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DISSERTATION

Aircraft Modifications

Assessing the Current State of Air Force Aircraft Modifications and the Implications for Future Military Capability

Owen J. Hill

This document was submitted as a dissertation in September, 2006 in partial fulfillment of the requirements of the doctoral degree in public policy analysis at the Pardee RAND Graduate School. The faculty committee that supervised and approved the dissertation consisted of Richard J. Hillestad (Chair), James N. Dertouzos, and Gregory G. Hildebrandt.

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Preface

The research presented in this dissertation began as a part of a study examining the costing of modifying Air Force weapon systems. Over the same time that the concept for this dissertation was evolving, the Air Force leadership has directed a significant amount of funding to research the past and present state of aircraft modifications with the goal of developing good modification policies for the Air Force in the 21st century.

This increased emphasis from Air Force leadership also helped reveal the complexity of the current modification policy. Therefore, the goal of this dissertation is two-fold: First, it is to describe the current policy in a succinct yet thorough manner; second, it is to use this understanding to direct the quantitative analysis in an attempt to refine future policy to better serve Air Force needs. This dissertation should aid future analysis in that it lays some of the groundwork for a comprehensive understanding of one important facet of the Air Force aircraft modernization effort.

This research should be of interest to policy planners and analysts of force planning and modernization. The project documented here was conducted within the *Costing of Modifications and Upgrades* program of RAND's Project AIR FORCE.

Project AIR FORCE

Project AIR FORCE (PAF), a division of RAND, is the Air Force's federally funded research and development center for studies and analyses. PAF provides the Air Force with independent analyses of policy alternatives affecting the development, employment, combat readiness, and support of current and future aerospace forces. Research is performed in four programs: Aerospace Force Development; Manpower, Personnel, and Training; Resource Management; and Strategy and Doctrine.

Additional information about PAF is available on our Web site at http://www.rand.org/paf.

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List of Acronyms

ABIDES	Automated Budget Interactive Data Environment System
ACC	Air Combat Command
AF EEIC	Air Force Element of Expense Investment Codes
AFMC	Air Force Material Command
AFTOC	Air Force Total Ownership Cost
ALC	Air Logistic Center
ANG	Air National Guard
APB	Acquisition Program Baseline
Appropriation 3010	Aircraft Procurement
Appropriation 3011	Ammunition Procurement
Appropriation 3020	Missile Procurement
Appropriation 3080	Other Procurement
Appropriation 3400	Operations and Maintenance (O&M)
Appropriation 3600	RDT&E
ASP	Acquisition Strategy Panel
AST	Acquisition Support Team
BA	Budget Authorization
BA 5	Budget Activity 5 "Modifications of Inservice Aircraft"
BAA	Backup Aircraft Authorization
BAC	Budget Activity Code
BAI	Backup Aircraft Inventory
BDSS	Budget Documentation Support Systems
BES	Budget Estimation Submission
BP	Budget Program
BP 11	Aircraft Modification Procurement
BP 21	Missile Modification Procurement
BPAC	Budget Program Account Code
CAIG	Cost Analysis Improvement Group
CAIG - 6.2	Modification Kit Procurement/Installation
CCB	Configuration Control Board
CDD	Capabilitt Development Document
CLC	Congressional Line Code
COTS	Commercial Off the Shelf
CPFH	Cost per Flying Hour
CRB	Configuration Review Board
DAES	Defense Acquisition Executive Summary
EA	Evolutionary Acquisition

List of Acronyms

ECP Engineering Change Proposal
EDM Engineering Development Module
EO Engine Overhaul
FAA Federal Aviation Administration
FAMS Fuel Automated Management System
FH Flying Hour
FOA Field Operating Agency
FRP Full Rate Production
ICD Initial Capabilities Document
IDECS Integrated Budget Documentation and Execution System
IDOCS Investment Budget Documentation System
IMMP Integrated Modification Management Plan
IMP Integrated Master Plan
IMS Integrated Master Schedule
IPT Integrated Product Team
LRIP Low-Rate Initial Production
MAJCOM Major Command
MAP Military Assistance Program
MD Mission Design
MDA Milestone Decision Authority
MDS Mission Design Series
MIP Material Improvement Project
MMH Maintenance Man-Hours
MNS Mission Need Statement
MSE Mean Squared Error
MSO Mission Support Office
MTBF Mean-time-between failure
O&M Operations and Maintenance
O&S Operations and Support
OLAP On-Line Analysis Processing (AFTOC Excel Database Interface)
OSS&E Operational Safety, Suitability, & Effectiveness
PA Program Authorization
PAA Preliminary Aircraft Assigned
PAI Primary Aircrafy Inventory
PB Presidential Budget
PBR Presidential Budget Request
PCO Procurement Contracting Officer
PEC Program Element Code

List of Acronyms

PEM	Program Element Monitor
PGM	Product Group Manager
PMD	Program Management Directive
POM	Program Objective Memorandum
RCM	Requirements Correlation Matrix
RDT&E	Research, Development, Test, and Evaluation
REMIS	Reliability and Maintainability Information System
ROI	Return on Investment
ROM	Rough Order of Magnitude
RR	Ready Reserve
SAF/AQ	Air Force Assistant Secretary for Acquisition
SAF/AQXR	Air Force Assistant Secretary for Acquisition, Program Integration Division
SAMP	Selected Acquisition Management Plan
SDD	System Development and Demonstration
SEP	Systems Engineering Plan
SM	Single Manager
SPD	System Program Director
SPO	System Program Office
TAI	Total Aircraft Inventory
TCTO	Time Compliance Technical Order
TDS	Technology Development Strategy
TEMP	Test and Evaluation Master Plan
TMS	Type Mission Series
TOA	Total Obligation Authority
TWCF	Transportation Working Capital Fund
WBS	Work Breakdown Structure
WPC	Work Performance Code
WSC	Weapon System Code
WSCRS	Weapon System Cost Retrieval System

Acknowledgements

RAND Project Air Force has provided generous support for this research through the *Costing of Modifications and Upgrades* study under the leadership of Obaid Younossi. In addition, the Air Force Institute of Technology has made this research possible through their sponsorship of the Pardee RAND Graduate School and Air Force Academy scholarship program.

This research would not be possible without the data support from IDECS. Michelle Sims, Keith Lymore, and Derrick Nicely all provided much needed assistance and insight into using the data they had provided. Jim Brunick at Lockheed and Rob Leonard at RAND both provided invaluable data for my analysis. Captain Eric Hawkes and Scott Adamson of the Air Force Cost Analysis Agency also provided important insights and direction for this research. Additionally, I am grateful to Brian Maue, Tom Lang, Mike Egner, Ed Keating, Dan Norton, and Mark Dawson for their contributions to my work and life in my time at RAND.

I am particularly grateful to my committee members for their accommodation, direction, and timely inputs. Dick Hillestad and Jim Dertouzos, thank you for your pivotal roles in helping me finish and meet my deadline. My outside reader, Chip Franck, was very kind to provide feedback within a tight time constraint; thank you for your comments and insight. Project Air Force, headed by Natalie Crawford, made completion a possibility in the first place. I am grateful for Bart Bennett's genuine concern for my success as my advisor. Alex Duke's contribution in the area of history, cycling, and friendships was invaluable—particularly because it had nothing to do with my dissertation topic. Finally, my wife Emily and son Kaiden were both the best support emotionally as well as the greatest distraction over the course of this program; I do not doubt that such apparently opposing contributions are inseparable.

The one name that I specifically have not mentioned yet belongs to the single most valuable contributor, not only for this dissertation, but also for my entire Air Force career. Even in the limited experience that I have, I am convinced beyond a doubt that there will never be one to compare with his impact in my life. His direction, motivation, support, insight, selflessness, generosity, personal concern, and tireless feedback have transformed me personally from a Lieutenant and college graduate to an Air Force Officer and critical thinker. I say this not to exalt myself, but to highlight the significance and potential impact of one dedicated individual. Air Force policy issues will come and go, and there is no dearth of intelligent men and women who will make valuable contributions to the future of policy. Without belittling the needed contribution of such policy analysts, I see now that a far more valuable contribution comes from such individuals who take a personal interest in the training, education, maturity, and indeed success of others, regardless of the costs to personal output. For his personal and selfless investment in my life, I am sincerely grateful for the opportunity to have worked with Greg Hildebrandt. Greg, My thanks for your contribution and impact to my life can not be expressed in words.

Despite the wealth of support and input that I have enjoyed in the process of researching this dissertation, any mistakes or discrepancies that are found herein are entirely the faults of the author.

Summary

The purpose of this dissertation is to expand the analysis of aircraft modifications to include an aggregate perspective of all recent modifications. The objective is to formulate good policy in order to help direct the future of modernization within the Air Force. Specifically, it will use a dataset constructed during this thesis describing all aircraft modifications from the years 1996 through 2005 to examine the impact of aging on modifications costs, the efficiency of procurement and installation planning, the implementation of safety modifications, and some expectations for the future of aircraft modifications. This summary will state the four research questions addressed in this dissertation as well as a brief explanation of the methods and conclusions related to each question.

What are the historical trends that have preceded the present environment for aircraft modifications in the Air Force? Changing circumstances are a common occurrence for the United States military. For the Air Force in particular, things are changing in such a way that demands a response from the organizational structure. These changes include: new aircraft, a new standard of evolutionary acquisition, and aging aircraft. Each of these changes indicates that the Air Force modification policy will be increasingly important in the future.

New Aircraft - Cost and schedule overruns have hampered the ability of the Air Force to procure next-generation aircraft in support of modernization efforts. Reductions in planned replacement aircraft for existing aircraft necessitate the use of the legacy aircraft for longer periods of time. If the Air Force is to continue to improve capability and remain the world's most advanced air force, then aircraft modifications for these legacy aircraft will necessarily play an increasingly important role.

Evolutionary Acquisition - For the replacement aircraft that are being procured for the Air Force, there is a new acquisition method that also serves to increase the importance of future aircraft modifications. This new method of acquisition has been termed evolutionary acquisition. Evolutionary acquisition is intended to partition new acquisitions into categories of increased capability. This results in a heterogeneous fleet of aircraft with many different levels of capability corresponding to the different partitions of the acquisition program. The F-22 presents an example of how evolutionary acquisition will only make aircraft modifications a more important policy issue for the Air Force in that by 2011, the Air Force is planning to spend $385 million to modify existing F-22s to reduce fleet heterogeneity.

Aging Aircraft - This research indicates that there is no increase in per-aircraft modifications costs with aircraft age at the aggregate level, but there may be alternative modeling and data techniques that will change this conclusion. The aggregate analysis conceals important phenomena occurring at the individual fleet level. While modifications are not as significant as operating and support costs from the standpoint of the total amount of obligations, the effect of age on aircraft modifications costs is expected to weigh significantly into analyses of alternatives and replacement decisions, and therefore may also provide an area for productive future research.

In light of these changes, the process for modifying Air Force aircraft is important to understand because it provides some important clues into the organization of efforts to change aircraft configurations as well as the decision process that creates the trends seen in the data. One important contribution of this research is the identification of the modification process as a subset of the larger organizational structure for changes to post-production aircraft. The current modification policy is foundational to the quantitative analysis comprising the second half of this dissertation. It is the starting point for the changes in future policy suggested in the conclusions.

Can aircraft modifications be implemented more efficiently? When the frame of reference is limited to aircraft changes defined by the Air Force as Modifications, analysis suggests that installation and procurement schedules are codependent due to an Air Force requirement to install a modification kit in the same year it is procured. It is hypothesized that operational constraints limit the installation schedule and therefore limit the procurement schedules. This results in acquisition inefficiency. With aircraft modifications around $2 billion per year, even small inefficiencies may be significant. This dissertation tests the effects on unit costs of changing the production and installation rate using regression techniques. Evidence presented in this research then suggests that an improvement to efficiency may be made if the constraint to install modifications in the same year they are procured is relaxed. Particularly, if acquisition planners are permitted to optimize procurement and installation separately, the Air Force will have more flexibility for both phases of a program and potentially realize a cost savings without adjusting the final outcome—resulting in an increase in modifications acquisition efficiency.

Does current modification policy address safety modifications in an expedient manner? Another conclusion that may be derived from the historical modifications data is that safety modifications are not installed any more quickly than are similarly sized non-safety modifications. Such a condition may be problematic if it does indeed signify a failure to implement the policy that safety modifications should be completed at the fastest rate possible. This conclusion warrants further analyses to determine a policy-relevant way to increase the completion of safety modifications if it is determined by policy-makers that the current rates are too low for Air Force needs. Another policy adjustment that may be appropriate is the reduction or elimination of documentation required to designate a safety modification since it is not clear that such documentation does significantly affect the time in which a program is implemented.

What are the future expectations for fighter modifications as a component of Air Force policy and doctrine? The F-15 and F-16 fleets are arguably the two most important aircraft fleets in the Air Force. Despite the findings that aging does not increase aircraft modifications for all aircraft fleets, both the F-15 and F-16 fleets have exhibited a general upward trend in modifications since their inception in the Air Force. Even as the production of these aircraft has ceased and inventory levels have begun to decline, the upward trend is still significant. This has important implications for the future replacement aircraft that will be added to the Air Force inventory. Since the initial technology levels in these aircraft are significantly higher and the composite airframes also pose a higher risk for modifications requirements, it is important that the Air Force be prepared for the significant increase in modifications costs that may occur as these aircraft mature.

Conclusions

- Aircraft modifications will become increasingly important as a tool of modernization for the US Air Force
- Policy adjustments to the procurement and implementation phase of a modification have the potential to increase modification efficiency
- The Air Force has historically been unable to implement important safety modifications as expediently as is hoped
- Total modifications expenditures for legacy and replacement Air Force fighters are expected to increase dramatically in future years

Chapter 1 – **Introduction**

"The battle, is fought and decided by the quartermasters before the shooting beings."

~ Field Marshall Erwin Rommel

The United States Air Force is facing the 21st century with an aging aircraft fleet and limited replacements. Modifying the legacy fleets is one of the primary ways in which the USAF maintains a technologically superior aircraft fleet. The objective of this research is to improve the ability of the Air Force to plan for and implement aircraft modifications.

Not very long into the course of this research, it became apparent that many different perceptions exist as to what exactly constitute aircraft modifications. As the research continued, it also became apparent that aircraft modifications are really just a subset of a larger group of processes that change an aircraft over time. As this background research continued, the framework within the Air Force for managing the evolution of aircraft became a twisted network of processes and regulations. Decision-makers involved in various facets of these processes and regulations each had a unique perspective on the framework, but no one expert on the aircraft change framework was found to help piece together each of the individual components. It also became obvious that there was a dearth of literature, particularly of a quantitative nature, on aircraft modifications of any type, including commercial, foreign, or aircraft from the other US military services.

This early background research then led to a shift in the final purpose of this dissertation. While it was originally planned to be primarily dedicated to quantitative analysis of historic modifications focused around some form of an optimal modification model, the complexity of the aircraft change framework showed that a formal explanation of the modification process as a part of the overall framework was needed. Therefore, this dissertation now includes an attempt to define modifications as a subset of the aircraft change framework as well as a simplified explanation of the modification process.

These two descriptions further highlight the need to understand the process that generates the data for quantitative analysis. In this research, the data is a comprehensive set of all aircraft modifications from the years 1996 through 2005. This set includes cost, quantity, and descriptions for various budget categories of each modification plan. As the data were compiled, it led not only to further questions about the process, but also provided insight in other areas as well. Additionally, as the process description evolved into the final form in Chapter 3, it also provided a better understanding of how to set up and use the modification data. Finally, the process description (and the understanding required to write the description) helped to formulate hypotheses about the data and provide a basis for the quantitative analysis contained in this research. Ideally, the descriptions provided herein will be used in conjunction with further data and analytic techniques in future studies in an attempt to aid the Air Force to better allocate a limited budget in pursuit of global reach, vigilance, and power[1].

In addition to the description of the modification process within the context of the aircraft change framework in the Air Force, historical trends help foster an understanding of the motivation and intentions of present modification policy as well as point toward future impacts of this policy. These trends include diminished planned procurement of new aircraft, new acquisition strategies, and new accounting practices. One component of the new acquisition strategy is to

[1] *Global reach, vigilance, and power* is the vision of the Air Force in support of the mission to "deliver sovereign options for the defense of the United States of America and its global interests—to fly and fight in Air, Space, and Cyberspace."

group production lots together into 'spirals' or 'increments'. These groupings, as well as an increased reliance on older aircraft, point to an increase in the importance of modifications in upcoming years. Therefore, in preparation for future Air Force needs, this analysis is a step towards updating the modification policy to allow more flexibility to support the demands of the warfighter. There are two particular improvements that are examined in this research: improving efficiency by decoupling procurement and installation of a modification, and analyzing the ability of the process to accommodate high-priority modifications.

The first part of this research (the part addressing improvements to current modification policy) uses a set of quantitative models known as policy response models. These policy response models are designed to analytically test specific relationships of independent variables on a dependent variable. This differs from prediction models that exploit intertemporal correlations within the data to hypothesize values for combinations of dependent and independent variables not included in the observed data. Policy response models typically have lower R^2 than one obtains in predictive models; however, they are still useful for predicting the individual effects of changes in the independent variables. In general, the R^2 values in the policy-response models in this dissertation are low because of the multitude of exogenous influences on unit cost that the reported econometric models are unable to account for. Nevertheless, with the large sample sizes used in these models, the effects of the dependent variables are still unbiased and efficient.

While policy specific analyses are important for shaping the future organizational framework, they provide only limited insight into decision-making involving potential aircraft modifications and cost implications for various replacement strategies. Therefore, this dissertation concludes with several prediction models that may be used to forecast future modifications budgets for various categories in support of aircraft investment and replacement decisions. These predictions use models differently than the previously described policy response models. Here, the models are prediction models and the fit is more important than the individual contributions of the independent variables. The distinction between policy response models and prediction models will be maintained throughout the remainder of this dissertation[2].

Over the course of this dissertation, the following four research questions will be addressed:

1. What are the historical trends that have preceded the present environment for aircraft modifications in the Air Force?

2. Can aircraft modifications be implemented more efficiently?

3. Does current modification policy address safety modifications in an expedient manner?

4. What are the future expectations for fighter modifications as a component of Air Force policy and doctrine?

This process of analyzing these research questions leads to the following basic outline for this research: Chapter 2 narrows the scope of analysis and defines modifications. It also reviews prior research on the planning and implementation of modifications. Chapter 3 presents the current process for modification planning and implementation while Chapter 4 describes some historical trends that impact modifications. Chapters 5 and 6 present an analysis of two potential improvements to the modification process. Chapter 7 predicts some future fighter modifications budgets and Chapter 8 summarizes the conclusions of this research.

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[2] For more information on the difference between policy response models and prediction models see Gilster, 1970.

Chapter 2 - **Background**

"Unexpected accidents cannot be easily prevented, but those foreseen may easily be obviated or remedied."
~ Machiavelli, The Art of War

Definition

Modifications are defined by AFI 63-1101, *Modification Management*, as:

> "permanent changes to correct material deficiencies, improve reliability and maintainability, improve performance, or add or remove capability. Permanent modifications should be accomplished on complete blocks or series of the system, equipment, or material."

The nuances of this definition are explored further in chapter 3; however, they provide a starting point for understanding past research. One thing to note is that modifications are typically grouped into "kits"—usually one for each airplane that is to be modified.

Literature Review

Despite the background and the clear importance of aircraft modifications in the present and future Air Force, there has been relatively little quantitative analysis of aircraft modifications. No previous studies were identified that specifically addressed modification policy. An overview of the previous literature is helpful however, in preparing the groundwork for this present analysis and to show how this research is a contribution.

World War II Study

Before the Air Force was an independent military service, the Army Air Force recognized the importance of aircraft modifications early in the development of modern air forces. The Army Air Forces Air Historical Office published a study on modifications to aircraft during World War II entitled: *The Modification of Army Aircraft in the United States 1939-1945.* Even at this early stage in aircraft planning and development, the decision-makers mention modifying aircraft for the purpose of "correcting defects, improving combat performance, or incorporating equipment necessary to adapt the aircraft to a particular function (Air Historical Office 1947)." The Historical Office then continues to describe the modification efforts in each year of World War II.

Birkler and Large Study

J.L. Birkler and J.P. Large published a RAND report in 1981 entitled *A Method for Estimating the Cost of Aircraft Structural Modification*. In it, the researchers used modification kit weight to predict the cost of production for major categories of aircraft structural modifications. These categories included wing, fuselage, empennage, and landing gear. Within these categories, Birkler and Large estimated equations for engineering, tooling, manufacturing, and material costs; however, they did not estimate the installation costs. These equations were then used to estimate modifications costs for major structural improvements to the B-52, C-141, C-5, and EF-111. The models use only the weight of the modification as an explanatory variable[3]. Such estimating relationships are impractical for modification planning if specific modification engineering data are unavailable.

Birkler and Large also make several other observations that are important to note. The first is that most of the modifications obligations are spent on avionics

[3] One estimating equation for the cost of fuselage engineering costs uses the speed of the aircraft as an explanatory variable as well as weight.

modifications. This trend continues 25 years later despite many changes in the age and technology of Air Force aircraft. Additionally, the researchers note the difficulty and constraints of estimating aircraft modification costs. Extensive knowledge of the modification program is needed to accurately predict the costs as well as an accurate evaluation of the hours required for various fabrication and assembly procedures. This constrains the cost estimator to developing estimates when program details are well known and precludes accurate estimates for "planning studies, preliminary tradeoff analyses, Independent Cost Analyses (ICAs), and the like." They conclude that there is "a need for a procedure to estimate modification costs early in the planning cycle, when resources are limited and detailed knowledge of design specification is unavailable."

ELSIE Study

The Analytic Sciences Corporation (TASC) prepared an aircraft modification study for the Aeronautical Systems Division in 1987. The main result from the study was a computer application entitled the Electronic Subsystem Integration Estimator (ELSIE). ELSIE estimates the budget requirements for an individual aircraft modification based on the inputs from an electronic worksheet. These inputs include estimated first unit costs, learning curves for manufacturing and installation, and complexity of installation. These inputs are then compared to a database of 28 historical aircraft modification programs to provide an updated estimate of the proposed modification program using analogous estimates. Since the ELSIE program in unavailable and the report associated with the program does not list the program specific analogues, it is not possible to replicate specific findings; however, it is important to note that these estimates require detailed engineering and programmatic knowledge of the proposed program that would be unavailable to planners interested in any macro-level fleet modifications planning. Like the Birkler and Large study, this study is of limited practical use to decision-makers before the modification has already made significant progress through the modification process.

Airframe Modifications Cost Study

James York and Richard Krens of Science Applications International Corporation prepared an airframe modification cost estimating relationship for the U.S. Army Cost and Economic Analysis Center and the Naval Center for Cost Analysis in 1994. York and Krens note the increasing number of aircraft modifications and decreased procurement of new aircraft as a justification for their research. The researchers used data from nine airframe modification programs to specify a cost estimating relationship for the 100th unit cost of an individual structural modification. York and Krens use a 78% learning rate in their estimation of the cost. This is interesting to note because the ELSIE studies assumes a standard 95% learning rate. In conclusion, the study found that for every one percent increase in weight of the modification, the modification cost would increase by 0.064%. This number was re-estimated with more segregated models three years later by MCR Federal, Inc.

C3 Platform Integration Cost Model (1997)

MCR Federal, Inc. prepared 23 cost estimating relationships (CERs) for the Air Force Cost Analysis Agency (AFCAA) relating to various categories within the work breakdown structure (WBS). These categories share a significant overlap with the categories now required of the single manager under AFI 63-1101, *Modification Management*. The cost drivers chosen for these CERs were "selected as a result of engineering considerations, and because they are known early in the planning and design phase." These selection criteria led to the inclusion of three cost drivers:

- Number of Line Replaceable Units (LRUs) in the Group B Equipment (Total number of modifications kits installed)
- Total weight of the modification kit
- Total weight added to the platform (Total weight of the kit less the weight removed from the legacy equipment)

Researchers used from 4 to 22 data points to generate the estimating relationships using the cost drivers stated above. The CERs show a 0.4-0.48% increase in cost with every one percent increase in weight of the modification kit. In an alternative model, the CERs indicate a $400 increase in unit cost for a one pound increase in modification weight.

<u>Technomics Study</u>

In December of 1999, Technomics, Inc. presented the Air Force Aeronautical Systems Center (ASC/XR) with an aircraft modifications cost estimating computer program. The models in the program are based on cost data for categories of both production and development. A total of 24 programs were evaluated. The Tecnhnomics study introduces several new explanatory variables in predicting the cost of modification kits. The additional variables included in the models included:

- Estimated vs. actual cost
- Weight removed from the aircraft
- Production/installation rate per year
- Percent electronics/mechanical/structural/cabling
- First kit installation hours

Like the ELSIE study, the individual results from this study are imbedded in a computer program that is unavailable at the time of this report. Nevertheless, it provides a starting point for variable selection for the models in this report. Finally, like the other studies reported in this literature review, it shows that the current analysis is focused on cost estimation for individual modification programs once the program has begun the modification process. Before the process begins for a particular program, this category of models provides only limited relevant information because the model parameters are not yet determined.

RAND Aging Aircraft Study

In 2003, Ray Pyles published an authoritative work on aging aircraft entitled *Aging Aircraft, USAF Workload and Material Consumption Life Cycle Patterns*. Pyles states:

> "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."

The data that Pyles was able to analyze was Time Compliance Technical Order (TCTO) data based on planned work for modifications. While my dissertation will not address the detailed empirical relationship between TCTOs and individual modifications, Pyles' findings are an important reference point for this work. The analysis of the modification process presented in this reserach, however, does help shed light on the relationship between modifications and TCTOs. Pyles concluded that modifications workloads do not grow over time, but spike between age 20 and 25 of the aircraft design. It is hypothesized that this corresponds to the initially designed service life of the aircraft. Some of these aging effects are discussed in greater detail in Chapter 4.

All of the results presented in the previous section lay the foundation for the research presented in this report. Several important lessons are available that should influence all future analysis:

- Aircraft modifications are highly varied and proper cost analysis demands a common reference point between modifications. Modification weight has historically been the reference point of choice.
- Modification data is difficult to compile and has historically limited the extent of cost analysis.
- Significant cost estimates are available only when the program has evolved to such an extent that specific program engineering and programmatic data is available.

This research marks a departure from each of these historical limitations. This research uses a constructed database showing all modifications from the year 1996-2005. As a result, it will be used to address policy-wide concerns instead of the individual CERs developed with previous small samples. With this large population, data limitations prevent the use of weight as an explanatory variable in any of the models. Future research may be able to incorporate weight and therefore provide a bridge between this analysis and prior studies. While this departure is intended to fill a gap in the current analysis, it does not answer all of the questions that might be raised. It should therefore be considered in conjunction with the historical research summarized here, and hopefully represents an additional step forward in understanding this important dimension of Air Force acquisitions.

Complex Aircraft Change Framework

Before beginning an analysis of Air Force aircraft modifications, it is important to understand how modifications are situated in the larger framework defining aircraft changes. The complexity of the framework described in the subsequent section helps lead to a conclusion that the framework complicates the aircraft change process and therefore complicates the analysis as well[4]. In light of this complexity and the frequency with which it was confusing over the course of this study, this research presents an overview to show how the specific policy of aircraft modifications is orchestrated within the larger framework. While the goal is to present the policy of interest—the modification policy—this section is not an exhaustive examination of the entire aircraft configuration change process.

One of the most important distinctions to make when describing aircraft change is change before an aircraft leaves the production line and change after the aircraft has already been delivered to the Air Force. Figure 2.1 shows this distinction graphically. From this pre/post-delivery division, the methods of aircraft change may be further described.

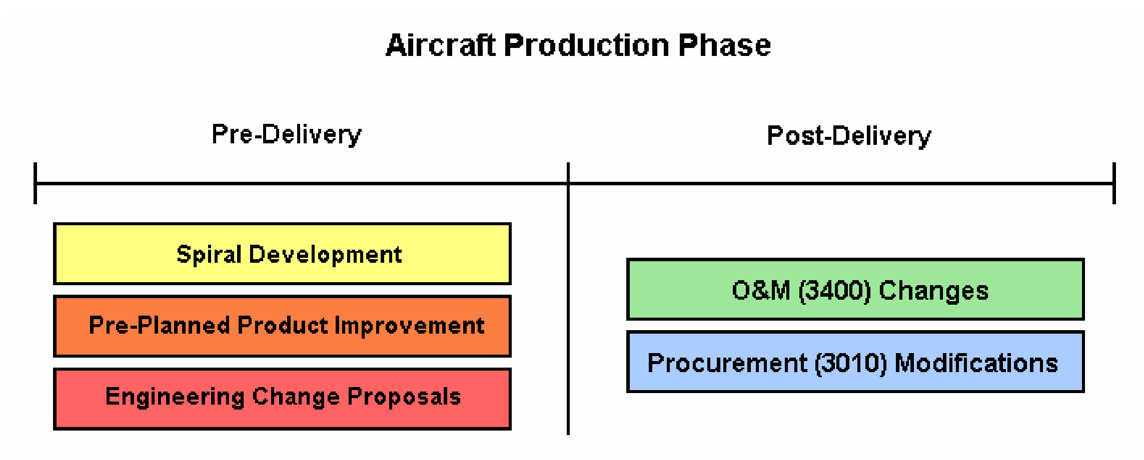

Figure 2.1 - Pre and Post-Production Aircraft Change Efforts

[4] As far as could be determined for this research, a comprehensive summary of the aircraft change framework has not been published before.

While pre-production changes occur before the aircraft is delivered to the Air Force, there are several ways that they may be implemented. DoD Instruction 5000.2 Operation of the Defense Acquisition System, May 12, 2003 states that:

> "Evolutionary acquisition is the preferred DoD strategy for rapid acquisition of mature technology for the user. An evolutionary approach delivers capability in increments, recognizing, up front, the need for future capability improvements. The objective is to balance needs and available capability with resources, and to put capability into the hands of the user quickly. The success of the strategy depends on consistent and continuous definition of requirements, and the maturation of technologies that lead to disciplined development and production of systems that provide increasing capability towards a materiel concept."

There are two forms of evolutionary acquisition: Spiral Development and Incremental Development. DoD 5000.2 further describes these as:

> "Spiral Development. In this process, a desired capability is identified, but the end-state requirements are not known at program initiation. Those requirements are refined through demonstration and risk management; there is continuous user feedback; and each increment provides the user the best possible capability. The requirements for future increments depend on feedback from users and technology maturation."

> "Incremental Development. In this process, a desired capability is identified, an end-state requirement is known, and that requirement is met over time by developing several increments, each dependent on available mature technology."

Pre-planned product improvement (P3I) is often used interchangeably with incremental development. The key distinction is that the end state of a spiral development program is not known while it is known for a P3I program[5]. Anecdotal evidence suggests that spiral development is the approach the Air Force employs for the aircraft while a P3I approach is reserved for specific aircraft components. Nevertheless, both evolutionary acquisition and pre-planned product improvement are implemented on entire aircraft lots and do not typically involve changes to an aircraft while it is on the production line. These different lots of aircraft are referred to as "spirals" or "increments".

The last method of pre-production aircraft to be discussed is engineering change proposals (ECPs). It is important to understand this method using the distinction between pre and post-production changes because ECPs may also be used in either the pre-production phase or the post-production phase. Despite multiple applications for an ECP, the pre-production ECPs are inherently different from the others. Typically, a pre-production ECP is a change to an aircraft once it has begun production. This change was unplanned when the spiral or increment was planned and the contract was written. Such changes may be the result of some other operational feedback, new engineering analysis, or some other factor that justifies a change before the current production lot is completed. Often, these types of changes are funded through appropriation code 3600 (research, development, test, and evaluation) budget activity 7 (operational system development).

One an aircraft is delivered to the Air Force it is no longer affected by pre-production aircraft change measures. All subsequent changes to the aircraft are

[5] More information is available on P3I in a RAND study by Frederick Biery and Mark Lorell. N-1794-AF

managed by the program office and are characterized generally by the funding method used to implement the changes. The two funding categories are defined by appropriation code 3400[6] operations and maintenance (O&M) and appropriation code 3010[7] aircraft procurement. Some evidence suggests that a third category, appropriation code 3600[8] (RDT&E), is also used to fund some aircraft changes; however, the formal method for such aircraft change is unavailable for publication at this time.

O&M funded aircraft change is further categorized into categories for normal and forced attrition. Normal attrition is the process of using scheduled maintenance to replace old and worn-out parts with new parts that represent an increase in functionality. This increase may be capability improvement, decreased mean-time-between failure (MTBF), or some other increase, but the new part must be form-fit-function compatible. (Form-fit-function compatibility is addressed in the following section.)

Alternatively, forced attrition may replace form-fit-function compatible components that result in an increase in capability; however, instead of waiting for the scheduled maintenance, there is an out-of-cycle effort to change out the parts. While it may result in an increase in capability, the motivation for this change must be a quantifiable cost savings. The forced attrition method of aircraft change is formally defined as the improved item replacement program (IIRP)[9].

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[6] This is spoken as "thirty-four hundred"
[7] This is spoken as "thirty-ten"
[8] This is spoken as "thirty-six hundred"
[9] IIRP is governed by AFMCI 21-121 found at http://www.e-publishing.af.mil/pubfiles/afmc/21/afmci21-121/afmci21-121.pdf

The final category of aircraft change that is discussed in this research and the focus of the remainder of the analysis is aircraft modifications. Modifications are funded with appropriation code 3010 aircraft procurement money. Aircraft modifications are further characterized by budget program code 11 (BP-11)[10,11] aircraft modifications. Aircraft modifications are also uniquely characterized by a change to the form, fit, function, or interface of a configured item. 3010 BP-11 aircraft changes, hereafter referred to specifically as modifications, are the focus of the remainder of this research. The process governing the planning and implementation of modifications is presented in the following chapter.

