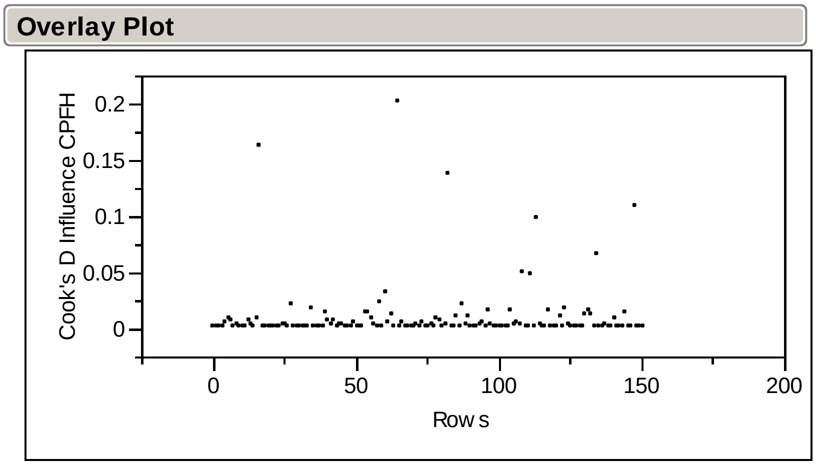


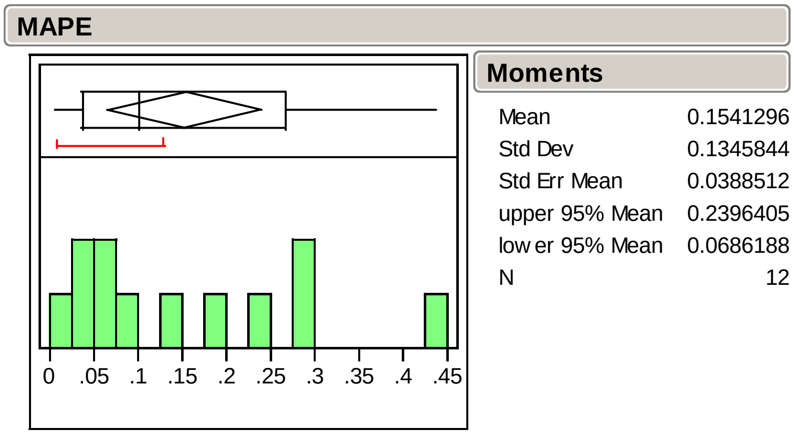
Figure 24: Cook's Distance Overlay Plot for Model B

Since there are no data points with a Cook's Distance of 0.5 or greater, there are no overly influential data points in either of these models. Additionally, from Figures 17 and 18, there are no data points with a studentized residual over 4.0, therefore the data did not contain any extreme outliers. In Chapter 3, two data points were removed because they had an abnormally large CPFH. If those points are reinserted into Model A, the R^2 – adj drops to 0.52 and the studentized residuals of the two data points are 5.5 and 4.5. Obviously, these two data points do not belong in the analysis.

Model Performance and Validation

Several of the explanatory variables are not known prior to the year of execution and, therefore, they have to be forecasted out. For the purposes of this research, the previous year's values are used as an estimate. In practice, identifying a more accurate estimate of the explanatory variables will yield better results. Using this forecasting technique, the Mean Absolute Percent Error (MAPE) and defined in Equation 2, is calculated for the 2004 data. The results are shown in Figures 25 and 26.

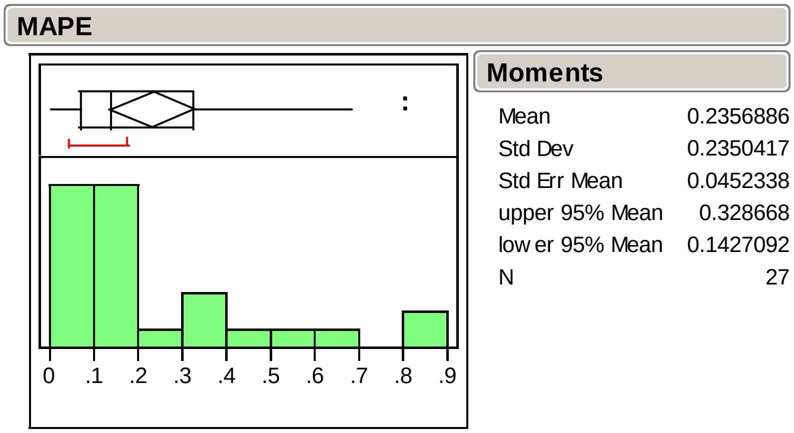
$$MAPE = \frac{\left|Actual - Predicted\right|}{Actual} \tag{2}$$



Moments

Mean	0.1541296
Std Dev	0.1345844
Std Err Mean	0.0388512
upper 95% Mean	0.2396405
lower 95% Mean	0.0686188
N	12

Figure 25: MAPE for Active duty Test Set



Moments

Mean	0.2356886
Std Dev	0.2350417
Std Err Mean	0.0452338
upper 95% Mean	0.328668
low er 95% Mean	0.1427092
N	27

Figure 26: MAPE for ANG Test Set

Additionally, the research uses the test set to validate the model by creating a 95% prediction interval and determining what percentage of the time the test set data fell within the range. Table 13 displays the results of this test. One would expect roughly 95% of the observations to fall in this range. Since this is the case, then the model is working properly.

Table 13: Validation Results

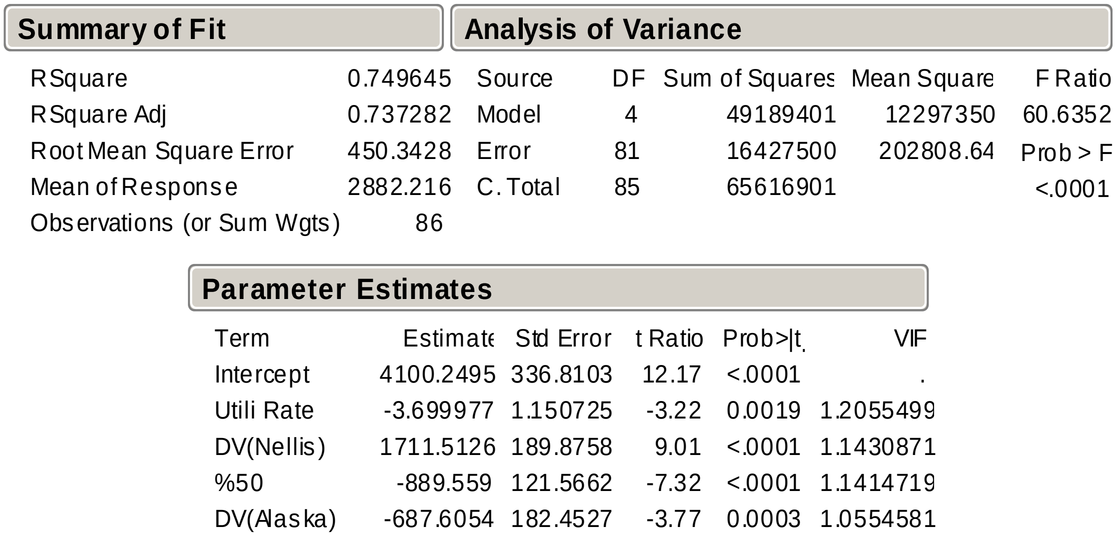
	Model A	Model B
Test Set Sample Size	27	12
Number of Squadrons within 95% Prediction Interval	26	11
Percent of Squadrons within 95 % Prediction Interval	96.2%	91.7%

Since both of these models pass the standard regression assumptions and are validated using the 2004 test set, this research now considers them to be legitimate. The 2004 data is now reinserted back into the database. This is done for two reasons. First, this research investigates how much the beta coefficients change when the 2004 data is added to the database. If the beta coefficients drastically change, then that would be a source of concern over the validity of the model. Secondly, with this larger database, 7 data points per fighter wing instead of 6, this research investigates whether any of the explanatory variables initially not included in the model actually belong in the model.

Re-insertion of 2004 Data

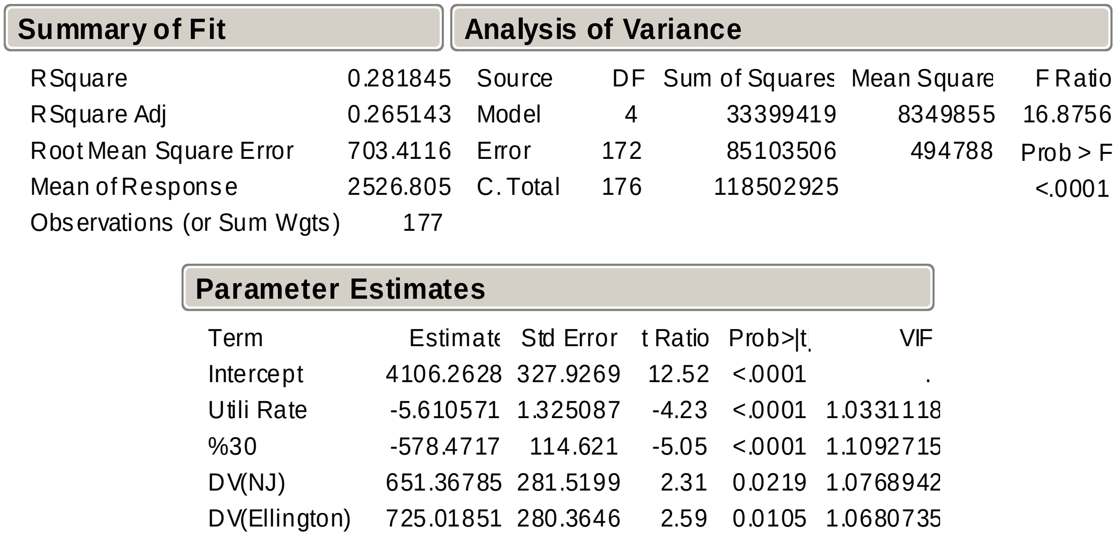
Effect on Beta Coefficients

Towards the first reason for reinserting the 2004 data, this research identifies the percent change by re-computing the beta coefficients. These next set of models, denoted Model C for active duty fighter wings and Model D for ANG fighter wings, are shown in Figure 27 and Figure 28. The only difference between these and Models A and B is that the 2004 data is reinserted. Following these figures, Figure 29 displays the percent change for each parameter in each model.



```
Summary of Fit                                  Analysis of Variance
RSquare                          0.749645       Source     DF  Sum of Squares  Mean Square   F Ratio
RSquare Adj                      0.737282       Model       4        49189401     12297350   60.6352
Root Mean Square Error           450.3428       Error      81        16427500    202808.64  Prob > F
Mean of Response                 2882.216       C. Total   85        65616901                 <.0001
Observations (or Sum Wgts)             86

                    Parameter Estimates
                    Term           Estimate   Std Error  t Ratio  Prob>|t|        VIF
                    Intercept     4100.2495   336.8103    12.17   <.0001            .
                    Utili Rate    -3.699977   1.150725    -3.22   0.0019    1.2055499
                    DV(Nellis)    1711.5126   189.8758     9.01   <.0001    1.1430871
                    %50            -889.559   121.5662    -7.32   <.0001    1.1414719
                    DV(Alaska)    -687.6054   182.4527    -3.77   0.0003    1.0554581
```

