Managing Supply Chain Risks in Government Acquisitions Programs – Success Factors and Lessons Learned from Fifth Generation Fighters

By Irene Gerlovin

A Dissertation submitted to the

Graduate School-Newark

Rutgers, The State University of New Jersey

in partial fulfillment of the requirements

for the degree of

Doctor of Philosophy

Graduate Program in Management

Written under the direction of

Dr. Yao Zhao

and approved by

Dr. Weiwei Chen________________________

Dr. Rudolph Leuschner ________________________

Dr. Lian Qi ________________________

Dr. Nan Yang ________________________

Newark, New Jersey

October, 2017

Copyright page:

Managing Supply Chain Risks in Government Acquisitions Programs – Success Factors and Lessons Learned from Fifth Generation Fighters

ABSTRACT OF THE DISSERTATION

By Irene Gerlovin

Dissertation Advisor:
Professor Yao Zhao, PhD

The combined capabilities and performance of US weapon systems are unmatched throughout the world, ensuring that US military forces have the advantage over any adversary[1]. The US government spends huge amounts of capital and manpower to develop and acquire advanced equipment for defense purposes. Unfortunately, only a few of such acquisition programs were successful[1]. Many of them, including F-35 and F-22, seem to have failed than succeeded. The US Government Accountability Office (GAO) has reported extensively on problems in cost, schedule overruns, and performance breakdowns for major defense acquisition programs. Combining multiple case studies (on F-35 and F-22 programs) and a statistical analysis of the FY2015 Major Defense Acquisition Programs (MDAPs) data from GAO, we look into the frequent challenges encountered by such programs. Focused on the areas of: program management and supply chain risk management, we will explore industry and government prospectives.

Our objective is to shed light on a fundamental issue in government acquisitions: "What conditions are necessary for successful procurement?" Identifying these conditions can lead to increased efficiency by helping the stakeholders to determine best practices and allocation of resources.

[1] GAO reports

This thesis first provides a statistical analysis on the data of FY2015 Portfolio of MDAPs, with the objective of identifying statistically significant factors for the delays and cost overruns. We provide an overall assessment on the performance of these programs, and study the impact of project age, quantity changes, service type and contractor on the total acquisition cost overrun, unit cost overrun and the schedule delay.

Based on public data, collected from GAO's reports and other publicly available sources, we identify issues in program and supply chain management practices of two large-scale acquisitions (F-22 and F-35). We compare the similarities and differences between the two MDAPs led by the largest global defense contractor, Lockheed Martin (LM). Our event analysis looks into the causes for the major delays and setbacks of these programs, outlines the important challenges on schedule, cost and execution in MDAPs, and relates the causes to their program and supply chain management strategies. We analyze and classify the causes by technical, managerial and governmental categories, provide the lessons learned, and recommend remedial strategies. We also provide a game theory explanation of the rationales behind the delays and cost overrun, and comment on the best practices and recent changes of the government's regulations / policy.

This dissertation contributes to the literature of government acquisitions in the following ways: First, despite the significant news media coverage of the two fifth-generation tactical aircrafts, there is no comprehensive case study (and event analysis) on them. Our research is the first attempt to systematically collect, summarize and analyze the major setbacks of these programs; Second, unlike the literature that focuses mostly on program management, our work also takes the supply chain management perspective by studying and tracking the performance of, not only the major contractors, but also their supply chains, and their roles in the development and setbacks of the programs; Third, our statistical analysis of the FY2015 MDAPs data, provides additional perspectives and insights on the driving factors behind cost overrun and schedule delays, as well as their connections.

ACKNOWLEDGEMENTS

I could not have had a more understanding, caring, or helpful advisor than Dr. Yao Zhao!

I am grateful for his time, attention, and friendship. Working with him will always be among my best experiences at RBS.

I also want to thank committee members: Professors Weiwei Chen, Rudolph Leuschner, Nan Yang and Lian Qi. Each of these mentors was instrumental in the successful completion of this dissertation.

My family has been a tremendous resource and provided so much love, support and understanding.

Thank you!

Keywords: Program Management, Supply Chain Risk Management, Major Defense Acquisition Programs (MDAPs), Joint Strike Fighter (JSF), F-35; Raptor, F-22 Program; Competitive Analysis; Historical Supply Chain Program Reconfiguration; Sourcing Strategy; Contracting

TABLE OF CONTENTS

List of Exhibits

List of Tables

List of Acronyms

ATF	Advanced Tactical Fighter
ATA	Advanced Tactical Aircraft
CAPF	Cost Plus Award Fee
CDD	Capability Development Document
CDR	Critical Design Review
CPM	Critical Path Method
DAU	Defense Acquisition University
DoD	Department of Defense
DOT&E	Director, Operational Test & Evaluation
DSB	Defense Science Board
EVM	Earned Value Management
EMD	Engineering and Manufacturing Development
F-35	Lockheed Martin's Lightning II aircraft, also known as (JSF) Join Strike Fighter
F-22 (F/A-22)	Lockheed Martin Fighter Aircraft, also known as Raptor
FRP	Full Rate Production
FSD	Full Scale Development
GAO	Government Accountability Office
IOC	Initial Operating Capability
IOT&E	Initial Operational Testing and Evaluation
JSF	Joint Strike Fighter
KPP	Key Performance Parameter
KSA	Key System Attributes
LRIP	Low Rate Initial Production
MDA	Milestone Decision Authority
MDAP	Major Defense Acquisition Program

MS A	Milestone A is defined as "Approval to Enter Concept and Technology Development."
MS B	Milestone B is defined as "Approval to Enter Systems Development and Demonstration."
MS C	Milestone C is defined as "Approval to Enter LRIP/Production and Deployment."
NAICS	The North American Industry Classification System is the standard used by Federal statistical agencies in classifying business establishments for the purpose of collecting, analyzing, and publishing statistical data related to the US business economy
NPV	Net Present Value
OEM	Original Equipment Manufacturers
OSD	Office of the Secretary of Defense
PAUC	Program Acquisition Unit Cost
PBL	Performance Based Logistics
PDR	Preliminary Design Review
PERT	Program Evaluation and Review Technique
PMI	Project Management Institute
PMIAA	The Program Management Improvement and Accountability Act of 2015
SAB	Air Force Scientific Advisory Board
SAR	Selected Acquisition Report
SPO	System Program Office
TMRR	Technology Maturation & Risk Reduction
TOC	Theory of Constraints
TPO	Team Program Office
WSARA	Weapons System Acquisition Reform Act

Chapter 1 Introduction and Overview

1.1 Overview and Structure of this Work

On Wednesday, December 14, 2016, President Obama signed bill S. 1550, "The Program Management Improvement and Accountability Act of 2015 (PMIAA)" into law[2]. This new bipartisan initiative modifies Federal project and program management by, among other provisions:

- "Creating Agency Program Management Improvement Officers and an Interagency Program Management Policy Council,
- Establishing new government-wide standards for program management and program management personnel, and
- Placing additional responsibilities on the Office of Management and Budget to oversee management of federal programs" (**More information on a new bill in**
- **Appendix 1).**

This new bill, and countless others, came into being to address the significant problems and challenges in the program management practice over the last few decades. This is the motivation for our study.

The U.S. government expends large amounts of capital and manpower to procure equipment for defense purposes. The system development, procurement and sustainment of a nation's defense equipment is vital to its national interests, but the process is complex, constantly changing and highly adaptive, as well as time consuming and costly[3].

As stated by the Undersecretary of Defense Comptroller in a FY2015 budget request: “Department of Defense (DoD) Systems Acquisition has been on the GAO high risk list since 1990, based on a variety of reasons: (1) DoD establishes requirements at the far limit of technological boundaries, (2) DoD lacks critical skills in the acquisition workforce, (3) DoD relies on overly optimistic cost estimates, and (4) DoD has a continuing responsibility to procure the critical capabilities our warfighters need in the years ahead [1].

As a result, DoD is not receiving expected returns on its investments in weapon systems. Programs continue to take longer, cost more, and deliver fewer quantities and capabilities than originally planned”[4].

Although GAO recognized the positive benefits of recent acquisition reform legislation – i.e., the 2009 Weapons System Acquisition Reform Act (WSARA), the GAO notes that poor outcomes persist and that DoD must get better returns on its weapons systems investments to deliver more capability to the warfighter for less than it has in the past **[Gertler 2014]**.

Cost and time overruns in government acquisitions have become a high-profile problem attracting the interest of Congress, GAO and watchdog groups, and even a president elect.

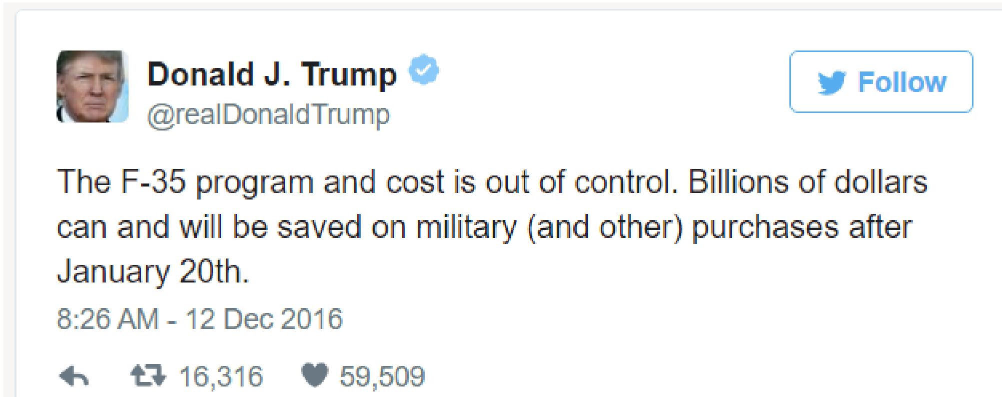


Exhibit 1-1: President-elect's tweet in December 2016 on a MDAP program.

The DoD acquisition is vital to the United States of America and her allies to stay technologically superior over potential threats. However, the DoD acquisition portfolio had only a few successes. Many more projects seemed to fail than succeed.

This research validates the importance and need for program management, supply chain management and systems engineering alignment which contain the potential to improve the complex and dynamic world we live in today.

1.1.1 Purpose of the Study

The combined capabilities and performance of U.S. weapon systems are unmatched throughout the world, ensuring that U.S. military forces have an advantage over any adversary [54]. The acquisition of weapons is very complex and involves very basic and strongly reinforced incentives to pursue weapons that are not always feasible and affordable[5]).

The process of acquiring new weapon platforms requires the U.S. government to invest substantial time and money in development, testing, and production. The Fiscal Year

(FY) 2015 acquisition funding request for the Department of Defense (DoD) totals $153.9 billion[6]. Of this amount, $69.6 billion is directed for programs that have been designated as Major Defense Acquisition Programs (MDAPs). Both the F-22 Raptor and F-35 Joint Strike Fighter (the subjects of our case studies[7]) are part of this portfolio.

According to the Government Accountability Office (GAO), the 84 MDAPs from the 2015 portfolio collectively ran $438 billion, or ~43% when assessed against first full estimates with an average schedule delay of more than 33 months, or over 39%. These increases are proportionally higher than those seen in past assessments[8].

This issue is not new. It was prominent in the Packard Commission's 1986 report to President Reagan on the top problems with the military procurement. The commission addressed significant defense management and execution problems, including acquisition inefficiency, cost growth, schedule delays, performance shortfalls, a lack of stability, and an unclear chain of authority. The commission considered input from both the Office of the Secretary of Defense (OSD) and the military departments in arriving at its conclusions[9].

The reform findings are aligned with our findings and can be summarized as:

1. Program schedule and cost growth
2. Waste due to the cancellations and poor performance and
3. Real and perceived abuses[10].

This is undeniably a long standing issue. For almost 70 years, actual costs of MDAPs in the Department of Defense have exceeded on average between 20% and 506% of their life cycle cost estimates, which are official expectations of actual program costs prior to completion[11]. Despite numerous DoD acquisition reform efforts and implementation of sophisticated cost estimation techniques, this cost growth continues to exist.

In RAND Report MG696 Mark V. Arena stated that:

"The escalating cost of aircraft and the downward cycle of procurement rates raise issues about the number of aircraft [the] DoD will ultimately be able to procure and operate" (Arena, 12). Further, the ability to control cost increase in these systems becomes even more relevant when one considers the actions being taken by congress in response to uncontrolled growth."[12]

From the point of view of the DoD and the defense industry, the fundamental question is, "What conditions are necessary for successful procurement?" Identifying these conditions can lead to greater efficiency by helping the DoD and the defense industry to determine where to put their resources and evaluate their business cases and program management processes.

The objective of this thesis is to shed some lights on the answers to the fundamental question by case studies of two recent MDAPs, F-22 and F-35, and a statistical analysis of the GAO MDAPs FY2015 data. By looking at the different aspects of the same problem, such as, statistical analysis of cost overruns and schedule delays, comparative statistics of the performance by contractors and by military services, regression and correlation analysis between the performance metric and various factors, and event analysis for root cause identification, we can (1) reveal and categorize the causes of delays and cost overruns in two of the most troubled and representative MDAPs, (2) assess the performance of MDAPs in the FY2015 portfolio, and (3) determine what management practices and strategies might contribute to the observed cost overruns in the execution of MDAPs. We further provide a game theoretical explanation of the rationale behind the overruns and lessons learned, make recommendations for implementing best practices, and comment on recent policy and program management changes in governmental acquisitions.

1.1.2 Organization of this Dissertation

Chapter 1 provides background information about defense industry landscape, government acquisition practices, program and supply chain risks and challenges. It also demonstrates the importance of the current state of MDAPs performance and the need for the study. A purpose statement describes the intent of the study, methodology and data sources. It summarizes the main results and contributions of this thesis in comparison to the literature.

Chapter 2 is focused on a statistical study of FY2015 MDAP Portfolio Analysis [21]. It takes a broad view of all MDAPs as of 2015 and aims to identify statistically significant drivers for cost and time overrun. It includes studies on the impact of project age, quantity changes, services and contractors on cost overrun and schedule delays, as well as the correlation between them.

Chapters 3 and 4 present our case studies of the F-22 Raptor and F-35 Lightning II programs. We describe the program's organization, contracts and government oversight, and supply chain management practices. We provide a detailed and comprehensive event analysis of the numerous issues and setbacks in these programs, and identify and categorize the causes. The key question to answer here is: "what really happened in these programs?" [7, 21]

Chapter 5 elevates and reconciles the statistical analysis and case studies to identify the common issues across different programs, compares the current strategies, such as the concurrency strategy, with the knowledge base evolutionary approach (advocated by GAO), and uses game theory to interpret the managerial implications of these practices. The key question to answer here is: "why did those issues happen in these programs?" We shall also comment on the recent acquisition policy changes.

1.1.3 Summary of Results and Contributions

The problem addressed by this multiple-case-based research is the need for a better understanding of program and supply chain management risks in Major Defense Acquisition Programs and determining the causes of the problems. We are basing our findings on our Lockheed Martin's F-22 vs F-35 case studies, and a statistical study analyzing the FY2015 portfolio of MDAPS performance.

This thesis presents our finding on the factors influencing MDAPs schedule delays, cost overruns and supply chain risks. We also analyze:

- DoD's new product development challenges;
- Competitive advantage and organizational performance and

- The effect of supply chain best practices.

We are looking into government management and oversight, the role of contractors and lead military services, levels of competition, and contract structures. We identify cost overruns and schedule delays, realism of baselines, supply chain risks, similarity and differences between the F-22 and F-35 programs, such as: weight problems, engine problems, untested technology, composite materials, unconventional supply chain, avionics cost growth, contract type impact, reserve analysis, and lessons learned.

This research advances the understanding of project and supply chain management in the areas of government acquisitions with contributions on root cause analysis of two major programs, statistical study of a portfolio of major defense acquisition programs, a game theory perspective to explain the adversary implications of some current practices and the advantages of best practice (advocated by GAO), and finally a commentary and recommendation on government acquisition policies / program management practices.

Past studies on this topic were focused on a critical but, narrow aspect of the problem, such as: technical maturity, contract type and competition. We are looking at:

- Accuracy of baseline: program cost and schedule estimates;
- The performance by contractors and military services;
- What factors might contribute to or be correlated with the observed cost overruns in the execution of MDAPs.

- This research will advance the understanding of DoD program and portfolio management with contributions to issues evaluation, literature review, a validated system dynamics model with analysis of the results, and recommendation for the future areas of studies.

1.2 Industry Landscape and Competitive Analysis

> *"The collapse of the Soviet Union was the equivalent of 1929 for the defense industry."* – Norman Augustine, Chief Executive of Lockheed Martin[13]

Since early 1990s, significant change has swept the defense industrial base. One of the key drivers is the U.S. defense budget related to the procurement of weapon systems, which fell by more than 65% in real terms following the end of the Cold War[14] (Perry, 1993).

1.2.1 Mergers and Acquisitions

At the beginning of the 1990s, there were 15 major companies competing for the defense business of the United States. After 22 mergers, there were only two giants – Lockheed Martin Loral and Boeing McDonnell Douglas, and three "major" companies, Hughes, Raytheon and Northrop, left **(Exhibit 1-2)**. Since the combined defense sales of Hughes, Raytheon and Northrop were less than either of the two giants, there was little doubt that the three smaller companies would eventually have to merge if they were to compete. This would leave the nation with three mega-companies competing for nearly $100 billion worth of defense business annually. The ostensible reason for these mergers was that the end of the cold war had drastically shrunk the defense business. The nation was spending less than it did at the height of the Reagan buildup, but defense employment was at about the same level as it was in the early 1980's.[15]

Year	Some Major Merger and Acquisition Events
1993	Martin Marietta purchased General Electric's defense division and General Dynamics' space division
	Lockheed purchased General Dynamics' aircraft business, including the F-16 division
	Loral purchased LTV, Ford Aerospace, and Unisys
1994	Lockheed and Martin Marietta merged to become Lockheed Martin
	Northrop outbid Martin for the Grumman aircraft company and became Northrop Grumman
	Northrop Grumman bought the defense division of Westinghouse
1995	Lockheed Martin purchased Loral to become Lockheed Martin Loral[16]
	Raytheon purchased E-Systems
1997	McDonnell-Douglas merged with Boeing

Exhibit 1-2: Some Major Merges and Acquisitions

(Source Merger Mania: Should the Pentagon Pay for Defense Industry Restructuring?) Based on [Korb, 1996] and Sterngold, 1996]

1.2.2 Politics and How Taxpayers Paid for Everything

Lockheed Martin and Boeing McDonnell had plants and operations in more than half of the states, which gave them tremendous political power. An attempt to cancel or terminate a weapon system could prove politically nearly impossible. For instance, for three years (from 1993 to 1996), Congress had continued to appropriate funds for Lockheed Martin's F-16 fighter planes and C-130 cargo aircraft even though the Pentagon said it had more than enough of these planes. In June 1993, at the request of industry executives, John Deutch, then Deputy Secretary of Defense, unilaterally reinterpreted federal regulations to allow defense companies to charge the Pentagon for the cost of carrying out the mergers [13].

"*According to Deutch, who had since been promoted to Deputy Secretary of Defense, and then to Director of Central Intelligence, the move was not a policy change but a clarification of existing policy. In Deutch's view, not only was the clarification necessary to promote the rational downsizing of the defense industry, it would also save taxpayers billions in the long run*."

Based on a New York Times article, "*Deutch was wrong on three counts. This was a major policy change. It was not necessary. And it would not save money. The cost to the Pentagon since 1993 could amount to $5 billion. This merger affected not only the price that the Pentagon paid for its planes and missiles, but also the innovation that competition among several companies frequently generates...Three companies bidding* *for about $100 billion in annual business from the Pentagon would not be healthy. It would be a near monopoly*." **[Korb, L. 1996]**

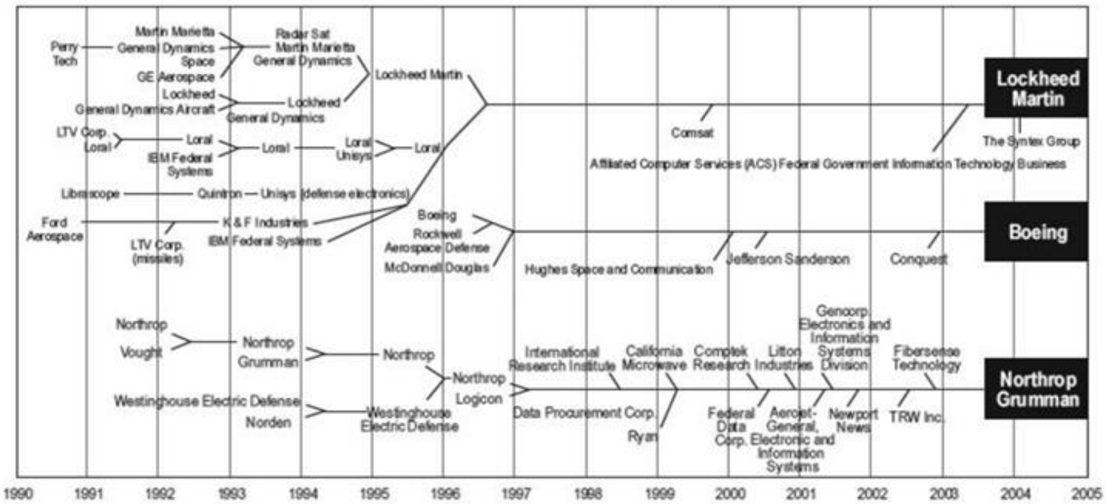


Exhibit 1-3: Consolidation of aircraft manufacturers
(From security Data Corporation database, 2004)[17]

1.2.3 The Herfindahl–Hirschman Index (HHI)[18]

During the period of the defense industry consolidation, mergers **(Exhibit 1-3)** significantly increased concentration and led to a highly concentrated market. Concentration indices are employed to measure the level of competition within an industry. Among the several indices proposed in the literature, the Herfindahl-Hirschman Index (HHI) and the Four-Firm Concentration Ratio (CR4) are among the most established. Specifically, the HHI requires the market shares of all market players to be known, while the CR4 requires just the top four. **(Naldi, 2014).**

Concentration indices and types of markets are presented in **Exhibit 1-4**.

Level of concentration	Type of market	Market power	*HHI*[1]	CR_4[2]
Non-concentrated market	Efficient competition, part of monopolistic competition	Low, if any	<1500	<45
Moderately concentrated market	Part of monopolistic competition, loose oligopoly	Moderate	1500-2500	45-60
Highly concentrated market	Tight oligopoly, dominant firm	High	>2500	>60

Exhibit 1-4: Concentration measures and types of markets
(*Pavic et al.; BJEMT, 13(1): 1-8, 2016)[19] Article no.BJEMT.23193*

The defense industry tried to create efficiencies, adopting this policy of mergers in order to enjoy economies of scale. In addition to that, the idea of globalization was introduced in the 1990s. The relatively loosely controlled antitrust environment, as well as the new global view of competition, gave rise to the formation of once-unthinkable combinations, like Lockheed Martin Loral and Boeing McDonnell-Douglas.

Exhibit 1-5 shows transformation from non-concentrated market to tight oligopoly.

	Year	CR4 (%)	HHI
NAICS[2] 336411 Aircraft	2002	85	2647
	1997	81	2526
	1992	79	2717
	1987	72	1686
	1982	64	1358

Source: Bureau of the Census, "Concentration Ratios in Manufacturing" for 1972-1997.
Bureau of the Census, "Concentration Ratios in Manufacturing" for 2002[20]

Exhibit 1-5: Defense Consolidation (Gerlovin, Zhao[21])

Interestingly, in 2009 the US House of representatives stated: "the United States must ensure, among other things that **more than one Aircraft Company** can design, engineer, produce and support military aircraft in the future." In 2011 Rand's MG1133 study concluded that: "the U.S. industrial base would be adequate if it was able to sustain at least two full-service prime contractors, each possessing approximately equal shares of research, development, test, and evaluation (RDT&E) funding and procurement funding.[22]"

The consolidation is still continuing: Lockheed Martin, the largest single contractor for the US government, announced in June of 2015 that it would buy Sikorsky from the United Technologies Corporation. Lockheed Martin's $9 billion purchase of Sikorsky

[2] **NAICS:** The North American Industry Classification System is the standard used by Federal statistical agencies in classifying business establishments for the purpose of collecting, analyzing, and publishing statistical data related to the U.S. business economy

Aircraft, the helicopter manufacturer, is part of a larger effort at Lockheed to focus more intently on military hardware than on less profitable government services[23].

1.2.4 Aircraft Teaming Arrangements

The combined impact of increased integration responsibilities and risk sharing leads to more distributed work within a technology market (i.e., Arora et al., 2001). This can be observed in an increased use of teaming by defense firms (Kovacic and Smallwood, 1994) (see **Exhibit 1-6**).

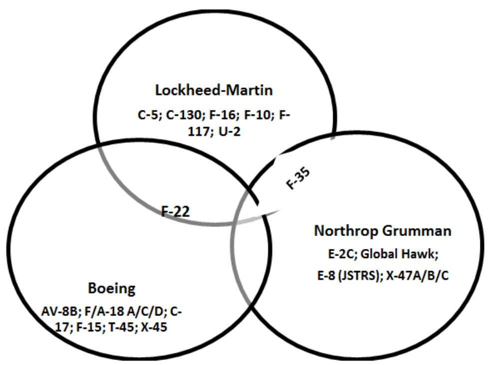


Exhibit 1-6: Military Aircraft Teaming Arrangements
Updated from Birkler et al., 2003[24]

Based on Birker at al. (2013), changes in the size and composition (i.e., mix of aircraft types) of demand for military aircraft have culminated in a fundamental shift in business processes. New, large, and complex systems have required that teams be formed to bring together the skills and experience needed to successfully design, develop, and produce modern aircraft systems.

1.2.5 Historical Supply Chain Program Reconfiguration

The supply chains of Lockheed Martin and Boeing are in transition driven by the teaming arrangement is shown on **Exhibit 1-7**.

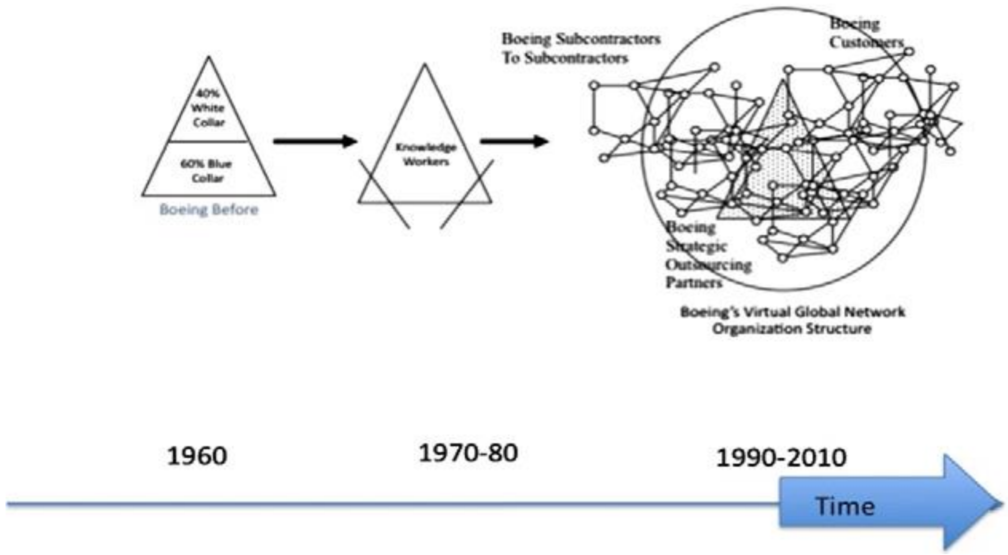


Exhibit 1-7: Supply Chain Historical Transformation (Nolan, 2012) [25]

The amount of work performed by defense prime contractors in-house has decreased over time. For example, in the early 1960s, prime contractors performed approximately 45% of work in-house (Hall and Johnson.1968). Currently, LM with the F-22 contract performs 25% of the work in-house. The transaction costs among contractors and their supply chains working to integrate subsystems into a final system helps determine the governance structure that the prime contractor uses to develop and produce a system[26].

> *"In the past, we used to make the majority of parts that went into our aircraft. Over the last decade, we have been outsourcing more and more of that. Now, the people manufacturing the detail-level parts are a loose confederation of machine shops. There is a need for them to build parts for us on a timely basis and to be able to get the materials in a cost-effective manner. As a contractor, we realized that we needed to generate a time-phased raw material forecast on behalf of those machine shops.[27]"*
> – Mike Jones, IT Project Manager and System Analyst for Ft. Worth, Texas-based LMAC (Atkinson, W. (2008))

The extended workload sharing and supply chain have significantly complicated procurement and program management.

1.2.6 Changes in Sourcing Strategy

Customer expectations for responsiveness, resiliency, and cost effectiveness, based on their needs and experience in the commercial sector, are rising. Indeed, customer frustration with expensive, slow, and unreliable support had, in part, been driving policy to outsource more weapon system support to the private sector, particularly to Original Equipment Manufacturers (OEMs) through Performance Based Logistics (PBL) contracts. More recently, the Air Force has retreated somewhat from outsourcing due to higher-than-expected costs of outsourced maintenance and repair as well as the breaching of the "50/50 rule," requiring that at least half of all maintenance be performed at a public depot. Uncertain deployment timing and destination, lower density of aircraft, and higher technological requirements, combined with pressures to make the support system more efficient and effective, can increase the likelihood, consequence, or duration of supply chain risks if they are not concurrently addressed. Such increased sustainment risks adversely impact the Air Force's ability to respond quickly and to sustain agile operations[28]. (**Exhibit 1-8**)

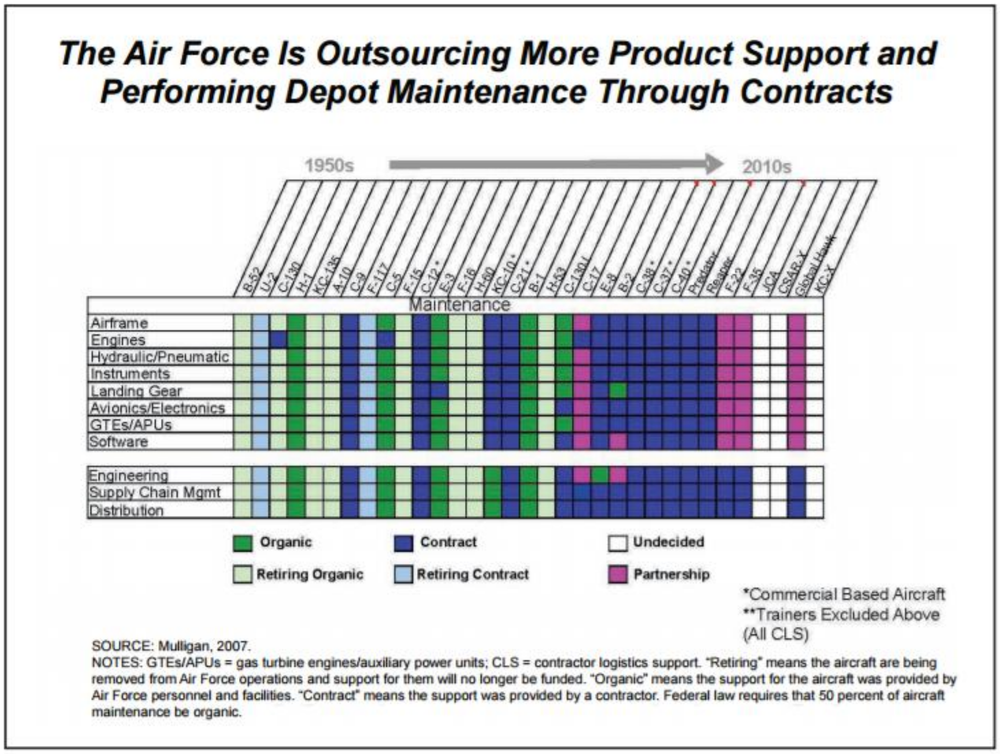


Exhibit 1-8: The Air Force's shift over time from organic-provided (i.e., internal) to contractor-provided (i.e., external) maintenance services [Moore, N. 2013].

Over time, the Air Force has increasingly relied on contract (and contractors) rather than solely organic support for its equipment; an important implication is that the Air Force must work with external partners to make its supply chains resilient and responsive and to mitigate risk. The above table shows the evolution of Air Force weapon system maintenance support in recent years. The top row lists major weapon systems by year of introduction. Each subsequent row in the table lists major support components (e.g., airframe, engines, landing gear) and support functions (i.e., engineering, supply chain management, distribution) for each system. The colors in each cell note the status of support. This table shows the Air Force's shift over time from organic-provided (i.e., internal) to contractor-provided (i.e., external) maintenance services. A significant amount of product support and depot maintenance is being performed through contracts on existing weapon systems, with more are planned for future systems (Mulligan, 2007).

While some elements of this strategy are being reviewed—for example, maintenance strategies for the C-17 and F-22 aircraft will use more organic support in coming years—it is unlikely that the Air Force will return, or even want to return, to 100 percent organic maintenance. Regardless of the contract strategy, both contractor and organic support have supply chain risks. What can vary are the types and dimensions of the risks as well as the access Air Force managers have to the information needed to adequately identify, assess, and manage them[29].

1.2.7 Air Force Generations of Key Fighter Aircraft

The F-22 and the multi-service F-35 Joint Strike Fighter (JSF) were the world's first fifth-generation tactical aircraft. Fifth-generation aircraft incorporate the most modern technology, and are considered to be generally more capable than earlier-generations. The future of DoD's tactical aircraft recapitalization depends largely on the outcomes of these programs, which continue to be burdened with issues. A historical prospective is provided in the **Exhibit 1-9**.

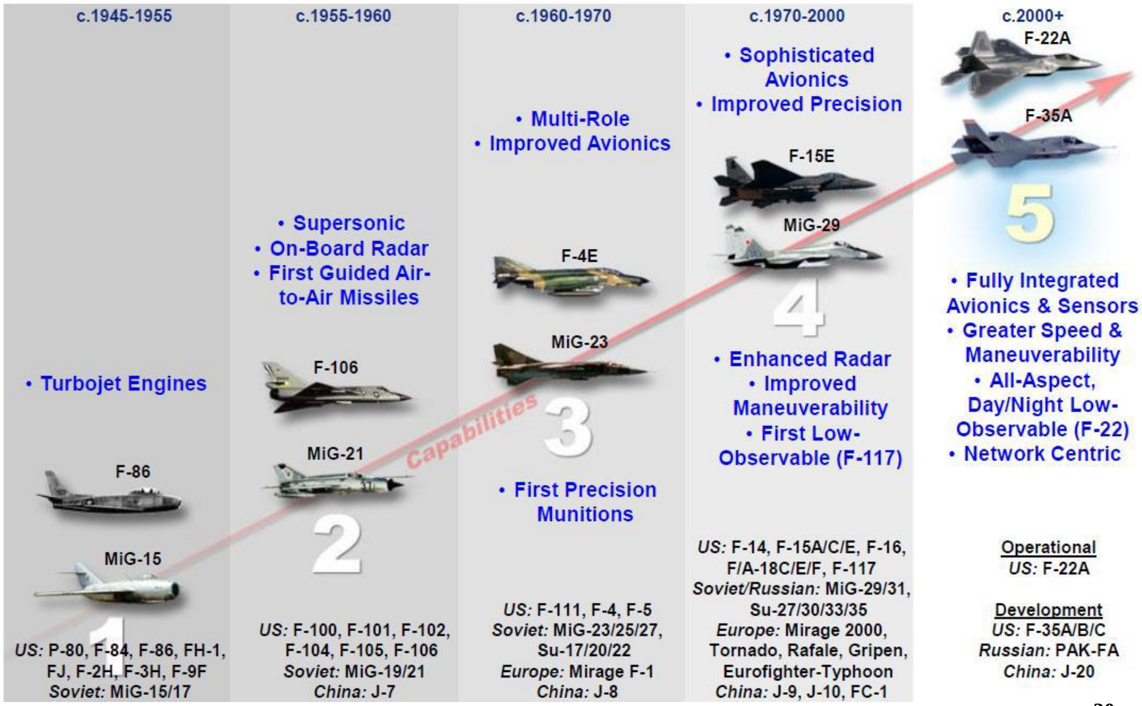


Exhibit 1-9: The Air Force Generations of Key Fighter Aircraft (As of 2/28/12)[30]

1.2.8 Top US DoD Contractors (as of 2015)

According to Forbes (**Exhibit 1-10)**, "Lockheed Martin is the largest single contractor for the U.S. government in 2015 by far with $36.2 billion contracted. Of that amount, $29.4 billion was contracted for defense purposes. Lockheed Martin is known for developing the C-130 Hercules, F-22 Raptor and the F-35 Lightning II. The latter is the most expensive U.S. weapons system ever, costing some $400 billion and due to cost another $1 trillion over the course of its life cycle"[31] .

Boeing (BA) is in a distant second place with its obligated contracts in 2015 coming to $14.6 billion. The KC-46 Pegasus tanker and EA-18G Growler carrier-based electronic warfare aircraft represent two major projects for Boeing. Raytheon whose products include missile and radar systems, is in third place with $12.3 billion. Lockheed Martin could also be set for a further boost with House legislation directing the Air Force to conduct a study associated with restarting F-22 production. However, Air Force officials have consistently poured cold water on reviving the production line which closed five years ago with 187 aircraft produced. **[Forbes 2016]**

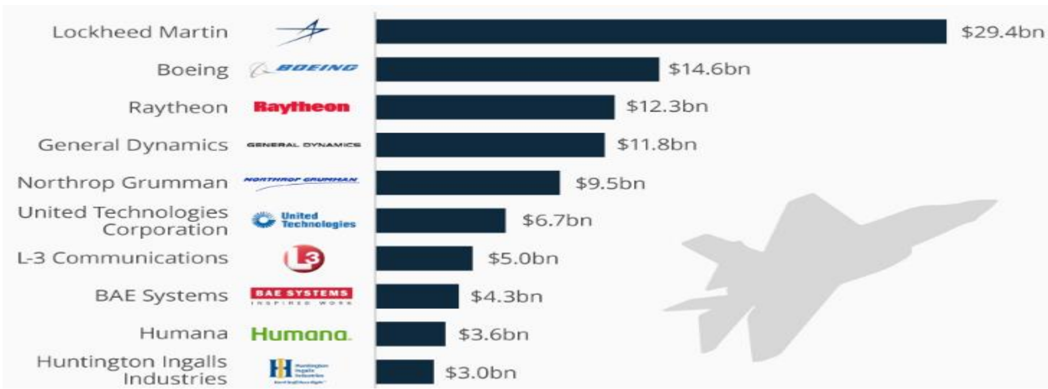


Exhibit 1-10: America's Biggest Defense Contractors (US DoD expenditure with contractors in 2015 [32]

Despite the disastrous project performance, the main contactors of such programs may be performing very well financially with ever increasing stock prices. **Exhibit 1-11** shows the stock prices of Lockheed Martin over the years of its F-35 development.

Exhibit 1-11: – Lockheed Martin Historical Stock Prices
https://www.thestreet.com/quote/LMT.html (Historical Stock Prices: S&P 500)

The company did very well, financially, despite records of mishandling and cost overruns and mismanagement of multiple programs. Stock prices reached their historic high just before the newly elected president threatened to shut down the F-35 program.

1.3 Literature Review

Previous research from the areas of government acquisitions, program management, supply chain management and risk management has provided a foundation for the current study. Past studies on government acquisition (especially for defense systems) were focused on some critical aspects of the problem, such as, portfolio and program management, technical maturity and different issues such as contract type and competition (Berteau, 2010)[33], risk management, process management, and cost / schedule estimation. The following literature review will highlight previous research that supports and guides the current study.

1.3.1 Portfolio and Program Management

DoD's weapon system acquisition programs have a total estimated acquisition cost of over $1.4 trillion **(GAO-15-466)**. Portfolio management is an approach used by organizations to evaluate, select, prioritize, and allocate resources to projects that best accomplish strategic or organizational goals. In March 2007, GAO recommended that DoD implement a department-wide portfolio management approach for weapon system investments[34].

As GAO stated in 2015: "The Department of Defense (DoD) is not effectively using portfolio management to optimize its weapon system investments, as evidenced by affordability challenges in areas such as shipbuilding and potential duplication among some of its programs. Best practices recommend assessing investments collectively from an enterprise-wide perspective and integrating requirements, acquisition, and budget information, but several factors inhibit DoD's ability to do so". (GAO-15-466)

In the broad context, the DoD weapon system acquisition community's use of the word "program" to describe weapon system developments like the F-35 and F-22. The Defense Acquisition Management System is an event-based process (**Exhibit 1-12**). Appendix 5 contains a history and the overview. Acquisition programs proceed through a series of milestone reviews and other decision points that may authorize entry into a significant new program phase. (DoD Instruction 5000.02, *Operation of the Defense Acquisition System*.)

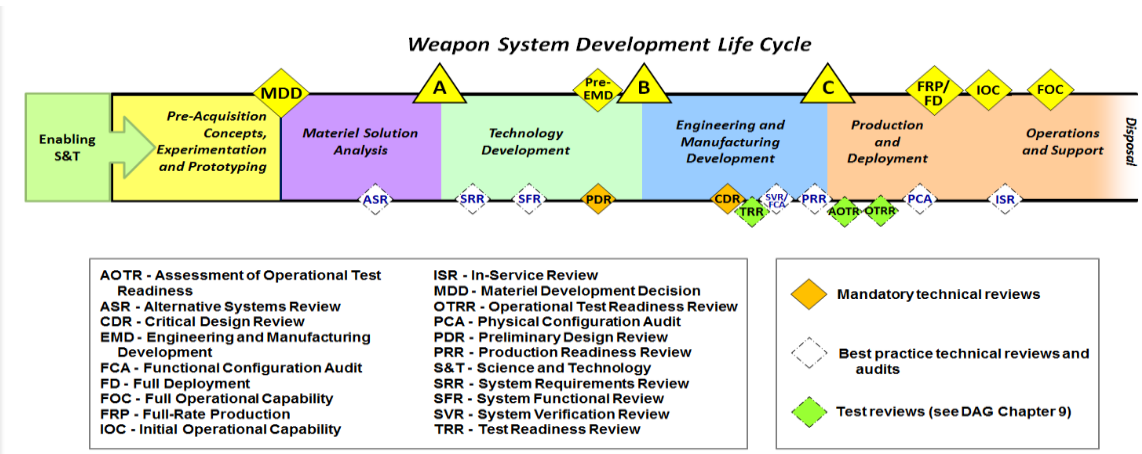


Exhibit 1-12: DoD weapon system development life cycle

Defense Acquisition University, "Defense Acquisition Guidebook," 15 May 2013. [Online]. Available: https://dag.dau.mil.

The goal of government acquisition and procurement is to obtain quality products that satisfy user needs in a timely manner at a fair and reasonable price. The procedure and flow charts above show the "how to" side of acquisitions. The sequence of events that comprise the process defined in policy reflects principles from science and engineering disciplines such as systems engineering, to manage principles such as lessons learned in program management, supply chain management and risk management.

Davidson and Huot (1991) evaluated the impact of cost overruns from large projects. The authors began by stating that indirect costs associated with delays and disruptions are three to eight times larger than that of direct costs. They continued a frequent note that most project tools were based on linear theory and ignored social elements. The authors also highlighted another trend: that public projects are almost always underestimated to appear attractive. They used a U.S. nuclear submarine as an example that was underestimated by 1.5 million man-hours of work and delivered two years behind schedule. The authors recommend a new open and dynamic approach as opposed to the traditional approaches that were closed and static (Davidson & Huot, 1991) [35]. This research supports the current effort and continues many of the deficiencies in traditional project management techniques.

Meier in his “Causal inferences on the cost overruns and schedule delays of large-scale U.S. federal defense and intelligence acquisition programs” utilized previous defense science board (DSB) findings, personal interviews, and RFIs to defense industries to best determine the factors in “large-scale DoD” programs cost overruns and schedule delays. The author concludes that there are three primary reasons for these problems[36].

- First, the DoD and Intelligence Community (IC) utilize poor human resources approaches by not providing more experienced personnel in critical decision-making positions and requiring frequent rotations (Ibid).
- Second, Meier notes that there are too many stakeholders involved in the development process which leads to changing requirements and additional program office work that is not originally budgeted.

- Third, the reduction of number of companies in the DoD industry that "…has resulted in aggressive bids by industry to win government contracts", and such actions cause poor estimates of true costs and schedules with limited ability to be refuted by the inexperienced decision-makers (Meier, 2010).

Reimer suggested that product portfolio management and better risk management as the way to address the worsening trends of defense acquisition. He suggested that if systems are managed as portfolios, trade-offs could be made across that portfolio, both to manage the throughput and also to optimize resource deployment to get better outcomes[37].

The Standard for Portfolio Management—Third Edition (2013). Recognized by ANSI as American National Standard BSR/PMI 08-003-2013[38]

According to Rios, et al (2006)[39], real-options can be used to:

- Identify different corporate investment decision pathways or projects that management can navigate given the highly uncertain business conditions;
- Value each of the strategic decision pathways and what it represents in terms of financial viability and feasibility;
- Prioritize the pathways or projects based on a series of qualitative and quantitative metrics;
- Optimize the value of your strategic investment decisions by evaluating different decision paths under certain conditions or determining how using a different sequence of pathways can lead to the optimal strategy;
- Time the effective execution of your investments and finding the optimal trigger values and cost or revenue drivers; and

- Manage existing or developing new options and strategic decision pathways for future opportunities.

On November 30th, 2016 the US Senate passed a bill to make improvements to program and project management policy across the U.S. government. Project Management Institute (PMI) called it “a landmark achievement for our profession”. (More information is included in Appendix 1)[40].

The findings of Copeland, et al (2013) indicate that system prototype demonstrations do indeed have a profound positive influence on the outcome of weapon systems development performance[41].

The literature has benchmarked best practices which have also been reflected in acquisition policy. Recent and significant changes to the policy include those introduced by the Weapon Systems Acquisition Reform Act of 2009[42] and the Department’s own “Better Buying Power” initiatives are aimed to strengthen practices that can lead to more successful acquisitions. The policy provides a framework for developers of new equipment to gather knowledge at appropriate stages that confirm the maturity of their technologies, the stability of their designs and their production processes. These steps are intended to ensure that a program will deliver the capabilities required utilizing the resources, cost, schedule, technology, and personnel available.

GAO provided recommendation for successful product developers: They must ensure that a high level of knowledge is achieved at key junctures (knowledge points) in development. A clear picture of "what to do" is offered in GAO-14-563T study. **Table 1** (below) summarizes these steps and best practices, organized around three key knowledge points in a defense system acquisition.

Knowledge Point 1: Start of product development activities (Milestone B)
Demonstrate technologies sufficiently to ensure they are mature and work as intended
Ensure that requirements are informed by a preliminary system design
Establish cost and schedule estimates based on the preliminary design and other system engineering tools (such as prototyping)
Constrain development to 5 years or so in anticipation of future upgrades
Conduct independent assessment of risks and cost
Develop a suitable contract strategy
Fully fund the planned development work
Hold major milestone decision review to begin product development
Knowledge Point 2: Critical design review (CDR) midway through product development
Complete 90 percent of engineering design drawing packages to ensure design is stable
Demonstrate with system integration prototype that design performs as intended
Identify critical manufacturing processes and key system characteristics
Establish targets and growth plan for product reliability
Conduct independent cost estimate
Conduct system critical design review to ensure design meets requirements
Knowledge Point 3: Initiation of production for delivery to customer (Milestone C)
Demonstrate critical manufacturing processes on a pilot production line
Build and test production-representative prototypes to demonstrate product in operational environment and to achieve reliability goal
Collect data on critical manufacturing processes and demonstrate that they are in statistical control to ensure quality
Conduct independent cost estimate
Conduct major milestone decision review to begin production

Table 1: DoD Best Practices for Knowledge-based Acquisitions
([21] Based on GAO-14-145T)

1.3.2 Cost and Delay Estimate

Accurate cost estimates are vital to the capital budgeting process for the DoD since they are used to set the affordability cap for each MDAP and across DoD Component weapon system program portfolios. Affordability is defined as the upper limit a DoD Component can allocate for a program without reducing costs or shifting resources between programs (Petrucci, 2005).

Arena et al. (2006) performed analysis of the cost growth of sixty eight completed MDAPs, based on Selected Acquisition Reports (SARs). Average adjusted total cost growth for the completed program is 46% from MS II (B) and 16% from MS III (C). Few correlations were observed between overall system characteristics and cost growth[43].

A number of publications include analyses of particular acquisition policies. Some qualitative studies look into:

- A set of related initiatives that had been successful, or
- Shortcomings of the acquisition process over a specific time period, such as a decade.

In contrast, there have been few broad quantitative assessments of the effectiveness of acquisition policy and process. David L. McNicol, in his “Cost Growth in Major Weapon Procurement Programs” studied 138 programs (1970-1997) but did not report the cost growth factor[44]). Tyson et al. showed cost growth measures highest in the 1960s, lower in the early part but higher in the latter part of 1970s, and lower yet again in the 1980s. The study concluded that “vehicle programs and electronics programs had the highest development cost growth of any equipment type” and even if the exact values of the cost growth factors do not agree, cost growth is clear: “since 1946 MDAPs do show a tendency to overrun baseline cost estimates”[45]. Obaid Younossi et al., (2007) published by The RAND Corporation, concluded from their careful study of trends in development cost growth that "despite the many acquisition reform and other DoD management initiatives over the years, the development cost growth of military systems has not been reduced.[46]"

In GAO's "Cost Estimating and Assessment Guide," March 2009, the best practices in cost estimation were examined. GAO covered the entire process of gathering data, analyzing historical costs, establishing assumptions and ground rules, generating quality cost estimates, addressing risk and uncertainty in estimates, maintaining and updating cost estimates, and presenting cost estimates to leadership. Seventeen best-practice checklists were presented and real-world case studies of many USG programs were used to support the document's procedures and conclusions. Overall, the procedures outlined in the document were very sophisticated in its treatment of risk and uncertainty. It appears that following these procedures would lead to more realistic MDAP cost estimates; however, despite publication of these advanced best practices, the systemic estimation bias continues. [**GAO, 2009]**

While researchers and practitioners may disagree on the efficacy of recent acquisition reforms upon improving cost estimates, clearly, there is ample room for improvement. Perhaps the problem didn't lie with the accuracy of the cost estimates, but with the fact that these estimates were accurately estimating the wrong thing. For example, when the RAND study corrected the cost data for changes in procurement quantity, the average cost errors dropped by over 20% (Arena et al., 2006a), and The GAO (2012a) study attributed nearly 40% of the $74 billion increase to quantity changes.