Form-Fit-Function Compatibility

Many of the discussions that occurred over the course of this research were, at some point, concerned with what exactly entails form-fit-function compatibility. The three categories of form, fit, and function, is sometimes thought of as follows:

- shape, size, material, interfacing, weight, and often appearance (form)
- connectors and ability to physically integrate with other pertinent items (fit)
- the action(s) the item is designed to perform; the outputs given appropriate inputs (function)

In general, the debate of the definition of form-fit-function compatibility was aimed at defining each of these categories; however, the consensus seems to be that it is often up to the Single Manager, or team in charge of the aircraft helps define each of these categories. For example, the issue of component weight may not be a relevant issue for certain potential cargo aircraft modifications, while

[10] 3010 BP-11 is identical to Budget Activity 5 (BA 5). In practice however, BA 5 is reserved for speaking verbally about RDT&E money expended in support of aircraft modifications.
[11] BP-11 separates modifications from BP-13 (Post-production charges) and BP-16 (Aircraft Initial Spares and Repair Parts) obligations.

weight may be a significant consideration for a potential fighter modification. Additionally, anecdotal evidence suggests that form-fit-function compatibility may sometimes be as simple as maintaining the same identification number for the replacement items as was used for the legacy items.

One clear conclusion may be made with regards to the issue of form-fit-function compatibility is that ambiguity in the definition has led to a variety of different decision outcomes. While this may be advantageous because it permits a decentralized form of decision-making in allowing the SM to make judgments based on a working knowledge of specific programs, it complicates a macro level analysis of aircraft change trends.

Other Conclusions

In describing the complex framework for aircraft change, it seems appropriate to consider how the entire framework may be simplified. Even if the different categories may not be reduced to less complex form, further definition of the criteria for the different categories may serve to reduce confusion and the time required to make decisions about classifying aircraft change initiatives. Furthermore, these definitions may benefit by explicitly stating when and where decision-makers are free to make judgments concerning different categories and where federal acquisition regulations specifically provide categorical definitions that leave no room for alternatives.

The complexity of defining a change to the form, fit, or function of an end-item on an aircraft serves to highlight the complexity of the Air Force environment for aircraft change processes. There are different methods for defining aircraft change processes, each governed by a unique set of regulations. As a result, it is difficult to conduct policy analysis of the modernization of Air Force aircraft without developing an overarching understanding of the different processes and their interactions. This research does not claim to do this; rather it is a step in that direction that also serves to define the specific category of aircraft modifications. This category is the focus of the remainder of the research, and all data and discussion are limited to the type of aircraft change defined as aircraft modifications and identified as Appropriation Code 3010 (aircraft procurement), Budget Program 11 (aircraft modifications) obligations.

Overview of Modifications Obligations

Now that modifications have been identified within the broader scope of aircraft changes, it is possible to begin to quantify the historic trends in modifications spending. In the past 10 years, modifications obligations (3010 BP-11) have risen approximately 39%, or about 5.5% per year, from $1.27 billion to $1.77 billion. However, as chart 2.1 indicates, there has not been a steady increase; rather obligations increased to a peak of over $2.17 billion in the year 2000, and dropped from then until the present. Additionally, as further analysis will show, it is not clear that this trend is indicative of modifications obligations outside of this year range. Chart 2.1 also shows the RDT&E obligations associated with aircraft modifications and there appears to be a clear upward trend. While RDT&E obligations are not the focus of this dissertation, they may be an important component of future modification analysis.

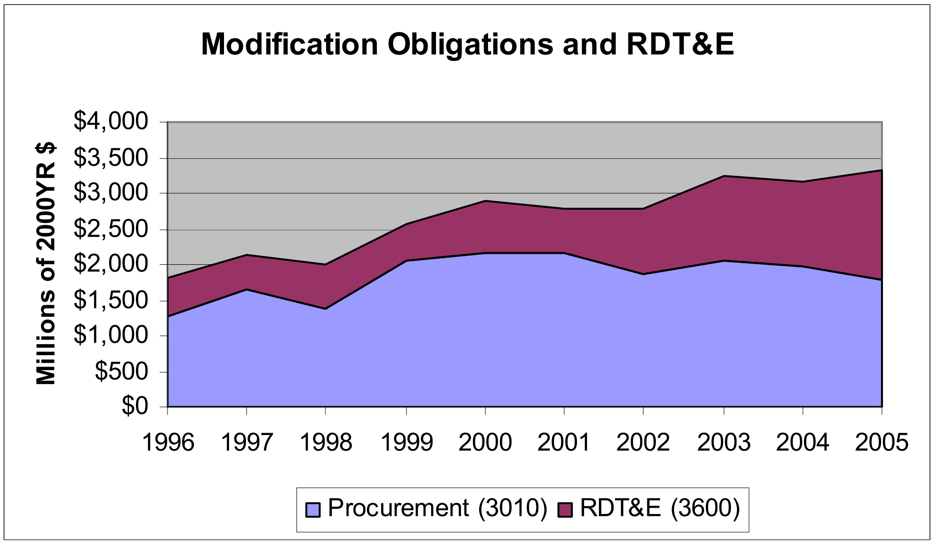

Chart 2.1 - Modification Obligations and RDT&E

Instead of just examining the trends of aircraft modifications obligations as independent values, it is also useful to compare modifications to total Air Force obligations authority (TOA) and total Air Force procurement obligations. This is done in chart 2.2 below[12].

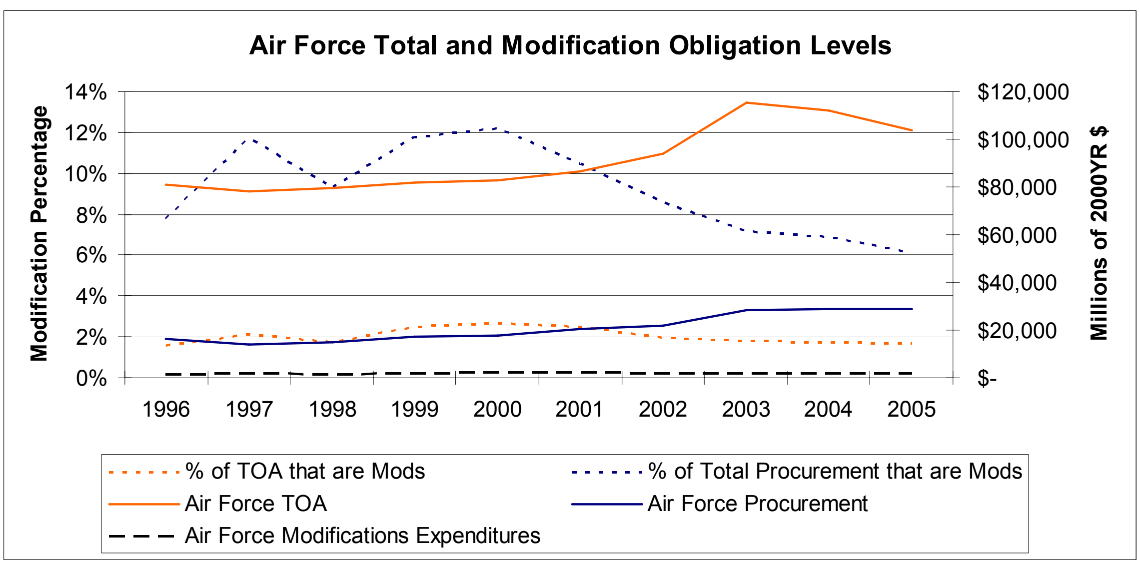

Chart 2.2 - Modifications as a Part of Air Force Spending

[12] All of the modification data presented in these charts was generated by a dataset constructed from the raw IDECS data provided by SAF/AQXR. More information is available in Appendix 1.

In this chart, the relatively constant percentage of TOA becomes apparent. This means that as a percentage of total Air Force spending, modifications have remained relatively steady over the past 10 years. In contrast, when compared to total Air Force procurement, modifications have actually declined. This may be due to a variety of factors, but it seems reasonable to assume that the procurement of replacement aircraft in the F-22 has decreased the value of modifications as a substitute good.

These types of hypothesized relationships are the foundation for the quantitative analysis presented in this dissertation. One potential way in which different components of the modification decision-making process may interact is shown graphically figure 2.2. Further analysis will use these types of hypothesized relationships to build an econometric model to test their formal structure as exhibited in historical data.

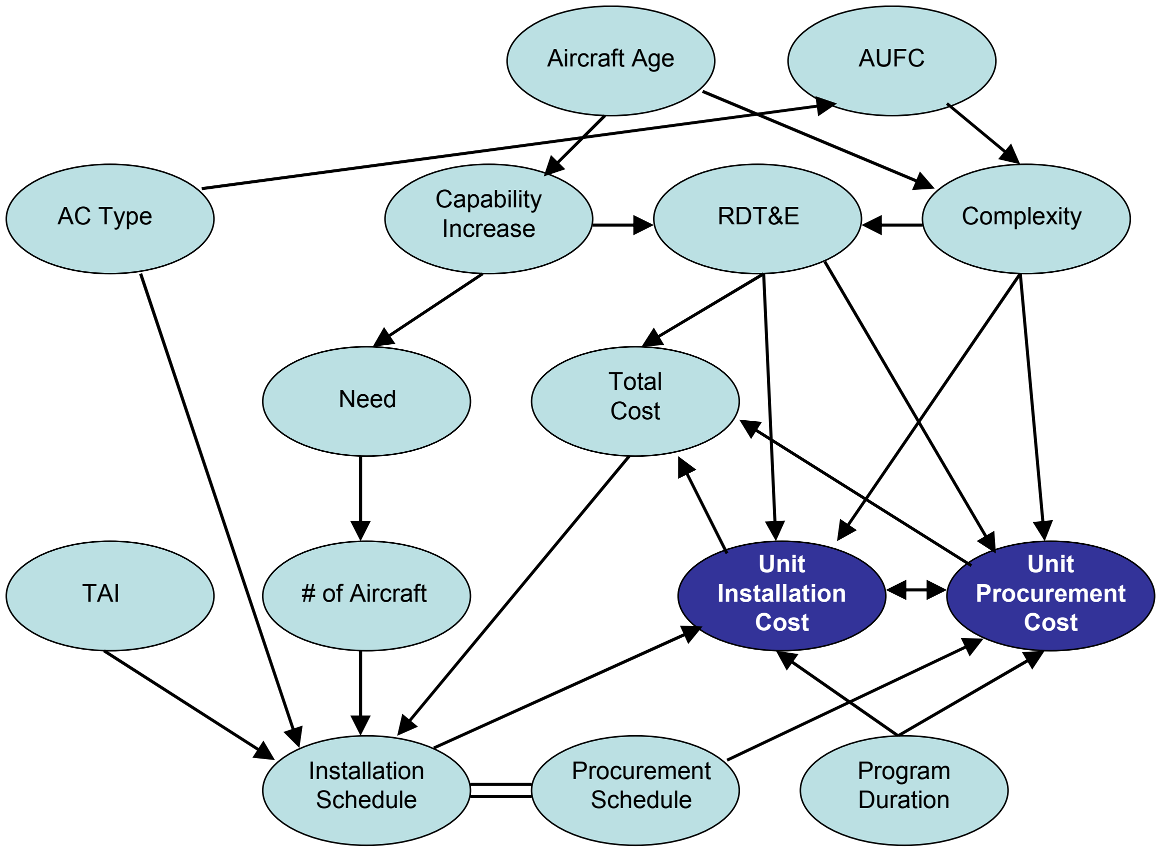

Figure 2.2 - Possible Relationships between Modification Variables

While some of the relationships presented in figure 2.2 are based on economic theory, some are based on the formal process that selects and implements aircraft modifications. For this reason, the Air Force modifications process is foundational to understanding the analysis presented in this dissertation, and as a starting point for future analysis. Therefore, the following chapter is an overview of the Air Force modifications process.

Chapter 3 – The Air Force Modification Process

[E]conomics is concerned with allocating resources—choosing doctrines and techniques—so as to get the most out of available resources.

~ Hitch and McKean, The Economics of Defense in the Nuclear Age

The process for modifying aircraft in the Air Force is important from both the decision-maker's and analyst's perspective. Because modifications represent approximately 2% of the Air Force total obligation authority (TOA)[13], they are a significant part of Air Force spending. Similarly, modifications affect decisions concerning the purchase of new aircraft and utilization of legacy aircraft. They impact Air Force capability and O&S costs and the process used to select which modifications will be implemented reveals important assumptions and decision policies. For these reasons, and because the modification process was difficult to piece together for the purposes of this research, it is presented here in a concise form to inform the analysis presented in this research and to provide future analysts and decision-makers with an overview that may aid in decisions for future policies.

Background

Air Force Instruction (AFI) 63-1101, *Modification Management* defines the Air Force modification process. This process implements Air Force Policy Directive (AFPD) 63-11, *Modification Systems. Modification Systems* is in turn a subset of a larger policy directive: AFPD 63-1, *Capability Based Acquisition System*. This hierarchy shows that a modification is a specialized type of acquisition program. As an acquisition program, it must conform to all DoD Acquisition guidance in

[13] This percentage fluctuates between 1.6% and 2.5% in the data.

addition to the specifics described in AFI 31-1101. This is stated explicitly in AFI 63-1101: "All permanent modifications will be managed as acquisition programs." This both simplifies and complicates the process. The process is simplified because once the framework for Air Force acquisition is understood, the modification process logically follows. Conducting aircraft modifications as acquisition programs also complicates the matter because Air Force modifications cannot be properly understood without a complimentary understanding of the acquisition process. This discussion of the modification process references the acquisition process as it applies to the modification process, but will not include a separate discussion of the acquisition process. The goal of this approach it to present a succinct but thorough overview of the modification process that is enhanced by an accompanying understanding of the acquisition process, but that is also informative where a working knowledge of the overall acquisition process does not exist.

Modifications Defined

The Air Force uses a non-traditional nomenclature to refer to modifications. In general, the military refers both to modifications and upgrades, but the Air Force does not include upgrades as a technical term when referring to changes to an aircraft configuration. In non-Air Force terminology, modifications refer to changes to an item that already exists in inventory. Alternatively, upgrades are replacements of legacy items with a new and "upgraded" item. However, as the Air Force refers to both upgrades and modifications simply as modifications, this report will do the same.

AFI 63-1101 identifies two types of modifications: temporary and permanent modifications. Temporary modifications apply only for test purposes or for a specific mission and will not be addressed further. Permanent modifications, the focus of this study, change the form, fit, function, or interface of a configured item and are further divided into two categories defined in AFI 63-1101: permanent and permanent-safety. Permanent modifications are the overwhelming majority and permanent-safety modifications may be considered a subset of permanent modifications.

Permanent-safety modifications "are permanent modifications which correct material or other deficiencies which could endanger the safety or health of personnel or cause loss or extensive damage to systems or equipment." While they follow the same guidelines for permanent modifications—described in a following section—they take precedence over other permanent modifications for funding and implementation. Specifically, "[a]ll [permanent]-safety modifications will be accomplished in the minimum amount of time required to ensure a safe and operationally effective fix." Safety modifications will be discussed in greater detail in chapter 6.

Permanent modifications are defined by AFI 63-1101 as

> "permanent changes to correct material deficiencies, improve reliability and maintainability, improve performance, or add or remove capability. Permanent modifications should be accomplished on complete blocks or series of the system, equipment, or material."

In order to simplify the remaining discussion, I will refer to all modifications (both permanent-safety and permanent) collectively as permanent modifications since both categories have the same modification process.

Unless approved by the Secretary of the Air Force, all permanent modifications (recall that "permanent" hereafter refers to both permanent and permanent-safety) will be installed no later than five years before the projected end of the service life of the modified aircraft.

Modification Programming and Budgeting

Budget information for the modification program is generated in three iterations: Program Objective Memorandum (POM), Budget Estimate Submission (BES), and President's Budget (PB). Of these three phases, only the PB is submitted to Congress as the President's Budget Report (PBR). The first two, POM and BES are separate but simultaneous documents that precede the PB. The POM addresses how the Air Force proposes to meet requirements with new and existing programs. The BES is the budget document supporting the POM. Together, they constitute the justification and cost estimate for the Air Force strategy for the future. The Air Force aircraft modification component of the PBRs is compiled of individual P-3A *Individual Modification Reports*. These reports are required for each individual modification program and are submitted online to IDECS, which is maintained by SAF/AQXR. The P-3A reports are summarized by Exhibit P-40, *Budget Item Justification* and P-1M *Modification Reports*. The aggregate P-3A, P-40, and P-1M reports are compiled and published as the United States Air Force Committee Staff Procurement Backup Book, Aircraft Procurement, Air Force, Volume II[14].

In addition to reporting all of the estimated costs for the entire modification program, the procurement must be scheduled in synchronization with the installation schedule. The requirements for reporting the modification in a P-3A stipulate that the entire program will be recorded in the report and that acquisition and installation of the modification kits will be synchronized. This synchronization necessitates that modification kits—the individual modified

[14] These reports are available to the public. One place to find them is at http://www.globalsecurity.org/military/library/budget/index.html.

components to be installed—be installed in the same year they are received from the contractor.

The Process, Phase I – Planning, Programming, and Budgeting

The Air Force aircraft modification process is a complicated and multi-dimensional process. This research will divide the process into two phases in order to simplify the explanation and provide a natural order for thinking about the activities involved. The two phases are:

- Phase I – Planning, Programming, and Budgeting
- Phase II – Acquisition Program

Figure 3.1 shows the distinction between the two phases in relation to the activities in each phase.

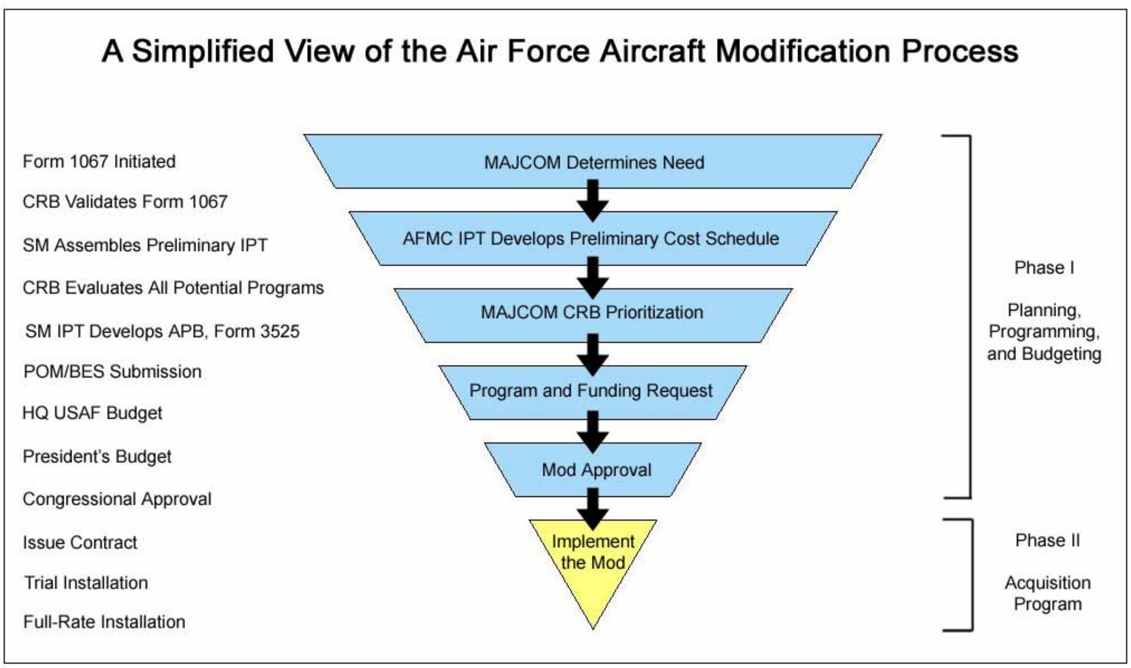

Figure 3.1 - A Simplified View of the Air Force Aircraft Modification Process[15]

[15] This chart is adapted from a Defense Acquisition University chart on modifications. It has been updated to provide added clarity in light of recent acquisition regulation changes.

Form 1067

All Air Force aircraft modifications begin with the initiation of an Air Force Form 1067 *Modification Proposal*. A blank AF Form 1067 is reproduced in the appendix. The Form 1067 may be initiated by anyone, but usually comes from someone directly involved with a weapon system. Often, working groups of pilots, maintainers, or decision-makers directly involved with a weapons system will regularly convene to discuss the potential for improvement. The result of these collaborations is often one or more Form 1067s. Within the body of the form, there are 3 primary inputs for justification. The first input is a description of the purpose. This section explains the need of deficiency to be corrected along with the expected results of the correction. The input for the second section is the impact description describing the urgency of the need and the impact if it is not satisfied. Thirdly and finally is a brief discussion of the constraints, assumptions, and proposed solutions. Once these justification fields are completed, the Form 1067 examined by the organizational leadership from which the proposal originated. If the justification is sufficient, the organization confirms that the Form 1067 proposes "an organizational need/requirement which requires action."

Upon organizational approval, the validated Form 1067 is forwarded to the Major Command (MAJCOM) that is the lead command for the weapon system. A lead command is the command that is responsible for a given weapon system[16]. The lead command is then responsible for scheduling a configuration review board (CRB). The CRB meets monthly to review all Form 1067s based on the need, practicality, estimated life-cycle cost, return on investment, and estimated reduction in total ownership cost over the expected service life of the

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[16] More information on the lead command may be found in Air Force Policy Document 10-9 *Lead Operating Command Weapon System Management*.

weapon system[17]. All Form 1067s approved and validated by the CRB are entered into a centrally managed database[18] and subsequently forwarded to the appropriate Air Force Materiel Command (AFMC) center Single Manager (SM) for engineering review and investigation. The SM is the individual responsible for all areas of a weapon system from concept development through disposal. After receiving the validated Form 1067, the SM is responsible for establishing an integrated product team (IPT) to manage the modification proposal. Membership on IPT varies with proposal size and characteristics. Within the context of the engineering review and investigation, the SM IPT is responsible for preliminary budgetary cost estimates for:

- Unit Cost
- Total Cost

As well as schedule estimates for:

- Lead Time
- Follow-on Time
- User/Depot Work Hours

Once these estimates are generated, the SM forwards the Form 1067 back to the lead command along with a recommendation whether or not to proceed with the modification proposal. The lead command CRB examines the estimates and the recommendation from the SM and either certifies or terminates the modification proposal as the final step in the Form 1067 process.

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[17] These are the criteria listed in AFI 63-1101 Air Mobility Command Supplement 1.

[18] The URL for this database is: https://amclg.scott.af.mil/cgi-bin/index.pl?dd=/a4/a44/a44b/a44m/a44mp&ti=CRB+Modifications. I have not examined the usefulness of this database for research methods; however, it is a potentially valuable source for future research. The URL is given in AFI 63-1101 Air Mobility Command Supplement 1 section 2.1.3.5.

<u>Formal Modification Planning</u>

After final certification by the CRB, the process will have different criteria depending on the cost of the proposed modification. The following is taken from AFI 10-601, *Capabilities Based Requirements Development* and details the approval authority associated with incremental levels in the modification program cost.

Modification ($) Amounts	Requirements Document	Approval Authority
< 10% of ACAT II Minimum Thresholds * & < $30M total expenditure **	AF Form 1067	Lead MAJCOM & PM
< 10% of ACAT II Minimum Thresholds * & > $30M total expenditure **	AF Form 1067 with RCT for KSAs & Attributes (use CPD RCT format)	HQ USAF/XOR
> 10% of ACAT II Minimum Thresholds *	ICD, CDD, CPD	AFROCC or JROC

* Consideration must be given to both RDT&E and procurement amounts

** Total dollar amounts are based on FY 2000 constant dollars

Figure 3.2 - Requirements and Approval Authority for Modifications[19]

The RCM and ICD are documents for presenting the requirement and capabilities and costs in a logical pattern that improve the opportunity for program evaluation. With the change in acquisition guidance, it is not clear what the new standards for the RCM are; however, the ICD is described in great detail in AFI 10-601, *Capabilities Based Requirements Development.*

After the criteria are evaluated and the requirements established for the program, the SM re-assembles the integrated product team (IPT) to manage the proposed modification for the remainder of the process. The members of the IPT are selected to correspond to the expectations of the needs of the proposed

[19] ACAT II programs are defined as programs with RDT&E obligations between $140 million and $365 million in FY 2000 constant dollars or between $660 millions and $2.19 billion in FY 2000 constant dollars.

program. Members may come from involved MAJCOMs, equipment specialists, item and financial managers, test and contract specialists, depot managers, engineers, and logistics personnel.

The assembled IPT establishes whether this proposed modification will be a material improvement project (MIP), engineering change proposal (ECP)[20], or an acquisition program. MIPs are usually in response to a specific deficiency causing specific problems and is already documented in a deficiency report.[21] ECPs are generally used when a contract is already written for a specific item—anything from software to a metal bracket to complete radar system—and a change to that item is desired by the Air Force rather than a replacement. Often, a modification program (acquisition program) includes some ECPs if there are multiple changes to a system and one of the existing components needs to be changed to incorporate the modification. Here it is helpful to use the afore-mentioned non-Air Force terminology in conjunction with the present discussion of a modification program. If the modification program is a modification—that is a change to an existing component—then an ECP will be required; alternatively, if the modification program is an upgrade—replacing an old component with a new and *upgraded* model—then no ECP will be required. The final category of programs that the IPT may select is a modification acquisition program. This is the only category that is actually considered a modification by the definition in AFI 63-1101; however it is possible that an acquisition program will include some ECPs to other aircraft components. MIPs and ECPs will not be discussed in the remainder of this report. Every future reference in this report to

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[20] ECPs in this case are not to be confused with ECPs pre-delivery. ECPs are not limited to use before the aircraft is delivered, but they can change the aircraft form, fit, or function in the pre-delivery stage. Alternatively, ECPs in the post delivery stage can only change a component, but not the form, fit, or function with the operational aircraft. With this distinction, a pre-delivery ECP may require a modification to make the same change to an aircraft that has already been delivered in order to accomplish the same change.

[21] More information on MIPs are provided in Technical Manual TO 00-35D-54 *USAF Deficiency Reporting and Investigating System*.

a modification or a modification program refers to the modification acquisition program as defined by AFI 63-1101.

Once the IPT is assembled, it also begins to prepare documentation for program justification and planning. Included in this documentation are an acquisition strategy, an acquisition program baseline (APB), an integrated modification management plan, financial documents and reports, and programmatic impact analysis. The APB is the first complete view of the program cost and implementation schedule. The SM prepares cost estimates for the APB in the following required modification categories:

- Research and development engineering
- Simulator/trainer requirements
- Initial aircrew and maintenance training
- Trial installation
- Common and peculiar support equipment
- Engineering data changes
- TCTO/Technical Manual changes
- Initial spares
- Readiness spares package
- Kit material and assembly cost
- Installation cost

The SM IPT is also responsible for determining the installation method for the modification. IDECS lists 8 distinct methods for installation. They are:

- Organizational/Intermediate
- Depot
- Depot Overhaul

- Depot Field Team
- Depot/Contractor Field Team
- Contractor Field Team
- Contractor Facility
- Contractor Logistics Support (CLS)

Each of these methods has advantages and disadvantages as well as a flexibility that permits varying implementation strategies for different modification programs. It is not the intention of this research to explore each installation strategy in detail due to the complex nature of each method. However, modification planners have indicated that the least flexible methods are where Air Force personnel conduct the entire modification. This includes the first four categories in the list above (Organizational/Intermediate-Depot Field Team). These methods of installation do not require any additional funding from the modification program, but they are constrained by the availability of Air Force personnel, experience, and installation facilities, as well as the foreordained schedule for programmed depot maintenance (PDM)[22].

Organizational /intermediate installation is accomplished by the organization that uses the aircraft[23]. One rule of thumb is that an installation that requires 25 man-hours or less will be accomplished at the organizational level, while those that require more than 25 hours are accomplished at the depot[24] (sometimes referred to as organic installation). Other organizations have indicated that their

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[22] It is assumed that blue-suit installations are funded with 3400 money.

[23] Sources within various modification decision-making organizations have indicated that intermediate-level installation is not typically used for modifications, but that is it either accomplished at the organizational level, or at the depot if it is accomplished by Air Force personnel.

[24] There are three depots available to accomplish a modification installation:

- Warner Robins Air Logistics Center at Robins AFB in Georgia
- Ogden Air Logistics Center at Hill AFB in Utah
- Oklahoma City Air Logistics Center at Tinker AFB in Oklahoma

rule of thumb is 50 man-hours for the cutoff. In either case, if the modification is accomplished at the organizational level, it may be installed overnight to limit aircraft down-time, or else, if the overnight option is not possible, at one of the phased inspections for the aircraft. Depending on the aircraft, these phased inspections occur at 100, 200, 225, or 250 flying-hour intervals. The phased inspections take from 3 to 5 days. If neither of these options is possible, the modification is accomplished organically (at the depot) when the aircraft is sent for PDM.

In some situations, organic installation is not the preferred option for the modification program. This may be the case if there is a capacity problem at one of the depots such that the modification cannot be installed quickly enough to meet warfighter needs. It is also possible that there is not sufficient organic capability to handle a modification such as with the F-22 where the aircraft has matured faster than the depot's capability to accommodate the modification needs of the warfighter. One other reason why organic installation is not the preferred option is if the complexity of the modification is significant enough such that the original equipment manufacturer's (OEM's) expertise is needed to install the modification kit. In these circumstances, a contractor is hired to conduct the installation. Contractor involvement does require additional funding[25] but allows for flexibility in the installation schedule. If the modification is high-priority and funding is available, contractor installation is often chosen because it can be accomplished at a higher installation rate and may also require less downtime for each individual aircraft. Once the installation method is chosen, the SM must coordinate with the appropriate Air Logistics Center and/or contractor to develop an installation schedule for the entire modification program. At this point, planners must incorporate an important requirement. This requirement is that all modification kits must be installed in

[25] This funding is categorized as 3010 BP-11 and is reported in each P-3A report.

the same year that they are procured. Thus, in determining the schedule with the appropriate installation facility, the procurement schedule is simultaneously and codependently determined. Further exploration of this requirement is presented in Chapter 5.

Schedule estimates is combined with the cost estimates already discussed and are documented in an Air Force Form 3525 *CCB Modification Requirements and Approval Document*. A copy of AF Form 3525 is attached in the appendix. The data from the Form 3525 is nearly identical to the data needed to complete the P-3A reports required for integration into the POM/BES. A sample P-3A report is provided in the appendix.

There are two levels for the Air Force POM/BES. Each MAJCOM is responsible for its own POM/BES. The MAJCOM version will then be forwarded to the Air Staff and acts as a request for funding and approval for the included programs. Before it is forwarded, the MAJCOM must determine what programs to include in the request. At this point, the modification program only advances in the process if the MAJCOM decides to place the program "above the funding line"—meaning that funding and approval has been requested. There is a similar process once the Air Staff receives all of the MAJCOMs' POM and BES submissions and decides which programs to place above the funding line for the final Air Force request. Once the budget documentation is submitted through the Secretary of the Air Force (SAF/FM) and the Office of the Secretary of Defense (OSD) and passes the vote in Congress, the program is considered authorized and appropriated. Practically, this means that money has been placed into an account for the program; however, before it may be spent (obligated), the Air Staff must issue budget and program authorization (BA/PA). This will not occur until after successful completion of Milestone A, which is described later in this process report.

In addition to the APB and Form 3525, the SM IPT also begins to prepare additional documentation for the Configuration Control Board (CCB). The CCB is a group of individuals responsible for the configuration of an Air Force item (in this case an aircraft). It is typically chaired by the Program Manger and comprised of subject matter experts relating to the item under control. As a group, the CCB is responsible for evaluating and approving (or disapproving) any changes to a configuration baseline[26]. The documentation for the CCB is the first comprehensive strategy for modifying the aircraft. It is comprehensive because it includes, in addition to the cost and schedule estimates, risk estimates and a strategy for coordination with other modifications. AFI 63-1101 indicates a preference for lower risk modification options and grouping modifications into block upgrades if possible:

"In general, the design solutions which incorporate the lowest overall program risk will be given higher preference."

"The program manager is encouraged to group modifications into block changes so overall kit cost can be reduced, man-hours for installation can be optimized, and weapon system downtime can be minimized."

Blocks are groups of aircraft that all have the same configuration. There are instances when an airframe changes between blocks, such as with the F-16, but the goal is to reduce the number of different aircraft configurations within a fleet.

Only when the CCB approves the proposed modifications does the program advance in the modification process. At this point, if the overall cost is greater

[26] More information on CCBs and Configuration Management may be found in the Military Handbook 61A(SE) *Configuration Management*. The requirement for a CCB is stated in DoD 5000.2-R C5.2.3.5.6.2.3.2.

than $10 million, then an acquisition strategy panel must convene and the formal acquisition process followed, otherwise, the SM IPT prepares program documentation and the Air Staff can issue budget and program authorization. The ASP process is described below, before an overview of the formal acquisition process.

While the documentation is very similar to that required for the configuration control board, the membership of the ASP is limited mainly to acquisition specialists. The ASP is involved to ensure that the strategy for acquiring the modification kits is reasonable and conforms to acquisition regulations. The acquisition plan presented to the ASP is also known as the Selected Acquisition Management Plan (SAMP) and is mandated by Air Force Federal Acquisition Regulation Part 5307. The SAMP is adjusted as the ASP deems necessary and once it is approved, the MDA is the next main step. Again, this ASP is only for modification programs greater than $10 million in total cost. The ASP is preparation for the formal acquisition program defined by the DoD 5000 series regulations.

Phase II – Acquisition Program

Modification programs that will cost over $10 million must complete milestones A, B, and C[27]. Programs less than $10 million enter into the following process after Milestone A and the Air Staff has the authority to issue Budget and Program Authorization without the formal acquisition strategy panel. To reiterate, all modification programs must follow the same process presented here, the only difference is that programs less than $10 million do not need an ASP and therefore the Air Staff may issue budget and program authorization without conducting Milestone A.

Concept Refinement - Milestone A

The MDA is the designated individual with overall responsibility for a program, including the programs progression and Congressional reporting. The documentation for the MDA is intended to justify progression from concept refinement to technology development—passing Milestone A. The following diagram shows key components of the modification process and their relevant position in the acquisition process[28]. The three milestones (A, B, and C) are the triangles on top of the colored squares.

[27] If the modification program is an ACAT I program, the DoD 5000.2-R is the standard for the entire acquisition activity.