Figure 27: Model C, Active Duty FW's Updated Model



Summary of Fit

RSquare	0.281845
RSquare Adj	0.265143
Root Mean Square Error	703.4116
Mean of Response	2526.805
Observations (or Sum Wgts)	177

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	4	33399419	8349855	16.8756
Error	172	85103506	494788	Prob > F
C. Total	176	118502925		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t	VIF
Intercept	4106.2628	327.9269	12.52	<.0001	.
Utili Rate	-5.610571	1.325087	-4.23	<.0001	1.0331118
%30	-578.4717	114.621	-5.05	<.0001	1.1092715
DV(NJ)	651.36785	281.5199	2.31	0.0219	1.0768942
DV(Ellington)	725.01851	280.3646	2.59	0.0105	1.0680735

Figure 28: Model D, Active Duty FW's Updated Model

Table 14: Percent Change in Beta Coefficients

	Parameter Estimate		
	Model A	**Model C**	**Percent Change**
Intercept	4106	4100	0.1%
Utilization Rate	-3.66	-3.699	1.1%
%50	-932.9	-889.5	4.7%
DV(Nellis)	1599	1711.5	7.0%
DV(Alaska)	-841	-687.6	18.2%

	Parameter Estimate		
	Model B	**Model D**	**Percent Change**
Intercept	4217.4	4106	2.6%
Utilization Rate	-5.71	-5.61	1.8%
%30	-688.9	-578.47	16.0%
DV(NJ)	623.3	651.3	4.5%
DV(Ellington)	858.6	725	15.6%

The reader should notice that most of the parameters changed very little while three of the parametes, (i.e DV(Alaska), DV(Ellington), and %30) changed more then 15%. In all three cases, the new estimate is less than one standard deviation of the original estimate. Therefore, the new parameter estimates are very similar to the original estimates.

Now that the influence of adding the 2004 test data has been captured, this research turns its attention to analyzing the variables that were not predictive with the 2004 data removed.

Analysis of Excluded Variables Using the Updated/Validated Models

Table 11 displays the significance of each explanatory variable without considering the antagonistic and synergistic effects of other variables. Now that a model has been developed and validated, variables not included in the model are reintroduced and their significance is determined while considering the effects of other variables. This is accomplished by introducing a variable into the model one at a time and then testing the beta coefficient. The same hypothesis used in the one-way analysis is used in this analysis. Additionally, the Variance Inflation Factor (VIF) score is documented. The VIF scores are used to determine if the information added by the introduction of this variable is redundant or not. Tables 15 and 16 displays the results for each groups of fighter wings.

Although Table 15 and Table 16 include the p-value for the original one-way analysis, recall that this analysis was done with database including both ANG and active duty fighter wings. Also take note that Table 15 does not include the explanatory variables Percent Block 50 and Percent Engine F0110129 since no ANG fighter wings contained Block 50s or engines of this type.

Table 15: Significance of Excluded Explanatory Variables for ANG FWs
(Shaded variables indicate significance at 0.05 confidence level. Bases not included are not significant)

Explanatory Variable	Original p-value	New p-value	New VIF
Average Age	0.854	0.79	1.08
Percent Deployed	0.0711	0.8835	1.14
Lag 1 CPFH	< 0.0001	0.0137	1.21
ASD	< 0.0001	0.765	2.33
Percent Engine F0100200/F0100220	< 0.0001	0.43	5.1
Percent Engine F0100229	0.0006	0.213	1.08
Percent Engine F0110100	< 0.0001	0.593	16.9
Percent Block 25	< 0.0001	0.214	1.97
Percent Block 32	0.0002	0.781	1.03
Percent Block 40	0.2235	0.593	1.01
Percent Block 42	0.2297	0.045	1.41
Percent Block 52	0.0006	0.213	1.08
Base = SELFRIDGE ANG BASE (MI)	0.0572	0.841	1.05
Base = BUCKLEY ANG BASE (CO)	0.043	0.898	1.09

Table 16: Significance of Excluded Explanatory Variables for Active Duty FWs

Explanatory Variable	Original p-value	New p-value	VIF
Average Age	0.854	0.235	1.32
Percent Deployed	0.0711	0.819	2.02
Lag 1 CPFH	< 0.0001	0.748	2.01
ASD	< 0.0001	0.0624	3.92
Percent Engine F0100200/F0100220	< 0.0001	0.817	1.52
Percent Engine F0100229	0.0006	0.058	1.09
Percent Engine F0110129	0.0011	0.607	1,711.5
Percent Engine F0110100	< 0.0001	0.123	2.33
Percent Block 25	< 0.0001	0.739	1.08
Percent Block 30	< 0.0001	0.478	1.16
Percent Block 32	0.0002	0.397	1231.1
Percent Block 40	0.2235	0.315	1.99
Percent Block 42	0.2297	0.85	1.56
Percent Block 52	0.0006	0.058	1.09
MajCOM = ACC	< 0.0001	0.47	1.25
MajCOM = AETC	0.1093	0.738	1.08
MajCOM = PACAF	0.499	0.34	1.27
MajCOM = USAFE	0.958	0.0645	1.19
Base = SHAW AFB (SC)	0.0075	0.055	1.37
Base = MISAWA AIR BASE (JAPAN)	0.0335	0.717	1.38
Base = MOUNTAIN HOME AFB (ID)	0.0465	0.0644	1.04

Recall in that in the original one-way analysis, Table 11, that the majority of explanatory variables tested significant. As stated earlier, the downfall of the one-way analysis is that it does not account for synergistic or antagonistic effects between explanatory variables. Now that a model have been developed, the true influence of these explanatory is tested. The result is that many of the explanatory variables that were originally significant are not (i.e ASD, Percent Engine, Percent Block, MajCOM, and Base) and one that was not significant is now significant, that being DV(Alaska). Also noteworthy from Table 16 is the VIF score for Percent Block 32 and Percent Engine

F0110129. This research interprets the extraordinarily high VIF scores as an indicator that an explanatory variable is contributing redundant information.

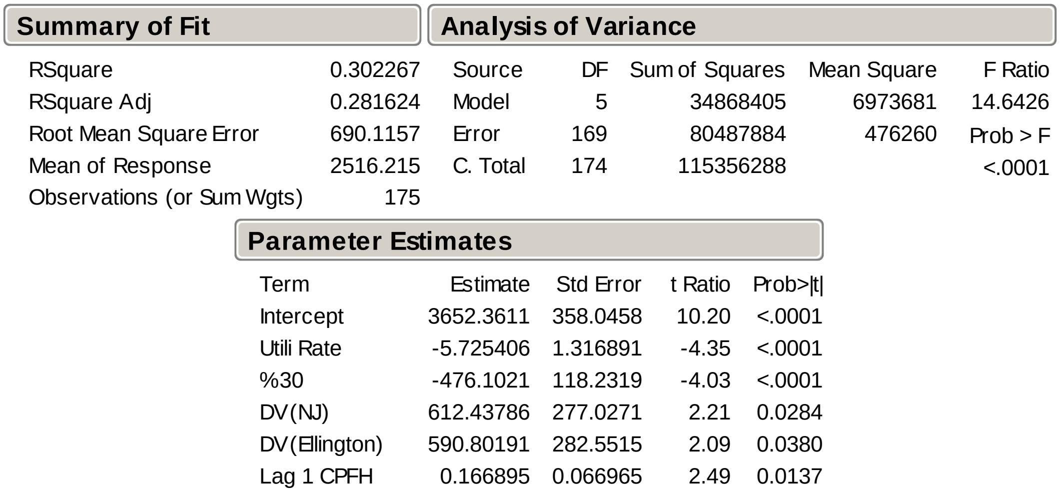
Modifications of Validated Models

Modifiying the ANG Model

For the original ANG model, Model A, recall that when the Lag 1 CPFH variable was introduced, the *p*-value was only 0.083. With the addition of the 2004 data, the *p*-value drops to 0.0137. Because of this, this research concluded that this explanatory variable does belong in the model. In Chapter 2, there were 7 studies that quantified the relationship between aircraft age and O&M costs. They found that the on average, O&M costs increase at a rate of 1.7% to 2.5% a year. This effect is partially modeled in the Lag 1 CPFH explanatory variable. The fact that this variable is significant in ANG fighter wings and not in the active duty fighter wings further highlights the major differences between them.

For ANG fighter wings, the explanatory variable, Block 40, also became significant when the 2004 data was added. This research tested a variety of models with Block 40, and in every case, the R^2 – Adj of those models was smaller then the original model.

Therefore, this research concludes that the final model for ANG fighter wings should include the Lag 1 CPFH and not any additional variables. Figure 29 displays the characteristics of this final model for ANG fighter wings, denoted Model E. The diagnostics were checked of this model and they the same as Model B. Next, this research modifies the active duty mode, Model D, and removes suspect data points.



Summary of Fit

RSquare	0.302267
RSquare Adj	0.281624
Root Mean Square Error	690.1157
Mean of Response	2516.215
Observations (or Sum Wgts)	175

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	34868405	6973681	14.6426
Error	169	80487884	476260	Prob > F
C. Total	174	115356288		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	3652.3611	358.0458	10.20	<.0001
Utili Rate	-5.725406	1.316891	-4.35	<.0001
%30	-476.1021	118.2319	-4.03	<.0001
DV(NJ)	612.43786	277.0271	2.21	0.0284
DV(Ellington)	590.80191	282.5515	2.09	0.0380
Lag 1 CPFH	0.166895	0.066965	2.49	0.0137

Figure 29: Model E, Final Model for ANG FWs

Modifying the Active Duty FW Model

Table 15 shows that when each explanatory variable is re-introduced one at a time into the model, none of them are significant. But, when this research did this analysis, it noticed that these results were being skewed by a single fighter wing's data. As an illustration, Figure 30 displays the leverage plot of the explanatory variable Average Aircraft Age.

