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Business case analysis of the Joint Strike Fighter's alternate engine program

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THESIS

BUSINESS CASE ANALYSIS OF THE JOINT STRIKE FIGHTER'S ALTERNATE ENGINE PROGRAM

by

BethAnn Shick

December 2007

Thesis Advisor: Diana Petross
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ABSTRACT (maximum 200 words)

This thesis is a Business Case Analysis (BCA) of the costs, benefits, issues, and effects associated with maintaining the Joint Strike Fighter's (JSF) alternate engine program. It compares the competition (dual-source) and sole-source scenarios with regards to the development, production, and life-cycle sustainment of the JSF engine. The study also explores past Department of Defense (DoD) engine acquisition programs, including the highly successful dual-sourced F-16 engine, to establish a precedent for the potential monetary and non-monetary benefits that can result from competition. Finally, the BCA examines the non-quantitative impacts the program's cancellation will have on the DoD, its allies, and the industrial base.

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BUSINESS CASE ANALYSIS OF THE JOINT STRIKE FIGHTER'S ALTERNATE ENGINE PROGRAM

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ABSTRACT

The Joint Strike Fighter (JSF) program is the largest Department of Defense (DoD) military aircraft acquisition program to date. The JSF will serve the Air Force, Navy and Marine Corps, as well as many of our key international allies. In 1998, the DoD initiated the JSF alternate engine program in an effort to achieve cost savings, performance improvements, and other non-tangible benefits, similar to those achieved during the F-16 Great Engine War.

Congress has periodically debated the pros and cons of the JSF alternate engine program, coming to no real consensus on the topic. The most recent debate coincided with the FY2007 budget request, which resulted in the proposed cancellation and elimination of funding for the F136 program. While Congress eventually restored the majority of the program's funding for that year, the DoD has again proposed elimination of the program in its FY2008 budget proposal. With a program of this magnitude, the savings and performance benefits to be gained are significant. Before DoD decides to terminate the alternate engine program, a thorough and unbiased analysis should be performed to weigh the costs and benefits of the second engine program.

This thesis is a Business Case Analysis (BCA) of the costs, benefits, issues, and effects associated with maintaining the JSF's alternate engine program. It compares the dual-source and sole-source scenarios with regard to the development, production, and life-cycle sustainment of the JSF engine. The study also explores past DoD engine acquisition programs, including the highly successful dual-sourced F-16/F-15 engine, to establish a precedent for the potential monetary and non-monetary savings that can result from competition. Finally, the thesis examines the non-quantitative impacts the program's cancellation will have on the DoD, its allies, and the industrial base.

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LIST OF ABBREVIATIONS, ACRONYMS, SYMBOLS