[28] This diagram is based on the acquisition process diagram presented in DoDI 5000.2 The Defense Acquisition Management Framework. The acquisition diagram is Figure 1 appearing in section 3.1.

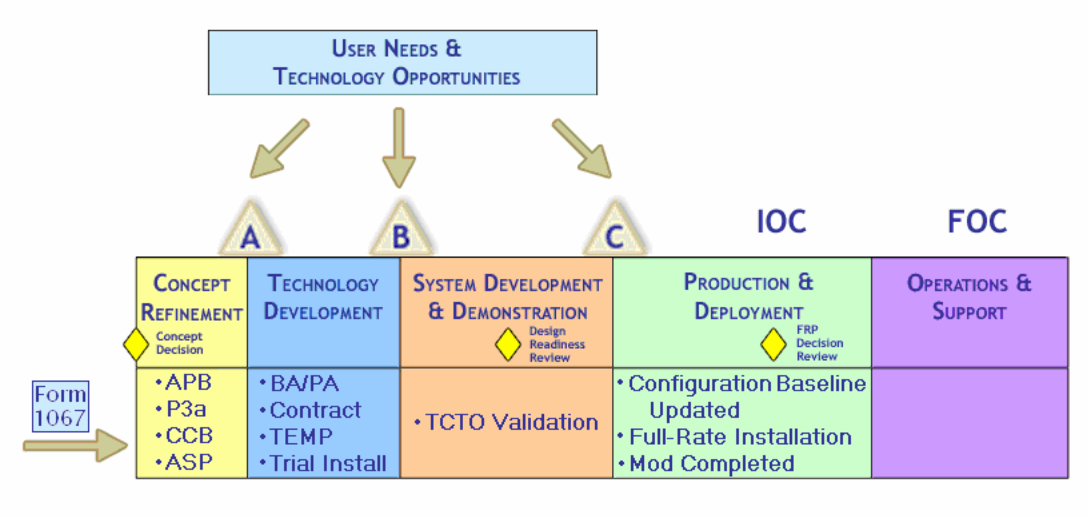

Figure 3.3 – Modifications as Acquisition Programs

Milestone A approval makes the proposed modification a requirement for the Air Force and so upon approval, the Air Staff must ensure that a Program Management Directive (PMD) exists for the new requirement. If the existing PMD does not include this newly approved requirement, it must be updated or a new PMD must be generated[29], since all requirements resulting in modification programs must have an associated PMD.

> "The Program Management Directive is the official document used to direct acquisition responsibilities to the cognizant MAJCOM, agency, Capabilities Director, Designated Acquisition Commander (DAC), Program Executive Officer (PEO) or Single Manager and defines the approach the program will follow to acquire a directed capability[30]."

[29] The PMD is regulated by Headquarters Operating Instruction 63-1 *HQ USAF Guidance on Preparing Program Management Directives.*

[30] This is from a memorandum to the acquisition community concerning Program Management Directive Updates from Mr. Blaise Durante.
https://www.safaq.hq.af.mil/acq_pol/documents/AQXPMDUpdatesMemo-signed.pdf

Technology Development – Milestone B

Following Milestone A approval, the Air Staff will issue budget and program authorization (BA/PA). This allows the SM to begin to obligate money through a contracting officer. In order to obligate money to fund the program, the SM must prepare and issue an acquisition package. Within this package is a request for proposal in which the Air Force formally asks for proposals from contractors to conduct the modification. The contracting officer uses the acquisition plan to issue a contract for the first step of the modification integration: the trial installation and testing of the modification.

The first step after the contract is issued and a prototype is developed is testing. Testing is the process by which the Air Force determines if the modification works well enough in the prototype to implement into the rest of the aircraft specified by the contract. Testing is conducted according to a test and evaluation master plan (TEMP). Testing must address Federal Aviation Administration (FAA) regulations as well as Operational Safety, Suitability, and Effectiveness (OSS&E) issues[31]. The testing phase includes prototype acceptance testing, trial installation(s) and at least one flight test. The SM collects the results of the testing phase and documents them in an updated acquisition package, which is then forwarded to the MDA for approval of Milestone B.

System Development & Demonstration – Milestone C

Approval of the updated documentation by the MDA at Milestone B marks the beginning of the Engineering Manufacturing Development phase. The main activity during this phase is TCTO validation, formerly referred to as kit-proofing. TCTOs, or Time Compliance Technical Orders are "instruction

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[31] For more information on OSS&E, including Air Force regulations, see http://engineering.wpafb.af.mil/osse/osse.asp.

manuals for modifying military systems of commodities within specified time limits[32]" and all modifications will have an associated TCTO. During the construction of the trial installation kit, the contractor (or depot) prepares a draft TCTO describing the installation instructions that will be followed for the TCTO validation and subsequent full-rate installations. The purpose of the validation is then to test the instructions for use in full-scale installation based on the installation according to the draft TCTO and the subsequent functional test and/or test flight. The TCTO is validated with the first available production kit.

While the trial installation is done under the contractor's (depot's) control and conditions, the following kit proofing is designed to prove that the modification may be implemented in the operational condition—either organically or as programmed depot maintenance (PDM)—in accordance with the TCTO. Secondly, the kit proofing validates that the form, fit, and function of the installation kit is compatible with the legacy system. Upon validation, the TCTO becomes the official installation instructions that will be used for the subsequent full rate modification installation.

The SM uses the results from the TCTO validation to update the acquisition package for Milestone C.

Production & Deployment

Milestone C approval is the production decision for the modification program. This also necessitates a change to the configuration baseline—maintained by the configuration control board—to update future support needs. At this point, the contracting officer exercises the production kit option on the trial installation contract issues after Milestone B, effectively initiating full-rate production

[32] The Air Force Tim Compliance Technical Order process is prescribed in Technical Manual TO 00-5-15.

according to the schedule detailed in the acquisition plan. Often, during the course of the modification (at least several years in most cases), there will be changes to the cost, schedule, and/or scope of the program. In this case, SM IPT changes the acquisition package and coordinates with the CCB. If changes in the funding profile are required, the P-3A budget documentation is updated to reflect these changes and the Air Staff works with the lead command to reprogram the modification. If this involves additional funding, the Air Force Council must appropriate it and issue a new budget and program authorization (BA/PA.)

At the completion of the modification, the SM IPT rescinds the TCTO and a history file of the modification is maintained in the program office for the life of the modified system.

Conclusion

The overview of the modification policy is an important step in this analysis because it is the foundation upon which all of the data is derived and is the focus of the conclusions of the research. It is also important because the various sources of information that define it have been integrated to provide a macro-level view of the process. It should be of interest to decision-makers involved in the process because it provides insight into how different components of the process work together. Finally, the process reveals the theoretical decision framework upon which the remainder of the analysis will build assumptions, inferences, and conclusions.

Chapter 4 - **Organizational and Programmatic Trends**

"And as water has no constant form, there are in war no constant conditions."

~ Sun Tzu, The Art of War

Overview

Trends in the past 10 years indicate a shift in the responsibility of aircraft modifications as a means of meeting Air Force capability needs. This chapter shows four different trends and their hypothesized impact on modifications. The trends discussed are:

- Evolutionary Acquisition and Spiral Development
- Reduced Aircraft Inventories
- New Accounting Regulations
- Aging Aircraft

This chapter will examine each of these four issues and present some potential impacts on future modification decision-making.

Evolutionary Acquisition and Spiral Development

Evolutionary acquisition was presented as one of the pre-production types of aircraft change in Chapter 2. Here it is presented again, not in the context of its direct impact on aircraft change, but as an acquisition strategy that will indirectly increase the importance of aircraft modifications in the post-production phase.

Evolutionary acquisition is intended to partition new acquisitions into batches of aircraft, with each subsequent batch representing increased capability. Depending on additional conditions, these batches of varying capability are either called increments or spirals. In either case however, the result of an evolutionary acquisition program is a heterogeneous fleet of aircraft with many different levels of capability corresponding to the different increments or spirals of the acquisition program. Figure 4.1 portrays the capability differential resulting from evolutionary acquisition.

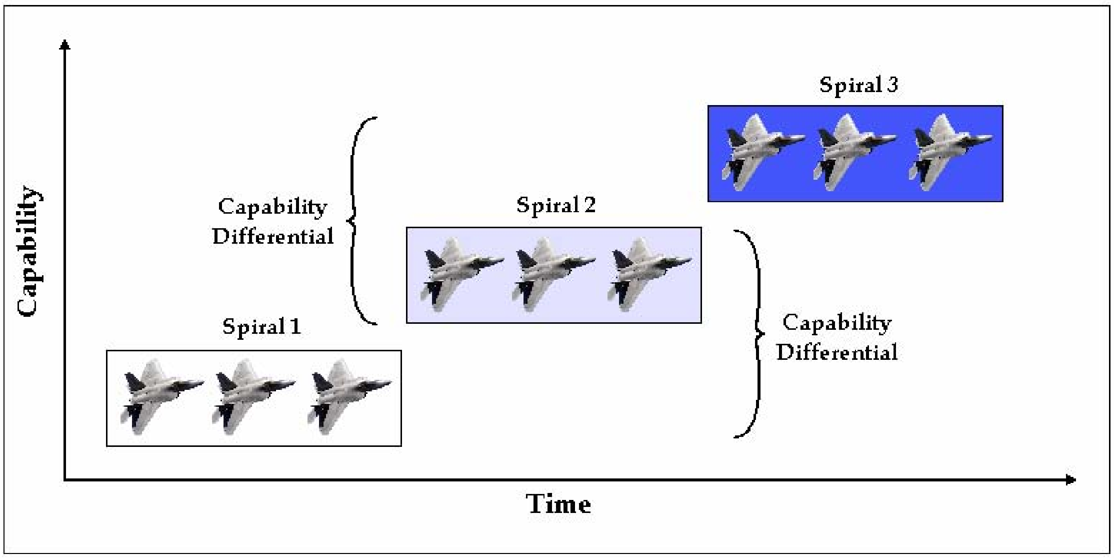

Figure 4.1 – Capability Differential Resulting from Evolutionary Acquisition

Heterogeneous aircraft fleets pose additional costs, both real and economic, which the Air Force has historically been unwilling to pay. These costs include additional support equipment for the aircraft, multiple sets of technical manuals, multiple levels of maintenance, uneven use of aircraft within a fleet, and even decreased pilot satisfaction[33]. One attempt to reduce this fleet heterogeneity and the associated costs is put forth in AFI 63-1101, *Modification Management*: "modifications should be accomplished on complete blocks or series of the system, equipment, or material.[34]"

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[33] One of the aircraft managers who contributed their knowledge to this dissertation had to specifically address the issue of pilots not wanting to fly aircraft with older technologies. These preferences among the pilots was resulting in an uneven distribution of the hours flown in the aircraft within the squadron.

[34] Air Force Instruction 63-1101 is the primary Air Force document regulating the process of aircraft modifications.

The F-22 Common Configuration modification is another example of how evolutionary acquisition will only make aircraft modifications a more important policy issue for the Air Force. By 2011, the Air Force is planning to spend $385 million to modify 49 existing aircraft to reduce fleet heterogeneity[35]. One of the specific goals of this modification is to "make early produced aircraft up to later configuration." As new spirals are delivered to the Air Force, there will be a continued need to modify the older spirals up to the new configuration.

When the F-35 Joint Strike Fighter (JSF) begins production, it seems likely that modifications driven by spiral development will be even more significant. This is due to a much longer expected production run with many more aircraft produced. If this acquisition strategy leads to more spirals of the JSF than in the F-22, then increased fleet heterogeneity will necessitate increased common configuration-type modifications.

Reduced Aircraft Inventories

One programmatic trend in the Air Force that is increasing both the need for new aircraft capabilities as well as the operational demands of existing aircraft is the decline in aircraft inventories. Chart 4.1 shows the reduction in inventories according to aircraft type. Although difficult to see on the chart, bombers have decreased the most, dropping 25% from 207 to 155 aircraft from 1996 to 2005. While bombers have decreased the most, the main constituents of the Air Force aircraft fleets are fighter, heavy[36], and trainer aircraft. These effects of the reductions in inventory are partially mitigated by an increase in the capabilities

[35] The 2006 President's Budget indicates that 49 F-22s are to be modified under the Common Configuration Implementation Program (CCIP) in order to "achieve a standardization".

[36] In this analysis, heavy aircraft refers to all cargo and tanker aircraft. Any aircraft that has a 'C' in the alphanumeric aircraft designation has been assigned to the category of 'heavy' aircraft type for simplicity and for consistency in the underlying assumptions about the relationships of various factors on the variables of interest.

of the remaining aircraft. Such an increase is accomplished through replacement and modifications.

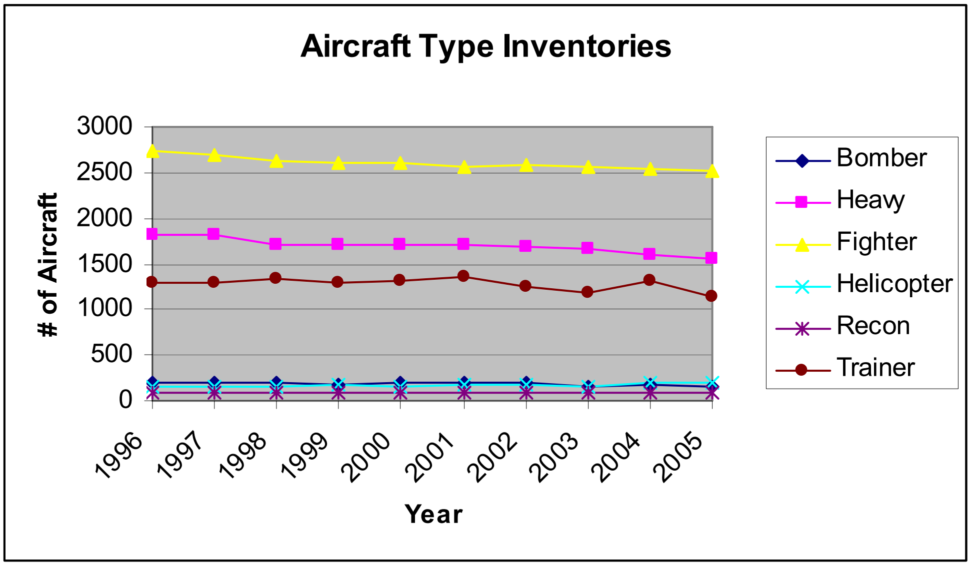

Chart 4.1 - Aircraft Inventories by Type

Cost and schedule overruns are an all-too-familiar trend for the Air Force in the efforts to procure next-generation aircraft in support of force modernization. When the F-22 program began in 1981, the Air Force planned for initial operational capability by 1996 and a total of 750 aircraft procured over the extent of the program. The F-22 did not reach operational capability until January 2006 and planned procurement is now only 178 aircraft.[37] Similarly, the Joint Strike Fighter (JSF), which was designed to replace over 1600 F-16s and A-10s, has fallen well below initial planned production levels. In planning, the JSF had a planned production of 1763 aircraft, but the current estimate is fewer than 1200 aircraft[38]. While the planned production has been reduced, expected unit costs have increased from $81 to $100 million since 2001[39].

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[37] Testimony before Congress by Michael Sullivan, http://www.gao.gov/new.items/d05519t.pdf
[38] Article in the Star Telegram on 9 February 2006: http://www.dfw.com/mld/dfw/business/13828766.htm
[39] Testimony before Congress by Michael Sullivan, http://www.gao.gov/new.items/d05519t.pdf

These reductions in planned replacement aircraft for existing aircraft necessitate the use of the legacy aircraft for longer periods of time. If the Air Force is to continue to improve capability and remain the world's most advanced air force, then aircraft modifications for these legacy aircraft will necessarily play an increasingly important role.

New O&S Guide

Another factor affect modifications as a component of modernization policy is an upcoming change in accounting rules. The draft Operations and Support (O&S) Manual published in 2003, is a forthcoming change in policy that will have a significant impact on accounting for modifications in the cost analysis division of the Air Force. Under this direction, most capability modifications[40] will be included in the accounts of aircraft O&S costs. This means that money that previously existed in a separately justified category (modifications) will now be included in the accounts for operating and support. Since this is only a draft manual, the 1992 manual is still in effect and categorizes capability modifications as acquisition programs but they do not appear in O&S costs; however, the chart here indicates that this change in accounting rules could result in a 8.1% increase in total Air Force O&S costs and up to 10.9% increase in O&S costs for various types of aircraft.

[40] Only major defense acquisition program (MDAP) modifications will not be included in O&S costs; however, this accounts for only a few of the modification programs since the criteria for an MDAP is over $365M in RDT&E or over $2.19B in procurement obligations.

	Total O&S*	Total Mods*	Ratio of Mods to O&S
Bomber	$18.46	$1.41	7.6%
Cargo/Heavy	$85.83	$6.35	7.4%
Fighter	$73.85	$6.59	8.9%
Helicopter	$7.00	$0.60	8.6%
Recon	$23.10	$1.68	7.3%
Trainer	$11.08	$1.21	10.9%
Total	$219.32	$17.84	8.1%

* - Figures in billions of FY 2000 dollars representing Years 1996-2005

Figure 4.2 - Ratio of Modifications to O&S

This change in accounting may be a step in the right direction to simplify and streamline the allocation of funds directed to aircraft, especially in light of the discussion in Chapter 2. One important caveat to this however, is that the money spent on aircraft change must be properly identified. One difficulty that exists in the current system of analysis is that changes to the aircraft are very difficult to identify in the cost data for all non-modification changes. As such, there is a significant amount of 3400-funded configuration changes that do not affect form, fit, or function, which cannot be separately identified from the rest of O&M funds.

Aging Modifications: An Aircraft Mission Approach

The effect of aging on different aircraft costs is a research area that has received considerable attention. One well-known study was conducted by Ray Pyles for the RAND Corporation and is cited in the literature review for this dissertation. In *Aging Aircraft*, Pyles reports an initial spike in time compliance technical order (TCTO) per aircraft workload[41] as well as another spike from 20-25 years. The initial spike is attributed to complications with initial use of "breaking-in" the

[41] TCTOs are the installation documents used to track modifications. The formal relationship between the TCTO data and the modification data is yet to be determined. There was limited success in the course of this research to link modification and TCTO data and eventually 62 modification programs were matched to respective TCTO data. Without any additional knowledge of the formal relationship between TCTOs and modifications, this matching cannot be validated. The relationship between TCTOs and Mods continues to be an area for future research.

aircraft, as well as changes that were unable to be incorporated during the production of the aircraft. The 20-25 year peak corresponds to a hypothesized design-age of the aircraft. Pyles' results are summarized below using a forecast of the TCTO workload per year per aircraft.

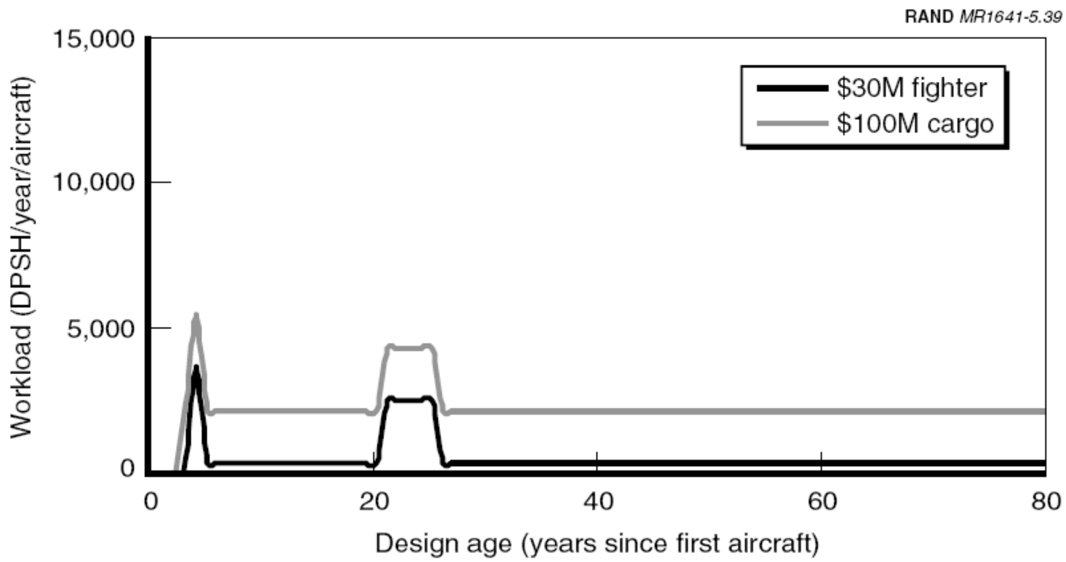

Figure 5.39—TCTO Workloads Stabilize After an Initial Unstable Period, Then Surge at the Start of the Third Decade of Operations

Chart 4.2 - Reproduction of Pyle's Forecast in *Aging Aircraft* (2003)

Pyles' work was the starting point for the age analysis in this research; however, when data are analyzed at the aircraft mission level, age-related effects were not obtained. At this level of aggregation, we conclude that modification obligation remained relatively constant as the aircraft ages.

Aging Effects Approach

There are three different measures of age that were attempted in the course of this research.

- WSCRS modified fleet peculiar age
- Initial operational delivery year for the mission design series

- Initial operational delivery year for the mission design

The WSCRS measure is a weighted average of aircraft ages within a particular fleet[42]. The initial operational delivery (IOD) for mission design series applies an age based on the number of years since a particular mission design series was delivered to the Air Force[43]. The IOD year for mission design is the most conservative approach and was selected for use in this research because it embodies a theoretical fixed technology level after initial operational delivery[44]. The IOD age of various mission designs is shown in chart 4.3.

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42 WSCRS, an Air Force financial system, calculates fleet peculiar age as the weighted average age of an average of the each of the individual aircraft ages weighted by the number of aircraft in each mission design series and averaged across the fleet of aircraft. A modified fleet peculiar aircraft would typically be an Aircraft Mission Class within an Aircraft MD. For example, all KC-135s are members of the same modified fleet peculiar aircraft. This was done because PDS data was only available for average MDS age. The calculation for this research reduces to the average age of each individual aircraft within a mission design. To see this consider that:

$$\frac{\sum_j \left(n * \left(\sum_{i=1}^{n} age_{i,j} / n \right) \right)}{m} = \frac{\sum_j \sum_{i=1}^{n} age_{i,j}}{m} = \frac{\sum_{i=1}^{m} age_i}{m}$$

since

$$\sum_j n_j = m_j$$

where

m = # of aircraft in a mission design, indexed by i
n = # of aircraft within a mission design series, indexed by j

43 For example, while the IOD year for the C-135 was 1957, the MDS KC-135R was introduced beginning in 1981. The WSCRS fleet peculiar age for the KC-135 in 2000 was 39.1.

44 In future research it seems a logical extension to apply a different age measure to different models. For example, while the capability is generally fixed after the initial operational delivery, it may be appropriate to apple an MD IOD year measure to models modeling capability modifications. Alternatively, the MDS may represent an increase in R&M and other cost saving measures and so an MDS IOD year approach may be more appropriate.

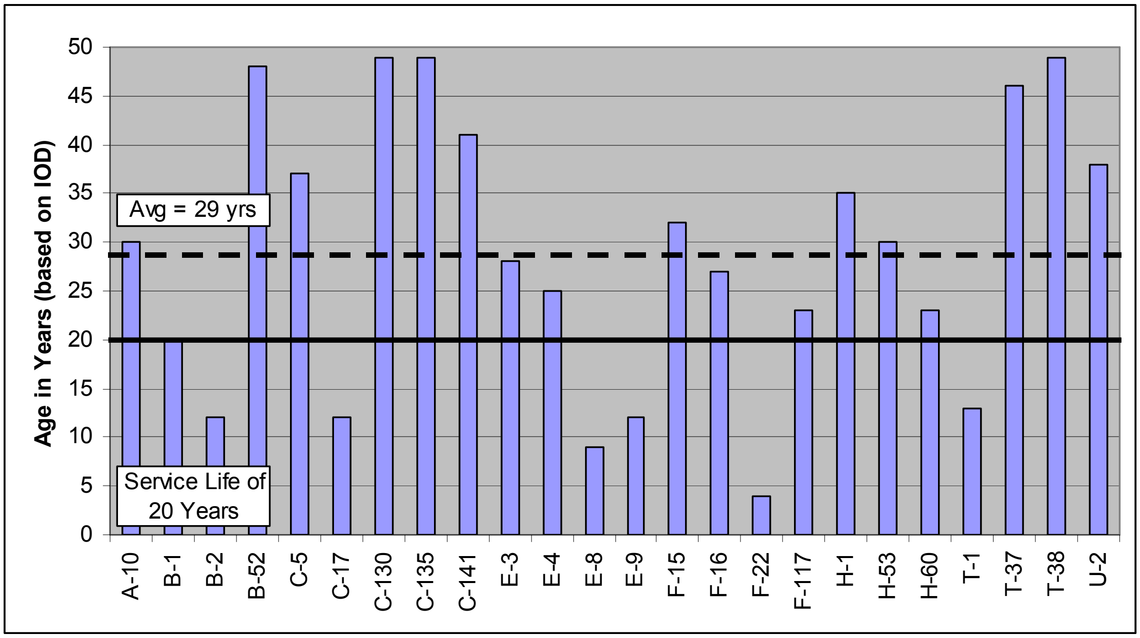

Chart 4.3 – 2005 IOD Age for Various Air Force Mission Design Fleets

A table of some of the IOD years used in this research is shown below.

MD	IOD Year	MD	IOD Year
A-10	1975	E-9	1993
B-1	1985	F-15	1973
B-2	1993	F-16	1978
B-52	1957	F-22	2001
C-5	1968	F-117	1982
C-17	1993	H-1	1970
C-130	1956	H-53	1975
C-135	1956	H-60	1982
C-141	1964	T-1	1992
E-3	1977	T-37	1959
E-4	1980	T-38	1956
E-8	1996	U-2	1967

Figure 4.3 - Initial Operational Delivery Years

For Various Mission Designs

In initial regression models a significant aging effect was found. There were two different forms that initially indicated that aircraft modifications were increasing as the aircraft aged. These two forms were a linear aging effect, and a dummy variable aging effect. In the case of the dummy variable approach, there was consistently a significantly higher effect when the aircraft was in the 15-20 year range.

Figure 5.3, in the next chapter shows a model with positive (significant) aging effects. The original interpretations for the significant positive aging effects based on these models provide one interpretation of aging. Instead of indicating an increase in total modifications costs as an aircraft ages, these models are revealing trends that modification programs are bigger as the age of the MD increases. This approach does not necessarily indicate an increase per-aircraft costs because there are not as many programs active at any given time. Chart 4.4 shows the relationship between modifications obligations and active programs.

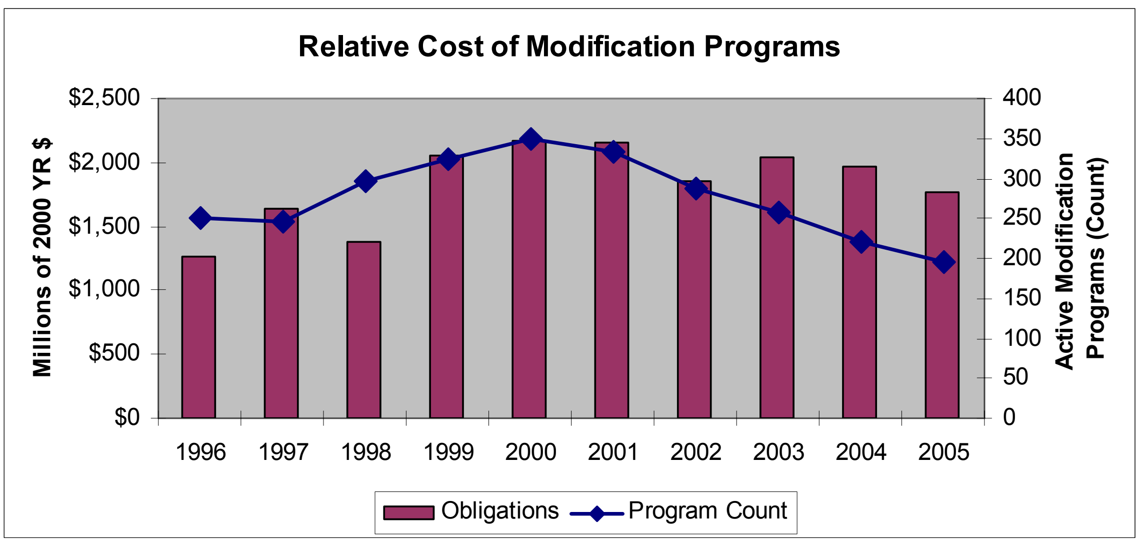

Chart 4.4 - Relative Cost of Modification Programs

When the reality of a decreasing number of active modification programs was brought into consideration, the actual effect of age on aircraft modification costs becomes more complex. Several separate models were estimated to investigate whether there was a significant increase in total costs per aircraft as an aircraft ages. These models incorporated two other aging relationships, in addition to the linear and dummy variable approach: a quadratic and a logarithmic effect.

The generic shapes that these different formulations take are displayed graphically in figure 4.3. Using MD level data, with various aging effect formulations, an aging effect was not identified.

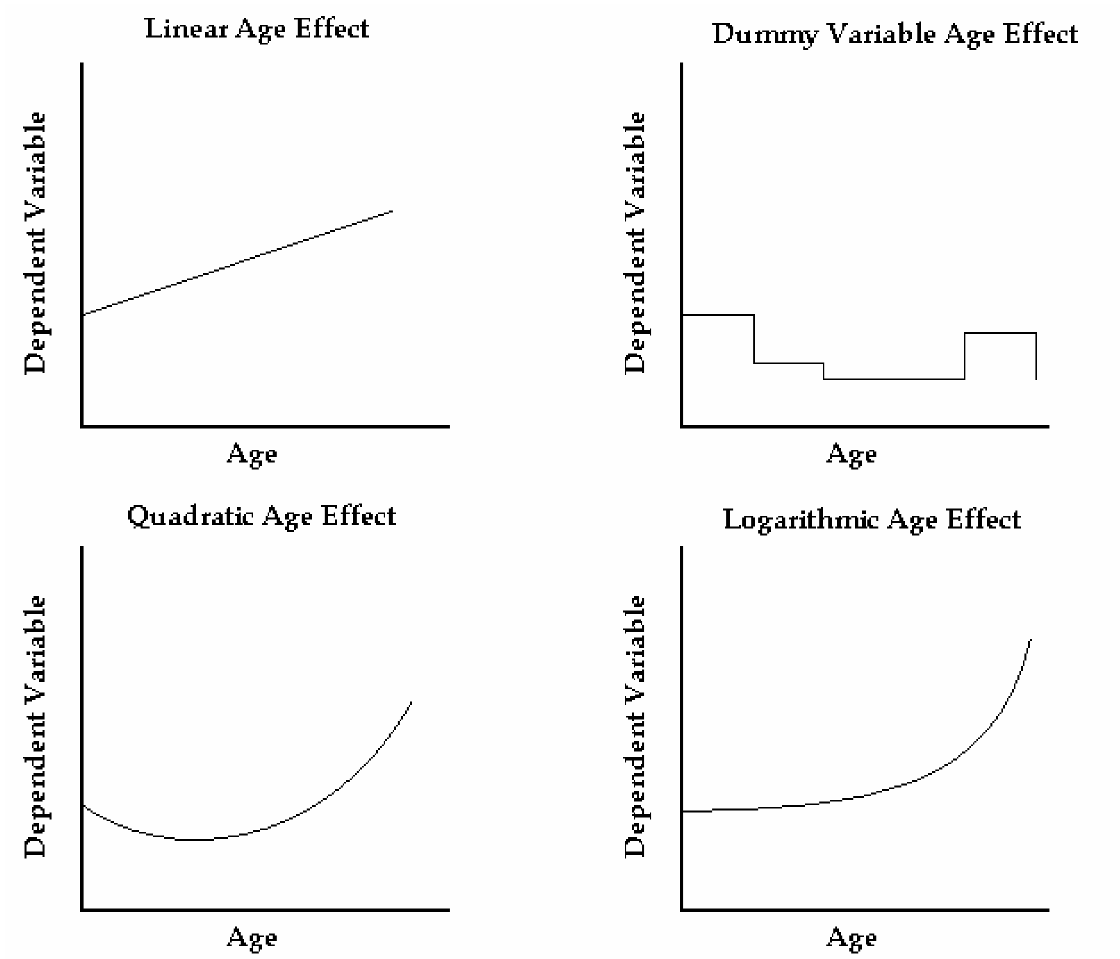

Figure 4.4 - Functional Formats of Aging Relationships

These per-aircraft aging models had the form:

$$ModsperAC_{MD,t} = \gamma_1 + \gamma_2 {}^* IODage_{MD,t} + \gamma_3 {}^* X_{MD,t} + \varphi_{MD,t}$$

where

$ModsperAC_{MD,t}$ = Modification Cost per mission design (MD) aircraft in year t

$IODage_{MD,t}$ = Age of Mission Design in the year t

$X_{MD,t}$ = Selected covariates for program i

When Air Force wide MD level data are modeled with interaction variables, which capture the interaction between age and aircraft mission type, significant linear aging effects are not identified. However, when plots of per-aircraft modifications by MD are examined (Figures 4.6 – 4.10), which frequently show peaks in modification costs, the situation proves to be more complex than can be captured with this aggregate model.

Figure 4.5 below shows one example of an aging model estimated in the goal of detecting a systematic per-aircraft aging effect. The model includes aircraft type and year fixed effects (FE), aircraft type and age interactions, and controls for total aircraft inventory and average unit flyaway cost for the aircraft. Similar models were also estimated using a logarithmic transformation on both the dependent and independent variables; however, there was not change in the significance of any of the aging parameters.