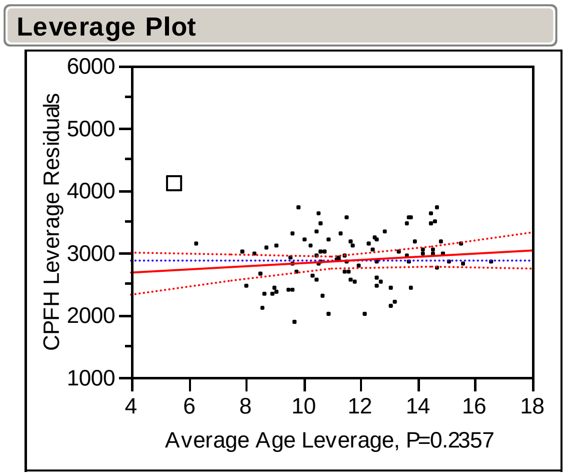
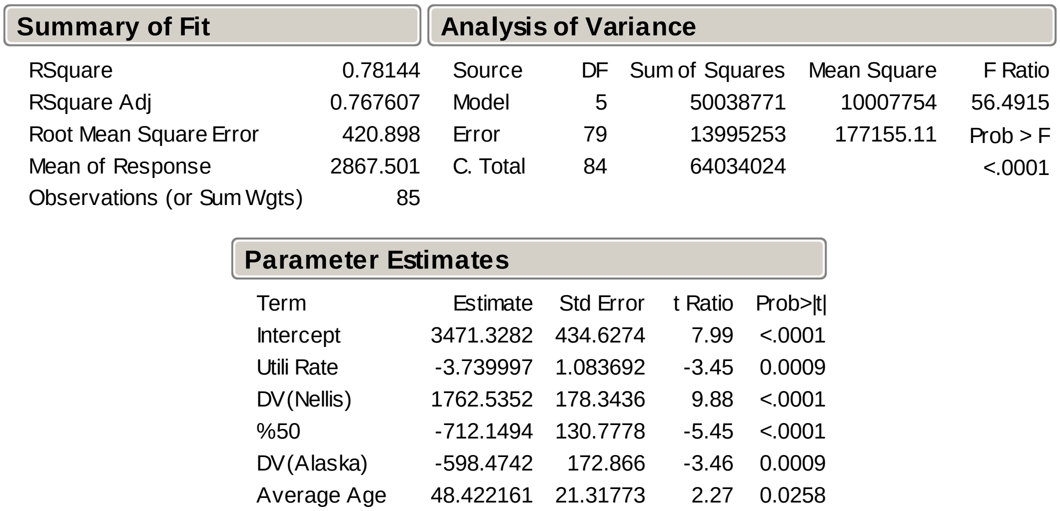


Figure 30: Leverage Plot Average Aircraft Age
(1998 Mt. Home data point squared for effect)

This research noticed that this one data point appears to greatly influence the slope, making it appear smaller than it is actually is. Also, the fact that every study in Chapter 2 stated that O&M costs increase with increasing age of aircraft further supported the belief that this explanatory variable should be statistically significant. Therefore, the response was regressed against the same four explanatory variables with this point excluded. Figure 31 displays these new results. This new model includes 2004 data, but does not include the data point squared in Figure 30.



Summary of Fit

RSquare	0.78144
RSquare Adj	0.767607
Root Mean Square Error	420.898
Mean of Response	2867.501
Observations (or Sum Wgts)	85

Analysis of Variance

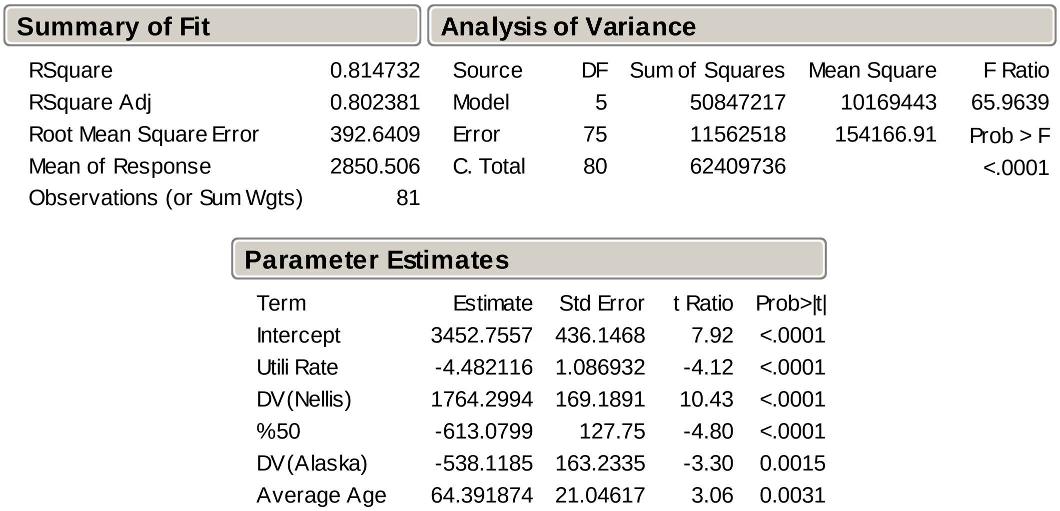
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	50038771	10007754	56.4915
Error	79	13995253	177155.11	Prob > F
C. Total	84	64034024		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	3471.3282	434.6274	7.99	<.0001
Utili Rate	-3.739997	1.083692	-3.45	0.0009
DV(Nellis)	1762.5352	178.3436	9.88	<.0001
%50	-712.1494	130.7778	-5.45	<.0001
DV(Alaska)	-598.4742	172.866	-3.46	0.0009
Average Age	48.422161	21.31773	2.27	0.0258

Figure 31: Model C with Mt. Home's 1998 Data Point Removed

Noticed the significant improvement of R^2 – adj and the steep drop in the *p*-value corresponding to the variable Average Aircraft Age, from 0.23 to 0.0258. Not surprisingly, this data point belonged to the same base that had two other points removed for being extremely dissimilar, Mt. Home AFB. Removing this point would be the third of the seven data points removed from base. This research questioned the integrity of the data from this base. To further investigate the effect this base is having on the model, the other four data points are excluded and the same model is regressed. Figure 32 displays this model's characteristics.



Summary of Fit

RSquare	0.814732
RSquare Adj	0.802381
Root Mean Square Error	392.6409
Mean of Response	2850.506
Observations (or Sum Wgts)	81

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	50847217	10169443	65.9639
Error	75	11562518	154166.91	Prob > F
C. Total	80	62409736		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	3452.7557	436.1468	7.92	<.0001
Utili Rate	-4.482116	1.086932	-4.12	<.0001
DV(Nellis)	1764.2994	169.1891	10.43	<.0001
%50	-613.0799	127.75	-4.80	<.0001
DV(Alaska)	-538.1185	163.2335	-3.30	0.0015
Average Age	64.391874	21.04617	3.06	0.0031

Figure 32: Active Duty Model with 2004 Data and Without Mt. Home AFB's Data

Notice how the R^2 – adj continues to climb while the *p*-value corresponding to the Average Age of Aircraft drops by another order of magnitude. This research concludes that there is a high likelihood that this base's data is suspect. Additionally, the purpose of this model is to capture a typical response from a F-16 fighter wing. The data from Mt. Home AFB appears to be atypical. For both of these reasons, this data is removed from the analysis.

Following the removal of Mt. Home's data, the residuals are analyzed and this research discovers the presence of an overly influential data point (Cook's Distance of 0.79). Figure 33 displays the explanatory variable that it is overly influencing, utilization rate. The data point in question is the 31st FW out of Aviano Italy in 1999. This research further investigated this point and found the utilization rate was 550 hrs/aircraft for the year in question. Additionally, this wing was deployed for over 50% of the time in direct support of Operation ALLIED FORCE. To determine how atypical this utilization rate is, this research standardized the explanatory variable, utilization rate, and determined that this observation was 5.5 standard deviations from the mean. During this eight year time period, the next closest wing had a utilization rate of only 420 hrs/aircraft and this observation was only 2.85 standard deviations from the mean.

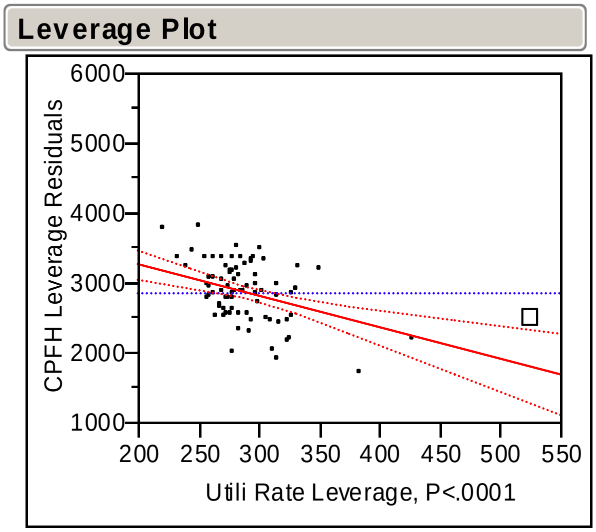
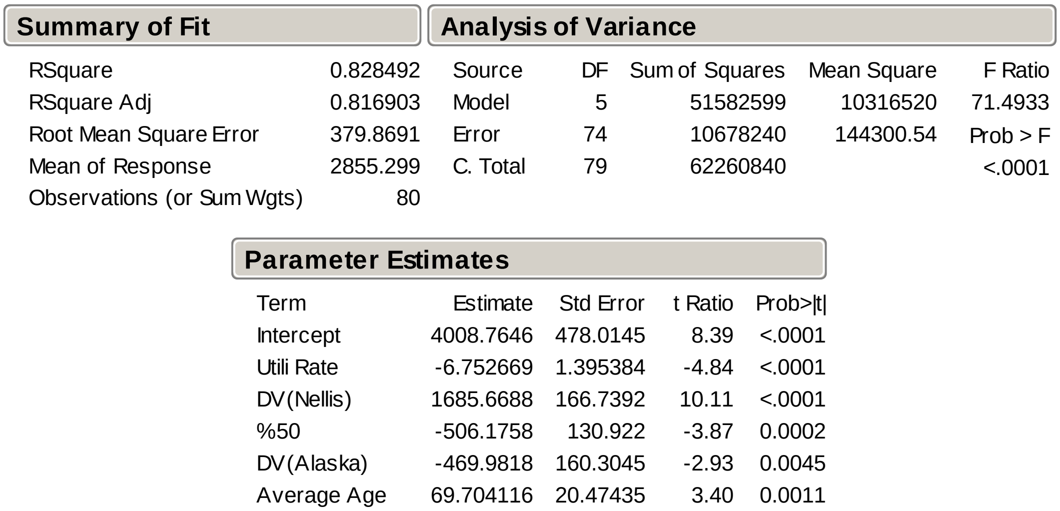


Figure 33: Leverage Plot of the Influence of Data Point on Utilization Rate
(Overly influential data point square for effect)

Now that all the overly influential and suspect data has been removed and all the predictive explanatory variables have been identified, this research presents its final model for predicting the CPFH for active duty fighter wings, denoted Model F, and displayed in Figure 34.