ASTOVL: Advanced Short Takeoff and Vertical Landing

BCA: Business Case Analysis

BUR: Bottom-Up Review

CTOL: Conventional Takeoff and Landing

CV: Carrier Variant

DARPA: Defense Advanced Research Projects Agency

DoD: Department of Defense

FET: Fighter Engine Team

FLTS: Flight Test Squadron

FMS: Foreign Military Sales

FY: Fiscal Year

FYDP: Future Years Defense Plan

GAO: General Accountability Office

GE: General Electric

IDA: Institute for Defense Analysis

JAST: Joint Advanced Strike Technology

JSF: Joint Strike Fighter

KPP: Key Performance Parameters

LCC: Life-Cycle Cost

LRC: Line-Replaceable Unit

MRF: Multi-Role Fighter

NPV: Net Present Value

OMB: Office of Management and Budget

O&S: Operating and Support

PBL: Performance-Based Logistics

P&W: Pratt & Whitney

QDR: Quadrennial Defense Review

SASC: Senate Armed Services Committee

SDD: System Development and Demonstration

STOVL: Short Takeoff and Vertical Landing

UK: United Kingdom

USAF: United States Air Force

USD (AT&L): Under Secretary of Defense for Acquisition, Training, and Logistics

USMC: United States Marine Corps

USN: United States Navy

I. INTRODUCTION

A. SUBJECT OF THIS BUSINESS CASE

This thesis is a Business Case Analysis (BCA) of the costs, benefits, issues, and effects associated with maintaining the JSF's alternate engine program. It compares the dual-source and sole-source scenarios with regard to the development, production, and life-cycle sustainment of the JSF engine. The study also explores past DoD engine acquisition programs, including the highly successful dual-sourced F-16/F-15 engine, to establish a precedent for the potential monetary and non-monetary savings that can result from competition. Finally, the BCA examines the non-quantitative impacts the program's cancellation will have on the DoD, its allies, and the industrial base.

B. BACKGROUND

1. Joint Strike Fighter Program Description

Much of today's U.S. fighter inventory consists of aircraft developed and produced in the 1970s. Service-life exhaustion combined with escalating threats have resulted in all three services slowly retiring their current fighter aircraft. The British Harrier fleet, which first flew more than 30 years ago, is encountering similar problems. (Fulghum & Butler, 2006) The F-35 Joint Strike Fighter is being tagged to replace the aging aircraft, while also supporting the expanding requirements of a modern-day tactical fighter. Specifically, the U.S. Air Force will employ it as a multi-role aircraft to replace the F-16 and A-10, and complement the F-22. The U.S. Navy will use it as a "first day of war" strike fighter aircraft to complement the F/A-18E/F. The Marine Corps will use the Short Take-off and Vertical Landing (STOVL) F-35 variant to replace the AV-8B and F/A-18A/C/D. The United Kingdom's Royal Navy and Royal Air Force will use the multi-role aircraft to replace the Sea Harrier and Harrier GR7.

The origin of the JSF dates back to 1993 when a Bottom-Up Review (BUR) of the Multi-Role Fighter (MRF) and Advanced Strike Aircraft (A/F-X) programs concluded that a separate tactical aviation modernization program by each Service was not affordable. Both programs were cancelled, and in their place the BUR initiated the Joint Advanced Strike Technology (JAST) program. The goal of JAST was to establish the building blocks for the affordable development of the next-generation strike weapons system. After a review of the JAST program in 1995, the DoD dropped the "T" in JAST and the JSF program began to emerge. Continuing to grow, the JSF program was merged with the Defense Advanced Research Projects Agency (DARPA) Advanced Short Take-off and Vertical Landing (ASTOVL) program in 1995. The United Kingdom (UK), which was already collaborating on the DARPA ASTOVL program, joined the JSF program. In the years following, the JSF program grew to its current status as the DoD's largest military aircraft acquisition program to date. It is a joint, multinational program involving the Air Force, Navy, Marine Corps, and eight international partners, including the UK, Denmark, Norway, the Netherlands, Canada, Italy, Turkey, and Australia.

The vision of the JSF program is to "deliver and sustain the most advanced, affordable strike fighter aircraft to protect the future generations worldwide." (461 FLTS, 2006, p.3) The single-seat, single-engine aircraft is being designed to operate by itself or as part of a multi-platform operation. It will be able to rapidly transition between air-to-surface and air-to-air missions while still airborne. The design includes three variants: a conventional takeoff and landing (CTOL) variant for the Air Force; a carrier variant (CV) for the Navy; and a STOVL variant for the Marine Corps and UK. The JSF is being designed to meet a wide range of operational requirements. One of these requirements is an extended combat radius which will allow the pilot to be less dependent on air refueling and have significantly greater time on station. Table 1. lists some of the other Key Performance Parameters (KPP) of the F-35. The requirement differences between the variants are primarily due to the differences in their missions. For example, the STOVL variant will have a slightly shorter range because some of the space used to carry fuel is used instead to house the lift fan of the STOVL propulsion system. The main differences in the carrier variant are associated with carrier operations. For example its internal structure is very strong to withstand the high loading of catapult-assisted launches and tailhook arrested landings. The carrier variant also has larger wing and tailcontrol surfaces for low speed approaches to the carrier. Larger leading edge flaps and foldable wingtip sections provide a larger wing area for increased range and payload capacity.