Dependent Variable: **per-aircraft modifications cost**	Coefficient (Std. Error)
constant	0.262 (0.588)
iodage	0.003 (0.026)
age*bomber interaction	0.005 (0.031)
age*heavy interaction	-0.002 (0.026)
age*helicopter interaction	-0.008 (0.041)
age*recon interaction	0.019 (0.035)
age*trainer interaction	0.012 (0.036)
bomber aircraft type FE	-0.170 (0.838)
heavy aircraft type FE	0.255 (0.621)
helicopter aircraft type FE	0.073 (0.946)
recon aircraft type FE	1.873 (0.695)
trainer aircraft type FE	-0.600 (1.225)
total aircraft inventory	-0.000 (0.003)
average unit flyaway cost	0.002 (0.000)
1997 year FE	0.155 (0.316)
1998 year FE	-0.081 (0.313)
1999 year FE	0.628 (0.318)
2000 year FE	0.139 (0.320)
2001 year FE	-0.024 (0.319)
2002 year FE	-0.158 (0.318)
2003 year FE	-0.135 (0.323)
2004 year FE	-0.058 (0.321)
2005 year FE	-0.089 (0.328)
N =	224
Adjusted R^2 =	0.310

Figure 4.5 – Aging Effects Model[45]

How then are the positive effects of age based on unit and modification program costs reconciled with the models that suggest that there is no change in total per-aircraft costs as an aircraft ages? It appears that over the time-period represented by the data, aircraft modification programs were consolidated and increased in size and scope. As a result, when the data are examined at the MD level either with or without controls for AC Mission, an aging effect is not identified. This is consistent with AFI 63-1101 guidance:

[45] In this model, the reference is fighters, so the constant and aging-effects may be interpreted in relation to fighter aircraft. This model also has results outside of the context of aging:

- Positive AUFC coefficient indicates that more expensive aircraft require more modifications
- Recon aircraft require more modifications per aircraft than do others

> "With the exception of safety-critical or operationally-critical modifications, the program manager is encouraged to group modifications into block changes so overall kit cost can be reduced, man-hours for installation can be optimized, and weapon system downtime can be minimized."

As a result, while individual modifications programs did grow in size and cost; however, there were fewer programs. Therefore, even though there is growth at the individual program level, there is no average increase at the aggregate aircraft mission level.

The lack of aging effects seems contrary to some past research as well as to logical reasoning and experience. Pyles (2003) shows a significant spike in workload at the 20 year point. One explanation for the difference in results, besides the fact that Pyles is measuring workload and this research is measuring cost, is that Pyles used Command level workload, which includes depot and line maintenance, whereas cost data evaluated in the IDECS data is based on contractor data. While contractor data may not grow over time or spike around 20 years, other workloads (and costs) which are not in the data used for this report may exhibit similar aging patterns[46]. Nevertheless, it is an important issue that future research will hopefully illuminate.

Another problem that exists with the results is that a positive aging effect seems logical and a failure to find this appears rationally inconsistent. One distinction that may prove useful in future analysis is between modifications for cost reasons and modifications for capability reasons. As aircraft age and some technologies become obsolete, modifications for cost reasons are expected to rise. In contrast, as an aircraft ages, the marginal capability increase provided by a

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[46] Some evidence suggests that TCTO's are generated for aircraft inspections. While these would certainly be expected to spike around the times corresponding to the increases shown in Pyle's work, they would not appear in contractor modifications data.

modification may actually decline due to form, fit, function, and integration constraints. As a result, capability modifications may actually decrease on a per-aircraft basis over time. Thus, one potential aging effect is that the proportion of modifications may shift as an aircraft ages from predominantly capability modifications to predominantly cost related modifications.

In order to help visualize the per-aircraft[47] trends for various aircraft in the Air Force, per-aircraft modifications are provided in the following charts. These charts show peaks in modification at various times for different aircraft. These peaks may indicate an implicit constrained optimization that occurs at the aircraft mission level that masks MD specific aging effects. Aging effects within a budget constraint are a logical extension to this research.

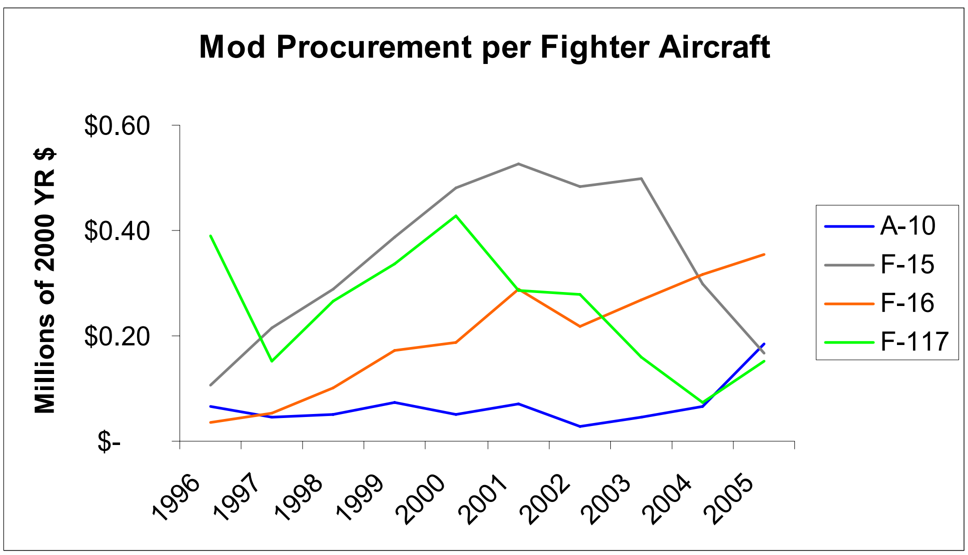

Chart 4.6 - Unit Modification Procurement Obligations per Fighter Aircraft

[47] Charts 4.6-4.10 show the modifications costs per aircraft in inventory in each of the years

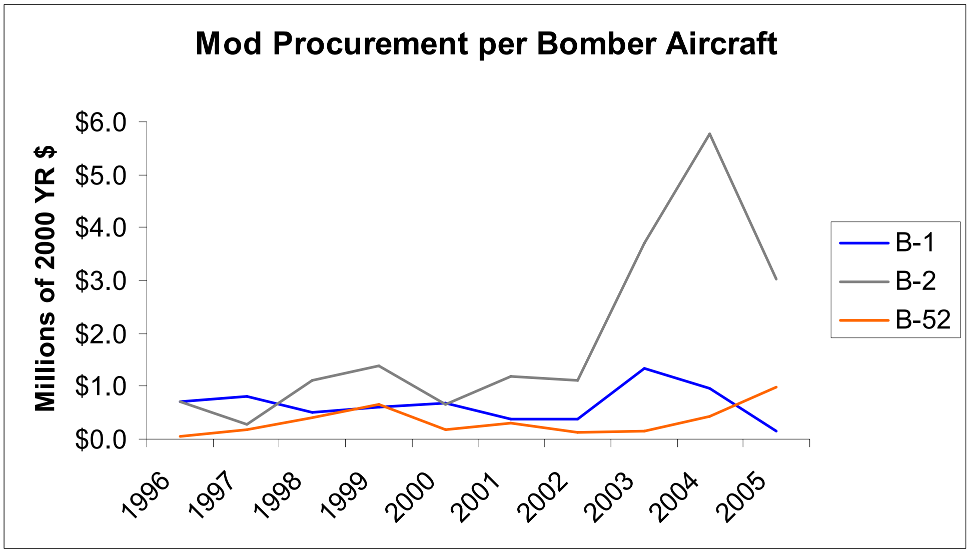

Chart 4.7 - Unit Modification Procurement Obligations per Bomber Aircraft

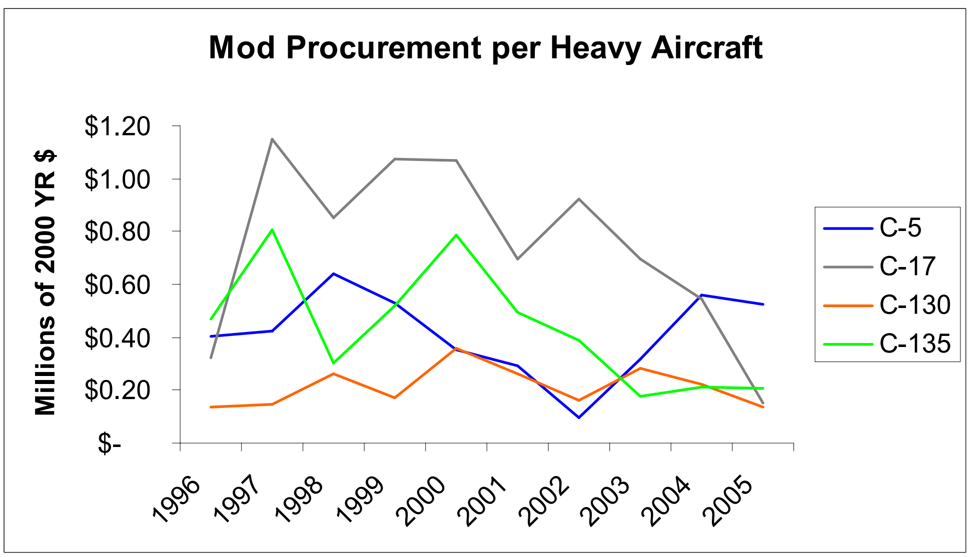

Chart 4.8 - Unit Modification Procurement Obligations per Heavy Aircraft

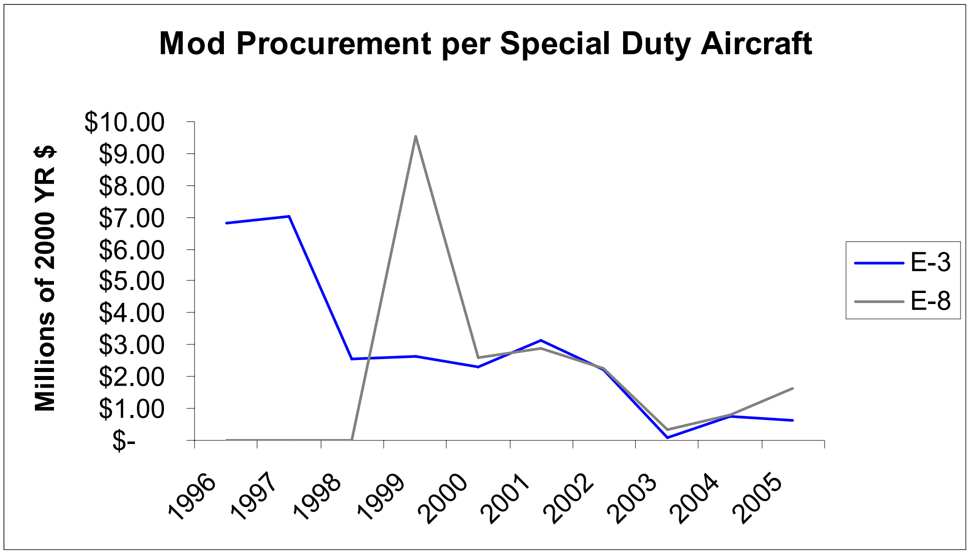

Chart 4.9 - Unit Modification Procurement Obligations per Special Duty Aircraft

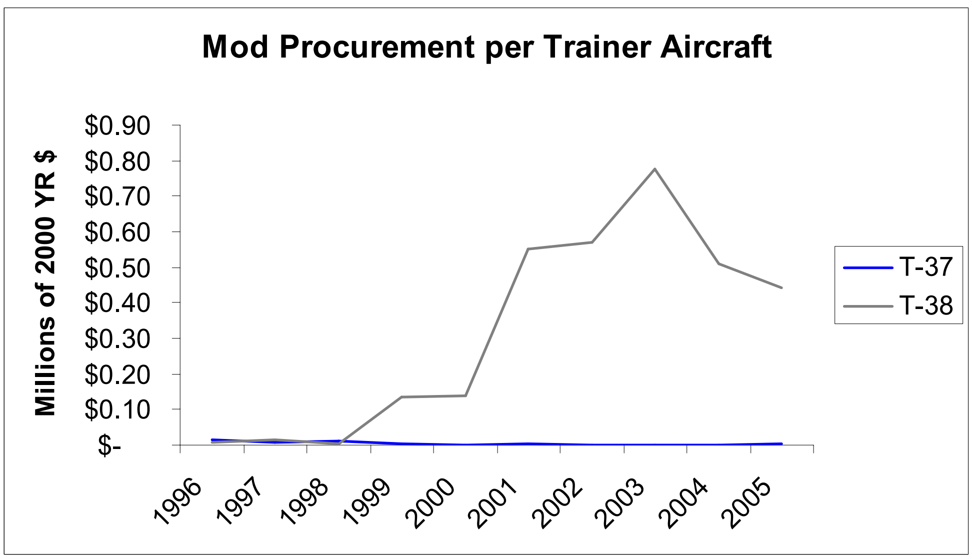

Chart 4.10 - Unit Modification Procurement Obligations Per Trainer Aircraft

Effects at the Individual MD Level

The lack of significant aging effects at the per-aircraft level was somewhat unexpected, particularly because, as charts 4.6-4.10 show, there appears to be an upward trend for several aircraft, especially the F-15 and F-16 (these aircraft will be discussed specifically in Chapter 7). While there are exceptions at the individual aircraft level, it is important to note that this analysis was formulated to find effects that exists either Air Force wide using aircraft MD level data with the aging effects assessed at the aircraft mission level. While these aggregate affects were not found in this research, modifications aging effects for particular aircraft should be explored using more MD specific data and substantive knowledge. While such effects will not be systematically explored in this research, they are an important area for future research.

Conclusions

The organizational and programmatic trends in the Air Force suggest that aircraft modifications will become an increasingly important component of Air Force policy. Spiral development, aging legacy fleets, and reduced replacement fleets all point towards an increasing role for modification to play as the Air Force marches forward in technology and capability. While it may be a step in the right direction to simplify the accounting for modifications and aircraft maintenance as suggested by the draft O&S guide, it will be important for future decision-makers that the money spent on aircraft change be properly identified so that continuing analysis in search of an optimal aircraft modification and replacement strategy is possible. Even without a systematic increase in modifications as an aircraft ages, modifications are increasingly important to maintaining a capable aircraft fleet that is aging and without prospect for total replacement in the near future.

Chapter 5 - **Separate Procurement Planning**

"The secret of all victory lies in the organization of the non-obvious"

~Marcus Aurelius

Overview

The analysis of the modification process presented in Chapter 3 revealed some subtle aspects of the current policy that may potentially be altered to better serve Air Force needs in the future. One such aspect is the requirement that a modification kit be installed in the same year that it is procured. This has the effect of inextricably linking the installation and procurement schedules. As is often the case, this constraint could potentially increase costs for the modifications selected through this policy. This goal of this chapter is to analyze historical modifications programs to ascertain whether or not cost savings may be realized in future years by relaxing this specific constraint built into the modification policy.

Jointly Dependent Procurement and Installation Schedules

The jointly dependent procurement and installation schedule policy issue is, in part, one of the results of the budget cutbacks after the Cold War. The high Cold War defense budgets contributed to a process of buying large quantities of aircraft equipment that were never installed or used due to aircraft availability constraints. In other words, the budget allowed the Air Force to purchase many aircraft parts and upgrades, but due to the scheduling of the Air Force's airplanes, there was never a convenient time to bring the aircraft in for the installation. As a result, these parts remained in storage until they became obsolete.

In response to this practice, RAND helped the Air Force develop the strategy of "lean acquisition." One component of lean acquisition is that modification kits must be installed in the year they are procured. Specifically, AFI 63-1101 para. 3.9.5 states:

> "Complete kits must be programmed each FY. If it is necessary to procure kits in more than one fiscal year to comply with phased procurement, each kit must be procured lead-time away from planned installation. Advance procurement is not authorized for mod programs unless specifically approved by Congress."

In other words, this means that a kit must be procured such that it will be installed in the same fiscal year it is received from the contractor. Only Congress can authorize procuring the modification kits in advance of the installation year.

While it is clear that this policy will reduce the costs of storing the modification kits, it also necessitates that procurement and installation be synchronized. Under this policy, procurement of modification kits follow decreased procurement rates and longer procurement durations. This chapter will examine the historical trends in modifications with the goal of determining the potential to save money by relaxing this constraint. In particular, the goal is to increase modification program efficiency by allowing a greater separation of the procurement phase of the program from direct linkage to the installation phase to allow for higher procurement rates of aircraft modification kits. In order to determine whether or not separating the procurement and installation planning of aircraft modifications is a feasible option, this research will estimate the effects on unit costs of increasing the rate of procurement and the rate of installation. Therefore, if the estimated effects are higher for procurement than for installation, it may be advantageous to the Air Force to consider planning each phase separately to obtain efficient rates for both procurement and installation. Even if separate procurement is not possible, increasing the amount of time permitted between procurement and acquisition may also prove to be cost effective.

Two Categories of Modifications

The models in this chapter are segregated into two categories: one for the avionics modifications and one for the non-avionics modifications. The reasons for having separate models are two-fold. One is summarized in figure 5.1: There are different structures for the two different programs.

	Avionics	Non-Avionics
Average Aircraft Modified per Program	148 aircraft	210 aircraft
Average Modification Program Cost	$58.6 million	$47.3 million
Average Modification Program Duration	5.6 years	4.9 years

Figure 5.1 - Avionics and Non-Avionics Program Characteristics

The second reason, and potentially the main reason to estimating different models for avionics and non-avionics modifications is that the two different types of modifications represent two fundamentally different reasons for modifying an aircraft. To see this, consider that once an aircraft mission design is designed, the flying performance characteristics of that aircraft are essentially fixed. They may be modified slightly in subsequent spirals or else by a modification program, but such changes are very limited and do not represent a significant departure from the initial design. The mission design platform has become, in effect, an "aerodynamic bus".

The term "aerodynamic bus" indicates that an airframe is an aerodynamic platform for the avionics suite. This avionics suite—all of the installed electronics—is the variable technology that will be constantly altered and improved both during production (for spiral development programs) and throughout the post-production life cycle. The avionics are therefore the variable technology in an aircraft. This concept is further described in the literature on open architecture in Air Force planning. A further generalization is that avionics modifications differ from non-avionics modifications in that former category represent an increase in the technological capability of the aircraft while the latter category of modifications are a form of investment in the durable good—the avionics bus.

Due to this inherent difference, it seems appropriate to focus the attention of the analysis and conclusions on avionics modifications. While this helps to consolidate the assumptions made in the model development and thus the resulting conclusions, it does not severely limit the data available for analysis. Chart 5.1 shows the relative distribution of modifications obligations across component groups. Avionics modifications are clearly the predominant category of the modifications conducted.

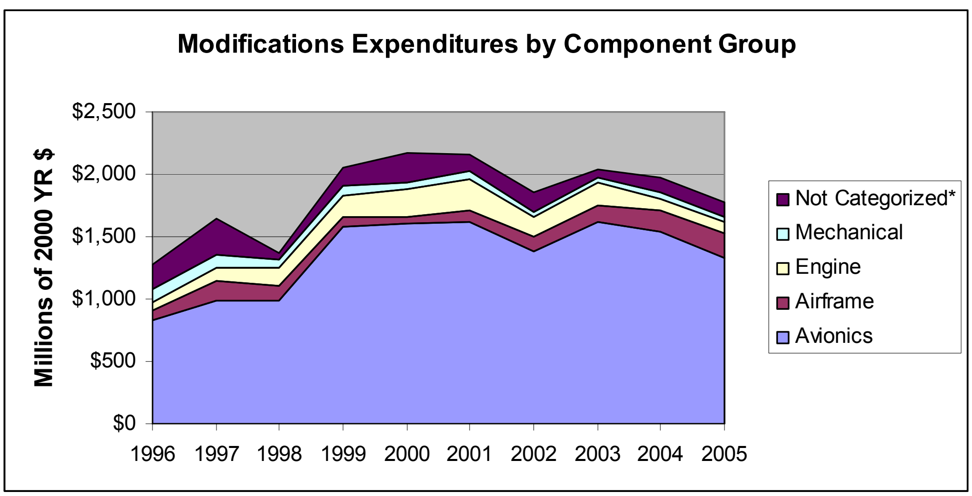

Chart 5.1 - Modification Obligations by Component Group[48]

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[48]* This footnote concerns the asterisk (*) in chart 5.1. Not Categorized indicates that the modification program was sufficiently complex to prevent any one component group being

While the focus of the model results and conclusions discussions in this research will be concerned with avionics modifications, the non-avionics modifications results will often be presented alongside the avionics models as a point of comparison and as a foundation for additional future analysis.

Modeling Procurement Unit Cost

This research examines the effect of the yearly procurement quantity and the average program procurement rate on the unit cost of a modification with a policy response model. In building the models, this relationship was estimated with a series of models that become progressively complex to control for various factors that might obscure the true relationship of the yearly quantity and average procurement rate to the yearly unit cost for the modification. The general form for these models is as follows:

$$ln(procurement\ uc_{i,t}) = \alpha + \beta_1 * ln(proc\ qty_{i,t}) + \beta_2 * ln(ac\ total_i) + \beta_3 * ln(duration_i) + \beta_4 * ln(comp\ val_i) + \lambda_i + \gamma_i + \tau_t + \varepsilon_{i,t}$$

Where:

proc qty	:	quantity procured in year t for program i
ac total	:	total aircraft modified for modification program i
duration	:	duration in years of modification program i
comp val	:	value of the component group modified in program i
γ_i	:	controls for the complexity of modification program i
λ_i	:	fixed effects for aircraft mission type for program i
τ_t	:	fixed effects for the installation year t

The progression of the avionics modification model is presented in figure 5.2.

assigned the obligations. It is often the case that these modifications involve some component of the avionics on the aircraft although they are not included in any of the avionics calculations.

		Avionics Unit Cost Equantions		T
Basic OLS				
	ln (unit cost) =	-0.195	constant	-0.83
		-0.644	ln (procurement quantity)	-15.46
		-0.164	ln (total aircraft modified)	-3.39
		0.824	ln (duration of procurement)	11.42
		0.122	(aircraft average unit flyaway cost)	3.34
	Adjusted R^2 =	0.498		N = 992
Complexity Controls				
	ln (unit cost) =	-0.794	constant	-2.90
		-0.610	ln (procurement quantity)	-15.25
		-0.279	ln (total aircraft modified)	-6.13
		0.689	ln (duration of procurement)	9.95
		0.015	start year age	3.90
		0.047	ln(value of component modified)	2.86
		NR	(other complexity controls)	NR
	Adjusted R^2 =	0.576		N = 935
Aircraft Type & Year Fixed Effects				
	ln (unit cost) =	-0.936	constant	-2.89
		-0.588	ln (procurement quantity)	-14.55
		-0.263	ln (total aircraft modified)	-5.27
		0.667	ln (duration of procurement)	9.36
		0.009	start year age	2.12
		0.051	ln(value of component modified)	2.90
		NR	(complexity controls)	NR
		NR	(aircraft type fixed effects)	NR
		NR	(year fixed effects)	NR
	Adjusted R^2 =	0.583		N = 935

NR - results not reported for the sake of overall clarity

Figure 5.2 - Progression of Avionics Model

Since the progression of the models is identical for avionics and non-avionics modifications, the non-avionics model is presented next (alongside the final avionics model in the progression above) with a discussion of the model parameters for both the avionics and non-avionics following. The interpretation of specific parameters of interest is reported last.

Dependent Variable: **ln (procurement unit cost)**	Avionics*	Non-Avionics*
constant	-0.936 (0.323)	-1.382 (0.440)
ln (procurement quantity)	-0.588 (0.040)	-0.527 (0.72)
ln (aircraft total)	-0.263 (0.050)	-0.422 (0.091)
ln (procurement duration)	0.667 (0.071)	1.084 (0.124)
start year age	0.009 (0.004)	0.009 (0.006)
ln (value of component group modified)	0.051 (0.018)	0.019 (0.014)
capability DV	0.292 (0.101)	0.275 (0.141)
form-fit-function DV	0.818 (0.142)	0.522 (0.394)
rdt&e DV	0.871 (0.107)	1.166 (0.235)
bomber aircraft type FE	0.124 (0.145)	0.557 (0.255)
heavy aircraft type FE	0.483 (0.127)	0.336 (0.172)
helicopter aircraft type FE	-0.265 (0.244)	0.497 (0.375)
recon aircraft type FE	0.132 (0.182)	0.890 (1.175)
trainer aircraft type FE	0.135 (0.322)	0.746 (0.312)
1997 year FE	-0.201 (0.177)	-0.139 (0.284)
1998 year FE	-0.294 (0.165)	-0.309 (0.269)
1999 year FE	-0.102 (0.155)	-0.320 (0.257)
2000 year FE	-0.244 (0.153)	-0.772 (0.240)
2001 year FE	-0.320 (0.158)	-0.658 (0.252)
2002 year FE	-0.177 (0.174)	-1.045 (0.291)
2003 year FE	-0.165 (0.172)	-0.379 (0.352)
2004 year FE	-0.049 (0.181)	-0.247 (0.346)
2005 year FE	-0.172 (0.202)	-0.045 (0.336)
N =	935	661
Adjusted R^2 =	0.583	0.511

* - parameters are in the form: coefficient (std. error)

Figure 5.3 - Procurement Unit Cost Models

<u>Progression of Model Development</u>

Both sets of models progress in identical form. The initial OLS relationship establishes two key inverse relationships: One relationship is between the natural log of procurement quantity in one year and the natural log of modification kit unit cost in the same year; the other is between the natural log of the total aircraft modified for the entire program and the natural log of modification kit unit cost in a given year.

Natural logs are used instead of the unadjusted quantities and rates because it ensures that proportional changes across programs of different magnitudes have the same comparable effects and because it stabilizes the variance across observations. The coefficients of these log-log models are interpreted as a 1% change in the independent variables has a [coefficient]% change in the dependent variable. The specific results of the two sets of models will be discussed following this joint discussion of model progression.

Complexity Controls

While the negative coefficients of quantity and rate are consistent with *a priori* hypothesized results, they do not sufficiently indicate a causal relationship between higher quantities and rates and lower unit costs. These relationships could be the result of factors external to the model. In particular, an explanation for these relationships that is consistent with production theory is that more complex modification kits take longer to produce and therefore it is not the constraint of installation that is causing the slower procurement, but rather the complexity of the modification kit[49].

In order to control for the influence of complexity on the model parameters, this model used five controls for complexity. Two of the controls are continuous variables, and three are dummy variables. The two continuous variables are the age of the aircraft at the start of the modification program and the (natural log) of the value of the component group modified. With respect to age, one may refer to the discussion in Chapter 4, where the start year age variable was modeled based on MD IOD age, MDS IOD age, and a weighted average age. These models use modification level unit cost data and show statistically significant level aging effects. However, as noted in Chapter 4, this can occur at the

[49] This is the classic omitted-variables bias. It can be shown that a variable positively correlated to the unit cost and negatively correlated to the production rate will cause the estimate of the effect of procurement rate to be biased downward. This is seen in figure 5.2, where the complexity controls reduce the absolute value (increase in real terms) the effect of procurement quantity on unit costs.

individual mod program level as the unit cost of programs rise, but be offset by a decrease in the number of programs over time.

The value of the component group modified was calculated from a subset of the D041 database, listing data for line replaceable and shop replaceable units (LRUs and SRUs). Of the dummy variables (DV), the form-fit-function variable was created based on a perusal of all of the modification descriptions in the dataset. It identifies any modifications that have a significant form, fit, or function constraint mentioned in the program description. The capability indicator was generated from the modification program type field included in the original IDECS data and the RDT&E indicator is triggered if there are any RDT&E expenditures reported for the modification program. For each of these five controls, the positive coefficient indicates that more complex modifications have higher unit costs. The specific numbers will not be discussed, but are presented for transparency in the model and for potential future use.

Aircraft Type Fixed Effects

Even when controlling for the complexity of the modification, there is still a possibility that differences in aircraft design and management may affect the yearly procurement quantities and procurement rates as well as the unit cost of the modification kits. If this does occur, then it violates the independence assumption of ordinary least squares. Therefore, the next progression of the model incorporates fixed effects for the aircraft type[50]. The reference type is fighters, so all comparisons are to be made with fighters.

[50] Models were also developed using aircraft MD fixed effects. On one hand this seems more intuitive since each MD is managed separately. Alternatively, it is useful to think of different MD within an aircraft type as substitutes. Because of this, and because the MD fixed effects did not change the model significantly, the type fixed effects are reported.

These fixed effects absorb any component of the error term that may impact both the independent and dependent variables and are related to the aircraft type. Therefore fundamental differences across aircraft types, such as type of flying, Major Command (MAJCOM), or importance in current Air Force missions, are prevented from impacting the parameters of interest: the coefficients of yearly procurement quantity and average procurement rate. The only significant effect suggests that heavy aircraft (cargo, transport, and refueling aircraft) have historically had higher modification unit costs.

Year Fixed Effects

When considering the aircraft type fixed effects, it seems a logical extension to consider changes within aircraft fleets across time. Time changes may impact contingency factors, MAJCOM management, modification management, contractor philosophy, and technology levels. Again, these characteristics may invalidate the assumptions of OLS and distort the true effect of production quantity and rate on unit costs. The final progression of the model uses year fixed effects to control for such variations across the 10-year period of data. These fixed effects exhibit not pattern that is deemed relevant to this policy issue, so specifics are not discussed in this report.

First-Difference Model and Alternate Specifications

Despite controlling for various effects in the OLS model, there are always unobserved/unmeasurable variables that are constant over time for a particular mod program that are omitted from the model. These omitted variables will always bias the other parameters in the model, either up or down. Also, explicitly controlling for these types of variables may affect the estimated quantity effects though the correlation of these variables with production quantity. One way to control for these omitted variables is to use a first-difference approach. In the first-difference model, the data from one prior year is subtracted from the current year data, and the difference is modeled using a regression technique (in this case OLS). The effect is that only those changes that occur from year to year are left in the first-difference model. To see this, consider the following equation that was used for modeling procurement unit costs in time *t* for the procurement unit cost models reported previously:

$$ln(procurement\ uc_{i,t}) = \alpha + \beta_1{*}ln(proc\ qty_{i,t}) + \beta_2{*}ln(ac\ total_i) + \beta_3{*}ln(duration_i) + \beta_4{*}ln(comp\ val_i) + \lambda_i + \gamma_i + \tau_t + \varepsilon_{i,t}$$

Similarly, an equation for modeling procurement unit costs in time t-1 is:

$$ln(procurement\ uc_{i,t-1}) = \alpha + \beta_1{*}ln(proc\ qty_{i,t-1}) + \beta_2{*}ln(ac\ total_i) + \beta_3{*}ln(duration_i) + \beta_4{*}ln(comp\ val_i) + \lambda_i + \gamma_i + \tau_t + \varepsilon_{i,t-1}$$

Subtracting the second equation from the first yields the following first difference model:

$$fd\_ln(proc\ uc_{i,t}) = \delta_1{*}fd\_\ ln(proc\ qty_{i,t}) + \upsilon_{i,t}$$

Where :

$$fd\_ln(proc\ uc_{i,t}) = \Delta ln(procurement\ uc_{i,t})$$

$$= ln(procurement\ uc_{i,t}) - ln(procurement\ uc_{i,t-1})$$

$$fd\_\ ln(proc\ qty_{i,t}) = \Delta ln(proc\ qty_{i,t}) = ln(proc\ qty_{i,t}) - ln(proc\ qty_{i,t-1})$$

$$\upsilon_{i,t} = \Delta\varepsilon_{i,t} = \varepsilon_{i,t} - \varepsilon_{i,t-1}$$

Estimating the first-difference model with the modification data yields the following estimates:

Dependent Variable: **first difference ln (proc unit cost)**	Avionics*	Non-Avionics*
first difference ln (procurement quantity)	-0.413 (0.022)	-0.316 (0.066)
N =	629	470
Adjusted R^2 =	0.366	0.597

* - parameters are in the form: coefficient (std. error)

Figure 5.4 - First Difference Procurement Unit Cost Model

While the first-difference model does attenuate the quantity effects of the standard OLS model, they are still significantly negative.

Alternate Model Specifications and Non-Constant Variance

There is a potential objection to using ordinary least squares (OLS) model to model unit costs for all aircraft in the Air Force inventory. The difference in fleet sizes, such as between the 1,335 F-16s and the 21 B-2s, is a likely source of heteroskedasticity in an OLS model. Tests for such non-constant variance do confirm a violation of the basic OLS assumptions with respect to constant variance. As a result, models using other techniques were estimated in order to gauge the effect of this violation. Two of these techniques, OLS with robust estimators and weighted least squares (WLS) models, are shown in figure 5.9.

Dependent Variable: **ln (procurement unit cost)**	OLS	OLS with Robust Standard Errors	WLS
constant	-0.936 (0.323)	-0.792 (-2.38)	-0.924 (-2.73)
ln (procurement quantity)	-0.588 (0.040)	-0.586 (-11.21)	-0.505 (-11.47)
ln (total aircraft modified)	-0.263 (0.050)	-0.247 (-4.33)	-0.337 (-6.66)
ln (duration of procurement)	0.667 (0.071)	0.701 (8.70)	0.792 (10.16)
ln(value of component modified)	0.051 (0.018)	0.049 (2.83)	0.062 (3.56)
(complexity controls)	not reported	not reported	not reported
(aircraft type fixed effects)	not reported	not reported	not reported
(year fixed effects)	not reported	not reported	not reported
N =	935	935	730
Adjusted R^2 =	0.583	0.591**	0.614

note: parameters are in the form: coefficient (t-statistic)

** - value is unadjusted (standard R^2)

Figure 5.5 – Alternate Procurement Models

The models shown above, as well as other models examined, all suggest that while there is evidence of heteroskedasticity, OLS models still do a reasonable job of estimating the proper effect of quantity and duration on unit costs.

Procurement Unit Cost Conclusions

All of the procurement unit cost models shown above indicate that increasing the procurement quantity in a given year will reduce the unit costs for that year. Similarly, those models that include duration indicate that there is a significant reduction in cost by reducing the total duration of procurement for a given program. Together, these conclusions suggest that the Air Force would realize a cost savings if procurement rates were increased and procurement durations were subsequently decreased. After reviewing the models for installation unit cost, some hypothetical scenarios will be generated to estimate the potential cost savings.