Capt Allen J. DeNeve, USAF, Lt Col Erin T. Ryan, USAF, Lt Col Jonathan D. Ritschel, USAF, and Christine Schubert Kabban, in “Taming the Hurricane of Acquisition Cost Growth—Or at Least Predicting It,” provided a statistically derived approach to forecasting how a program’s baseline is likely to change over time, instead of assuming it will remain static, which promises to improve the prediction of a program’s likely cost growth and thus to develop more realistic cost estimates.

A regression technique is used to predict cost growth in new acquisition programs by associating these programs with previous ones. This technique reduces cost estimate error in the earliest estimates by over one third[47].

Bolten et al. (2008) analyzed 35 completed and ongoing programs in order to determine causes of cost growth in development and procurement. The study found evidence of 60% overall cost growth from initial estimates, resulting largely from changes in quantities, additional requirements, and schedule changes[48].

1.3. Process Management

The government has invested heavily in the process improvement of acquisitions over the past several years, with decidedly mixed results in the field of acquisition[49] (Browning & Sanders, 2012; Fox, 2011; Smith, 2003). In its 2014 report, GAO stated that: “To a large extent, the improvements we have seen tend to result from external pressure exerted by higher level offices within DoD on individual programs. In other words, the reforms have not yet been institutionalized within the services. We still see employment of other practices—not prescribed in policy—such as concurrent testing and production, optimistic assumptions, and delayed testing. These are the same kinds of practices that perpetuate the significant cost growth and schedule delays that have persisted in acquisitions through the decades. They share a common dynamics: moving forward with programs before the knowledge needed to reduce risk and make those decisions is sufficient". **(GAO-14-563T)**

Miller and Ray explore how governmental organizations can successfully overcome the challenges of turning their isolated best practices into widespread standard practices. A decade of acquisition process improvement efforts has produced numerous best practices that have not spread to become standard practices[50]. The findings from Copland's research indicated that system prototype demonstrations do indeed have a profound positive influence on the outcome of weapon systems development performance[51].

1.3.4 Supply Chain Risk Management

Moore and Laredo have defined supply chain risk as the "effect of uncertainty at any point in the end-to-end supply chain on its objectives."[52] Simchi-Levi and Kaminsky (2000) define supply chain management as "the integration of key business processes among a network of interdependent suppliers, manufacturers, distribution centers, and retailers in order to improve the flow of goods, services, and information from original suppliers to final customers, with the objectives of reducing system-wide costs while maintaining required service levels". Supply Chain Risk Management (SCRM): the coordination of activities to direct and control an enterprise's end-to-end supply chain with regard to supply chain risks. (Adapted from: International Organization for Standards, 2009b)

Despite Department of Defense acquisition rules, program managers continue to field commercial proprietary solutions that do not integrate easily with other logistics information systems and databases that are already in operation (Behrens, 2010a, 2010b; GAO, 2009). Augustine (2015) argues that the world of systems acquisition is governed by certain "laws" that are as immutable as the natural laws that govern the universe. It's an amusing look at some very real and very serious problems. His most famous law, on the increasing cost of tactical aircraft, jokingly states that due to the consistent cost overruns “in the year 2054 the entire defense budget will purchase just one aircraft. This aircraft will have to be shared by the Air Force and Navy 3-1/2 days each per week except for leap year, when it will be made available to the Marines for the extra day”[53].

Chapter 2: MDAPs FY2015 Portfolio Analysis

2.1 Introduction

Our research is focused on a statistical study of FY2015 MDAP Portfolio Analysis. It takes a broad view of all MDAPs as of 2015 and aims to identify statistically significant drivers for cost and time overrun. It includes studies on the impact of project age, quantity changes, services and contractors on cost overrun and schedule delays, as well as the correlation between them.

The Fiscal Year 2015 acquisition funding request for the Department of Defense (DoD) totals $154.2 billion for the base budget. Of this amount, $69.6 billion is for programs that have been designated as MDAPs[54].

According to the Government Accountability Office (GAO), the 84 MDAPs from 2015 portfolio collectively ran $438 billion, or ~43% when assessed against first full estimates with an average schedule delay of more than 33 months, or over 39%. These increases are proportionally higher than those seen in past assessments[55]. See **Exhibit 2-1:** for Cost Overrun by Contractor and **Table 2:** for Cost variance by service.

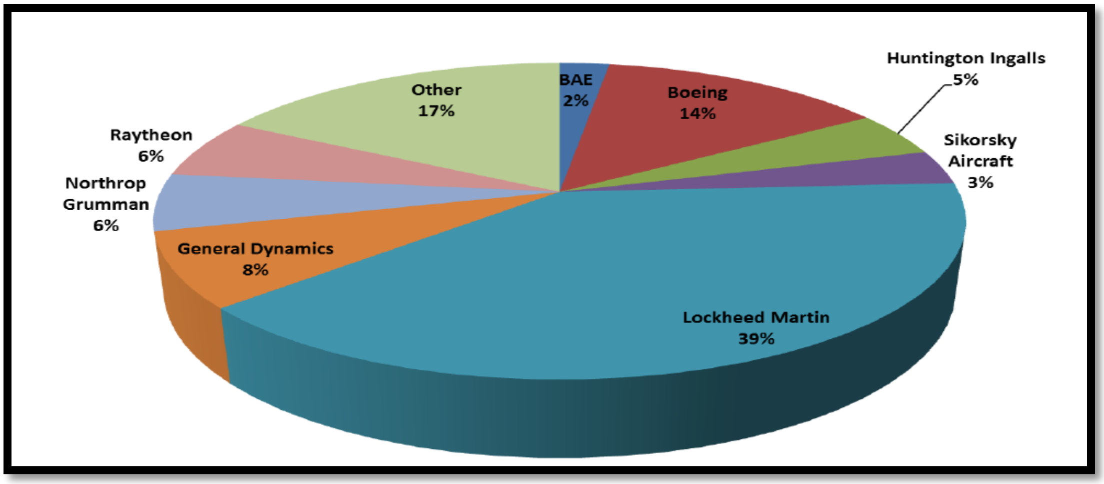


Exhibit 2-1: – Cost overrun by contractor ($457 billion over budget)

Gerlovin, Zhao, [21][56], [57]

	Air Force (23)	DoD (3)	Navy (39)	Army (19)
Current Acq. Cost	$268,006	$373,566	$658,278	$156,040
1st full Est. Milestone B	$149,517	$253,023	$456,376	$158,350
Variance %	79.25%	47.64%	44.24%	-1.46%

Table: 2 -Cost Variance by Service

Gerlovin, Zhao, [21]

2.1.1 Research Objective

Our research objective is to

- Assess the performance of the program portfolio in 2015,
- Identify the major drivers behind MDAPs delays and cost overruns,
- Test potential connection and correlations between delays and cost overruns,

We employ the following statistical analysis:

- Descriptive statistics on cost overruns and schedule changes.
- Regression analysis on the cost overruns and delays with respect to various factors, such as project age, change in quantity, the lead branch of military service and the primary contractor.

2.1.2 Methodology Overview and Primary Data Sources

The primary source of data for this study was (**GAO-15-342)** - Assessments of Selected Weapon Programs: DoD's FY2015 Portfolio of Major Defense Acquisition Programs (A fragment of GAO's table is presented in **Exhibit 2-2).**

Furthermore, we reviewed corresponding Selected Acquisition Reports (SARs). The SARs track MDAPS reporting on their schedule, unit counts, total spending, and progress through milestones.

Additional data sources:

- **DOT&E** (Operational Test & Evaluation) Reports**:** 2014 Update
- Federal Procurement Data System (FPDS): The FPDS is a database of every government contract, with millions of entries each year. Each entry has extensive data on the contractors, contract type, competition, place of performance, and a variety of other topics as mandated by Congress. Cross-referencing individual contracts with MDAPs is possible using the system equipment codes (which match up with those of MDAPs). This source provides the most in-depth data on the government contracting process. Department of Defense Budget Documents: In addition to budget data, these documents provide topical information on each MDAP and its subcomponents. They will primarily be used to categorize projects as well as to support and double check spending figures from the other two sources.

Using these data sources, we conducted the following statistical studies (See details in segment 2.4 Descriptive study).

- **First study:** Descriptive analysis to assess the overall performance of the programs and to identify potential independent variables

- **Second study:** Regression analysis of cost overrun and program delays to identify their major drivers.

2.1.3 Hypothesis

These analyses provide insight into potential cause and-effect association and aim to identify statistically significant drivers for cost and time overrun. They include studies on the impact of project age, quantity changes, services and contractors on cost overrun and schedule delays, as well as the correlation between them.

This essay tests the following research hypotheses:

H1 First, we examine **total program cost growth** between the original (MS B) estimate and current estimate and the impact of following factors: project age, quantity changes, services and contractors.

Change in **total program cost overrun** is dependent on:

I: Program age;

II: Quantity changes;

III: Service / Prime contractor

H2 We also look into **unit cost growth** between the original (MS B) estimate and current estimate and the impact of the same factors: project age, quantity changes, services and contractors

Change in **unit cost** is dependent on:

I: Program age;

II: Quantity changes;

III: Service / Prime contractor

H3 Our third hypothesis looks into **Initial Operational Capability (IOC) delays**. We are looking into delays/variances between the original (MS B) estimate and current estimate and the impact of the same factors: project age, quantity changes, services and contractors

Program IOC delay is dependent on:

I: Program age;

II: Quantity changes;

III: Service / Prime contractor

H4 IOC delays and cost overruns are correlated.

We are looking into the variances between the original (MS B) estimate and current estimate in IOC dates and program/unit costs.

I: Change in total program cost is strongly correlated with IOC delay

II: Change in unit cost is strongly correlated with IOC delay

Additional variable definition is provided in section **2.3**.

2.2 Data extraction and validation

The required information is scattered in multiple documents with quite some inconsistencies. In order to conduct this analysis we collected cost data from GAO-15-342SP Assessments of Selected Weapon Programs report. A fragment of GAO's table is presented in **Exhibit 2-2.** All programs (84 data points) in FY2015 portfolio were analyzed.

Although specific details, related to program performance, schedule milestones, primary contractor, and testing results are not readily available, we developed a methodology, to collect and verify important relevant entities (for which information is publicly available).

All costs are in FY2015 Dollars. We use "First Full Estimate Total Acquisition Cost" (e.g. the MS B estimate) from Exhibit 2-2. Methodology and validation rules are explained below.

Step 1: From **Exhibit 2-2** (below) we obtained the following:

- Program name **(A);**
- Current total acquisition cost (FY2015 dollars (in millions)) **(B);**
- First Full Estimate total acquisition cost (FY2015 dollars (in millions)) **(C);**

Fiscal year 2015 dollars (in millions)

Program name (A)	Current total acquisition cost (B)	First Full Estimate total acquisition cost (C)	Change in total acquisition cost from first full estimate (percent)	Change in total acquisition cost within the past year (percent)	Change in total acquisition cost within the past 4 years (percent)
Advanced Extremely High Frequency Satellite (AEHF)	$14,474	$6,747	114.5%	-1.3%	4.2%
AGM-88E Advanced Anti-Radiation Guided Missile (AGM-88E AARGM)	$2,249	$1,696	32.6%	8.3%	14.6%
AH-64E Apache New Build (AH-64E New Build)	$2,280	$2,510	-9.2%	6.8%	-9.2%
AH-64E Apache Remanufacture (AH-64E Remanufacture)	$13,894	$7,671	81.1%	10.4%	22.2%
AIM-120 Advanced Medium Range Air-to-Air Missile (AMRAAM)	$24,548	$11,575	112.1%	1.3%	-4.5%
AIM-9X Block II Air-to-Air Missile	$3,623	$4,231	-14.4%	-5.1%	-14.4%
Air and Missile Defense Radar (AMDR)	$5,193	$5,920	-12.3%	-12.3%	-12.3%
Airborne & Maritime/Fixed Station Joint Tactical Radio System (AMF JTRS)	$3,473	$8,636	-59.8%	-3.7%	-60.7%
Airborne Warning and Control System Block 40/45 Upgrade (AWACS Blk 40/45 Upgrade)	$2,803	$2,957	-5.2%	-2.8%	-5.2%
B-2 Extremely High Frequency SATCOM and Computer Increment 1 (B-2 EHF Inc1)	$578	$752	-23.1%	-3.4%	-13.1%
B61 Mod 12 Life Extension Program Tailkit Assembly (B61 Mod 12 LEP TKA)	$1,381	$1,385	-0.3%	0.2%	-0.3%
C-130J Hercules Transport Aircraft	$16,746	$1,005	1566.1%	1.1%	1.6%
C-5 Reliability Enhancement and Re-engining Program (C-5 RERP)	$7,494	$11,550	-35.1%	-2.9%	-5.1%
CH-47F Improved Cargo Helicopter	$15,788	$3,410	363.0%	4.5%	8.5%
CH-53K Heavy Lift Replacement Helicopter	$25,335	$17,536	44.5%	1.4%	7.6%
Chemical Demilitarization-Assembled Chemical Weapons Alternatives (Chem Demil-ACWA)	$10,888	$2,799	289.1%	3.0%	27.5%
Cooperative Engagement Capability (CEC)	$5,578	$3,118	78.9%	0.9%	2.5%
DDG 1000 Zumwalt Class Destroyer	$22,497	$36,858	-39.0%	1.5%	5.6%

#	Program name (A)	Current total acquisition cost (B)	First Full Estimate total acquisition cost (e.g. MS B) (C)
1	**Advanced Extremely High Frequency Satellite (AEHF)**	**$14,474**	**$6,747**
2	**AGM-88E Advanced Anti-Radiation Guided Missile (AGM-88E AARGM)**	**$2,249**	**$1,696**
3	**AH-64E Apache New Build (AH-64E New Build)**	**$2,280**	**$2,510**
4	**AH-64E Apache Remanufacture (AH-64E Remanufacture)**	**$13,894**	**$7,671**
5	**AIM-120 Advanced Medium Range Air-to-Air Missile (AMRAAM)**	**$24,548**	**$11,575**
6	**AIM-9X Block II Air-to-Air Missile**	**$3,623**	**$4,231**
7	**…issile Defense Radar (AMDR)**	**$5,193**	**$5,920**

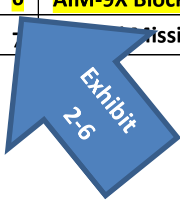


Exhibit 2-2: Current & First Full Estimates for DoD's 2014 Portfolio of MDAPs (fragment) [GAO-15-342SP] **and mapping**

Additional data items (columns) were pulled from publicly available data sources (**Exhibit 2-3**).

Additional data columns	Various Data Sources
Service	**1. Selected Acquisition Reports (SAR); (2014-2015);**
Original Prime Contractor (e.g. at Milestone B)	**2. Program Acquisition Cost Summary Tables (1978-2014)**
Milestone B Date (YYYY/MM/01) (Development starts)	**3. Annual GAO Assessments of Selected Major Weapon Programs reports**
Original Total Quantity Development Estimate	**4. Reasons Behind Program Delays 2014 Update (DOT&E)**
Current Quantity	**5. Performance of the Defense Acquisition System, 2015 (DoD)**
Original IOC (Initial Operational Capability) Date (e. g. MS B)	**6. The Nunn-McCurdy Act: Background, Analysis, and Issues for Congress**
Current IOC (Initial Operational Capability) Date	
Nunn-McCurdy Breaches	
Reason categories behind program delays (DOT&E)	

Exhibit 2-3: -Additional Data Columns and Their Sources

#	Service	Original Prime Contractor / Milestone B	Initial Milestone B year/mm/01	T/QTY (MS B) Estimate	Total Quantity Current Estimate	Current Unit cost	First Full Estimate (MS B) Unit cost	IOC deadline year/mm/01	2015 IOC deadline year/mm/01 estimate	Nunn-McCurdy Breaches
1	Air Force	Lockheed Martin	10/1/2001	5	6	2412.33	1349.40	2/1/2009	6/1/2015	3
2	Navy	Alliant TechSystems (ATK)	7/1/2003	1790	1919	1.17	0.95	**9/1/2010**	7/1/2012	0
3	Army	Boeing	7/10/2006	**56**	**63**	36.19	44.82	1/1/2013	11/1/2013	1
4	Army	Boeing	7/10/2006	602	639	21.74	12.74	1/1/2013	11/1/2013	1
5	Air Force	Raytheon	11/1/1982	**24335**	16540	1.48	0.48	9/1/1986	9/1/1993	0
6	Navy	Raytheon	12/1/2011	6000	6000	0.60	0.71	9/1/2014	3/1/2015	0
7	Navy	Raytheon	10/4/2013	22	22	236.05	269.09	9/1/2023	9/1/2023	0

Exhibit 2-4: -Additional Data Columns for programs in Exhibit 2-2

Step 2:

We grouped 84 programs on our list into two categories:

- **Category 1:** contains 37 programs reviewed by GAO in **GAO-15-342SP** assessment. Please refer to **Exhibit 2-5 Two-Page Assessment of Individual Programs (fragment)** below.

- **Category 2:** contains 47 programs, which are not on GAO's "Two-Page assessment".

  We explain data collection and validation methodology for both categories below (1 program in each category is used as a detail example of our methodology).

Step 2: Category 1:

"Two-Page Assessment" contains 37 programs reviewed by GAO in the same report We used "Two-Page Assessment" section **(Exhibit 2-5)** to collect some additional information for 37 programs. It wasn't as easy as it sounds…**GAO states:** "Each two-page assessment contains a comparison of total acquisition cost from the first full estimate for the program to the current estimate. The first full estimate is generally the cost estimate established at **development start**; however, for a few programs that did not have such an estimate, we used the estimate at **production start instead**. For shipbuilding programs, we used their planning estimates if those estimates were available. For programs that began as non–major defense acquisition programs, we used the first full estimate available. Thirty-five of these 37 two-page assessments are of major defense acquisition programs, most of which are in development or early production and two assessments are of programs that were projected to become major defense acquisition programs during or soon after our review" [**GAO-15-342SP**].

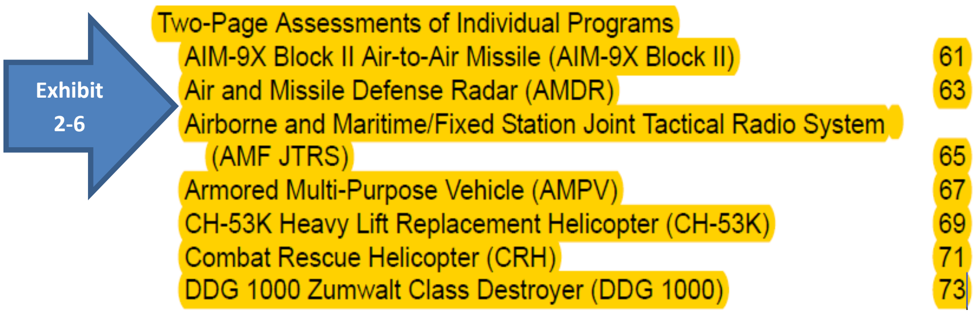
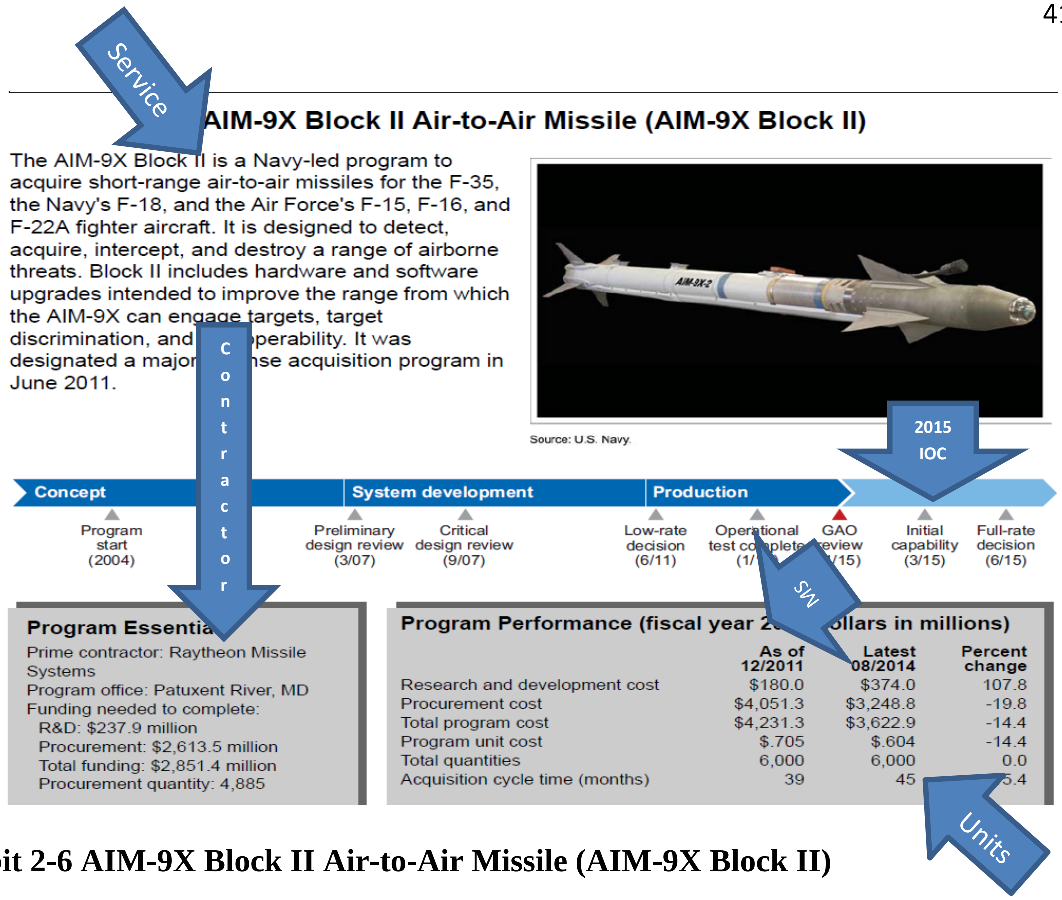


Exhibit 2-5: Two-Page Assessment of Individual Programs (fragment) [GAO-15-342SP]

Program AIM-9X Block II Air-to-Air Missile **Exhibit 2-6** is a 1st program in the "Two-Page Assessment" section **Exhibit 2-5**. Please note that it is the 6th program on the **Exhibit 2-2** list.

Programs 1-5 (**Exhibit 2-2)** are Category 2 programs in this research. Methodology and data validation for category 2 programs is explained in **Step 2: Category 2** segment.

Program **AIM-9X Block II Air-to-Air Missile** (category 1) in this research is used as a detail example of our methodology **(Exhibit 2-6).**



AIM-9X Block II Air-to-Air Missile (AIM-9X Block II)

The AIM-9X Block II is a Navy-led program to acquire short-range air-to-air missiles for the F-35, the Navy's F-18, and the Air Force's F-15, F-16, and F-22A fighter aircraft. It is designed to detect, acquire, intercept, and destroy a range of airborne threats. Block II includes hardware and software upgrades intended to improve the range from which the AIM-9X can engage targets, target discrimination, and ...perability. It was designated a major ...nse acquisition program in June 2011.

Source: U.S. Navy.

Program Essentia...
Prime contractor: Raytheon Missile Systems
Program office: Patuxent River, MD
Funding needed to complete:
R&D: $237.9 million
Procurement: $2,613.5 million
Total funding: $2,851.4 million
Procurement quantity: 4,885

Program Performance (fiscal year 2... ...ollars in millions)

	As of 12/2011	Latest 08/2014	Percent change
Research and development cost	$180.0	$374.0	107.8
Procurement cost	$4,051.3	$3,248.8	-19.8
Total program cost	$4,231.3	$3,622.9	-14.4
Program unit cost	$.705	$.604	-14.4
Total quantities	6,000	6,000	0.0
Acquisition cycle time (months)	39	45	...5.4

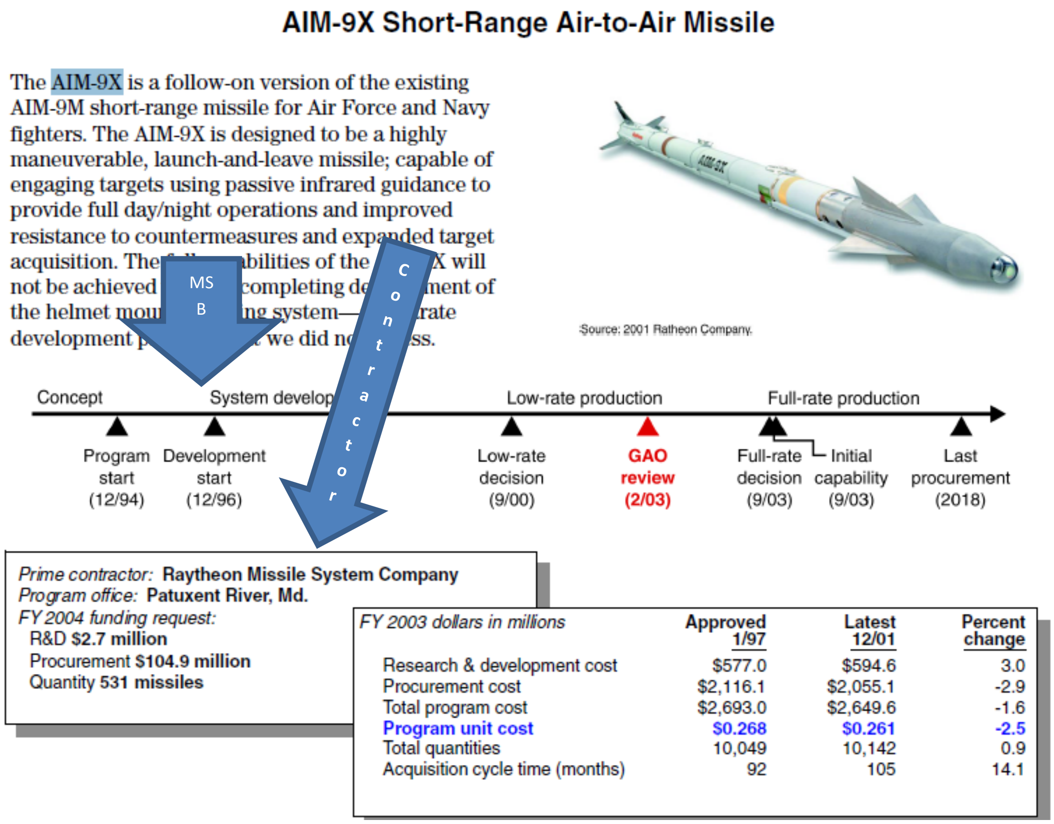
Exhibit 2-6 AIM-9X Block II Air-to-Air Missile (AIM-9X Block II)

Step 3: Additional Information Category 1:

AIM-9X Block II program is an enhanced version of its predecessor **Exhibit 2-7** (below). MS B of Block I is highlighted with an arrow. AIM-9X Block II program didn't have a Milestone B. As per **Exhibit 2-6** and below justification, we included a date of Dec. 2011 as an approved APB baseline (a placeholder for milestone B).

(SAR 2014) "**Antecedent Information:** "The AIM-9X Block I is the antecedent system to the AIM-9X Block II. Antecedent costs were derived based on historical data collected via the Visibility and Management of Operating and Support Costs database and estimated through the remainder of the life (FY 2032). A total of 3,097 AIM-9X Block I missiles were procured. The last year of procurement was FY 2010.

There is a 20-year service life assumption for the AIM-9X Block I AUR and a 13-year service life assumption for the CATM. The AIM-9X Block I system included a warranty period that accounted for missile repair costs. The AIM-9X Block II system did not include a warranty and was estimated accordingly."



FY 2003 dollars in millions	Approved 1/97	Latest 12/01	Percent change
Research & development cost	$577.0	$594.6	3.0
Procurement cost	$2,116.1	$2,055.1	-2.9
Total program cost	$2,693.0	$2,649.6	-1.6
Program unit cost	$0.268	$0.261	-2.5
Total quantities	10,049	10,142	0.9
Acquisition cycle time (months)	92	105	14.1

Exhibit 2-7 AIM-9X Short-Range Air-to-Air Missile (GAO-03-476)

Unit cost calculation: We calculate program unit costs for our analysis by taking total program costs and dividing those costs by respective number of units. Please refer to the **Exhibit 2-2 :**"Current total acquisition cost" **(B)** and First Full Estimate total acquisition cost **(C)** are divided by the number of units in columns **(D)** and **(E)** of the **Exhibit 2-8**. Both: program costs and unit costs are represented in FY2015 dollars. Our unit cost calculations are matching with **[GAO-15-342SP] Exhibit 2-6.**

IOC Date(s) Logic: In order to calculate schedule variances consistently, we selected IOC date milestone or GAO's approved replacement. Ex: **FUE** – First unit equipped. Please refer to **Exhibit 1-12**.

The Initial Operational Capability (IOC) is a point in time during the production and deployment (PD) phase where a system can meet the minimum operational (Threshold and Objective) capabilities for a user's stated need. The operational capability consists of support, training, logistics, and system interoperability within the DoD operational environment[58].

						D	E	F	G	H
#	Service	Original Prime Contractor / Milestone B	Initial Milestone B year/mm/01	T/QTY (MS B) Estimate	Total Quantity Current Estimate	Current Unit cost	First Full Estimate (MS B) Unit cost	IOC deadline year/mm /01	2015 IOC deadline year/mm/ 01 estimate	Nunn-Mc Curdy Breach es
6	Navy	Raytheon	12/1/2011	6000	6000	0.60	0.71	9/1/2014	3/1/2015	0

Exhibit 2-8: Additional Mapping

Milestones	SAR Baseline Prod Est	Current APB Production Objective/Threshold		Current Estimate	
MS C	JUN 2011	JUN 2011	DEC 2011	JUN 2011	
OT Start	APR 2012	APR 2012	OCT 2012	MAY 2012	
OT Complete	APR 2013	APR 2013	OCT 2013	NOV 2014[1]	(Ch-1)
IOC	SEP 2014	SEP 2014	MAR 2015	MAR 2015	(Ch-1)
FRP Decision	DEC 2013	DEC 2013	JUN 2014	JUN 2015[1]	(Ch-1)
FOC	OCT 2015	OCT 2015	APR 2016	OCT 2015	

[1] APB Breach

Exhibit 2-9: Schedule Milestone Dates
Source: AIM-9X Blk II SAR (2014) (page 8)

Nunn-McCurdy Breaches: Our data source for this analysis is: *Defense Acquisition System, 2015 Annual Report*. Washington, DC: Under Secretary of Defense, Acquisition, Technology, and Logistics (USD (AT&L) [57]).

AIM-9X Block II had an APB Breach but not a Nunn-McCurdy breach;

However AIM-9X Block Ib program did have a Nunn-McCurdy breach: Breach resulted from a decision to terminate the program[59]

Reasons behind program delays: We are using DOT&E's Reasons Behind Program Delays 2014 Update [60]. Fragment, related to program AIM-9X Blk II is in **Exhibit 2-11.** Additional data columns for delay analysis are in **Exhibit 2-10.**

# I	Nunn-McCurdy Breaches	Manufacturing, SW dev., Integration	Programmatic	Problems in DT	Problems in OT	Problems in Test Conduct
6	0	0	0	0	1	0

Exhibit 2-10 AIM-9X Block II Delay Categories
Source (DOT&E) AIM-9X Block II Delay Categories Exhibit 2-11

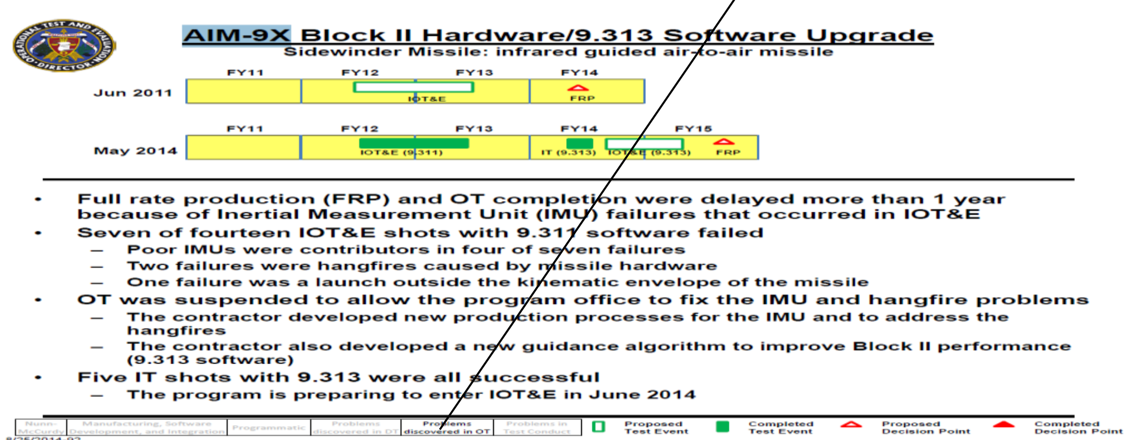


Exhibit 2-11: (DOT&E) AIM-9X Block II Delay Categories

Step 4: Data Validation Category1:

Summary Tables: (Dates, costs and units verification): SELECTED ACQUISITION REPORT (SAR) SUMMARY TABLES As of December 31, 2011: New program in 2011 tables: AIM-9X Block II $ 4,738.3

SELECTED ACQUISITION REPORT (SAR) SUMMARY TABLES
As of December 31, 2012:

Navy:													
AGM-88E AARGM	2003	PdE	1,528.5	1,861.4	1,919	112.3	151.6	-	1,640.8	2,013.0	1,919	7.3	8.1
AIM-9X Blk II	2011	PdE	3,967.3	4,856.1	6,000	-386.4	-520.4	-	3,580.9	4,335.7	6,000	-9.7	-10.7

Exhibit 2-12: Additional sources for data validation (sample)

Category 2 Data Collection and Validation Methodology:

Program AEHF Advanced Extremely High Frequency Satellite (AEHF) is not on the "Two-Page Assessment" section **Exhibit 2-5**. It is the 1th program on the **Exhibit 2-2** list. Step 1 for category 2 is the same as for category 1 **Exhibit 2-13**.

- Program name **(A);**
- Current total acquisition cost (FY2015 dollars (in millions)) **(B);**
- First Full Estimate total acquisition cost (FY2015 dollars (in millions)) **(C);**

#	A Program name	B Current total acquisit ion cost	C First Full Estimate total acquisition cost (MS B)
1	Advanced Extremely High Frequency Satellite (AEHF)	$14,474	$6,747

Exhibit 2-13: AEHF Advanced Extremely High Frequency Satellite (step 1)

Step 2: Category 2: Validation methodology:

See **Exhibit 2-14:** for a sample of data collection methodology and **Exhibit 2-15** for data sources.

The antecedent system for AEHF is Milstar which consists of a five satellite constellation and associated ground segment. The cost estimate is based on validated requirements in the Air Force Space Command Logistics Support Requirements Brochures built for the FY 2004 President's Budget Request. The Milstar O&S costs cover all operational activities for both the space and ground segment for FY 2009 - FY 2018 The December 2011 O&S POE **included AEHF 1-6** through FY 2030. The MILSATCOM Directorate will develop a new O&S cost model in FY 2015 after award of the Combined Orbital Operation, Logistics Sustainment (COOLS) contract. (SAR-15).

Program name	Current total acquisition cost	First Full Estimate total acquisition cost	Change in total acquisition cost from first full estimate (percent)	Change in total acquisition cost within the past year (percent)	Change in total acquisition cost within the past 4 years (percent)
Advanced Extremely High Frequency Satellite (AEHF)	$14,474	$6,747	114.5%	-1.3%	4.2%

1 AEHF	Service	Contractor	MS B Date	MS B Qty	Current Qty	MS B IOC	Current IOC
	Air Force (GAO-03/GAO-10)	Lockheed Martin (GAO-03/GAO-10)	10/01/2001 (GAO-03/GAO-10) SARs	5 (Cost Summary Table-2001)	6 (Table-2014)	2/1/09 (GAO-03 /GAO-04)	6/01/15 Sar14

Program Acquistion Cost Summary In Millions of Dollars
As of Date: December 31, 2001

Weapon System	Base Year	Type of Baseline	Baseline Estimate Cost Base Year $	Baseline Estimate Cost Current Year $	Baseline Estimate Quantity	Changes To Date Cost Base Year $	Changes To Date Cost Current Year $	Changes To Date Quantity	Current Estimate Cost Base Year $	Current Estimate Cost Current Year $	Current Estimate Quantity	Percent Cost Change To Date Adjust for Qty Base Year $	Percent Cost Change To Date Adjust for Qty Current Year $
USAF:													
AEHF	02	PE/DE	3,798.1	4,071.0	2	1,451.2	1,490.3	3	5,249.3	5,561.3	5	38.2	36.6

Program Acquisition Cost Summary (Dollars in Millions)
As of December 31, 2014

Program	Base Year	Baseline Type	Baseline Estimate Base-Year Dollars	Baseline Estimate Then-Year Dollars	Baseline Estimate Quantity	Changes To Date Base-Year Dollars	Changes To Date Then-Year Dollars	Changes To Date Quantity	Current Estimate Base-Year Dollars	Current Estimate Then-Year Dollars	Current Estimate Quantity	% Change To Date Adjusted for Qty Base-Year Dollars	% Change To Date Adjusted for Qty Then-Year Dollars
Air Force													
AEHF - AEHF SV 1-4	2002	PdE	5,800.7	6,085.7	3	3,536.7	4,464.3	1	9,337.4	10,550.0	4	41.8	50.0
AEHF - AEHF SV 5-6	2002	PdE	2,715.1	3,488.2	2	-624.8	-767.5	-	2,090.3	2,720.7	2	-23.0	-22.0

AEHF December 2014 SAR

AEHF SV 1-4

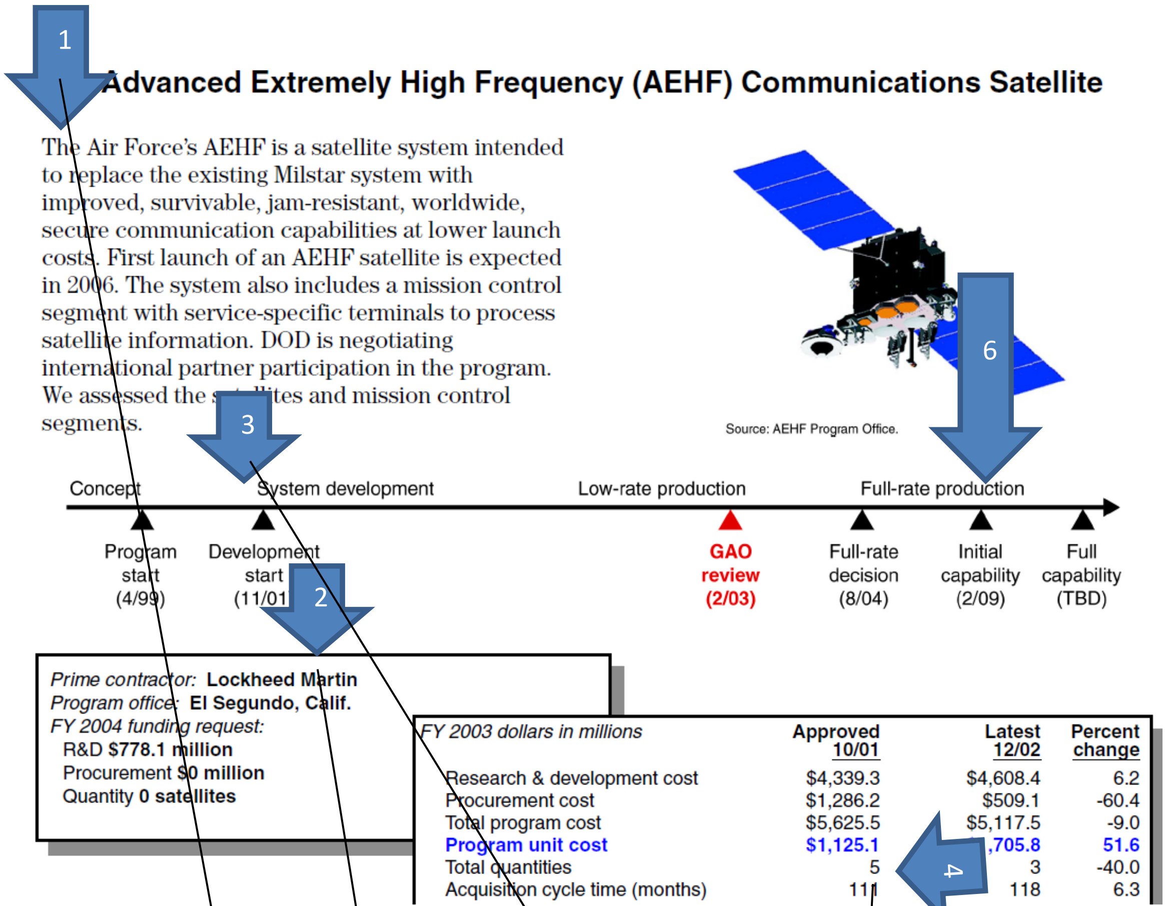
Schedule Events

Events	SAR Baseline Production Estimate	Current APB Production Objective/Threshold		Current Estimate
Milestone I	Apr 1999	Apr 1999	Apr 1999	Apr 1999
Contract Award System Definition	Aug 1999	Aug 1999	Aug 1999	Aug 1999
Milestone B (DAB)	Jun 2001	Sep 2001	Sep 2001	Sep 2001
Contract Award EMD/Production	Jun 2001	Nov 2001	Nov 2001	Nov 2001
Follow on Buy Decision	Jun 2004	Jun 2004	Jun 2004	Jun 2004
IOC	Jun 2010	Jun 2015	Dec 2015	Jun 2015

Exhibit 2-14: A sample of data collection methodology

Additional data columns
1. Service
2. Prime Contractor (at Milestone B)
3. Milestone B Date (YYYY/MM/01) (Development starts)
4. Total Quantity Development Estimate (MS B)
5. Current Quantity
6. Original IOC (Initial Operational Capability) Date (MS B)
7. Current IOC (Initial Operational Capability) Date
8. Nunn-McCurdy Breaches
9. Reason categories behind program delays (DOT&E)

Exhibit 2-15: Data Mapping Sources



Advanced Extremely High Frequency (AEHF) Communications Satellite

The Air Force's AEHF is a satellite system intended to replace the existing Milstar system with improved, survivable, jam-resistant, worldwide, secure communication capabilities at lower launch costs. First launch of an AEHF satellite is expected in 2006. The system also includes a mission control segment with service-specific terminals to process satellite information. DOD is negotiating international partner participation in the program. We assessed the satellites and mission control segments.

Source: AEHF Program Office.

Concept | System development | Low-rate production | Full-rate production

Program start (4/99) | Development start (11/01) | GAO review (2/03) | Full-rate decision (8/04) | Initial capability (2/09) | Full capability (TBD)

Prime contractor: **Lockheed Martin**
Program office: **El Segundo, Calif.**
FY 2004 funding request:
R&D $778.1 million
Procurement $0 million
Quantity 0 satellites

FY 2003 dollars in millions	Approved 10/01	Latest 12/02	Percent change
Research & development cost	$4,339.3	$4,608.4	6.2
Procurement cost	$1,286.2	$509.1	-60.4
Total program cost	$5,625.5	$5,117.5	-9.0
Program unit cost	$1,125.1	$1,705.8	51.6
Total quantities	5	3	-40.0
Acquisition cycle time (months)	111	118	6.3

GAO-03 (GAO-04; GAO-07; GAO-10 assessments are consistent)

Exhibit 2-15:

#	Program name	Service	Original Prime Contractor / Milestone B	Current total acquisition cost	First Full Estimate total acquisition cost (milestone B*)	Initial Milestone B year/mm/01	Total Quantity Development Estimate (DE)	Total Quantity Current Estimate	Current Unit cost	First Full Estimate (MS B) Unit cost
1	Advanced Extremely High Frequency Satellite (AEHF)	Air Force	Lockheed Martin	$14,474	$6,747	10/1/2001	5	6	$2412.33	$1349.40

Exhibit 2-16: Fragment 1 of our file (with data references) for program #1- AEHF

Program Acquisition Cost Summary (Dollars in Millions)
As of December 31, 2014

Program	Base Year	Baseline Type	Baseline Estimate: Base-Year Dollars	Baseline Estimate: Then-Year Dollars	Baseline Estimate: Quantity	Changes To Date: Base-Year Dollars	Changes To Date: Then-Year Dollars	Changes To Date: Quantity	Current Estimate: Base-Year Dollars	Current Estimate: Then-Year Dollars	Current Estimate: Quantity	% Change To Date Adjusted for Qty: Base-Year Dollars	% Change To Date Adjusted for Qty: Then-Year Dollars
Air Force													
AEHF - AEHF SV 1-4	2002	PdE	5,800.7	6,085.7	3	3,536.7	4,464.3	1	9,337.4	10,550.0	4	41.8	50.0
AEHF - AEHF SV 5-6	2002	PdE	2,715.1	3,488.2	2	-624.8	-767.5	-	2,090.3	2,720.7	2	-23.0	-22.0

Exhibit 2-17: : Summary tables 2014 (AEHF)

Step 3: Additional Information Category 2:

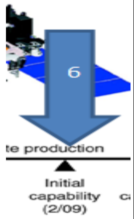
#	Program name	IOC  deadline year/mm/01	2015 IOC deadline year/mm/01 estimate	Nunn-McCurdy Breaches	Manufacturing, SW dev., Integration	Programmatic	Problems in DT	Problems in OT	Problems in Test Conduct
1	Advanced Extremely High Frequency Satellite (AEHF)	2/1/2009 (GAO-03)	6/1/2015 (SAR-15)	3	1	0	0	0	0

Exhibit 2-18: Fragment #2 of our file (with data references) for program #1-AEHF

AEHF December 2014 SAR

AEHF SV 1-4

Schedule Events				
Events	SAR Baseline Production Estimate	Current APB Production Objective/Threshold		Current Estimate
Milestone I	Apr 1999	Apr 1999	Apr 1999	Apr 1999
Contract Award System Definition	Aug 1999	Aug 1999	Aug 1999	Aug 1999
Milestone B (DAB)	Jun 2001	Sep 2001	Sep 2001	Sep 2001
Contract Award EMD/Production	Jun 2001	Nov 2001	Nov 2001	Nov 2001
Follow on Buy Decision	Jun 2004	Jun 2004	Jun 2004	Jun 2004
IOC	Jun 2010	Jun 2015	Dec 2015	Jun 2015

Exhibit 2-19: Current IOC Estimate (GAO-15)

Nunn-McCurdy Breaches: Exhibit 2-20 (below).
3 Nunn-McCurdy Breaches mapping is reflected in Exhibit 2-18.

Table 2-2. Official DoD List of Nunn-McCurdy Breaches (1997–2015)

SAR Year	Critical	Significant#
1997		• Chem Demil (Legacy/ NSCMD
1998		• FMTV • Javelin • Longbow Apache
1999	• ATIRCM/CMWS • B-1B CMUP	• NAVSTAR GPS/ Satellite
2000		
2001	• CH-47F • Chem Demil-CMA/ CSD • F-22 • GMLRS • H-1 Upgrades (4BW/4BN) • LPD 17 • Navy Area TBMD[a] • SBIRS High	• B-1B CMUP • MH-60R • V-22
2002	• ATACMS-BAT: BAT P3I[b]	• Comanche • SSN 774
2003	• EELV	• F-35
2004	• Chem Demil-CMA • Chem Demil-CMA Newport	• AEHF • RQ-4A/B UA[illegible]awk • SBIRS High
2005*	• NPOESS • RQ-4A/B UAS Global Hawk • SBIRS High	• ATIRMC/CMW[illegible] • C-130 AMP* • Chem Demil-CMA* • Chem Demil- CMA Newport* • EFV* • F/A-18E/F* • F-35* • JASSM* • JPATS* • MH-60S* • SSN 774* • ASDS[b] • GMLRS
2006	• C-130 AMP • Chem Demil-ACWA • EFV • GMLRS • JASSM • JPATS • Land Warrior[b] • WIN-T	• FBCB2
2007	• C-5 RERP	• AEHF • ARH • JAVELIN • JTRS GMR
2008	• AEHF • ARH[a] • VH-71[a,d]	• H-1 Upgrad[illegible]N)

Exhibit 2-20: Nunn-McCurdy Breaches ((USD[AT&L]'s report [57])

Reasons behind program delays: We are using DOT&E's Reasons Behind Program Delays 2014 Update [61]. Fragment, related to program **Advanced Extremely High Frequency Satellite (AEHF)** is in **Exhibit 2-21.**

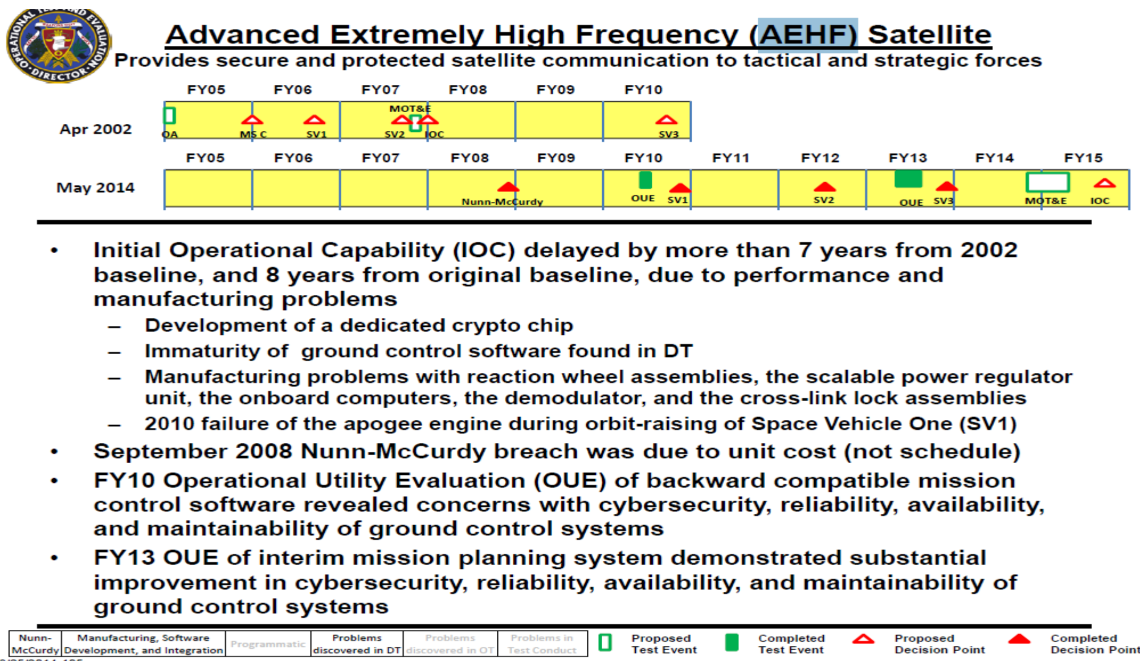


Exhibit 2-21: Delay Reasons (DOT&E)

2.3 Variable Definition

Program Acquisition Unit Cost (PAUC) is defined by statute (10 United States Code [U.S.C.], sections 2430a and 2432) consisting of the total acquisition funding divided by the acquisition quantity as reported in the SARs. For PAUC, "cost" is synonymous with the total amount of funding because it reflects the prices paid on RDT&E and production contracts as well as program execution costs **[57].**

We consider the cost overrun and schedule changes relative to what is specified and agreed upon in acquisition performance baseline (APB, see Exhibit 2-22). APB is an agreement between the Program Manager (PM) and the Milestone Decision Authority (MDA) that reflects the approved program and contains schedule, performance, and cost parameters that are the basis for satisfying an identified mission need. The first APB is approved by the MDA prior to a program entering Engineering and Manufacturing Development, or at program initiation, whichever occurs later. As a minimum, the APB contains the objective and threshold values for major milestones and significant schedule events, key performance parameters from the approved requirements document, and the life-cycle cost estimate approved for the program.