Summary of Fit

RSquare	0.828492
RSquare Adj	0.816903
Root Mean Square Error	379.8691
Mean of Response	2855.299
Observations (or Sum Wgts)	80

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	51582599	10316520	71.4933
Error	74	10678240	144300.54	Prob > F
C. Total	79	62260840		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	4008.7646	478.0145	8.39	<.0001
Utili Rate	-6.752669	1.395384	-4.84	<.0001
DV(Nellis)	1685.6688	166.7392	10.11	<.0001
%50	-506.1758	130.922	-3.87	0.0002
DV(Alaska)	-469.9818	160.3045	-2.93	0.0045
Average Age	69.704116	20.47435	3.40	0.0011

Figure 34: Model F, Final Model for Active Duty FWs

Notice how all the p-values significantly dropped and how the R^2 – adj climbed. Also of interest for this final model is the leverage plot of the average aircraft age explanatory variable. Recall that this variable was not significant during the one-way analysis or during the model-building with the Mt. Home data included. Now that those data points have been removed, this variable is clearly significant as seen in Figure 35.

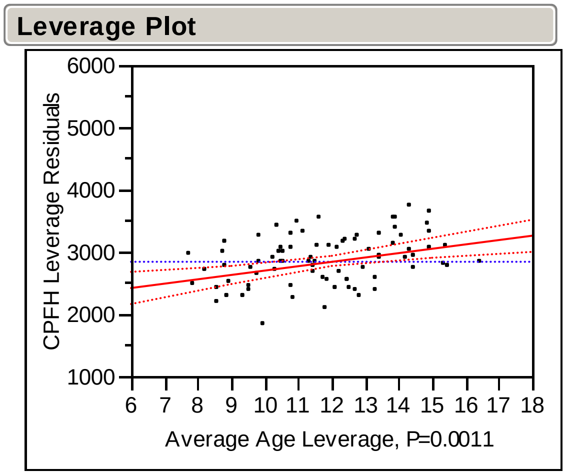
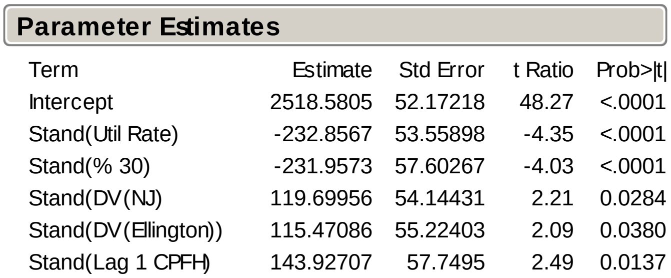


Figure 35: Leverage Plot of Average Aircraft Age in Model F

Determining the Relative Influence of Each Explanatory Variable

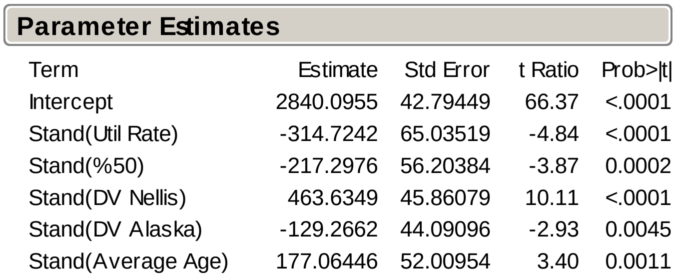
The relative influence of each explanatory variable is determined by directly comparing the magnitude of each standardized beta coefficient. Before the model is regressed, each explanatory variable is standardized. That is, the distribution of each explanatory variable is transformed such that its mean is zero and the variance is one. This process of standardization removes complications created when explanatory variables have different units. Once the response is regressed upon the standardized explanatory variables, the resulting beta coefficients are dimensionless and can be compared with one another to determine which explanatory variable is the most influential. Figures 36 and 37 present the computed standardized beta coefficients for Models E and F. Then, Figures 38 and 39 display a graphical plot of each standardized beta coefficient.



Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	2518.5805	52.17218	48.27	<.0001
Stand(Util Rate)	-232.8567	53.55898	-4.35	<.0001
Stand(% 30)	-231.9573	57.60267	-4.03	<.0001
Stand(DV(NJ)	119.69956	54.14431	2.21	0.0284
Stand(DV(Ellington))	115.47086	55.22403	2.09	0.0380
Stand(Lag 1 CPFH)	143.92707	57.7495	2.49	0.0137

Figure 36: Standardized Beta Coefficients for Model E, ANG FWs



Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	2840.0955	42.79449	66.37	<.0001
Stand(Util Rate)	-314.7242	65.03519	-4.84	<.0001
Stand(%50)	-217.2976	56.20384	-3.87	0.0002
Stand(DV Nellis)	463.6349	45.86079	10.11	<.0001
Stand(DV Alaska)	-129.2662	44.09096	-2.93	0.0045
Stand(Average Age)	177.06446	52.00954	3.40	0.0011

Figure 37: Standardized Beta Coefficients for Model F, Active Duty FWs

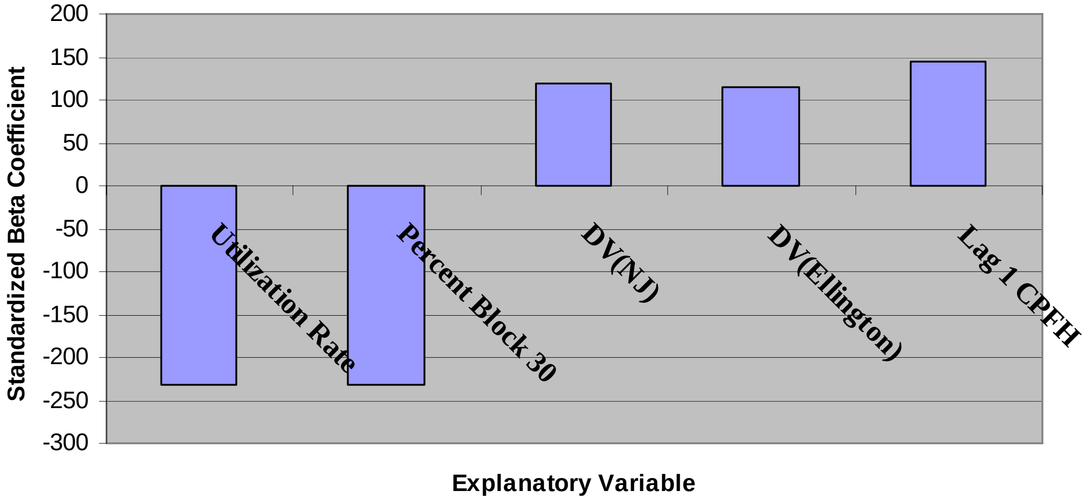


Figure 38: Relative Influence of Explanatory Variables for ANG FW’s

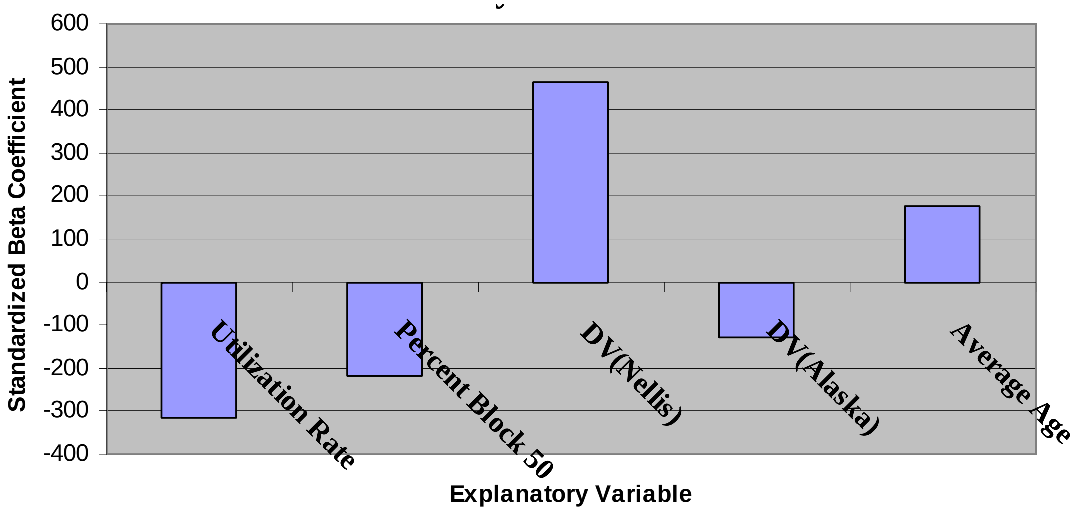


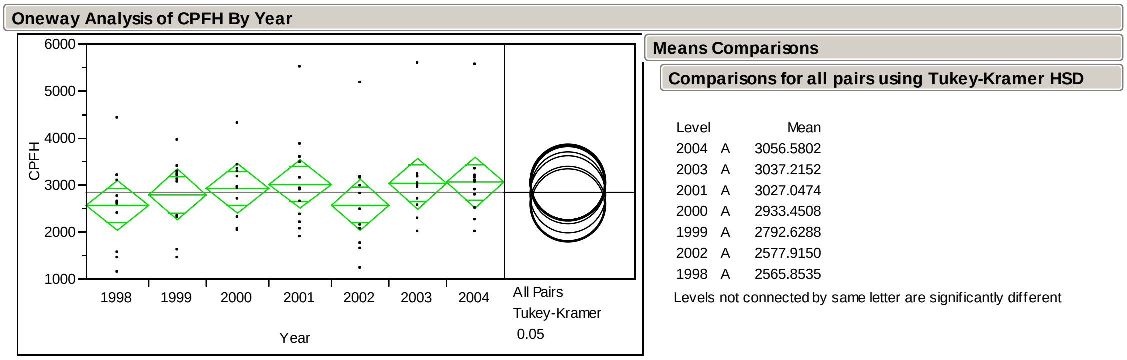
Figure 39: Relative Influence of Explanatory Variables for Active Duty FW’s

Although this research modeled ANG and active duty fighter wings separately, the relative influence of the main explanatory variables are very similar. Both Utilization Rate and Percent Block variables are negative and roughly the same when compared to one another and to the other explanatory variables. Likewise, the Average Age explanatory variable for active duty fighter wings is very similar is ANG’s Lag 1 CPFH.

This observation supports the claim that both of these variables are measuring the same effect. Also noteworthy is the magnitude of the explanatory variable DV(Nellis). More discussion is presented in Chapter 5, but this research believes that it is not the location of the base that is causing the CPFH to much larger then other bases. Rather, this research believes it is due to the fact that one of the two squadrons assigned to this base is the Air Force's demo team, the Thunderbirds.

The Year Effect

The year variable is not used in any of the models and therefore, these models are useful for any time period. Though this variable is not used, analysis of this variable yields some interesting insights. Figures 40 displays the one-way analysis of variance of the CPFH by year for all active duty fighter wings. Figure 41 duplicates this analysis only with the residuals of Model F as the response instead of the CPFH. Also in Figure 41 is Tukey's pairwise comparisons that show which years are significantly different. This is shown by the comparison circles, which is a visual display of each year's mean. This same analysis is performed using ANG fighter wings in Figures 42 and 43.