Modeling Installation Unit Cost

Installation unit cost models were developed in similar manner to those of the procurement unit cost models. The intention of these models is to determine if there is a structural difference between procurement and installation that would justify separating the planning and permitting higher procurement rates by relaxing the requirement to install in the same year as procurement. Again, the distinction between avionics and non-avionics was made. Installation unit cost as the dependent variable is defined as the total installation costs in a period divided by the number of aircraft on which the modifications were installed. The final regression used for both the avionics and non-avionics models was:

$$ln(installation\ uc_{i,t}) = \alpha + \beta_1 * ln(inst\ qty)_{i,t} + \beta_2 * ln(ac\ total)_i + \beta_3 * duration_i + \lambda_i + \gamma_i + \tau_t + \varepsilon_{i,t}$$

Where:

inst qty	:	quantity installed for program *i* in year *t*
ac total	:	total aircraft modified for modification program *i*
duration	:	duration in years of modification program *i*
γ_i	:	controls for the complexity of modification program *i*
λ_i	:	fixed effects for aircraft mission type for program *i*
τ_t	:	fixed effects for the installation year *t*

This formulation led to the results reported in figure 5.5.

Dependent Variable: **ln (installation unit cost)**	Avionics*	Non-Avionics*
constant	-3.379 (0.410)	-1.230 (0.421)
ln (installation quantity)	-0.284 (0.042)	-0.316 (0.066)
ln (aircraft total)	-0.372 (0.056)	-0.464 (0.093)
ln (installation duration)	0.132 (0.015)	0.233 (0.022)
ln (value of component group modified)	0.074 (0.022)	-0.084 (0.014)
capability DV	0.077 (0.120)	-0.358 (0.158)
rdt&e DV	0.937 (0.118)	0.789 (0.214)
bomber aircraft type FE	0.321 (0.165)	0.001 (0.328)
heavy aircraft type FE	1.054 (0.141)	1.161 (0.194)
helicopter aircraft type FE	0.731 (0.319)	0.678 (0.461)
recon aircraft type FE	1.124 (0.210)	N/A**
trainer aircraft type FE	0.824 (0.389)	0.283 (0.300)
year Fixed Effects	not reported	not reported
N =	899	470
Adjusted R^2 =	0.437	0.597

* - parameters are in the form: coefficient (std. error)

Figure 5.6 - Installation Unit Cost Models

<u>First-Difference Installation Unit Cost Model</u>

Similar to the procurement unit cost model, installation unit can be modeled with a first-difference approach. The model was developed using the same logic as described for procurement unit cost and is estimated as:

$$fd\_ln(inst\ uc_{i,t}) = \delta_1 * fd\_\ ln(inst\ qty_{i,t}) + \upsilon_{i,t}$$

This formulation yields the following estimates:

Dependent Variable: **first difference ln (inst unit cost)**	Avionics*	Non-Avionics*
first difference ln (installation quantity)	-0.151 (0.025)	-0.114 (0.029)
N =	658	363
Adjusted R^2 =	0.051	0.038

* - parameters are in the form: coefficient (std. error)

Figure 5.7 - First-Difference Installation Unit Cost Model[51]

As in the case with modeling procurement unit cost, the fixed-effects model attenuates the (negative) magnitude of the quantity effect; however, the estimates are still significantly negative.

Interpreting the Models Together

The differences between the procurement and installation unit cost models are suggestive of an inherent structural difference between the procurement and installation phases of a modification program. Because of these differences, it is likely that the requirement to install a modification kit in the same year that it is procured will constrain one or both of these phases by making them codependent. In accordance with anecdotal evidence presented throughout the course of this research that suggests that installation schedules are relatively fixed, these models will not be used to make a case for increasing installation rates. While the evidence presented here suggests that doing so will reduce unit costs, operational requirements present many opportunity costs for modification installation that will further complicate such an analysis and so it will not be addressed within the scope of this research.

Instead of adjusting procurement rates indirectly by adjusting the installation schedule, if the requirement to install within the same year of procurement is relaxed such that procurement rates may be increased, this analysis suggests that a cost savings may be realized. Such a change will not affect the characteristics

[51] The installation unit cost model for avionics has more observations than does the procurement unit cost (658 > 629) This is because of gaps in the procurement schedule that limit a first-difference model did not occur in the installation schedule.

of the modification kit or the operations tempo and installation schedule. Additionally, it must be noted that these results are not intended to be universally applicable; indeed, if all programs adopt this strategy, storage costs and additional planning resources may be more inefficient than the current policy. It is quite possible however, that providing for this option will allow planners to choose on an individual program level whether or not cost savings may be realized and plan accordingly. Therefore, the final section of this chapter will be devoted to providing specific estimates of cost savings under several scenarios.

Implementing These Results

The procurement unit cost model may be used to estimate the savings associated with increasing the yearly procurement quantities such that the procurement duration is subsequently shortened. The chart below estimates the savings associated with changing an F-16 avionics modification program to modify 240 aircraft beginning at an aircraft IOD age of 20 (year 1998). The originally planned modification is to take 6 years with a uniform procurement rate (40 per year). The modification is an increase in capability, will require a significant form, fit, and/or function modification, and will require an research, development, test & evaluation (RDT&E) investment. Based on an estimated unit cost of $730,000 and total cost of $175.1 million, doubling the procurement rate to 80 kits per year for 3 years will reduce unit costs to $485,000 based on the OLS estimated effect, or $548,000 based on the first-difference (FD) estimated effect. When these savings are aggregated, they represent between a $43.6 million (based on the first-difference estimate) and $58.6 million cost savings (based on the OLS estimate) for the avionics program. A similar change for an identically planned non-avionics modification program is estimated to save between $13.8 million and $21.5 million.

		F-16 Modification 1		Adjustment		
Procurement Quantity		**40**		**80**		
Aircraft Total		240		240		
Procurement Duration		**6**		**3**		
Age at Program Start		20		20		
Capability Modification?		yes		yes		
Form-Fit-Function Constraint?		yes		yes		
RDT&E Required?		yes		yes		
				OLS Estimate		FD Estimate
Avionics Unit Cost Prediction	$	729,710	$	485,450	$	548,056
Avionics Total Cost Prediction	$	175,130,291	$	116,507,969	$	131,533,350
Non-Avionics Unit Cost Prediction	$	293,017	$	203,353	$	235,379
Non-Avionics Total Cost Prediction	$	70,324,004	$	48,804,602	$	56,490,850
				total program savings		
Avionics Program				**$43,596,941 - $58,622,322**		
Non-Avionics Program				**$13,833,154 - $21,519,401**		

Figure 5.8 - Estimated F-16 Modification Program Cost Savings[52]

Using a similar approach, 4 more modification program changes are modeled, along with the estimated total program savings associated with increasing the procurement rate. These estimates are summarized in Figure 5.9.

[52] The installation unit cost model for avionics has more observations than does the procurement unit cost (658 > 629) This is because of gaps in the procurement schedule that limit a first-difference model did not occur in the installation schedule.

	F-16 Modification 2	Adjustment	C-5 Modification	Adjustment
Procurement Quantity	40	80	25	42
Aircraft Total	240	240	125	125
Procurement Duration	6	3	5	3
Age at Program Start	20	20	40	40
Capability Modification?	yes	yes	yes	yes
Form-Fit-Function Constraint?	no	no	yes	yes
RDT&E Required?	no	no	no	no
		total program savings		total program savings
Avionics Total Cost	$32,347,289	$17,046,089 - $18,793,983	$61,897,553	$26,246,133 - $29,294,873
Non-Avionics Total Cost	$13,002,130	$2,557,597 - $3,978,699	$31,260,181	$15,970,331 - $17,532,627

	KC-135 Modification	Adjustment	B-52 Modification	Adjustment
Procurement Quantity	60	99	24	47
Aircraft Total	595	595	94	94
Procurement Duration	10	6	4	2
Age at Program Start	50	50	45	45
Capability Modification?	no	no	yes	yes
Form-Fit-Function Constraint?	no	no	yes	yes
RDT&E Required?	no	no	yes	yes
		total program savings		total program savings
Avionics Total Cost	$98,285,832	$41,675,687 - $46,516,717	$110,910,322	$58,446,543 - $64,439,610
Non-Avionics Total Cost	$41,198,829	$21,047,828 - $23,106,831	$71,916,654	$44,665,338 - $48,373,202

Figure 5.9 – Estimated Modification Program Cost Savings

While all of these estimated savings are generated using hypothetical aircraft modification programs, it is reasonable to assume that there would be savings may be made by making similar adjustments to future planned modification programs. Although the estimated effects of such changes may be artificially high[53], these numbers nevertheless indicate that an increase in efficiency may be possible through a policy adjustment.

[53] Such high price-quantity relationships may be indicative that an accounting artifact is inflating the true elasticity. While the IDECS data does not provide insight into this, it offers another area of future research.

Chapter 6 – **Safety Modifications**

"War is the province of chance. In no other sphere of human activity must such a margin be left for this intruder. It increases the uncertainty of every circumstance and deranges the course of events."

- Karl von Clausewitz, On War

Overview and Definition

Safety modifications are an important component of the modification policy. They represent an improvement to one of the most important components of Air Force flying: aircrew safety. AFI 63-1101 para. 1.2.2. formally defines safety modifications as: "[P]ermanent modifications which correct material or other deficiencies which could endanger the safety or health of personnel or cause loss or extensive damage to systems or equipment[54]."

The paragraph continues to describe the relative importance of safety modifications in the modification planning and implementation processes.

> "Safety modifications have priority and precedence over all other permanent modifications. Safety modifications will follow the same procedures as permanent modifications, but shall take priority over all other modifications for funding and implementation. All safety modifications will be accomplished in the minimum amount of time required to ensure a safe and operationally effective fix."

[54] One of the effects of this research was to identify a category of safety modifications within the modification type described in IDECS. Such modifications were not labeled "Permanent-Safety" modifications. This was brought to the attention of decision-makers involved with the IDECS database and the issue is being resolved. Both identifications for safety modifications are intended to identify a safety modification and that there has been an accidental proliferation of designations within the data.

Due to the priority placed on safety modifications, this analysis should also be of interest to deceision-makers involved with other, non-safety, high-priority modification programs.

Background on Safety Modifications

Although safety modifications are an important component of the modification policy, they have historically been a small component of the modifications obligations. Averaging just under $46 million per year in the period from 1996 to 2005, safety modifications make up less than 3% of all modification obligations. During this time there were 66 safety modifications implemented for an identifiable deficiency[55]. Charts 6.1 and 6.2 show that safety modifications are subdivided among four different component groups with a distribution that is contrary to some presuppositions.

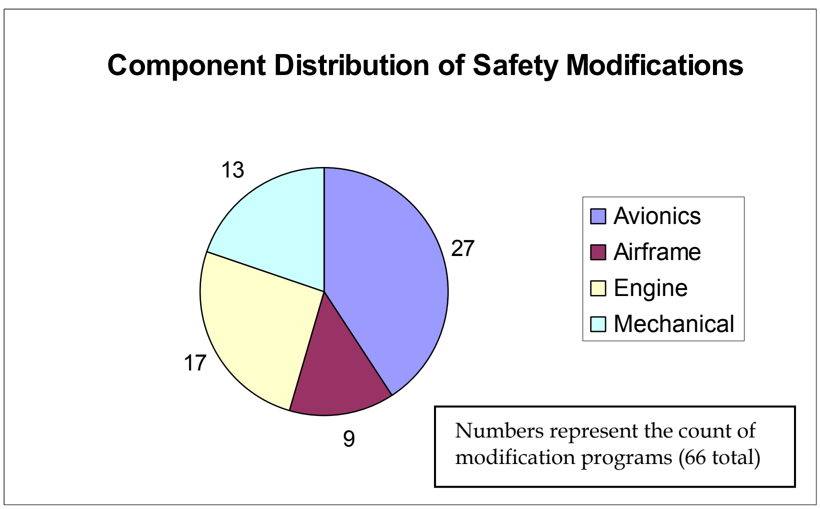

Chart 6.1 - Component Distribution of Safety Modifications

[55] There are an unknown number of additional low-cost safety modifications that were not used in this dataset because of data limitations. The 66 programs used were all significant enough to warrant individual attention in the procurement documents (P-Docs: see Appendix 1)

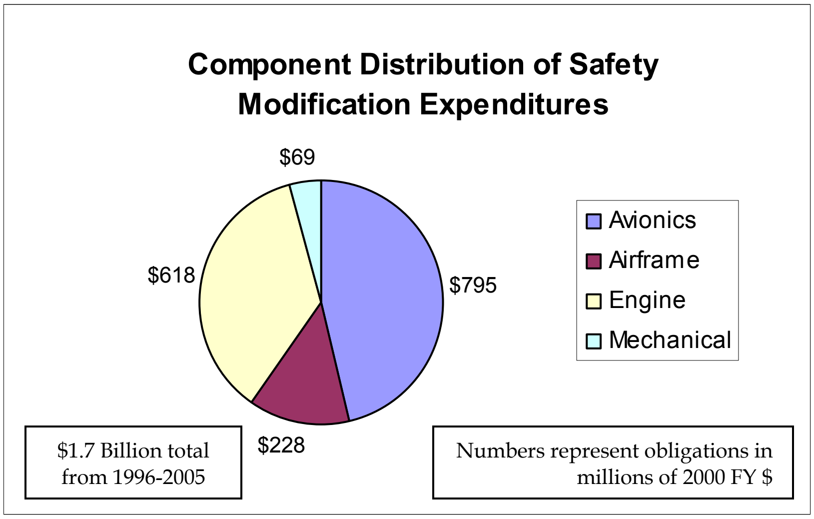

Chart 6.2 - Component Distribution of Safety Modification Obligations

One of the insights from this chart is that the safety modifications are not necessarily distributed according to the relative capital values of the different component groups. One of the most surprising statistics is the engine component group. This is surprising because engine modifications play such a minor role in the non-safety modifications; however, it is reasonable to assume that such a highly-specialized mechanical component and the power-plant for the entire aircraft will be a critical component in the safety considerations of the aircraft.

Charts 6.3 and 6.4 also provide some insight into the distribution of safety modifications. In this case, the surprising category is the "Heavy" category.

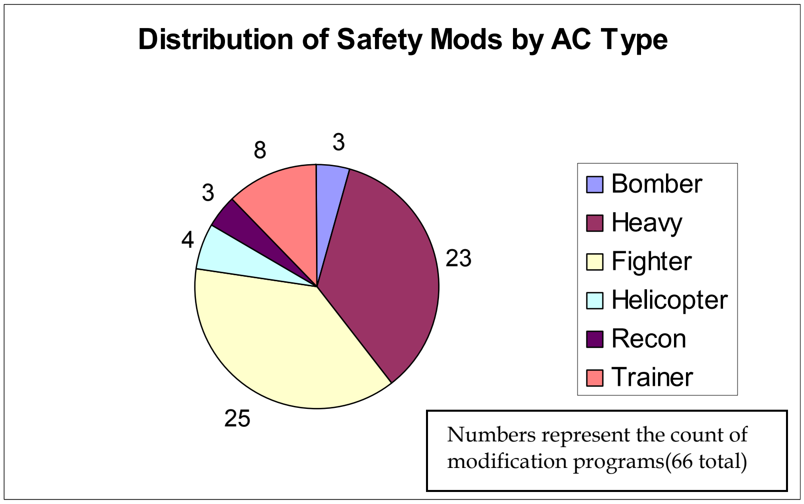

Chart 6.3 - Distribution of Safety Modification by Aircraft Type

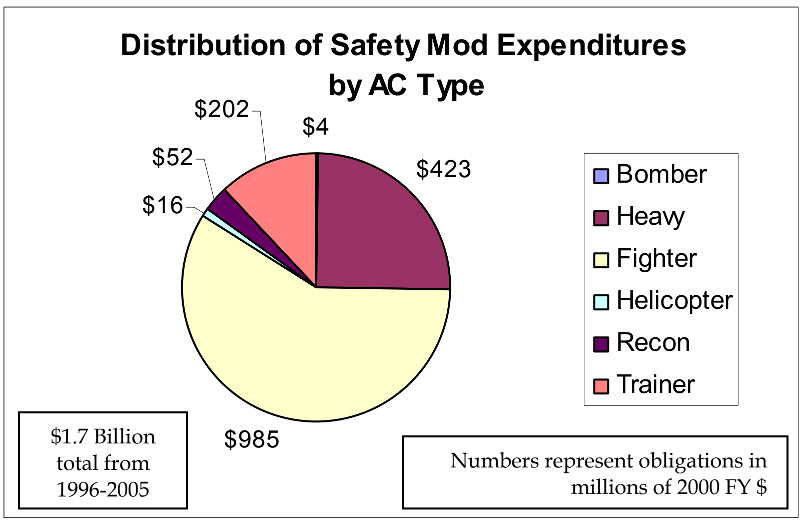

Chart 6.4 - Expenditure Distribution of Safety Mods by AC Type

By way of reminder, heavy aircraft include all cargo transports and tanker aircraft. The unexpectedly high count of safety modifications for transports and tankers is a possible subject of future analysis.

Requirements for Documentation

Safety modifications are not an arbitrary subset of all modifications; they must be designated according to a prescribed manner. A modification may be designated a safety modification in one of two ways:

1 – The modification corrects a material deficiency that caused a class A mishap[56] or,

2 – The single manager (SM) or the commander of the lead command pursues 'safety' designation through a 4 step process. This process is:

> 1 – The modification will correct a deficiency that is determined "to have the potential to cause, at a minimum, serious injury to personnel or extensive damage to systems/equipment."
>
> 2 – Risk analysis determines a modification is necessary and identifies "elements of procedure and schedule associated with its optimal accomplishment."
>
> 3 – The SM takes "appropriate interim actions to limit operational risk prior to modifications occurring, including the consideration of system grounding or restrictions."
>
> 4 – Finally, "[t]he SM and lead command/CC must forward a request for a safety modification designation, to the Chief of Air Force Safety for approval. If approved, the modification shall be identified as a safety modification."

There are two ways in IDECS to identify a safety modification. One way is to specify a modification as a "Permanent-Safety" modification, which is a subset of permanent modifications. In this situation, the modification type may be

[56] A Class A mishap is defined as one where there is loss of life, injury resulting in permanent total disability, destruction of an AF aircraft, and/or property damage/loss exceeding $1 million.

separately specified as either "Capability Improvement", "Service Life Extension", "Reliability & Maintainability", or "Safety". While it may seem appropriate that all permanent-safety modifications would necessarily be designated as safety modification in the modification type, this is not the case. It does, however, lead to the second way of designating a safety modification. The modification type may be designated as "Safety"; although a modification may belong to the subset of "Permanent" modifications (as opposed to permanent-safety).

Once a potential modification has been designated as a safety modification, modification planners may begin to implement the modification with reprogrammed funds before the completion of the current budget cycle. This reduces the amount of time necessary to begin implementation the modification but does not affect the installation schedule.

High-priority Safety Modifications

Safety is a crucial component of Air Force operations. Safety modifications in particular are a way to address necessary changes to an aircraft in response to safety concerns. Because of such importance, the Air Force regulations specifically state that "[a]ll safety modifications will be accomplished in the minimum amount of time required to ensure a safe and operationally effective fix." Based on this requirement, it is expected that safety modifications will have a higher installation rate. Figure 6.1 reveals that the rate is indeed higher on average for safety modifications.

Modifiction Type	Installation Rate	Installation Duration	Unit Cost	Aircraft Total
Safety Modifications	104 AC per Year	5.2 Years	$ 305,014	343 Aircraft
Non-Safety Modifications	49 AC per Year	4.9 Years	$ 1,605,996	154 Aircraft

Figure 6.1 - Comparison of Safety and Non-Safety Modifications

The installation rate is significantly higher for safety modifications (significant at the 99.9% level); however, the installation durations are not statistically different between the two categories[57]. There is also a large unit cost difference between safety and non-safety modifications. On average, a safety modifications costs $305,000 per aircraft while a non-safety modification costs slightly over $1.6 million. The final difference that appears from the chart is that on the whole, safety modifications affect a greater number of aircraft: 343 per modification on average, compared to 154 for non-safety modifications.

These descriptive statistics lead to further questions however. Although there is such a big difference between safety and non-safety modifications from a programmatic standpoint, it is not clear that safety modifications are installed any more expediently than are non-safety modifications. If, instead of testing on a program level, the test is extended to examine whether equal numbers of safety modifications kits are installed as non-safety modification kits grouped by aircraft mission design and year, the test indicates a marginally significant difference. More specifically, in a given year, the hypothesis that a greater number of safety modification kits are installed is not significant at the 90% level[58]. At this level, it is not clear that safety modifications are actually installed more quickly than are safety modifications. The differences between these two tests and some caveats will be further discussed at the end of this chapter.

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[57] Both tests were conducted on 66 observations, using an one-sample t-test. With 65 degrees of freedom the null hypothesis that the installation rates are equal can be rejected in favor of the alternative hypothesis that safety modifications have a greater rate. This test has a significance greater than 99.9%. Alternatively, a similar test fails to reject the hypothesis that the durations of safety and non-safety modifications are different.

[58] This result was generated by conducting a paired t-test with the null hypothesis that safety modification kits for an MD were equivalent to non-safety kits installed in the same year. This hypothesis may be rejected in favor of the alternative that safety kits were greater in number with $P > t = 0.163$; DOF=57.

The tests reported in the previous paragraph seem somewhat inconclusive as to whether safety modifications are actually installed more quickly than are non-safety modifications. Therefore, in order to further test this hypothesis, a series of regressions was estimated. These coefficients of interest are compared for these regressions in figure 6.2.

Dependent Variable: Installation Rate (Aircraft per Year)	Aircraft Type, Component, and Year F.E.	Controlling for Mod Unit Cost	Controlling for Aircraft Total
safety modifications	**+ 57.06 (18.64)**	**+ 32.09 (19.49)**	**+ 8.53 (16.03)**
ln (unit procurement cost)	-	- 25.52 (2.24)	- 14.12 (1.95)
aircraft total	-	-	+ 0.225 (0.013)
Adjusted R^2 =	0.07	0.24	0.49
N =	751	638	638

Std. Error is reported in the parenthesis

Figure 6.2 - Comparison of Installation Rate Regressions

The first regression (shown in the second column of figure 6.2) shows the effect of safety modifications when controlling for aircraft type, component modified, and budget year in a fixed effects model. These controls serve to increase the estimated effect of safety modifications on installation rate. The interpretation for this coefficient is that safety modifications have an average installation rate of 57 aircraft per year higher than do non-safety modifications. This is consistent with the planning requirements in AFI 63-1101 and is significant with a t-statistic of 3.06.

As noted previously, safety modifications differ significantly in the average cost per aircraft modified, and so the second regression (column 3 of figure 6.2) shows the effect of safety modifications on installation rate to be lower than the first regression. The new estimated effect is that safety modifications install about 32 more kits per year than do non-safety modifications. Since the standard error remains relatively unchanged, this estimate is significant with a t-statistic of 1.65.

Finally, the third regression includes the total aircraft modified in the program as a control as prescribed by the descriptive statistics previously reported. With this control, the increased installation rate for safety modifications drops to an additional 8.5 aircraft per year on average; however, since the standard error still remains relatively constant, this effect is statistically insignificant with a t-statistic of slightly less than 0.6.

This series of regression models suggests that despite the increased importance of safety modifications and the resultant policy of higher priority and increased installation rates, there is, in fact, no difference between safety modifications and non-safety modifications for installation when controlling for program characteristics. This evidence supports the hypothesis posed by several decision-makers in the modification process and restated in this dissertation that the limit on modification planning is the availability of aircraft for other-than-operational use. The analysis suggests that safety modifications are not installed more quickly than non-safety modifications is consistent with this hypothesis.

Early Budget Results

In order to examine this hypothesis further, this model will use the earliest budgets available for the modification programs to examine whether safety modifications were originally planned for a faster installation[59]. Figure 6.3 shows the regressions using the earliest budgets available in the data.

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[59] This is possible because of the structure of the IDECS data. One budgeting requirement is that all modifications budgets include cost figures for the entire program. Thus the first program budget shows all of the planned cost and quantity figures. This is what is used for modeling using "earliest budgets".

Regressions using data from the earliest budgets	Aircraft Type, Component, and Year F.E.	Controlling for Mod Unit Cost	Controlling for Aircraft Total
safety modifications	**+ 51.22 (17.68)**	**+ 27.99 (16.40)**	**+ 3.18 (13.95)**
ln (unit procurement cost)	-	- 23.12 (1.99)	- 12.69 (1.81)
aircraft total	-	-	+ 0.233 (0.015)
Adjusted R^2 =	0.06	0.23	0.45
N =	748	658	658

Figure 6.3 - Comparison of Initially Budgeted Installation Rate Regressions

The series of three regression models reported in figure 6.3 follows the same logic as the three models using the most recent budgets in figure 6.2. Because the discussion of those regression models applies in this series as well, the coefficient of interest is the one for safety modifications in the third model, with a value of 3.18. Again, this coefficient is insignificant and we fail to reject the hypothesis that safety modifications have a higher installation rate than do non-safety modifications when controlling for program characteristics.

Interpreting the Results for Policy Use

One of the problems in controlling for program characteristics in the regression models and specifying a greater disaggregation in the paired t-test is that such manipulations may in fact control for the very variance that is of policy interest. To see this, consider that a safety modification is often a relatively small change to the aircraft and applied to all aircraft in a mission design. Alternatively, many non-safety modifications are more significant changes and applied only to a particular block (or other subset) of a mission design. Thus, in controlling for these differences, safety modifications are only compared to other small, non-safety modifications applied to the entire MD. When this comparison is made, safety modifications are not found to be significantly different. This has two possible policy interpretations. One is that, as has been posited throughout this dissertation, safety modifications have the same limitations in installation planning and therefore are not able to be implemented any faster. In this case, the clause in AFI 63-1101 requiring safety modifications to be installed as fast as possible, is redundant. Under this circumstance, safety modifications are constrained by all of the demands placed upon the aircraft and the process of identifying and classifying safety modifications is an unnecessary measure to take because it will not hasten the modification installation.

The other policy interpretation to the results presented in this chapter is that safety modifications are implemented as quickly as possible according to regulations, and that other similarly structured modifications are also. Designating a modification as a safety modification does not does not appear to alter the installation in a significant way. This would also indicate that the process of identifying and classifying safety modifications is redundant and an impediment to efficiency.

Conclusions

The analysis in this chapter suggests that on average, a modification program designated as a safety modification will be scheduled and installed more quickly than the average non-safety modification program. However, when compared to similar modification programs in a systematic way, safety modification programs do not appear to have significantly different installation rates. This indicates that unless there are other advantages to the process of identifying and classifying safety modifications that are not addressed in this chapter, the process is using limited Air Force resources without achieving a significant effect. If this is the case, it may be worthwhile to re-examine the process of designating safety modifications and see if it may be simplified to free up resources for alternative planning efforts.

Chapter 7 – **The Future of Aircraft Modifications**

"Strategy is the art of making use of time and space. I am less concerned about the latter than the former. Space we can recover, lost time never."
~Napoleon Bonaparte

The first 6 chapters of this research have explored the historic trends of Air Force aircraft modifications. This final chapter will examine implications for the future, by using the historical data to predict future budgets for F-15 and F-16 modifications. The chapter will then conclude with some observations on these budget predictions. As mentioned previously, there are potentially other effects, such as budget constraints, that are controlling modifications budgets and convoluting the effect of age on modifications costs. Chart 7.1 suggests that rather than a particular aging effect, there are more complex budget constraint effects, operational needs/constraints, and potentially time effects at work.

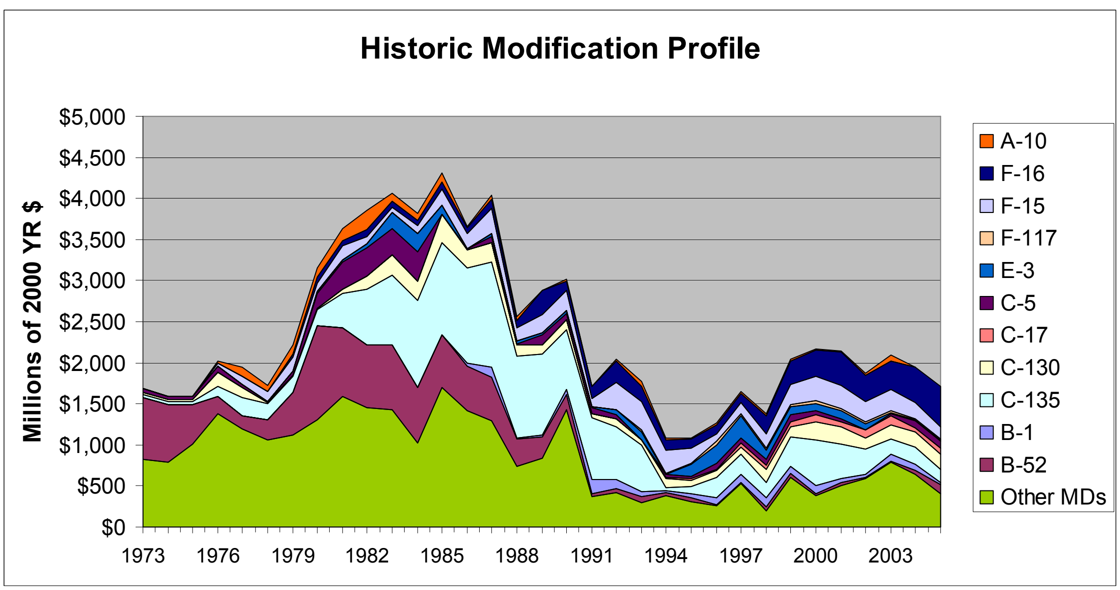

Chart 7.1 - Historic Modifications Obligations for Select Mission Designs[60]

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[60] This chart is a combination of the IDECS data used throughout this research and data compiled by Rob Leonard for the RAND Corporation. See Leonard, 2002.

Since the data used for chart 7.1 is only available in aggregate form, it was not used in the preceding chapters; however, it will be useful in broadening the historical perspective to decrease the variance of predictions. This modification data will be used to generate predictions for the categories of F-15 and F-16 modifications levels. These categories were selected because fighters have historically played such an important role and there is a high degree of uncertainty associated with expectations for the next generation of fighters. These models are intended as a starting point for decision-making and should lead easily to future policy-analysis that incorporates a more in-depth examination of modification predictions.

Predicting Future F-15 and F-16 Modifications

While this research was not able to identify any significant aging effect in the aggregate date, it may be possible that this is because of the complexity of the aircraft change framework that exists in the Air Force. If the two capability work-horse aircraft of the Air Force are singled out, that is analysis is focused on the F-15 and F-16, there are some lessons that may be gleaned for the for the near as well as the not-so-near future Air Force where replacement aircraft have been integrated into the aircraft inventory.

Chart 7.2 supports the theory that modifications and replacement aircraft are complimentary goods, particularly in the years 1996-1998. The sharp decline in these years for F-15 and F-16 modifications corresponds to a $2.1 billion investment in the F-22 program and a $600 million investment in the Joint Strike Fighter (F-35 JSF) program[61]. While this correlation between investment in replacement aircraft and a drop in legacy aircraft modifications is not explicitly stated in DoD records, it is consistent with economic theory.

[61] Numbers used from a Department of Defense news article. http://www.defenselink.mil/news/Mar1996/n03061996_9603063.html

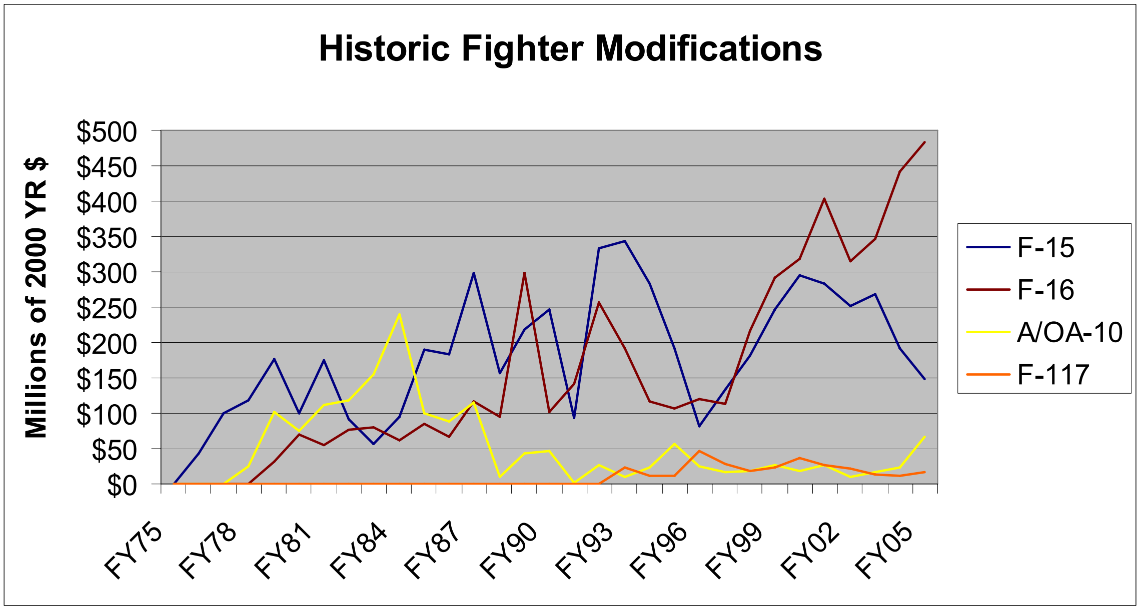

Chart 7.2 - Historic Fighter Modification Obligations

The drop in F-15 modifications since fiscal year 2000 may also be somewhat convoluted because the complex aircraft change environment in the Air Force (see chapter 2). On June 7th, 2002, the Air Force awarded a contract to Goodrich to produce 12 line replaceable units (LRUs) for more than 700 F-15s in inventory to increase the life span of select control surfaces. Know as *Gridlock*, this contract is worth approximately $250 million over 8 years. While the program is not a modification program as defined by AFI 63-1101 and explained in Chapter 2, it does represent a significant change to the F-15 and may be competing for modification funding. If this program were funded with 3010 BP-11 modification funding, the last 4 years of F-15 modifications data would look significantly different.

The F-16 was not initially designed to be a highly modifiable aircraft. At the time of conception the F-16 was designed to be a small and highly maneuverable fighter to complement the shortcomings of the large and expensive F-15. While the F-15 was designed with approximately 15 cubic feet of empty space to accommodate future installations, the F-16 had only about 2 cubic feet[62].