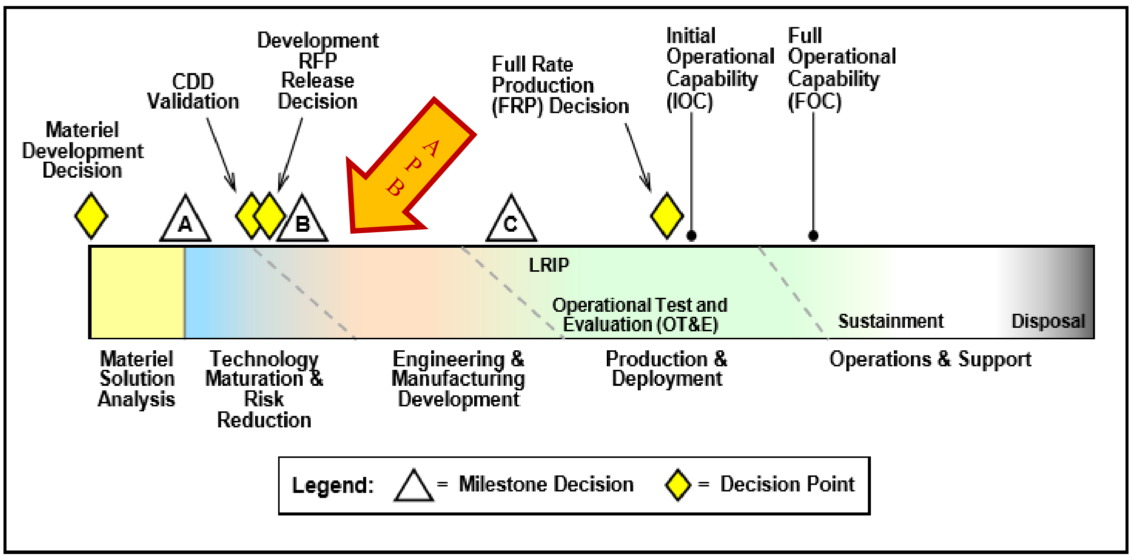


Exhibit 2-22: System Acquisition Milestones

We define the following dependent variables:

- Program total cost overrun: 2015 total acquisition cost – initial total acquisition cost
- Percentage total cost overrun (or percentage change in the total acquisition cost from first full estimate): program total cost overrun / initial total acquisition cost

- Program unit cost overrun (or percentage change in the unit cost): 2015 PAUC – initial PAUC
- Percentage unit cost overrun: program unit cost overrun / initial PAUC
- Program delay (IOC delay): 2015 IOC deadline – initial IOC deadline
- Percentage delay: program delay / (initial IOC deadline – initial Milestone B)

We define the following independent variables:

- Service: independent variable, categorical
- Primary contractor: independent variable, categorical
- Program age: GAO 2015 report date – Milestone B date
- Percentage change in quantity: 2015 quantity estimate – initial quantity estimate / initial quantity estimate

2.4 Descriptive study

The objective of this study is to understand the overall performance of the programs and select the categorical variables. We shall also perform a correlation study among the dependent and independent variables.

We first provide some descriptive statistics on some important variables:

	% Change in total acquisition cost from first full estimate	% change in unit cost	IOC delay (Years)	% IOC delay	% Change in acquisition Quantity
Mean	94.18%	42.00%	3.74	78.63%	75.90%
Median	32.94%	10.79%	2.75	39.38%	0.00%
Standard Deviation	215.49%	83.46%	3.55	120.51%	257.58%
Minimum	-83.61%	-83.61%	-0.25	-7.28%	-90.25%
Maximum	1566.27%	291.59%	13.26	647.03%	1500.00%

Exhibit 2-23: Descriptive statistics of key variables

Exhibit 2-23 shows that the % change in the total cost, unit cost and IOC delay can be negative, which implies a decrease in cost and shorter project duration for some programs (projects). That said, a majority of the projects seem to have cost overrun and delay. We also note that at least half of the projects experienced quantity increase or constant. Histograms on these metrics provide more information.

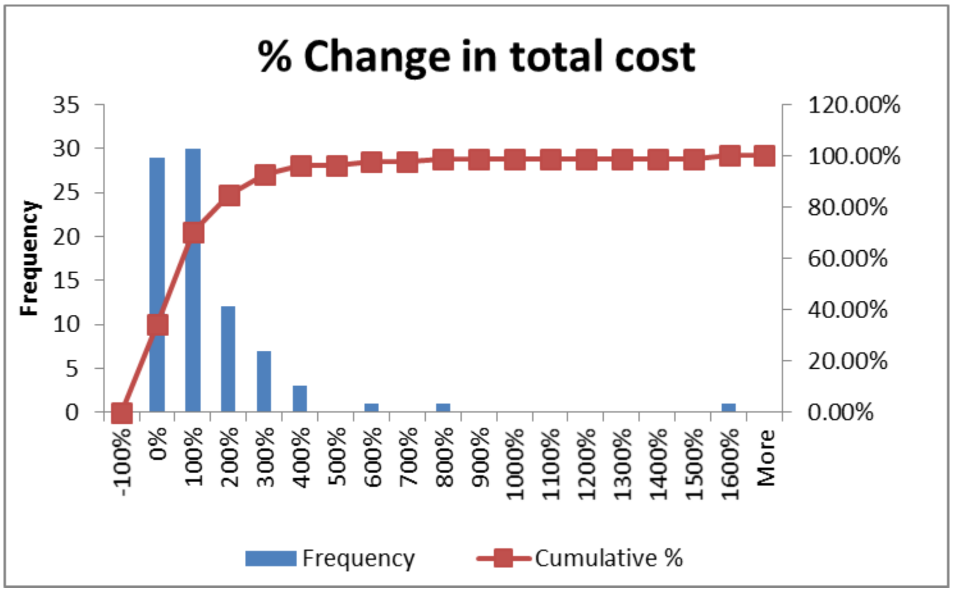


Exhibit 2-24: Histogram on % changes in the total acquisition cost

Exhibit 2-24 shows that about 35% of projects have a reduction on the total acquisition cost. About 50% of programs have a total cost overrun between 0% and 200%.

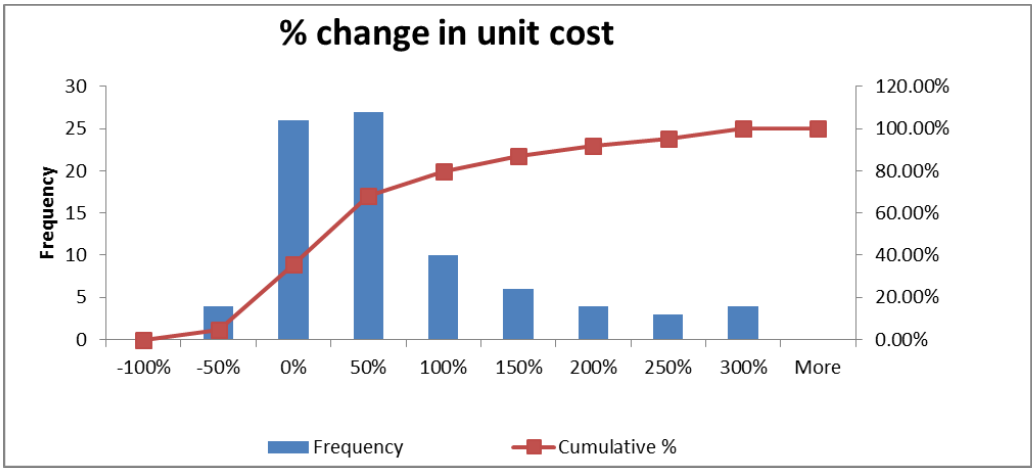


Exhibit 2-25: Histogram on % changes in the unit acquisition cost

Exhibit 2-25 shows that about 35% of projects have a reduction on the unit cost (PAUC), and about 55% of projects have a cost overrun between 0% and 200%. Note that the % unit cost overrun has a much smaller spread than the % total cost overrun.

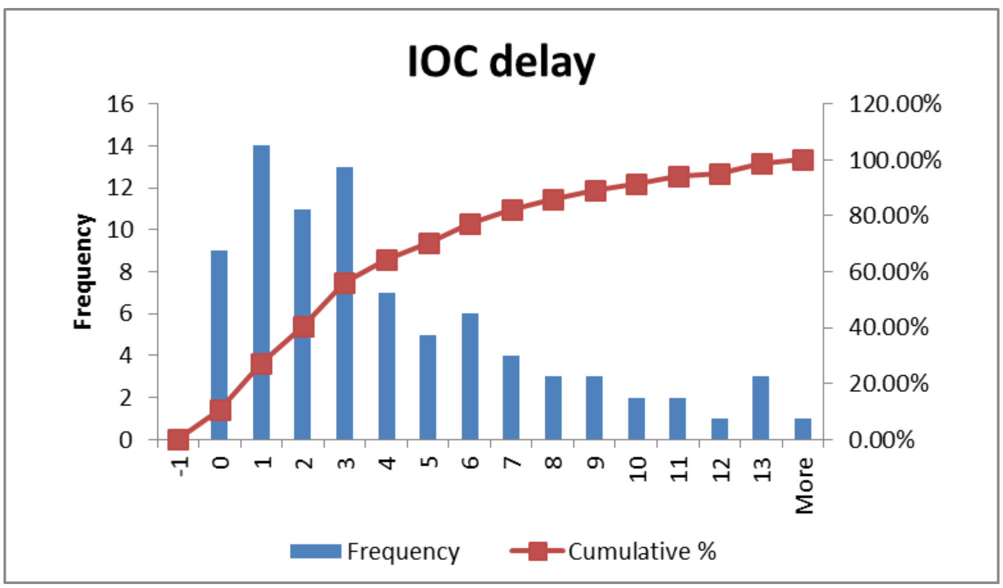


Exhibit 2-26: Histogram on the IOC delay

Exhibit 2-26 shows that the IOC delays are fairly constantly distributed with the longest one equal 13 years or more.

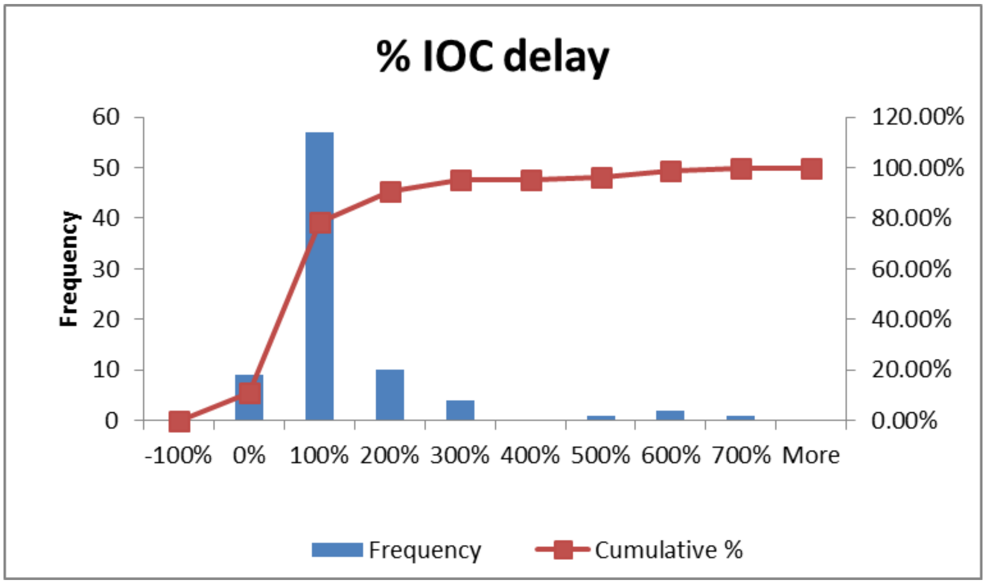


Exhibit 2-27: Histogram on % of IOC delay

Exhibit 2-27 shows that about 10% of project have an earlier estimate of IOC in 2015 than the first estimate. All others are delayed, with the most (nearly 70%) of a delay within 100% of the original IOC duration.

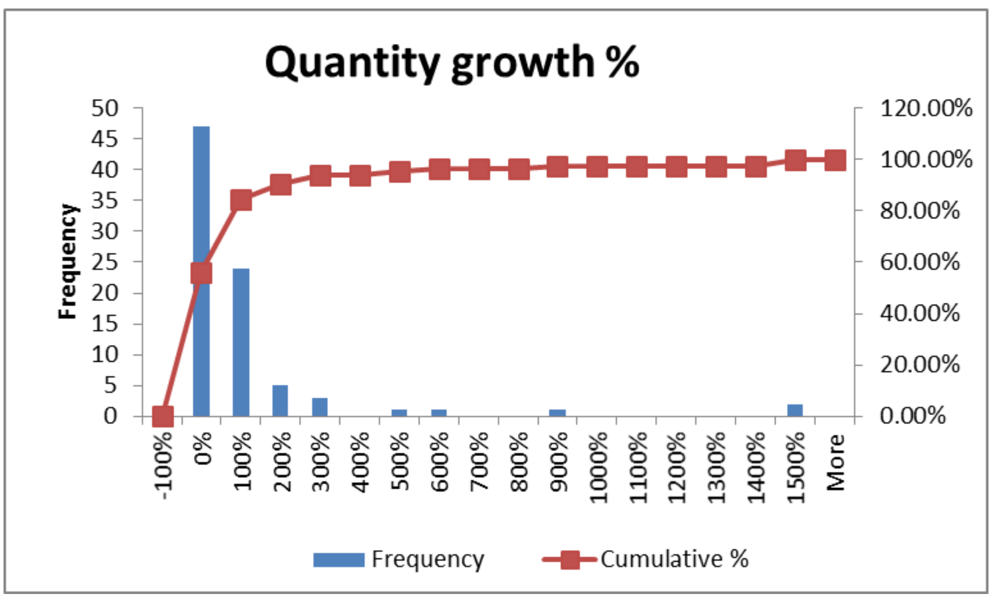


Exhibit 2-28: Histogram on % changes in the acquisition quantity

Finally, Exhibit 2-28 shows that about 55% of projects has reduce the quantity in 2015 relative to the initial estimate. Others have increased the quantity in 2015 relative to the initial estimate by as much as 1500%.

Now we perform a correlation study among the dependent variables and two independent variables.

	% Change in total acquisition cost from first full estimate	*% change in the unit cost*	*IOC delay*	*% IOC delay*	*% change in quantity*	*Project Age*
% Change in total acquisition cost from first full estimate	1					
% change in the unit cost	0.1156	1				
IOC delay	0.2425	0.2790	1			
% IOC delay	0.1065	0.0240	0.7347	1		
% change in quantity	0.8207	-0.2617	0.1454	0.1412	1	
Project Age	0.2656	0.3991	0.3004	0.1965	0.1100	1

Exhibit 2-29: Correlations

First let us examine the correlation among the dependent variables. By Exhibit 2-29, we note that the % change in the total cost is quite independent of the % change in the unit cost (PAUC) with a correlation coefficient of 0.1156. This is not intuitive unless the quantity of acquisition changed significantly from initial estimate to 2015 estimate. Our second observation is the significant positive correlation, 0.8207, between the % change in the total cost and the % change in quantity. We also note that the % change in the total cost is weakly and positively correlated with IOC delay and project age but seem to be independent of the % IOC delay. These results seem to indicate that the changes in the total acquisition cost is mainly driven by the changes in the acquisition quantity; and it is weakly dependent on the IOC delay and project age, but almost independent of the % IOC delay. Clearly we can yet draw the conclusion without controlling other important variables such as project age, services and contractors.

The % change in the unit cost is weakly correlated with IOC delay, indicating a potential weak causal relationship between actual delay and cost overrun; but it is nearly independent of the % IOC delay. The negative correlation between the % change in quantity and the % change in the unit cost is intuitive as the increase in quantity means a reduction on the unit acquisition cost. Note that the % change in the unit cost is also positively correlated with the project age, indicating a higher % change in the unit cost as the project comes into existent for a longer time.

The strong positive correlation between IOC delay and % IOC delay is intuitive. The IOC delay is weakly correlated with the project age. Finally, the % IOC delay does not have a strong correlation with the % change of quantity and project age, and the latter two seem un-correlated and thus can be used as independent variables in the same time.

To select categorical variable for the services, we provide some descriptive statistics on the cost by services.

	# of programs	Original Total Cost $M	2015 Total Cost $M	% cost overrun	Ave Cost per program $M
Navy	39	$456,376	$658,278	44.24%	$16,879
Air Force	23	$149,517	$268,006	79.25%	$11,652
Army	19	$158,350	$156,040	-1.46%	$8,213
DoD	3	$253,023	$373,566	47.64%	$124,522

Exhibit 2-30: Descriptive statistics by services

As we can see from Exhibit 2-30 that the per program total acquisition cost and the % cost overrun may differ significantly across the services. We shall select DoD as the default and define an independent categorical variable each for Navy, Air force and Army.

To select categorical variables for contractors, we provide some descriptive statistics on the cost by contractors.

	# of programs	Original Total Cost $M	2015 Total Cost $M	% cost overrun	Ave Cost per program $M
Lockheed Martin	21	432922	610244	40.96%	$29,059
Raytheon	17	80536	96661	20.02%	$5,686
Boeing	12	116026	145279	25.21%	$12,107
Northrop Grumman	8	48712	67403	38.37%	$8,425
General Dynamics	4	95923	111861	16.62%	$27,965
Sikorsky	3	34989	59357	69.64%	$19,786
Multiple contractors	5	112520	135248	20.20%	$27,050
Others	14	95638	229837	140.32%	$16,417

Exhibit 2-31: descriptive statistics by contractors

Given the importance (the large number of programs and high $ value, see Exhibit 2-31) of Lockheed Martin, Raytheon, Boeing, Northrop Grumman, General Dynamics, and Sikorsky, we shall define a categorical independent variable for each, and leave the rest, that is, multiple contractors and others as default.

2.5 Regression studies

The objective of this study is to identify the impact of service, contractor, project age and the percent change in quantity on the: % total cost overrun, % unit cost overrun, IOC delay and % IOC delay through a multiple linear regression analysis.

Study 1: The Percent (%) of Total Cost Overrun

We first study the % total cost overrun as the dependent variable with the independent variables being Air Force, Army, Navy, Boeing, Lockheed Martin, Northrop Grumman, Raytheon, General Dynamics, Sikorsky, project age and % change in quantity.

Regression Statistics	
Multiple R	0.853681512
R Square	0.728772124
Adjusted R Square	0.687334531
Standard Error	1.204929649
Observations	84

	Coefficients	*P-value*
Intercept	0.381077223	0.6101504
Air Force	-0.4575855	0.56139594
Army	-0.631891165	0.4235854
Navy	-1.048788806	0.16220736
Boeing	0.01966231	0.96883077
Lockheed Martin	0.029684709	0.94493667
Northrop Grumman	0.191588083	0.71853838
Raytheon	-0.258537634	0.55089526
General Dynamics	-0.156886066	0.82539723
Sikorsky	0.316652323	0.67828599
Project age	0.064641926	0.00201931
% Change in Quantity	0.663860731	3.0656E-19

Exhibit 2-32: Regression report for the % total cost overrun

By Exhibit 2-32, we observe a high R^2 of 72.9% which implies the strong explanation power of the independent variables on the variation of the % total cost overrun. From the coefficient table, we can see the significance of the independent variables where project age and % change in quantity have a significant and positive impact (at a 0.01 level). However, the services and contractors do not have a significant impact.

The following exhibits (Exhibits 2-33 and 2-34) illustrate the dependence of the % total cost overrun on the % change in quantity and project age.

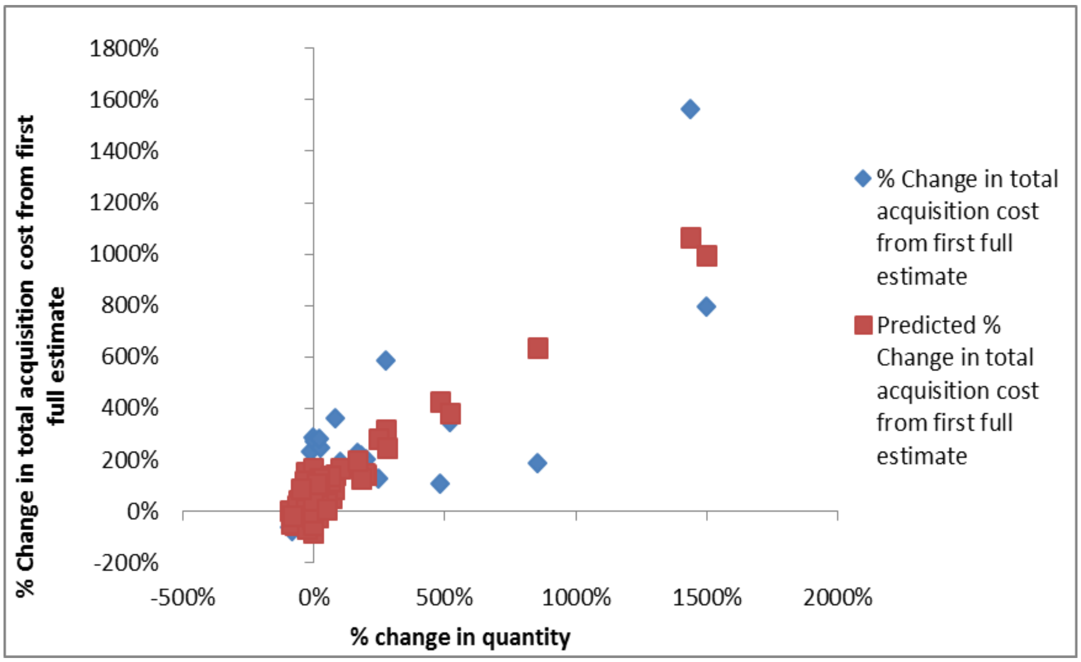


Exhibit 2-33: Line fit plot for the % change in total cost vs. the % change in quantity

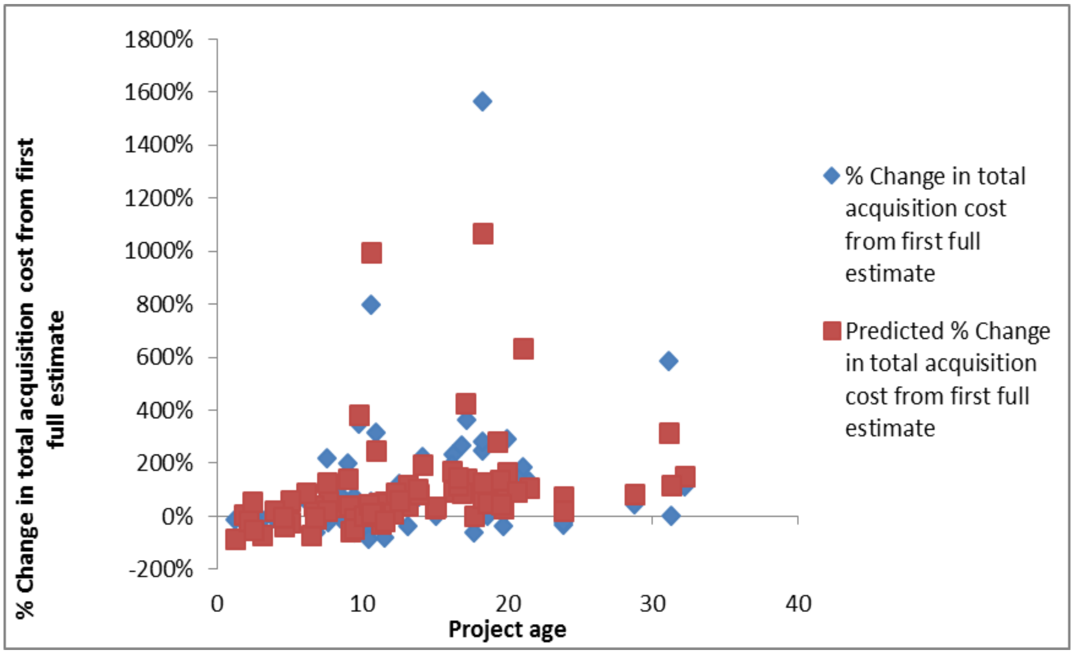


Exhibit 2-34: Line fit plot for the % change in total cost vs. project age

Exhibit 2-35 provides the residual plots, which provide a reasonable justification of the model in term of linearity and independence. The criterion on equal variance may be an issue and the model may be improved by nonlinear regression models.

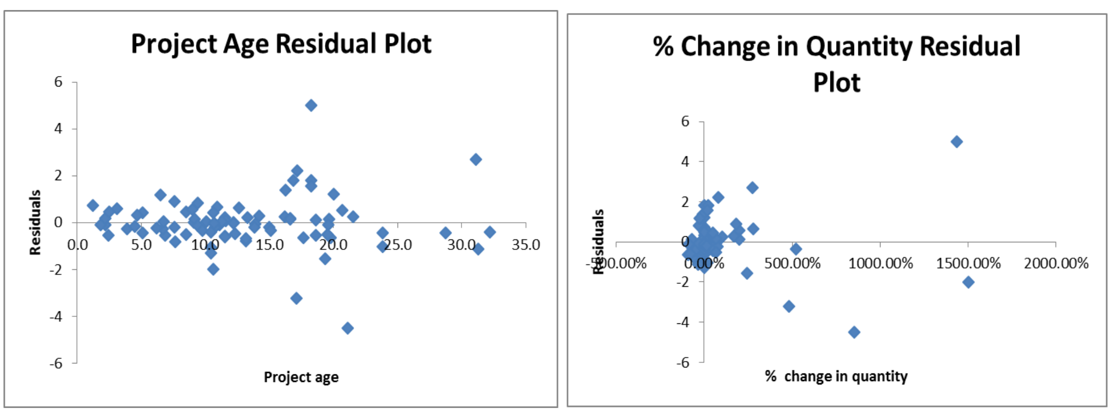


Exhibit 2-35: Residual plot for project age and % change in quantity.

Note that our correlation study in Section 2.4 eases the collinearity concern between the independent variables of the % change in quantity and project age. Thus we can conclude that for the % change in total acquisition cost, the main drivers are

1. % change in quantity,
2. Project age, and the services and contractors do not seem to have a significant impact.

The % unit cost overrun

We then study the % unit cost (PAUC) overrun as the dependent variable with the independent variables being Air Force, Army, Navy, Boeing, Lockheed Martin, Northrop Grumman, Raytheon, General Dynamics, Sikorsky, project age and % change in quantity.

Regression Statistics	
Multiple R	0.60381086
R Square	0.364587555
Adjusted R Square	0.267510653
Standard Error	0.714288173
Observations	84

	Coefficients	*P-value*
Intercept	0.608677	0.171919649
AirForce	-0.51727	0.269562185
Army	-0.374	0.424307881
Navy	-0.95749	0.032930406
Boeing	-0.39831	0.184486185
Lockheed Martin	-0.34971	0.17266298
Northrop Grumman	0.029827	0.924560214
Raytheon	-0.16201	0.528461221
General Dynamics	-0.63521	0.134843756
Sikorsky	-0.20796	0.645892463
Project age	0.059996	3.65587E-06
% Change in Quantity	-0.10295	0.002055126

Exhibit 2-36: Regression report for the % total cost overrun

By Exhibit 2-36, we observe a medium R^2 of 36.5% which implies some explanation power of the independent variables on the variation of the % unit cost overrun. From the coefficient table, we can see that the Navy, project age and % change in quantity are significant (at a 0.05 level) where Navy enjoys a significantly smaller % unit cost overrun than the default (DoD), project age tends to increase the % unit cost overrun, and the % change in quantity tends to reduce the % unit cost overrun. However, other services and all contractors do not seem to have a significant impact.

The following exhibits (Exhibits 2-37 and 2-38) illustrate the dependence of the % unit cost overrun on the % change in quantity and project age.

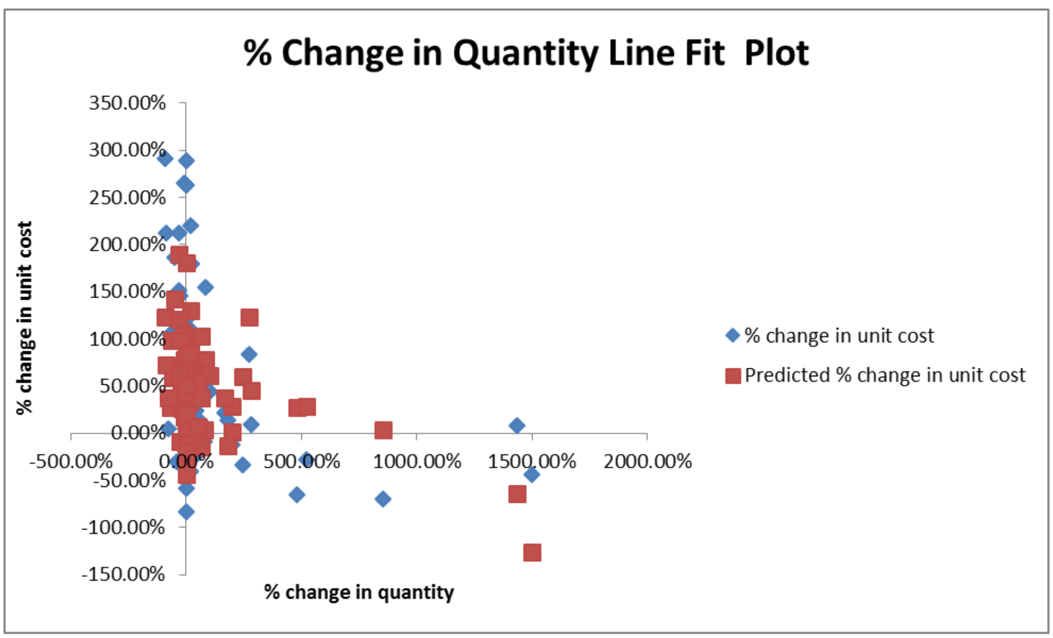


Exhibit 2-37: Line fit plot for the % change in unit cost vs. the % change in quantity

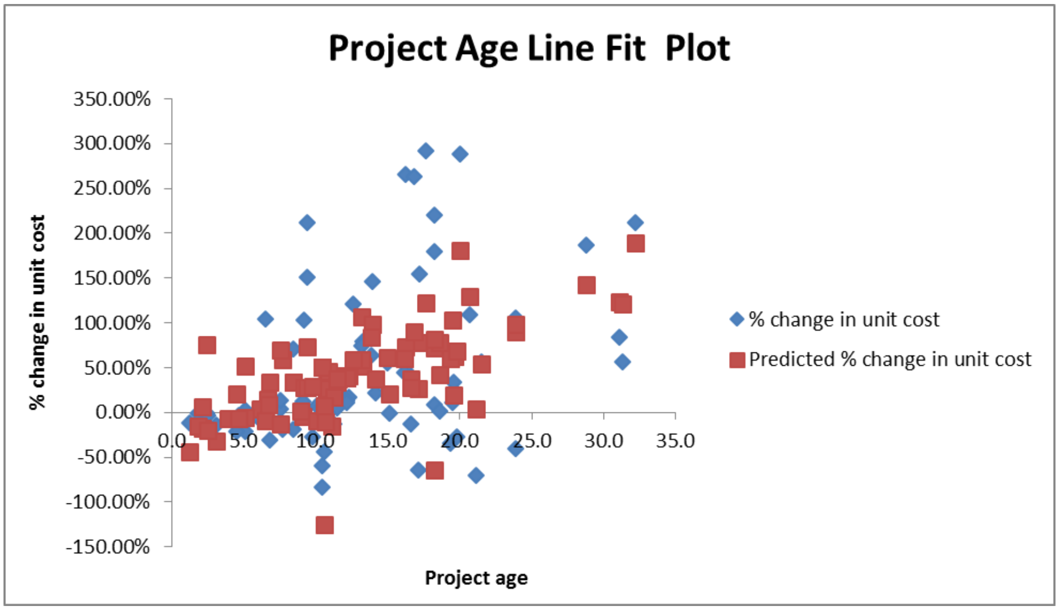


Exhibit 2-38: Line fit plot for the % change in unit cost vs. project age

The residual plots are shown in Exhibit 2-39, which reasonably justifies the model in term of linearity, independence and equal variance.

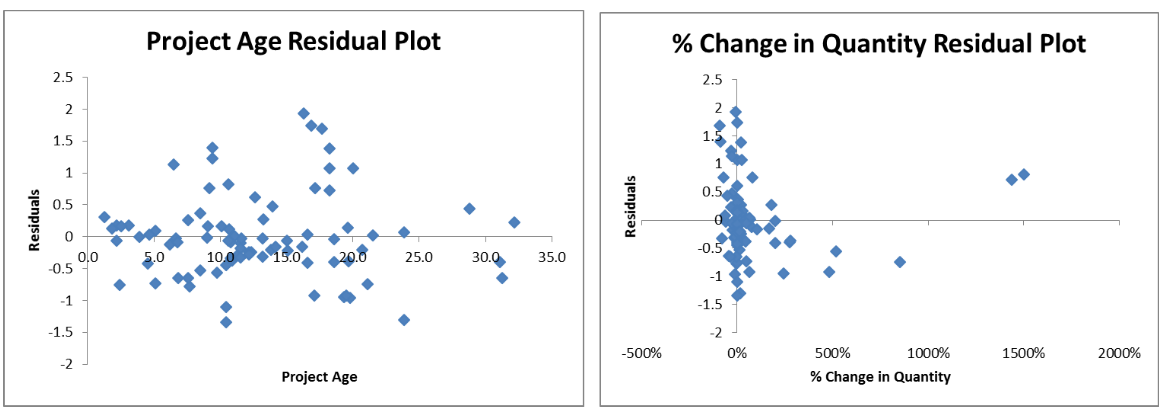


Exhibit 2-39: Residual plot for project age and % change in quantity

Based on this study, we can conclude that the % unit cost overrun depends strongly on project age and % change in quantity (potentially due to the scaled economies). Navy seems to have a significantly lower % unit cost overrun than DoD.

<u>IOC delay</u>

We next study the IOC delay as the dependent variable with the independent variables being Air Force, Army, Navy, Boeing, Lockheed Martin, Northrop Grumman, Raytheon, General Dynamics, Sikorsky, project age and % change in quantity.

Regression Statistics	
Multiple R	0.48241999
R Square	0.232729046
Adjusted R Square	0.115507095
Standard Error	3.34190561
Observations	84

	Coefficients	*P-value*
Intercept	4.122513	0.049559
AirForce	-2.61123	0.233878
Army	-2.69999	0.219051
Navy	-3.15802	0.129624
Boeing	-1.53883	0.272218
Lockheed Martin	1.871626	0.11951
Northrop Grumman	0.559	0.70459
Raytheon	0.828611	0.490877
General Dynamics	-0.11495	0.95352
Sikorsky	2.214188	0.297207
Project age	0.13479	0.018559
% Change in Quantity	0.175327	0.248187

Exhibit 2-40: Regression report for the IOC delay

By Exhibit 2-40, we observe a weak R^2 of 23.3% which implies the weak explanation power of the independent variables on the variation of the IOC delay. From the coefficient table, we can see that only project age is significant (at a 0.05 level) where project age tends to increase the IOC delay. All other variables (services, contractors and % change in quantity) do not seem to have a significant impact.

The following exhibits (Exhibits 2-41) illustrate the dependence of the IOC delay on the project age.

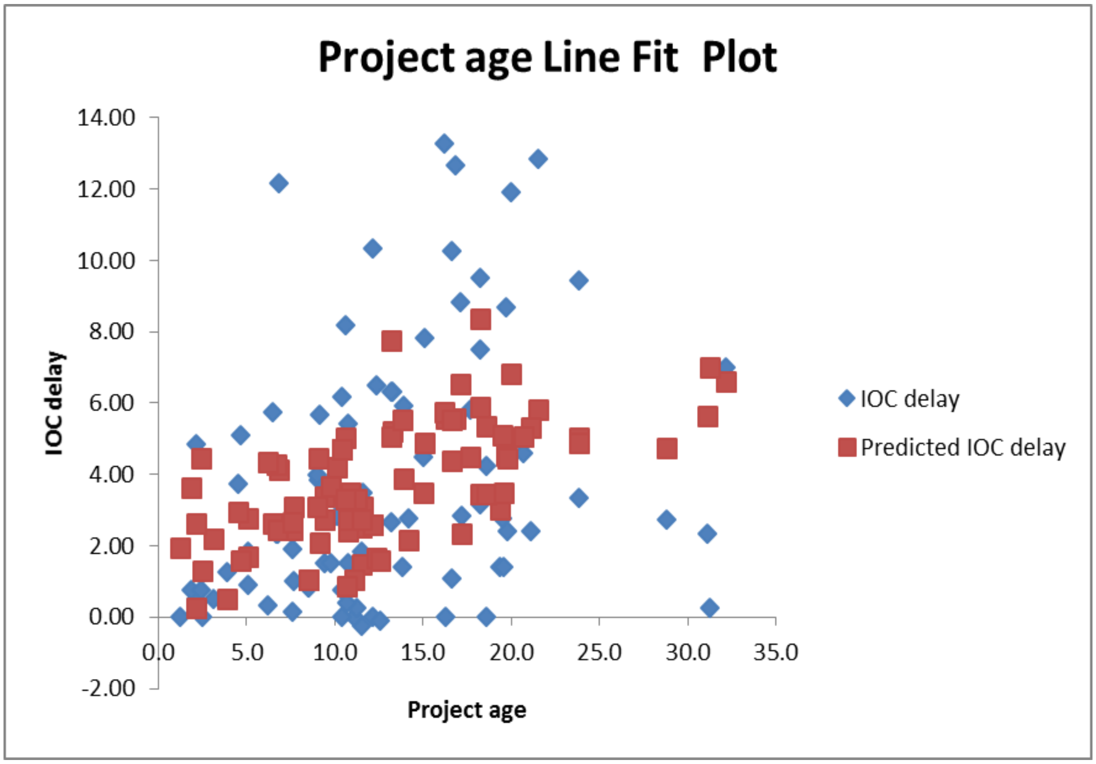


Exhibit 2-41: Line fit plot for the IOC delay vs. project age

The residual plot is shown in Exhibit 2-42, which reasonably justifies the model in term of linearity, independence and equal variance.

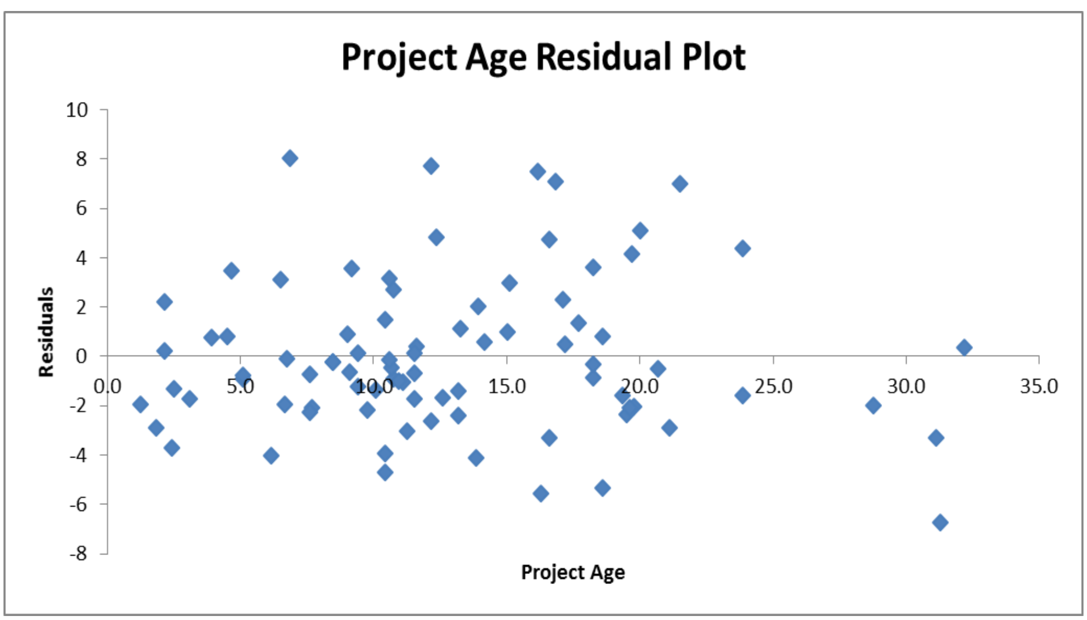


Exhibit 2-42: Residual plot for IOC delay in terms of project age

By this study, we conclude that the IOC delay is strongly dependent on the age of the project but independent of all other variables, such as services, contractors and % change in quantity.

<u>% IOC delay</u>

Lastly, we study the % IOC delay as the dependent variable with the independent variables being Air Force, Army, Navy, Boeing, Lockheed Martin, Northrop Grumman, Raytheon, General Dynamics, Sikorsky, project age and % change in quantity.

Regression Statistics	
Multiple R	0.338638275
R Square	0.114675881
Adjusted R Square	-0.02058197
Standard Error	1.217456743
Observations	84

	Coefficients	*P-value*
Intercept	0.318611	0.673012
Air Force	0.266294	0.737801
Army	-0.04115	0.958778
Navy	0.021351	0.97738
Boeing	-0.54311	0.287332
Lockheed Martin	0.220308	0.612251
Northrop Grumman	-0.2018	0.707145
Raytheon	0.33438	0.445559
General Dynamics	0.063163	0.929943
Sikorsky	0.036012	0.962739
Project age	0.025086	0.222459
% Change in Quantity	0.054119	0.327221

Exhibit 2-43: Regression report for the % IOC delay

By Exhibit 2-43, we can't see a strong dependence between the % IOC delay and any of the independent variables.

2.6 Conclusion

In this chapter, we provide a statistical study of the FY2015 MDAPs Portfolio of 84 programs with the objective of assessing the overall performance of the programs and identifying statistically significant factors for cost overrun and schedule delay.

Our study leads to the following main observations:

- Overall, these programs suffer significant cost overrun and schedule (IOC) delays despite the fact that some programs have a reduced total acquisition cost and shortened schedule.
- The percentage change of the total acquisition cost is strongly dependent on the percentage of quantity changes and project age
- The percentage change in the unit cost is strongly dependent on the same independent variables as well as Navy.
- The schedule delay, IOC delay, is strongly dependent on the project age but the percentage of IOC delay is independent of all independent variables examined.

These statistical results shed the following insights:

- The changes in the total acquisition cost may be mainly affected by the changes in acquisition quantities;
- As the project progresses (ages), the total acquisition cost, the unit cost (PAUC) and IOC delay increases steadily and linearly.
- Navy has a significantly lower percentage unit cost overrun than DoD.
- There is only a weak correlation between % changes in the unit cost and IOC delay.

Chapter 3 Case Study: F-22 Raptor Program Analysis

3.1 Background

The Air Force's F-22 "Raptor" is "the most capable fighter aircraft ever built, period."[62] It made its combat debut in Sept. 2014 in airstrikes against terrorist targets in Syria[63]. The objectives of this study are: to examine the program's successes and failures from a supply chain project management prospective and to analyze how different causes impacted the outcomes of the project.

The history of the F-22 program goes back 35 years. In the early 1980s, the Air Force began to develop a stealth aircraft called the Advanced Tactical Fighter (ATF), which was then expected to enter service in the 1990s as the replacement for the F-15. The ATF program was initiated in response to advances in Soviet combat aircraft that were expected to occur in the 1990s[64].

The F-22 (ATF)'s mission - air superiority, included the capability to deliver air-to-ground weapons. It's most significant advanced technology was to include supercruise, the ability to fly efficiently at supersonic speeds without using fuel-consuming afterburners; low observability to adversary systems; and integrated avionics to significantly improve the pilot's situational awareness[65]

Procurement of F-22s began in FY1999, and a total of 195 (177 production aircraft, 16 test aircraft, and 2 development aircraft) were procured through FY2009. Ongoing issues for Congress regarding the program include questions regarding the F-22's supply of oxygen to pilots, the possible resumption of production, the reliability and maintainability of in-service Raptors, the F-22 modernization program, and the potential sale of F-22s to other countries[66]**.** Major Milestones, issues and delays are summarized in **Table 4.**

Although the F-22 was originally conceived as an air superiority fighter with minimal air-to-ground capability, the Air Force subsequently placed more emphasis on the F-22's air-to-ground capability. In September 2002, in recognition of the aircraft's air-to-ground capability, the F-22 was re-designated the F/A-22, with the A standing for attack. In December 2005, the Air Force changed the aircraft's designation back to F-22 **[Getler, (2013)]**

3.2 F-22 Supply Chain

According to Casey (2005), the Raptor program was a complex structure organizationally diverse and geographically extended **Exhibit 3-1** (below).

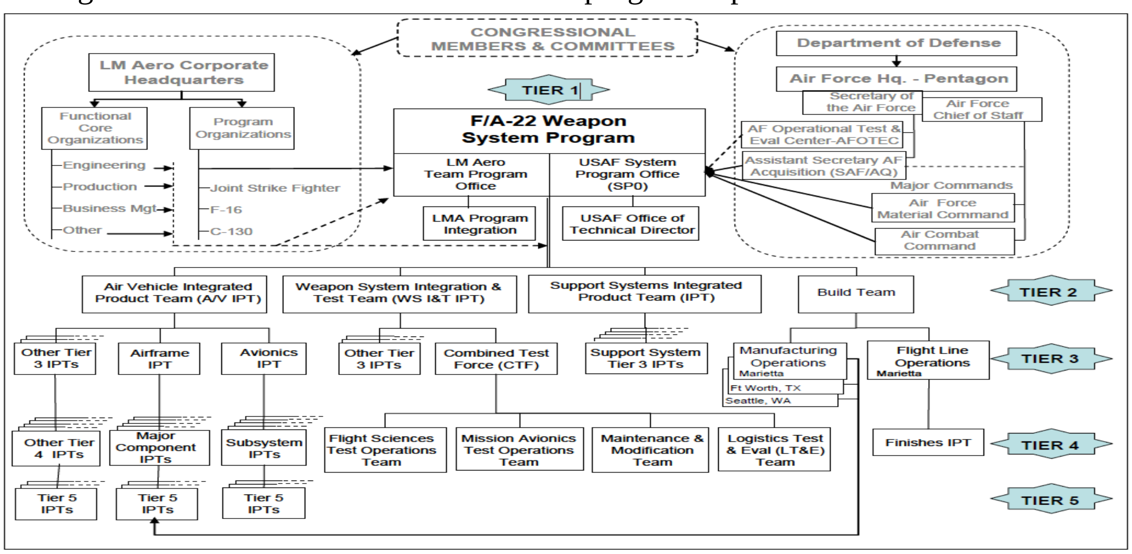
It reflects the two lines of authority:

- One came from the government, led by the F/A-22 System Program Office (SPO) at Wright Patterson AFB, Dayton, OH.
- Other direction originates from the contractor F/A-22 Team Program Office (TPO) located in Fort Worth, TX, headquarters for LM Aero.

Exhibit 3-1: Geographical Arrangement of Key Stakeholders
Source (Casey, 2005)

The F/A-22 SPO was responsible for the oversite and alignment with the Secretary of the Air Force. Among other actions, it directed the Air Force Scientific Advisory Board (SAB) to conduct a study; gather and evaluate information; and recommend any corrective actions on aircraft using on-board oxygen generation systems[67].

The organizational resource matrix of F/A-22 program is presented on **Exhibit 3-2.**



Tier 1	Top program leadership and supporting staffs led by System Program Director (SPD) for the government and the his counterpart, the VP/GM for the LM Aero-prime contractor. Tier 1 also includes suppliers under direct contract to either LM Aero or its primary subcontractor and major partner, Boeing.
Tier 2- **Tier 5**	Lower tiers: the major Integrated Product Teams, e.g., Air Vehicle, Support Systems, etc. Tier 2 (and below) suppliers that are under contract to a supplier at the next higher level, but not directly with LM Aero for a particular product or service.

Exhibit 3-2: Representation of the internal F/A-22 organization and external stakeholders
(Casey, 2005)

3.3 Work Distribution

The actual distribution of work on the F-22 program is shown on **Figure 3-3** and it illustrates that LM acted as the final systems integrator, performing a minority of the work on billable materials. Billable materials represent the summation of all supplier costs (i.e. raw material, recurring labor, direct product engineering, factory support, overhead, general and administrative, and profit) to the prime contractor that performs final assembly. Using this measure allows examining relationships below the prime contractor level that have not been examined in extant research[68].