Oneway Analysis of CPFH By Year

Means Comparisons

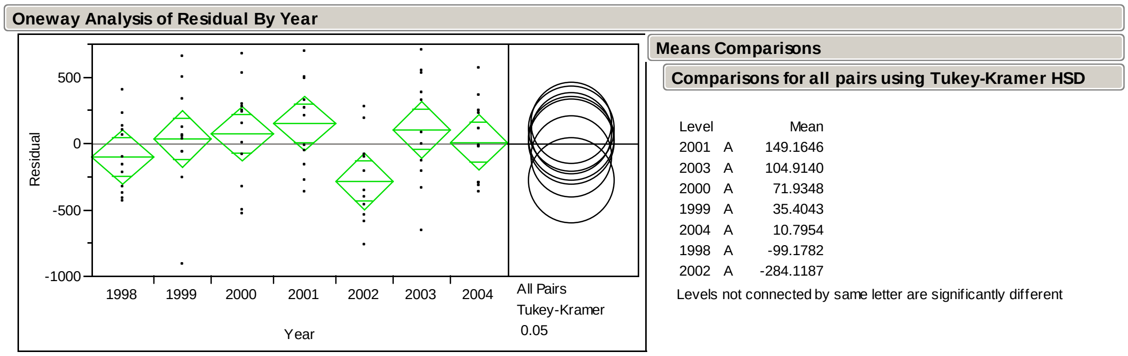
Comparisons for all pairs using Tukey-Kramer HSD

All Pairs
Tukey-Kramer
0.05

Level		Mean
2004	A	3056.5802
2003	A	3037.2152
2001	A	3027.0474
2000	A	2933.4508
1999	A	2792.6288
2002	A	2577.9150
1998	A	2565.8535

Levels not connected by same letter are significantly different

Figure 40: One-Way Analysis of CPFH by Year for Active Duty FWs



Oneway Analysis of Residual By Year

Means Comparisons

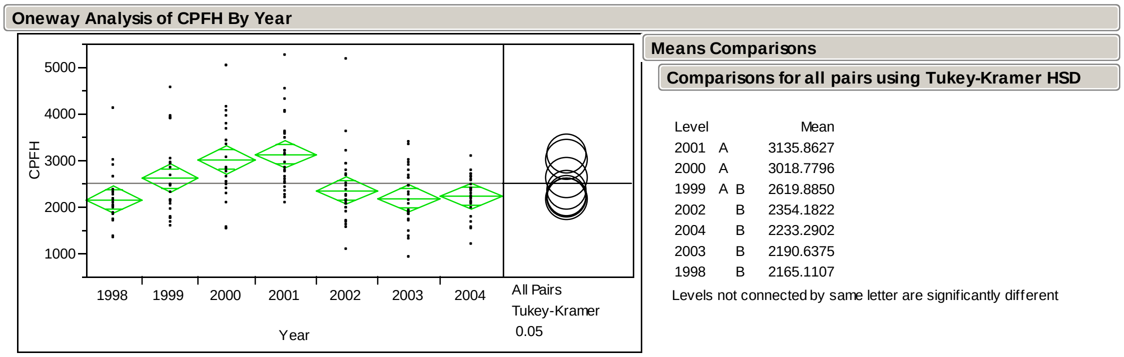
Comparisons for all pairs using Tukey-Kramer HSD

All Pairs
Tukey-Kramer
0.05

Level		Mean
2001	A	149.1646
2003	A	104.9140
2000	A	71.9348
1999	A	35.4043
2004	A	10.7954
1998	A	-99.1782
2002	A	-284.1187

Levels not connected by same letter are significantly different

Figure 41: One-Way Analysis of Model F's Residuals by Year



Oneway Analysis of CPFH By Year

Means Comparisons

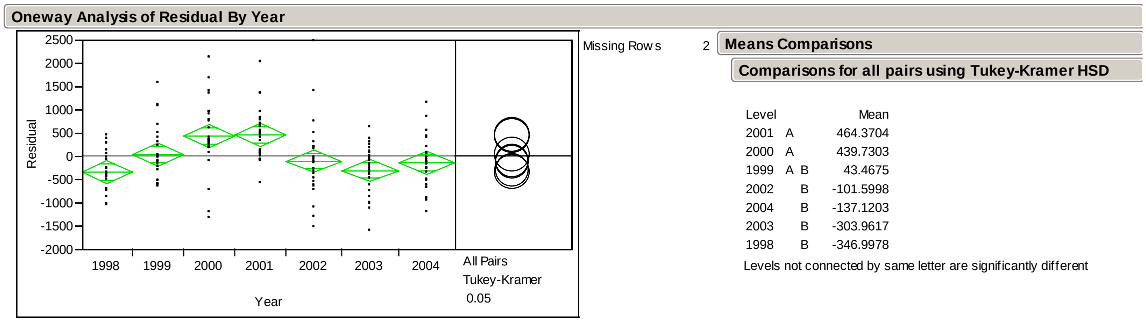
Comparisons for all pairs using Tukey-Kramer HSD

All Pairs
Tukey-Kramer
0.05

Level			Mean
2001	A		3135.8627
2000	A		3018.7796
1999	A	B	2619.8850
2002		B	2354.1822
2004		B	2233.2902
2003		B	2190.6375
1998		B	2165.1107

Levels not connected by same letter are significantly different

Figure 42: One-Way Analysis of CPFH by Year for ANG FWs



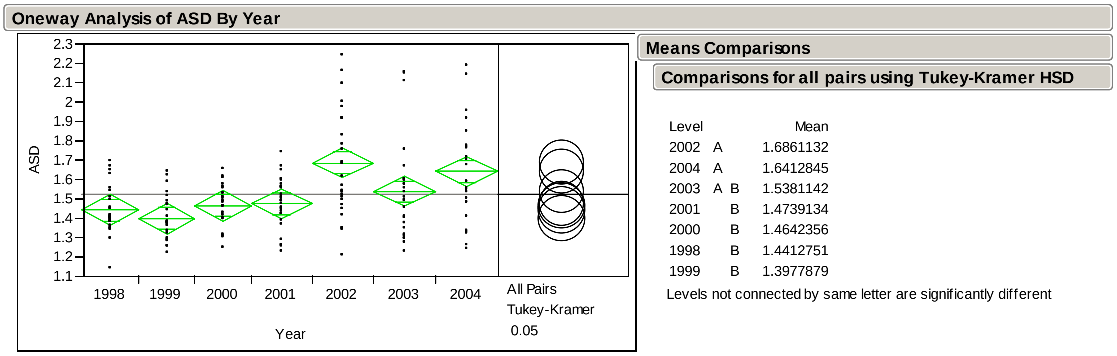
```
Missing Rows      2

Level            Mean
2001  A      464.3704
2000  A      439.7303
1999  A B     43.4675
2002    B   -101.5998
2004    B   -137.1203
2003    B   -303.9617
1998    B   -346.9978
Levels not connected by same letter are significantly different
```

Figure 43: One-Way Analysis of Model E's Residuals by Year

These figures support the claim that there is another lurking variable in both the active duty and ANG fighter wings. Additionally, this variable appears to have a stronger influence among ANG fighter wings. This research also notices that for both groups of fighter wings, there is the same general trend in both the one-way analysis of the response and the residuals. For example, among active duty fighter wings, the years 1998 to 2001 there is a general increase. Additionally, in 2002 there is a sudden drop followed by a steep increase in 2003. In both figures, the distribution goes slightly down in 2004. The same phenomenon occurs in the ANG fighter wings as well. Therefore, the mechanism that is driving this variation is not accounted for by the explanatory variables included in either model. There is at least one other variable that is significantly influencing the CPFH besides these operational and programmatic variables.

Even though the explanatory variable ASD is not significant if re-introduced back into the final model (*p*-value of 0.129 for Active duty fighter wings and 0.46 for ANG fighter wings) the changes in ASD by year appear to inversely related to the same trend seen in the both the response and residuals. Figures 44 and 45 display the changes in

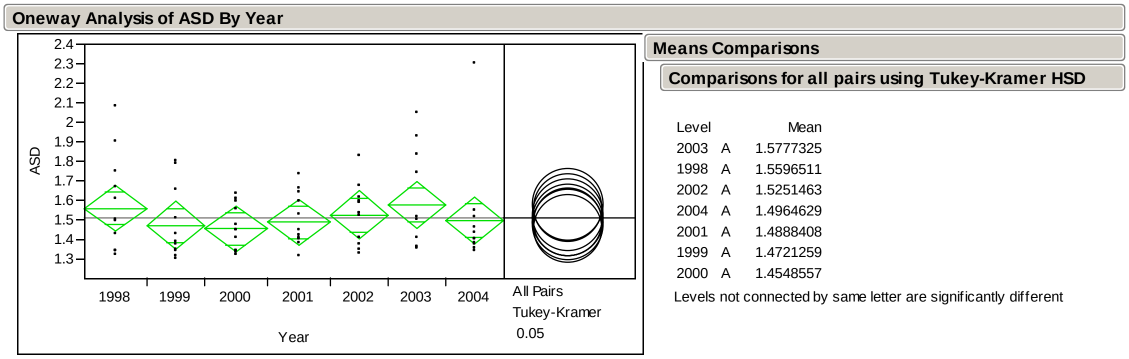
ASD by year for both active duty and ANG fighter wings along with comparison circles and Tukey's multiple comparison.



Level			Mean
2002	A		1.6861132
2004	A		1.6412845
2003	A	B	1.5381142
2001		B	1.4739134
2000		B	1.4642356
1998		B	1.4412751
1999		B	1.3977879

Levels not connected by same letter are significantly different

Figure 44: One-Way Analysis of ASD by Year for ANG FWs



Level		Mean
2003	A	1.5777325
1998	A	1.5596511
2002	A	1.5251463
2004	A	1.4964629
2001	A	1.4888408
1999	A	1.4721259
2000	A	1.4548557

Levels not connected by same letter are significantly different

Figure 45: One-Way Analysis of ASD by Year for Active Duty FWs

The similarities between Figure 44 and Figures 42 and 43 and between Figure 45 and Figures 40 and 41 are prominent, but not statistically significant. For one, these figures show that the ASD varies more from year to year in ANG fighter wings then active duty fighter wings. Even if this explanatory variable is not the culprit for the "Year Effect", these figures support the claim that major changes in mission profile occurred in 2002. Perhaps these changes in mission profile, which are correlated with ASD, caused the "Year Effect".

Reasonableness of Key Assumption

The key assumption that this research makes is that the block number that a particular F-16 has in 2004 is the same for every year going back to 1998. AFTOC is in the process of creating a database that contains the historic block number by tail number by year. Until this database is completed, analysis must be performed with this assumption.

To ensure that this is a reasonable assumption, this research excluded all the data points except for a particular year. Then, the beta coefficients were estimated for that year. This process was repeated for each year. In this manner, the significance of the block explanatory was determined independently of future years. Then, the sign and magnitude of the beta coefficient along with the statistical significance of this variable is compared across this timeframe. Table 17 presents the results of this analysis.