Regardless of the design limitations imposed to prevent aircraft growth, significant changes and upgrades have been made. A combination of small and large modification programs results in billions of dollars of modification obligations over the life of the aircraft. This is shown in detail in the following chart.

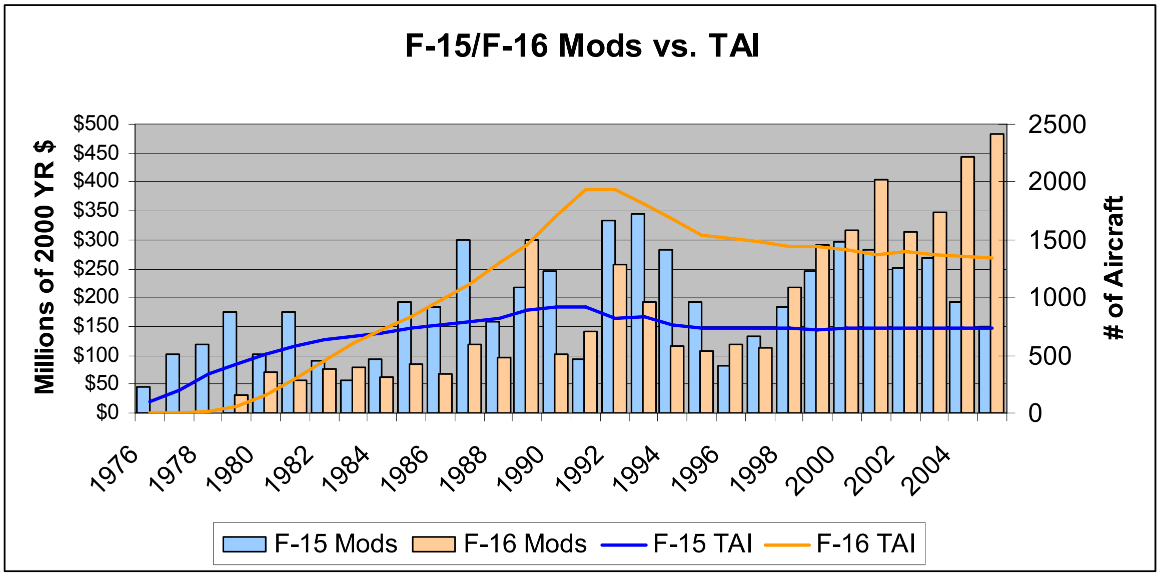

Chart 7.3 – F-15/F-16 Mods vs TAI

Why Simple Linear/Log-linear Models are Appropriate

Over the course of preparing estimates for the F-15 and F-16, various relationships between programmatic data for the F-15 and F-16 as well as different models for the error structures were computed. Least squares regressions, fixed-effects, and autoregressive integrated moving average (ARIMA) models were all estimated. Two different criteria for selecting a model used as well: One was the mean squared error (MSE) of the estimation while the

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[62] For more details see the Federation of American Scientists: http://www.fas.org/man/dod-101/sys/ac/f-16.htm.

other involved dropping a subset of the data for the estimation and then using that estimation to predict for the missing subset and computing the mean square error of the prediction[63]. Once the models were selected according to these criteria, it became apparent that such criteria were inappropriate. In fact, both the F-15 and F-16 have different historic modification profiles that warrant more substantive judgment when selecting a model. First, consider the F-15.

As shown in chart 7.2, the F-15 has a very cyclical pattern of modifications. At first, this was modeled by incorporating a seasonal adjustment; however, the seasons are not of uniform length and so the estimations were not appropriate. Upon analyzing the structure of the modifications data available in IDECS, it appears that the F-15 profile is characterized by a significant number of small-scale modifications with several large-scale modifications incorporated in from time to time. These large-scale modifications do not tend to overlap however, thus creating the seasonal patters. Chart 7.8 shows the peaks generated by large-scale modification programs[64].

[63] There are different theories for the appropriate number of data-points to drop for the estimation. Models were experimented using anywhere between 10% and 30% of the data points; however, 20% of the datapoints were chosen as the final value for selecting the best model.
[64] The data in chart 7.8 is incomplete outside of the years 1996-2005. However, the chart is still useful for depicting the effect of the various modification programs and the apparent "seasonal" effect.

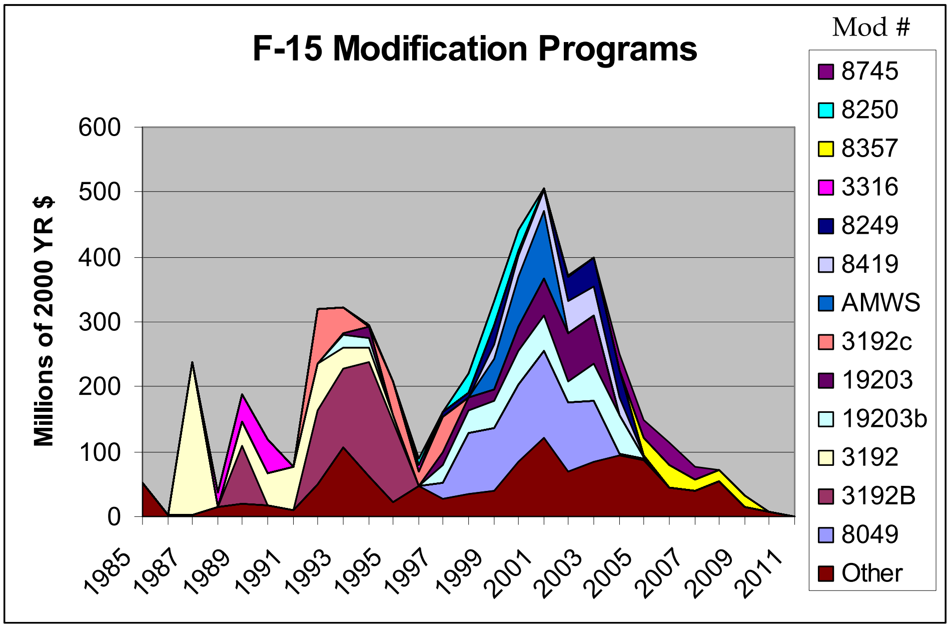

Chart 7.4 – IDECS F-15 Historic Modification Programs

Because of these large-scale modification programs in the F-15 historic profile, it is not clear that an advanced specification of the error terms for a prediction model will be appropriate. It may be possible to estimate a base level of modifications expenditures and then incorporate case-by-case estimates of expected future large-scale modification programs. Because this is outside of the scope of this research, a simple linear time trend for the F-15 is an appropriate prediction model for future modifications obligations. Chart 7.5 shows the F-15 modifications prediction model with the explicit model following in Figure 7.1.

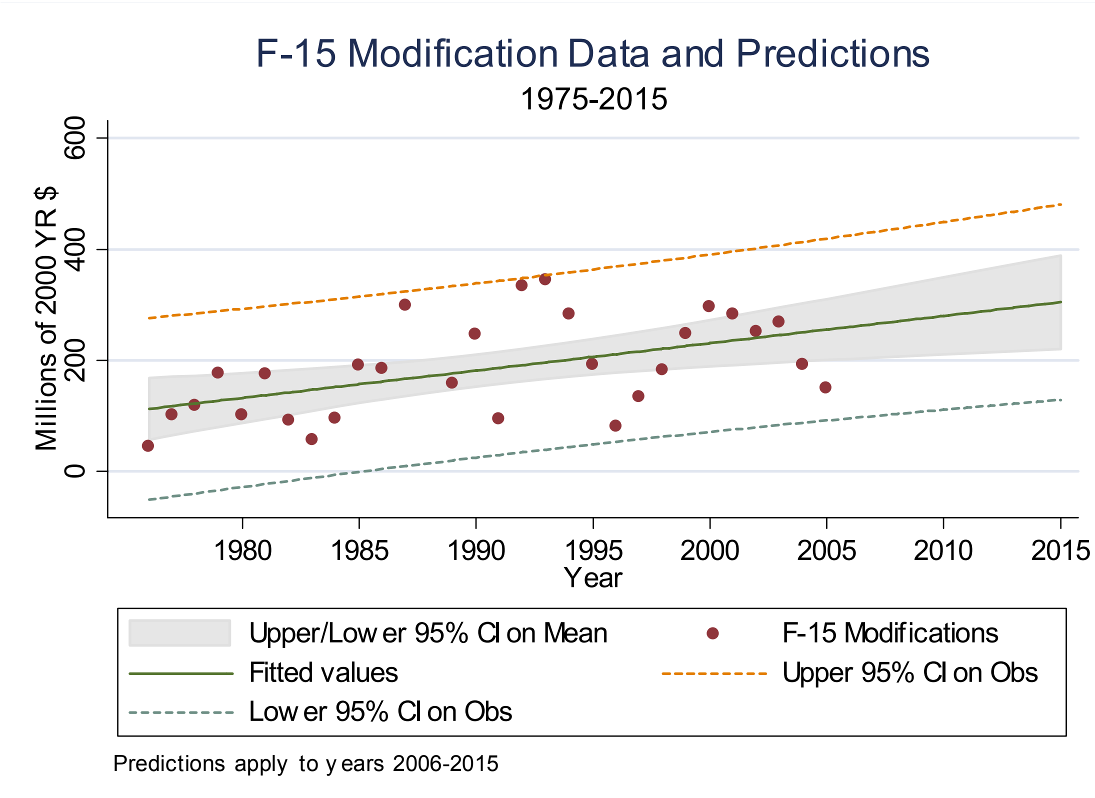

Chart 7.5 - F-15 Modifications Predictions

Dependent Variable	Constant*	Year Effect*	N	R^2
F-15 Yearly Modifications	-9604.86 (-3.04)	+ 4.92 (3.10)	29	0.263
F-16 Yearly Modifications	-27240.84 (-7.44)	+ 13.77 (7.49)	26	0.701

* - t-statistic in parenthesis

Figure 7.1 – F-15 and F-16 Modification Prediction Models

This linear time trend model indicates that the F-15 modifications are increasing at a rate of $4.9 million each year on average. This corresponds to an approximate growth rate of 3.3% per year[65]. One expectation that is outside the quantitative nature of this research, is that there will be another peak—corresponding to another large modification program—coming up for the F-15.

[65] It is noted that a linear trend and a percentage change (logarithmic trend) are not identical; however, with the relatively small change of 3.3%, they are sufficient close for the purposes of this study.

The F-16 has a noticeably different modification profile than does the F-15. Instead of regular large-scale modification efforts that produce a seasonal effect in the data, the F-16 has smoother growth profile[66]. One exception to this profile is a spike in modifications from 1990 to 1994[67]. Compared to the F-15, the F-16 profile seems ideally suited for an auto-regressive (AR) type model. The problem here comes with the data in years 2000 through 2005. These points indicate a quadratic trend that significantly impacts all estimated AR models. While they do a good job of fitting the observed data, the predictions are problematic from a qualitative standpoint. Several of the alternative models are depicted in chart 7.10.

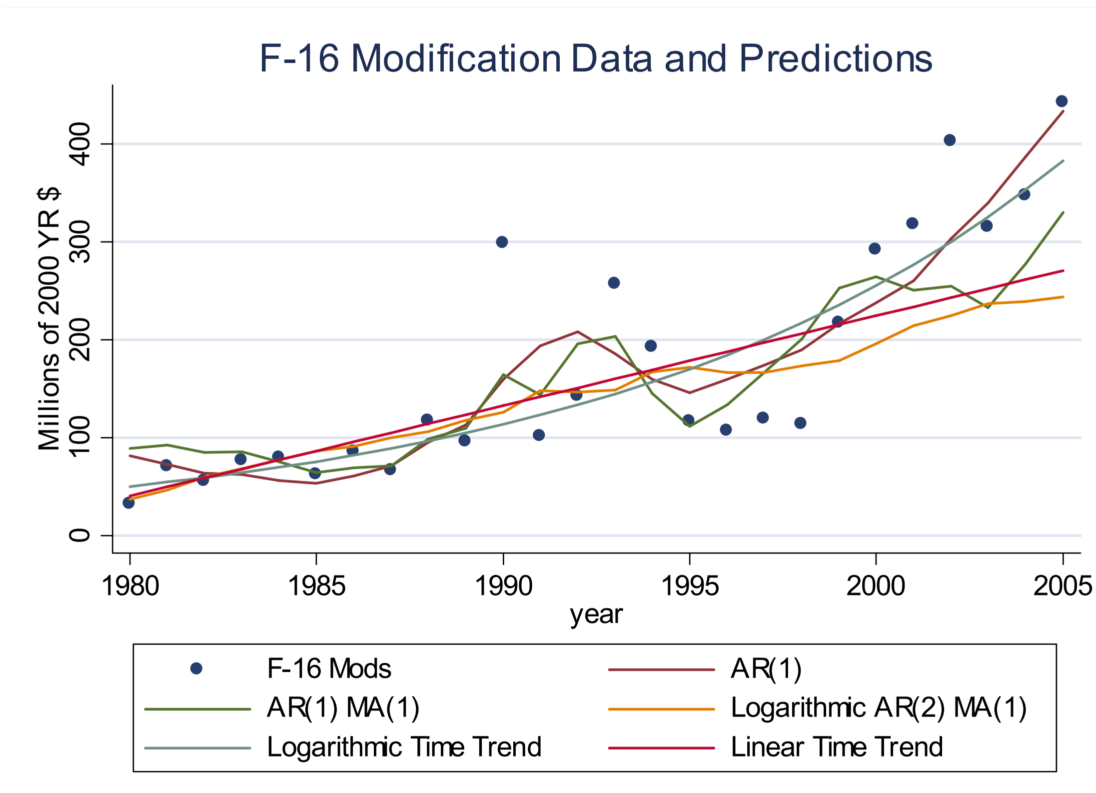

Chart 7.6 – Various F-16 Modification Prediction Models

[66] It is likely that this smoother profile is due to the larger inventory of F-16s. This might have the effect of spreading obligations over a larger period of time and so they are more likely to overlap.
[67] This spike may be related to a combination of modular mission computer modifications as well as the F-100-220E (re)engine modification.

Those models that best fit the data all predict modifications in 2015 between $800 million and $1 billion per year. This prediction seems highly unrealistic and that the models are unduly affected by data late in the series. For these reasons, it again seems appropriate to use a linear time trend model to predict F-16 modifications[68]. The prediction and errors are shown in Chart 7.7 below.

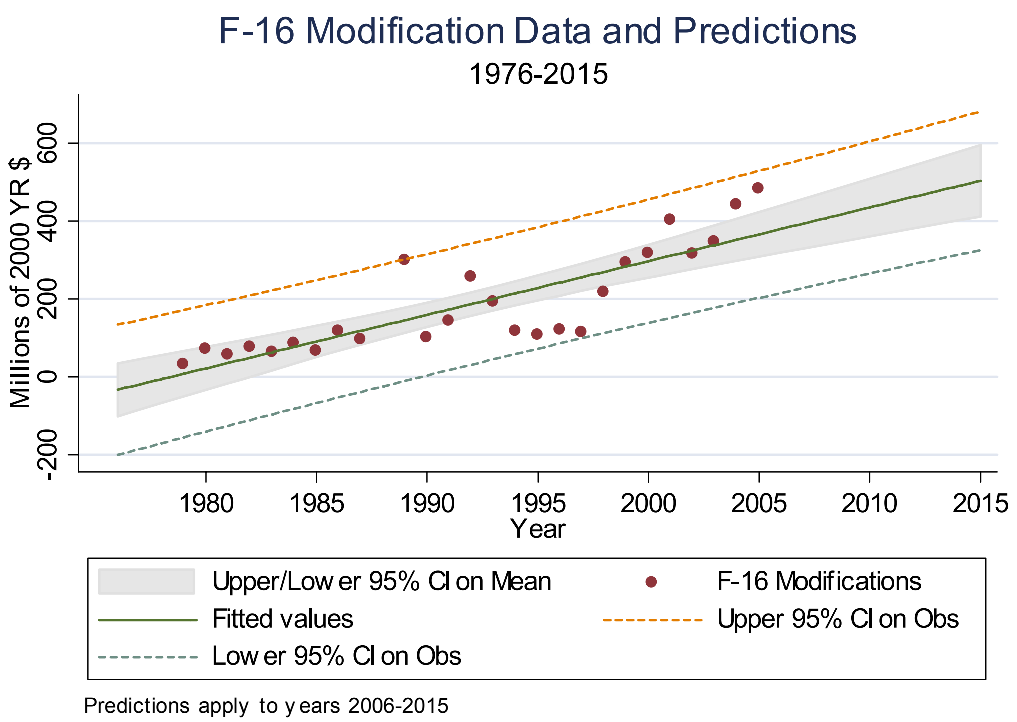

Chart 7.7 - F-16 Modifications Predictions

This model suggests that F-16 modifications are increasing at a rate of $13.9 million per year, or approximately 8%[69] per year and was reported previously in Figure 7.1 along with the F-15 model.

Conclusions

The figures presented in this chapter represent a set of base-level estimates for future AF modifications budgets. They are simplified models and should be

[68] In this case, appropriateness is judged not by a quantitative measure, but by a substantive expectation for average modifications obligations in the upcoming years.
[69] The percentage changes is based on an identical using a logarithmic transformation of mods per year.

regarded as such. What they lack in complexity however, they make up for in interpretation and ease of use. As such, they should provide a framework for future studies involving aggregate Air Force modifications, F-15 and F-16 modifications and replacement decisions, and for future fighter modifications such as the F-22 and JSF. They should also provide a reference point for future analyses concerning the same figures. Hopefully, these numbers can be refined and improved to increase the ability of the Air Force to plan for the future. This being stated, these numbers suggest that the F-15 and particularly the F-16 are expected to garner a larger portion of the budget in upcoming years. Decision-makers should be aware of these trends because as future replacement aircraft become fully integrated into the Air Force, it is likely that they will place an additional burden on the modification resources of the Air Force.

Chapter 8 – **Conclusions**

"There is no victory at bargain basement prices."

~General Dwight D. Eisenhower

This chapter is a brief overview of the conclusions following from the research presented in this dissertation. It is not likely that any one of these conclusions stands alone, but they are presented here as a summary that will serve as a reference for decisions involving future modification policy.

<u>Shortage of analyses</u> - One of the first results that were revealed in the process of this research is a lack of quantitative analysis for aircraft modifications. Further narrowing the scope of analysis to Air Force aircraft modifications further restricts available research. This dearth of analysis has resulted in a relatively ill-defined and unknown state of aircraft modifications for Air Force and DoD decision-makers. This adverse condition should be altered in the near future with this and other upcoming studies. Nevertheless, the modification process is the unifying characteristic of all of the potential studies of aircraft modifications and therefore, this research began with a succinct presentation of this process.

<u>Complex aircraft change framework</u> - Before the modification process could be presented, however, aircraft modifications had to be defined. This process of defining modifications resulted in another conclusion that the framework for changing aircraft configurations in the Air Force is a complex blend of conditions, colors of money, and supporting documentation. As a result, aggregate aircraft changes are difficult to track and decision-analysis is even more difficult to conduct in a comprehensive manner. The complex and often nebulous framework for aircraft change further exacerbated an already limited field of quantitative analyses, but also points to potential for gains in

understanding and efficiency if the complex framework is simplified. This represents a potentially valuable area for further research.

Codependent Installation and Procurement Schedules – When the frame of reference is limited to aircraft changes defined by the Air Force as Modifications, analysis suggests that installation and procurement schedules are codependent. It is hypothesized that the installation limitations then serve to limit the procurement schedules and result in acquisition inefficiency. With aircraft modifications around $2 billion per year, even small inefficiencies may be significant. Evidence presented in this research then suggests that an improvement to efficiency may be made if the constraint to install modifications in the same year they are procured is relaxed. Particularly, if acquisition plans are permitted to optimize procurement and installation separately, the Air Force will have more flexibility for both and realize a cost savings without adjusting the final outcome—resulting in an increase in modifications acquisition efficiency.

Safety modification rates may not be significantly higher – Another conclusion that may be derived from the historical modifications data is that safety modifications are not installed any more quickly than are similarly sized non-safety modifications. Such a condition may be problematic if it does indeed signify a failure to implement the policy that safety modifications should be completed at the fastest rate possible. This conclusion warrants further analyses to determine a policy-relevant way to increase the completion of safety modifications if it is determined by policy-makers that the current rates are too low for Air Force needs, or else to streamline the safety process to reduce the expenditure of resources that do not provide significant benefit.

<u>MD Level Aging Effect for Per-Aircraft Modification Costs</u>– One important component of Air Force analysis is the effect of aircraft aging on costs. An analytical model indicates that, using MD level data, an increase is cost is not identified for different aircraft mission types as aging occurs. However, this is a complex issue and plots of individual aircraft MD over time do frequently identify increases during particular periods, and for several aircraft, particularly the F-15 and F-16 signs of an aging effect are identified. As a result, there may be alternative modeling and data techniques that will change this conclusion. The aggregate analysis conceals important phenomena occurring at the individual fleet level and so aging effects may be found at the MD/MDS level. In fact, when individual modification programs costs are estimated, a significant aging effect is found. However, as was discussed in Chapter 4, the cost of an individual modification program can increase at the same time as the modification cost per-aircraft MD does not. This is because the number of modification programs changes over time. Decreases in the number of modification programs for older aircraft can offset the increase in the cost of a particular modification program. While modifications are not as significant as operating and support costs from the standpoint of the total amount of obligations, the effect of age on aircraft modifications costs is expected to weigh significantly into analyses of alternatives and replacement decisions, and therefore may also provide an area for productive future research.

<u>Fighter Modifications are Expected to Increase</u> – The F-15 and F-16 fleets are arguably the two of the most important aircraft fleets in the Air Force. Both fleets have exhibited a general upward trend in modifications since their inception in the Air Force. Even as the production of these aircraft has ceased and inventory levels have begun to decline, the upward trend is still significant. This has important implications for the future replacement aircraft. Since the initial technology levels in these aircraft are significantly higher and the composite

airframes also pose a higher risk for modifications requirements, it is important that the Air Force be prepared for the significant increase in modifications costs that may occur as these aircraft mature.

Steps for Future Analysis

One critical component to future modification analysis is developing a metric for the technical progress provided by a modification. Unfortunately this is not an easy task. Many potential modifications do not have a quantifiable progress because it is only after they are used that the Air Force is able to gauge the progress that is actually made. This difficulty should not proscribe the search for such a metric however, because this component of analysis will permit the development of an economic model for optimal modification as well as provide a control for cost estimation.

Without a proper measure of the technological progress, it is very difficult to predict costs at an aggregate level. Instead, it seems more appropriate to conduct analyses at the level of an individual mission design, or even in some cases, at the level of an individual modification. While costs will limit such studies in the future, it is important for those decision-makers involved in the selection and implementation of aircraft modifications to have a familiarity with the concepts presented in this dissertation and in additional literature of the economics and decision analysis of aircraft modifications so that the Air Force may effectively and efficiently continue to modernize the aircraft fleet to meet the needs of the warfighter.

Appendix A – Data Sources

IDECS

The research primarily uses data from Integrated Budget Documentation and Execution System (IDECS). IDECS is maintained by the Assistant Secretary of the Air Force for Acquisition, Program Integration Division (SAF/AQXR). The IDECS database is populated by yearly submissions of budget documents for modification programs. These modification programs are for both aircraft and missile modifications[70]. Only aircraft modifications data are used in this research. The yearly budget submissions are required by *AFI 63-1101 Modification Management* and apply to each individual modification program. The electronic submission is in the form of a P-3a Individual Modification Report[71]. The form is important because the P-3a is the report used in the official Air Force and Presidential Budgets.

IDECS data is program level data detailing the yearly costs within prescribed budget categories for aircraft modification programs for each of the years from 1997 until 2006, with the exception of 2001 and 2005. These two years are not included due to data collection limitations; however, the absence of these two budget years does not significantly affect the usefulness or structure of the data. The limitation does not have a large effect because of the Financial Management Regulation (FMR) that requires all modification programs to be fully funded. This means that once a modification program is entered into the budget process, the budget and installation schedule (jointly referred to as the cost schedule) for the entire program must be included in the budget documentation. Therefore, in any given year, all of the past obligations are reported, as well as budgets for future years. The effects of the missing years and the full-funding requirement are described in more detail in the following section on data preparation.

The IDECS data for an entire year is categorized by the respective President's Budget Request (PBR). Each PBR represents the Budget Request that the President presents to Congress by the first Monday in February. The available PBRs and their applicability to my research are summarized in the figure A1.1.

---

[70] Aircraft Modifications are classified as Appropriation (Appn) Code 3010, Budget Program (BP) – 11 and missile modifications are Appn 3020 BP-21. Missile modifications include space-launch vehicles and such data are promising for future space analysis.

[71] The P-3a report is a budget report for aircraft modification programs. The report specifics are described in DoD 7000.14-R *Department of Defense Financial Management Regulations (FMRs),* Vol IIB, Chapter 4.

Year	1997 PBR	1998 PBR	1999 PBR	2000 PBR	2001 PBR	2002 PBR	2003 PBR	2004 PBR	2005 PBR	2006 PBR
Pre 1996	IC	IC	IC	IC	U	IC	IC	IC	U	IC
1996	A	A	A	A	U	A	A	A	U	A
1997	B	A	A	A	U	A	A	A	U	A
1998	B	B	A	A	U	A	A	A	U	A
1999	B	B	B	A	U	A	A	A	U	A
2000	B	B	B	B	U	A	A	A	U	A
2001	B	B	B	B	U	A	A	A	U	A
2002	B	B	B	B	U	B	A	A	U	A
2003	B	B	B	B	U	B	B	A	U	A
2004	B	B	B	B	U	B	B	B	U	A
2005	B	B	B	B	U	B	B	B	U	A
Post 2005	B	B	B	B	U	B	B	B	U	B

IC - Incomplete Data
U - Unavailable Data
B - Budget (Predicted) Data
A - Actual Obligations

Figure A1.1 – Data Availability

Figure A1.1 shows the type of data available from each PBR for all of the available PBRs. The years prior to 1996 are labeled IC because the data is incomplete for these years. Some of this data is available in the 1997 and later PBRs if the programs extend into these years; however, for programs ending in 1995, they will not necessarily appear in the 1997 PBR and therefore the data is incomplete. As mentioned previously, the 2001 and 2005 PBRs are unavailable in the data used for this research and as a result, all of the data for those PBRs are labeled as unavailable (U). The remaining sections are either the predicted budgets (B) or actual obligations (A) depending on the year of interest and the PBR used.

In order to clarify the issue of data availability for a particular PBR, figure (A1.2) shows whether or not a particular program will appear in the 2000 PBR. The final case in which the program begins in 2001 and ends in 2005 may appear in the 2000 PBR if the program is planned by the Air Force and future funding is requested. Alternatively, if the program planning and budgeting is not conducted before the Air Force budget is submitted in September of the calendar year prior to the fiscal year corresponding to the PBR, then the program will not appear until the following PBR. Using the dates in figure A2.2 for this example, if the program beginning in 2001 is not planned[72] before September of 1999, then the 2000 PBR will not contain budget information for the program.

[72] Planning in this sense refers to the appropriate progress in the modification process described in this report.

Start Year	End Year	2000 PBR
1984	1999	No
1984	2000	Yes
2000	2005	Yes
2001	2005	Maybe

Figure A1.2 – Program PBR Reporting

As seen from figure A1.1, the structure of the data also allows budgeted to actual obligations comparisons for different lengths of time. Specifically, there are 28 different budget-year comparisons ranging from 1 year budgeted versus actual comparisons to a 9 year budgeted versus actual comparison. The year differences and the respective budget comparisons are summarized in figure A1.3.

Year Difference	1 Year	2 Years	3 Years	4 Years	5 Years	6 Years	7 Years	8 Years	9 Years
Applicable Budget Years	1997-1998	1997-1999	1997-2000	1998-2002	1997-2002	1997-2003	1997-2004	1998-2006	1997-2006
	1998-1999	1998-2000	1999-2002	1999-2003	1998-2003	1998-2004	1999-2006		
	1999-2000	2000-2002	2000-2003	2000-2004	1999-2004	2000-2006			
	2002-2003	2002-2004	2003-2006	2002-2006					
	2003-2004	2004-2006							

Figure A1.3 – Budgeted vs. Actual Comparison Data Availability

The IDECS data has proved to be very useful because of the comprehensive coverage of recent modification programs and the detail of the program cost-schedule data. Nevertheless, the IDECS data was provided in a raw form and required significant manipulation in order to create a useful dataset. Appendix 3 describes the process followed for data preparation. It should be of particular interest to any researchers intending to use the IDECS data for future research.

<u>AFTOC</u>

Air Force Total Operating Cost (AFTOC) is an information management system contracted by the Air Force. The goal is to provide the users with information on direct costs for specific weapon systems. The data in AFTOC is obtained from the Automated Budget Interactive Environment System (ABIDES) and allocated based on Budget Appropriation. AFTOC data is used in this report as a validation for the IDECS data and as a compliment to the IDECS data.. Data validation is described in further detail in Appendix 3.

The complimentary data from AFTOC includes programmatic data relating to aircraft fleet structure and obligation data relating to aircraft fleet costs. Such variables include: total aircraft inventory, aircraft flying hours, and operations and maintenance historical costs

WSCRS, D041, and A10-1

The Weapon System Cost Retrieval System is an Air-Force specific accounting database. WSCRS provided data on IOD year, average unit flyaway cost, aircraft age. Additionally, the D041 data system provided all of the data concerning component group costs. The A10-1 data, which routinely appears in the Air Force Magazine, was used for aircraft inventories.

Appendix B – AF Modification Documents

Overview of P-Docs

AF Form 1067

AF Form 3525

Sample P-3A Report

P-Docs

The P-Docs for Air Force aircraft are the procurement documentation provided to Congress in support of procurement requests in each budget. The official report is submitted by the Office of the Secretary of the Air Force for Financial Management and Budget (SAF/FMB) to Congress. The report is entitled *United States Air Force Committee Staff Procurement Backup Book* and is sometimes referred to as "The Book" or "The Blue Book", is divided into two volumes (I and II). The procurement documentation is grouped by Budget Activity Code. The following 7 codes are used for Air Force Aircraft.

BA 1 – Combat Aircraft
BA 2 – Airlift Aircraft
BA 3 – Trainer Aircraft
BA 4 – Other Aircraft
BA 5 – Modification of Inservice Aircraft
BA 6 – Aircraft Spares and Repair Parts
BA 7 – Aircraft Support Equipment and Facilities

Volume I

Volume I is concerned with all of the Budget Activity Codes except BA 5. BA 5 contains no data in Volume I, but it is submitted separately as Volume II. Within Volume I, there are 6 main exhibits. They are described below.

Exhibit P-40 – Budget Item Justification

Exhibit P-40 is found for each airframe for which there are production costs in Volume I. It is a summary level chart describing the different categories of aircraft procurement including:

- Procurement Quantity
- Cost
- Production Modernization
- Advance Procurement Cost
- Weapon System Cost
- Initial Spares
- Total Procurement Cost
- Flyaway Unit Cost
- Weapon System Unit Cost

Exhibit P-5 – Weapon System Cost Analysis

There is a P-5 report corresponding to each P-40 in Volume I. The intention of the document is to provide detailed sub-assembly costs for the aircraft. These costs are broken out into sub-categories under Flyaway Cost and Support Cost for the production of the aircraft.

Exhibit P-5a – Procurement History and Planning
This document supports exhibit P-5 and lists contract information for aircraft production including contractor, contract type, award date, unit cost, total quantity, and date of first delivery.

Exhibit P-21 – Production Schedule
Exhibit P-21 provides monthly production data for each aircraft with a P-40.

Exhibit P-43 – Simulator and Training Device Requirement
Exhibit P-43 is the details and justification for the procurement of simulators and training devices to support the aircraft in the associated P-40.

Exhibit P-10 – Advance Procurement Requirements Analysis
Exhibit P-10 is a justification and description for all requests for advance procurement in support of the aircraft procurement requested in the P-40.

Volume II

As mentioned previously, Volume II is only used for BA 5, Modification of Inservice Aircraft. In this category, there are two main exhibits used to categorize the data. These two exhibits are described below.

Exhibit P-1M – Modification Summary
The modification summary is compiled for each mission design (MD) in service in the Air Force. The only exception in the 2006 Volume II is that there is an extra P-1M for the C-130J. The P-1M report summarizes the individual modification efforts by modification number and modification title. The total costs (3010 BP-11) for each year are reported for each program. This is the level to which congress approves modification money. It may be moved around within the modification programs reported in each P-1M.

Exhibit P-3A – Individual Modification Report
A P-3A is reported in Volume II for each modification program reported in the P-1M. Additionally, some P-3A reports exist in IDECS which never are entered into “the blue book.” However, these are never presented to congress and therefore never have the potential to be funded. Each P-3A describes the modification to the aircraft as well as the cost schedule for implementing the modification. Program managers are encouraged to use broad terminology for these justifications and modification titles because it allows future potential modifications which fall into the description to be implemented under the umbrella of the existing modification program.

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PAGE 1 OF

MODIFICATION PROPOSAL

PART I - REQUEST FOR ACTION		DATE:
1. INITIATOR	2. INITIATOR'S POC ORGANIZATION	3. USING COMMAND HQ POINT OF CONTACT
4. TITLE:		
5. ORGANIZATION CONTROL NUMBER	6. OTHER NUMBERS	
7. AFFECTED CONFIGURED ITEM/SYSTEM:		
A. MDS/TMS/CEIL/CPIN	B. WUC	C. NSN
D. SRD CODE	E. NOUN	F. OTHER
8. PURPOSE *(State the need or deficiency to be corrected. Include expected results.)*		
9. IMPACT *(Urgency of need and impact if not satisfied.)*		
10. CONSTRAINTS/ASSUMPTIONS/PROPOSED SOLUTIONS		
11. ORGANIZATION VALIDATION		DATE RECEIVED:
☐ A. PROPOSED REQUEST IS VALIDATED AS AN ORGANIZATION NEED/REQUIREMENT WHICH REQUIRES ACTION.		
☐ B. PROPOSED REQUEST IS DISAPPROVED AND IS NOT AN ORGANIZATION NEED/REQUIREMENT WHICH REQUIRES ACTION.		
☐ C. PROPOSED REQUEST IS RETURNED TO SUBMITTER FOR ADDITIONAL INFORMATION.		
D. DATE	E. NAME, GRADE, TITLE, and DSN *(Type or Print)*	F. SIGNATURE

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PART II - USING COMMAND VALIDATION DATE RECEIVED:

12. USING COMMAND VALIDATION

☐ A. PROPOSED REQUEST IS VALIDATED AS AN ORGANIZATION NEED/REQUIREMENT WHICH REQUIRES ACTION.