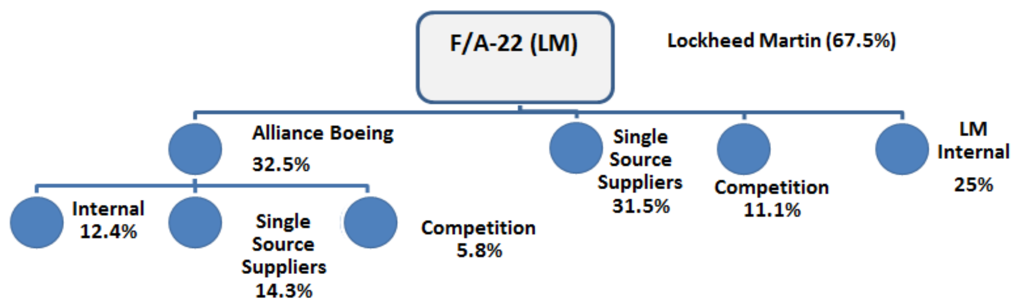


Exhibit 3-3: Percentages, representing portfolio of total billable material
(Source: LM Corporation) Updated from: DAVID R. KING and JOHN D. DRIESSNACK

Split in Workload

EMD (engineering, manufacturing and development) work was equally divided among the three major contractors. Lockheed Martin, the prime contractor, was clearly the leader in stealth aircraft design with F-117 experience. As team members, it chose General Dynamics for its fighter aircraft experience and Boeing for its innovative manufacturing approaches that had made it the industry leader. Both the contractors and the government justified the work split as a way to ensure that each contractor maintained its capability to remain competitive as prime contractors for future business **[Younossi, et al]**

This work split may have led to an artificial distribution of the development effort. As shown in **Exhibit 3-4**, the F/A-22 EMD work was divided among the three contractors in such a way that the major elements of the airframe, avionics, and support systems were given to different team members. For instance, although the F/A-22 avionics suite is a highly integrated system, various elements are managed and controlled by different team members.

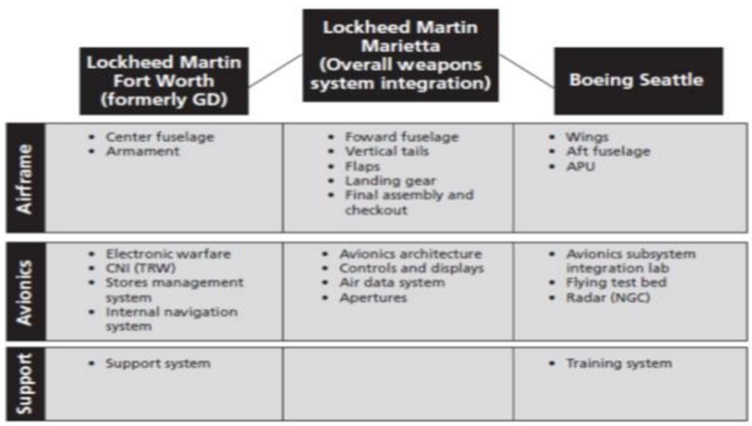


Exhibit 3-4: F/A-22 EMD work was artificially distributed among the contractors
(RAND MG276-2.1)

According to RAND, other business base concerns with respect to the program teaming structure as well as a move from Burbank, CA to Marietta, GA may have contributed to the program's instability and ultimately to its cost growth and schedule delays **(RAND MG276-2.1)**

Contract Types

In August, 1991 the Air Force awarded Cost Plus Award Fee (CAPF) EMD contracts to Lockheed and Pratt & Whitney. Based on our research, 89% of contracts, awarded to LM from 1994 to 2012 were Cost-Plus-Award-Fee (CPAF) (**Exhibit 3-5)**.

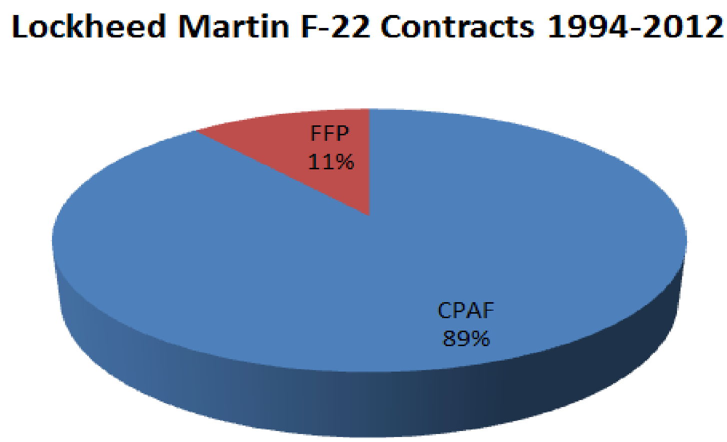


Exhibit 3-5: F-22 LM Contract Summary by Type (1994-2012)
(Source: Gerlovin and Zhao [21])
(Based on: http://www.defense.gov/Contracts/Contract.aspx)

The contract type determines the risk shared between the government and the contractor. One extreme is the "Cost Plus" contract (e.g., CPAF) **(Exhibit 3-6)**. This type of contract pays actual costs plus an award fee that is usually determined as some percentage of a cost estimate. The government additionally compensates all legally allowable costs incurred by the contractor in fulfilling the project. The cost plus contracts have the significant drawback of providing no incentive for cost reduction, which results in a well-known tendency to cost overrun. The opposite extreme is the "fixed price" contract (Firm Fixed Price = FFP). Here the contractor agrees to fulfill the project for a fixed dollar price, which, once negotiated, will not be readjusted to reflect actual cost incurred. With every dollar of cost saved ending up a dollar of extra profit, a strong incentive is created to reduce project cost. The disadvantage of FFP is that the firm, bearing all the risks, must be compensated by a fee representing on average a high nominal profit rate[69].

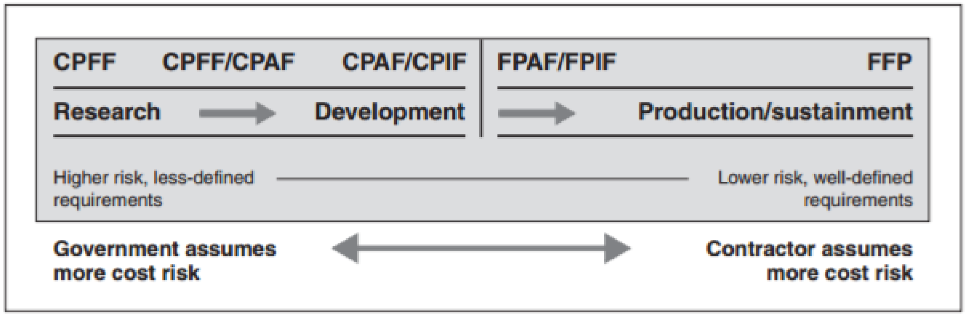


Exhibit 3-6: Cost Risk and Acquisition Phases Related to Contract Type[70]

3.4 Performance Metrics

Table 3 provides an overview of the complimentary fifth generation air force fighters (F-22 vs F-35). More information is in **Appendix IV.**

F-22		**F-22 Raptor (USAF)** **Lockheed-Martin (Marietta, GA)** **Air Dominance =** Stealth + Spercruise + Sensors, Maueurevability + Integrated Avionics Mission: Provides enhanced U.S. air superiority capability against the projected threat and will provide the United States Air Force both offensive and defensive capabilities to defeat all existing threats. The F-22A will penetrate enemy airspace and achieve first-look, first-kill capability against multiple targets. It has unprecedented survivability and lethality, ensuring the Joint Forces have freedom from attack, freedom to maneuver, and freedom to attack. FY 2015 Program: Continues critical F-22 modernization through incremental capability upgrades and key reliability and maintainability efforts to include the Reliability, Availability, and Maintainability Maturation Program (RAMMP), which provides for the development and integration of upgrades for F-22 aircraft to reach mature reliability, availability and maintainability. Continues to retrofit the combat-coded F-22 fleet with increment 3.1, which provides an initial ground attack kill chain capability via inclusion of emitter-based geolocation of threat systems, ground-looking synthetic aperture radar modes, electronic attack capability, and initial integration of the Small Diameter Bomb (SDB-1). Continues development of Increment 3.2, providing Advanced Medium Range Air-to-Air Missile-120D and Air Intercept Missile-9X integration, radar electronic protection, enhanced speed and accuracy of target geo-location, intra-flight data link improvements, Automatic Ground Collision Avoidance System, and other enhancements to improve system safety and effectiveness. Supports advance procurement in FY 2015 to begin 3.2B retrofit. Other Contractors: **Lockheed Martin, Marietta, GA;** Fort Worth, TX; and Palmdale, CA; Boeing, Seattle, WA; Pratt & Whitney, Hartford, CT

F-35	 	**F-35A Lightning II (DoD-JOINT)** **Lockheed-Martin (Ft Worth, TX)** **Lethal and Survivable Strike =** Stealth + Sensors + Integrated Avionics The F-35 Joint Strike Fighter (JSF) is the next-generation strike fighter for the Navy, Marine Corps, Air Force, and U.S. Allies. The F-35 consists of three variants: the F-35A Conventional Take-Off and Landing (CTOL), the F-35B Short Take-Off and Vertical Landing (STOVL), and the F-35C Carrier variant (CV). The F-35A (CTOL) replaces the Air Force F-16 and A-10, and complements the F-22; the F-35B (STOVL) replaces the Marine Corps AV-8B and F/A-18A/C/D; the F-35C (CV) complements the F/A- 18E/F for the Navy, and will also be flown by the Marine Corps. Mission: Provides all–weather, precision, stealthy, air–to–air, and ground strike capability, including direct attack on the most lethal surface–to–air missiles and air defenses. FY 2015 Program: Continues development of the air system, F-135 single engine propulsion system, and conducts systems engineering, development and operational testing, and supports Follow-on Development. Procures a total of 34 aircraft: 2 CV for the Navy, 6 STOVL for the Marine Corps, and 26 CTOL for the Air Force in FY 2015. Prime Contractors: Lockheed Martin Corporation, Fort Worth, TX Pratt & Whitney, Hartford, CT

Table 3: Fifth generation fighters (F22 vs F35 overview)
Source: [1][71] [72]
Additional information in Appendix IV

As of December 31, 2010, the final Selected Acquisition Report for F-22 procurement, **Exhibit 3-7** estimated DOD Program Acquisition Unit Cost (or PAUC) to be: $358.176. It is 134.18% higher than the development estimate 152.946. IOC was delayed by more than 2 years[73].

SAR Baseline History

Item/Event	SAR Planning Estimate (PE)	SAR Development Estimate (DE)	SAR Production Estimate (PdE)	Current Estimate
Milestone I	OCT 1986	OCT 1986	OCT 1986	OCT 1986
Milestone II	JUN 1991	JUN 1991	JUN 1991	JUN 1991
Milestone III	DEC 1999	DEC 1999	SEP 2004	MAR 2005
IOC	SEP 2003	SEP 2003	DEC 2005	DEC 2005
Total Cost (TY $M)	99109.0	99109.0	61323.7	67337.0
Total Quantity	648	648	181	188
Prog. Acq. Unit Cost (PAUC)	152.946	152.946	338.805	358.176

Exhibit 3-7: SAR Baseline History (December 31, 2010 SAR) [73]

3.5 Event and Cause Analysis

The Pentagon collected its final F-22 Raptor from Lockheed Martin Corp. four years ago. Amid the Cold War's end and shrinking defense budgets, the most advanced fighter jet ever built was deemed both "unnecessary and unaffordable"[74]. The F-22 finally flew on its first combat mission on September 2014, nine years after its entry into service, against Islamic State forces in Syria. "Any effort to revive it faces enormous obstacles", said Richard Aboulafia, a defense analyst with Teal Group. He's described the F-22 as a brilliant fighter without a mission, while the F-35 has a clear mission but troubles as an aircraft. "It's not impossibly far-fetched," he said of the F-22's resurrection. "It's just that there are very big hurdles." [74]

Table 4 is a timeline of the milestones and issues of the F-22 program.

#	Date	Milestone / Issue	Issue Analysis			Explanation
			Variances	Causes	Category	
1.	1980	(M) Program initiated				**Objective**: to develop a highly capable successor to the F-15 and Navy's F-14 **Initial estimates: Duration: 9 Years; QTY-750**
2.	Oct. 1986	(M) MS I/ MS A				**Approval to Enter Concept & Technology Development:** **Two competitive prototypes to be built by 2 teams of contractors:** ***Team 1***: LM /Boeing/ General Dynamics ***Team 2***: Northrop / McDonnell Douglas
3.	1989	***(I) Technical challenges with engines & avionics***	2 month delay	Aggressive timeline	GOV, MGMT, TECH	***Problems with engines and avionics*** (Overcapacity in LM production facilities, unstable supply base), problems with portfolio management
4.	Aug. 1990	(M) First flight (prototype)				**First flight (Industry prototype)** Each contractor team reportedly spent over $1 billion in company funds to develop their competing prototypes.
5.	Jan 1991					**F-22 program begins relocation to Marietta, Georgia;**
6.	Jun. 1991	(M) MS II/MS B approval to enter System development & Demonstration				**MS B estimates: Duration (IOC): 12 Years; QTY-648** **Estimated Total cost: $99,109.0; PAUC (Unit cost) 152.946**

7.	**Aug. 2, 1991**	**(M)/(I) EMD Contract Award**		Contract management (high risk for a buyer)	**GOV**	**EMD Contract Award** ***Cost Plus Incentives Contracts*** **(High risk)** totaling $11 billion were awarded to LM and P&W (F119 engine) for Engineering and Manufacturing (EMD) of F-22
8.	**1992-early 1993**	***(I) Technical challenges***	**1st flight delay**	Concurrency, untested technologies, misalignment with regulations, unmitigated risks:	**MGMT, TECH**	Issues with performance of the F119 engine (P/W), other problem areas included low-observable materials and structures, engine durability, and weight and drag management. **Concurrency: LRIP was Used to Buy Weapon Systems Prematurely.**
9.	**Sept. 1993**	**(I) Cost overruns**			**MGMT**	**Bottom-Up Review** **Major quantity reduction due to cost overruns** The planned quantity of F-22s was reduced **to 442** at an estimated cost of $71.6 billion.
10.	**1994 – 1996**	***(I) Technical*** **disasters continue**	**1st flight (with integrated avionics) delayed by 2 years**	Concurrency	**MGMT, TECH**	**Impacts of "Cost +" contract; Major Cost increase (about $20 million + additional $110 million for production); Engine costs also increased by $218** million (No penalty to LM or P/W) **SC Risk MGMT:** problems with process control, single source supplier, unavailable tools; untested material and technologies; **Concurrency: 1st flight test to begin in Sept. 1999: 2 years after the start of production.** **Tech problems:** Software testing, aircraft weight, issues with titanium, design of low observable features and manufacturing processes; delamination of longerons, structural weaknesses in aft fuselage, anomalies in brakes, inertial reference system and environmental control system, fuel leaks, problems with engine low pressure turbine blades, high pressure turbine blades, and engine combustors, and problems with excessive engine vibration.
11.	**FY1995-FY1996**	**(I) Cost overruns**			**MGMT**	**Impacts of "Cost +" contract; FY1995: additional $2.5 billion** requested to continue program development ($2,461 mil/ R&D and $4.6 mil/military construction). **FY1996**: **$2,150.8 million** requested ($2,138.7 million in Air Force R&D funding and $12.1 million in military construction funds).
12.	**June 1996**	**(I) Cost overruns**			**MGMT**	**Major Budget increases $1.45 billion over the previous Estimate; Unit cost increase (40%); Joint Estimating Team (JET) is formed**-consisting of personnel from the Air Force, DoD, and private industry experts
13.	**May 19, 1997**	**(I) Cost overruns, delays**	**1st flight 3.3 month delay**		**MGMT**	**The Defense Department's Quadrennial Defense Review (QDR): Restructuring/**(QDR) released on May 19, 1997, recommended a further reduction of quantity to **341**
14.	**Sept. 1997**					The Low Rate Initial Production (LRIP) was scheduled to start (delayed till Aug. 2001)

15.	**Sept. 1997**	**(I) Problem with flight test data**			**MGMT, TECH**	**The first flight delayed by 3.3 months, till Sept. 1997, caused a problem with flight test data;**
16.	**Sept. 1997**	**(I) Cost overruns**			**MGMT**	**(I)JET recommendations had not been included; error in a contract, due to cost overrun,** Two-seat configuration has been deferred;
17.	**Nov.1997**	**(I) Cost overruns**			**MGMT**	The National Defense Authorization Act (NDAA)/ FY1998 is enacted NDAA imposed cost limitations of $18.688 billion on the EMD program and $43.4 billion on the production. The limitation on production cost did not specify a quantity of aircraft to be procured.
18.	**Jan/June 1998**	**(I) Mismanagement + Technical disasters again**	**4 Months delay**		**MGMT, TECH**	**Worsening trend in the accomplishment of planned work:** Jan. 1998: Planned work valued at $70.9 million is not completed by LM. By June 1998, the value of uncompleted planned work had increased to $111.5 million. **Additional technical issues**: with titanium wing casting, airframe and avionics, leading to cost overruns **Significant reduction in testing to catchup with delays and cost overruns**
19.	**February 1999**	***(I) Technical* disasters continue**			**MGMT, TECH**	**Problems fabricating the wings from composites (Boeing)** Cost increase ($22 million); **Risk mgmt.:** This problem forced Boeing to qualify a 2nd supplier to speed deliveries, thereby exacerbating the cost and schedule problems.
13.	**Aug. 2001**	**(M)/(I) LRIP is approved**	**4 Years delay**	Concurrency, untested technologies	**GOV, MGMT**	The program was granted approval for Low Rate Initial Production (LRIP)
14.	**Sept. 2001**	***(I)* Additional cost increase**			**GOV, MGMT**	**OT&E estimated the program cost had grown $8 billion higher** than projected. The Pentagon's Cost Analysis Improvement Group **(CAIG)** similarly estimated that the production program would be **$9 billion over the $37.6 billion congressional cost cap.**
15.	**2002**	***(I)* A machinists' strike + Lack of skills in Marietta facility**		Poor PGM, HR and SCM risk management	**MGMT**	**Strike further delayed the delivery of test aircraft.** **LM is unable to attract skilled engineers and managers** during the early phase of development from **Burbank to Marietta**, along with Marietta's lack of a design team.
16.	**June 2003**	**(M) The 1st LRIP F-22 was delivered**	**2.5 Years late**			**The first LRIP F-22 was delivered**
17.	**2003**	**(M) Modernization & Sustainment of In-Service F-22s starts**			**GOV, MGMT**	**Due to many unresolved technical issues and capabilities, the Air Force in 2003 established a program to modernize its in-service F-22s.** The program includes upgrades to the aircraft's air-to-ground and intelligence, surveillance and reconnaissance (ISR) capabilities, to be applied in four.
18.	**Sept. 28 2004**	***(I)* Technical issues again**		Poor PGM, & SCM risk management	**MGMT, TECH**	**Problems with flight control software / the aircraft was grounded**
19.	**Dec. 2004**	***(I)* Crash**			**MGMT, TECH**	**A Raptor crashed and was destroyed at Nellis AFB**
20.	**Dec. 2005**	***(I)* Technical issues again**			**MGMT, TECH**	**Problem with titanium fuselage (101 aircraft are impacted),**

						Oxygen problems are also reported
21.	**Dec. 2005**	***(M)* IOC is achieved**	**2 Years late**			**IOC is achieved!**
22.	**Aug. 2008**	***(I)* Technical problems continue**			**MGMT, TECH**	**Technical problems:** Issue with intelligence, surveillance and reconnaissance (ISR) capabilities, Restricted communications capability **$85 Million is needed to accelerate an upgrade to enable the information sharing with other aircraft.**
23.	**2010**	***(I)* Corrosion problem**			**MGMT, TECH**	**Corrosion problem (aluminum-skin panels) at unusually high rates; DoD planned to spend $228 million through 2016 to fix the deteriorating aluminum-skin panels**.
24.	**Nov. 2010**	***(I)* Fatal crash in Alaska**		Program & SCM risk MGMT, design problems, untested material/technology	**MGMT, TECH**	**Fatal crash of an F-22 in Alaska** (Oxygen problems again) At least 25 "physiological incidents" were recorded from 2005-2012.
25.	**FY2010**	***(M)* The end of F-22 procurement**				In the FY2010 budget, the Administration proposed to end F-22 procurement at 187, and Congress approved that termination. **Final QTY: 195 (8 test + 187 operational)**
26.	**Dec. 2011**	***(M) The final aircraft delivery***				**That final aircraft had come off the Lockheed Martin production line in Marietta, GA Final QTY: 195 (8 test + 187 operational)**
27.	**May 2012**	***(I)* F-22 Modernization Program problems**	**Full capabilities delayed by 7 years**	Program & SCM risk MGMT, design problems, untested material/technology	**MGMT**	**F-22 Modernization Program cost is doubled and full capabilities slipped 7 years; Costs are doubled,** from $5.4 billion to $11.7 billion; Increment 3.2 B will be managed as **MDAP**
28.	**July 2013**	***(I)* Technical problems**				**Super-cruise wasn't achieved**

Table 4: F-22 Raptor - Timeline Milestones/Issues/Major Delays
(Additional information is provided in Appendix II)

Our event analysis **(Table 4)** shows that 23 setbacks are management related, 12 of them are also caused by technical issues. Government issues contributed to 5 of these setbacks. These issues are outlined in the following section:

Technology Maturity and Concurrent Development Issues:

In mid-1990s GAO reported:

- "Although laboratory tests are underway and simulations of the avionics are planned, the Air Force does not plan to flight test several of the critical F-22 technology advances on an F-22 until well after the start of production in September 1997”

- Flight tests of low observability are not scheduled to begin until September 1998.
- Although the highest risk element of the F-22 program was reported to be the integrated avionics, the first flight test of an F-22 equipped with a complete integrated avionics system is not scheduled to begin until September 1999, **2 years after the start of production**. By the time that testing begins, the Air Force will have already made commitments to procure 20 aircraft and long lead-time materials for an additional 24[75].”
- The production also started well before (ground) testing is completed. The Air Force planned to procure 80 F-22s under LRIP (low rate initial production), or 18 percent of the total planned procurement, at an estimated cost of $12.4 billion, before completing testing (IOT&E). This was the so-called currency strategy, which aimed to speed up the development and production of the airplane **[GAO/NSIAD-95-59].**
- GAO expressed concern about the significant reduction of the testing that should be completed before the government award contracts to initiate procurement of F-22 production. In March 1999, GAO reported that it was unlikely that the Air Force would be able to keep the F-22 EMD program, as planned, within the cost limit established by the Congress. In the end, the integrated avionics, engine, and stealth characteristics are the primary areas that increased the cost, duration, and technical risk in the F-22 program[76].

Technical and R&D issues:

In January 1991, just before the F-22 contract was awarded, Lockheed Martin moved the EMD program management and design oversight responsibilities from Burbank, CA, to Marietta, GA, for cost cutting purposes (**Table 4**, lines 4 and 15). The Marietta facility, mainly a production facility with transport aircraft experience, lacked an in-house design team that understood the technology and innovation required for this most advanced and technically challenging airplane. Less than 10% of the core team that had worked on the ATF during Dem/Val as well as the early stages of the EMD phase moved from Burbank to Marietta, which caused numerous technical and resource related issues. **[RAND *MG276-2.*1]**

Supply Chain Risks and Industry Base Issues:

A number of issues were reported in this category:

- Due to the lack of an industrial base and complexity of the program, supply chain network participants had problems working with each other in fabricating, assembling, and producing the high-technology components;
- Many components were single sourced, causing delays and cost overruns due to (several) suppliers' bankruptcies and poor-performance **[Gertler 2013];**
- Avionics and software integration has been regarded as one of the highest risks to the successful development of the F-22. Indeed, the estimated 1.3 million lines of software code needed for the F-22 represented the largest software task ever for an attack/fighter onboard software program**[GAO/NSIAD-95-59]**.
- The F-22's software work is spread out to the more than 25 geographically dispersed contractors who need to use the same automated tools to facilitate

software design, development, test, integration, and support. However, some of these tools, known collectively as the system/software engineering environment (S/SEE), were not available or were not working as planned. As a result, the software contractors developed their own solutions, using a variety of manual and automated tools that were not standard across the F-22 program**. GAO/AIMD-94-177X**

Contracting and cost overrun issue:

As shown on **Exhibit 3-5,** over 85% of LM F-22 contracts (for both EMD and production) were cost plus contracts! Under this contract type, the risk is on the buyer: US DoD. The numerous technical difficulties and/or management issues led to significant cost overruns, which were paid by the taxpayers. In response, the government kept cutting quantities and changing the scope of work trying to stabilize the budget.

Chapter 4: F-35 Joint Strike Fighter Program Analysis

4.1 Program Background

The Joint Strike Fighter (JSF), or F-35, is a fighter jet airplane developed for the US Navy, Air Force and Marines in cooperation with eight partner countries. "*Its mission is to provide all-weather, precision, stealthy, air–to–air, and ground strike capability, including direct attack on the most lethal surface-to-air missiles and air defenses*." [1]

This acquisition strategy is unique as there is no other example of a prime US contractor co-developing a US combat aircraft with foreign countries. The program is based on a complex arrangement of stakeholders with sometimes clashing priorities and requirements.

The roots of the JSF concept go back to the mid-1990s, when Department of Defense (DoD) officials envisioned the F-35 "as simple and affordable, like a Chevrolet of the skies". They hoped to create three versions of the planes sharing 70-80% of their parts. The planes would be versatile, capable of fighting other planes, but focused mainly on attacking ground targets[77]. The rationale behind designing and building such a versatile fighter that meets the diverse needs of air force, marine and navy was the scaled economies in development and production, and the cost efficiency in operations and maintenance (O&M) which typically account for more than 40% of DoD's annual budget (and about $330 billion per year in FY 2015 constant year dollars from 1962 to 2014, see **Exhibit 4-1**).

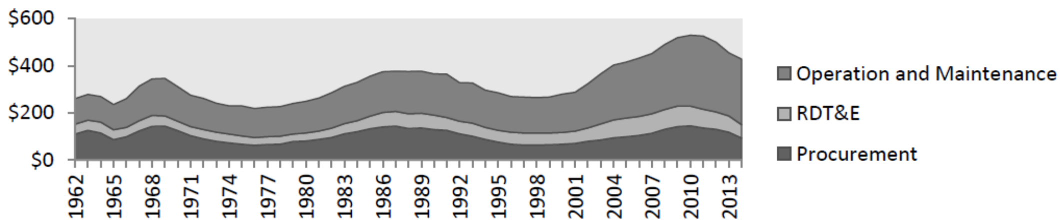


Exhibit 4-1: $Billions (FY 2015 Constant) in Defense Department Outlays
Data source is FY15 Green Book Table 6-11 [78]

DoD had set the objectives of the program to develop and deploy a technically superior and affordable fleet of aircrafts that support the warfighter in performing a wide range of missions in a variety of theaters. The single-seat, single-engine aircraft was designed to be self-sufficient or part of a multisystem and multiservice operation, and to rapidly transition between air-to-surface and air-to-air missions while still airborne. To achieve its mission, JSF would incorporate low observable technologies, defensive avionics, advanced onboard and off-board sensor fusion, internal and external weapons, and advanced prognostic maintenance capability. According to the DoD, these technologies represented a quantum leap over legacy tactical aircraft capabilities[79].

The JSF aircraft design includes three variants: a conventional takeoff and landing variant (CTOL) for the Air Force; an aircraft carrier-suitable variant (CV) for the Navy; and a short-range takeoff and vertical landing variant (STOVL) for the Marine Corps, the Air Force, and the United Kingdom. JSF was intended to replace a substantial number of aging fighters and attack aircrafts in the DoD's current inventory **(Table 5)**

Military Services	Variant	Planned Use / Role* (GAO-13-309 Joint Strike Fighter Pg3 and Wikipedia)	Current Prime Contractor (Wikipedia)
Air Force	**CTOL F-35A**	**Replacement for the F-16 Falcon (Air superiority)**	**Lockheed Martin (LM)**
		Replacement for the A-10 Thunderbolt / Warthog (Ground attack)	**Lockheed Martin (LM)**
		Complement the F-22 (Air Dominance Fighter)	**Lockheed Martin (LM)**
Marine Corps	**STOVL F-35B**	**Replacement for the AV-8B Harrier II (Vertical lift)**	**McDonnell Douglas, now Boeing**
		Replacement for the F/A-18 A/C/D (Short-Range Take-off)	**McDonnell Douglas, now Boeing**

Navy	CV F-35C**	Complement F/A-18 E/F (Multi-role Aircraft)	Boeing

Table 5: Airplanes to be replaced by F-35s
(Gerlovin and Zhao [7])

***Conflicting technical requirements: Vertical lift has stringent requirement on weight; Ground attack requires more weight**

Will also be flown by the Marine Corps **[DoD (2014, March 1) [1]

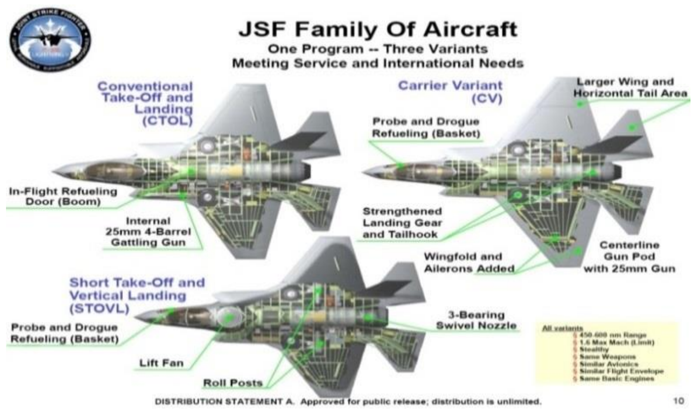


Exhibit 4-2:[80] JSF Program Three Variants

What is known today as the F-35 Joint Strike Fighter Program was originally known as the Joint Advanced Strike Technology (JAST) program. In March 1996, the ASTOVL (Advanced Short Take-Off/Vertical Landing) program was merged into JAST, and the combined program was renamed to JSF. Two companies, Boeing Aerospace and Lockheed Martin, were awarded the contracts of building prototype models, X-32 and X-35, for JSF in November 1996. Each company would build and fly two full-scale prototypes – one land-based conventional take off (CTOL) version for the Air Force, and one short-takeoff vertical landing (STOVL) aircraft required by the Marines.[81]

Table 6: Timeline (October 1994 to October 2001) before JSF contract award

(Source: The F-35 Lightning II http://www.jsf.mil/history/hist_jast.htm).

October 1994	March 1996	November 1996	January 2001	October 2001
ASTOVL Program merged into JAST	JAST Program is renamed to JSF	The concept demonstration phase	SDD (System Development and Demonstration Phase)	Milestone B approved; Contract is awarded to Lockheed Martin
JAST program		Boeing Aerospace and Lockheed	The UK signed a	An international team

competition: - Boeing Aerospace, - McDonnell-Douglas - Lockheed Martin	Martin were awarded the contracts to build the demonstrator aircraft for 3 different configurations of JSF.	memorandum of understanding to cooperate in the SDD phase of JSF	led by Lockheed Martin was awarded the contract to build JSF

4.2 The Contract Award and the JSF Effectiveness Team (JET)

In October 2001, Lockheed Martin was awarded the F-35 contract **(Exhibit 4-3**). An initial 22 aircrafts (13 flying-test aircrafts and 8 ground-test aircrafts) were to be built in the System Development and Demonstration (SDD) phase[82]. The ten-year contract was worth an estimated $200 billion, called for construction of 6,000 airplanes – approximately 3,000 for the U.S. military and another 3,000 for foreign sales, at the relatively modest price of $38 million each.[83]

The JSF Effectiveness Team (JET)			
Lockheed Martin – Prime Contractor Responsible for Center wings and final assembly			
←================== Major Subcontractors ==================→			
Northrop Grumman	BAE Systems	Pratt & Whitney	GE/R&R
Responsible for the F-35's 'center barrel' section, where the wings attach to the fuselage. Also provides the aircraft's AN/APG-81 AESA radar, other key radar and electro-optical subsystems, the aircraft's communication, navigation and identification avionics, mission systems and mission-planning software, and pilot and maintenance training systems	Responsible for the design, manufacture and assembly of the F-35's aft fuselage and empennage (vertical and horizontal tails). Also involved in areas including the crew escape system, fuel system, life support system and proactive aircraft diagnostics system integration.	Awarded a contract for more than $4 billion to develop the F135 propulsion system. This contract will cover ground and flight testing and production qualification of the Pratt & Whitney propulsion system.	Responsible for the 2nd propulsion system. The team of General Electric and Rolls Royce will compete, in production, with Pratt & Whitney. The P&W and GE/RR engines will be physically and functionally interchangeable in both the aircraft and support systems.

Table 7: The JSF Effectiveness Team (JET) formed by the JSF Program Office as of 2001 [84] [85].

(Gerlovin and Zhao [7])

Contract Structure as of 2001:

"*At the time when the F-35 contract was written, the Pentagon was operating under a principle called **Total System Performance Responsibility**. The idea was that government oversight was unduly burdensome and costly; the solution was to put more power in the hands of contractors. In the case of the Joint Strike Fighter, Lockheed was given near-total responsibility for design, development, testing, fielding, and production. In the old days, the Pentagon would have provided thousands of pages of minute specifications. For the Joint Strike Fighter, the Pentagon gave Lockheed a pot of money and a general outline of what was expected.*"[86]

No: 544-01, October 26, 2001
(N00019-02-C-3002).
Lockheed Martin Corp., Lockheed Martin Aeronautics Co., Fort Worth, Texas, is being awarded an $18,981,928,201 ***cost-plus-award-fee*** contract for the Joint Strike Fighter Air System Engineering and Manufacturing Development Program. The principal objectives of this phase are to develop an affordable family of strike aircraft and an autonomic logistics support and training system. This family of strike aircraft consists of three variants: conventional takeoff and landing, aircraft carrier suitable, and short takeoff and vertical landing.

Exhibit 4-3: A fragment of the original contract awarded to Lockheed Martin (2001)
Source: http://www.defense.gov/Contracts/

4.3 Major Stakeholders

The JST program is a joint effort of multiple countries with the U.S. taking the leading role. The SDD phase of the F-35 Lightning II program had eight cooperative program partners (CPP) – Australia, Canada, Denmark, Italy, Netherlands, Norway, Turkey and the United Kingdom. Additionally, Israel, Japan, South Korea Singapore, Malaysia and New Zealand were considering acquisition of the F-35 through the U.S. Government's Foreign Military Sales program.

> *"Given a ban on exporting the F-22, the top stealth fighter, moving quickly on the F-35 would lock up foreign buyers and keep Europe from creating its own stealth planes. There was this big desire to kill the competition."* – Richard L. Aboulafia, Analyst at the Teal Group in Fairfax, VA[87]

Stakeholder management presented challenges not only in complex and even conflicting requirement but also in the selection of subcontractors. For instance, United Kingdom's BAE clearly indicated it would be essential for a UK company to oversee the overall design and architecture of a project so central to the UK defense capability.

> *"BAE Systems must be put in charge of building the Royal Navy's two new aircraft carriers. If BAE is not the systems prime [contractor] for this, it will give us some real problems."*
> – Chris Geoghegan, Chief Operating Officer of BAE[88]

A number of agreements were signed between the U.S. and foreign governments in this phase of the program. **Table 8** provides a summary of international participation and key contractors from each country.

International Participant	Level of Partner-ship	Type of Agreement	Date of Agreement	Initial orders	Orders as of 12/13	Investment	Key Contractors of International Participant
United States	Leader			~ 3,000	2443		Lockheed Martin, Northrop Grumman, Pratt & Whitney
United Kingdom	I	MOU*/PSFD**	2002/2006	138	138	$2.06 billion	BAE, Rolls-Royce, Martin-Baker
Italy	II	MOU/PSFD	2002/2007	131	90	$1.03 billion	Stork, Fokker
Netherlands	II	MOU/PSFD	2002/2006	85	85	$800 million	Finmeccanica/Alenia, Oto Melara
Turkey	III	MOU/PSFD	2002/2007	100	100	$175 million	TAI, TEI, Roketsan, Aselsan, Havelsan
Canada	III	MOU/PSFD	2002/2006	80	65	$150 million	Quickstep Holdings
Australia	III	MOU/PSFD	2002/2006	100	100	$150 million	Avcorp, CAL, CAE, Heroux Devtek, Magellan
Denmark	III	MOU/PSFD	2002/2007	48	30	$250 million	Therma, Maersk,
Norway	III	MOU/PSFD	2002/2007	52	52		Kongsberg Systems
Singapore	SCP	FMS***/LOA****	2003	NA	NA	~$50 million	ST Aerospace
Israel	SCP	FMS/LOA	2003	19	19	Tens of millions	Elbit Systems, Israeli Aerospace Industries
Japan		FMS/LOA	2013		42		Mitsubishi Electric

Table 8: Summary of International Participation [89] [90]
(Gerlovin and Zhao [7])

***MOU – A memorandum of Understanding;**
**** PSFD - Production, Sustainment, and Follow-On Development; *** FMS - foreign military sale; **** LOA - Letter of Offer and Acceptance**

Partnership Agreements

The JSF program structure was established through Memorandums of Understanding (MOU) framework and individual supplemental MOUs between each partner country's defense department/ministry and DoD, negotiating on behalf of the U.S. government **(Table 9).** These agreements identified the roles, responsibilities, and expected benefits for all participants and were negotiated for each acquisition phase. DoD also contributed to the implementation of MOUs by acting as a “court of appeals” to address partners’ concerns, including industrial participation issues. Representatives from partnering countries participate in senior-level management meetings, including Chief Executive Officer meetings, system acquisition executive meetings, the senior warfighters group, and the configuration steering board with DoD, JSF Program Office, and contractor officials. These meetings offered opportunities for partners to gain insight into and, in some cases, influence over the progress of the JSF program. In addition, the system development and demonstration MOU established the JSF executive committee with one representative from the US and each partnering country. This provided executive level oversight for the program, such as reviewing progress toward program objectives, ensuring compliance with MOU financial provisions, and resolving program-related issues identified by the JSF international director.

JSF International Participant Contributions and Benefits by Level of Partnership		
Level I Partnership: United Kingdom	**Value of contributions:**	* U.S. target: ~ 10% or $2.5 billion; * Negotiated contribution: $2.056 billion.
	National deputy:	At the director level reports to the JSF program manager.
	JSF Program Office staff:	Ten fully integrated staff, including the deputy director of the systems engineering integrated product team.
	Data use rights:	Purposes: includes use for the performance of project activities under SDD MOUs and future efforts by the United Kingdom (collaboratively, nationally, or under U.S. foreign military sales arrangements) for the design, development, manufacture, operation, and support of any JSF aircraft.
	Benefits during production:	* Delivery priority based on level of SDD contributions; * Waiver of all non-recurring research and development costs; * Levies from sales to non-partners based on level of SDD contributions.
Level II Partnership: Italy	**Value of contributions:**	* U.S. target: ~ 5% or $1.25 billion; * Negotiated contribution: $1.028 billion.
	National deputy:	Reports to the JSF international director.
	JSF Program Office staff:	Five integrated staff, including a logistics manager on the autonomic logistics integrated product team.
	Data use rights:	Purposes: includes use for the performance of project activities under SDD MOUs and future efforts by the Italian Ministry of Defense (either collaboratively, nationally, or under U.S. foreign military sales arrangements) for the design, development, manufacture, operation, and support of the JSF CTOL and STOVL variants.

	Benefits during production:	* Delivery priority based on level of SDD contributions; * Waiver of all non-recurring research and development costs; * Levies from sales to non-partners based on level of SDD contributions.
Level II Partnership: Netherlands	**Value of contributions:**	* U.S. target: ~ 5 percent or $1.25 billion; * Negotiated contribution: $800 million.
	National deputy:	Reports to the JSF international director.
	JSF Program Office staff:	Three integrated staff.
	Data use rights:	Purposes: includes use for the performance of project activities under SDD MOUs and future efforts by the Netherlands (either collaboratively, nationally, or under U.S. foreign military sales arrangements) for the design, development, manufacture, operation, and support of the JSF CTOL and F-16 aircraft.
	Benefits during production:	* Delivery priority based on level of SDD contributions; * Waiver of all non-recurring research and development costs; * Levies from sales to non-partners based on level of SDD contributions.
Level III Partnership: Turkey, Australia Canada, Denmark, Norway;	**Value of contributions:**	* U.S. target: ~ 1-2 percent or $250-500 million; * Negotiated contribution: $175 million.
	National deputy:	Reports to the JSF international director.
	JSF Program Office staff:	One integrated staff, who performs both national deputy duties and participates on the C4I IPT**.
	Data use rights:	Purposes: includes use for the performance of project activities under SDD MOUs.
	Benefits during production:	* Delivery priority based on level of SDD contributions; * Consideration for waiver of all non-recurring research and development costs; * Levies from sales to non-partners based on level of SDD contributions.
Security Cooperation Participant: Israel; **Singapore;**	**Value of contributions:**	$50 million spread over two phases;
	National deputy:	* None;
	JSF Program Office staff:	* None;
	Data use rights:	* Assessment of JSF's ability to meet Israeli/ Singapore Ministry of Defense requirements; * Studies on incorporation of unique Israeli/ Singapore systems; * Program updates on the design, development, and qualification of the JSF aircraft;
	Benefits during production:	* Opportunity to request purchase of a version of the JSF aircraft; * Delivery priority based on level of SDD contributions.

****C4I IPT = command, control, communications, computers, and intelligence integrated product team:**

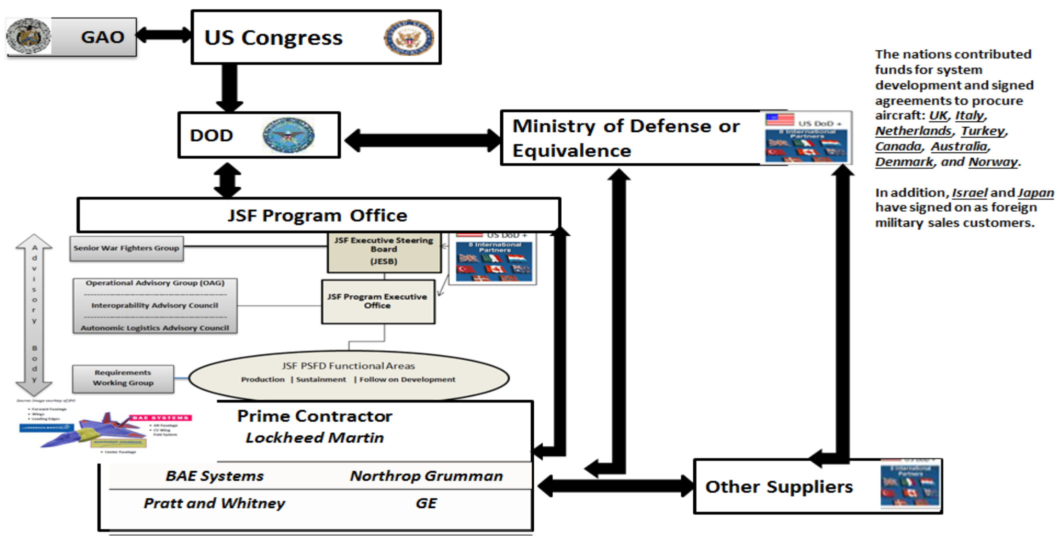
Table 9: JSF International Participant Contributions and Benefits by Level of Partnership

(Source: GAO's summary of JSF MOUs and letters of intent[91])

(Gerlovin and Zhao [7]

4.4 Organizational Structure

The F-35 Program is managed by the Joint Program Office (PO) (**Exhibit 4-4**), located in Arlington, VA. It is the military-led organization in charge of putting the planes in the air for the 3 services. National deputies act as partner representatives in the JSF PO. They served as the principal interface between the PO and the departments/ministries of defense of partnering countries. This was to ensure proper execution of the system development and demonstration phase and to provide support and guidance on all country-specific program execution and integration issues. In addition to providing program information, national deputies may act as advocates for industry in their respective countries. National deputies and other partner staff also served functional roles on integrated product teams – multidisciplinary teams that represented a variety of areas, including systems engineering, logistics, and command, control, communications, computers, and intelligence.



* Figure does not reflect relationships that the prime contractors may have with suppliers in non-partner countries.

Exhibit 4-4: JSF Program Relationships (Source: GAO-03-775)

(Gerlovin and Zhao [7])

The JSF Executive Steering Board, or JESB, is the highest decision making body within the F-35 program (**Table 10**). It is made up of representatives from all nine partner nations. The JESB meets twice a year to follow up on program progress and determine future development opportunities[92]. The F-35 Lightning II Joint Program Office is the Department of Defense's agency responsible for developing and acquiring the F-35A/B/C for the Navy, Air Force, Marines, and many allied nations. This program structure opened up opportunities for the F-35 program to draw on the aerospace expertise of a global network of allies. While Lockheed Martin was the systems integrator, almost 70% of the aircraft was produced by suppliers across the global network. This was a significant change from past programs, where the prime contractors usually built about 70% of the aircraft.

JSF Management Groups		
External	**JSF Executive Steering Board (JESB): Management Organization and Responsibilities**	A JESB was established to exercise executive level guidance and oversight for the Project and to provide a forum for discussions, consultations, and decisions on Project matters. JESB Participants: • Australia, Director General New Air Combat Capability; • Canada, Assistant Chief of the Air Staff (ACAS); • Denmark, Director Air Force Projects; • Italy, Chief Programs Department of the National Armaments Directorate; • Netherlands, Director of Projects and Procurement; • Norway, National Armaments Director; • Turkey, Deputy Undersecretary for Defense Industries or Turkish Air Force Chief Plans and Principles; The United Kingdom, Capability Manager (Precision Attack)
	JSF Program Executive Officer	The JSF Program is directed by the U.S. DoD JSF PEO who heads the JSF PO and who is responsible for managing the cost, schedule, performance requirements, and technical aspects of the JSF Program; For management of the Project on behalf of the Participants in accordance with this MOU, and for promotion of international cooperation in the JSF Program Office in order to meet the requirements of the MOU.
	JSF Program Office	The JSF Program Office will establish and maintain a business continuity plan for sustainment support.
	The Senior Warfighters Group (SWG)	Will provide senior-level guidance to the JESB regarding the JSF Program from the warfighters' and sustainment communities' perspective, and will review and discuss the operational significance and sustainment impact of proposed JSF Program and configuration baseline changes. The SWG will consist of Flag and General officers representing the Participants' warfighting and sustainment communities.
	Operational Advisory Group (OAG)	OAG will provide a conduit for liaison between the JSF PO and the Participants' requirements and operational communities. It will participate in and review relevant trade studies, and will provide operational and sustainment advice on requirements issues.
	Autonomic Logistics Advisory Council (ALAC)	ALAC will provide a multi-service, international forum of senior executives to advise the JSF PO of the design and delivery of JSF Air System support capabilities from the perspective of the operational and logistics support user communities. The ALAC will consist of Flag and General officers or equivalent-level civilian officials representing the Participants' logistics communities.
	The Interoperability Advisory Council (IAC)	IAC will address JSF interoperability issues that are beyond the cognizance of the JSF. Program Office and will provide advice to the JSF PEO.
Internal	**Multi-disciplined and product-focused Integrated Product Teams (IPTs)**	The JSF Program Office will employ IPTs to efficiently manage and execute Project requirements. The IPTs will consist of representatives of the Participants from a variety of subject matter areas (i.e., program management, engineering, environmental, manufacturing, contracting, financial management, quality assurance, safety, supportability, and training).
	The Requirements Working Group (RWG)	RWG will function as the Follow-on Development process manager. The RWG will coordinate the JSF Air System Product Roadmap, provide a forum for new requirements and science and technology inputs, and make requirements disposition recommendations to the JSF PEO.

Table 10: JSF internal and external management groups[93]

(Gerlovin and Zhao [7])

The JSF program is jointly managed and staffed by the Departments of the Air Force and the Navy. Service Acquisition Executive (SAE) responsibility alternates between the two departments: When the Air Force has Service Acquisition Executive (SAE) authority, the F-35 program director is from the Navy, and vice versa. ***The Navy*** resumed SAE authority when ***Air Force*** *Lt. Gen. Christopher Bogdan* was confirmed by the Senate as program manager on September 22, 2012. F-35 program managers currently serve two-year terms. DoD is reportedly considering revising the program's charter, to remove the fixed term, leaving the program manager's tenure up to the Secretary of Defense. **[Gertler, J (2014)].** Description of groups and their roles and responsibilities is presented in the **Table 10.**

Partners have identified industrial return as vital to their participation in the program. If return-on-investment (ROI) expectations were not met, partners told the JSF Program Office, that the program would lose political support, domestically. To realize this return, partner industry must win JSF contracts through competition, which was a departure from other cooperative programs that tied contract awards directly to partners' financial contributions. To this day, the program office and the prime contractor have a great deal of responsibility for providing a level playing field for JSF competitions, including opportunities for partner industries to bid on subcontracts and visibility into the subcontracting process. If Lockheed Martin's efforts to meet partner ROI expectations came into conflict with program cost, schedule, and performance goals, the program office would ultimately have to make decisions to balance expectations and program execution. The award fee in Lockheed Martin's system development and demonstration contract provided the program office with a mechanism to focus contractor efforts to achieve both, U.S. and international program goals **(Source: GAO-03-775).**

"While the JSF PO is responsible for ensuring that program objectives are met for all participants, Lockheed Martin bears most of the responsibility for managing partner industrial expectations and needs to balance its ability to meet program milestones and collect program award fees against meeting these expectations, which could be the key in securing future sales of the JSF for the company." (Source: GAO-03-775*)*

Overall JSF Program Strategies, Goals and Objectives	
Lockheed Martin Goal:	To be the world's best systems integrator in aerospace, defense and technology services; to be the company our nation and its allies trust most to integrate their largest, most complex and important advanced technology systems.
JSF Strategy:	To clearly align F-35 capabilities with customer needs, providing F-35 unique capabilities for operational flexibility to address a changing war-fighting environment; to fully leverage the international customer base at program onset to capitalize on economies of scale, stabilize domestic annual support and expand international market share.
Success Criteria:	Successful demonstration of F-35 capabilities and expansion of F-35 domestic and international customer base are measures of our progress.
Program Operational Goals*:*	**Customer Engagement**: Unique to the JSF program is the extensive multi-tier customer involvement in monitoring and controlling program progress. We jointly establish annual Program Priorities with our customer and together monitor a balanced scorecard that summarizes program health. The scorecard provides three perspectives into program health: by Integrated Product Team (IPT), by F-35 progress, and by Program Priority. It summarizes data gathered from an extensive and government compliant program management toolset. For example, each IPT maintains a logic-based schedule linked to other IPTs. This allows extensive use of Critical Path Methodology to focus resources on areas of critical need. **F-35 Performance Priorities**: Early in the program we jointly established a set of critical-to-quality parameters, referred to as Key Performance Parameters (KPPs). These take clear precedence and are not compromised. We continually review performance with the customer to ensure compliance to critical needs. F-35 KPPs include mission radius, the ability to land vertically while "Bringing Back" fuel and weapons, the ability to perform Short Take-offs from U.S. and U.K. carriers, high mission reliability and various sortie generation and logistic footprint requirements.