Table 1. JSF Key Performance Parameters

KPP	USMC	USAF	USN	UK
Radio Frequency Signature	Low Observable			
Combat Radius (nautical miles)	450 nm	590 nm	600 nm	450 nm
Sortie Generation (Surge / Sustained)	4 / 3	3 / 2	3 / 2	3 / 2
Logistics Footprint	< 8 C-17 equivalent loads	< 8 C-17 equivalent loads	< 46,000 cu ft	< 21,000 cu ft
Mission Reliability	95%	93%	95%	95%
Interoperability	Meet 100% of critical, top-level Information Exchange Requirements Secure Voice and Data			
Vertical Lift Bring Back	2 x 1K JDAM, 2 x AIM-120 with reserve fuel	N/A	N/A	2 x 1K JDAM, 2 x AIM-120 with reserve fuel
Maximum Approach Speed	N/A	N/A	145 knots	N/A

From: GAO-06-391, 2006.

2. Joint Strike Fighter Propulsion Acquisition

The future financial investment potential of the JSF propulsion system is significant considering the number of aircraft engines and spare parts to be purchased, along with lifetime support to sustain the engines. It is expected that the DoD will develop, procure, and maintain over 2,443 JSF aircraft of the program's life-cycle. This doesn't include the 2,000 to 3,500 additional aircraft expected in international sales. (Sullivan, 2007) Given the scope of the program's potential, Congress first expressed concern over a lack of engine competition on the JSF program at the fiscal year (FY) 1996 defense authorization conference. In that year, Congress directed the DoD to ensure the program "provides for adequate engine competition." Then in FY1998 it further directed the DoD to certify that "the Joint Strike Fighter Program contains sufficient funding to carry out an alternate engine development program that includes flight qualification of an alternate engine in a joint strike fighter airframe." (Bolkcom, 2006)

In 1998, and again in 2002, DoD program management advisory groups conducted studies to determine the advantages and disadvantages for the alternate engine program. In both years the advisory groups determined that "developing an alternate JSF engine had significant benefits in the areas of contractor responsiveness, industrial base, aircraft readiness, and international participation." (Sullivan, 2007, p.3) The advisory groups also reported finding marginal benefits in the areas of cost savings and the ability to make future engine improvements.

In August 2005, DoD awarded a $2.1 billion contract to the General Electric (GE) and Rolls-Royce Fighter Engine Team (FET) for the development and demonstration of an alternate engine system, designated the F136. The requirement is for the F135 and F136 engines to be physically and functionally interchangeable. They will share common modules, such as the exhaust and lift system, and will use many of the same components. All three JSF aircraft variants will be able to use either engine. The F136 development program, which lags the F135 program by approximately five years, will be ready for procurement competition beginning in the year 2013. (Amick, 2005)

The competitive sourcing strategy for the JSF engine was succinctly summarized by Michael Sullivan, the Director of Acquisition and Sourcing Management at the Government Accountability Office as follows:

> According to current JSF program plans, beginning in fiscal year 2007, the program office will award the first of three annual production contracts to Pratt & Whitney for its F135 engine. In fiscal years 2010 and 2011, noncompetitive contracts will be awarded to both Pratt & Whitney and to the Fighter Engine Team for the F136 engine. Beginning in fiscal year 2012, contracts will be awarded on an annual basis under a competitive approach for quantities beyond each contractor's minimum sustaining rate. Full-rate production for the program begins in fiscal year 2014 and is expected to continue though fiscal year 2034. (Sullivan, 2007, p.4)