☐ B. PROPOSED REQUEST IS DISAPPROVED AND IS NOT AN ORGANIZATION NEED/REQUIREMENT WHICH REQUIRES ACTION.

☐ C. PROPOSED REQUEST IS RETURNED TO SUBMITTER FOR ADDITIONAL INFORMATION.

☐ D. FORWARD TO LEAD COMMAND | E. USING COMMAND CONTROL NO.

F. DATE	G. NAME, GRADE, TITLE, and DSN *(Type or Print)*	H. SIGNATURE

PART III - LEAD COMMAND VALIDATION DATE RECEIVED:

13. LEAD COMMAND ACTION OFFICER	14. THRU *(Optional Routing)*	15. SINGLE MANAGER OFFICE

16. MODIFICATION TYPE ☐ T-1 ☐ T-2 ☐ PERMANENT (P) ☐ P(S)-SAFETY | 17. LEAD COMMAND CONTROL NO.

18. LEAD COMMAND REMARKS *(Identify any constraints or assumptions)*

19. LEAD COMMAND VALIDATION

☐ A. VALIDATED REQUEST ☐ B. DISAPPROVED

20. NAME, GRADE, TITLE, AND DSN *(Type or Print)*	21. SIGNATURE	22. DATE

PART IV - SINGLE MANAGER REVIEW AND APPROVAL DATE RECEIVED:

23. SM ACTION OFFICER

24. CENTER CONTROL NUMBERS
- A. CENTER MIP NO:
- B. ECP NO:
- C. TCTO NO:

25. TOTAL BP/EEIC:

Type Funds	Amount	Type Funds	Amount

26. NR OF CIS AFFECTED: | 27. TOTAL KITS NEEDED:

28. ALSO AFFECTS: ☐ SUPPORT EQUIP ☐ AIRCREW TRAINING ☐ TRAINING DEVICES/VISUAL AIDS *(Maint)* ☐ TECH DATA
☐ SPARES ☐ SOFTWARE ☐ OTHER *(Identify)*

29. KIT OR UNIT COST	30. TOTAL COST	31. LEAD TIME	32. INSTALLATION *(Begin)* *(Completed)*

33. LEVEL OF ACCOMPLISHMENT. ☐ USER ☐ DEPOT ☐ BOTH ☐ OTHER

34. USER WORK HOURS	35. DEPOT WORK HOURS:	36. TOTAL WORK HOURS:

37. MANUFACTURER: | 38. AIRCRAFT BREAKOUT:

39. ENGINEERING REVIEW RECOMMENDATION*(S)*

☐ APPROVED ☐ DISAPPROVED *(See attached remarks)*

40. NAME, GRADE, TITLE, AND DSN *(Type or Print)*	41. SIGNATURE	42. DATE

PART V - LEAD COMMAND CERTIFICATION/APPROVAL

☐ TEMPORARY MOD APPROVED ☐ PERMANENT MOD APPROVED *(Proceed to Budgeting)*

☐ MOD DISAPPROVED ☐ MNS/ORD TO BE DEVELOPED

43. NAME, GRADE, TITLE, AND DSN *(Type or Print)*	44. SIGNATURE	45. DATE

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CCB MODIFICATION REQUIREMENTS AND APPROVAL DOCUMENT

1. MOD NUMBER	2. MOD MANAGER		3. DOCUMENT PREP DATE
4. DOCUMENT PRODUCTION DATE	5. MOD TITLE		
6a. SYSTEM/EQUIP	6b. REMARKS	7. MOD CLASS	8. USING COMMAND
9. AGENCIES INVOLVED ☐ a. AIR FORCE ☐ b. SAP ☐ c. OTHER			10. LEVEL OF COMPETITION
11. KIT INSTALLATION LEVEL	12a. INSTALLATION HOURS PER UNIT	12b. TOTAL INSTALLATION HOURS	
13a. MODIFICATION MANAGER			DSN
13b. PROJECT OFFICER			DSN

14. WHERE ENGINEERING SOURCE OBTAINED ☐ a. SINGLE MANAGER ☐ b. CONTRACTOR ☐ c. OTHER

15. REQUIREMENT AND JUSTIFICATION NARRATIVE:

a. DESCRIPTION:

b. JUSTIFICATION:

16. SOLUTION:

17. RELATED DOCUMENT NUMBERS: 1

a. MIP/MNS/ECP:	b. PMD:	c. TCTO:	d. MSTG:

18. KIT QTY REQ/APPL	a. SYS/EQUIP	b. SPARES	c. OWRM	d. TRAINERS	e. SIMULATORS	f. GROUP A/B	g. TOTAL

19. ACTION	☐ a. NEW PROPOSAL	☐ b. ADDITIONAL REQMT	☐ c. COST INCREASE	☐ d. SCHEDULE SLIP
	☐ e. CANCELLATION	☐ f. REVALIDATION	☐ g. SUMMARY	

20. Cost and schedule estimates herein must be revalidated if modification is not approved by this date:

(Last entered/changed by):

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21. FINANCIAL PLAN, MOD # , BPAC for System

PREPARATION DATE

(MODIFICATION COSTS)	FPY: QTY/COST	PPY: QTY/COST	PY: QTY/COST	CY: QTY/COST	AY: QTY/COST	BY: QTY/COST	BY+1: QTY/COST
a. A & B KIT ENGINEERING							
b. ENGINEERING CHANGE ORDERS							
c. ENGINEERING DATA/TECH MANUALS							
d. GROUP "A" KIT PROOF							
e. GROUP "A" RECURRING KITS							
f. "A" NONRECURRING KITS							
g. GROUP "B" KIT PROOF							
h. GROUP "B" RECURRING KITS							
i. GROUP "B" NONRECURRING KITS							
j. MOD OF SPARES							
k. PECULIAR SUPPORT EQUIPMENT							
l. SIMULATORS							
m. TRAINERS							
n. TOOLING							
o. SOFTWARE							
p. KIT PROOF							
q. RECUR INSTALLATION LABOR							
r. OTHER							
s. BP COST SUBTOTAL							
(NON-MODIFICATION COSTS)							
t. RDT&E (3600)							
u. WRSK/BLSS SPARES INVENTORY							
v. WRSK/BLSS EXPENSE							
w. INITIAL POS SPARES INVENTORY							
x. INITIAL POS SPARES EXPENSE							
y. COMMON SUPPORT EQUIPMENT							
z. SUSTAINING ENGINEERING (583)							
aa. OTHER							
bb. NON-BP COST SUBTOTAL							
cc. TOTAL ALL COSTS							

(All costs inflated, in $ Millions)

NOTES:

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21. FINANCIAL PLAN, MOD # , BPAC for System							PREPARATION DATE
(MODIFICATION COSTS)	BY+2: QTY/COST	BY+3: QTY/COST	BY+4: QTY/COST	BY+5: QTY/COST	BY+6: QTY/COST		TOTAL QTY/COST
a. A & B KIT ENGINEERING							
b. ENGINEERING CHANGE ORDERS							
c. ENGINEERING DATA/TECH MANUALS							
d. GROUP "A" KIT PROOF							
e. GROUP "A" RECURRING KITS							
f. "A" NONRECURRING KITS							
g. GROUP "B" KIT PROOF							
h. GROUP "B" RECURRING KITS							
i. GROUP "B" NONRECURRING KITS							
j. MOD OF SPARES							
k. PECULIAR SUPPORT EQUIPMENT							
l. SIMULATORS							
m. TRAINERS							
n. TOOLING							
o. SOFTWARE							
p. KIT PROOF LABOR							
q. RECUR INSTALLATION LABOR							
r. OTHER							
s. BP COST SUBTOTAL							
(NON-MODIFICATION COSTS)							
t. RDT&E (3600)							
u. WRSK/BLSS SPARES INVENTORY							
v. WRSK/BLSS EXPENSE							
w. INITIAL POS SPARES INVENTORY							
x. INITIAL POS SPARES EXPENSE							
y. COMMON SUPPORT EQUIPMENT							
z. SUSTAINING ENGINEERING (583)							
aa. OTHER							
bb. NON-BP COST SUBTOTAL							
cc. TOTAL ALL COSTS							

(All costs inflated, in $ Millions)

NOTES:

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22. APPLICABLE LEAD TIMES (IN MONTHS):					
a. INITIAL ADMINISTRATION	b. TRIAL INSTALL	c. KIT PROOF INSTALL	d. KIT PROOF	e. INITIAL PRODUCTION	f. TOTAL PROCUREMENT
g. FOLLOW-ON ADMIN	h. FOLLOW-ON PRODUCTION		i. TOTAL FOLLOW-ON PROCUREMENT		j. DOCK TIME

23. MILESTONES:					
a. ECP DATE	b. CCB DATE	c. ADVANCE PR DATE	d. CONTRACT AWARD DATE	e. TRAIL INSTALL DATE	f. KIT PROOF DATE

	FY												FY											
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S
g. KIT DELIVERY QTYS																								
h. KIT INSTALL QTYS-DEPOT																								
i. KIT INSTALL QTYS-TEAM																								

	FY												FY											
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S
g. KIT DELIVERY QTYS																								
h. KIT INSTALL QTYS-DEPOT																								
i. KIT INSTALL QTYS-TEAM																								

	FY												FY											
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S
g. KIT DELIVERY QTYS																								
h. KIT INSTALL QTYS-DEPOT																								
i. KIT INSTALL QTYS-TEAM																								

	FY												FY											
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S
g. KIT DELIVERY QTYS																								
h. KIT INSTALL QTYS-DEPOT																								
i. KIT INSTALL QTYS-TEAM																								

24. INFLATED COST SUMMARIES BY BUDGET PROGRAM ACTIVITY:			(All costs inflated, in $ Millions)
a. TOTAL MOD $	b. COMMON SUPPORT EQUIPMENT $	c. REPARABLE REPLENISHMENT SPARES $	d. INITIAL INVESTMENT SPARES $
e. INITIAL AND RSP SPARES $	f. SUSTAINING ENGINEERING & SOFTWARE $	g. RDT&E $	h. OTHER $

25. AVERAGE RAW KIT EXPENSE:

26. TECHNICAL RISK:	☐ HIGH	☐ MEDIUM	☐ LOW
27. COST RISK:	☐ HIGH	☐ MEDIUM	☐ LOW

28a. MOD SPECIFICATION AVAILABLE: ☐ YES ☐ NO	28b. SPEC REVISION REQUIRED: ☐ YES ☐ NO	28c. DATE SPEC REV. AVAILABLE

29. ALTERNATE MEANS OF SATISFYING REQUIREMENT INVESTIGATED?: ☐ YES ☐ NO ☐ MAINTENANCE ACTIONS ☐ PREFERRED SPARES

30. PRODUCTION/PROCUREMENT CUT IN	a. APPROVED FOR CUT IN: ☐ YES ☐ NO	b. SERIAL NUMBER OF FIRST UNIT:	c. PROJECTED DELIVERY DATE:

REMARKS

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31. COORDINATION:

	FUNCTION	NAME	OFFICE	DATE
a.				
b.				
c.				
d.				
e.				
f.				
g.				
h.				
i.				
j.				
k.				
l.				
m.				
n.				
o.				
p.				
q.				
r.				
s.				
t.				
u.				
v.				
w.				
x.				
y.				
z.				

32. RESPONSIBLE PM	☐ APPROVED	☐ DISAPPROVED	
SIGNATURE			DATE
33. LEAD COMMAND CRB	☐ APPROVED	☐ DISAPPROVED	
SIGNATURE			DATE
34. SINGLE MANAGER CCB	☐ APPROVED	☐ DISAPPROVED	
SIGNATURE			DATE
35. LEAD COMMAND CRB	☐ APPROVED	☐ DISAPPROVED	
SIGNATURE			DATE

36. COMMENTS

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CCB REVIEW PAGE

37. MODIFICATION REVIEW CHECKLIST:

a. PRODUCT SUPPORT MANAGEMENT PLAN *(PSMP)* REQUIRED	☐ YES	☐ NO	p. SUBSYSTEM HAZARD ANALYSIS TO INCLUDE SYSTEM INTERFACE REQUIRED	☐ YES	☐ NO
b. REVISION OF ENGINEERING DATA *(DESIGN DOCU-MENTS, SPECS, ETC.)* REQUIRED	☐ YES	☐ NO	q. SYSTEM HAZARD ANALYSIS REQUIRED	☐ YES	☐ NO
c. FLIGHT/MAINTENANCE MANUALS AFFECTED	☐ YES	☐ NO	r. OPERATING & SUPPORT HAZARD ANALYSIS REQUIRED	☐ YES	☐ NO
d. SPEEDLINE OPERATIONS AFFECTED	☐ YES	☐ NO	s. RISK ASSESSMENT REQUIRED AND ACCOMPLISHED	☐ YES	☐ NO
e. SYSTEM/EQUIPMENT CALIBRATION AFFECTED	☐ YES	☐ NO	t. CORROSION POTENTIAL ITEMS AFFECTED	☐ YES	☐ NO
f. IMPACT ON THE ENVIRONMENT	☐ YES	☐ NO	u. IMPACT OF MOD ON R&M CONSIDERED	☐ YES	☐ NO
g. HUMAN FACTOR ENGINEERING COORDINATION REQUIRED	☐ YES	☐ NO	v. ENVIRONMENTAL STRESS SCREENING CONSIDERED	☐ YES	☐ NO
h. COST/SCHEDULE CONTROL SYSTEM CRITERIA	☐ YES	☐ NO	w. POTENTIAL GROUP B TECH INTERFACE IMPACT EVALUATED BY AFFECTED SPOs AND SMs	☐ YES	☐ NO
i. OSHA STANDARDS CONSIDERED	☐ YES	☐ NO	x. TEST & EVALUATION REQUIREMENTS CONSIDERED	☐ YES	☐ NO
j. NON-NUCLEAR MUNITIONS SAFETY INVOLVED	☐ YES	☐ NO	y. SUPPORTABILITY ANALYSIS CONSIDERED	☐ YES	☐ NO
k. NUCLEAR CERTIFICATION REQUIRED	☐ YES	☐ NO	z. FAA CERTIFICATION REQUIREMENTS	☐ YES	☐ NO
l. TRAINING REQUIRED	☐ YES	☐ NO	aa. AIRCRAFT STRUCTURAL INTEGRITY CONSIDERED	☐ YES	☐ NO
m. AIRCRAFT/STORES COMPATIBILITY *(SEEK EAGLE)* CERTIFICATION REQUIRED	☐ YES	☐ NO	bb. AIR-WORTHINESS RE-CERTIFICATION REQUIRED	☐ YES	☐ NO
n. MOD AFFECTS SURVIVABILITY/VULNERABILITY	☐ YES	☐ NO	cc. HARDWARE/SOFTWARE INTERFACE AFFECTED	☐ YES	☐ NO
o. PRELIMINARY HAZARD ANALYSIS REQUIRED	☐ YES	☐ NO	dd. OTHER IMPACTS *(IDENTIFY)*	☐ YES	☐ NO

38. REVIEW REMARKS

02/15/2003
FY 2004 PBR
Modification Title and No: FALCON STAR MN-6023

Models of Aircraft Affected: F-16 BLOCKS 25/30/32/40/42/50/52

UNCLASSIFIED
MODIFICATION OF AIRCRAFT

Center: ASC - Wright Patterson AFB, OH

Exhibit P3A Congressional
Appropriation: Aircraft Procurement, Air Force
CLC: F-16 Class P
PE 0207133F Team POWER

Description/Justification

Engineering test, analysis, and field experience indicate that under current operational usage the F-16 will not reach the 8,000 hour service life needed to support force structure plans. This shortfall is due to structural fatigue driven primarily by usage severity and gross weight, which have both increased significantly over design parameters with the incorporation of new systems and capabilities. Falcon STAR (Structural Augmentation Roadmap) is a depot-level upgrade program that replaces or reworks known life-limited structure to preclude the onset of widespread fatigue damage, maintain safety of flight, enhance aircraft availability, and extend the life of affected components to 8,000 hours. Life-limited components and required installation dates vary by aircraft block as follows: Blocks 25/30/32 (FY04-11) -- FS 110 Canopy Hook Support Frame, FS 158 Bulkhead, BL 19 Forward Longerons, FS 293 Strake Frame & Closure Rib, Upper and Lower Wing Attach Fittings, Lower Wing Skin, Vertical Skin at Flaperon Cutout, Leading Edge Flaps, FS 446 Lower Bulkhead, Horizontal Tail Support Beam, Ventral Fins, and Engine Access Covers; Blocks 40/42 (FY05-09) -- FS 158 Bulkhead, FS 462 Upper Bulkhead, FS 479 Upper Bulkhead, and Engine Access Covers; Blocks 50/52 (FY08-14) -- FS 158 Bulkhead, FS 462 Upper Bulkhead, and FS 479 Upper Bulkhead. Without modification of these components, the F-16 will experience continued structural degradation, which will adversely affect mission capable rates and become increasingly costly to correct. Because of variation in modification requirements and installation schedules among aircraft blocks, the quantity and unit cost of kit procurement and hardware installation differs from year to year, depending on the mix of aircraft involved. The upgrades included in Falcon STAR are distinct from those included in previous F-16 structures improvement programs and have been identified through the Aircraft Structural Integrity Program (ASIP) as the system has aged and operational usage has evolved.

Aircraft Breakdown: Active 702, Reserve 62, ANG 436

Development Status

Development costs are being shared with the European Participating Governments (EPG) and several FMS customers. Engineering is being focused on Blk 15s in FY01, Blk 30 in FY01 and FY02, and Blk 40/blk 50s in FY03-FY04. There is almost no concurrency. Blk 40 kits will not be ordered until FY04.

Projected Financial Plan

	PRIOR		FY-02		FY-03		FY-04		FY-05		FY-06	
	QTY	COST	QTY	COST	QTY	COST	QTY	COST	QTY	COST	QTY	COST
RDT&E (3600)		1.4		6.0		4.7		5.0				
PROCUREMENT (3010)												
INSTALL KITS					53	10.3	116	18.4	108	14.0	124	15.4
KITS NONRECUR						2.0		2.0				
EQUIPMENT												
EQUIP												
NONREC												
CHANGE ORDERS						0.7		1.2				1.9
DATA												
SIM/TRAINER												
SUPPORT-EQUIP						2.2		1.1		0.8		1.3
OGC						0.7		0.7		0.7		0.7

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UNCLASSIFIED

Fact Sheet: F-16 MN-6023 FALCON STAR

(Continued)

Projected Financial Plan Continued

	PRIOR		FY-02		FY-03		FY-04		FY-05		FY-06	
	QTY	COST	QTY	COST	QTY	COST	QTY	COST	QTY	COST	QTY	COST
INSTALLATION OF HARDWARE												
FY-03 53 KITS							[47]	19.7	[6]	2.6		
FY-04 116 KITS									[71]	26.7	[27]	7.8
FY-05 108 KITS											[88]	29.0
FY-06 124 KITS												
FY-07 185 KITS												
FY-08 197 KITS												
FY-09 203 KITS												
FY-10 123 KITS												
FY-11 69 KITS												
FY-12 22 KITS												
TOTAL INSTALL							47	19.7	77	29.3	115	36.8
TOTAL COST (BP-1100)					53	15.9	116	43.0	108	44.8	124	56.1

(Totals may not add due to rounding)

Fact Sheet: F-16 MN-6023 FALCON STAR (Continued)

(Continued)

	FY-07 QTY	FY-07 COST	FY-08 QTY	FY-08 COST	FY-09 QTY	FY-09 COST	TO COMP QTY	TO COMP COST	TOTAL QTY	TOTAL COST
RDT&E (3600)										17.0
PROCUREMENT (3010)										
INSTALL KITS	185	18.4	197	19.4	203	19.9	214	25.9	1,200	141.6
KITS NONRECUR										4.0
EQUIPMENT										
EQUIP NONREC										
CHANGE ORDERS				0.9		0.9		1.3		6.9
DATA										
SIM/TRAINER										
SUPPORT-EQUIP		1.0		1.1		1.1		1.5		10.1
OGC		0.7		0.8		0.8		2.4		7.4
INSTALLATION OF HARDWARE										
FY-03 53 KITS									[53]	22.3
FY-04 116 KITS	[3]	1.1	[3]	1.2	[3]	1.5	[9]	5.0	[116]	43.3
FY-05 108 KITS	[18]	6.2			[1]	0.2	[1]	0.3	[108]	35.6
FY-06 124 KITS	[97]	34.4	[27]	9.1					[124]	43.5
FY-07 185 KITS			[146]	46.0	[35]	10.7	[4]	0.9	[185]	57.5
FY-08 197 KITS					[162]	50.9	[35]	7.6	[197]	58.5
FY-09 203 KITS							[203]	69.6	[203]	69.6
FY-10 123 KITS							[123]	57.0	[123]	57.0
FY-11 69 KITS							[69]	27.3	[69]	27.3
FY-12 22 KITS							[22]	5.3	[22]	5.3
TOTAL INSTALL	118	41.7	176	56.2	201	63.3	466	173.0	1,200	420.1
TOTAL COST (BP-1100)	185	61.9	197	78.3	203	86.1	214	204.0	1,200	590.1

(Totals may not add due to rounding)

Method of Implementation: DEPOT

Initial Lead Time: 15 Months Follow-On Lead Time: 15 Months

Milestones

	FY-01	FY-02	FY-03	FY-04	FY-05	FY-06	FY-07	FY-08	FY-09	FY-10	FY-11	FY-12	FY-13	FY-14
Contract Date (Month/CY)			01/03	12/03	12/04	12/05	12/06	12/07	12/08	12/09	12/10	12/11		
Delivery Date (Month/CY)			04/04	03/05	03/06	03/07	03/08	03/09	03/10	03/11	03/12	03/13		

Installation Schedule

	FY-01				FY-02				FY-03				FY-04				FY-05				FY-06				FY-07				FY-08			
Quarters	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Input															25	22	15	19	21	22	25	30	30	30	29	29	30	30	40	45	45	46
Output																	25	22	15	19	21	22	25	30	30	30	29	29	30	30	40	45

	FY-09				FY-10				FY-11				FY-12				FY-13				FY-14			
Quarters	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Input	50	50	50	51	50	50	55	55	40	40	32	30	22	22	22	19	8	7	7	7				
Output	45	46	50	50	50	51	50	50	55	55	40	40	32	30	22	22	22	19	8	7	7	7		

Appendix C – IDECS
Data Preparation Specifics

Purpose:
The intention of this Appendix is to provide an account of the IDECS data preparation that was conducted for this research. This account may be used to validate the results reported here, but perhaps more importantly, it may also be used as a beginning for additional research on the area of Air Force aircraft modifications. This appendix should provide the strategy for building a database of all reported aircraft modifications. The final page of this appendix is a color-coded chart of all of the tables in the IDECS database.

Data Preparation

Step 1 – Write queries for IDECS data

The data that I received from SAF/AQXR was in raw form in 97 different Microsoft Access tables. Upon receiving the raw IDECS data, the first step I took to create a useful dataset was to write queries to join the raw data in the proper structure. Each query is an algorithm for matching data from separate locations into one unified aggregate structure. The specific methodology for these queries and the related data structure is described at the end of this appendix as the *Data Preparation Log*.

I organized the queries (and therefore the aggregate data) into two categories: program-constant data, and program-variable data. The program-constant data are information that does not change over time within the program. Examples of these types of data are modification title and description, modification type, start and end year, and number of aircraft modified[73]. The second data category, the program-variable data, is those variables that are not unchanging in each year of the program. These variables are the cost and installation variables.

Together, the program-constant and program-variable categories include all of the IDECS data. Figure A3.1 is an example of the data for the F-16 Tactical Data Link.

Budget	ModNum	ModTitle	Models	ModType	Active	Reserve	ANG	ACTotal	Year	Qty	Amt	RowName
2004 PBR	661651	F-16 TACTICAL DATA LINK (TDL)	F-16 Blocks 40/42/50/52	Capability Improvement	434	0	85	519	2008	18	12.224	EQUIPMENT
2004 PBR	661651	F-16 TACTICAL DATA LINK (TDL)	F-16 Blocks 40/42/50/52	Capability Improvement	434	0	85	519	2007	77	19.096	EQUIPMENT
2004 PBR	661651	F-16 TACTICAL DATA LINK (TDL)	F-16 Blocks 40/42/50/52	Capability Improvement	434	0	85	519	2005	91	22.236	EQUIPMENT
2004 PBR	661651	F-16 TACTICAL DATA LINK (TDL)	F-16 Blocks 40/42/50/52	Capability Improvement	434	0	85	519	2006	91	22.285	EQUIPMENT
2004 PBR	661651	F-16 TACTICAL DATA LINK (TDL)	F-16 Blocks 40/42/50/52	Capability Improvement	434	0	85	519	2004	98	23.599	EQUIPMENT
2004 PBR	661651	F-16 TACTICAL DATA LINK (TDL)	F-16 Blocks 40/42/50/52	Capability Improvement	434	0	85	519	2003	144	34.9	EQUIPMENT

Figure A3.1 - Example Program Data from IDECS[74]

[73] These program-constant variables may change from budget to budget, such as if the scope of the program is increased or decreased; however, for a given budget, these data do not change from year to year as do the cost and installation variables.
[74] This figure and some others in the report have been reduced to fit the page; if there are any request for additional information, they may be addressed to Owen Hill at emilyandowen@yahoo.com.

In figure A3.1, the yellow-highlighted cells starting on the left until the column for AC Total are program-constant data. The four right-hand columns are program-variables data.

Step 2 – Write queries for non-IDECS data

Once the IDECS data was sorted into the appropriate categories and formatted for statistical analysis, I then incorporated the non-IDECS data by writing additional queries. There are two categories for the non-IDECS data: yearly-variable data and constant data. The yearly-variable data includes all data that changes from year to year. There are four variables that I have included in the data that are yearly-variable: total aircraft inventory (TAI), primary aircraft authorized (PAA), flying hours (FH), and Operations and Maintenance (O&M). All of these data come from Air Force Total Operating Cost (AFTOC). The second category of non-IDECS data, the constant data, is comprised of variables representing aircraft type, initial operational delivery (IOD) year, and average unit flyaway cost (AUFC). The data that constitute this category was aggregated from a variety of sources including Air Force Magazine, AFTOC, Federation of American Scientist (FAS.org), and Air Force archives (af.mil).

Step 3 – Filter Data

Once the queries were written that structured the raw data into a dataset useful for statistical analysis, I developed filters that would increase the accuracy of the data. There are three circumstances that I identified in the data that I had to code for. The first category is programs that were never initiated. If a program was budgeted for out years such that budget authorization was granted, but the funds were never obligated, then the program never materialized. I identified each program in the data that never has a record of actual obligations for the first filter. There were 202 modification programs filtered out of the final dataset that never materialized[75].

The second filter is to identify any classified programs in the data. The classified programs either have only budgeted or actual totals without any sub-categories, or else there are no totals reported. In most cases, there were no program descriptions to accompany the limited budget information. Based on both of these limitations, the classified data is not useful in my analysis and was

[75] This number includes some programs that may begin outside of the time frame of this research. For example, a program budgeted in 2004 that is scheduled to begin in 2007 will be filtered through this process. This is not a problem because my analysis does not examine cancelled programs and the criteria of whether a program was cancelled or beyond the scope of this research does not factor into any of the research conducted.

therefore filtered out. There were 11 classified programs filtered out of the final dataset.

The third filter is the most important filter for accurate construction of the dataset. Based on the structure of the IDECS data, it is possible for one program to appear up to 8 times in the data. This is due to the fact that a modification program will be reported in each of the PBRs in which the program is active. Specifically, a program may be reported in each of the PBRs from 1997 to 2006 with the exception of 2001 and 2005, which I do not have data for. The question then becomes: which PBR should I use to report each program in the final dataset? Logically, the answer is to use the most recent PBR which contains the data since the data is updated yearly. Based on this logic, I generated a filter that identifies each program and the most recent report for the program. It is this filtered set of most-recent program data that I then used for the remainder of the analysis, with the exception of the longitudinal analysis. Once all of the filters have been applied, there are 806 modification programs remaining in the dataset.

Step 4 – Classify Data

The remaining 806 modification programs will be used as the primary data source for this analysis. In order to both familiarize myself with the aircraft modification programs of the last decade and to generate a useful list of dummy variables to classify each modification program, I printed out each modification program description. This is a text portion of the P-3a describing the modification program and providing a brief justification for seeking budget support. Using these descriptions, I manually coded each program for the following categories:

- Heterogeneous fleet modification
- Significant form-fit-function constraints
- Multi-attribute modifications
- Significant life cycle cost (LCC) implications
- Overhaul modifications
- Reengining modifications
- Inter-fleet modifications
- Spiral development modifications
- Avionics modifications
    - GPS
    - Radar
    - Countermeasures
    - Communications
- Engine modifications
- Airframe modifications
- Interface modifications

- Mechanical modifications
- TAWS
- GATM
- TCAS
- NAVSTAR
- ILS

These variables are described in further detail in section ****; however, they show the level of insight afforded by the program descriptions. These categories are now coded for each program as a dummy variable[76] and incorporated into the dataset.

Step 5 – Write summation queries

The final step of data preparation is to write summation queries that describe the data based on different perspectives. These queries sum the most basic data into different categories depending on different criteria. One of the criteria that I used is an overall summation of the modification obligations for each of the years of the data. This summation is compared with a summation from AFTOC as a means to validate the data preparation process that I used. Chart A3.1 shows this comparison.

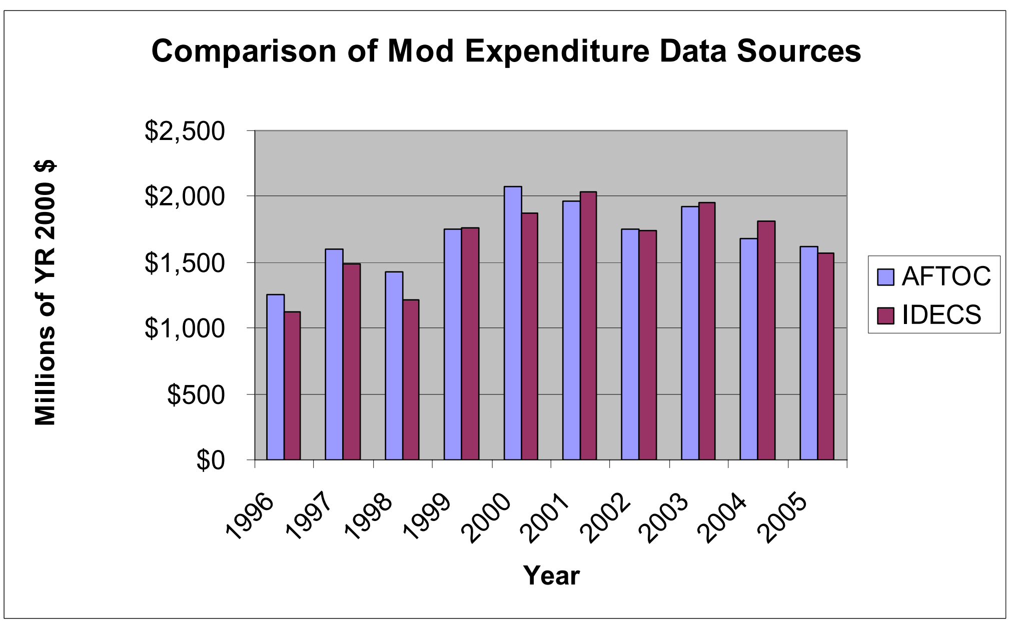

Chart A3.1 - Comparison of IDECS and AFTOC Data

[76] A dummy variable is simply a 0 or 1 indicator for inclusion into a certain category. In this case, there is a 1 for each category into which a program falls.

The numbers are similar; however, there is a noticeable difference for each of the years. Sources at AFTOC indicate that both aggregations are correct and that different allocation rules in the AFTOC data may limit the comparability of the two numbers beyond what is shown in this figure. Additionally, the tutorial published by AFTOC entitled *About Appropriations Data Products* states: "[IDECS] provides a far better allocation mechanism that can then be applied to the ABIDES mod dollars" used to compute AFTOC totals.

The result of this data preparation process is a comprehensive database of all of the modification programs from 1996 until 2005 including program specific details. I will use this database in the next section to describe the past 10 years of aircraft modifications.

<u>IDECS Process:</u>
The tables that must be updated from all of the legacy databases to the most recent database are:

- BudElement
- BudElementParentData
- BudElementProperty
- BudGridColumn
- BudGridFYData
- BudGridRow
- BudGridSection
- BudModProperty
- BudModsGridData
- BudModsHeaderData
- BudWorkingBudget

These are the tables that are needed for the modification data as presented in this research; however, there is additional data on spares, installations, missiles, and requirements in the database that I have not explored. Because this data exists in the raw form, I have not worked to examine the structure of these additional tables beyond the field names that I have reported in the layout diagram at the end of this section.