Table 11: JSF Program Goals and Strategies[94]
(Gerlovin and Zhao [7])

Department of Defense Organizational Structure[95]:

DoD is America's oldest and largest government agency (**Exhibit 4-5)**. The Secretary of Defense (SOD) is the chief executive officer of the DoD. The three military branches, Army, Navy, and Air Force, are under the direct control of SOD. The Secretary of Defense for Acquisition, Technology, and Logistics (USD-AT&L) is the Principal Staff Assistant and advisor to SOD for all matters relating to the DoD acquisition, research and development, testing and evaluation, production and logistics, etc. The USD-AT&L

is also the Defense Acquisition Executive (DAE) and the Defense Procurement Executive (DPE). As the DAE, the USD-AT&L uses the Defense Acquisition Board (DAB) and its Overarching Integrated Product Teams (OIPTs) to provide the senior-level decisions for the acquisition of weapon systems, e.g., F-35 (**Exhibit 4-6)**. DAE responsibilities include establishing policies for acquisition (including procurement, research and development, logistics, developmental testing, and contracts administration).

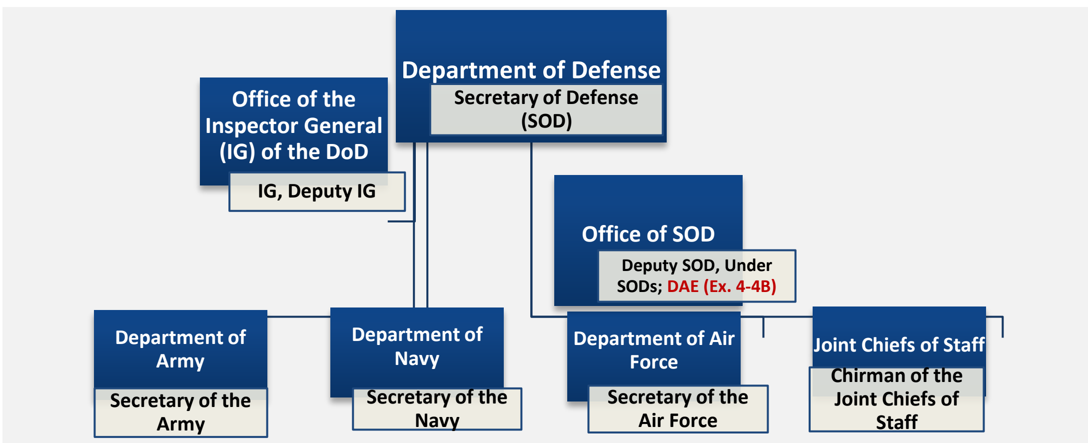


Exhibit 4-5: Organization of the Department of Defense[96] (Gerlovin and Zhao [7])

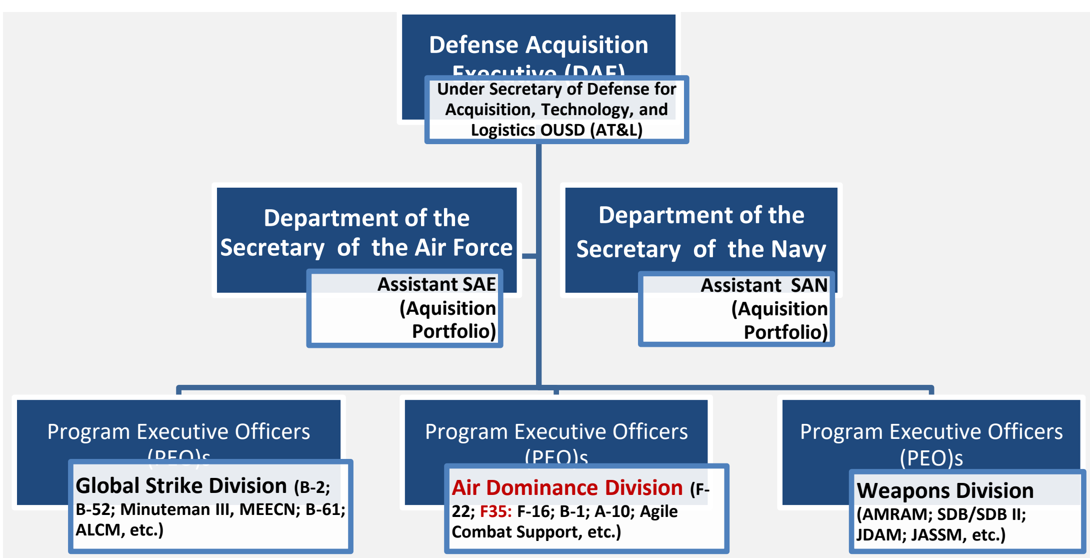


Exhibit 4-6: Air Force Acquisition Structure *Joint Program Executive Office* (JPEO) F-35[97] [98](Gerlovin and Zhao [7])

GAO (Government Accountability Office)

The U.S. Government Accountability Office (GAO) is an independent, nonpartisan agency that works for Congress, often called the "congressional watchdog." GAO investigates how the federal government spends taxpayer dollars. The head of GAO, the Comptroller General of the United States, is appointed to a 15-year term by the President from a slate of candidates proposed by Congress. GAO evaluates and published reports for a selected number of programs (JSF is one of them) **Exhibit 4-7**. GAO's work is done at the request of congressional committees or subcommittees or is statutorily required by public laws or committee reports, per Congressional protocols. GAO also undertakes research under the authority of the Comptroller General[3]. The Ronald W. Reagan National Defense Authorization Act for Fiscal Year 2005 (P.L. 108-375) required GAO to review the JSF program annually for the next 5 years.[99]

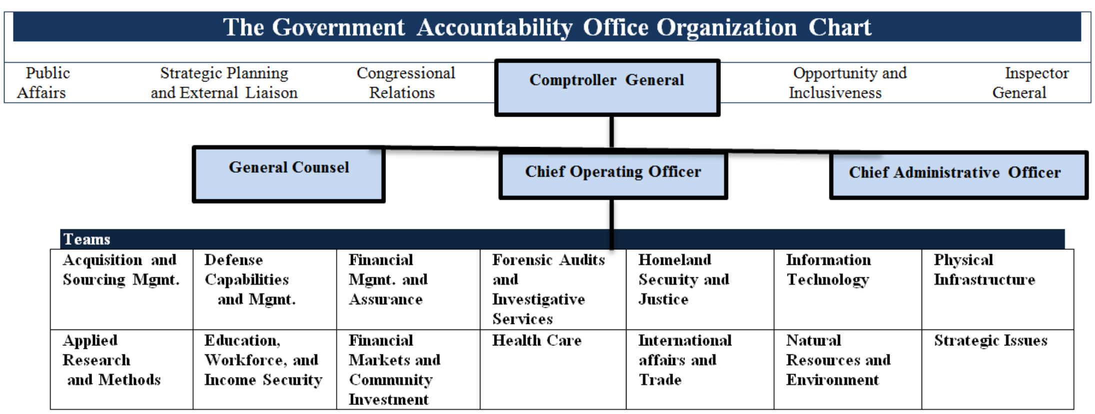


Exhibit 4-7: GAO's Organizational Structure[100] (Gerlovin and Zhao [7])

4.5 The F-35 Supply Chain

It is hard to imagine a bigger supply chain challenge than the one created by Lockheed Martin Aeronautics Co., when it took on the role of principal contractor for construction

---

[3] Source: http://www.gao.gov 2014

of the F-35 Joint Strike Fighter (JSF). The program had partners from nine countries around the world, and Lockheed's role became *"a weapons systems integrator."* Large portions of the JSF were being outsourced to manufacturing partners around the world with Lockheed performing final assembly. JSF included more than 1,300 suppliers from 47 U.S. states and Puerto Rico. Additionally, large portions of the JSF were outsourced to manufacturing partners with the production occurring in more than 600 suppliers in 30 countries.[101] Many of those entities had little or no direct contact with one another, let alone the ability to convey forecasting or demand data on a real-time basis.[102]

Tier 1 Suppliers

While Lockheed Martin Aeronautics Co. (LMAC) was the prime contractor, Northrop Grumman and BAE Systems were principal partners in the program **(Exhibit 4-8)**. Responsibility for manufacturing the F-35 major structures were shared among the three companies; and all of them had outsourced large assemblies and hundreds of component parts to their sub-tier suppliers.

> *"Lockheed performed the final assembly as a weapons systems integrator at the top of the food chain."*
> – Mike Jones, Senior Business Operations Manager at Lockheed Martin

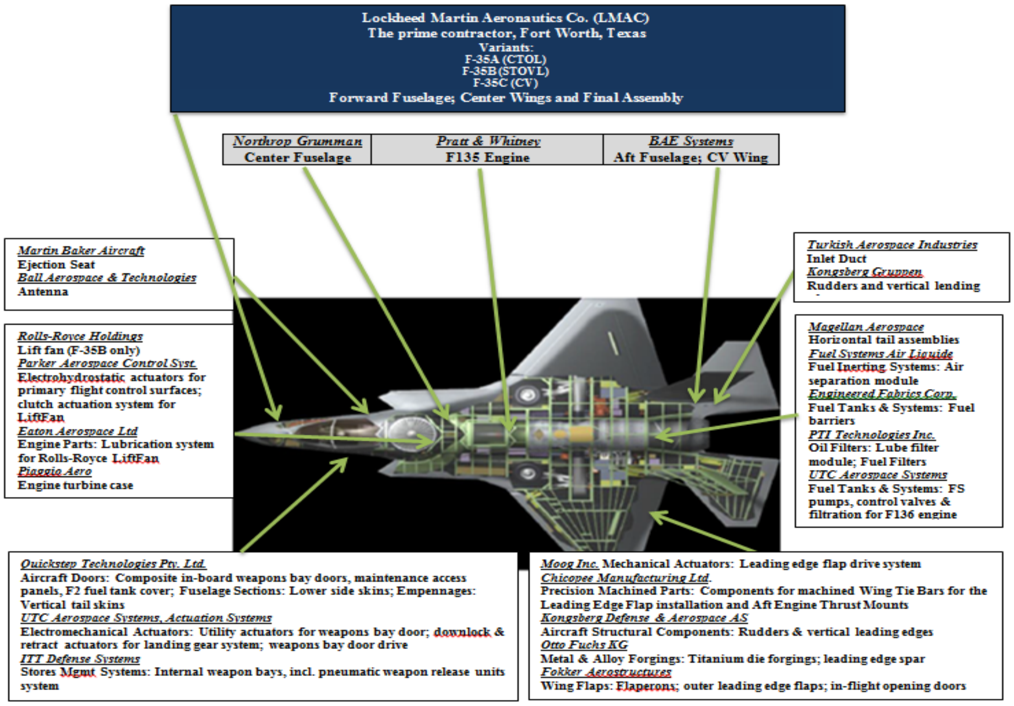


Exhibit 4-8: F-35 Tier-1 suppliers (Gerlovin and Zhao [7])

Workload Distribution

The original plan was to have only one final assembly and checkout location (FACO) at Lockheed Martin's Fort Worth plant in Texas. However, it was announced in 2010, that another FACO location would be built in Italy. The facility was constructed to allow for long-term maintenance, repair and overhaul of the single-engine fighters and was intended to become a regional maintenance facility for aircrafts in Europe and Israel. **[28]**

The F-35 Joint Strike Fighter program selected Japan and Australia to provide heavy airframe and engine maintenance in the Pacific. In Japan, Mitsubishi Industries is building a Final Assembly and Checkout facility (FACO) that will assemble 38 of the 42 F-35's that the country is slated to purchase.[103] Australia will be the center of heavy engine maintenance starting in 2018; Japan will follow as an engine maintainer three to five years later. General Bogdan said that Japan would handle heavy maintenance for the jets in the northern Pacific from early 2018, with Australia to handle maintenance in the southern Pacific.[104]

> *"It is unknown if political considerations would keep South Korea from having its jets serviced in Japan. Korea likes the option of having the work done in Australia, but Bogdan would not comment on the situation except to say that the JPO continually discusses "sovereign requirements" with each programme partner nation."*[105]

Fuselage Supply Chain

Major subassemblies were produced by Northrop Grumman Integrated Systems at El Segundo, CA and BAE Systems at Samlesbury, Lancashire, England. BAE Systems was responsible for the design and integration of the aft fuselage, horizontal and vertical tails and the wing-fold mechanisms for the CV variant, using experience from the Harrier STOVL program. Terma of Denmark and Turkish Aerospace Industries were supplying sub-assemblies for the center fuselage. Lockheed Martin manufactured the forward fuselage and wings and performed final integration and final aircraft verification at the Fort Worth, Texas, facility. Fuselage Supply Chain is shown on **Exhibit 4-9** below.

Forward Fuselage	***Lockheed Martin;*** *Fort Worth, Texas, USA*
Center Fuselage	***Northrop Grumman Aerospace Systems,*** *El Segundo and Palmdale, CA;* ***Turkish Aerospace Industries (TA,*** *Second source for center fuselage*
Aft Fuselage	***BAE;*** *Samlesbury, United Kingdom (Aft Fuselage Integrator);*

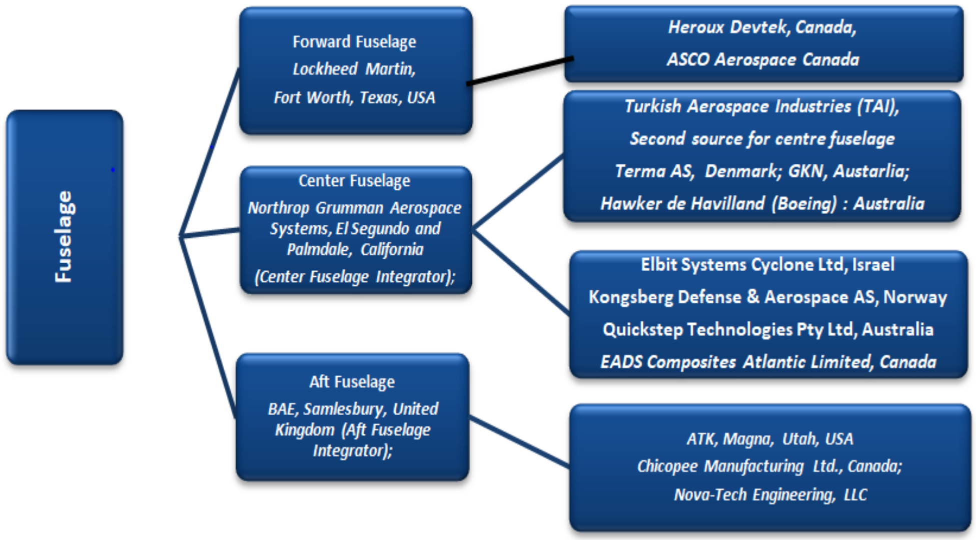


Exhibit 4-9: F-35 Fuselage supply Chain (Gerlovin and Zhao [7])
(Source: http://www.pmi-media.com/wp-content/uploads/2014/03/PMiLockheedMartinF35.pdf)

Engine Supply Chain

The F-35 is powered by the Pratt and Whitney F135 engine, which was derived from the F-22's F119 engine. The F135 is produced in Pratt and Whitney's facilities in East Hartford and Middletown, CT. Rolls-Royce builds the vertical lift system for the F-35B as a subcontractor to Pratt and Whitney. Consistent with congressional direction for the FY1996 defense budget, DoD established a program to develop an alternate engine for the F-35. The alternate engine, the F136, was developed by a team consisting of GE Transportation—Aircraft Engines of Cincinnati, OH, and Rolls-Royce PLC of Bristol, England, and Indianapolis, IN. The F136 was a derivative of the F120 engine originally developed to compete with the F119 engine for the F-22 program. DoD included the F-35 alternate engine program in its proposed budgets through FY2006, although Congress in certain years increased funding for the program above the requested amount and/or included bill and report language supporting the program. The George W. Bush Administration proposed terminating the alternate engine program in FY2007, FY2008, and FY2009. The Obama Administration did the same in FY2010. Congress rejected these proposals and provided funding, bill language, and report language to continue the program. The General Electric/Rolls Royce Fighter Engine Team ended their effort to provide an alternate engine on December 2, 2011. **[Gertler, J (2014)]**

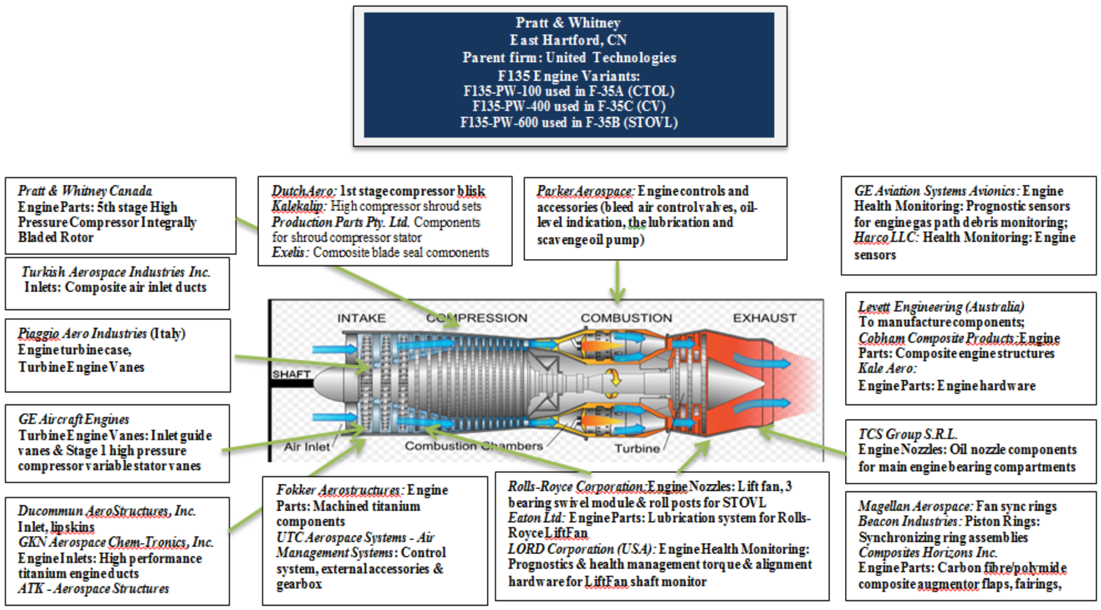


Exhibit 4-10: F135 Engine supply chain (tier one suppliers)

(Gerlovin and Zhao [7])

Source: http://www.airframer.com/aircraft_detail.html?model=F-35_JSF#Engine Components
Picture source: http://en.wikipedia.org/wiki/Rolls-Royce_LiftSystem#mediaviewer/File:JetEngineGraph-LiftFan.PNG)

4.6 Event and Cause Analysis

The $400 billion F-35 program was one of the Pentagon's most troubled programs. Drama is inherent in such a high-stakes procurement that involves three of the Pentagon's military services, several international partners and the world's largest defense contractor. The F-35 program encountered many issues and challenges.

Exhibit 4-11 shows 2017 GAO's current assessment, related to changes in F-35 Joint Strike Fighter Program Cost, Quantity, and Deliveries.

	October 2001 initial baseline	March 2012 latest baseline	December 2015 estimates	Percentage Change from 2001 to 2012	Percentage Change from 2012 to 2015
Expected quantities (number of aircraft)					
Developmental quantities	14	14	14	0	0
Procurement quantities	2,852	2,443	2,443	-14	0
Total quantities	**2,866**	**2,457**	**2,457**	**-14**	**0**
Cost estimates (then-year dollars in billions)[a]					
Development	34.4	55.2	55.1	60	-0.18
Procurement	196.6	335.7	319.1	71	-4.94
Military construction	2.0	4.8	4.8	140	0
Total program acquisition	**233.0**	**395.7**	**379.0**	**70**	**-4.22**
Unit cost estimates (then-year dollars in millions)[a]					
Program acquisition	81	161	154.3	99	-4.16
Average procurement	69	137	130.6	99	-4.67
Estimated delivery and production dates					
Initial operational capability	2010-2012	Undetermined[b]	2015-2018	Undetermined	5-6 years
Full-rate production	2012	2019	2019	7 years	0 years

Source: GAO analysis of Department of Defense (DOD) data. | GAO-17-351

Exhibit 4-11: Changes in Reported F-35 Joint Strike Fighter Program Cost, Quantity, and Deliveries, 2001-2015 (GAO-17-351)

Apart from many partners and their diversified requirements, the complex organizational structure and extensive supply chains, the program also faced significant technical challenges, as detailed below in **Table 12**.

#	Date	Milestone / Issue	Issue Analysis: Variances	Issue Analysis: Causes	Issue Analysis: Category	Explanation
1.	**1983-1996**	**(M) Program initiated**				**Objective**: to develop and deploy a technically superior and affordable fleet of aircrafts that support the warfighter in performing a wide range of missions at the relatively modest price of $38 million. **QTY-6038 (US&UK)**
2.	**Nov. 1996**	**(M) MS I/MS A approval**				**Approval to Enter Concept and Technology Development** **2 Competitive prototypes to be built by 2 teams of contractors:** ***Team 1***: Lockheed ***Team 2***: Boeing
3.	**Oct. 2001**	**(M) MS II/MS B approval + EMD Contract award to LM**		Contract management (high risk for a buyer)	**GOV**	**Approval to Enter Systems Development & Demonstration** **EMD Contract Award *Cost Plus Incentives Contracts* (High risk),** worth an estimated $200 billion, called for construction of as many as 6,000 airplanes; ~ 3,000 for the US military and another 3,000 anticipated in FMS

4.	**Nov. 2001**	***(I) Technical challenges and Stakeholder MGMT issues***		Aggressive timeline, untested technologies, poor PGM, stakeholders and SCM risk management	**MGMT, TECH**	***Technical Problems and Stakeholder issues*** **Organizationally** complex issues: variety of stakeholders: internal teams, outside suppliers, and multiple customers. **Technical:** Lift fan, clutch systems and weight, problems
5.	**Dec. 2001**	***(I)* Strike (P/W) + Technical problems**		Poor HR, PGM, SCM risk management; Untested Tech.	**MGMT, TECH**	***Strike:*** P/W workers union rejected final contract offer. **Technical:** communications problem JASSM (joint air-to-surface stand-off missile) and possible replacement with JASSM-ER with turbofan engine (new technology)
6.	**Jan. 2002**	***(I)Financial and Technical disasters***		Poor PGM, SCM risk management; Untested Tech.	**MGMT, TECH**	**Management & *Financial* issues (LM's net loss of $1bn) Technical disasters:** Weight problem, Rolls-Royce is making a change to nozzle and lift fan to make them lighter (untested technologies)
7.	**Mar. 2002**	***(I)Cost overruns,* Restructuring;**		Aggressive time-line, untested technologies, poor PGM and SCM risk management	**MGMT**	**Due to cost overruns , delays and budgetary pressures:** DoD considered accelerating the JSF program in order to bring the plane on line faster. STOVL QTY is cut from 609 to 350 and the number of the carrier version from 480 to 430.
8.	**Jun. 2002**	***(I)* Stakeholder Management issues**		Poor PGM, stakeholders, requirements and SCM risk MGMT	**MGMT**	**New stakeholders are added with new requirements: (**Level II partners: Italy and the Netherlands). **Italy wants to have its own F-35 final assembly line.**
9.	**Jul. 2002**	***(I) Technical challenges***		Untested Tech.	**MGMT, TECH**	***Technical challenges***: Lift-fan had a number of problems and lasers issue
10.	**Aug. 2002**	***(I)* Concurrent development**		Concurrent development, SC risks, new tech., misalignment with best practices	**GOV, MGMT**	LM relied on SGI visualization and HPC technologies to engineer higher-quality, lower-cost and more- competitive designs. **LM used computer simulation instead of testing, to keep costs down.** The Pentagon allowed LM to design, test, and produce the F-35 all at the same time concurrency).
11.	**Sept. 2002**	***(I)* Stakeholder management; technology transfer**		Poor PGM, stakeholders and SCM risk management	**MGMT**	**Stakeholder management:** Other nations signed up to the SDD phase (new FICO facilities), Friction over Work Shares **Technology transfer issues** Global project authorization (GPA);
12.	**Apr. 2002**	***(I)* Technical problems; Contract management**		Procurement management, Untested Tech. SCM risk management	**MGMT, TECH**	**Technical problems:** Weight issues **SC Risk Management** (sole source contract) Issue with a supplier: Ingersoll Milling Machine Co filed for bankruptcy
13.	**Dec. 2003**	***(I)Cost overruns and schedule delay*- Nunn-McCurdy Breach; *weight & technical problems; strike***	**2 years delay**	Poor PGM, stakeholders and SCM risk management	**MGMT**	**1st Nunn-McCurdy Breach (Significant) PAUC** **Re-baseline: New: Dev. Est: 44.8 Billion; Avg. Proc. 82 mil** **Weight problems**: Lift fan and clutch redesign in favor of a lighter versions; **Technical:** problems with JASSM (joint air-to-surface stand-off missile) software and technology integration; ***Strike:*** P/W workers union again; **Friction between DoD and foreign partners.**

14.	**2004**	***(I) Technical*** **disasters continue**	**IOC delayed by 1 year**	Poor PGM & Risk MGMT, untested technologies	**MGMT, TECH**	**Schedule delay;** **Technical problems:** Weight problems, software problems, Interoperability problems (info sharing)
15.	**2005**	***(I)Cost overruns and schedule delay*- Nunn-McCurdy Breach; *weight & technical problems;***		Poor PGM & SC Risk MGMT, Untested Tech.	**MGMT, TECH**	**2nd Nunn-McCurdy Breach (Significant) PAUC & APUC** The program undergoes re-plan to address higher than expected design weight; configuration updates, increase airframe material cost, change in prime subcontractor,
16.	**2006**	***(I)* Restructuring, Cost increases**		Concurrency, Poor PGM & SC Risk MGMT, Untested Tech.	**MGMT**	**The program planned to enter production with less than 1% of testing complete.**
17.	**2007**	***(I)* Technical problems; Funding issues**		Poor PGM & SC Risk MGMT, Untested Tech.	**MGMT**	**Technical problems: Critical engine issues**: turbine blades broke off, metal fatigue (several incidents); Testing overlap (concurrency); funding is reduced by a Congress
18.	**2008**	***(I) Technical*** **disasters continue**		Poor PGM & Risk MGMT, untested tech., concurrency, misalignment with best practices	**MGMT, TECH**	**Technical problems:** Critical engine problem, issues with ground cooling fan electrical circuitry, & other components. **Engine redesign, retest, and recertification;** **Funding:** Management reserves replenishment**: from** $400 million to about $1 billion ***by reducing testing to save money***
19.	**2009**	***(I)* Technical problems; Cost increase**	**1 year delay**	Contract structure; Poor PGM & Risk MGMT, untested tech., concurrency, misalignment with best practices	**MGMT, TECH**	**Serious engine problems** with P/W new redesigned F-135 engine with redesigned turbine blades. The program **increased the cost estimate** and adds a year to development but accelerated the production ramp up. **Moving forward with an accelerated procurement plan and use of cost reimbursement contracts is very risky.**
20.	**2010**	***(I)Cost overruns and schedule delay*- Nunn-McCurdy Breach; *weight & technical problems;***	**2 years delay**	Poor PGM & Risk MGMT, untested tech., concurrency, misalignment with best practices	**MGMT, TECH**	**3rd Nunn-McCurdy Breach (Critical) PAUC & APUC** **Technical problems:** Lift fen, problem with a fuel pump, caused by a software bug; **The program was restructured**: **Costs and schedule delays inhibit the program's ability to meet needs on time.**
21.	**2011**	***(I) Technical problems, restructuring*** **continues**	**1 year delay**	Poor PGM & Risk MGMT, untested tech., concurrency, misalignment with best practices	**MGMT, TECH**	**Technical** problem with a generator caused by a faulty maintenance handling; 6 days fleet grounding due to a problem with software; another grounding – a valve in the Integrated Power Package (IPP); **Restructuring continued with additional development cost increases; schedule growth;**
22.	**2012**	***(I) Technical problems, restructuring***	**2 years delay**	Poor PGM & Risk MGMT, untested tech., concurrency	**MGMT, TECH**	**Technical problems:** 12 days grounding due to improperly installed parachutes **Restructuring continued**

23.	**2013**	***(I) Technical problems***		Poor PGM & Risk MGMT, untested tech., concurrency	**MGMT, TECH**	**Technical problems:** Propulsion system issues (a failure of a fueldraulic line); Additional problem: a crack in a low pressure turbine blade in an engines of a F-35A
24.	**2016**	***(I) Technical problems and*** **affordability and oversight challenges**		Poor PGM & Risk MGMT, untested tech., concurrency	**MGMT**	**The remaining significant and complex 3F mission systems** software developmental testing, continuing issues with ALIS, and new issues with the ejection seat and F-35C wing structures pose ongoing risks. **Going forward, the program will likely continue to experience affordability and oversight challenges.** (GAO-16-489T

Table 12: F-35 (JSF) - Timeline Milestones/Issues/Major Delays
(Additional information is provided in Appendix III)

Our F-35 event analysis **(Table 12)** shows that 21 setbacks are management related, 13 of them are also caused by technical issues. Government issues contributed to 2 of these setbacks. These issues are outlined in the following section:

Organizational and Stakeholder Management issues[106]:

In addition to the technical challenges of the F-35 program, Maj. Gen. Christopher Bogdan identified yet another concern. “In a high-profile speech at the Air Force Association (AFA) Conference he dropped a bombshell, saying the dismal relationship among stakeholders, the Pentagon’s joint program office and prime contractor Lockheed Martin, is the biggest threat to the success of the F-35 program”. “…It is the worst I have ever seen. In some cases, the industry team takes seven months to respond to a request for data from the program office” he said. Bogdan says it is unacceptable that the LRIP Lot 4 talks took more than a year, given that the partners had worked together for 11 years.

“Multiple current and former senior Air Force and Pentagon officials said the approach taken by Lockheed Martin leadership in contract negotiations for the F-22 has carried into the company's practices for the F-35. Both programs are managed out of the company's aeronautics sector headquartered in Fort Worth. One official suggests that the company would intentionally stall the Air Force procurement staff in F-22 negotiations in order to protract talks dangerously close to the end of the fiscal year, when Pentagon comptrollers would reclaim unused funding from a program. This would force service officials to quickly conclude deals that were less beneficial to the taxpayer, the official says. That strategy worked for years, the official says, adding that contract terms were often disproportionately favorable to Lockheed on the F-22". Lockheed Martin spokesman Joe Lamarca disagrees: "We negotiate all of our contracts with transparency and respect for our customers and suppliers." According to Aviation Week, "Poor industry relations have nagged the Air Force for years." General Kwast called for "humility" on the part of industry and the Air Force in a speech at the conference.

"*The parties need to 'let go of our sense of control, and we need to collaborate to do the right thing'.*"

– Maj. Gen. Steven Kwast, a head of requirements for Air Combat Command (2011)

The F-35 program suffered significant technical and organizational complexity (3 versions for 3 services, many partnering countries, etc.). As commented by Charles T. (Tom) Burbage, executive vice president and general manager for Lockheed Martin's Joint Strike Fighter program, "I'm not worried about the technical challenges ... my concerns focus on the organizational dimensions"[107]. Burbage said the chief challenge facing the company is whether "we can scale up the organization and maintain all of the team's aspects, integrate various demands from outside parties to become part of the JSF enterprise and keep the huge customer set fully engaged, onboard and excited about the airplane."

United Kingdom's BAE clearly indicated it would be essential for a UK company to oversee the overall design and architecture of a project so central to the UK defense capability.

> *"BAE Systems must be put in charge of building the Royal Navy's two new aircraft carriers. If BAE is not the systems prime [contractor] for this, it will give us some real problems."*
> – Chris Geoghegan, Chief Operating Officer of BAE[108]

Friction also existed between DOD and foreign partners, such as, Denmark, Italy, the Netherlands, Norway, and Turkey. In 2003-2004, these countries expressed dissatisfaction with the quality and quantity of the work that their companies had been awarded on the F-35. They threatened to reduce their participation in the program, or purchase other European fighters instead of the F-35. The governments of Italy and the United Kingdom have lobbied for F-35 assembly facilities to be established in their countries[109].

Technical Challenges and Concurrency Issues

At the beginning, the JSF Program Office tracked 23 program level risks for F-35 – 3 are low risks, 19 are moderate, and 1 is high (aircraft weight). It was discovered, even before the signing of the initial contract, that the F-35 Joint Strike Fighter (JSF) was having weight problems – about 2% above target at the preliminary design review point. However, Tom Burbage, the company's JSF general manager, said the weight was still below the not-to-exceed level where performance would be affected, particularly for the short takeoff vertical landing version.

In FY 2012, review of the F-35 Joint Strike Fighter (JSF) program by the office of Director of Operational Test and Evaluation (DOT&E[4]) described F-35 weight reduction efforts and their implications:

- The first test series confirmed Polyalphaolefin (PAO) coolant and fueldraulic systems fire vulnerabilities. The relevant protective systems were removed from the aircraft in 2008 as part of a weight reduction effort. A Computation of Vulnerable Area Tool analysis shows that the removal of these systems results in a 25 percent increase in aircraft vulnerability. The F-35 Program Office may consider reinstalling the PAO shutoff valve feature based on a more detailed cost-benefit assessment. Fueldraulic system protection is not being reconsidered for the F-35 design.
- Attempts to lighten the JSF by 11 pounds may have left the fifth-generation stealth fighter more vulnerable than the aircraft would replace.
- In 2008, the JSF Executive Steering Board (JESB) directed the removal of PAO shutoff valves from the F-35 design to reduce the aircraft weight by 2 pounds. Given the damage observed in this test, the JESB directed the program to re-evaluate installing a PAO shutoff system through its engineering process based on a cost/benefit analysis and the design performance capabilities. The ballistic test results defined the significance of this vulnerability.
- The removal of two safety features in an attempt to reduce weight on the F-35 - left the plane vulnerable to fuel explosions if hit by enemy fire.
- The program will need to continue rigorous weight management through the end of SDD to avoid performance degradation and operational impacts. The small

[4] **The office of Director, Operational Test and Evaluation (DOT&E), is a principal adviser to the Secretary of Defense**

difference between the current weight estimate and the not-to-exceed weight allows for weight growth of 0.32 percent per year. - Managing weight growth with such small margins will continue to be a significant program challenge.[110]

In July 2009, the then head of the JSF Program Office, Marine Corps Maj. Gen. David R. It was discovered, even before the signing of the initial contract, that the F-35 Joint Strike Fighter (JSF) was having weight problems – about 2% above target at the preliminary design review point. However, Tom Burbage, the company's JSF general manager, said the weight was still below the not-to-exceed level where performance would be affected, particularly for the short takeoff vertical landing version.

In FY 2012, review of the F-35 Joint Strike Fighter (JSF) program by the office of Director of Operational Test and Evaluation (DOT&E[5]) described F-35 weight reduction efforts and their implications:

- The first test series confirmed Polyalphaolefin (PAO) coolant and fueldraulic systems fire vulnerabilities. The relevant protective systems were removed from the aircraft in 2008 as part of a weight reduction effort. A Computation of Vulnerable Area Tool analysis shows that the removal of these systems results in a 25 percent increase in aircraft vulnerability. The F-35 Program Office may consider reinstalling the PAO shutoff valve feature based on a more detailed cost-benefit assessment. Fueldraulic system protection is not being reconsidered for the F-35 design.

[5] **The office of Director, Operational Test and Evaluation (DOT&E), is a principal adviser to the Secretary of Defense**

- Attempts to lighten the JSF by 11 pounds may have left the fifth-generation stealth fighter more vulnerable than the aircraft would replace.
- In 2008, the JSF Executive Steering Board (JESB) directed the removal of PAO shutoff valves from the F-35 design to reduce the aircraft weight by 2 pounds. Given the damage observed in this test, the JESB directed the program to re-evaluate installing a PAO shutoff system through its engineering process based on a cost/benefit analysis and the design performance capabilities. The ballistic test results defined the significance of this vulnerability.
- The removal of two safety features in an attempt to reduce weight on the F-35 - left the plane vulnerable to fuel explosions if hit by enemy fire.
- The program will need to continue rigorous weight management through the end of SDD to avoid performance degradation and operational impacts. The small difference between the current weight estimate and the not-to-exceed weight allows for weight growth of 0.32 percent per year. - Managing weight growth with such small margins will continue to be a significant program challenge.[111]

Engine:

The F-35 is powered by the Pratt and Whitney (P&W's parent firm is United Technologies) F135 engine, which is produced in Pratt and Whitney's facilities in East Hartford and Middletown, CT. Consistent with congressional direction for the FY1996 defense budget, DOD established a program to develop an alternate engine for the F-35, the F136, was developed by a team of GE Transportation – Aircraft Engines of Cincinnati, OH, and Rolls-Royce PLC of Bristol, England, and Indianapolis, IN. The P&W and GE/RR engines were planned to be physically and functionally interchangeable in both the aircraft and support systems. All JSF aircraft variants should have been able to use either engine. The competition was planned to start in FY 2011 and continue through the life of the program to reduce risks. The F136 engine began ground testing in July 2004. However, in the 2007 US Military Budget, no funding was allocated for the development of the F136 engine. The US Congress voted to restore funding for the F136 in October 2006. In FY2011, Congress agreed not to fund the alternate engine, and the alternate engine program was terminated in April 2011. The General Electric/Rolls Royce Fighter Engine Team ended their effort to provide an alternate engine on December 2, 2011. Please see below for the Timeline of the engine related issues. [112]

Table 13: Timeline of Engine Related Issues[113] (Source: defense-aerospace.com 2013)	
Redesign of the engine in 2008 and 2007	The 1st incident was recorded in May 2007, when the F-35A prototype AA-1 experienced an electrical short that disabled flight controls on the horizontal stabilizer. Grounding was ordered and continued until December 2007, due to time needed to redesign several parts of the 270-volt electrical system and F135 engine problems.
	In August 2007 and February 2008 there were serious problems. Turbine blades broke off suddenly by a form of metal fatigue. The cause was sought in a combination of factors. On 30 August 2007 in test engine FX634, after 122 hours of testing, a turbine blade in the 3rd LPT stage broke off completely. On February 4, 2008 something similar happened to engine FTE06, also in the 3rd LPT stage, after 19 hours. These problems with the engine contributed significantly to the delays in the JSF test program for the period 2007-2008.
	In early 2008, an engine, the FX640 ground test engine, was equipped with numerous sensors and instruments. On April 21, 2008 a test process was started to find the cause of the problem. Through a detailed test plan the forces and tensions that arise in the engine were mapped in different power ranges. At that moment it seemed to be primarily an issue of the F-35B STOVL (vertical landing) version. The cracks in the turbine blades were created in exactly the same place, and seemed to occur when switching from forward to vertical drive. Later in 2008, the results became available. The blade cracks seemed to have been caused by certain vibrations that triggered a material failure. This led to a redesign of a number of elements in the engine. One of the upgrades was a change of the distance between the turbine blades. After the redesign the engine was retested and recertified. At the end of 2008 Pratt & Whitney issued a press statement, saying that they were convinced that the problems were solved.
	On July 23, 2008, both flying F-35 prototypes were grounded after problems were detected with ground cooling fan electrical circuitry, DCMA reported on Aug 18, 2008 that tests were delayed as a result of testing anomalies on the 28 Volt and 270 Volt Battery Charger/Controller Unit, the Electrical Distribution Unit and the Power Distribution Unit. It was due to design problems. Flights were resumed first week of September-2008. December 2008: On Dec 12, 2008 the F-35 was grounded again as a result of engine and ejection seat anomalies. Seat anomalies were observed in ejection seat sequence during an escape system test on Nov. 20, 2008. It took nearly 3 months to solve the problems and aircraft AA-1 did not return to the skies until Feb. 24, 2009.
In 2009, problems with redesigned engine	May 2009: The F-35 fleet didn't fly between May 7, 2009 (84th flight of prototype AA-1) and Jun 23, 2009. No comments were available from JPO or L-M.
	In July 2009, the then head of the JSF Program Office, Marine Corps Maj. Gen. David R. Heinz, was still was not happy with the F135 problems. He told the press: "The problems include too many individual blades that fail to meet specifications, as well as combined "stack-ups" of blades that fail early. I'm not satisfied with the rates that I'm getting." A few days later he was ordered by the Pentagon not to comment publicly on problems with the F135

	engine. In September 2009, serious engine problems were again revealed during testing of the Pratt & Whitney F135 engine. At a crucial moment in the debate in the U.S. Congress on the choice of two competing engine types (the Pentagon wanted to axe the alternate engine (the GE / Rolls Royce F136), a Pratt & Whitney F135 engine broke down. Again, the cause seemed to lie in broken turbine blades. However, this time the same problem occurred in the new, redesigned engine with redesigned turbine blades.
2010 -2011	October 2010: F-35 fleet grounded after the fuel pump shut down above 10,000ft (3,050m). The problem was caused by a software bug.
	March 2011: The entire F-35 fleet was grounded some weeks after test aircraft AF-4 experienced a dual generator failure. After both generators shut down in flight, the IPP activated and allowed the F-35's flight control system to continue functioning. The problem was traced to faulty maintenance handling.
	June 2011: Carrier-based F-35C suspended from flying after engineers at NAS Patuxent River discovered a software problem that could have affected the flight control surfaces. Grounding was from 17 June until 23 June, 2011.
	August 2011: A precautionary grounding of all 20 F-35s that had reached flying status was ordered Aug. 3, 2011 after a valve in the Integrated Power Package (IPP) of F-35A test aircraft AF-4 failed. On 18 August 2011 the flight ban was lifted to allow monitored operations. A permanent resolution would be installed later.
2012 -2013	January 2012: 15 Lockheed Martin F-35s are grounded for about 12 days to repack improperly installed parachutes (reversed 180 degrees from design). The grounded aircraft are equipped with new versions of the Martin Baker US16E ejection seat, designated as -21 and -23.
	January 2013: The F-35B STOVL variant was grounded Jan 18, 2013 after detection of a failure of a fueldraulic line in the aircraft's propulsion system. The Pentagon cleared all 25 F-35B aircraft to resume flight tests on February 12, 2013. Problem caused by a manufacturing quality problem (wrongly crimped fuel line).
	February 2013: On Feb. 21, 2013, the Pentagon ordered a grounding for all F-35 aircraft, after a routine check at the Edwards Air Force Base revealed a crack in a low pressure turbine blade in an engines of a F-35A.
On October 14, 2014 WSJ reported: "Investigators have pinned down the probable cause of the engine problems that triggered fire on a F-35 fighter jet, paving the way for the Pentagon to resume awarding deals for new aircraft and engines.[114]	

On-Board Inert Gas Generating System (OBIGGS) Concerns

Tests of the fuel tank inserting system in 2009 identified deficiencies in maintaining the required lower fuel tank oxygen. The test flights were "not permitted" within 25 miles of known lightning conditions due to a needed redesign to the On-Board Inert Gas Generating System, which maintained correct oxygen levels in the fuel tank. In November of 2012 the **DOT&E** reported that "the program was redesigning OBIGGS to address deficiencies identified in earlier fuel system simulator test series (LF-09B) to meet the vulnerability requirements during all critical segments of a combat mission and to provide an inert tank atmosphere for internal lightning protection. The system is crucial to protecting the engine from exploding in case of a lightning strike."[115]

“From the beginning, Lockheed assured Pentagon officials that technological innovation, including heavy reliance on computer simulation, which could take the place of real-world testing, would keep costs down. The Pentagon bought those assurances and allowed the company to design, test, and produce the F-35 all at the same time, instead of insisting that Lockheed identify and fix defects before firing up its production line. Building an airplane while it is still being designed and tested is referred to as concurrency.” (Ciralsky, A. 2013). Indeed, the F-35 program planned to enter production with less than 1% of testing complete.

Tail Hook System Issue and Unexpected “Adaptation” of L-class ships[116]

In 2013 Lockheed traced the potential problems in carrier landings experienced by the Navy's F-35C to the design of the aircraft's tailhook. Lockheed had the unique challenge of designing the jet with a tailhook that had to be concealed when it wasn’t being used. The tailhook had to fit within the outer mold line of the F-35, the device had to be fitted farther forward on the jet's ventral surface than on other naval aircraft. Another factor that affected landing on the carrier was the sheer force of the impact. Unlike conventional land-based aircraft, naval aircraft do not flare on landing. *“Our original design was not performing as expected,”* said Lorraine Martin, Lockheed Martin’s executive vice president for the F35 Lightning II program. Martin said the “toe” of the tailhook, the part that grabs the wire, had been re-designed along with the “hold down damper” gear that forced the tailhook down on the deck. In other testing, the Navy found that its L-class ships would have to be adapted to the F-35, and “ship change notices were going out to the L-class ships,” said Rear Adm. Mark Darrah, commander of the Naval Air Warfare

Center Aircraft Division. "We have to adapt the ships to the new environment" that comes with the F-35s, he said.

Engine Shipping Problem[117]

Behind the scenes, the Navy was struggling to remedy a significant design oversight that posed a major potential hindrance to its ability to successfully deploy and maintain the F-35C Lightning II, the carrier-based variant of the joint strike fighter: Its powerful single engine, when packed for shipping, was too large to be transported to sea by normal means when replacements were required. "That is a huge challenge that we currently have right now," said Capt. Chris Kennedy of the JSF Program Office. Regular wear and tear, as well as mishaps such as an engine sucking a foreign object off a carrier deck, made the availability of replacement aircraft engines critical. High-tempo combat operations only increased the need. Carriers typically packed spares, but heavy demanded drain those stores, requiring at-sea replenishment. However, the F-35C's Pratt & Whitney F135 engine, contained in its Engine Shipping System, was too large for the cargo door on a standard carrier onboard delivery plane and for the V-22 tilt-rotor aircraft. The program office acknowledged this in a response to a follow-on query from Navy Times. He indicated that the engine could be broken down into five component parts, but just its power module and packaging alone would not fit into the COD or the V-22. The JSF Program Office said that the V-22 Osprey, like the MH-53E helicopter, could externally carry the F135 engine module, the heaviest of the five components, at least 288 miles "in good weather."

The helmet mounted display

The helmet, which provides flight data, targeting, and other sensor data to the pilot, is integral to the mission system's architecture, to reduce pilot workload, and to achieve the F-35's concept of operations. The original helmet mounted display encountered significant technical deficiencies. *"The primary helmet was developed by VSI, an Elbit and Rockwell Collins joint venture and had been suffering problems with jitter in displaying data on the visor, and resolution wasn't high enough for its night*-vision *capability. BAE Systems won a contract in 2012 to provide pilot helmets for the F-35 after persistent problems with the primary helmet. The program ended development of the alternate F-35 helmet as further testing indicated it is acceptable for USMC initial operating capability.*[118] *"*

Software Issues

The F-35 software development effort is one of the largest and most complex in DOD history. It is essential to achieve capabilities such as sensor fusion, weapons and fire control, maintenance diagnostics, and propulsion. Recent management actions to refocus software development activities and to implement improvement initiatives appear to be beneficial, but software will continue to be a very challenging and high risk undertaking for this program, especially for mission systems. Over time, software requirements have grown in size and complexity and the contractor has taken more time and effort than expected to write computer code, integrate it on aircraft and subsystems, conduct lab and flight tests to verify it works, and to correct defects found in testing.

> *"You can see from its angled lines, the F-35 is a stealth aircraft designed to evade enemy radars. What you can't see is the 24 million lines of software code which turn it into a flying computer. That's what makes this plane such a big deal".*
> – Lt. Col. David Berke **[**Martin, D. (2014), CBS News**]**

The Government Accountability Office also reported on the F-35 software delays.

"(P)ersistent software problems have slowed progress in mission systems flight testing, which is critical to delivering the warfighting capabilities expected by the military services. These persistent delays put the program's development cost and schedule at risk. As a result, DOT&E now projects that the warfighting capabilities expected by the Marine Corps in July 2015, will not likely be delivered on time, and could be delayed as much as 13 months.[119]"

Supply Chain Issues with Tires:

In the summer of 2002, Lockheed Martin placed a $12.3-million order with Ingersoll Milling Machine Co. for custom-made machine tools to produce parts for the stealthy tactical aircraft. As of April of this year, Lockheed Martin had paid Ingersoll more than half the contract price but it still had no machines delivered. Then came the jarring news: Ingersoll had shut down and sought court protection under Chapter 11 of the code. On June 17 Lockheed hired Cincinnati Machine, an Ingersoll rival and the only other US company that can build both metal-cutting and composite-forging machinery, to complete the work on two of the machines at the Ingersoll plant in Rockford. Since Ingersoll International went out of business in April, Cincinnati Machine of Ohio became "the only operative, sophisticated machine-tool business left" in the United States, Mr. Hunter said. Goodyear Tire & Rubber Co. of Akron is the only U.S. company that makes military tires[120].

Landing-gear tires[121]

Landing-gear tires made by Dunlop Aircraft Tyres Ltd. for the Marine Corps version of the fighter had *"been experiencing an unacceptable wear rate when operating as a* *conventional aircraft,"* according to Joe DellaVedova, spokesman for the Defense Department's F-35 program office. He said that the tires, which cost about $1,500 a piece, demonstrate "adequate wear" when the aircraft performs short takeoffs and vertical landings intended for amphibious warfare vessels and improvised runways. While replacing worn-out tires may pale as a challenge compared with keeping combat-ready software on track, fixing jittery images in the pilot's helmet (see more under 9.8 and 9.9) and reining in rising production costs, these issues were emblematic of challenges that the Pentagon needed to resolve to reduce what had become a $1.1 trillion estimate for operating and supporting a planned fleet of 2,443 aircraft for 55 years. Bloomberg News reported at the end of 2013 that: "The Pentagon was working with Lockheed Martin and Birmingham, U.K.-based Dunlop Tyres on a new design for the landing-gear" DellaVedova said in an e-mailed statement. In the meantime, Dunlop had provided a tire that was "improved but still unacceptable," he said

Estimates as of 2014 and Sustainability Concerns

Based on **GAO-14-778,** the program is "unsustainable": "*DOD currently has or is developing several plans and analyses that will make up its overall F-35 sustainment strategy, which is expected to be complete in fiscal year 2019. The annual F-35 operating and support (O&S) costs are estimated to be considerably higher than the combined annual costs of some legacy aircrafts* (that are to be replaced by F-35)." (**Exhibit 4-10**).