Table 17: Block Parameter Estimation for Both Models by Year

% Block 50 Parameter for Model F (Active Duty)				**% Block 30 Parameter for Model E (ANG)**			
Year	Beta Coefficient	Std error	p-value	Year	Beta Coefficient	Std error	p-value
1998	-1777.9	516	0.0088	1998	-549	174.5	0.0053
1999	-1190	185.6	0.0002	1999	-1175	256.98	0.0002
2000	-574.34	267.4	0.0688	2000	-713.8	381.9	0.0771
2001	-629.18	246.64	0.038	2001	-1147.39	176.25	< 0.0001
2002	-1014.26	324.1	0.0166	2002	-222.26	349.4	0.5316
2003	-459.81	353.3	0.23	2003	-418.2	221.76	0.072
2004	-571.3	291.9	0.0913	2004	23.01	189.03	0.904
Overall	-889.5	121.56	< 0.0001	Overall	-578.47	114.6	< 0.0001

This research believes this is a reasonable assumption because the *p*-values corresponding to the block variable are small for the years 1998 and 1999. If a significant percentage of the aircraft changed configurations during the past eight years, then these early years would lose their predictive ability. There is change from year to year, but the trend is that the estimated beta coefficient is significant regardless of year. Also, some years the beta is not significant. This can be partially explained by the small sample size. For example, Model F estimates six parameters with only 12 or 13 datapoints depending on the year. Therefore, one would expect these estimates and there standard error to vary dramatically.

Chapter Summary

This chapter began by performing one-way analysis on each of the explanatory variables. These results, combined with the results of previous studies covered in Chapter 2, led to the model building portion this research. It was at this point in the process key differences between ANG and active duty fighter wings were identified. The differences were severe enough to merit a separate model for each group of fighter wings.

After a separate model was built for each group of fighter wings, this chapter analyzed the residuals to ensure that none of the standard regression assumptions were violated and to check for data points that were overly influential or extreme outliers. Then, the models were validated using the 2004 test set and the beta coefficients were updated. Next, the excluded variables, such as ASD, percent deployed, and average age, were reinserted into the model to determine their significance while accounting for the effects of the main drivers. It was at this time that Lag 1 CPFH became significant for the ANG model. This variable was then included and the model was finalized. Additionally, this research noticed that Mt. Home AFB’s data points appeared to skew the results for the variable Average Age of Aircraft. These data points were removed along with one other overly influenced data point corresponding to Aviano AFB, 1999. The Average Aircraft Age variable was then included and the model was finalized.

From there, this chapter compared the standardized beta coefficients to determine the relative influence of each explanatory variable. Also, this chapter performed additional analysis on the year variable and identified an underlying trend that the explanatory variables in the model did not account for. The source of this variation remains unknown, but more analysis on the explanatory variable, ASD, showed that major changes to ASD occurred at the same time as the underlying trend. Following that analysis, this chapter analyzed the key assumption and found to be a reasonable one. Using the results presented in this chapter, this research next answers the ten investigative questions and makes recommendations for future action in Chapter 5.

V. Conclusion

Chapter Overview

This chapter integrates the results from Chapter 4 with the results of previous studies presented in Chapter 2 and answers the investigation questions presented in Chapter 1. Following that, the "Year effect" is more thoroughly discussed and possible explanations are given for the similar trend seen in both the response and the residuals when plotted by year. This chapter then summarizes its contribution to the literature and presents areas of future research.

Investigation Questions Answered

Does the CPFH of an F-16 fighter wing increase in a linearly fashion with increasing age of aircraft?

From the data analyzed in this research, there is ample evidence to support the claim that the CPFH increases with the age of the aircraft for active duty fighter wings. There is no evidence to support this claim for ANG fighter wings. The rate at which the average age of active duty aircraft results in higher CPFH is estimated by the beta coefficient that corresponds to that explanatory variable. This research estimates that for every additional year of an F-16C/D fighter wing, the expected CPFH increase is $69.7 (CY04$).

Does the CPFH of F-16 fighter wing significantly change during contingencies?

This research found no evidence to support the claim that the CPFH changes during contingencies. It did find that utilization rate is a key driver and that percent deployed and utilization rate are roughly correlated. As so far as this research is concerned, the percent deployed is not a useful variable when predicting changes in the CPFH for F-16C/D. The “Physic’s Based Model” discussed in Chapter 2 is a tool that can be used to predict O&M costs when the flying profile suddenly changes. This model does not use the fact that an aircraft is or is not deployed, but rather it uses operational characteristics, such as time of the ground, number of sorties and landings, to predict O&M costs. Therefore, the results of this variable are consistent with the literature review.

Is the CPFH of an F-16 fighter wing dependent on the previous year’s CPFH?

This research concludes that the CPFH for ANG fighter wings is linearly related to the previous year’s CPFH. This is not the case for Active duty fighter wings. The estimated slope for this explanatory variable is 0.166. This is interpreted as rate at which the previous year’s CPFH is adding to the current year’s CPFH. For example, if the previous year’s CPFH was 1000, then the current year’s CPFH would increase around 166, or 16.6%. In the opinion of this researcher, it is a significant amount.

Does the Average Sortie Duration (ASD) of an F-16 fighter wing influence that wing’s CPFH?

This research did not find any evidence to support the claim that ASD influences the CPFH of F-16C/Ds. This conclusion is in agreement with six of the seven studies identified in Chapter 2 that analyzed this variable. The one study that found ASD to be significant used transport aircraft, not fighters, in the analysis. As far as fighter aircraft go, there has yet to be a study that supports this claim.

Does the utilization rate of an F-16 fighter wing influence that wing's CPFH?

There is a strong mathematical association between increased utilization and decreased CPFH. The one-way analysis, the analysis when other variables are included, and every study covered in the literature review supports this claim. The age old adage "the more you fly, the less you break" is supported by this research and by past research.

Does the percent engine type of an F-16 fighter wing influence that wing's CPFH

Yes, but this explanatory variable is not nearly as predictive as the percent block. This may be due to the fact that there are five different types of engine in use, but this research had to combine two of the engines together due to data limitations. Furthermore, the block an aircraft has includes other technological differences, mainly different avionics. The percent engine type variable is predictive, but the information contained in this variable is already captured in the percent block variable. This can be seen in Table 16 where some of the VIF scores exceed 1,200.

Do different F-16C/D blocks have a statistically significant influence on the CPFH?

Yes, and this knowledge can be used to increase the predictive power of a model. In the opinion of this researcher, this variable is low hanging fruit because it has serious punch and it can be very accurately forecasted out.

Does MajCOM influence the CPFH for F-16 fighter wings?

The only MajCOM that significantly influences the CPFH is the ANG. The differences between this MajCOM and the other MajCOMs are stunning. Explanatory variables, such as percent block 30 and Lag 1 CPFH, are predictive for ANG fighter wings and not predictive for active duty fighter wings. Also, explanatory variables, such as percent block 50 and average aircraft age, are predictive for active duty fighter wings and not for ANG fighter wings. This research also identified how the distribution of the CPFH is different for ANG fighter wings when compared to active duty fighter wings. This researcher believes these differences are caused by the ANG fighter wings utilizing older, less advanced F-16's and flying them far less.

Does base location influence the CPFH for F-16 fighter wings?

This research believes there is ample evidence to support the claim that location of the base influences the CPFH. Eielson AFB, Alaska, has a significantly lower CPFH then the rest of the bases and the ANG base in Ellington and the ACC base in Nellis had significantly higher CPFH the rest of the bases. This researcher also notes that there were bases in hot climates that did not have a significantly higher CPFH. They are: Luke AFB in Arizona, Cannon AFB in New Mexico, Kelly ANG in Texas, and Tucson ANG in Arizona. Also, Atlantic City ANG in New Jersey had a significantly higher CPFH even though this location is not considered to have a hot climate.

This researcher also notes how much larger Nellis AFB's CPFH is relative to the rest of the explanatory variables. The beta coefficient corresponding to that dummy variable is estimated to be $1,685. This is interpreted as the amount above the rest of the fighter wings in active duty fighter wings that Nellis AFB's estimate needs to be adjusted even after taking into account all of the other explanatory variables. Therefore, this researcher believes there is something else occurring at Nellis AFB besides the hot climate that is causing this extraordinarily high CPFH. In the literature review, Sherbrooke estimated that aircraft that fly demanding training sorties had three times as many removals per sortie as long cross-country sorties. Sherbrooke's research also observed that the demand rate for A-10's at Nellis AFB was five times larger then other bases. Since Nellis AFB is site of Red Flag and other training exercises, it is very plausible that the higher CPFH is driven by these differences in mission profile. Also, the fighter wing at Nellis owns the Thunderbirds. This, too, may contribute to Nellis AFB's abnormally high CPFH.

What is the relative influence of each of these factors?

This empirical question is answered by comparing the standardized beta coefficients of each explanatory variables. Figures 38 and 39 display these results for ANG fighter wings and active duty fighter wings, respectively. In both groups of fighter wings, the percent block and utilization are both negative and carry roughly the same amount of influence on the response. Similarly, the Lag 1 CPFH for ANG fighter wings and the Average Age of Aircraft for active duty fighter wings are both positive and also carry about the same amount of influence on the CPFH.

The Year Effect

This research noticed that the trend seen when the response is plotted by year, Figures 40 and 42, is very similar to the trend in the residuals of each of the final models, Figure 41 and 43. Also of interest is the fact that the trend is definitely different between ANG fighter wings and Active duty fighter wings. Additionally, the amount of variation due to the year effect is much greater for ANG fighter wings then for active duty fighter wings. From these observations, this research makes three conclusions.

1) The explanatory variables in the model are not causing this year to year variation. If they were, then there would not be the same trend between the responses and the residuals.
2) The "Year Effect" is much more prominent among ANG fighter wings.
3) Something occurred in 2001-2002 that dramatically changed the nature of the response. This research did not identify the causal agent, but proposes two possible culprits, changes in mission profile following 9/11, and modifications to the F-16 fleet.
    a. The first possible culprit, changes in mission profile following the attacks on 9/11, is plausible because this research knows that changes in mission profile strongly affect the CPFH of F-16s. After the attacks, our nation's military transformed from a peacetime mission to a wartime mission. Additionally, this research identified one measure of mission profile, ASD, and observed two things. First, the ASD for ANG fighter wings changed much more then the ASD for active duty fighter wings during this time period. This research already concluded that the "Year Effect" is much more prominent among ANG fighter wings. Secondly, this research observed that there were major changes in ASD in 2002 for ANG fighter wings. In these fighter wings, the ASD suddenly increased while at the same time, the CPFH suddenly decreased. The active duty fighter wing's ASD stayed mostly stagnant at this time. What makes this explanation unappealing to this researcher is that the ASD is statistically significant. If changes in mission profile were the culprit, then the statistics would

support it. The p-values are not even close to being significant (*p*-value of 0.129 for active duty fighter wings and 0.46 for ANG fighter wings). Considering that each data point is a wing's annual expenditures and that this research analyzes 40 of 44 Air Force active duty FWs from 1998 to 2004, the analysis would have detected a difference if one were present.

b. The second possible culprit is modifications to the F-16 fleet. This explanation is attractive because this research quantified how percent engine type and percent block influence the CPFH of the F-16. Knowing that these programmatic variables are significant and understanding that the Air Force is constantly performing Time Change Technical Orders on aircraft, it very plausible that this variable is the culprit. In the literature review, Raymond Pyles of the RAND Corp. noted that there were not any studies on the effect of modifications on material consumption cost. The fact there has been so little research on this topic leads this researcher to include it as a possible culprit.