<u>Data Preparation Log</u>

Aircraft Breakout: 1actangreserve

```
SELECT BudElementParentData.ElementGridID, BudElementParentData.TimeSpanInDomainID,
BudElementParentData.ElementID, BudElementParentData.WorkingBudgetID,
BudModsGridData.CellAmount, BudModsGridData.GridColID
```

```
FROM BudColumn INNER JOIN ((BudElementParentData INNER JOIN BudModsGridData ON
BudElementParentData.ElementGridID = BudModsGridData.ElementGridID) INNER JOIN
BudGridColumn ON BudModsGridData.GridColID = BudGridColumn.GridColID) ON BudColumn.ColID
= BudGridColumn.ColID
GROUP BY BudElementParentData.ElementGridID, BudElementParentData.TimeSpanInDomainID,
BudElementParentData.ElementID, BudElementParentData.WorkingBudgetID,
BudModsGridData.CellAmount, BudModsGridData.GridColID
HAVING (((BudModsGridData.GridColID)=3 Or (BudModsGridData.GridColID)=4 Or
(BudModsGridData.GridColID)=5));
```

Procurement Obligations: 1allprocamt

```
SELECT BudElementParentData.ElementGridID, BudElementParentData.TimeSpanInDomainID,
BudElementParentData.ElementID, BudElementParentData.WorkingBudgetID,
BudModsGridData.CellAmount, BudModsGridData.AmountTypeID, AmountType.AmountTypeName,
BudModsGridData.GridColID, BudRow.RowID, BudRow.RowName, BudGridRow.EnabledFlag,
BudGridRow.IncludeInCalcFlag, BudGridRow.OverrideFlag, BudGridRow.ColOffsetInfo
FROM (((BudElementParentData INNER JOIN BudModsGridData ON
BudElementParentData.ElementGridID = BudModsGridData.ElementGridID) LEFT JOIN BudGridRow ON
BudModsGridData.GridRowID = BudGridRow.GridRowID) LEFT JOIN BudRow ON BudGridRow.RowID
= BudRow.RowID) INNER JOIN AmountType ON BudModsGridData.AmountTypeID =
AmountType.AmountTypeID
GROUP BY BudElementParentData.ElementGridID, BudElementParentData.TimeSpanInDomainID,
BudElementParentData.ElementID, BudElementParentData.WorkingBudgetID,
BudModsGridData.CellAmount, BudModsGridData.AmountTypeID, AmountType.AmountTypeName,
BudModsGridData.GridColID, BudRow.RowID, BudRow.RowName, BudGridRow.EnabledFlag,
BudGridRow.IncludeInCalcFlag, BudGridRow.OverrideFlag, BudGridRow.ColOffsetInfo
HAVING (((BudModsGridData.AmountTypeID)=1) AND ((BudModsGridData.GridColID)>1980));
```

Procurement Obligation Quantities: 1allprocqty

```
SELECT BudElementParentData.ElementGridID, BudElementParentData.TimeSpanInDomainID,
BudElementParentData.ElementID, BudElementParentData.WorkingBudgetID,
BudModsGridData.CellAmount, BudModsGridData.AmountTypeID, AmountType.AmountTypeName,
BudModsGridData.GridColID, BudRow.RowID, BudRow.RowName, BudGridRow.IncludeInCalcFlag
FROM (((BudElementParentData INNER JOIN BudModsGridData ON
BudElementParentData.ElementGridID = BudModsGridData.ElementGridID) LEFT JOIN BudGridRow ON
BudModsGridData.GridRowID = BudGridRow.GridRowID) LEFT JOIN BudRow ON BudGridRow.RowID
= BudRow.RowID) INNER JOIN AmountType ON BudModsGridData.AmountTypeID =
AmountType.AmountTypeID
GROUP BY BudElementParentData.ElementGridID, BudElementParentData.TimeSpanInDomainID,
BudElementParentData.ElementID, BudElementParentData.WorkingBudgetID,
BudModsGridData.CellAmount, BudModsGridData.AmountTypeID, AmountType.AmountTypeName,
BudModsGridData.GridColID, BudRow.RowID, BudRow.RowName, BudGridRow.IncludeInCalcFlag
HAVING (((BudModsGridData.AmountTypeID)=2) AND ((BudModsGridData.GridColID)>1980) AND
((BudRow.RowID)<>70 And (BudRow.RowID)<>71));
```

Installation Obligations: 1allinstamt

```
SELECT BudElementParentData.ElementGridID, BudElementParentData.TimeSpanInDomainID,
BudElementParentData.ElementID, BudElementParentData.WorkingBudgetID,
BudModsHardInstGridFYData.CellAmount, BudModsHardInstGridFYData.GridColID AS InstYear,
BudModsHardInstGridFYData.GridRowID AS ProcYear, BudModsHardInstGridFYData.AmountTypeID,
AmountType.AmountTypeName, 'Installation' AS Details
FROM (BudRow RIGHT JOIN ((BudElementParentData INNER JOIN BudModsHardInstGridFYData ON
BudElementParentData.ElementGridID = BudModsHardInstGridFYData.ElementGridID) LEFT JOIN
BudGridRow ON BudModsHardInstGridFYData.GridRowID = BudGridRow.GridRowID) ON
```

BudRow.RowID = BudGridRow.RowID) INNER JOIN AmountType ON
BudModsHardInstGridFYData.AmountTypeID = AmountType.AmountTypeID
GROUP BY BudElementParentData.ElementGridID, BudElementParentData.TimeSpanInDomainID,
BudElementParentData.ElementID, BudElementParentData.WorkingBudgetID,
BudModsHardInstGridFYData.CellAmount, BudModsHardInstGridFYData.GridColID,
BudModsHardInstGridFYData.GridRowID, BudModsHardInstGridFYData.AmountTypeID,
AmountType.AmountTypeName
HAVING (((BudModsHardInstGridFYData.AmountTypeID)=1));

Installation Quantities: 1allinstqty

SELECT BudElementParentData.ElementGridID, BudElementParentData.TimeSpanInDomainID,
BudElementParentData.ElementID, BudElementParentData.WorkingBudgetID,
BudModsHardInstGridFYData.CellAmount, BudModsHardInstGridFYData.GridColID AS InstYear,
BudModsHardInstGridFYData.GridRowID AS ProcYear, BudModsHardInstGridFYData.AmountTypeID,
AmountType.AmountTypeName, 'Installation' AS Details
FROM (BudRow RIGHT JOIN ((BudElementParentData INNER JOIN BudModsHardInstGridFYData ON
BudElementParentData.ElementGridID = BudModsHardInstGridFYData.ElementGridID) LEFT JOIN
BudGridRow ON BudModsHardInstGridFYData.GridRowID = BudGridRow.GridRowID) ON
BudRow.RowID = BudGridRow.RowID) INNER JOIN AmountType ON
BudModsHardInstGridFYData.AmountTypeID = AmountType.AmountTypeID
GROUP BY BudElementParentData.ElementGridID, BudElementParentData.TimeSpanInDomainID,
BudElementParentData.ElementID, BudElementParentData.WorkingBudgetID,
BudModsHardInstGridFYData.CellAmount, BudModsHardInstGridFYData.GridColID,
BudModsHardInstGridFYData.GridRowID, BudModsHardInstGridFYData.AmountTypeID,
AmountType.AmountTypeName
HAVING (((BudModsHardInstGridFYData.AmountTypeID)=2));

Budget Iteration: 1BudgetDescription

SELECT BudModProperty.ElementID, BudModProperty.TimeSpanInDomainID,
TimeSpanInDomain.Comment, BudModProperty.WorkingBudgetID,
BudWorkingBudgetDesc.WorkingBudgetDescName, BudWorkingBudget.WorkingBudgetDescID
FROM BudWorkingBudgetDesc INNER JOIN ((BudModProperty INNER JOIN TimeSpanInDomain ON
BudModProperty.TimeSpanInDomainID = TimeSpanInDomain.TimeSpanInDomainID) INNER JOIN
BudWorkingBudget ON (TimeSpanInDomain.TimeSpanInDomainID =
BudWorkingBudget.TimeSpanInDomainID) AND (BudModProperty.WorkingBudgetID =
BudWorkingBudget.WorkingBudgetID)) ON BudWorkingBudgetDesc.WorkingBudgetDescID =
BudWorkingBudget.WorkingBudgetDescID
WHERE (((BudWorkingBudget.WorkingBudgetDescID)=5));

Congressional Line Code (CLC): 1CLC

SELECT BudElement.TimeSpanInDomainID, BudElement.ElementID, BudElement.WorkingBudgetID,
BudElement.ElementDescID, ElementDesc.ElementDescName AS CLC, ElementDesc.ElementTypeID
FROM (BudElement INNER JOIN ElementDesc ON BudElement.ElementDescID =
ElementDesc.ElementDescID) INNER JOIN BudWorkingBudget ON BudElement.WorkingBudgetID =
BudWorkingBudget.WorkingBudgetID
WHERE (((ElementDesc.ElementTypeID)=17) AND ((BudWorkingBudget.WorkingBudgetDescID)=5));

Description/Justification: 1Desc_Justification

SELECT BudElementParentData.TimeSpanInDomainID, BudElementParentData.ElementID,
BudElementParentData.WorkingBudgetID, BudModsGridData.GridRowID, BudModsGridData.CellInfo AS
Description, BudRow.RowID
FROM ((BudModsGridData INNER JOIN BudGridRow ON BudModsGridData.GridRowID =
BudGridRow.GridRowID) INNER JOIN BudRow ON BudGridRow.RowID = BudRow.RowID) INNER

JOIN BudElementParentData ON BudModsGridData.ElementGridID = BudElementParentData.ElementGridID
WHERE (((BudRow.RowID)=45) AND ((BudModsGridData.GridColID)=1) AND ((BudModsGridData.AmountTypeID)=3));

Modification Method: 1Method

SELECT BudElementParentData.TimeSpanInDomainID, BudElementParentData.ElementID, BudElementParentData.WorkingBudgetID, BudModsHeaderDefinition.Description, ElementDesc.ElementDescName
FROM ((((BudModsHeaderData INNER JOIN BudModsHeaderDefinition ON BudModsHeaderData.DefinitionID = BudModsHeaderDefinition.DefinitionID) INNER JOIN ElementDesc ON BudModsHeaderData.CellAmount = ElementDesc.ElementDescID) INNER JOIN ElementType ON ElementDesc.ElementTypeID = ElementType.ElementTypeID) INNER JOIN BudElementParentData ON BudModsHeaderData.ElementGridID = BudElementParentData.ElementGridID) INNER JOIN BudWorkingBudget ON BudElementParentData.WorkingBudgetID = BudWorkingBudget.WorkingBudgetID
WHERE (((BudModsHeaderDefinition.DefinitionID)=1) AND ((BudWorkingBudget.WorkingBudgetDescID)=5));

Models Affected: 1Models

SELECT BudElementParentData.TimeSpanInDomainID, BudWorkingBudget.WorkingBudgetID, BudElementParentData.ElementID, BudModsHeaderData.CellInfo AS Models
FROM ((BudElementParentData INNER JOIN BudModsHeaderData ON (BudElementParentData.CopyNumber = BudModsHeaderData.CopyNumber) AND (BudElementParentData.ElementGridID = BudModsHeaderData.ElementGridID)) INNER JOIN BudModsHeaderDefinition ON BudModsHeaderData.DefinitionID = BudModsHeaderDefinition.DefinitionID) INNER JOIN BudWorkingBudget ON BudElementParentData.WorkingBudgetID = BudWorkingBudget.WorkingBudgetID
WHERE (((BudModsHeaderDefinition.DefinitionID)=4) AND ((BudWorkingBudget.WorkingBudgetDescID)=5));

Modification Title: 1ModTitle

SELECT BudElement.TimeSpanInDomainID, BudElement.ElementID, BudElement.WorkingBudgetID, BudElement.ElementDescID, ElementDesc.ElementDescName AS ModNum, ElementDesc.ElementDescDetail, BudWorkingBudget.WorkingBudgetDescID, BudWorkingBudgetDesc.WorkingBudgetDescName
FROM (((BudElement INNER JOIN ElementDesc ON BudElement.ElementDescID = ElementDesc.ElementDescID) INNER JOIN ElementType ON ElementDesc.ElementTypeID = ElementType.ElementTypeID) INNER JOIN BudWorkingBudget ON BudElement.WorkingBudgetID = BudWorkingBudget.WorkingBudgetID) INNER JOIN BudWorkingBudgetDesc ON BudWorkingBudget.WorkingBudgetDescID = BudWorkingBudgetDesc.WorkingBudgetDescID
WHERE (((BudWorkingBudget.WorkingBudgetDescID)=5) AND ((ElementType.ElementTypeDesc)="Mod"));

Modification Type: 1ModType

SELECT BudElementProperty.ElementID, BudElementProperty.TimeSpanInDomainID, BudElementProperty.WorkingBudgetID, ElementDesc.ElementDescID, ElementDesc.ElementDescName AS ModType, ElementDesc.ElementDescDetail
FROM (BudElementProperty INNER JOIN ElementDesc ON BudElementProperty.ElementDescID = ElementDesc.ElementDescID) INNER JOIN BudWorkingBudget ON BudElementProperty.WorkingBudgetID = BudWorkingBudget.WorkingBudgetID
WHERE (((ElementDesc.ElementDescID)<3980 And (ElementDesc.ElementDescID)>3971) AND ((BudWorkingBudget.WorkingBudgetDescID)=5));

Program Type: 1ProgramType

SELECT BudElementProperty.ElementID, BudElementProperty.TimeSpanInDomainID, BudElementProperty.WorkingBudgetID, ElementDesc.ElementDescID, ElementDesc.ElementDescDetail AS ProgramType, ElementDesc.ElementDescName
FROM (BudElementProperty INNER JOIN ElementDesc ON BudElementProperty.ElementDescID = ElementDesc.ElementDescID) INNER JOIN BudWorkingBudget ON BudElementProperty.WorkingBudgetID = BudWorkingBudget.WorkingBudgetID
WHERE (((ElementDesc.ElementDescID)=3969 Or (ElementDesc.ElementDescID)=3970) AND ((BudWorkingBudget.WorkingBudgetDescID)=5));

Follow on Lead Time: 1FollowTime

SELECT BudModsHeaderData.ElementGridID, BudElementParentData.TimeSpanInDomainID, BudElementParentData.ElementID, BudElementParentData.WorkingBudgetID, BudModsHeaderDefinition.Description, BudModsHeaderData.CellAmount AS FollowOnTime
FROM ((((BudModsHeaderData INNER JOIN BudModsHeaderDefinition ON BudModsHeaderData.DefinitionID = BudModsHeaderDefinition.DefinitionID) INNER JOIN ElementDesc ON BudModsHeaderData.CellAmount = ElementDesc.ElementDescID) INNER JOIN ElementType ON ElementDesc.ElementTypeID = ElementType.ElementTypeID) INNER JOIN BudElementParentData ON BudModsHeaderData.ElementGridID = BudElementParentData.ElementGridID) INNER JOIN BudWorkingBudget ON BudElementParentData.WorkingBudgetID = BudWorkingBudget.WorkingBudgetID
WHERE (((BudModsHeaderDefinition.Description)="Follow-On Lead Time") AND ((BudModsHeaderData.CellAmount)<4000) AND ((BudWorkingBudget.WorkingBudgetDescID)=5));

Initial Lead Time: 1InitialTime

SELECT BudModsHeaderData.ElementGridID, BudElementParentData.TimeSpanInDomainID, BudElementParentData.ElementID, BudWorkingBudget.WorkingBudgetID, BudModsHeaderDefinition.Description, BudModsHeaderData.CellAmount AS InitialLeadTime
FROM ((((BudModsHeaderData INNER JOIN BudModsHeaderDefinition ON BudModsHeaderData.DefinitionID = BudModsHeaderDefinition.DefinitionID) INNER JOIN ElementDesc ON BudModsHeaderData.CellAmount = ElementDesc.ElementDescID) INNER JOIN ElementType ON ElementDesc.ElementTypeID = ElementType.ElementTypeID) INNER JOIN BudElementParentData ON BudModsHeaderData.ElementGridID = BudElementParentData.ElementGridID) INNER JOIN BudWorkingBudget ON BudElementParentData.WorkingBudgetID = BudWorkingBudget.WorkingBudgetID
WHERE (((BudModsHeaderDefinition.Description)="Initial Lead Time") AND ((BudModsHeaderData.CellAmount)<4000) AND ((BudWorkingBudget.WorkingBudgetDescID)=5));

The next set of queries use the previously defined queries.

All Procurement Data: 2AllProcData

SELECT [1allgridamt].TimeSpanInDomainID, [1allgridamt].ElementID, [1allgridamt].WorkingBudgetID, [1allgridamt].GridColID AS [Year], [1allgridqty].CellAmount AS Qty, [1allgridamt].CellAmount AS Amt, [1allgridamt].RowName, [1allgridamt].RowID, [1allgridamt].IncludeInCalcFlag, [2IncludedinQtyCalc].IncludedinQtyCalc
FROM (1allgridamt LEFT JOIN 1allgridqty ON ([1allgridamt].RowID = [1allgridqty].RowID) AND ([1allgridamt].GridColID = [1allgridqty].GridColID) AND ([1allgridamt].WorkingBudgetID = [1allgridqty].WorkingBudgetID) AND ([1allgridamt].ElementID = [1allgridqty].ElementID) AND ([1allgridamt].TimeSpanInDomainID = [1allgridqty].TimeSpanInDomainID)) LEFT JOIN 2IncludedinQtyCalc ON ([1allgridqty].RowID = [2IncludedinQtyCalc].MinOfRowID) AND ([1allgridqty].WorkingBudgetID = [2IncludedinQtyCalc].WorkingBudgetID) AND ([1allgridqty].ElementID = [2IncludedinQtyCalc].ElementID) AND ([1allgridqty].TimeSpanInDomainID = [2IncludedinQtyCalc].TimeSpanInDomainID);

All Installation Data: 2AllInstData

SELECT [1allinstamt].TimeSpanInDomainID, [1allinstamt].ElementID, [1allinstamt].WorkingBudgetID, [1allinstamt].InstYear AS [Year], [1allinstqty].CellAmount AS Qty, [1allinstamt].CellAmount AS InstCost, [1allinstamt].RowName, [1allinstamt].RowID
FROM (1allinstamt LEFT JOIN 1allinstqty ON ([1allinstamt].RowID = [1allinstqty].RowID) AND ([1allinstamt].GridColID = [1allinstqty].GridColID) AND ([1allinstamt].WorkingBudgetID = [1allinstqty].WorkingBudgetID) AND ([1allinstamt].ElementID = [1allinstqty].ElementID) AND ([1allinstamt].TimeSpanInDomainID = [1allinstqty].TimeSpanInDomainID));

All Program Years: ProgramYears

SELECT [2AllInstallData].TimeSpanInDomainID AS TimeSpanInDomainID, [2AllInstallData].ElementID AS ElementID, [2AllInstallData].WorkingBudgetID AS WorkingBudgetID, [2AllInstallData].InstYear as Year
FROM 2AllInstallData
UNION SELECT [2AllProcData].TimeSpanInDomainID AS TimeSpanInDomainID, [2AllProcData].ElementID AS ElementID, [2AllProcData].WorkingBudgetID AS WorkingBudgetID, [2AllProcData].Year
FROM 2AllProcData;

Calculation Indicatiors: 2IncludedinQtyCalc

SELECT [1allgridqty].TimeSpanInDomainID, [1allgridqty].WorkingBudgetID, [1allgridqty].ElementID, Min([1allgridqty].RowID) AS MinOfRowID, 1 AS IncludedinQtyCalc
FROM 1allgridqty
GROUP BY [1allgridqty].TimeSpanInDomainID, [1allgridqty].WorkingBudgetID, [1allgridqty].ElementID, 1
HAVING (((Min([1allgridqty].RowID))=53 Or (Min([1allgridqty].RowID))=55));

Combined Procurement and Installation Data: 2AllGridData

SELECT ProgramYears.TimeSpanInDomainID, ProgramYears.ElementID, ProgramYears.WorkingBudgetID, ProgramYears.Year, [2AllProcData].Qty AS ProcQty, [2AllProcData].Amt AS ProcAmt, [2AllProcData].RowName AS ProcCategory, [2AllInstallData].InstQty, [2AllInstallData].InstCost, [2AllProcData].RowName, [2AllProcData].RowID, [2AllProcData].IncludeInCalcFlag, [2AllProcData].IncludedinQtyCalc
FROM (ProgramYears LEFT JOIN 2AllProcData ON (ProgramYears.Year = [2AllProcData].Year) AND (ProgramYears.WorkingBudgetID = [2AllProcData].WorkingBudgetID) AND (ProgramYears.ElementID = [2AllProcData].ElementID) AND (ProgramYears.TimeSpanInDomainID = [2AllProcData].TimeSpanInDomainID)) LEFT JOIN 2AllInstallData ON (ProgramYears.Year = [2AllInstallData].InstYear) AND (ProgramYears.WorkingBudgetID = [2AllInstallData].WorkingBudgetID) AND (ProgramYears.ElementID = [2AllInstallData].ElementID) AND (ProgramYears.TimeSpanInDomainID = [2AllInstallData].TimeSpanInDomainID);

All Modification Constants: 5allModConstants1

SELECT [1ModProgramIDs].TimeSpanInDomainID, [1ModProgramIDs].ElementID, [1ModProgramIDs].WorkingBudgetID, [1ModProgramIDs].Comment AS Budget, [1ModProgramIDs].ModNum, [1ModProgramIDs].ElementDescDetail AS ModTitle, [1InitialTime].InitialLeadTime, [1FollowTime].FollowOnTime, [1models].Models, [1ModType].ModType, [1ProgType].ProgramType, [2actangreserve].Active, [2actangreserve].Reserve, [2actangreserve].ANG, [1Desc_Justification].Description, [1Method].ElementDescName AS Method
FROM (((((((1ModProgramIDs LEFT JOIN 1FollowTime ON ([1ModProgramIDs].WorkingBudgetID = [1FollowTime].WorkingBudgetID) AND ([1ModProgramIDs].ElementID = [1FollowTime].ElementID) AND ([1ModProgramIDs].TimeSpanInDomainID = [1FollowTime].TimeSpanInDomainID)) LEFT JOIN 1InitialTime ON ([1ModProgramIDs].WorkingBudgetID = [1InitialTime].WorkingBudgetID) AND ([1ModProgramIDs].ElementID = [1InitialTime].ElementID) AND ([1ModProgramIDs].TimeSpanInDomainID = [1InitialTime].TimeSpanInDomainID)) LEFT JOIN 1models ON ([1ModProgramIDs].TimeSpanInDomainID = [1models].TimeSpanInDomainID) AND

([1ModProgramIDs].ElementID = [1models].ElementID)) LEFT JOIN 1ModType ON ([1ModProgramIDs].ElementID = [1ModType].ElementID) AND ([1ModProgramIDs].TimeSpanInDomainID = [1ModType].TimeSpanInDomainID)) LEFT JOIN 1ProgType ON ([1ModProgramIDs].TimeSpanInDomainID = [1ProgType].TimeSpanInDomainID) AND ([1ModProgramIDs].WorkingBudgetID = [1ProgType].WorkingBudgetID) AND ([1ModProgramIDs].ElementID = [1ProgType].ElementID)) LEFT JOIN 2actangreserve ON ([1ModProgramIDs].TimeSpanInDomainID = [2actangreserve].TimeSpanInDomainID) AND ([1ModProgramIDs].WorkingBudgetID = [2actangreserve].WorkingBudgetID) AND ([1ModProgramIDs].ElementID = [2actangreserve].ElementID)) LEFT JOIN 1Desc_Justification ON ([1ModProgramIDs].WorkingBudgetID = [1Desc_Justification].WorkingBudgetID) AND ([1ModProgramIDs].ElementID = [1Desc_Justification].ElementID) AND ([1ModProgramIDs].TimeSpanInDomainID = [1Desc_Justification].TimeSpanInDomainID)) LEFT JOIN 1Method ON ([1ModProgramIDs].WorkingBudgetID = [1Method].WorkingBudgetID) AND ([1ModProgramIDs].ElementID = [1Method].ElementID) AND ([1ModProgramIDs].TimeSpanInDomainID = [1Method].TimeSpanInDomainID);

All Data Combined: 6CSTS_1

SELECT [5allModConstants2].TimeSpanInDomainID, [5allModConstants2].ElementID, [5allModConstants2].WorkingBudgetID, [5allModConstants2].Budget, [5allModConstants2].ModNum, [5allModConstants2].ModTitle, [5allModConstants2].Description, [5allModConstants2].Method, [5allModConstants2].InitialLeadTime, [5allModConstants2].FollowOnTime, [5allModConstants2].Models, [5allModConstants2].ModType, [5allModConstants2].ProgramType, [5allModConstants2].Active, [5allModConstants2].Reserve, [5allModConstants2].ANG, [Active]+[Reserve]+[ANG] AS ACTotal, [2AllGridData].Year, [2AllGridData].RowID, [2AllGridData].IncludedinQtyCalc, [2AllGridData].RowName AS ProcCategory, [2AllGridData].ProcQty, [2AllGridData].ProcAmt, [2AllGridData].InstQty, [2AllGridData].InstCost
FROM 5allModConstants2 INNER JOIN 2AllGridData ON ([5allModConstants2].WorkingBudgetID = [2AllGridData].WorkingBudgetID) AND ([5allModConstants2].ElementID = [2AllGridData].ElementID) AND ([5allModConstants2].TimeSpanInDomainID = [2AllGridData].TimeSpanInDomainID);

Most Recent Data: 2MostRecentMods

SELECT Max([6CSTS_1].WorkingBudgetID) AS MaxOfWorkingBudgetID, [6CSTS_1].ModNum, [6CSTS_1].ModTitle, 1 AS MostRecentD
FROM 6CSTS_1
GROUP BY [6CSTS_1].ModNum, [6CSTS_1].ModTitle, 1;

All Data Combined Identifying Most Recent Data: 6CSTS_2

SELECT [6CSTS_1].*, [2ModsRecentMods].MostRecentD
FROM 6CSTS_1 LEFT JOIN 2ModsRecentMods ON ([6CSTS_1].ModNum = [2ModsRecentMods].ModNum) AND ([6CSTS_1].WorkingBudgetID = [2ModsRecentMods].MaxOfWorkingBudgetID);

The following page shows the table layout of the IDECS database (Figure A3.2)

AdminLookupElementDesc	TimeSpanInDomainID	ElementDescID									
ABIDESMapping	TimeSpanInDomainID	ElementID	ElementDescID	AbidesRowID							
ABIDESData	TimeSpanInDomainID	ElementID	ColID	AbidesRowID	AmountTypeID	PersonID	AmountValue				
AmountType	AmountTypeID	AmountTypeName	AmountTypeDesc								
BudColumn	ColID	FundingStreamTypeID	ColName	ColDesc							
BudElement	TimeSpanInDomainID	ElementID	WorkingBudgetID	ParentID	ElementDescID	ActionID	SortOrder	LevelNumber	Ancestry		
BudElementDescAssociation	TimeSpanInDomainID	ElementDescID	AssociatedElementDescID								
BudElementDescLink	TimeSpanInDomainID	ElementID	LinkElementDescID								
BudElementOfficeLink	TimeSpanInDomainID	ElementID	OfficeID								
BudElementParentData	ElementGridID	CopyNumber	TimeSpanInDomainID	ElementID	WorkingBudgetID	GridID	ValidationText				
BudElementPermission	TimeSpanInDomainID	ElementID	WorkingBudgetID	PersonID	GrantorID	AccessLevel	Ancestry				
BudElementProperty	TimeSpanInDomainID	ElementID	WorkingBudgetID	CopyNumber	ElementDescID						
BudElementTypeGridLink	ElementTypeID	GridID	SortOrder								
BudElementViewLink	TimeSpanInDomainID	ElementID	ViewId								
BudFundingStreamType	FundingStreamTypeID	FundingStreamTypeName	FundingStreamTypeDesc								
BudGrid	GridID	GridName	GridClassName	GridTitle							
BudGridColumn	GridColID	TimeSpanInDomainID	GridID	ColID	SortOrder	VisibleFlag	EnabledFlag	IncludeInCalcFlag	OverrideFlag		
BudGridFYData	ElementGridID	CopyNumber	RowFYID	ColFYID	ColOffset	SortOrder	CellAmount	CellInfo			
BudGridRow	GridRowID	TimeSpanInDomainID	RowID	SortOrder	VisibleFlag	EnabledFlag	IncludeInCalcFlag	HeadingFlag	UnclassifiedF	OverrideF	ColOffset
BudGridSection	GridSectionID	TimeSpanInDomainID	GridID	SectionID	SortOrder	DataTableName					
BudImageData	ElementGridID	CopyNumber	SortOrder	ImageData	FileName						
BudModProperty	TimeSpanInDomainID	ElementID	WorkingBudgetID	CopyNumber	FiscalYear	OfficeID					
BudModsGridData	ElementGridID	CopyNumber	GridRowID	GridColID	AmountTypeID	CellAmount	CellInfo				
BudModsHardInstGridFYData	ElementGridID	CopyNumber	GridRowID	GridColID	ColOffset	AmountTypeID	CellAmount	CellInfo			
BudModsHeaderData	ElementGridID	CopyNumber	DefinitionID	CellAmount	CellInfo						
BudModsHeaderDefinition	DefinitionID	GridID	Description								
BudModsObsGridData	ElementGridID	CopyNumber	GridRowID	GridColID	ColOffset	AmountTypeID	CellAmount	CellInfo			
BudModsUserGridData	ElementGridID	CopyNumber	GridSectionID	SortOrder	GridColID	ColOffset	AmountTypeID	CellAmount	CellInfo		
BudP40MemoData	TimeSpanInDomainID	ElementID	WorkingBudgetID	P40Memo							
BudP5CostElementCategory	TimeSpanInDomainID	BPElementDescID	ElementDescID	SortOrder	IndentFlag	SubtotalRowFlag					
BudPDocsFYHeadingData	ElementGridID	CopyNumber	HeadingDescriptionID	FiscalYear	AdditionalText						
BudPDocsFYHeadingGridData	ElementGridID	CopyNumber	HeadingDescriptionID	GridColID	ColOffset	SortOrder	AmountTypeID	CellAmount	CellInfo		
BudPDocsGridData	ElementGridID	CopyNumber	GridRowID	GridColID	ColOffset	AmountTypeID	CellAmount	CellInfo			
BudPDocsHeaderData	ElementGridID	CopyNumber	DefinitionID	CellAmount	CellInfo						
BudPDocsHeaderDefinition	DefinitionID	GridID	Description								
BudPDocsP21GridFYData	ElementGridID	CopyNumber	ProcYear	ServiceID	FiscalYear	CalendarMonth	CalendarYear	CellAmount	CellInfo		
BudPDocsP21GridProcData	ElementGridID	CopyNumber	ProcYear	ServiceID	FiscalYear	AddFlag	ProcQty	PriorProcQty			
BudPDocsP21GridRemarksData	ElementGridID	CopyNumber	FiscalYear	Remarks							
BudPDocsGridUserData	ElementGridID	CopyNumber	GridSectionID	SortOrder	GridColID	ColOffset	AmountTypeID	CellAmount	CellInfo		
BudPersonRoleElementAssignment	TimeSpanInDomainID	PersonID	RoleID	ElementID	WorkingBudgetID	PrimaryFlag					
BudRDocsCostTableData	TimeSpanInDomainID	ElementID	WorkingBudgetID	ColID	AmountTypeID	CellAmount	CellInfo				
BudRDocsGridData	ElementGridID	CopyNumber	GridRowID	GridColID	ColOffset	AmountTypeID	CellAmount	CellInfo			
BudRDocsUserGridData	ElementGridID	CopyNumber	GridSectionID	SortOrder	GridColID	ColOffset	AmountTypeID	CellAmount	CellInfo		
BudRow	RowID	RowName	RowDesc								
BudSection	SectionID	SectionName	SectionTypeID								
BudSectionType	SectionTypeID	SectionTypeDesc									
BudSourceDataAssociation	TimeSpanInDomainID	ElementDescID	LinkElementDescID	ElementDescDetail	MidifiedDate	ActiveFlag					
BudSparesGridData	ElementGridID	CopyNumber	GridRowID	GridColID	ColOffset	AmountTypeID	CellAmount	CellInfo			
BudSparesHeaderColumn	ColID	SortOrder	ColName								
BudSparesHeaderData	ElementGridID	CopyNumber	ColID	CellAmount	CellInfo						
BudSparesUserGridData	ElementGridID	CopyNumber	GridSectionID	SortOrder	GridColID	ColOffset	AmountTypeID	CellAmount	CellInfo		
BudSubmission	TimeSpanInDomainID	WorkingBudgetID	ElementID	CreatedDate	SubmissionDate	LockedDate					
BudTableList	GridID	TableName	SortOrder								
BudView	ViewId	ViewClassName									
BudWorkingBudget	WorkingBudgetID	TimeSpanInDomainID	WorkingBudgetDescID	SortOrder							
BudWorkingBudgetDesc	WorkingBudgetDescID	RoleID	WorkingBudgetDescName	WorkingBudgetDesc	ActiveFlag	OfficialFlag	HQUSAFFlag				
DomainFunction	DomainID	FunctionID	ResourceID	ResourceIDName	ResourceIDDesc	SetAccessFlag					
ElementAction	ActionID	ActionDescription									
ElementDesc	ElementDescID	ElementDescName	ElementDescDetail	ElementTypeID	ActiveFlag	ModifiedDate					
ElementType	ElementTypeID	ElementTypeDesc	ElementTypeAbbrev	ActiveFlag	DisplayDetailFlag						
ExActionCodeCategory	CategoryID	Category									
ExOACType	OACTypeID	OACType									
GlobalFuncPermission	DomainID	RoleID	AccessLevel								
Office	OfficeID	OfficeSymbol	OfficeName	ActiveFlag							
OfficeRoleLink	OfficeRoleID	OfficeID	RoleID								
StatusLookup	StatusID	Status	StatusDesc								
SysDomain	DomainID	TimeSpanInDomainID	DomainName	DomainDesc							
TableStatus	TableStatusID	TableName	TimeSpanTypeID	PrimaryKeys	ABIDESFlag	UpdateDate	ModifiedDateFlag				
TimeSpan	TimeSpanID	CreateDate	LockDate	ActiveFlag							
TimeSpanField	TimeSpanID	FieldTypeID	FieldValueID								
TimeSpanFieldType	FieldTypeID	FieldTypeName	FieldTypeDesc								
TimeSpanFieldTypeOrder	TimeSpanTypeID	FieldTypeID	SortOrder								
TImeSpanFieldValue	FieldTypeID	FieldValueID	FieldValue	FieldValueDesc	ActiveFlag						
TimeSpanInDomain	TimeSpanInDomainID	DomainID	TimeSpanID	OfficialFlag	SortOrder	LockFlag	Comment				
TimeSpanType	TimeSpanTypeID	TimeSpanType									

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