F-35 (A/B/C)	$19.9 Billion			
F-15C/D F16C/D AV-8B F-18A-D	$11.1 Billion		<<< $8.8 billion difference >>> Represents an increase of more than 79% in annual O&S costs	
In billions of dollars	5	10	15	20

Exhibit 4-12: Comparison of the Annual Estimated F-35 Operating and Support (O&S) Cost at Steady State to Actual Legacy Aircraft (O&S) Cost in Fiscal Year 2010 (Source GAO-14-778)

"*DOD had begun some cost-savings efforts and established sustainment affordability targets for the F-35 program, but DOD did not use the military services' budgets to set these targets. Therefore, these targets may not be representative of what the services can afford and do not provide a clear benchmark for DOD's cost*-savings efforts. In addition, *DOD had not fully addressed several issues that have an effect on affordability and operational readiness, including aircraft reliability and technical-data rights, which could affect the development of the sustainment strategy*." **(GAO-14-778).**

According to Cost Assessment and Program Evaluation (CAPE)'s analysis, the combined O&S costs of several legacy aircraft—the F-15C/D, F-16C/D, AV-8B, and F-18A-D fleets—in 2010 exceeded $11 billion. Comparatively, based on CAPE's 2013 O&S cost estimate, the annual cost to sustain the F-35 will be about $19.9 billion (in base year 2012 dollars) in 2040—the end of its steady-state years. This $8.8 billion difference represents an increase of more than 79% in annual O&S costs for the F-35 as compared with several legacy aircraft (see exhibit 2-4). Moreover, the Program Executive Officer has continued to express concerns over the affordability of the program's sustainment approach, stating that "F-35 sustainment costs remain a concern" and that affordability continues to be a top priority for the program.

As Dave Majumdar reported for Daily Beast in 2014 citing military official: *"When the F-35 achieves [initial operational capability], it will not have the weapons or sensor capability, with respect to the CAS [close air support] mission set, that legacy multi-role fighters had by the mid-2000s. The problem stems from the fact that the technology found on one of the stealth fighter's primary air-to-ground sensors—its nose-mounted Electro-Optical Targeting System (EOTS)—is more than a decade old and hopelessly obsolete. The EOTS, which is similar in concept to a large high-resolution infrared and television camera, is used to visually identify and monitor ground targets. The system can also mark targets for laser-guided bombs. EOTS is a big step backwards. The technology is 10-plus years old, hasn't been able to take advantage of all the pod upgrades in the meantime, and there were some performance tradeoffs to accommodate space and stealth. When the Pentagon had initially drawn up the Joint Strike Fighter program's specifications during the later half of the 1990s, the EOTS would have been bleeding-edge technology. However, in the 14 years that have passed since the Pentagon awarded Lockheed the contract to develop the F-35, technology has evolved—and the services have gained experience from over a decade of war.,"* said one Air Force official affiliated with the F-35 program.[122]

Chapter 5: Challenges and Management Practices

This final chapter is organized into six sections. It elevates and reconciles the statistical analysis and case studies to identify the common issues across different programs, compares the current strategies, such as the concurrency strategy, with the knowledge base evolutionary approach (advocated by GAO), and uses game theory to interpret the managerial implications of these practices. The key question to answer here is: "why did those issues happen in these programs?" We shall also comment on the recent acquisition policy changes.

5.1 The Problems and Challenges

> "*Simply put, the Department of Defense (DOD) acquisition process is broken. The ability of the Department to conduct the large scale acquisitions required to ensure our future national security is a concern of the committee. The rising costs and lengthening schedules of major defense acquisition programs lead to more expensive platforms fielded in fewer numbers*".
>
> - Moshe Schwartz Specialist in Defense Acquisition, Congressional Research Service[123]

MDAPs are extremely complex, large scale government acquisition programs, with thousands of stakeholders, high risk performance specifications, technically challenging requirements with estimated procurement costs of more than $2.79 billion FY2014 dollars (Ibid).

Due to the significant technical challenges and organization uncertainties, the outcome of such projects is often uncertain, and subjected to iterations, revision and rework. The following graph provides an overview of the process of such programs.

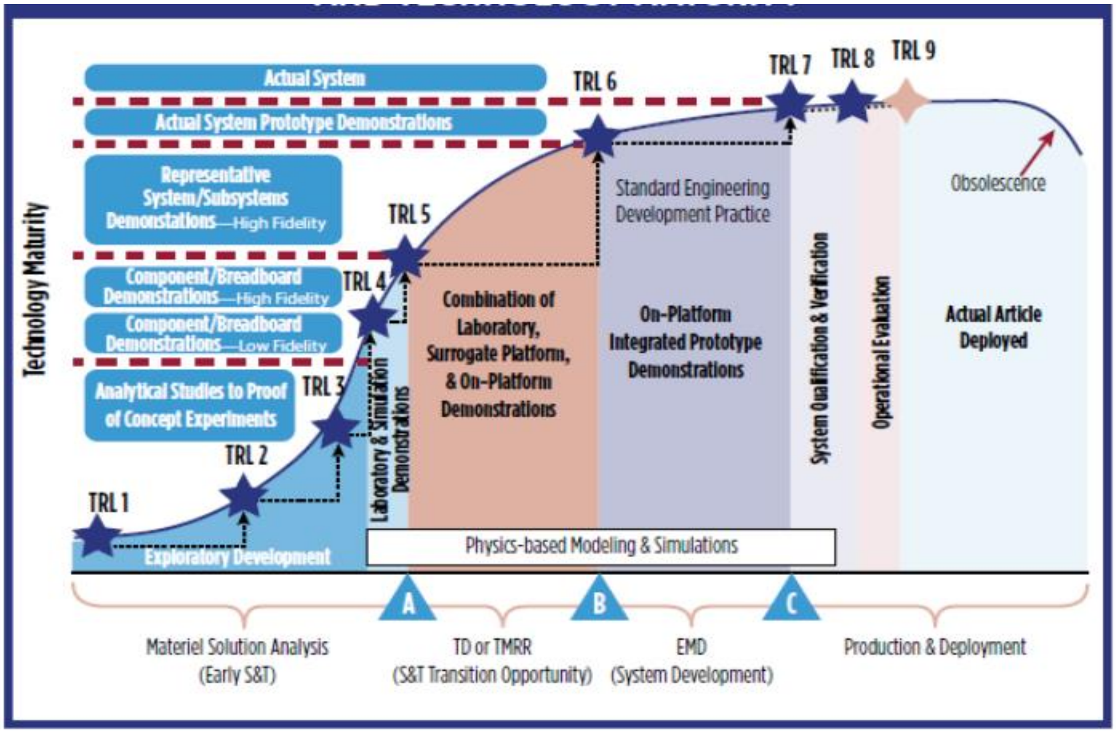


Exhibit 5-1: Level of Prototype Demonstrations, Venue, and Technology Maturity [124]

Thus, the performance (cost, schedule and quality) of such programs may depend on government management and oversight, technology, the role of contractors and lead military services, levels of competition, contract structures, and supply chain risks.

5.1.1 The Major Reasons for Programs Delays (FY2015 MDAPs)

Based on our analysis of the programs in the FY2015 MDAPs portfolio, provided by The Director, Operational Test & Evaluation (DOT&E), we perform some descriptive analysis below. Overall, the major reasons for program delays over all services and contractors are provided below.

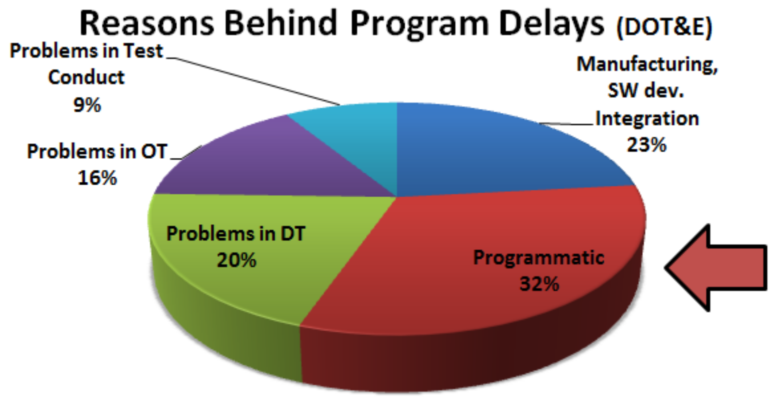
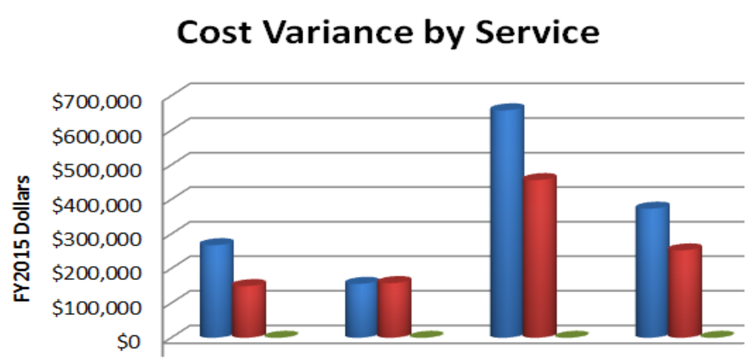


Exhibit 5-2: Categories (DOT&E) Reasons behind Program Delays.

- Statistically, it is more likely to experience delays from programmatic issues **(Exhibit 5-2);**
- Air force has the highest % cost overrun **(Exhibit 5-3)** and the highest number of Nunn-McCurdy breaches **(Exhibit 5-4);**



	Air Force	Army	Navy	DoD
Current Acq. Cost	$268,006	$156,040	$658,278	$373,566
1st Full Est. MS B.	$149,517	$158,350	$456,376	$253,023
Variance %	79.25%	-1.46%	44.24%	47.64%

Exhibit 5-3: FY2015 Cost overrun by Service

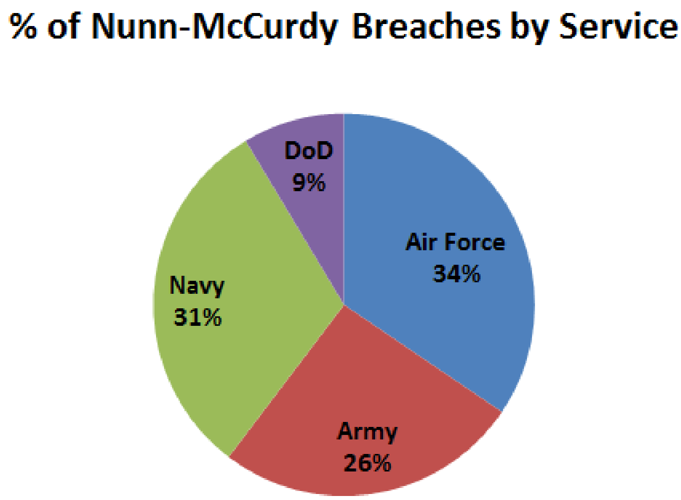


Exhibit 5-4: FY2015 % of Nunn-McCurdy Breaches by Service

Delay Causes by service:

For different services, the causes may be different. Please see below stats.

- Air Force delays are mostly caused by Manufacturing and Programmatic issues (66%) **Exhibit 5-5;**

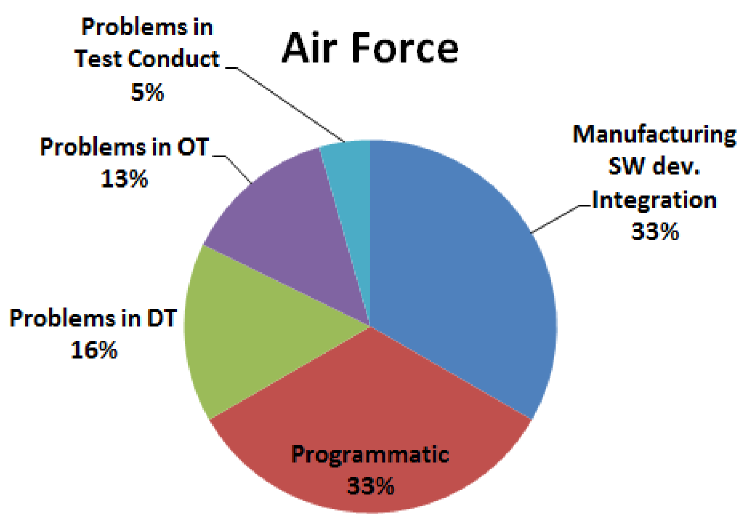


Exhibit 5-5: FY2015 Air Force: Causes of Program Delays

- Army programs are delayed mostly due to programmatic problems

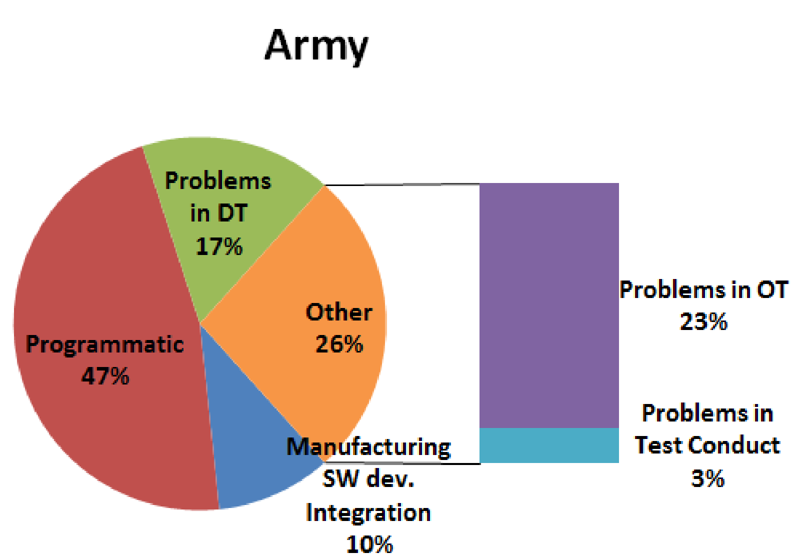


Exhibit 5-6: FY2015 Army: Causes of Program Delays

Programmatic Problems are also responsible for 50% of DoD (**Exhibit 5-7)** and 24% of Navy programs **(Exhibit 5-8)** delays.

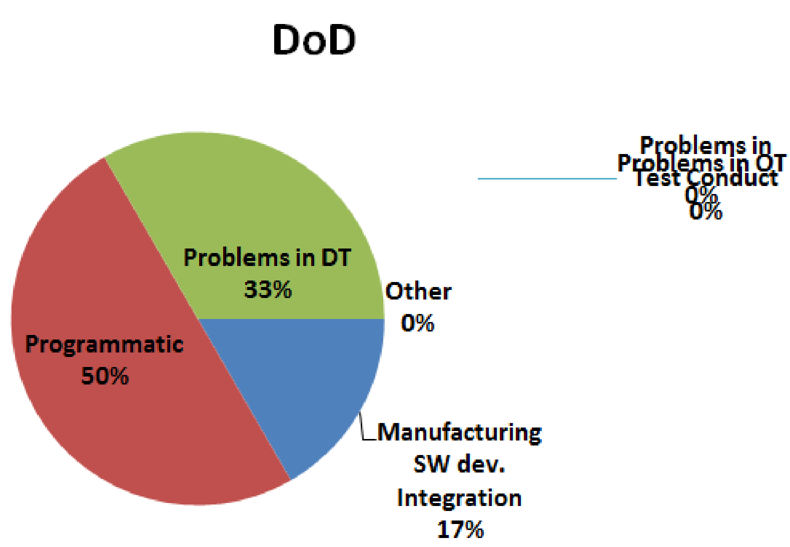


Exhibit 5-7: FY2015 DoD Causes of Program Delays

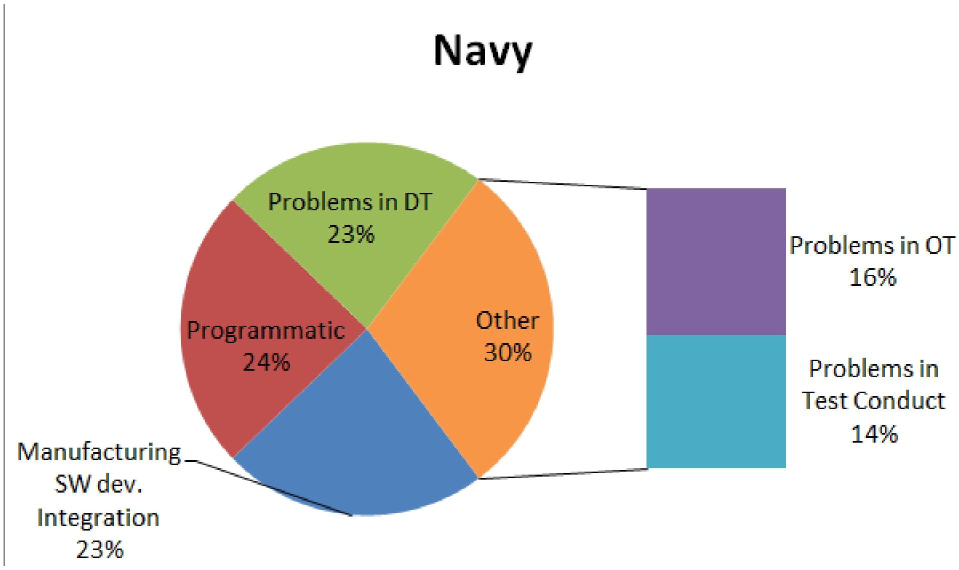


Exhibit 5-8: FY2015 Navy Causes of Program Delays

By Contractors:

Based on FY2015 Portfolio, Lockheed Martin is responsible for:

- 42% of current acquisition costs **Exhibit 5-9;**
- 40% of cost overruns **Exhibit 5-10** and
- 34% of Nunn-McCurdy breaches **Exhibit 5-11**
- The largest delay cause for LM programs (FY2015) is Programmatic **Exhibit 5-12**

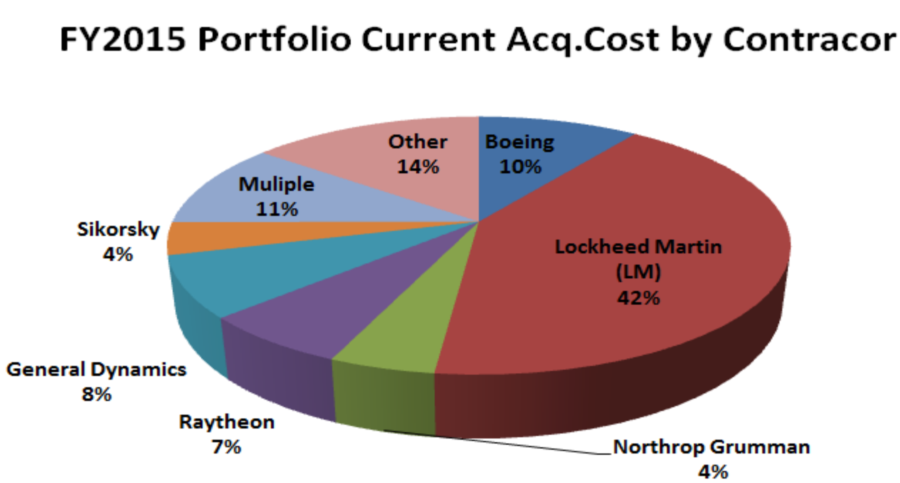


Exhibit 5-9: FY2015 Portfolio: Current acquisition cost by contractor

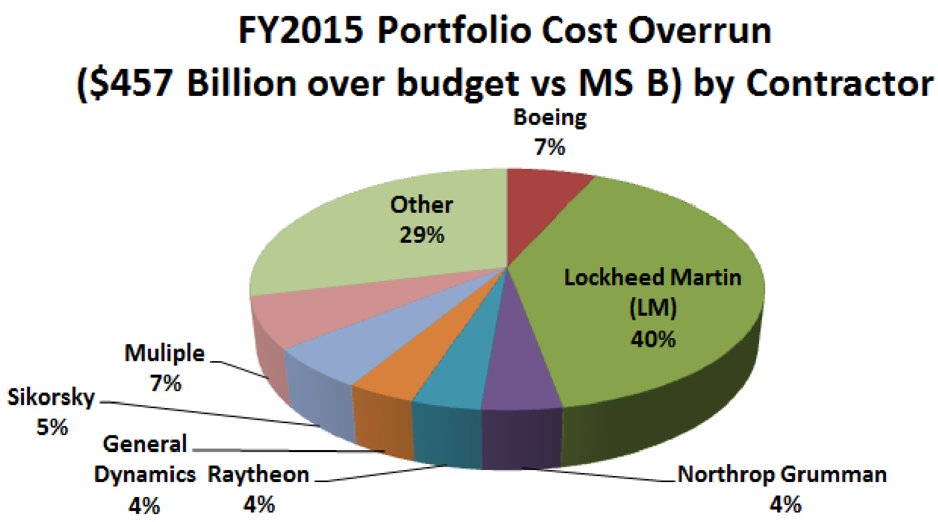


Exhibit 5-10: FY2015 Portfolio: Cost overrun by contractor

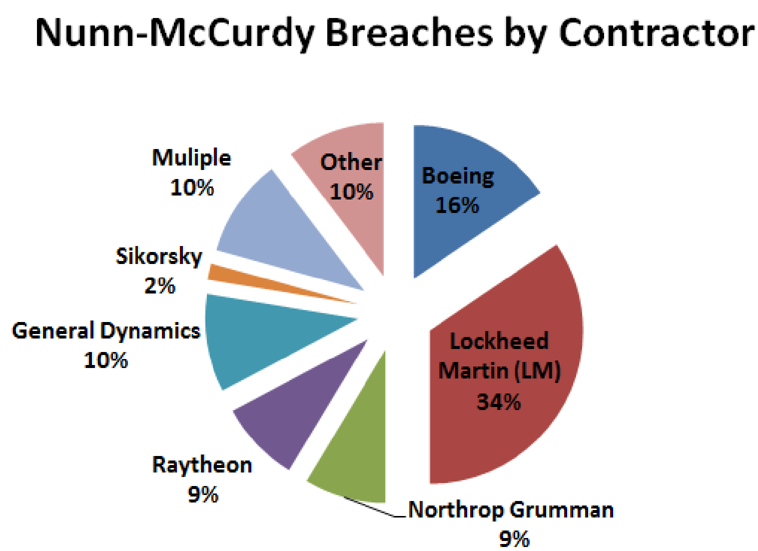


Exhibit 5-11: Nunn-McCurdy Breaches by Contractor (in FY2015 Portfolio of programs).

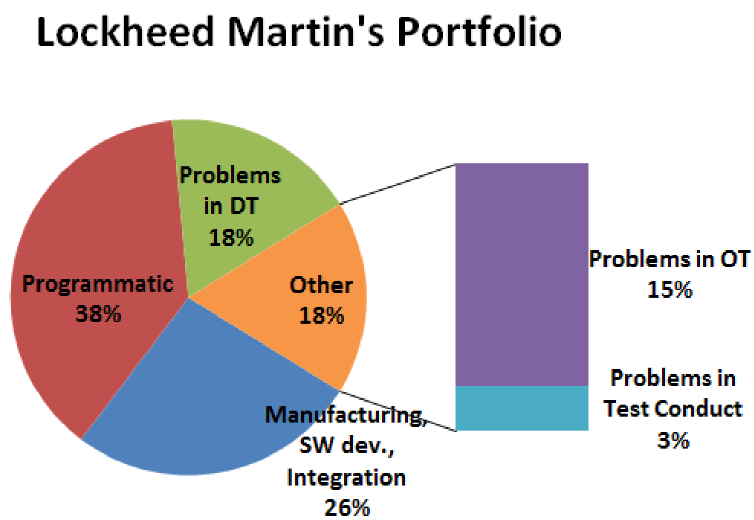


Exhibit 5-12: Lockheed Martin's Causes for Delays (in FY2015 Portfolio)

The following graph summarizes the causes by contractor. Programmatic is still the highest for Boeing, LM, Northrop, Raytheon, and General Dynamics)

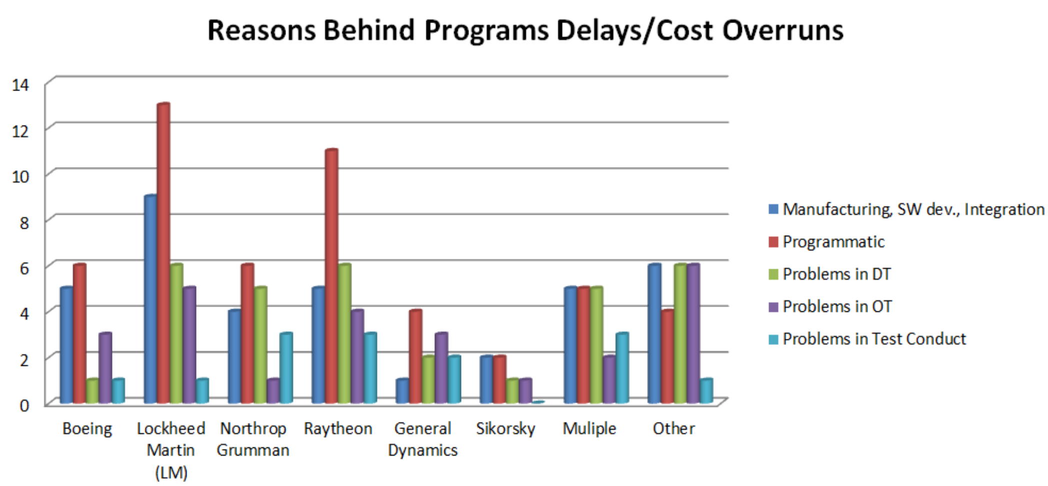


Exhibit 5-13: Programs Delay Reasons by Contractor (in FY2015 Portfolio)

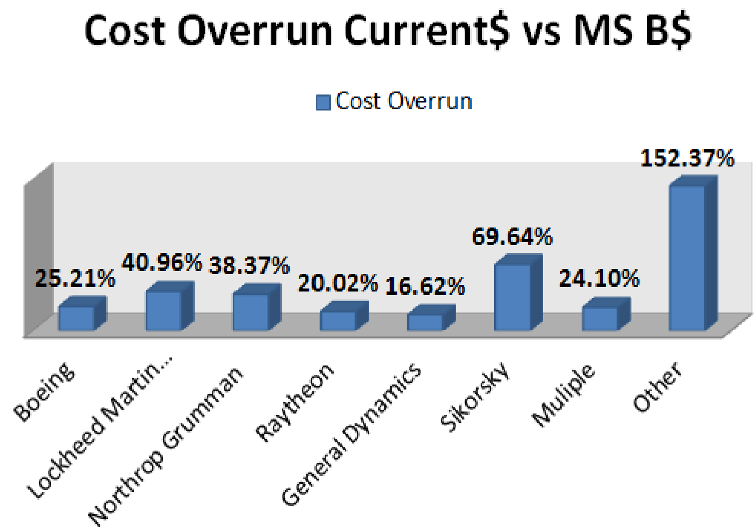


Exhibit 5-14: Cost overruns by contractor

5.2 Immature Technologies

In 2001, GAO testified that a part of the strategy - entering into engineering and manufacturing development with low technical risk—would not be achieved because technologies critical to meeting the program's cost and requirement objectives were at low levels of technical maturity. Technology Readiness Levels (TRL) should be used to assess the maturity of technology and would reveal whether a gap existed between the technology's maturity and the maturity demanded for successful inclusion in the intended product. Readiness levels should have been measured along a scale of one to nine, starting with studies of the basic concept, proceeding with laboratory demonstrations, and ending with technology that has proven itself on the intended product. The Air Force Research Laboratory considers TRL 7 an acceptable risk for starting the engineering and manufacturing development phase. F-35's readiness in 2001 is shown in **Table 13.**

		Critical Technologies Readiness Level (TRL)	
	Critical Technologies	**Description**	**(TRL7-Acceptable Risk*)**
1.	**Prognostics and health management**	Involves the ability to detect and isolate the cause of aircraft problems and then predict when maintenance activity will have to occur on systems with pending failures. Life-cycle cost savings are dependent on prognostics and health management through improved sortie generation rate, reduced logistics and manpower requirements, and more efficient inventory control.	**TRL6**
2.	**Integrated flight propulsion control**	Includes integration of propulsion, vehicle management system, and other subsystems as they affect aircraft stability, control, and flying qualities (especially short take-off and vertical landing). Aircraft improvements are to reduce pilot workload and increase flight safety.	**TRL4**
3.	**Subsystems**	Includes areas of electrical power, electrical wiring, environmental control systems, fire protection, fuel systems, hydraulics, landing gear systems, mechanisms, and secondary power. Important for reducing aircraft weight, decreasing maintenance cost, and improving reliability.	**TRL4**
4.	**Integrated support systems**	Involves designing an integrated support concept that includes an aircraft with supportable stealth characteristics and improved logistics and maintenance functions. Life-cycle cost savings are expected from improved low observable maintenance techniques and streamlined logistics and inventory systems.	**TRL5**
5.	**Integrated core processor**	Includes the ability to use commercial-based processors in an open architecture design to provide processing capability for radar, information management, communications, etc. Use of commercial processors reduces development and production costs and an open architecture design reduces future development and upgrade costs.	**TRL5**
6.	**Radar**	Includes advanced integration of communication, navigation, and identification functions and electronic warfare functions through improved apertures, antennas, modules, radomes, etc. Important for reducing avionics cost and weight, and decreasing maintenance cost through improved reliability.	**TRL5**
7.	**Manufacturing**	Involves lean, automated, highly efficient aircraft fabrication and assembly techniques. Manufacturing costs should be less through improved flow time, lower manpower requirements, and reduced tooling cost.	**TRL4**
8.	**Mission systems integration**	Involves decreasing pilot workload by providing information for targeting, situational awareness, and survivability through fusion of radar, electronic warfare, and communication, navigation, and identification data. Improvements are achieved through highly integrated concept of shared and managed resources, which reduces production costs, aircraft weight, and volume requirements, in addition to improved reliability.	**TRL6**

Table 14: Eight Critical Technologies without "acceptable maturity levels" TRL<7) in early 2001.
*The Air Force Research Laboratory considers Technologies Readiness Level 7 (TRL7) to be an acceptable risk for entry into engineering and manufacturing development phase (GAO-02-39 Joint Strike Fighter Acquisition).

However, at the time the contract was awarded in 2001, only two of the JSF's eight critical technologies were at TRL6 and three were approaching maturity. Yet, three technologies (mission systems integration, prognostics and health management, and manufacturing technologies) were immature despite being past the design review. Immature technologies raised risks. The JSF Program Office tracked 23 program level risks – 3 were low risks, 19 were moderate, and 1 was high, which related to aircraft weight. Therefore, GAO recommended that DOD ensures that critical technologies mature before proceeding into engineering and manufacturing to improve the likelihood of meeting program expectations or to take additional actions if the DOD chose to accept the risk of immature technologies. As indicated in previous GAO reports from the late 1990s, using unproven technologies usually causes significant delays and a high level of risk[125].

These immaturities were slow to be corrected. For instance, the JSF program's production processes were not mature until 2011, as only about 12% of its critical manufacturing processes were in statistical control (as required by DOD policy). The delays in drawings release and supplier problems resulted in late part deliveries, and contributed to inefficient manufacturing processes, which were not fully corrected until 2010. The JSF designs were slow to be fully proven and tested. Flight testing, begun in late 2006, and was only about 2% completed as of November 2008. A fully integrated aircraft was not expected to enter flight testing until 2012, subject to risks of design and production changes and retrofits of the completed aircraft (**GAO-11-233SP**).

5.3 Concurrent vs. Evolutionary and Knowledge Based Strategies

Both F-35 and F-22 programs used heavily the concurrent strategy, see Sections 3.5 and 4.6. Building an airplane while it was still being designed and tested is referred to as *concurrency*. *"Effectively, the concurrency strategy moved the program forward in a* *loop: build a plane, fly a plane, find a flaw, design a fix, and retrofit the plane, rinse, repeat."*[126]

Pentagon testing experts and Congressional auditors warned as the program got under way, that it would be wiser to "fly before you buy." They cautioned that some of the new technologies were not ready and that years of flight tests would find flaws that the simulations had not anticipated. Lockheed and the joint Air Force and Navy offices that ran the program countered that the sooner they started building a sizable number of planes, the sooner they could realize economies of scale that would lower the price of each plane, even if some needed updating. While most military programs start production before all the testing is done, the Pentagon started production of the F-35s in 2007 before flight tests even began.[127]

The concurrent strategy does have its advantage. Recall that due to the significant technical challenges and technical / organizational complexity, such a program typically require multiple iterations to resolve all the glitches. Simultaneous development and production may cost more in the development due to revisions, rework and waste, etc. But it should be faster and cheaper because manufacturing is done in the same time as design and development. Thus it can save time and also ramp up production faster! This is consistent to our MDAPs statistical study where we found cost overrun is not strongly correlated with schedule delays.

However, the concurrency strategy that made production commitments before system development and testing were completed, increased the risk of cost overruns due to design changes and manufacturing inefficiencies. Nevertheless, DOD planned to bear the financial risk of concurrently developing and producing the JSF on a cost reimbursement basis with the prime contractor, until the design and manufacturing processes were mature. Mr. Harrison, the analyst at the budget center, said the willingness to "roll the dice" (the concurrency strategy) reflected the peculiar incentives at the Pentagon, where rushing into production created jobs and locked in political support, even if the program drifed into trouble. Lockheed and its suppliers on the F-35 employ 35,000 workers, with some in nearly every Congressional district. "*The military services want to get the planes as quickly as possible*," Mr. Harrison said. "*The defense industry wants to start producing as quickly as possible. But it's not in the best interest of taxpayers, and it ends up catching up with you*." **(3 NYT)**

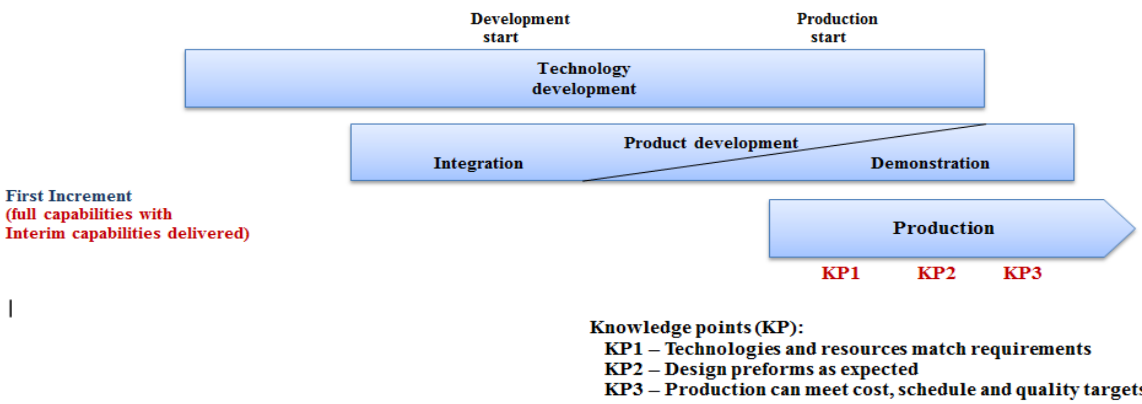


Exhibit 5-15: The Concurrent Strategy

In fact, Lockheed stated that as of 2009, the F-22 program supported a total of 8,800 direct jobs at Lockheed's Marietta, GA, and Fort Worth, TX, locations, and at Boeing and Pratt & Whitney. Lockheed estimated, on the basis of purchase order receipts, that the F-22 program supported an additional 16,200 supplier-firm jobs in 44 states around the country. Lockheed combined these two figures to estimate that the F-22 supported a total of about 25,000 direct jobs. Using a multiplier of 2.8 to estimate jobs elsewhere in the economy that were indirectly supported by these 25,000 jobs, Lockheed estimated that an additional 70,000 jobs were indirectly supported by the F-22 program. Lockheed combined the figures of 25,000 and 70,000 to estimate that a total of 95,000 jobs were supported either directly or indirectly by the F-22 program. A map provided by Lockheed shows roughly 25,800 direct F-22-related jobs in 44 states. According to the map, states with more than 1,000 direct F-22-related jobs included California.

This approach of JSF was in sharp contrast to the best practice of an **evolutionary, knowledge-based** (E&KB) approach, where one must ensure that appropriate technology, design, and manufacturing knowledge are captured at key milestones before committing to increased investments. It is an incremental and evolutionary approach aiming to deliver increasingly better performance over time as funding and technologies permit. Past programs showed that when programs demonstrate a high level of knowledge before making significant commitments, they are able to deliver products within identified resources.[128] **Exhibit 5-15** shows a comparison between the Evolutionary, Knowledge-Based Acquisition Process (E&KB) process and JSF's concurrency approach.

E&KB essentially breaks down a large and high risk project into many smaller parts, each with more achievable and less risky (more incremental) targets with much less scope of work. Each part is managed as a separate project with its own budget and contracts (reduced risk enables fixed price contracts). Each part should be scrutinized and closely supervised by government project management offices. The award of the next project depends on success and knowledge accumulation of previous ones.

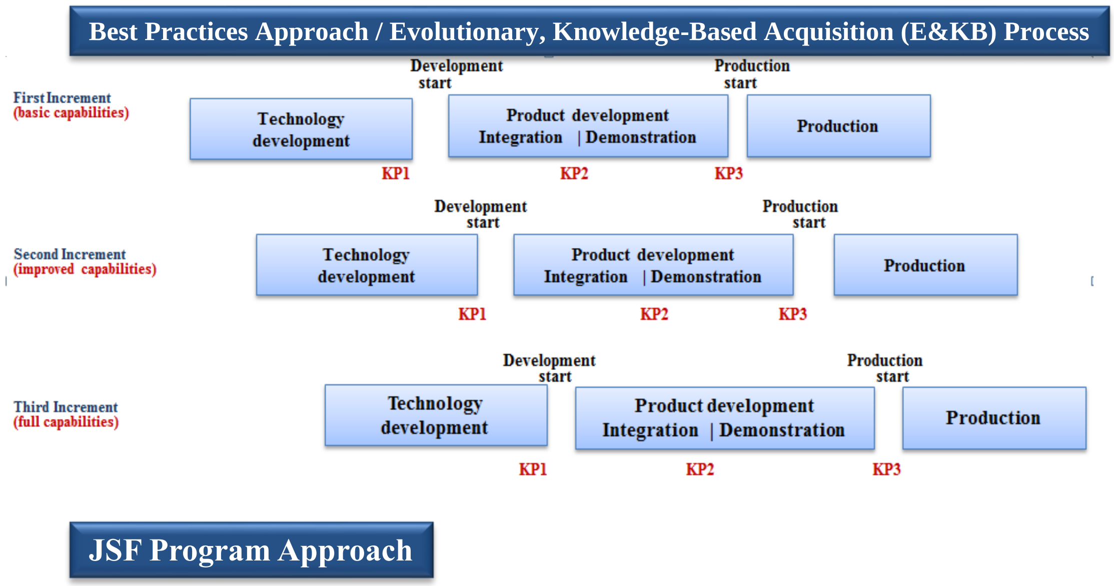


Exhibit 5-16 Evolutionary, Knowledge-Based Acquisition Process vs. JSF Acquisition Approach (GAO-05-271)

5.4 Contracting

For R&D programs, a fixed price contract may not work due to iterations and significant technical challenges. Also, firm-fixed-price contracting may not result in fixed prices in the end because those contracts can be modified to change content as needed. On the other hand, a pure time / material (as in consulting) encourage delay and cost overrun.

The cost plus contract provides for payment of allowable incurred costs, to the extent prescribed in the contract. They are used when uncertainties involved in contract performance do not permit costs to be estimated with sufficient accuracy to use any type of fixed price contract and place greater cost risk on the buyer—in this case, DOD. In the case of the JSF, a fixed price contract will not be possible until late in the development program.

The contract type determines the risk shared between the government and the contractor. One extreme is the "cost plus" contract (e.g., Cost Plus Award Fee = CPAF) **(Exhibit 5-16)**. This type of contract pays actual costs plus an award fee that is usually determined as some percentage of a cost estimate. The government additionally compensates all legally allowable costs incurred by the contractor in fulfilling the project. The cost plus contracts have the significant drawback of providing no incentive for cost reduction, which results in a well-known tendency to cost overrun. The opposite extreme is the "fixed price" contract (Firm Fixed Price = FFP). Here the contractor agrees to fulfill the project for a fixed dollar price, which, once negotiated, will not be readjusted to reflect actual cost incurred. With every dollar of cost saved ending up a dollar of extra profit, a strong incentive is created to reduce project cost. The disadvantage of FFP is that the firm, bearing all the risks, must be compensated by a fee representing on average a high nominal profit rate. (Source: Office of the Undersecretary of Defense for Acquisition acq.osd.mil 2001)

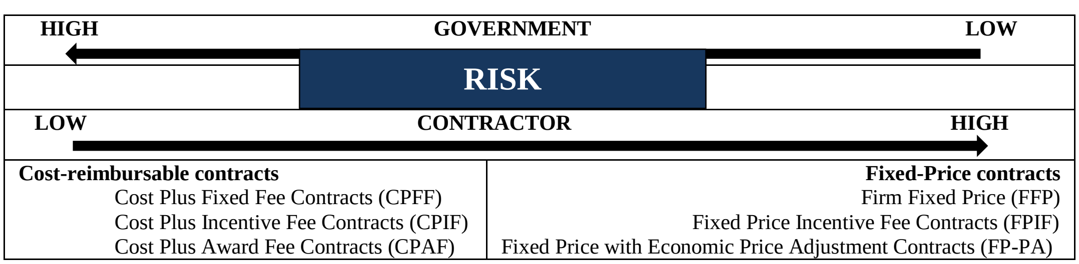


Exhibit 5-17: **Firm-Fixed-Price versus Cost-Reimbursable Contracts** (Source: http://www.acq.osd.mil/dpap/cpf/docs/contract_pricing_finance_guide/vol4_ch1.pdf 2001)

Under the cost plus contracts, the countless setbacks and significant cost overrun have put a significant burden on the government. In December of 2011, Reuters reported that Senators McCain and Levin expressed discontent with previous “cost-plus” contracts that paid Lockheed’s costs for producing the aircraft plus a profit margin on top of that. They believed the contracts had enabled the cost of the F-35 program, the Pentagon’s most expensive procurement program, to balloon over the years.

> *“We take umbrage at the idea that they would proceed on Lot 5 while we are negotiating whether or not there should be a prohibition on a cost-plus contract on Lot 5. So what we did is we said no cost-plus starting on Lot 6.”* – Senator Carl Levin (2011)

Future Pentagon purchases of the F-35 Joint Strike Fighter from Lockheed Martin had to be based on **fixed-price contracts** under a defense authorization measure approved on December 12, 2011 by a joint congressional panel. The provision, part of the National Defense Authorization Act, **would require fixed-price** contracts beginning with the sixth low-rate production batch of fighters from Lockheed Martin. Lawmakers inserted the fixed-price language into the bill after learning about the Lot 5 contract, angered that the decision had been taken even as the Senate was debating whether or not to require the deal to be a fixed-cost contract. Senator Carl Levin, Democratic chairman of the Senate Armed Services Committee, said he and the panel’s top Republican, Senator John McCain, were upset that the Pentagon had acted, even though it knew lawmakers were looking at the contract language. McCain criticized the Pentagon’s acquisition practices:

> *“One would assume that a fixed-cost contract means that it wouldn't allow any additional cost to the taxpayers,” he said. “Not true anymore. Now it has to be called a firm fixed cost contract. And maybe next year it'll be a firm fixed cost*

> *maybe-this-time-we-really-mean-it ... contract by golly. I mean it's insane, it's become insane."*
> – Senator John McCain (2011)

"Most of the risk on this program when we signed this contract in early 2001 was on the government squarely." "We pay Lockheed Martin whatever it costs them to do a particular task. And if they fail at that task, then we pay them to fix it. And they don't lose anything." Lt. Gen. Bogdan explained that, since taking office, he has made burden-shifting a priority. **[16]**

> *"Beginning with more recent batches of F-35s, Lockheed Martin will cover increasingly larger shares of cost overruns as well as a percentage of "known aircraft retrofit requirements" – that is, the cost to fix flaws discovered on planes that have already come off the assembly line."*
> – Lt. Gen. Christopher Bogdan, Executive Officer of the F-35 program.[129]

Contract Structure as of 2014: On December 12, 2011 a new defense authorization measure was approved by a joint congressional panel. Future Pentagon purchases of the F-35 Joint Strike Fighter had to be based on **fixed-price contracts.[130]** (Please see additional details in 9.4 Contract Type Issues and **Exhibit 5-18**).

No: CR-054-14 March 25, 2014 CONTRACTS (N00019-14-C-0002)

NAVY

Lockheed Martin Corp., Fort Worth, Texas, is being awarded a $698,032,385 **fixed-price-incentive, firm target,** advanced acquisition contract to procure long lead parts, materials and components in support of 57 Low Rate Initial Production Lot IX F-35 Lightning II Joint Strike Fighter (JSF) aircraft, including: 26 F-35A Conventional Takeoff and Landing (CTOL) aircraft for the Air Force; six F-35B Short Takeoff Vertical Landing (STOVL) aircraft for the Marine Corps; two F-35C Carrier Variant aircraft for the Navy; six F-35A CTOL aircraft for the government of Norway; one F-35A CTOL for the government of Italy; seven F-35A CTOL aircraft for the government of Israel; two CTOL aircraft for the government of Japan; six F-35B STOVL for the United Kingdom, and one F-35B STOVL aircraft for the government of Italy. Work will be performed in Fort Worth, Texas, and is expected to be completed in May 2015.

Exhibit 5-18: A fragment of one of the contracts, awarded in 2014.
(Source: http://www.defense.gov/Contracts/Contract.aspx?ContractID=5143)

Thus incentive contracts (cost-plus-incentive-fee and fixed-price-incentive) may be a good choice for contracts between the client and contractor under the condition of close oversight by the former and open book by the latter. Each situation depends on risk, cost knowledge, uncertainty, and a number of other factors.

5.5 Game Theory Interpretation [131]

To interpret the events in the F-22 and F-35 programs from a game theory perspective, we first take the perspective of the taxpayer whose best interest is to complete these programs on time and on budget and achieve the desired quality.

5.5.1 The Program Perspective

These programs are risky and ambitious with substantial technological challenges, as well as organizational and supply chain risks. Clearly, for a large and complex project with immature technologies, the evolutionary – knowledge based approach with extensive owner oversight and a fixed price contract for production is a better choice than a cost-plus long-term contract with soft due-dates and no oversight at all. However, a firm fixed-price contract may not work for the EMD part of a project with significant technical risks. Because the technology is not mature or even mature but for complex projects, errors and iterations are likely to occur. The concurrent strategy that blurs the edge between EMD and production can be deadly because it enforces a cost plus contract not only to high risk EMD but also low risk production.

More specifically, establishing a more realistic and affordable objective first, do not go too far and be too ambitious! Breaking a large and risk project into many smaller pieces so each of them is less risky, and easier to achieve (to estimate cost and time as well). Each piece is treated as a distinct acquisition project with its own contractors, contracts, and business case (return on investment). This approach ensures attainment and use of demonstrated product knowledge before making future investments for each product increment.

5.5.2 The Contractor’s Perspective

The game is played between the world largest defense contractors and the world’s large defense customer (US government) under the operating environment of frequent (annual) and significant policy risks, and technically challenging, immature, at the far limit of the technology, ambitious projects.

It is in the contractors’ best interest to kill competition though mergers and acquisition (strategically buy out key competitors and suppliers), and to be politically correct by spreading jobs to all states early in the program development to secure support and so making the program politically impossible to kill. It is also in the contractor’s best interest to shift all risks (technical, organizational, project management and supply chain) in both the development and production to the client. The concurrent strategy is one way to achieve these goals. Under this strategy, production becomes equally risky as development, and thus is entitled to be governed by a cost plus contract (if the production begins only after all the development work and testing are done, then production becomes much less risky and thus should be governed by a fixed price contract). The strategy starts production well before development and testing are completed and so ties in early investment for production and jobs, making it hard to kill despite numerous setbacks.

The concurrent strategy and the cost plus contract also induce risk-seeking and aggressive decisions in both development and production, leading to a higher chance of delay and cost overrun. This is true because at development, contractors faces options and tough choices such as trade-off in time, cost, technological capability and risk. The cost plus contract motivate them to take risk and choose more expensive (complex and exquisite) solutions that take longer time than cheap (simple and sturdy) solutions that can be done quickly, because they are free to try with all costs paid (they are free of responsibility for failures and glitches) and secure support politically. That is why, F-35 is so exquisite (cost so much, take so long, and only work under restrict conditions). Clearly, some of these strategies (spreading work, concurrency) may reduce operational efficiency and increase cost. But these political and market power considerations are more important than getting the job done fast and well. The concurrency strategy is the root (cost plus contract even for production is a consequence) can really hurt the tax-payers.

Another issue created by the concurrent strategy and the cost plus contract is about governing the supply chain. If suppliers cause problems and delays, who is responsible? What motivates the main contractor to regulate suppliers' behaviors? By the cost plus contract, the main contractor may not be really responsible; government eventually pays the bill. Even if the main contractor works hard, if the suppliers do not care, the program will not work. This happened quite a few times in F-22 and F-35 development. Many questions and complex issues remain to be solved, such as who supervises suppliers' work and progress, the main contractor or the client? If a supplier causes a delay, does the main contractor have incentive to catch up? How about a foreign supplier? Should the main contractor supervise the foreign supplier directly or has to go through the foreign government to supervise the supplier?

5.5.3 Explanation of the Events

Both F-22 and F-35 programs experienced the same project management practice, that is, cost plus contracts where the contractors assumed the total responsibility without oversight from the government and with a soft due date. With the significant technical challenges and organizational complexity, the concurrent strategy, the two programs ended up with the same outcome: significant delay and cost overrun.

Our event analyses show many technical issues, e.g., repeated errors such as F-35, engine blades, lift fan; reduce functionality to save weight (F-35); Many project management and supply chain issues (see Sections 3.5 and 4.6). In response, many governmental issues such as, funding stability issues, scope changes, reduce quantities, etc.