Significance of Research

This research accomplished three goals: it identified and quantified variables that influence the CPFH of F-16, it built a model to predict the CPFH for F-16, and it identified the presence of a lurking variable, titled the "Year Effect". First, it identified and quantified variables that influence CPFH. The variables that most influence the CPFH of the F-16 are: ANG/Active duty, Percent Block, Utilization Rate, Base, Lag 1 CPFH (for ANG fighter wings) and Average Aircraft Age (for active duty fighter wings).

Secondly, this research built a predictive model for both ANG and active duty fighter wings. These models were then used to determine the relative contribution of each explanatory variable. Finally, this research identified a lurking variable that the explanatory variables investigated did not account for. Two possible explanations were given: changes in mission profile following the 9/11 attacks and modifications to the F-16 fleet.

Recommendations for Future Research

This research recommends three important areas of future research.

1) Further identification of explanatory variables to include more emphasis on economic, mission profile, and modification variables. Eventually, these lead to identifying what is causing the “Year Effect”. Although this research did contribute to our current understanding between CPFH and operational variables, it did not fully exhaust all of the operational variables. Additionally, this research did not consider economic variables that also may significantly influence the CPFH.
2) Further investigation to explain why Mt. Home AFB behaved so differently. This entire base was removed from analysis because it overly influenced the analysis. The reason why this occurred is unclear. Two possible explanations exist. First, this research may have received erroneous data from the two sources or this research may have accidentally corrupted the database creation process. Since human interaction is heavily involved in every step, this explanation seems plausible. Secondly, this data from Mt. Home AFB could

be accurate. In this case, this research would have less justification to remove it, but removing it may still be acceptable. The purpose of building a model is to predict the average response. Since Mt. Home AFB data was so atypical, this research would not want to model this atypical response. Furthermore, in this case, a separate methodology may have to be generated to predict the CPFH of that base.

3) Determine if using CPFH factors is the best way to budget for O&M expenditures. The current process of using of factors to develop budgets presumes that hours flown is directly proportional to costs. This assumption is testable. Two important research questions for this topic include:
    a. Are there any fixed costs associated with DLRs?
    b. Is a wing's annual DLR expenditure a function of number of hours flown? In other words, is this relationship best described as linear, quadratic, exponential, etc?

Thesis Summary

This thesis investigated the predictive capability of nine operational and programmatic variables on the CPFH for F-16C/Ds by examining data from 40 Air Force fighter wings from 1998 to 2004. This research contributed new information regarding the influence of the explanatory variables: percent block, percent engine type, percent deployed, and lag 1 CPFH. Furthermore, this research re-affirmed the influence of known explanatory variables such as base, utilization rate, and ASD. Unlike past research, this research quantified the relative influence of each of these explanatory variables. Also noteworthy, this research identified an underlying trend and determined which variables were not causing the variation as well proposing two possible causes. In closing, this research presents two models to predict the CPFH for F-16 fighter wings and a methodology for analysts to use when developing models for other airframes.

Appendix

Appendix A: Change in Maintenance Write-Ups per Mission Code for the Fire Control System of the F-4

Mission Code	Oberserved Write-Ups	Expected Writed-Ups	(Obs - Exp)^2	Chi-Square Statistic
ADIX	244	157.03	7563.78	48.17
ACTX	87	32.66	2952.84	90.41
AGXX	976	1011.23	1241.15	1.23
DACT	152	91.09	3710.03	40.73
FCFX	53	57.99	24.90	0.43
LCLX	68	118.11	2511.01	21.26
NPXC	71	93.78	518.93	5.53
PROF	71	77.94	48.16	0.62
MISC	78	163.67	7339.35	44.84
RNAG	41	36.06	24.40	0.68
RGAT	35	39.6	21.16	0.53
NAGX	77	78.51	2.28	0.03
ACMX	76	66.06	98.80	1.50
A119	30	35.92	35.05	0.98
DAGX	55	54.18	0.67	0.01

Appendix B: Data Set 5, Contingency Mission Symbols with Description

MSN SYM	Description
01AF	COMBAT
01AG	ANG
01CA	COMBAT, CREDIT AMC = COMBAT MSN NORTHERN WATCH
01CG	COMBAT
01DW	COMBAT SORTIES(ACC FIGHTER/BOMBER) ENDURING FREEDOM
01EW	COMBAT SORTIES(ACC AIR REFUELING) ENDURING FREEDOM
01FW	COMBAT SORTIES ENDURING FREEDOM (ALL OTHERS)
01GD	COMBAT SUPPORT
01GG	COMBAT
020N	ONW COMBAT SUPPORT (Operation Northern Watch)
020R	970 COMBAT SUPPORT
020S	OSW COMBAT SUPPORT (Operation Southern Watch)
02AD	DENY FLIGHT OVERWATER MISSION (ETTF)
02AG	COMBAT SUPPORT - SPT OF FRIENDLY FORCES IN ARMED CONF.
02CA	AMC = COMBAT SUPPORT MSN NORTHERN WATCH
02DF	DELIB GUARD/PHONE DUKE ANG CBT SPT REF/DUAL
02DG	DELIB GUARD/PHONE DUKE ANG CBT SPT AIRLIFT
02DW	COMBAT SUPPORT SORTIES OEF ACC FIGHTER/BOMBERS (Operation Enduring Freedom)
02EK	ONW SORTIES (Operation Northern Watch)
02EW	COMBAT SUPPORT SORTIES OEF ACC AIR REFUELING/SURV
02FW	COMBAT SUPPORT SORTIES OEF ALL OTHERS
02MR	ONW RESERVE OPS
02NL	COMBAT SUPPORT SW SORTIE--ACC (Southwest Asia)
02TA	COOP ASSOCIATE 03 - ACTIVE IF TF CA
02WC	AIR-OPS
A50A	POSITIONING/DEPOSITIONING
A50R	POSITIONING/DEPOSITIONING
A5AR	ACFT POSITIONING/REPOSITIONING
A5BA	AMC REPOSITION/DEPOSITION--C37A
A5NB	DEPLOYMENT
A5ND	DEPLOY TO OPERATION LOCATION
A5NR	REDEPLOY FROM OPERATION LOCATION
A5NU	USAFE REFUELING/AIRLIFT DEPLOY/REDEPLY
A5NV	USAFE TANKER REFUELING/DUAL ROLE
A76A	PROVIDE COMFORT SORTIE
A78A	SPECIAL MISSION
A78S	DESERT SHIELD
A79A	KC135 RIYADH SORTIES
A79B	DESERT STORM
A79G	KC135 RIYADH SORTIES
A79K	OPERATIONAL MISSION
A79R	DESERT SHIELD RECON SUP
A7BN	DEPLOYMENT/REDEPLOYMENT SORTIE
A7DA	KC135 RIYADH DEPLOYMENT AND ACC DEPLOYER/REDEPLOYER 03
A7DF	ACC--DELIBERATE FORGE (BOSNIA/BALKINS)
A7DG	KC135 RIYADH DEPLOYMENT (GUARD)
A7DS	AFSOC -- OEF
A7GA	DESERT TIME
A7GW	DESERT SHIELD FLYING TIME
A7RA	KC135 RIYADH REDEPLOYMENT (ACTIVE)
A7RG	KC135 RIYADH RE-DEPLOYMENT (GUARD)
A7RR	KC135 RIYADH REDEPLOYMENT (RESERVE)
A7YA	SW ASIA / DESERT HOURS
A7ZG	OTHER DESERT SHIELD

MSN SYM	Description
A80A	970HHQ CONTINGENCY
A80R	970HHQ CONTINGENCY
A8CU	CONTINGENCY OPERATIONS/USAFE AIRLIFT
A8DA	970HHQ CONTINGENCY
c2cg	NORTHERN WATCH
N8CA	PROVIDE COMFORT 90/91/92/93/94/95 (KURDISTAN)
N8CR	PROVIDE COMFORT 90/91/92/93/94/95 (KURDISTAN)
O1%	COMBAT
o10a	Combat
O10G	COMBAT MISSIONS
O10L	COMBAT - SWA
O10M	COMBAT - ONW
O10N	COMBAT - OJG (Operation Joint Guardian)
O10Z	01 & 02 MSG R021922Z JAN 96--BOSNIA/HERTZAGOVINA
O11A	COMBAT, CREDIT HOSTILE ACTIVITY
O11D	COMBAT
O1A0	COMBAT TIME
O1AA	COMBAT, CREDIT HOSTILE ACTIVITY
O1AD	DENY FLIGHT OVERLAND MISSION (ETTF)
O1AF	COMBAT
O1AG	COMBAT MISSION (DIRECT HOSTILE FIRE)
O1AJ	COMBAT, CREDIT HOSTILE ACTIVITY
O1AK	OP JOINT GUARDIAN -COMBAT ZONE
O1AL	COMBAT, CREDIT SWA
O1AM	COMBAT (ETTF)
O1AN	OP NORTHERN WATCH - NO FLY OPERATIONS
O1AO	COMBAT TIME
O1AR	COMBAT, CREDIT
O1AW	DESERT TIME
O1BA	COMBAT SUPPORT
O1BG	PROVIDE COMFORT II (PCII)
O1BK	COMBAT OPS RECON ODF
O1BL	SWA COMBAT SORTIE (Operation Southwest Asia)
O1BW	DESERT TIME
o1cf	NOTHERN WATCH - ANG COMBAT MISSION (REFUEL/ DUAL ROLE)
O1DK	OEF COMBAT SORTIE
O1DW	OEF COMBAT MISSION ANG JSTARS (03)
o1ef	ENDURING FREEDOM (CBT SPT) - ANG TANKER TWCF MISSION
O1EU	COMBAT ENDURING FREEDOM RC135U
O1GA	COMBAT OPERATION SOUTHERN WATCH
O1GD	COMBAT SUPPORT
O1GG	COMBAT
O1HA	COMBAT ONW NO FLY OPERATIONS
O1IG	JOINT GAURDIAN/JOINT FORGE
O1JB	JOINT FORGE - AMC COMBAT MISSION (REFUEL/ DUAL ROLE)
O1LA	COMBAT
O1LR	COMBAT SWA (RC135)
O1NL	SWA COMBAT SORTIE
O1OA	DESERT STORM
O1OM	COMBAT OPERATION NORTHERN WATCH
O1PA	PROVIDE COMFORT
O1PB	AEF
O1PG	COMBAT
O1SF	ANG-PID103ID OPNS-TNKR TWCF,FTR,AFSOC,RESQ,JSTARS COMB
O1VA	COMBAT
O1WD	COMBAT SORTIES(ACC FIGHTER/BOMBER) ENDURING FREEDOM
O1XM	COMBAT (100 ARF)
O1ZF	COMBAT MISSION DESERT SHIELD
O1ZG	COMBAT MISSION DESERT SHIELD
O1ZH	COMBAT MISSION DESERT SHIELD
O1ZY	COMBAT MISSION DESERT SHIELD