The concurrent strategy between development and production in both programs led to,

- Cost plus contract even on production (also early investment), and many unexpected changes, rework, and waste in both development and production.
- Production typically has less risk than development if the development is well done and tested, so we should use fixed price contract. But in concurrency, production also bears high risk due to frequent development changes.
- Concurrency in both programs: initial low rate production quantity far exceeded E&KB best practice even after E&KB becomes the DoD’s acquisition policy (since 2003).

To be fair, both F22 and F35 programs achieved most of the targeted requirements as of today. However, both programs suffered disastrous project performance in cost overrun and schedule. The program management disaster compromised the technical success because after such a long time of delay (especially for F35), their technology is more or less obsolete. Plus, the programs dried up the government funds (reduce DoD's buying power) and so it cannot support other programs.

5.6 Recommendations

The DOD's system environment is overly complex and error prone and is characterized by (1) little standardization across the department, (2) multiple systems performing the same tasks. Ineffective portfolio governance, due to changes in leadership and policies: DOD has numerous processes, organizations, and decision makers to oversee weapon system investments that operate in stove-pipes, not as an integrated whole. The requirements and acquisition processes also focus on individual programs rather than assessing investments collectively, as best practices recommend.

"A key part of improving a system is objectively measuring its performance and the effects of policies, processes, and inputs on the outcomes of the system. Without this, we cannot tell where we have problems, what is working (or not), and whether management changes are making things better (or worse). In the case of defense acquisition, the primary outcome is the value of operational capabilities delivered in time for our warfighters to address threats".

DOD 2015 report [59]

This issue is not new and it was prominent in the Packard Commission's 1986 report to the President on the top problems with the military procurement. The reform findings are aligned with our findings and can be summarized as:

- Program schedule and cost growth;
- Waste due to the cancellations and poor performance and
- Real and perceived abuses[132].

In addition to this guidance, the DoD Strategic Management Plan for fiscal years 2014-2015 calls for improved capital budgeting management[133]

GAO states that the best practices recommend assessing investments collectively from an enterprise-wide perspective and integrating requirements, acquisition, and budget information, but several factors inhibit DOD's ability to do so and lists below problems:

Table 15: List of Current Issues in DoD Process (GAO)

Fragmented governance	DOD has numerous processes, organizations, and decision makers to oversee weapon system investments that operate in stove-pipes, not as an integrated whole. The requirements and acquisition processes also focus on individual programs rather than assessing investments collectively, as best practices recommend.
Lack of sustained leadership and policy	DOD stopped implementing its portfolio management efforts and policy, in part due to changes in leadership. DOD's policy is also dated, does not fully reflect best practices, and does not identify an office with sufficient authority to implement it.
Perceived lack of decision-making authority	Enterprise-level involvement is a key for optimizing investments across DOD because the military services prioritize needs and optimize investments within their services rather than across the military. Title 10, which gives the services responsibility over equipping the force, does not preclude enterprise-level influence over service investment decisions, but some DOD officials said it limits their influence.

The government also rolled out program management improvement strategies to better control risks, optimize the supply base and better align contractor incentives, in particular, problems with testing and the concurrency issues.

GAO is raising a concern about the substantial concurrency, or overlap, of JSF development, test, and production activities and the heightened risk it poses to achieving good program outcomes. Because of the risk created by the extreme overlap of development and production, the program office plans to place initial production orders on a cost reimbursement contract, placing a higher cost risk burden on the government than is normal. These contracts provide for payment of allowable incurred costs, to the extent prescribed in the contract. They are used when uncertainties involved in contract performance do not permit costs to be estimated with sufficient accuracy to use any type of fixed price contract and place greater cost risk on the buyer—in this case, DOD. In the case of the JSF, a fixed price contract will not be possible until late in the development program. The concurrency strategy is a shelter to protect the contractors from nearly all risks (controllable and uncontrollable), is one of the root causes of the disaster.

Misalignment of JSF's acquisition strategy with DOD's (revised in 2003) acquisition policy to support an evolutionary, knowledge-based approach for acquiring major weapon systems based on best practices, does not fully follow the intent of this policy. Instead, it strives to achieve the ultimate JSF capability within a single product development increment. While the acquisition strategy calls for delivering a small number of aircraft with limited capabilities, the program has committed to deliver the full capability by the end of system development and demonstration in 2013 within an established cost and schedule, contrary to an evolutionary approach.

JSF's failure to adequately match requirements and resources has already resulted in increases in cost, schedule, and performance estimates, and a reduction in DOD's buying power. The program should have been accompanied by an acquisition strategy that adopts an evolutionary approach to product development—one that enables knowledge-based investment decisions to maximize remaining program dollars. While the customers may not receive the ultimate capability initially, an evolutionary approach provides a useful product sooner and in sufficient quantities to start replacing the rapidly aging legacy equipment. May 2003, DOD has revised its acquisition policy to support an evolutionary, knowledge-based approach for acquiring major weapon systems based on best practices.

The new DOD acquisition policy to support an evolutionary, knowledge-based approach is expected to benefit the nation and taxpayers by reducing the money spent on waste and the associated labor. But it may not benefit the contractors, congressional representatives (who only care about jobs in their districts), and services who want really ambitious projects at the far edge of the technology. This approach may be implemented in certain areas of defense projects with plenty of competing contractors. But for Navy and Airforce, this approach may not be feasible due to a lack of competition – there is only a few contractors and critical suppliers left. In addition, just breaking down a big job into smaller ones may not work, for instance, the enhancement and modernization program of F-22 has doubled its cost and delayed by 7 years.

5.6.1 Summary of Results and Contributions

The DoD acquisition is vital to the United States of America and her allies to stay technologically superior over potential threats. This research validates the importance and need for program management, supply chain management and systems engineering alignment which contain the potential to improve the complex and dynamic world we live in today.

This thesis presents our finding on the factors influencing MDAPs schedule delays, cost overruns and supply chain risks. We also analyze:

- DoD's new product development challenges;
- Competitive advantage and organizational performance and
- The effect of supply chain best practices.

We are looking into government management and oversight, the role of contractors and lead military services, levels of competition, and contract structures. We identify cost overruns and schedule delays, realism of baselines, supply chain risks, similarity and differences between the F-22 and F-35 programs, such as: weight problems, engine problems, untested technology, composite materials, unconventional supply chain, avionics cost growth, contract type impact, reserve analysis, and lessons learned.

This research advances the understanding of project and supply chain management in the areas of government acquisitions with contributions on root cause analysis of two major programs, statistical study of a portfolio of major defense acquisition programs, a game theory perspective to explain the adversary implications of some current practices and the advantages of best practice (advocated by GAO), and finally a commentary and recommendation on government acquisition policies / program management practices.

Past studies on this topic were focused on a critical but, narrow aspect of the problem, such as: technical maturity, contract type and competition. We are looking at:

- Accuracy of baseline: program cost and schedule estimates;
- The performance by contractors and military services;
- What factors might contribute to or be correlated with the observed cost overruns in the execution of MDAPs.

This research will advance the understanding of DoD program and portfolio management with contributions to issues evaluation, literature review, a validated system dynamics model with analysis of the results, and recommendation for the future areas of studies.

Appendix I: The Program Management Improvement and Accountability Act of 2015 (PMIAA)

Nov. 30th 2016: The U.S. House of Representatives approved S.1550, **the Program Management Improvement and Accountability Act of 2015 (PMIAA)** which will enhance accountability and best practices in project and program management throughout the federal government.
The Project Management Institute (PMI) strongly supports this important legislation reforming federal program management policy in four important ways: 1. Creating a formal job series and career path for program managers in the federal government. 2. Developing a standards-based program management policy across the federal government. 3. Recognizing the essential role of executive sponsorship and engagement by designating a senior executive in federal agencies to be responsible for program management policy and strategy. 4. Sharing knowledge of successful approaches to program management through an interagency council on program management.
“This critical legislation will help maximize efficiency within the U.S. federal government, thereby generating more successful program outcomes and increasing the value that Americans receive for their tax dollars,” said PMI President and Chief Executive Officer Mark A. Langley. “We are pleased this landmark bill has passed the House of Representatives and the Senate, and we would like to thank Rep. Todd Young from Indiana, Rep. Gerry Connolly from Virginia, Chairman Jason Chaffetz from Utah, Ranking Member Elijah Cummings from Maryland, for their leadership in advancing this bipartisan, legislation.” The legislation will return to the United States Senate, where it was previously approved unanimously, to be re-passed as a final piece of legislation. “We encourage the Senate to accept the changes made by the House and send this bill to President Barack Obama’s desk as soon as possible.” Langley said. “The PMIAA is an important step to improving the government’s ability to effectively manage its portfolio of projects and programs and will help ensure program managers are able to serve as stewards of taxpayer dollars.” The reforms outlined in the PMIAA are consistent with PMI member input and research that demonstrates that organizations that invest in program management talent and standards improve outcomes, accountability and efficiency. The findings demonstrated by PMI’s Pulse of the Profession® report also indicate that standardized approaches, engaged executive sponsors and certified professionals are fundamental building blocks to all organizations achieving their highest levels of performance. Improving program management leads to benefits such as increased collaboration, improved decision making and reduced risk.

PMI's report also uncovered that only 64% of government strategic initiatives ever meet their goals and business intent — and that government entities waste $101 million for every $1 billion spent on project and programs. The research also shows that these best practices result in improved efficiency and less money being wasted. Most importantly, organizations see more projects delivering expected value to stakeholders on time and within budget.

https://www.pmi.org/about/press-media/press-releases/house-of-representatives

Appendix II: F-22 Raptor Timeline with additional explanations and references

#	Date	Event / Issue	Cause / SC Risks	Dura-tion	Qty.	Result /Effect	Category	Explanation
1.	**1980**	**F-22 Program was initiated** **Objective**: to develop a highly capable successor to the F-15 and Navy's F-14 fighter. **Initial Estimates**	Aggressive timeline, Untested technologies	Initial estimated duration: 9 Years	750	Delays and cost overruns	Government	**F-22 program was initiated** In the early 1980s, the Air Force began to develop a stealth aircraft called the Advanced Tactical Fighter (ATF), which was then expected to enter service in the 1990s as the replacement for the F-15. The ATF program was initiated in response to advances in Soviet combat aircraft that were expected to occur in the 1990s. A naval variant of the ATF that could operate from aircraft carriers—the NATF—was initiated as the replacement for the Navy's F-14 fighter, but the NATF program was subsequently terminated. (Getler, 2013)
2.	**Oct. 1986**	**Milestone I** (A) **approval** Two Competitive prototypes to be built by 2 teams of contractors. Air Force awarded each team a $691-million ***fixed-price contract*** to build two prototypes.	Aggressive timeline, Untested technologies, Misalignment with DoD directive 5000.1 regulation Uncompleted (MSA) Materiel Solution Analysis (or Phase 0-Concept Exploration Phase in 1980s (appendix 4))	Initial estimated duration: 9 Years	750	Delays and cost overruns	Government	**Two Competitive prototypes to be built by 2 teams of contractors:** ***Team 1***: Lockheed (LM) /Boeing/ General Dynamics ***Team 2***: Northrop / McDonnell Douglas Air Force awarded each team a $691-million ***fixed-price contract*** to build two prototypes. Lockheed's prototype was designated the YF-22, while Northrop's was designated the YF-23. The prototypes were powered by new-design engines. One YF-22 prototype and one YF-23 prototype were powered by Pratt & Whitney's F119 engine, while the other YF-22 prototype and YF-23 prototype were powered by General Electric's F120 engine. (Getler, 2009)
3.	**1989 –**	***Delays***	Aggressive	2 month		Delays	Governmen	*The Air Force announced in*

	early 1991	***(Technical challenges)***	timeline, Untested technologies, misalignment with regulations, High degree of concurrency, unmitigated SC risks (Overcapacity in LM production facilities, unstable supply base), problems with portfolio management	delay		and cost overruns	t, Manageme nt & Technical	*1989 that the full scale development phase would be delayed to allow more time for development of* ***engines and avionics.*** Each contractor team reportedly spent over $1 billion in company funds to develop their competing prototypes, which were flight-tested and evaluated in late 1990[1]. *Gertler, J (2013). "Air Force F-22 Fighter Program" Retrieved from:* ***https://fas.org/sgp/crs/weapons/RL31673.pdf*** **(GAO reports)**
4.	**Aug. 1990**	**First flight (Industry prototype)**	Aggressive timeline, Untested technologies, SC risks	2 month delay	648	Delays and cost overruns	Manageme nt & Technical	First flight of an F-22 industry prototype occurred in August 1990. Each contractor team reportedly spent over $1 billion in company funds to develop their competing prototypes, which were flight-tested and evaluated in late 1990
5.	**Dec. 31 1990**	**F-22 Proposal is submitted**	Lockheed, Boeing & General Dynamics submit F-22 Proposal to USAF					Lockheed/Boeing/General Dynamics submit F-22 Proposal to USAF **http://www.f22-raptor.com/about/chronology.html**
6.	**Jun. 1991**	**Milestone II (B) approval** APB Baseline is set	Aggressive timeline, Untested technologies, misalignment with regulations	Est. 12 years (IOC)	648	Delays and cost overruns	Governmen t	Milestone III (LRIP) is projected to start in Dec. 1999/IOC is planned in Sep. 2003 **Estimated Total cost (TY $M) 99109.0** **PAUC (TY $M) 152.946**
7.	**Aug.2, 1991**	EMD Contract Award	High risk procurement LM is given near total responsibility for design, development, fielding and production, Cost Plus Incentives Contracts (high risk to a buyer)		648	Delays and cost overruns	Governmen t	Original contracts and cost estimates. ***Cost Plus Incentives Contracts*** totaling $11 billion were awarded to LM and P&W (F119 engine) for Engineering and Manufacturing (EMD) of F-22. At that time, the Air Force planned to acquire 648 F-22 operational aircraft at a cost of $86.6 billion
8.	**1992-early 1993**	A number of technical issues are identified by Task Force .	Contract structure, No oversite, Risk management issues, Untested technologies Problems with avionics and software integration; Issues with performance of the F119 engine; Misalignment with regulations.	The first flight date was delayed by **11 months**	64 8	Delays and cost overru ns	Manageme nt & Technical	The compounding of the technical challenges, adverse economic factors, and cost uncertainties, posed a serious risk to the program. The F-22 program was rescheduled in late 1992 for funding and other reasons. Issues with performance of the F119 engine (P/W), other problem areas included low-observable materials and structures, engine durability, and weight and drag management. LRIP was Used to Buy Weapon Systems Prematurely.
9.	**Sept.**	**Bottom-Up**	Major quantity		442	Cost	Governmen	The planned quantity of F-22s

	1993	**Review**	reduction			overruns	t	was reduced to 442 at an estimated cost of $71.6 billion.
10.	**1994 – 1996**	**Technical disasters continue:** Problems with Engine testing (P/W), Stealthiness, low observability, Weight, new materials, aircraft radar, software quality assurance, tools are not available, titanium casting, fuel leaks.	Contract structure (impacts of Cost plus contracts), Risk management, Untested technologies, Concurrent development Issues	First flight delayed by **2 years**	442	Major Cost increase for both Airframe and Engine	Manageme nt & Technical	**Impacts of "Cost +" contract;** The Air Force increased the target cost of the engine development contract by $218 million Uncoordinated software testing, poor management strategy, tools are not available Problem with aircraft weight, issue with titanium and other component materials, which never were used for this purpose, • Design of certain low observable features and applicable manufacturing processes; Early problems with process control and minute but unallowable defects had to be overcome and a second casting supplier qualified to reduce risk. In addition: delamination of longerons, structural weaknesses in aft fuselage, anomalies in brakes, inertial reference system and environmental control system, nagging fuel leaks, problems with engine low pressure turbine blades, high pressure turbine blades, and engine combustors, and problems with excessive engine vibration. (No penalty to LM) **Major Cost increase (about $20 million + additional $110 million for production);** **Engine costs also increased**
11.	**FY1995 - FY1996**	Major Budget increases	Contract structure (impacts of Cost plus contracts), Risk management, Untested technologies	IOC delays	442	Major Budget increases	Manageme nt	**Impacts of "Cost +" contract;** For FY1995, the Administration requested $2.5 billion to continue development of the F-22 ($2,461 million in R&D and $4.6 million in military construction funds). The Administration's FY1996 budget requested $2,150.8 million for the F-22 program ($2,138.7 million in Air Force R&D funding and $12.1 million in military construction funds). **CRS Issue Brief for Congress Christopher Bolkcom (2001)**
12.	**June 1996**	**Joint Estimating Team (JET)** consisting of personnel from the Air Force,	Contract structure (impacts of Cost plus contracts), Risk management, Untested	2 Years delay of the First Flight with integrate d	442	Major Budget increases $1.45 billion over the previous	Governmen t & Manageme nt	The objectives of the JET were to estimate the most probable cost of the F-22 program and to identify realistic initiatives that could be implemented to lower program costs. In January

		the Department of Defense (DoD), and private industry was created	technologies, concurrent development	avionics		estimate Unit cost increase (40%);		1997, the JET estimated the F-22 EMD program would cost $18.688 billion, an increase of about $1.45 billion over the previous Air Force estimate. First flight test of an F-22 equipped with a complete integrated avionics system is not scheduled to begin until September 1999, 2 years after the start of production.
13.	**Feb. 1997**	**Restructuring,** due to delay and unit cost increase (40%)	Significant cost overrun, **Scope reduction (**A branch of the program was cut off**),** Funding differed		**341**	Unit cost increase (40%); Quantity reduction	Management	JET estimated that the **development cost would increase by about $1.45 billion**. Also, JET concluded that F-22 **production cost could grow by about $13 billion (from $48 billion to $61 billion.**
14.	**May 19, 1997**	**The Defense Department's Quadrennial Defense Review (QDR)**			341		Government	(QDR) released on May 19, 1997, recommended a further reduction of quantity **(GAO/NSIAD-97-156)**
15.	**Sept. 1997**	The first flight of a development version	Contract structure (impacts of Cost plus contracts), Risk management	**3.3 month delay (first flight)**	341			The first flight delayed by 3.3 months, till Sept. 1997, causing a problem with flight test data;
16.	**Sept. 1997** **Nov.1997**	**Change to the contract is negotiated** Scope reduction The National Defense Authorization Act (NDAA)/ FY1998 is enacted	Error in a contract, Contract structure (still Cost plus contracts), JET recommended changes had not been included; Risk management		341	Program is re-baselined again	Government	Air Force negotiated changes with the prime contractors to more closely align the **cost-plus-award-fee** contracts with the JET cost estimate and revised schedule. Two-seat configuration has been deferred and the applicable costs deleted from the estimated total cost of the program. Many substantial planned changes recommended by the JET had not been incorporated into the LM's contract, (changes to the avionics estimated to cost $221 million). NDAA imposed cost limitations of $18.688 billion on the F-22 EMD program and $43.4 billion on the production program. The limitation on production cost did not specify a quantity of aircraft to be procured.
17.	**Jan.-June 1998**	**Technical disasters again:** with titanium wing casting, airframe and avionics, leading to cost overruns	SC risk management Program management, Contract structure, Questionable practices: concurrent development, reduction in	Schedule delays (4 month)	341	Delays and cost overruns	Management, Technical	**Worsening trend in the accomplishment of planned work:** January 1998: LM reported that it had not completed planned work valued at $70.9 million. By June 1998, it reported that the value of planned work not accomplished had increased to $111.5 million.

			testing to save time and cost					(GAO/NSIAD-99-55 F-22 Aircraft) **Significant reduction in testing,** Additional technical issues with titanium wing casting, airframe and avionics, leading to cost overruns **Significant reduction in testing to catchup with delays and costs** (GAO/NSIAD-98-67 F-22 Development Program)
18.	**Feb. 1999**	Problems fabricating the wings from composites (Boeing)	Technical risk, supply chain risk management; poor program management;	Schedule delays	339	Cost increase ($22 million)	Manageme nt, Technical	This problem forced Boeing to qualify a second supplier to speed deliveries, thereby exacerbating the cost and schedule problems.
19.	**Aug. 2001**	LRIP is approved			333			The program was granted approval for Low Rate Initial Production (LRIP)
20.	**Sept. 2001**	Additional cost increase.	Poor program mgmt. Disregard to congressional cost cap, Contract structure		333	Delays and cost overruns	Manageme nt	The DoD office of OT&E Operational Test and Evaluation estimated the program cost had grown $8 billion higher than Air Force projections. The Pentagon's Cost Analysis Improvement Group (CAIG) similarly estimated that the production program would be $9 billion over the $37.6 billion congressional cost cap.
21.	**2002**	A machinists' strike + Lack of skills in Marietta facility	Poor program, HR and SCM risk management		333	Delays and cost overruns	Manageme nt	Strike further delayed the delivery of test aircraft. This inability to attract engineers and managers who gain specialized experience during the early phase of development from Burbank to Marietta along with Marietta's lack of a design team capable of meeting the engineering challenges arguably may have been the root of many problems during development.
22.	**June 2003**	The first LRIP F-22 was delivered	Poor program & SCM risk management	2.5 Years late	333		Manageme nt	The first LRIP F-22 was delivered
23.	**2003**	**Modernizatio n and Sustainment of In-Service F-22s starts**			333		Governmen t	The Air Force in 2003 established a program to modernize its in-service F-22s. The program includes upgrades to the aircraft's air-to-ground and intelligence, surveillance and reconnaissance (ISR) capabilities, to be applied in four scheduled increments.
24.	**April 2004**	**Technical disasters again:** Overheating in key Raptor components	Poor program, & SCM risk management		270	Delays and cost overruns	Manageme nt, Technical	In April 2004 it was reported that Air Force testers had encountered unexpected **overheating** in key Raptor components. Software modifications were required to ameliorate the problem, but a long term solution was not immediately apparent. (Amy Klamper, "Pentagon's Stealth Fighter Plagued by Rising Temperatures," *National Journal's Congress Daily,* April 30, 2004)

25.	**Sept. 28 2004**	**Technical issues again:** Problems with **flight control software / the** aircraft was grounded	Poor program, & SCM risk management		276	Delays and cost overruns	Management, Technical	During flight testing on September 28, 2004, an F-22A experienced more "G" forces (gravitational) than designed. The aircraft was grounded, and it was subsequently reported that the problem was caused by flight control software. **David Fulghum, "Questions Abound After F/A-22 Crash," *Aviation Week & Space Technology*, January 3, 2005.**
26.	**Dec. 2004**	**Crash**	Program & SCM risk management		276	Delays and cost overruns	Management, Technical	On December 20, 2004, a Raptor crashed and was destroyed at Nellis AFB. **(Bolkcom, 2008 Report to Congress)**
27.	**Dec. 2005**	Problem with titanium fuselage (101 aircraft are impacted) Oxygen problems are reported	Program, SCM risk management, untested material/technology		277	Delays and cost overruns	Management, Technical	In December 2005 it was discovered that 91 F-22s suffered a "heat treatment anomaly" in a titanium fuselage structure. This figure was later revised to 101 aircraft. **(Bolkcom, 2008 Report to Congress)**
28.	**Dec. 2005**	IOC is achieved	Program & SCM risk management	2 Years late	277		Management	The F-22 achieved Initial Operational Capability (IOC) in December 2005. Total cost (TY $M) 61323.7 PAUC (TY $M) 152.946
29.	**May 2006**	F-22 program would require $100 million to carry out a structural retrofit program for 41 of the existing aircraft**.**	Program & SCM risk management, untested material/technology		179	Delays & Cost overruns ($100 million)	Management	In May 2006 it was reported that the F-22 program would require $100 million to carry out a structural retrofit program for 41 of the existing aircraft, but Air Force officials state that no remedial action is required. However, these faulty titanium forgings will require increased inspections during the Raptor's 8,000 hour lifetimes to avoid catastrophic failures. In April 2008, it was reported that Boeing was suing the titanium forgings supplier for $12 million. **(Bolkcom, 2008 Report to Congress)**
30.	**Aug. 2008**	Issue with intelligence, surveillance and reconnaissance (ISR) capabilities; Restricted communications capability	Program & SCM risk management, design problem, untested material/technology		183	Delays & Cost overruns ($85 million	Management, Technical	Although the F-22 may have effective on-board sensors and the ability to receive additional information from other ISR platforms, it has limited ability to transmit targeting information to other platforms or command and control (C2) assets. This restricted communications capability was intended to make the F-22 more elusive to enemy defenses. $85 Million is needed to accelerate an upgrade that would enable the F-22 to more effectively share information with other aircraft. **(Marcus Weisgerber, "Air Force Loots to Shuffle $85 Million to Accelerate F-22A Mods," *Inside the Air Force.*August 8, 2008.)**

31.	**2010**	Corrosion problem (aluminum-skin panels)	Program & SCM risk management, design problem, untested material/technology		183	Delays & Cost overruns ($228 million	Management, Technical	F-22s were encountering corrosion at unusually high rates, "and the DoD planned to spend $228 million through 2016 to fix the deteriorating aluminum-skin panels." A LM spokesman said "the F-22s experienced corrosion because of 'interaction' with stealth materials used to hide them from enemy radar. LM has developed alternative material that 'eliminated that interaction' and began changing the fleet in early 2010." **"GAO: F-22s Are Corroding, Need Costly Fix,"** ***Bloomberg News*****, December 17, 2010.**
32.	**Nov. 2010**	**Fatal crash of an F-22 in Alaska** (Oxygen problems again) At least 25 "physiological incidents" were recorded from 2005-2012.	Program & SCM risk management, design problem, untested material/technology		183		Management, Technical	At least 25 "physiological incidents" were recorded from 2005-2012. The symptoms: oxygen deprivation or hypoxia, in pilots flying the plane; Symptoms of hypoxia include dizziness, wooziness and, in extreme cases, blackouts.
33.	**FY2010**	The end of F-22 procurement	Technical risk, supply chain risk management; poor program management;		195 **(Final QTY)**	Delays and cost overruns	Government	In the FY2010 budget, the Administration proposed to end F-22 procurement at 187, and Congress approved that termination. 195 (8 test + 187 operational)
34.	**Dec. 2011**	That final aircraft had come off the Lockheed Martin production line in Marietta, GA			195 **(Final QTY)**			That final aircraft had come off the Lockheed Martin production line in Marietta, GA .**"Lockheed Martin Delivers Final F-22 Raptor To Air Force ,"** ***Defense Daily*****, May 3, 2012.**
35.	**May 2012**	**F-22 Modernization Program cost is doubled and full capabilities slipped 7 years** Increment 3.2 B will be managed as **MDAP**	Program & SCM risk management, design problem, untested material/technology	7 years delay		Cost is doubled	Management,	GAO found: "total projected cost of the F-22A modernization program and related reliability and maintainability improvements more than doubled since the program Started–from $5.4 billion to $11.7 billion–and the schedule for delivering full capabilities slipped 7 years, from 2010 to 2017." Causes: (1) Additional requirements, (2) Unexpected problems and delays during testing, and (3) Research, development, testing, and evaluation funding fluctuations" (4) Program accountability and oversight have been hampered by how the modernization program was established, managed, and funded, as the F-22 modernization program

								has not been treated as a major defense acquisition program (MDAP). Beginning with Increment 3.2B, future F-22 modernization programs will be managed as MDAPs.
36.	**July 2013**	**Supercruise wasn't achieved**	Program & SCM risk management, design problem, untested material/technology					The F-22 incorporates a high degree of stealth, as well as Supercruise is the ability to cruise at supersonic speeds without using engine afterburners.

Appendix III: F-35 (JSF) Timeline with additional explanations and references

#	Date	Event / Issue	Cause / SC Risks	Dura-tion	Qty.	Result /Effect	Category	Explanation
1.	**1983-1996**	The JSF program was the result of the merger of many DoD's previous efforts						**JSF program was initiated** What is known today as the F-35 Joint Strike Fighter Program was originally known as the Joint Advanced Strike Technology (JAST) program. A number of those programs failed or were only partially successful.
2.	**Mar. 1996**	**JAST program was renamed to JSF**						In March 1996, the ASTOVL (Advanced Short Take-Off/Vertical Landing) program was merged into JAST, and the combined program was renamed to JSF.
3.	**Nov. 1996**	**Milestone I** (A) **approval:** Boeing and Lockheed Martin, were awarded the contracts of building prototype models, X-32 and X-35, for JSF	High risk (3 variants), Aggressive timeline, Untested technologies, Misalignment with DoD regulation		6038 US & UK	Delays and cost overruns	Government	Two companies, Boeing Aerospace and Lockheed Martin, were awarded the contracts of building prototype models, X-32 and X-35, for JSF in November 1996. Each company would build and fly two full-scale prototypes – one land-based conventional take off (CTOL) version for the Air Force, and one short-takeoff vertical landing (STOVL) aircraft required by the Marines Preliminary planning estimated over 3,000 F-35s for DoD and the UK: 2,036 for the Air Force, 642 for the Marines, 300 for the U.S. Navy, and 60 for the Royal Navy. **("IHS Jane's Defence Insight Report • Air Platforms," June 2013. In 1996)**
4.	**1997-2001**	**Concept Demonstratio**						The Secretary of Defense certified to that the program had successfully completed

		n Phase						the CDP exit criteria and demonstrated sufficient technical maturity to enter SDD. On October 26, 2001, the SDD contracts were awarded to Lockheed and Pratt and Whitney.
5.	**Oct. 2001**	**Milestone II (B) approval:** The Cost Plus contract, worth an estimated **$200 billion was awarded** Original Dev. Est: 34.4 Billon; Avg. Proc. 69 mil	High risk procurement, Aggressive timeline, Untested technologies, Misalignment with DoD regulation, Program & Portfolio management, Contract type	10 years	**~6000** (3000 for US+ FMS)	Delays and cost overruns	Government, Management Technology	An international team led by Lockheed Martin (LM) was awarded the contract to build JSF. The Cost Plus contract, worth an estimated $200 billion, called for construction of as many as 6,000 airplanes—approximately 3,000 for the U.S. military and another 3,000 anticipated in foreign sales An initial 22 aircraft (13 flying test aircraft and eight ground-test aircraft) will be built in the program's system development and demonstration (SDD) phase.
6.	**Nov. 2001**	**Issues:** Organizational, Stakeholders Technical problems	Program management, Stakeholder management, Many stakeholders with conflicting objectives, untested technologies			Delays and cost overruns	Management Technology	Organizationally complex issues are harder than technical challenges, including internal teams, outside suppliers, and multiple customers. Technical: Lift fan, clutch systems and weight, problems
7.	**Dec. 2001**	**Strike** (P/W) + **Technical** problems	Program management, Stakeholder management, untested technologies			Delays and cost overruns	Management Technology	The union, which represents the P/W workers, voted on Dec. 2 to go on strike after rejecting the company's final contract offer. Technical: communications problem JASSM (joint air-to-surface stand-off missile) and possible replacement with JASSM-ER with turbofan engine (new technology)
8.	**Jan. 2002**	**Management & Fanatical issues (LM's net loss of $1bn) Technical disasters:** Weight problem,	Program management, Stakeholder management, untested technologies			Delays and cost overruns	Management Technology	Rolls-Royce is making a change to nozzle and lift fan to make them lighter (untested technologies) **(AW&ST Sept. 24, 2001, p. 52). Kandebo, S. W. (2002). New Nozzle Eyed For Stovl F-35. *Aviation Week & Space Technology, 156*(14), 41** Lockheed Martin reported a net $1.5bn loss for the fourth quarter of 2001 after taking $1.7bn of charges on its telecommunications activities, some of which it plans to sell. The result pushed it into a full-year net loss of $1bn. **Nicoll, A. (2002, Jan 26). Lockheed upbeat despite net loss. *Financial Times*.**
9.	**Mar. 2002**	**Program restructurin**	Program management,		Qty redu	Delays and cost	Government,	Facing budgetary pressures, the DoD considered

		g; SCM Risks: Scope and Schedule changes, Quantity reduction	Stakeholder management, untested technologies		ction by 309 units	overruns	Manageme nt	accelerating the JSF program in order to bring the plane on line faster. The specifics of the Navy proposal called for cutting the number of Marine Corps STOVL JSF jets from 609 to 350 and the number of the carrier version from 480 to 430. According to Loren Thompson, a defense analyst at the Lexington Institute, the Navy and Marine Corps' announcement of their intention to cut the program, issued so soon after the entire JSF program was approved. The cuts would push unit costs up by 5 to 10 percent (approved by Pentagon). (Cato)
10	**Jun. 2002**	**Stakeholder Management issues**	Program management, Stakeholder management Conflicting objectives: (Every country wants more work to be done in their countries for knowledge transfer and jobs)			Delays and cost overruns	Manageme nt	Level II partners consist of Italy and the Netherlands, contributing $1 billion and $800 million, respectively. On June 24, 2002, Italy became the senior Level II partner ("F-35 Joint Strike Fighter (JSF) Lightning II: International Partners," **http://www.globalsecurity.org/military/systems/aircraft/f-35-int.htm).** Italy wants to have its own F-35 final assembly line, which would be in addition to a potential F-35 maintenance and upgrade facility. The Netherlands signed on to the F-35 program on June 17, 2002, after it had conducted a 30-month analysis of potential alternatives.
11	**Jul. 2002**	**Technical problems** **L**ift fan **(**Rolls Royce) and lasers	Program management, Requirements management, Concurrent development, SC Risks			Delays and cost overruns	Manageme nt Technology	Lift-fan had a number of problems: leaks developed in the fan-clutch lubrication and cooling system, accompanied by an alarming rise in clutch temperature. In transitioning to vertical hover, doors closing off the fan on top and underneath the fuselage open.
12	**Aug. 2002**	**Concurrent development** **New** SGI advanced visualization software purchase **(**multimillion-dollar purchase)	Program management, Requirements management, Concurrent development, SC Risks, New technology, Integration issues				Manageme nt Technology	LM relied on SGI visualization and HPC technologies to engineer higher-quality, lower-cost and more- competitive designs." From the beginning, LM assured Pentagon officials that technological innovation, including heavy reliance on computer simulation, which could take the place of real-world testing, would keep costs down. The Pentagon allowed the company to design, test, and produce the F-35 all at the same time, instead of insisting that Lockheed identify and fix defects before firing up its

								production line. Building an airplane while it is still being designed and tested is referred to as concurrency. In effect, concurrency creates an expensive and frustrating non-decision loop: build a plane, fly a plane, find a flaw, design a fix, and retrofit the plane, rinse, repeat (**9 NYT).**
13.	**Sept. 2002**	**Stakeholder management** (new FICO facilities), Friction over Work Shares **Technology transfer issues** Global project authorization (GPA);	Program management, Stakeholder management;			Delays and cost overruns	Manageme nt Technology	1. UK selected the STOVL variant for (FJCA); 2. Other nations signed up to the SDD phase are: Australia, Canada, Denmark, Italy, Netherlands, Norway, Singapore and Turkey; 3. State Department completed work the arms exports license for the F-35 under the first-time use of the Global Project Authorization (GPA) practice:--an "umbrella" export authorization that allows LM and other U.S. suppliers on the program to enter into agreements with over 200 partner suppliers to transfer certain unclassified technical data--from the Department of State
14.	**Apr. 2002**	**Technical problems:** Weight issues **SC Risk Management** (sole source contract) Issue with a supplier: Ingersoll Milling Machine Co filed for bankruptcy	Program management, Procurement management, untested technologies, SC Risks				Manageme nt Technology	To compensate for the problem, the company has redesigned the internal structure of the tri-service aircraft to make it more efficient, carry loads differently and reduce its weight. Known issues published by Asker, J. R. (2003). **WASHINGTON OUTLOOK. *Aviation Week & Space Technology*, *158*(16), 21 4/21/2003** Issue with a supplier: Ingersoll Milling Machine Co bankruptcy filing, which sought court protection under Chapter 11.LM's attorneys cited risks to national security if the machine tools were further delayed. On June 17 it hired Cincinnati Machine, an Ingersoll rival and the only other US company that can build both metal-cutting and composite-forging machinery. **Ott, J. (2003). MONKEY Wrench. *Aviation Week & Space Technology*, *159*(4), 48-50.**
15.	**Dec. 2003**	**1st Nunn-McCurdy Breach (Significant) PAUC**	Program management, Procurement management, untested technologies, SC	2 years		Delays and cost overruns	Manageme nt Technology	**Weight problems**: Lift fan and clutch redesign in favor of a lighter versions; **Risk Management**: New, untested technologies, Concurrency threats, Financial risks, Global Project Authorization (GPA) was

		Re-baseline **New:** Dev. Est: 44.8 Billon;Avg. Proc. 82 mil	Risks Contract structure, Luck of incentives Decrease in commonality in 3 variants					delayed due to suppliers concerns, related to liability and compliance requirements **Technical:** Communication problems during the test related to JASSM (joint air-to-surface stand-off missile) software, technology integration **Stakeholder Management**: Strike at Pratt & Whitney (P&W). Friction between DoD and foreign partners in the JSF program. Denmark, Italy, the Netherlands, Norway, and Turkey in 2003, expressed dissatisfaction with the quality and quantity of the work their companies had been awarded on the F-35 **Scope Management**: Changes related to FICO facilities
16	**2004**	**Schedule delay; Technical problems:** Weight problems, software problems, Interoperability problems	Program management, Procurement management, untested technologies, SC Risks, Interoperability issues	IOC delayed by 1 year		Delays and cost overruns	Management Technology	IOC faces about a one year delay approximately the same amount of time that the development program has slipped. The main reasons: the aircraft's weight growth and Interoperability issues (the ability to share information) with other systems, is one of JSF's key performance parameters
17	**2005**	**2nd Nunn-McCurdy Breach (Significant) PAUC & APUC** The program undergoes re-plan to address higher than expected design weight	Program management, Procurement management, untested technologies, SC Risks	12 years		Delays and cost overruns	Management Technology	Configuration updates; increased airframe materials cost; change in subcontractor manufacturing plan for wing; change in prime/subcontractor work share resulting in increased labor rates **Impact of Immature Technologies** Weight problems Misalignment with the knowledge base Schedule delay, Interoperability challenges Software problems, Requirement management problems, Procurement issues
18	**2006**	**Restructuring, Cost increases**	Program management, Procurement management, untested technologies, SC Risks, Concurrency	12 years		Cost overruns	Management Technology	The program planned to enter production with less than **1% of testing complete.** **Estimated dev. Cost: 45.7 Billion** **Average Procurement: 86 Million**
19	**2007**	**Technical problems:** Critical engine issues **Funding is**	Concurrent development Weight problems, Untested technologies, Misalignment	12 years	2 (prod)	Cost overruns	Government, Management Technical	Turbine blades broke off suddenly by a form of metal fatigue (several incidents); Congress reduces funding for first 2 low-rate productions; Concerns remained about

		reduced, Cost increases	with the knowledge base					undue overlap in testing and production. **Estimated dev. Cost: 44.5 Billion** **Average Procurement: 104 Million**
20.	**2008**	**Technical problems:** Critical engine problem, issues with ground cooling fan electrical circuitry, and other components. **Funding:** Management reserves replenishment**, testing reduced**	Risk Management: Mismanagement, Financial risks Inadequate testing	12 years	12		Government, Management Technical	The blade cracks damage (material failure). This led to a redesign of a number of elements in the engine. One of the upgrades was a change of the distance between the turbine blades. After the redesign the engine was retested and recertified. On July 23, 2008, both flying F-35 prototypes were grounded after problems were detected with ground cooling fan electrical circuitry, DCMA reported on Aug 18, 2008 that tests were delayed as a result of testing anomalies on the 28 Volt and 270 Volt Battery Charger/Controller Unit, the Electrical Distribution Unit and the Power Distribution Unit. DoD implemented a Mid-Course Risk Reduction Plan to replenish management reserves from about $400 million to about $1 billion by reducing testing to save money
21.	**2009**	**Technical problems:** Critical engine issue again **Cost increase, High risks**	Risk Management: Program management, Contract structure	13 years	14		Management Technical	Serious engine problems were again revealed during testing of the P/W F-135 engine. The Pentagon wanted to axe the alternate engine (the GE / Rolls Royce F-136), a Pratt & Whitney F-135 engine broke down. Again, the cause seemed to lie in broken turbine blades. However, this time the same problem occurred in the new, redesigned engine with redesigned turbine blades. The program increased the cost estimate and adds a year to development but accelerated the production ramp up. Independent DoD cost estimate (JET I) projects even higher costs and further delays. Moving forward with an accelerated procurement plan and use of cost reimbursement contracts is very risky. Revision in air vehicle and propulsion estimate based on actual SDD and early LRIP costs; added risk funding due to JET assessment; change in production quantity and profile.

22	**2010**	**Technical problems:** Lift fen, problem with a fuel pump, caused by a software bug **3rd Nunn-McCurdy Breach (Critical)** **PAUC & APUC**	Risk Management: Program management, Contract structure	15 years	30		Manageme nt Technical	3 Major technical issues emerged for the F-35B: premature wear on hinges for the auxiliary; inlet door feeding; the F-35B's lift fan, which caused the F-35B fleet to be grounded. F-35 fleet grounded again after the fuel pump shut down above 10,000ft (3,050m). The problem was caused by a software bug. The program was restructured to reflect findings of recent independent cost team (JET II) and independent manufacturing review team. As a result, development funds increased, test aircraft were added, the schedule was extended, and the early production rate decreased. Costs and schedule delays inhibit the program's ability to meet needs on time. **Estimated dev. Cost: 49.3 Billion** **Average Procurement: 112 Mil .** **Development length: 15 years**
23	**2011**	**Technical problems:** Issue with a generator caused by a faulty maintenance handling; software problems **Restructuring continued**	Program management, Risk Management: Concurrency,	16 years	42		Manageme nt Technical	Technical problem with a generator caused by a faulty maintenance handling; Technical: Grounding was from 17 June until 23 June, 2011 due to a problem with software; Technical: grounding – a valve in the Integrated Power Package (IPP) of F-35A test aircraft AF-4 failed. Restructuring continued with additional development cost increases; schedule growth; further reduction in near-term procurement quantities; and decreased the rate of increase for future production. The Secretary of Defense placed the STOVL variant on a 2 year probation; decoupled STOVL from the other variants; and reduced STOVL production plans for fiscal years 2011 to 2013. **Estimated dev. Cost: 51.8 Billion** **Average Procurement: 133 Mil.** **Development length: 16 years**
24	**2012**	**Technical problems:** 12 days grounding due	Program management, Risk Management: Concurrency,	18 years	31		Manageme nt Technical	-15 F-35s are grounded for about 12 days to repack improperly installed parachutes; - Most of the program's

		to improperly installed parachutes **Restructuring continued**						instability continues to be concurrency of development, test, and production; The program established a new acquisition program baseline and approved the continuation of system development, increasing costs for development and procurements and extending the period of planned procurements by 2 years.
25.	**2013**	**Technical problems:** Propulsion system issues	Program management, Risk Management:		29		Management Technical	Technical: a failure of a fueldraulic line in the aircraft's propulsion system; Additional problem: a crack in a low pressure turbine blade in an engines of a F-35A
26.	**2016**			18 years			Management Technical	

Appendix IV: Complimentary 5th Generation Air Force

F-22 Raptor **Lockheed-Martin (Marietta, GA)**	**F-35A Lightning II** **Lockheed-Martin (Ft Worth, TX)**
	
Mission The F-22 Raptor is the Air Force's newest fighter aircraft. Its combination of stealth, super-cruise, maneuverability, and integrated avionics, coupled with improved supportability, represents an exponential leap in warfighting capabilities. The Raptor performs both air-to-air and air-to-ground missions allowing full realization of operational concepts vital to the 21st century Air Force. The F-22, a critical component of the Global Strike Task Force, is designed to project air dominance, rapidly and at great distances and defeat threats attempting to deny access to our nation's Air Force, Army, Navy and Marine Corps. The F-22 cannot be matched by any known or projected fighter aircraft.	**Mission** The F-35A is the U.S. Air Force’s latest fifth-generation fighter. It will replace the U.S. Air Force’s aging fleet of F-16 Fighting Falcons and A-10 Thunderbolt II’s, which have been the primary fighter aircraft for more than 20 years, and bring with it an enhanced capability to survive in the advanced threat environment in which it was designed to operate. With its aerodynamic performance and advanced integrated avionics, the F-35A will provide next-generation stealth, enhanced situational awareness, and reduced vulnerability for the United States and allied nations

Features	**Features**
A combination of sensor capability, integrated avionics, situational awareness, and weapons provides first-kill opportunity against threats. The F-22 possesses a sophisticated sensor suite allowing the pilot to track, identify, shoot and kill air-to-air threats before being detected. Significant advances in cockpit design and sensor fusion improve the pilot's situational awareness. In the air-to-air configuration the Raptor carries six AIM-120 AMRAAMs and two AIM-9 Sidewinders. The F-22 has a significant capability to attack surface targets. In the air-to-ground configuration the aircraft can carry two 1,000-pound GBU-32 Joint Direct Attack Munitions internally and will use on-board avionics for navigation and weapons delivery support. In the future air-to-ground capability will be enhanced with the addition of an upgraded radar and up to eight small diameter bombs. The Raptor will also carry two AIM-120s and two AIM-9s in the air-to-ground configuration. Advances in low-observable technologies provide significantly improved survivability and lethality against air-to-air and surface-to-air threats. The F-22 brings stealth into the day, enabling it not only to protect itself but other assets. The F-22 engines produce more thrust than any current fighter engine. The combination of sleek aerodynamic design and increased thrust allows the F-22 to cruise at supersonic airspeeds (greater than 1.5 Mach) without using afterburner -- a characteristic known as supercruise. Supercruise greatly expands the F-22 's operating envelope in both speed and range over current fighters, which must use fuel-consuming afterburner to operate at supersonic speeds. The sophisticated F-22 aerodesign, advanced flight controls, thrust vectoring, and high thrust-to-weight ratio provide the capability to outmaneuver all current and projected aircraft. The F-22 design has been extensively tested and refined aerodynamically during the development process. The F-22's characteristics provide a synergistic effect ensuring F-22A lethality against all advanced air threats. The combination of stealth, integrated avionics and supercruise drastically shrinks surface-to-air missile engagement envelopes and minimizes enemy capabilities to track and engage the F-22. The combination of reduced observability and supercruise accentuates the advantage of surprise in a tactical environment. The F-22 will have better reliability and maintainability than any fighter aircraft in history. Increased F-22 reliability and maintainability pays off in less manpower required to fix the aircraft and the ability to operate more efficiently. **Background** The Advanced Tactical Fighter entered the	The conventional takeoff and landing (CTOL) F-35A gives the U.S. Air Force and allies the power to dominate the skies – anytime, anywhere. The F-35A is an agile, versatile, high-performance, 9g capable multirole fighter that combines stealth, sensor fusion, and unprecedented situational awareness. The F-35A's advanced sensor package is designed to gather, fuse and distribute more information than any fighter in history, giving operators a decisive advantage over all adversaries. Its processing power, open architecture, sophisticated sensors, information fusion and flexible communication links make the F-35 an indispensable tool in future homeland defense, Joint and Coalition irregular warfare and major combat operations. Because logistics support accounts for two-thirds of an aircraft's life cycle cost, the F-35 is designed to achieve unprecedented levels of reliability and maintainability, combined with a highly responsive support and training system linked with the latest in information technology. The Autonomic Logistics Information System (ALIS) integrates current performance, operational parameters, current configuration, scheduled upgrades and maintenance, component history, predictive diagnostics (prognostics) and health management, operations scheduling, training, mission planning and service support for the F-35. Essentially, ALIS performs behind-the-scenes monitoring, maintenance and prognostics to support the aircraft and ensure continued health and enhance operational planning and execution. The F-35's electronic sensors include the Electro-Optical Distributed Aperture System (DAS). This system provides pilots with situational awareness in a sphere around the aircraft for enhanced missile warning, aircraft warning, and day/night pilot vision.. Additionally, the aircraft is equipped with the Electro-Optical Targeting System (EOTS). The internally mounted EOTS provides extended range detection and precision targeting against ground targets, plus long range detection of air-to-air threats. The F-35's helmet mounted display system is the most advanced system of its kind. All the intelligence and targeting information an F-35 pilot needs to complete the mission is displayed on the helmet's visor. The F-35 contains state-of-the-art tactical data links that provide the secure sharing of data among its flight members as well as other airborne, surface and ground-based platforms required to perform assigned missions. The commitment of JSF partner nations to common communications capabilities and web-enabled logistics support will enable a new level of Coalition interoperability. These capabilities allow the F-35 to lead the defense community in the migration to the net-centric war fighting force of the future. The F-35's engine produces 43,000 lbs of thrust and consists of a 3-stage fan, a 6-stage compressor, an annular combustor, a single stage high-pressure turbine, and a 2

Demonstration and Validation phase in 1986. The prototype aircraft (YF-22 and YF-23) both completed their first flights in late 1990. Ultimately the YF-22 was selected as best of the two and the engineering and manufacturing development effort began in 1991 with development contracts to Lockheed/Boeing (airframe) and Pratt & Whitney (engines). EMD included extensive subsystem and system testing as well as flight testing with nine aircraft at Edwards Air Force Base, Calif. The first EMD flight was in 1997 and at the completion of its flight test life this aircraft was used for live-fire testing. The program received approval to enter low rate initial production in 2001. Initial operational and test evaluation by the Air Force Operational Test and Evaluation Center was successfully completed in 2004. Based on maturity of design and other factors the program received approval for full rate production in 2005. Air Education and Training Command, Air Combat Command and Pacific Air Forces are the primary Air Force organizations flying the F-22. The aircraft designation was the F/A-22 for a short time before being renamed F-22A in December 2005.	stage low-pressure turbine. The F-35 is designed to provide the pilot with unsurpassed situational awareness, positive target identification and precision strike in all weather conditions. Mission systems integration and outstanding over-the-nose visibility features are designed to dramatically enhance pilot performance. With nine countries involved in its development (United States, United Kingdom, Italy, Netherlands, Turkey, Canada, Denmark, Norway and Australia), the F-35 represents a new model of international cooperation, ensuring U.S. and Coalition partner security well into the 21st Century. The F-35 also brings together strategic international partnerships, providing affordability by reducing redundant research and development and providing access to technology around the world. Along these lines, the F-35 will employ a variety of US and allied weapons. Background The F-35 is designed to replace aging fighter inventories including U.S. Air Force F-16s and A-10s, U.S. Navy F/A-18s, U.S. Marine Corps AV-8B Harriers and F/A-18s, and U.K. Harrier GR.7s and Sea Harriers. With stealth and a host of next-generation technologies, the F-35 will be far and away the world’s most advanced multi-role fighter. There exists an aging fleet of tactical aircraft worldwide. The F-35 is intended to solve that problem. On October 26, 2001, Under Secretary of Defense for Acquisition, Technology and Logistics Edward C. "Pete" Aldridge Jr. announced the decision to proceed with the Joint Strike Fighter (JSF) program. This approval advanced the program to the System Development and Demonstration (SDD) phase. The Secretary of the Air Force James G. Roche announced the selection of Lockheed Martin teamed with Northrop Grumman and BAE to develop and then produce the JSF aircraft. During this SDD phase, the program will focus on developing a family of strike aircraft that significantly reduces life-cycle cost while meeting operational requirements. The requirements represent a balanced approach to affordability, lethality, survivability and supportability. The program will use a phased block approach that addresses aircraft and weapons integration and provides a validated and verified air system for Initial Operational Capability requirements.
General characteristics **Primary function:** air dominance, multi-role fighter **Contractor:** Lockheed-Martin, Boeing **Power plant:** two Pratt & Whitney F119-PW-100 turbofan engines with afterburners and two-dimensional thrust vectoring nozzles. **Thrust:** 35,000-pound class (each engine) **Wingspan:** 44 feet, 6 inches (13.6 meters) **Length:** 62 feet, 1 inch (18.9 meters) **Height:** 16 feet, 8 inches (5.1 meters) **Weight:** 43,340 pounds (19,700 kilograms)	**General Characteristics** **Primary Function:** Multirole fighter **Prime Contractor:** Lockheed Martin **Power Plant:** One Pratt & Whitney F135-PW-100 turbofan engine **Thrust:** 43,000 pounds **Wingspan:** 35 feet (10.7 meters) **Length:** 51 feet (15.7 meters) **Height:** 14 feet (4.38 meters) **Maximum Takeoff Weight:** 70,000 pound class **Fuel Capacity: Internal:** 18,498 pounds

Maximum takeoff weight: 83,500 pounds (38,000 kilograms) **Fuel capacity:** internal: 18,000 pounds (8,200 kilograms); with 2 external wing fuel tanks: 26,000 pounds (11,900 kilograms) **Payload:** same as armament air-to-air or air-to-ground loadouts; with or without two external wing fuel tanks. **Speed:** mach two class with supercruise capability **Range:** more than 1,850 miles ferry range with two external wing fuel tanks (1,600 nautical miles) **Ceiling:** above 50,000 feet (15 kilometers) **Armament:** one M61A2 20-millimeter cannon with 480 rounds, internal side weapon bays carriage of two AIM-9 infrared (heat seeking) air-to-air missiles and internal main weapon bays carriage of six AIM-120 radar-guided air-to-air missiles (air-to-air loadout) or two 1,000-pound GBU-32 JDAMs and two AIM-120 radar-guided air-to-air missiles (air-to-ground loadout) **Crew:** one **Unit cost:** $143 million **Initial operating capability:** December 2005 **Inventory:** total force, 183 (Current as of September 2015)	**Payload:** 18,000 pounds (8,160 kilograms) **Speed:** Mach 1.6 (~1,200 mph) **Range:** More than 1,350 miles with internal fuel (1,200+ nautical miles), unlimited with aerial refueling **Ceiling:** Above 50,000 feet (15 kilometers) **Armament:** Internal and external capability. Munitions carried vary based on mission requirements. **Crew:** One

Appendix V: Changes to the DoD Acquisition Process 1971 to 2017

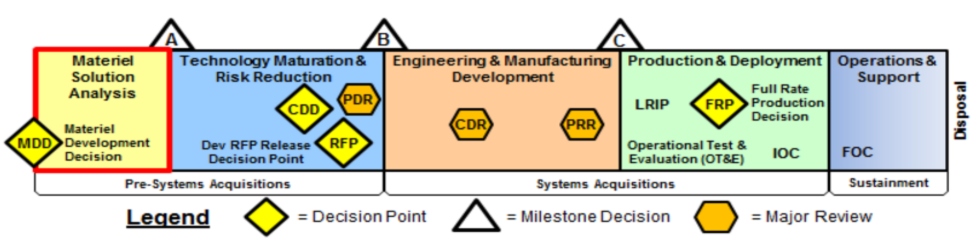
CHANGES TO THE ACQUISITION PROCESS DoD DIRECTIVE 5000s.01 and 5000.02 1971 TO 2017

http://history.defense.gov/Portals/70/Documents/acquisition_pub/CMH_Pub_51-3-1.pdf

1971	Deputy Secretary of Defense David Packard signed the first DoD Directive 5000.1 in 1971. • The Defense Systems Acquisition Review Council (DSARC) is created. • SECDEF (Secretary of Defense) decisions are documented in an approved Decision Coordinating Paper (DCP). • Major programs are defined as $50 million for RDT&E (research, development, test, and evaluation) or $200 million for procurement.
1975	• Milestones are defined as: – "Program Initiation" – "Full-Scale Development Decision" – "Production Go-Ahead Decision" • Major programs are redefined as $75 million for RDT&E or $300 million for procurement (in FY 1972 dollars). • Milestones are unchanged or redefined as follows: – Milestone one remains unchanged: "Program Initiation." – Milestone two is redefined from "Full-Scale Development Decision" to "Full-Scale Engineering Development Decision." – Milestone three is redefined from "Production Go-Ahead" to "Production and Deployment Decision." • The acquisition phases are redefined: – From "Conceptual Effort" to "Validation Phase." – From "Full-Scale Development" to "Full-Scale Engineering Development." – "Production/Deployment" phase remains the same.
1977	• The names of the acquisition phases are changed and numbered as follows: – Phase 0 is redefined as "Exploration of Alternative System Concepts." – Phase I is redefined as "Demonstration and Validation." – Phase II is redefined as "Full-Scale Engineering Development." – Phase III is redefined as "Production and Deployment." • Milestones are redefined and numbered as follows: – Milestone 0 becomes "Mission Element Need Statement" (MENS), Program Initiation approved by the secretary of defense. – Milestone I becomes "Approval to Enter Demonstration and Validation." – Milestone II becomes "Approval to Enter Full-Scale Engineering Development."

	– Milestone III becomes "Approval to Enter Production and Deployment." • MENS appears as the first DoD-level requirements document.
1980	• Major programs are now defined as $100 million for RDT&E or $500 million for procurement (FY 1980 dollars). • Phases: – Phase 0 is changed from "Exploration of Alternative System Concepts" to "Concept Exploration." – Phase II is changed from "Full-Scale Engineering Development" to "Full-Scale Development." – Phase III remains the same, "Production and Deployment." • Milestones: – Milestones 0, I, II, and III remain unchanged. – SECDEF Decision Memorandum (SDDM) is implemented to document milestone decisions.
1982	• Major programs are now defined as $200 million RDT&E or $1 billion procurement (FY 1980 dollars). • Milestones: – Milestone 0 is changed from "Million Element Need Statement" to "Approval of JMSNS (Joint Materiel System Need Statement) in PPBS, Program Initiation." The designation "Milestone 0" is discontinued. (PPBS = Planning, Programming, and Budgeting System) – Milestone I is changed from "Enter Demonstration and Validation" to "Concept Selection." – Milestone II is changed from "Approval to Enter Full-Scale Development" to "Program Go-Ahead." – Milestone III is changed from "Enter Production and Deployment" to "Production Decision" (Delegated to Components). • Programs may proceed to FSD (Full-Scale Development) with delayed MS II (Milestone II). Contracts must be written so program can be terminated at least cost to the government.
1985	• Milestone 0 returns and is named "Approval of JMSNS in PPBS, Program Initiation." • Production Decision (may be delegated to Components).
1987	• Phases: – Phase 0 is changed from "Concept Exploration" to "Concept Exploration/ Definition." – Phase I is changed from "Demonstration and Validation" to "Concept Demonstration/ Validation." – Phase II is changed from "Full-Scale Engineering Development" to "FullScale Development and LRIP (Low-Rate Initial Production)." – Phase III is changed to "Production, Fielding/Deployment, Operational Support." • Milestones: – Milestone 0 remains the same: "Approval of JMSNS in PPBS, Program Initiation." – Milestone I is changed from "Concept Selection" to "Approval to Enter Concept Demonstration/Validation." – Milestone II is changed from "Program Go-Ahead" to "Approval to Enter Full-Scale Development and LRIP." – Milestone III is changed from "Production Decision" (Delegated to Components) to "Approval for Full-Rate Production and Deployment." – Milestone IV is introduced as "Logistics Readiness and Support Review." • Competitive Prototyping Strategy is required by law and by DoD Instruction 5000.2. • Joint Requirements Management Board (JRMB) is renamed JROC (Joint Requirements Oversight Council). • Defense Systems Acquisition Review Council (DSARC) is renamed JRMB. • JRMB is renamed Defense Acquisition Board (DAB).
1991	• Major programs are now defined as $300 million for RDT&E or $1.8 billion for procurement (FY 1980 dollars). • Milestones: – Milestone 0 is redefined as "Approval to Conduct Concept Studies." – Milestone I is redefined as "Concept Demonstration Approval." – Milestone II is redefined as "Development Approval." – Milestone II redefined as "Production Approval." – Milestone IV is redefined as "Major Modification Approval." • Phases: – A new phase, "Determination of Mission Need," is inserted before Milestone 0. – Phase I is redefined as "Demonstration and Validation." – Phase II is redefined as "Engineering and Manufacturing Development." – Phase III is redefined as "Production and Deployment." – A new Phase IV is introduced as "Operations and Support." • Acquisition Decision Memorandum (ADM), signed by the USD (A), replaces SDDM (SECDEF Decision Memorandum). • The provision for a delayed Milestone II is eliminated. • The acquisition category (ACAT) structure is created. • The JROC-approved MENS replaces the secretary of defense– approved JMSNS at Milestone 0. • Operational Requirements Document (ORD) appears in DoD Instruction 5000.2 and is required at Milestone II and Milestone III.
1996	• Phases: – Phase 0 is redefined as "Concept Exploration." – Phase I is redefined as "Program Definition and Risk Reduction." – Phase II is redefined as "Engineering and Manufacturing Development." – Phase III is redefined as "Production, Fielding/Deployment, and Operational Support." – A new phase appears following Phase III: "Demilitarization and Disposal." • Milestones: – Milestone I is redefined as "Approval to Begin a New Acquisition Program." – Milestone II is redefined as "Approval to Enter Engineering and Manufacturing Development." – Milestone II is redefined as "Production or Fielding/Deployment Approval." • Program Initiation is moved to Milestone I. • Automated Information System (AIS) acquisition programs are folded into the DoD 5000 process.

	• Competitive Prototyping requirement is eliminated.
2000	• Major programs are redefined as $365 million for RDT&E or $219 billion for procurement (FY 2000 dollars). • Milestone identifications are changed from numbers to letters "A," "B," and "C." • Phases: – Phase A becomes "Concept and Technology Development (Decision Review)." – Phase B becomes "System Development and Demonstration (Interim Progress Review)." – Phase C becomes "Production and Deployment (FRP Decision Review)." – A phase following Phase C appears and is named "Operations and Support." • Milestones: – Milestone A is defined as "Approval to Enter Concept and Technology Development." – Milestone B is defined as "Approval to Enter Systems Development and Demonstration." – Milestone C is defined as "Approval to Enter LRIP/Production and Deployment." • Program Initiation occurs at Milestone B. • Commitment to Production occurs at Milestone C (LRIP). • Evolutionary Acquisition (EA) becomes the preferred approach to major systems acquisition.
2002	• "Technology Opportunities and User Needs" is changed to "User Needs and Technology Opportunities." • "Critical Design Review" is added to Phase B. • Deputy Secretary of Defense cancels all three DoD 5000 documents. • Interim Guidance documents are issued: "Defense Acquisition" for basic policy and "Operation of the Defense Acquisition System" for implementation procedures. • DoD 5000.2-R becomes the "Interim Defense Acquisition Guidebook."
2003	• Phases: – A phase preceding Milestone A becomes "Concept Refinement (Concept Decision)." – Phase A becomes "Technology Development." – Phase B becomes "System Development and Demonstration (Design Readiness Review)." • Milestones: – A new milestone is created at the beginning of the Concept Refinement Phase. The milestone is named "Approval to Enter Concept Refinement." – Milestone A is redefined as "Approval to Enter Technology Development." • The Defense Acquisition Guidebook (DAG) is made available online. • "Joint Capabilities Integration and Development System" (JCIDS) is created. MNS (Mission Need Statement) and ORD (Operational Requirements Document) are replaced. • "Initial Capabilities Document" is required at Milestone B; the "Capability Production Document" is required at Milestone C.
2008	• Definition of major acquisition programs remains the same: $365 million for RDT&E or $2.19 billion for procurement (FY 2000 dollars). • "User Needs and Technology Opportunities" becomes "User Needs and Technology Opportunities and Resources." • Phases: – The phase preceding Milestone A is redefined to "Materiel Solution Analysis (Materiel Development Decision)." – Phase B is redefined as "Engineering and Manufacturing Development" with two submilestones: "Post-PDR A" and "Post-CDR A." • Milestones: – The milestone at the beginning of the Materiel Solution Analysis Phase is redefined as "Approval to Enter Acquisition Process." – Milestone B is redefined as "Approval to Enter Engineering and Manufacturing Development." • The Materiel Development Decision precedes entry into any phase of the acquisition process. • Competitive Prototyping returns and is required during the Technology Development Phase. • A Preliminary Design Review (PDR) after Milestone B requires a Post-PDR. The assessment is made by the Milestone Decision Authority
2013 / 2017	Instruction 5000.02 (issued as a new interim instruction November 26, 2013) are static documents, the Defense Acquisition Guidebook is constantly updated to reflect best practices and updated guidance. As of September 16, 2013, the guidebook was more than 1,200 pages. https://fas.org/sgp/crs/natsec/RL34026.pdf



The Materiel Solution Analysis (MSA) Phase assesses potential solutions for a needed capability in an Initial Capabilities Document (ICD) and to satisfy the phase-specific Entrance Criteria for the next program milestone designated by the Milestone Decision Authority (MDA). The MSA phase is critical to program success and achieving materiel readiness because it's the first opportunity to influence systems supportability and affordability by balancing technology opportunities with operational and sustainment requirements. During this phase, various alternatives are analyzed to select the materiel solution and develop the Technology Development Strategy (TDS) to fill any technology gaps.

The MSA phase also includes identifying and evaluating affordable product support alternatives with their associated requirements to meet the operational requirements and associated risks. Consequently, in describing the desired performance to meet mission requirements, sustainment metrics should be defined in addition to the traditional performance design criteria.

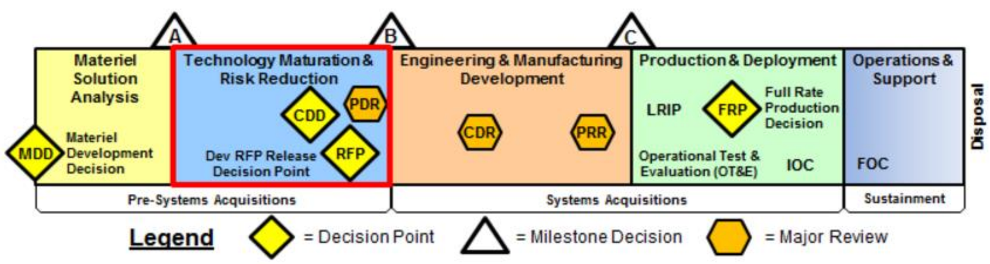
The main task during this phase is to conduct an Analysis of Alternatives (AoA). The purpose of an AoA is to evaluate the mission effectiveness, operational suitability, and estimated Life-Cycle Cost (LLC) of alternative solutions to meet a mission capability in an ICD in determining the system concept.
The purpose of the Materiel Solutions Analysis (MSA) Phase is to: (See MiIlestone Activity Map)

- Assess all potential solutions for a stated need
- Develop a preliminary Acquisition Strategy,
- Develop a Technology Development Strategy (TDS)
- Develop program goals for any needed development of critical enabling technologies
- Conduct an Analysis of Alternatives (AoA) leading to selection and approval of a materiel
- Develop a draft Capabilities Development Document (CDD)
- Develop a Systems Engineering Plan (SEP)
- Develop Initial Support and Maintenance Concepts (Life-Cycle Sustainment Plan)
- Develop the Life-Cycle Signature Support Plan (LSSP)
- Understand Research and Development Costs

The MSA Phase is critical for establishing the overarching trade space available to the Program Manager (PM) in subsequent phases. User capabilities are examined against technologies, both mature and immature, to determine feasibility and alternatives to fill user needs. Once the requirements have been identified, a gap analysis should be performed to determine the additional capabilities required to implement the support concept and its drivers within the trade space.
The MSA Phase ends when the AoA has been completed, materiel solution options for the capability need identified in the approved ICD have been recommended by the lead DoD Component conducting the AoA, and the phase-specific Entrance Criteria for the initial review milestone have been satisfied.
The following reviews take place during the MSA Phase:

- Initial Technical Review (ITR)
- Alternative System Review (ASR)

2013 / 2017



The purpose of **the Technology Maturation & Risk Reduction (TMRR)** Phase is to reduce technology risk, engineering integration, life-cycle cost risk and to determine the appropriate set of technologies to be integrated into a full system. The TMRR phase conducts competitive prototyping of system elements, refines requirements, and develops the Functional and Allocated Baselines of the end-item system configuration. The objective of the TMRR phase is the buying down technical risk and developing a sufficient understanding of a solution in order to make sound business decisions on initiating a formal acquisition program in the Engineering, Manufacturing and Development (EMD) Phase. (See Milestone Requirements Matrix)
The TMRR phase develops and demonstrates prototype designs to reduce technical risk, validate designs, validate cost estimates, evaluate manufacturing processes, and refine requirements. Based on refined requirements and demonstrated prototype designs, integrated systems design of the end-item system can be initiated. Additionally, the TMRR Phase efforts ensure the level of expertise required to operate and maintain the product is consistent with the force structure.

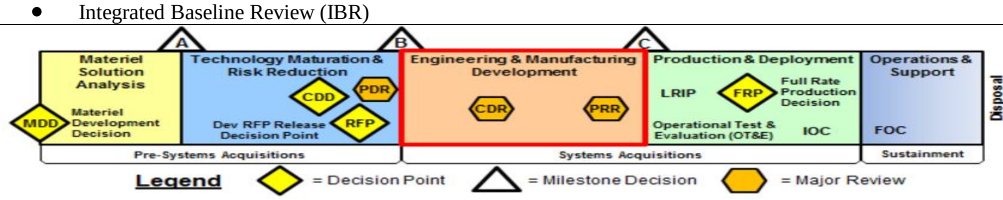
During this phase the Program Manager (PM) will conduct a systems engineering trade-off analysis showing how cost and capability vary as a function of the major design parameters. The analysis will support the assessment of refined Key Performance Parameters (KPP) / Key System Attributes (KSA) in the Capability Development Document (CDD). Capability requirements proposed in the CDD (or equivalent requirements document) should be consistent with program affordability goals. [1]
Technology development is an iterative process of maturing technologies and refining user performance parameters to accommodate those technologies that are not sufficiently mature. The Initial Capabilities Document (ICD), the Technology Development Strategy (TDS), draft Capability Development Document (CDD), and draft System Requirements Document (SRD) guide the efforts of this phase, leading to an approved CDD.
The Technology Maturation & Risk Reduction (TMRR) Phase should:

- Develop Live-Fire T&E Waiver request (if appropriate),
- Develop Test and Evaluation Master Plan (TEMP),
- Develop Risk Assessment,
- Develop Systems Engineering Plan,
- Develop Programmatic Environment, Safety, and Occupational Health Evaluation (PESHE),
- Develop Compliance Schedule for National Environmental Policy Act (NEPA),
- Develop Program Protection Plan (PPP),
- Develop Technology Readiness Assessment,
- Develop Should Cost,
- Develop Cost Capability Analysis (CCA),
- Develop Capability Development Document (CDD), & System Requirements Document (SRD),
- Validated System Support and Maintenance Objectives and Requirements,
- Provide Inputs to the Integrated Baseline Review (IBR), Information Support Plan (ISP), System Threat Assessment (STAR), Acquisition Strategy, Affordability Assessment, Cost and Manpower Estimates, and System Safety.

The Technical Reviews conducted during the Technology Maturation & Risk Reduction (TMRR) Phase are:

- System Requirements Review (SRR)
- System Functional Review (SFR)
- Preliminary Design Review (PDR)
- Technology Readiness Assessment (TRA)
- Integrated Baseline Review (IBR)

2013 / 2017



The **Engineering & Manufacturing and Development (EMD)** Phase is where a system is developed and designed before going into production. The EMD Phases starts after a successful Milestone B and Pre-EMD Review and is considered the formal start of any program. The goal of this phase is to complete the development of a system or increment of capability, complete full system integration, develop affordable and executable manufacturing processes, complete system fabrication, and test and evaluate the system before proceeding into the Production and Deployment (PD) Phase.

The purpose of the EMD Phase is to: (See MiIlestone Activity Map)

- Develop a system or increment of capability,
- Design-in critical supportability aspects to ensure materiel availability with particular attention to reducing the logistics footprint,
- Integrate hardware, software, and human systems,
- Design for producibility,
- Ensure affordability and protection of critical program information,
- Demonstrate system integration, interoperability, supportability, safety, and utility, and
- Ensure operational supportability with particular attention to minimizing the logistics footprint
- Demonstrate Reliability, Availability, Maintainability, and sustainment features are included in the design of a system

In the EMD phase the system architecture and system elements down to the configuration item (hardware and software) level are defined based upon the technology selected and integrated during the Materiel Solution Analysis (MSA) and the Technology Maturation & Risk Reduction (TD) Phase. During this phase the system design requirements are allocated to the major subsystem level and are refined as a result of developmental and operational tests. The support concept and strategy are also refined with detailed design-to requirements determined for the product support package elements.

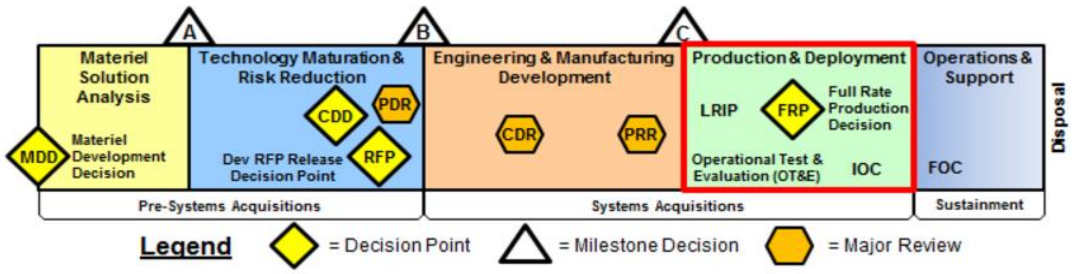
The EMD phase consists of two major efforts: **(1)** Integrated System Design and System Capability and **(2)** Manufacturing Process Demonstration. These two major efforts integrated the end item components and subsystems into a fully operational and supportable system. They also complete the detailed design to meet performance requirements with a producible and sustainable design and reduce system level risk. EMD typically includes the demonstration of production prototype articles or Engineering Development Models (EDM).

Below are the major reviews conducted during the EMD Phase:

- Integrated Baseline Review (IBR)
- Critical Design Review (CDR)
- Test Readiness Review (TRR)
- Flight Readiness Review (FRR)
- System Verification Review (SVR)

	• Functional Configuration Audit (FCA) • Production Readiness Review (PRR) • Technology Readiness Assessment (TRA)

2013 / 2017



The **Production and Deployment (PD) Phase** is where a system that satisfies an operational capability is produced and deployed to an end user. The phase has two major effort; **(1)** Low-Rate Initial Production (LRIP) and **(2)** Full-Rate Production and Deployment (FRP&D). The phase begins after a successful Milestone C review and Engineering, Manufacturing and Development (EMD) Phase.

The activities during the Production and Deployment (PD) Phase include:

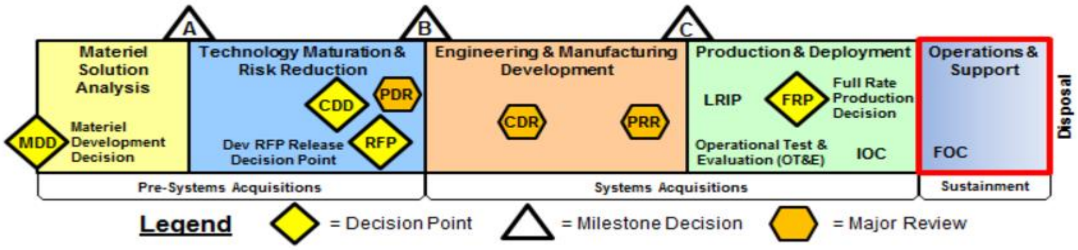
- Update Product Baseline
- Update Test and Evaluation Plan
- Conduct a Risk Assessment
- Update the Life-Cycle Sustainment Plan
- Ensure Programmatic Environment, Safety, and Occupational Health Evaluation (PESHE),
- Compliance Schedule for National Environmental Policy Act (NEPA)
- Update the Systems Engineering Plan (SEP)
- Provide Inputs to Cost and Manpower Estimate
- Update System Safety Analyses to include finalizing hazard analyses

The Technical Reviews conducted during the Production and Deployment (PD) Phase are:

- Integrated Baseline Review (IBR)
- Operational Test Readiness Review (OTRR)
- Physical Configuration Audit (PCA)
- Full-Rate Production Decision Review (FRDR)
- **AcqTips:**
- In this phase, the test and evaluation processes frequently reveal issues that require improvements or redesign. As the testing environment more closely approaches that of the users' needs, the required improvements might be complex and/or subtle.
- The initial manufacturing process may also reveal issues that were not anticipated. It may be discovered that changing the product somewhat may provide enhancements in the manufacturing or other supporting processes

http://www.acqnotes.com/acqnote/acquisitions/production-and-deployment

2013 / 2017



The Operations and Support (O&S) Phase is where a system is used and supported by users in the field. The main focus on this phase is the execution of a support system that sustains the system in the most cost effective manner possible. The second main focus of this phase is the disposal of a system when it has reached its useful life. See Disposal.

A major focus during the sustainment effort of the Operations and Support (O&S) Phase is identifying root causes and resolutions for safety and critical readiness degrading issues. These efforts include participating in Trade Studies and decision making relative to changes to the product support package, process improvements, modifications, upgrades, and future increments of the system. All these changes need to consider the operational needs and the remaining expected service life, Interoperability or technology improvements, parts or manufacturing obsolescence, aging aircraft (or system) issues, premature failures, changes in fuel or lubricants, and Joint or service commonality.

The Operations and Support (O&S) Phase should produce: (See Milestone Requirements Matrix)

- Input to Capability Development Document (CDD) for next increment
- Modifications and upgrades to fielded systems
- System Safety Analyses to include Environmental, Safety, Occupational and Health (ESOH) risk analysis, sustaining hazard analyses for the fielded system, and input to the next increment
- Data for next In-Service Review
- Programmatic Environment, Safety, and Occupational Health Evaluation
- Periodic updates to maintenance procedures through Reliability Centered Maintenance Analysis
- Compliance Schedule for National Environmental Policy Act (NEPA) (as required)
- Updated Systems Engineering Plan (SEP)

The Major Review during the Operations and Support (O&S) Phase is:

- In-Service Review

http://www.acqnotes.com/acqnote/acquisitions/operations-and-support

Reference:

[1] DoD (2014, March 1). FY 2015 Program Acquisition Cost by Weapon System. Retrieved March 17, 2015, from http://comptroller.defense.gov/Portals/45/documents/defbudget/fy2015/fy2015_Weapons.pdf

[2] https://www.whitehouse.gov/the-press-office/2016/12/15/statement-press-secretary-hr-3471-hr-4419-hr-5111-hr-5509-hr-5995-s-795

[3] Schwenn, K. (2015, March). Toward Agent-based Modeling of the U.S. Department of Defense Acquisition System.

[4] Overview – FY 2013 Defense Budget http://comptroller.defense.gov/Portals/45/Documents/defbudget/fy2013/FY2013_Budget_Request_Overview_Book.pdf

[5] http://www.gao.gov/products/GAO-14-563T

[7] Gerlovin, Zhao, Supply Chain Program Management (SCPM) to the Rescue! *F-35 PROGRAM: The Multi-variant, Multirole 5th Generation Fighter*

[8] DEFENSE ACQUISITIONS Assessments of Selected Weapon Programs, GAO-15-342SP http://www.gao.gov/assets/670/668986.pdf

[9] Nemfakos [et al.] The perfect storm: the Goldwater-Nichols Act and its effect on Navy acquisition [RAND http://www.rand.org/pubs/occasional_papers/OP308.html]

[10] Packard Commission. A quest for excellence: Final report to the President. Washington, DC 1986.

[11] Petrucci, D (2005) http://seari.mit.edu/documents/theses/SDM_PETRUCCI.pdf

[12] Arena, Mark V. "Why Has the Cost of Fixed-Wing Aircraft Risen?: A Macroscopic Examination of the Trends in U.S. Military Aircraft Costs over the Past Several Decades." RAND Monographs Project Air Force (2008). Web. 1 July 2010. <http://www.rand.org/pubs/monographs/MG696>.

[13] Korb, L. (1996, Dec. 21). A Military Monopoly. *The New York Times*

Retrieved from: http://www.nytimes.com/1996/12/21/opinion/a-military-monopoly.html

[14] Perry, W. ''Three Barriers to Major Defense Acquisition Reform.'' Defense Issues, 8, 1993, 1.

[15] Korb, L. (1996, Summer). Merger Mania: Should the Pentagon Pay For Defense Industry Restructuring? *Brookings*. Retrieved from: http://www.brookings.edu/research/articles/1996/06/summer-defenseindustry-korb

[16] Sterngold, James. (1996, Jan. 9th) "Lockheed to Acquire Loral In a Deal Worth $10 Billion". *NYT*.

Retrieved from: http://www.nytimes.com/1996/01/09/business/lockheed-to-acquire-loral-in-a-deal-worth-10-billion.html

[17] **http://www.au.af.mil/au/afri/aspj/airchronicles/apj/apj06/spr06/king.html**

[18] Zahos, Christos (2008), Defense industry consolidation and weapon systems cost growth http://calhoun.nps.edu/bitstream/handle/10945/4017/08Jun_Stratogiannis.pdf?sequence=1&isAllowed=y

[19] *Pavic et al.; BJEMT, 13(1): 1-8, 2016* Similarities and Differences between the CR and HHI as an Indicator of Market Concentration and Market Power

[20] Major, Davis J. USAF "THE IMPACT OF THE DEFENSE INDUSTRY CONSOLIDATION ON THE AEROSPACE INDUSTRY THESIS"

[21] Gerlovin, Zhao, (2017) Managing Supply Chain Risks in Government Acquisitions Programs – Success Factors and Lessons Learned from Fifth Generation Fighters

[22] http://www.rand.org/content/dam/rand/pubs/monographs/2011/RAND_MG1133.sum.pdf

[23] https://www.nytimes.com/2015/07/21/business/dealbook/lockheed-martin-to-buy-sikorsky-aircraft-for-9-billion.html

[24] Birkler, J., A. Bower, J. Drezner, G. Lee, M. Lorell, G. Smith, F. Timson, W. Trimble, and O. Younossi. Competition and Innovation in the U.S. Fixed-Wing Military Aircraft Industry. Santa Monica, CA: RAND,

[25] R. Nolan, "Ubiquitous IT: The case of the Boeing 787 and implications for strategic IT" Elsevier (2012).

---

[26] King, R. (2007) ANALYSIS OF COMPETITION IN THE DEFENSE INDUSTRIAL BASE: AN F-22 CASE STUDY

[27] Atkinson, W. (2008). “Lockheed martin builds forecasting tool for F-35”. *Purchasing, 137*(10), 19-n/a. Retrieved from http://search.proquest.com/docview/214445059?accountid=458

[28] http://www.rand.org/content/dam/rand/pubs/documented_briefings/DB600/DB649/RAND_DB649.pdf

[29]http://www.rand.org/content/dam/rand/pubs/documented_briefings/DB600/DB649/RAND_DB649.pdf

[30] http://secure.afa.org/events/Breakfasts/Breakfast_2-28-12_LtGen_Carlisle.pdf

[31] *http://www.forbes.com/sites/niallmccarthy/2016/05/30/americas-biggest-defense-contractors-infographic/#46ba1dac4c1e*

[32] http://www.forbes.com/sites/niallmccarthy/2016/05/30/americas-biggest-defense-contractors-infographic/#46ba1dac4c1e

[33] Berteau, D (2010) Cost and Time Overruns in Major Defense Acquisition Programs.

[34] http://www.gao.gov/assets/680/672205.pdf

[35] Davidson, Frank P. , & Huot, Jean-Claude. (1991). Large-scale projects: management trends for major projects. *Cost Engineering*, *33*(2), 15-23.

[36] Meier, Steven R. (2010). Causal inferences on the cost overruns and schedule delays of large-scale U.S. federal defense and intelligence acquisition programs. *Project Management Journal, 41*(1), 28-39. doi: 10.1002/pmj.20142

[37] Reimer, M.G.J., *Structure Programs for Success*. 2008, AFPEO F-22: Washington, D.C.

[38] The Standard for Portfolio Management—Third Edition (2013). Recognized by ANSI as American National Standard BSR/PMI 08-003-2013

[39] Rios, C., Housel, T., & Mun, J. (2006). *Integrated portfolio analysis [electronic resource] : Return on investment and real options analysis of intelligence information systems (cryptologic carry on program).* Monterey, CA: Naval Postgraduate School.

[40] https://www.congress.gov/bill/114th-congress/senate-bill/1550

[41] Copeland, E. J., Holzer, h. H., Eveleigh, T. J., & Sarkani, S. (2015). The Effects of System PROTOTYPE DEMONSTRATIONS ON WEAPON SYSTEM. *Defense Acquisition Research Journal: A Publication Of The Defense Acquisition University*, *22*(1), 106-134.

[42] Weapon Systems Acquisition Reform Act of 2009 http://www.acq.osd.mil/se/docs/PUBLIC-LAW-111-23-22MAY2009.pdf

[43] Arena, Mark V., Robert S. Leonard, Sheila E. Murray, and Obaid Younossi. *Historical Cost Growth of Completed Weapon System Programs.* Santa Monica, CA: RAND Corporation, 2006. Rand report: TR-343-AF

[44] McNicol, D. L. (2005). *Cost growth in major weapon procurement programs.* 2nd ed. [Alexandria, Va.]: Institute for Defense Analyses.

[45] Tyson et al., “The Effects of Management Initiatives on the Costs and Schedules of Defense Acquisition Programs, Vol. I Main Report,” IDA Paper P-2722 (Alexandria, VA: Institute for Defense Analyses, 1992). http://www.dtic.mil/dtic/tr/fulltext/u2/a269696.pdf

[46] Younossi, Obaid. & Project Air Force (U.S.). (2007). *Is weapon system cost growth increasing? : a quantitative assessment of completed and ongoing programs*. Santa Monica : RAND Project Air

[47] DeNeve, A. J., Ryan, E. T., Ritschel, J. D., & Kabban, C. S. (2015). Taming the HURRICANE of ACQUISITION COST GROWTH--Or At Least Predicting It. *Defense Acquisition Research Journal: A Publication Of The Defense Acquisition University*, *22*(1), 84-105

[48] Bolten, Joseph G., Robert S Leonard, Mark V. Arena, Obaid Younossi, and Jerry M. Sollinge. *Sources of Weapon System Cost Growth.* Santa Monica, CA: RAND Corporation, 2008. Rand report: MG-670-AF

[49] Browning, T. R., & Sanders, N. R. (2012). Can innovation be lean? *California Management Review*, *54*(4), 5–19.

[50] Miller, A., & Ray, J. L. (2015). Moving from BEST PRACTICES to STANDARD PRACTICES in Defense Acquisition. *Defense Acquisition Research Journal: A Publication Of The Defense Acquisition University*, *22*(1), 64-82.

[51] Copeland, E. et al The Effects of System Prototype Demonstrations on Weapon Systems Development

[52] Moore, N. (2013) Identifying and Managing Air Force Sustainment Supply Chain Risks
Retrieved from: http://www.rand.org/content/dam/rand/pubs/documented_briefings/DB600/DB649/RAND_DB649.pdf

[53] Augustine, N. R. (2015). Augustine's Laws and Major System Development Programs. *Defense Acquisition Research Journal: A Publication Of The Defense Acquisition University*, *22*(1), 8-34.

[54] http://comptroller.defense.gov/Portals/45/Documents/defbudget/fy2015/fy2015_Weapons.pdf

[55] DEFENSE ACQUISITIONS Assessments of Selected Weapon Programs, GAO-15-342SP http://www.gao.gov/assets/670/668986.pdf

[56] **DOT&E** (Operational Test & Evaluation) Reports**:** FY2014 Update

[57] Gerlovin and Zhao (2017), Empirical Study of DoD's 2015 Portfolio of Major Defense Acquisition Programs (MDAPs).

[58] http://www.acqnotes.com/acqnote/acquisitions/initial-operational-capability

[59] *Defense Acquisition System, 2015 Annual Report.* Washington, DC: Under Secretary of Defense, Acquisition, Technology, and Logistics (USD[AT&L]) 2015 https://www.defense.gov/Portals/1/Documents/pubs/Performance-of-Defense-Acquisition-System-2015.pdf

[60] Reasons Behind Program Delays Briefing http://www.dote.osd.mil/pub/presentations/ProgramDelaysBriefing2014_8Aug_Final-77u.pdf

[61] Reasons Behind Program Delays Briefing http://www.dote.osd.mil/pub/presentations/ProgramDelaysBriefing2014_8Aug_Final-77u.pdf

[62] Richard Aboulafia, Teal Group aerospace analyst, quoted in Jim Wolf, "U.S. to mothball gear to build top F-22 fighter," *Reuters.com*, December 13, 2011.

[63] https://www.washingtonpost.com/news/checkpoint/wp/2014/09/23/at-long-last-f-22-raptor-fighter-makes-its-debut-in-combat-over-syria/?utm_term=.5c69a7b38adc

[64] Gertler, J. (2009). Air Force F-22 Fighter Program: Background and Issues for Congress: RL31673. *Congressional Research Service: Report*, 1.

[65] GAO/NSIAD-98-67 F-22 Development Program http://www.gao.gov/assets/230/225271.pdf

[66] https://fas.org/sgp/crs/weapons/RL31673.pdf

[67] Casey, R. (2005) Casey, An Innovative Approach to Schedule Management on the F/A-22 Major Defense Acquisition Program (MDAP): Demonstration of Critical Chain Project Management https://theses.lib.vt.edu/theses/available/etd-05202005-143545/unrestricted/01casey-Phd-Dissertation-final.pdf

[68] *Lt Col John D. Driessnack and Maj David R. King, PhD, "*ANALYSIS OF COMPETITION IN THE DEFENSE INDUSTRIAL BASE: AN F-22 CASE STUDY

[69] Office of the Undersecretary of Defense for Acquisition acq.osd.mil 2001

[70] GAO-09-630 Federal Contracting

[71] http://www.lockheedmartin.com/content/dam/lockheed/data/aero/documents/f-35/collateral/f35_brochure_a11-34324e001.pdf

[72] http://www.lockheedmartin.com/content/dam/lockheed/data/aero/documents/f22_collateral/f22_brochure_a11-34324u001.pdf

[73] http://www.globalsecurity.org/military/library/budget/fy2010/sar/f-22_sar_25-dec-2010.pdf

[74] https://www.bloomberg.com/news/articles/2016-06-07/the-f-22-raptor-back-from-the-grave

[75] GAO/NSIAD-95-59 Tactical Aircraft

[76] GAO/T-NSIAD-00-58

[77] Drew, C. (2013, Feb. 27). Chief of F-35 Jet Program Rebukes Main Contractors. *The New York Times*. Retrieved from http://www.nytimes.com/2013/02/28/business/lockheed-criticized-by-f-35-jet-program-chief.html?ref=f35airplane&_r=1&

[78] Under Secretary of Defense (Comptroller). National Defense Budget Estimates for FY 2015. Report no. 6-D34CF28, 24 Mar 2014)

[79] **GAO-06-356 http://www.gao.gov/products/GAO-06-356**

[80] Weigel, J., Jahner, T., JSF interoperability initial capabilities and beyond – Presentation, Pp 1-25 Lockheed Martin Aeronautics Company Fort Worth (2009)

[81] Preble, Christopher (2002 Dec. 5) "Joint Strike Fighter Can a Multiservice Fighter Program Succeed?" *CATO.* Retrieved from: *http://object.cato.org/sites/cato.org/files/pubs/pdf/pa460.pdf*

[82] *New York Times (NYT 2001) "*Smart Shopping by the Pentagon Published": October 31, 2001 http://www.nytimes.com/2001/10/31/opinion/smart-shopping-by-the-pentagon.html?ref=f35airplane
[83] *New York Times (NYT 2001) "*Smart Shopping by the Pentagon Published": October 31, 2001 http://www.nytimes.com/2001/10/31/opinion/smart-shopping-by-the-pentagon.html?ref=f35airplane

[84] Lockheed Martin Corporation (LMC). (2003) F-35 Year in Review "A Letter From Our F-35 JSF Program Manager" by *Tom Burbage*

[85] AvionicsZone Volume 3 / No. 1 Spring 2003 http://www.honeywell.com/sites/docs/DZHZL77WSTHRHWKLQS9EKSY4C4A68QR9.pdf

[86] Ciralsky, A. 2013, Sept. 16 Will It Fly? *Vanity Fair.* Retrieved from http://www.vanityfair.com/news/2013/09/joint-strike-fighter-lockheed-martin

[87] Stewart, B. (2012, Dec. 13) Super-costly F-35s, a global wrecking ball. *CBS News*.

Retrieved from: http://www.cbc.ca/m/touch/news/story/1.1296106

[88] World News (2002) "BAE demands control of Royal Navy aircraft carrier contracts." Retrieved from:

http://article.wn.com/view/2002/06/27/BAE_demands_control_of_Royal_Navy_aircraft_carrier_contracts/

[89] Vucetic, S., & Nossal, K. R. (2013). The international politics of the F-35 joint strike fighter. *International Journal, 68*(1), 3-12. Retrieved from http://search.proquest.com/docview/1464752925?accountid=458

[90] Cook et al., 2003 "Assembling and Supporting the Joint Strike Fighter in the UK Issues and Costs" *RAND.org*. Retrieved from: http://www.rand.org/content/dam/rand/pubs/monograph_reports/2005/MR1771.pdf

[91] http://www.jsf.mil/downloads/documents/JSF_PSFD_MOU_-_Update_4_2010.PDF

[92] Lockheed Martin Corporation (LMC). (2014 Sep. 25) "F-35 International Integration: Q&A with Tom Burbage."

https://www.f35.com/news/detail/f-35-international-integration-qa-with-tom-burbage

[93] **http://www.state.gov/documents/organization/102378.pdf)**
[94] http://events.aviationweek.com/programexcellence/files/2008/LM)

[95] http://www.defense.gov/ 2014

[96] Source: http://odam.defense.gov/Portals/43/Documents/Functions/Organizational%20Portfolios/Organizations%20and%20Functions%20Guidebook/DoD_Organization_March_2012.pdf)

[97] SAF/AQE, (2013) 703-614-0969 "Headquarters U.S. Air Force Air Force Acquisition Mission Briefing"

– Presentation, Pp 1-24 SAF/AQE (August 2013) Retrieved from: http://ww3.safaq.hq.af.mil/shared/media/document/AFD-120828-030.pdf

[98] Gertler, J (2014). "F-35 Joint Strike Fighter (JSF) Program." Retrieved from: http://fas.org/sgp/crs/weapons/RL30563.pdf

[99] Congressional Budget Office, *The Budget and Economic Outlook: An Update.*(Washington, DC: September 2004).

[100] http://www.gao.gov/about/workforce/orgchart.html and http://www.gao.gov/dsp/SPDraft.pdf 2014
[101] Inspector General U.S. Department of Defense (IG US DoD 2013) Sept. 30, 2013 "Quality Assurance Assessment of the F-35 Lightning II Program" Retrieved from: **http://www.globalsecurity.org/military/library/report/2013/f-35-oig-report-2013-140.pdf**

[102] Supplychainbrain.com (2009) “In an Outsourced Supply Chain, Lockheed Keeps the Raw Materials Flowing.”

http://www.supplychainbrain.com/content/newsletters/global-trade-managment/january-2009/

[103] Mehta, Aaron 2013 “Lockheed, Mitsubishi Sign F-35 FACO Deal,” Defense News, June 21, 2013, available athttp://www.defensenews.com/article/20130621/DEFREG03/306210017/Lockheed-Mitsubishi-Sign-F-35-FACO-Deal

[104] Mehta, A. 2014, Dec. 17 “Japan, Australia Selected for Pacific F-35 Sustainment” Defense News.

http://www.defensenews.com/story/defense/international/asia-pacific/2014/12/17/japan-australia-selected-for-pacific-f-35-sustainment-/20548393/

[105] Parsons, D. 17 Dec 2014 “Australia, Japan tapped to maintain Asia-Pacific F-35s”

Source: Flightglobal.com http://www.flightglobal.com/news/articles/australia-japan-tapped-to-maintain-asia-pacific-f-35s-407232/

[106] Butler, A. (2012, Sept. 24). “Incoming F-35 Director Thumps Lockheed Leadership Incoming F-35 Director Thumps Lockheed Leadership”. ***Aviation Week & Space Technology.*** Retrieved from: http://aviationweek.com/awin/incoming-f-35-director-thumps-lockheed-leadership

[107] http://aviationweek.com/awin/lockmart-bracing

[108] World News (2002) “BAE demands control of Royal Navy aircraft carrier contracts.” Retrieved from:

http://article.wn.com/view/2002/06/27/BAE_demands_control_of_Royal_Navy_aircraft_carrier_contracts/

[109] Gertler (2012) F-35 Joint Strike Fighter (JSF) Program

[110] DOTE FY2012 F-35 Joint Strike Fighter (JSF) The office of Director, Operational Test and Evaluation (DOT&E) http://www.dote.osd.mil/pub/reports/FY2012/pdf/dod/2012f35jsf.pdf

[111] DOTE FY2012 F-35 Joint Strike Fighter (JSF) The office of Director, Operational Test and Evaluation (DOT&E) http://www.dote.osd.mil/pub/reports/FY2012/pdf/dod/2012f35jsf.pdf

[112] Gertler, J (2014). “F-35 Joint Strike Fighter (JSF) Program.” Retrieved from: http://fas.org/sgp/crs/weapons/RL30563.pdf

[113] defense-aerospace.com “F-35 Grounded After New F-135 Engine Problems” (Source: JSFNieuws.nl; published February 22, 2013) http://www.defense-aerospace.com/articles-view/feature/5/142927/the-long-history-of-f_35-engine-problems.html

[114] Cameron, D. (2014, Oct. 14) **“**Pentagon Resumes F-35 Deals as Engine Problem Fixed**.** Pratt & Whitney Wins New $592 Million Pentagon Deal**.”** http://www.wsj.com/articles/pentagon-resumes-f-35-deals-as-engine-problem-fixed-1413325294

[115] Majumdar, D. 2015 “America’s New Invisible Air Force.”

http://www.thedailybeast.com/articles/2015/02/02/america-s-new-invisible-air-force.html

[116] Sisk, R. (2013, Apr.10) “Lockheed promises tailhook fix to Navy’s F-35C”. *dodbuzz.com* Retrieved from: http://www.dodbuzz.com/2013/04/10/lockheed-promises-tailhook-fix-to-navys-f-35c/

[117] McMichael, W. H. (2010). JSF's power plant problem. *Navy Times*, , 20. Retrieved from http://search.proquest.com/docview/818667341?accountid=458

[118] U.S. Government Accountability Office, *DEFENSE ACQUISITIONS: Assessments of Selected Weapon Programs*, GAO-14-340SP, March 2014, p. 70.

[119] U.S. Government Accountability Office, *F-35 JOINT STRIKE FIGHTER: Problems Completing Software Testing May Hinder Delivery of Expected Warfighting Capabilities*, GAO-14-322, March 2014.

[120] **Ott, J. (2003). MONKEY Wrench. *Aviation Week & Space Technology*, *159*(4), 48-50.**
[121] Capaccio, T. (2013, Sept. 17). "F-35's Landing-Gear Tires Wear Out Too Soon, Pentagon Finds." Retrieved from: http://www.w54.biz/showthread.php?38-F-35-in-all-it-s-Variations/page121

[122] Majumdar, D. 2014. "Newest U.S. Stealth Fighter '10 Years Behind' Older Jets." http://www.thedailybeast.com/articles/2014/12/26/newest-u-s-stealth-fighter-10-years-behind-older-jets.html

[123] https://fas.org/sgp/crs/natsec/RL34026.pdf

[124] *http://dau.dodlive.mil/2015/01/02/the-effects-of-system-prototype-demonstrations-on-weapon-systems/*

[125] GAO-02-39 Joint Strike Fighter Acquisition
[126] Wicht, A. C., & Crawley, E. F. (2012). Relieving joint pain: Planning government acquisition of complex common systems.*Defense AR Journal*, *19*(3), 221-248. Retrieved from http://search.proquest.com/docview/1026948157?accountid=458

[127] http://www.cbsnews.com/news/f-35-60-minutes-david-martin/
[128] GAO-05-271"TACTICAL AIRCRAFT Opportunity to Reduce Risks in the Joint Strike Fighter Program with

Different Acquisition Strategy" *GAO* March 2005

[129] Martin, D. (2014 Feb. 16). Is the F-35 worth it? *CBS News*. Retrieved from http://www.cbsnews.com/news/f-35-60-minutes-david-martin/

[130] Schwartz, M. (2014, Apr. 30) Reform of the Defense Acquisition System.

Retrieved from: http://www.armed-services.senate.gov/imo/media/doc/Schwartz_04-30-14.pdf

[131] Steinfeld, J. (2009) UNITED STATES AIR SUPREMACY: GOVERNMENT PURCHASING AND SUPPLY CHAIN MANAGEMENT OF THE F-22 RAPTOR
[132] Packard Commission. A quest for excellence: Final report to the President. Washington, DC 1986.
[133] Office of the Deputy Chief Management Officer, "Strategic Management Plan: The Business of Defense FY2014-2015," 1 July 2013. [Online]. Available: http://dcmo.defense.gov/. [Accessed 12 August 2013].