MSN SYM	Description
P10A	PROVIDE PROMISE
P1GA	PROVIDE COMFORT
P1QG	PROVIDE PROMISE - AIR NATIONAL GUARD ONLY
P1TR	AFR UE JOINT FORGE - DEP - USAFE FUNDED
P1UR	AFR UE JOINT FORGE - EMP - USAFE FUNDED
P1VR	AFR UE JOINT FORGE - REDEP - USAFE FUNDED
P20A	AFSOC--NOBLE EAGLE
P2AS	OPERATION NOBLE EAGLE
P2BD	NOBLE EAGLE MSCA SPT NY - AFR ASSOC DEPLOYMENT MISSION
P2BF	NOBLE EAGLE MSCA SPT NY - AFR ASSOC REDEPLOYMENT MSN
P2BX	PACOM--AFR--NOBLE EAGLE ASSOC ALFT TWCF MSN CA
P2D0	OPERATION NOBLE EAGLE (FIGHTERS)
P2DO	OPERATION NOBLE EAGLE
P2EO	NOBLE EAGLE --ACC
P2ER	OPERATION NOBLE EAGLE (RESERVES)
P2JA	OPERATION NOBLE EAGLE
P2KA	OPERATION NOBLE EAGLE
P2KZ	OPERATION NOBLE EAGLE
P2PA	RESTORE HOPE
P3IC	NORTHERN WATCH DEPLOY/REDEPLOY
P3QA	PROVIDE COMFORT
P3TR	AFR UE - NORTHERN WATCH DEP - USAFE FUNDED
P3UR	AFR UE - NORTHERN WATCH EMP - USAFE FUNDED
P3VR	AFR UE - NORTHERN WATCH REDEP - USAFE FUNDED
P4DA	OPERATION SOUTHERN WATCH (DESERT STORM)
P4DK	OPERATION SOUTHERN WATCH (DESERT STORM)
P4EA	OPERATION SOUTHERN WATCH (DESERT STORM)
P4EK	OPERATION SOUTHERN WATCH (DESERT STORM)
P4FA	OPERATION SOUTHERN WATCH (DESERT STORM)
P4GA	OPERATION SOUTHERN WATCH/AVIANO AB OR RAF LAKENHEATH
P4GN	OP NORTHERN WATCH - TRAINING FLIGHTS
P4QG	SOUTHERN WATCH - AIR NATIONAL GUARD ONLY
P4RA	SOUTHERN WATCH
P50D	DENY FLIGHT
P5DA	DENY FLIGHT
P5DC	DENY FLIGHT
P5GD	OPERATION DENY FLIGHT (USAFE)
P5GP	DENY FLIGHT (PISA)
P5IA	OPERATION DELIBERATE FORCE/LAKENHEATH
P5ID	OPERATION DENY FLIGHT
P5QG	DELIBERATE GUARD/DECISIVE GUARD (PISA)
P7AL	ENDURING FREEDOM (SWA) SORTIES
P7AM	ENDURING FREEDOM (ONW) SORTIES
P7D0	OPERATION ENDURING FREEDOM (FIGHTERS/BOMBERS)
P7DA	ENDURING FREEDOM FIGHTER/BOMBERS
P7DO	"OPERATION ENDURING FREEDOM"
P7EC	"OPERATION ENDURING FREEDOM" (552 WING)
P7F0	OPERATION ENDURING FREEDOM (ALL OTHERS)
P7FA	ENDURING FREEDOM ALL OTHERS SORTIE
P7JA	ENDURING FREEDOM
P7JC	USAFE FIGHTER OPS -- OEF (OPERATION ENDURING FREEDOM)
P7JT	USAFE--OPERATION ENDURING FREEDOM (TNG SORTIES)
P7JZ	ENDURING FREEDOM
P7KA	OPERATION ENDURING FREEDOM
P7KJ	OPERATION ENDURING FREEDOM
p8aa	OEF I--ACTIVE TANKER MSN(P&M)
P8DC	ACC--OPERATION IRAQI FREEDOM (OIF) FIGHTER/BOMBER
P8DO	ACC--OPERATION IRAQI FREEDOM (OIF)--FTR/BOMBER
P8DS	ACC--OPERATION IRAQI FREEDOM(OIF) FIGHTER/BOMBER
P8FC	ACC--OPERATION IRAQI FREEDOM(OIF)ALL OTHER AIRCRAFT
P8FO	ACC--OPERATION IRAQI FREEDOM(OIF)--ALL OTHER AIRCRAFT
P8FS	ACC--OPERATION IRAQI FREEDOM(OIF)--ALL OTHER AIRCRAFT

MSN SYM	Description
P8JC	USAFE FIGHTER OPERATIONS--OPERATION IRAQI FREEDOM(OIF)
P8JE	AFE--OPERATION ENDURING FREEDOM IRAQ (OEF-I)
P8JR	AFE--OPERATION IRAQI FREEDOM (OIF)
P8JT	USAFE--OPERATION IRAQI FREEDOM (TNG SORTIES)
P8JZ	USAFE--OIF
P8UR	OIF EMPLOYMENT--AFR
P8VR	OIF REDEPLOYMENT--AFR
P91K	ALLIED FORCE
P9AA	JOINT ENDEAVOR
P9DA	JOINT ENDEAVOR
P9GE	DELIBERATE GAURD DEPLOY/REDEPLOY/NONOPERATIONAL SORTIE
P9IB	USAFE--JOINT GUARDIAN (BOSNIA)
P9IK	USAFE--OPERATION JOINT GUARDIAN (KOSOVO)
P9PA	IN SUPPORT OF OPERATION JOINT ENDEAVOR
P9TR	CONTINGENCY
P9UR	CONTINGENCY
P9VR	CONTINGENCY
S5GG	NOBLE EAGLE - ANG SPECIAL MISSION SUPPORT
S5GR	NOBLE EAGLE - AFR SPECIAL MISSION SUPPORT

Appendix C: MajCOM-MDS Specific Conversion Factors for DLRs

Year	MAJCOM	1999	2000	2001	2002	2003	2004
1998	ACC	1.1323	1.2799	1.2114	1.4016	1.5385	1.7789
1998	AETC	1.3404	1.2013	1.4061	1.7125	1.8021	1.9299
1998	ANG	1.2060	1.2475	1.3022	1.5457	1.7010	1.8370
1998	PACAF	1.2337	1.3650	1.3657	1.5244	1.6514	2.0141
1998	USAFE	1.1371	1.3667	1.2876	1.4353	1.5977	1.8721
1999	ACC	0.0000	1.1527	1.1550	1.2630	1.3602	1.5935
1999	AETC	0.0000	0.9727	1.1739	1.3403	1.3804	1.5425
1999	ANG	0.0000	1.0028	1.1247	1.2976	1.3745	1.5095
1999	PACAF	0.0000	1.1211	1.1772	1.2715	1.3785	1.6788
1999	USAFE	0.0000	1.2258	1.2315	1.3584	1.5076	1.7109
2000	ACC	0.0000	0.0000	0.9954	1.0877	1.1969	1.3515
2000	AETC	0.0000	0.0000	1.0173	1.0815	1.3914	1.4790
2000	ANG	0.0000	0.0000	1.0406	1.2014	1.3917	1.4092
2000	PACAF	0.0000	0.0000	1.0531	1.1265	1.2490	1.4559
2000	USAFE	0.0000	0.0000	1.0081	1.1066	1.3038	1.4269
2001	ACC	0.0000	0.0000	0.0000	1.1022	1.1769	1.3362
2001	AETC	0.0000	0.0000	0.0000	1.1573	1.1909	1.3114
2001	ANG	0.0000	0.0000	0.0000	1.1565	1.2611	1.3401
2001	PACAF	0.0000	0.0000	0.0000	1.0963	1.1996	1.4437
2001	USAFE	0.0000	0.0000	0.0000	1.1062	1.2521	1.4041
2002	ACC	0.0000	0.0000	0.0000	0.0000	1.0364	1.1796
2002	AETC	0.0000	0.0000	0.0000	0.0000	1.0328	1.1458
2002	ANG	0.0000	0.0000	0.0000	0.0000	1.0350	1.1587
2002	PACAF	0.0000	0.0000	0.0000	0.0000	1.0231	1.2640
2002	USAFE	0.0000	0.0000	0.0000	0.0000	1.0610	1.2189
2003	ACC	0.0000	0.0000	0.0000	0.0000	0.0000	1.1915
2003	AETC	0.0000	0.0000	0.0000	0.0000	0.0000	1.0655
2003	ANG	0.0000	0.0000	0.0000	0.0000	0.0000	1.1229
2003	PACAF	0.0000	0.0000	0.0000	0.0000	0.0000	1.2051
2003	USAFE	0.0000	0.0000	0.0000	0.0000	0.0000	1.1470

Appendix D: Estimated Percent Block for ANG and Active Duty FWs from 1998 to 2004

	ANG	Active Duty
Block 25	24.7%	4.1%
Block 30	52.0%	10.6%
Block 32	2.4%	2.9%
Block 40	2.0%	42.3%
Block 42	14.6%	7.1%
Block 50	0.0%	25.1%
Block 52	3.9%	7.9%

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14. ABSTRACT

This research analyzes operational and programmatic data from all Air National Guard and 13 of 14 active duty F-16C/D Fighter Wings (FW) from 1998 to 2004 in search of explanatory variables that influence a wing's Cost Per Flying Hour (CPFH). Using data from both the Air Force Total Ownership Cost database and from the Air Force Knowledge Systems database, this research evaluates the predictive ability of the following nine explanatory variables: aircraft age, average sortie duration, MajCOM, base location, utilization rate, percent engine type, percent block, percent deployed, and previous year's CPFH, the last four of which were previously untested. Additionally, this research builds regression models that accurately predict the CPFH of an F-16C/D FW using these operational and programmatic variables. This research concludes that the following variables are highly predictive and quantifies the relative influence of each of these variables: utilization rate, base location, percent block, percent engine type, average age of aircraft, and the previous year's CPFH. Finally, this research identifies a lurking variable and proposes two possible explanations.

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