Congress has periodically debated the pros and cons of the JSF alternate engine program, coming to no real consensus on the topic. The most recent debate coincided with the FY2007 budget request, which resulted in the proposed cancellation and elimination of funding for the F136 program. While Congress eventually restored the majority of the program's funding for that year, the DoD has again proposed elimination of the program in its FY2008 budget proposal. The advocates of the cancellation cite a savings of $1.8 billion over the Future Years Defense Plan (FYDP) with little operational risk. Critics argue that the cancellation decision is being driven by immediate budget pressures rather than an analysis of the long term positive and negative aspects of the program. Supporting the claim, Secretary of the Air Force, Michael Wynne, is reported to have said that "the idea of canceling the F136 came up during the QDR, in the course of attempts to identify ways to save costs at the Pentagon." (Bolkcom, 2006, p.2)

3. Pratt & Whitney F135 Engine Description

The F135 engine, which is being developed specifically for the JSF, is an evolution of the F119-PW-100 turbofan engine that currently powers the F-22 Raptor. It integrates the proven F119 core with a high-performance six-stage compressor, single-stage turbine unit and new low-pressure stool. It also features an advanced prognostic and on-condition management system that provides "maintenance awareness, autonomic logistic support, and automatic field data and test systems." (P&W, 2007)

The engine is currently in the System Development and Demonstration (SDD) phase. The first CTOL F135 engine test occurred in October 2003 and the first STOVL engine test followed in April 2004. The first flight of the CTOL-variant JSF aircraft, powered by the F135 engine, took place in December 2006. To date, over 2,000 hours have been accumulated on the F135 test engines. (P&W, 2007)

The F135 engine represents a maintenance-focused design. According to the company's website, the engine has approximately 40 percent fewer parts, which improves the engine's supportability, maintainability, and reliability. In addition, all line-replaceable components (LRCs) on the engine can be removed and replaced with a set of six common hand tools. Finally, the F135 has a 50 percent lower infrastructure support requirement compared to current engines. (P&W, 2007)

4. General Electric / Rolls Royce F136 Engine Description

The F136 engine, which lags the F135 in development by approximately five years, has had the advantage of being able to design the engine to match as closely as possible the final aircraft configuration. The F136 engine consists of a three-stage fan, five-stage compressor, a three-stage low-pressure turbine section, single-stage high-pressure turbine, and a radial augmentor. The F136 team is cooperating with the F135 team in the development of common propulsion system components.

The first F136 CTOL engine was successfully tested in July 2004 and testing on the first F136 STOVL engine began in Feb 2005. First flight of the F136 engine on a joint strike fighter aircraft is planned for 2009. (GE, 2007)

The F136 engine is being jointly developed by GE and Rolls-Royce. In 2002, the two companies formed the "Fighter Engine Team" company. Its charter is to develop, deploy, and support the F136 engine for the JSF program. GE, which has responsibility for 60 percent of the engine program, is developing the compressor, coupled turbine, controls and accessories, structures, and the augmentor. Rolls-Royce, with 40 percent of the program, is responsible for the fan, combustor, low-pressure turbines and gear boxes. (GE, 2007)

C. SCOPE AND METHODOLOGY

This study uses a cost-benefit structure to examine and compare the quantitative and non-quantitative factors involved. The financial costs are compared using life-cycle cost analysis adjusted for the time value of money. Sources of data include the JSF joint program office, congressional budget data, data collected through government-sponsored assessments, contractor provided data, and historical data from other relevant engine acquisition programs. Data collected are analyzed with the intent of quantitatively comparing, where possible, the costs and benefits of the alternate engine program. Qualitative data are used to complete the assessment of overall costs and benefits.

D. GOVERNING MANDATES

To achieve the goals of affordability, supportability, and safety, the JSF program intends to use a combination of competition, contract incentives, and performance-based logistics (PBL) to reduce engine operating and support costs. The DoD has entered into numerous PBL contracts in recent years, including on the C-17 and F/A-18 programs, and intends to use PBL extensively in the JSF program. (Ahern, 2007)

As directed by the 2004 Quadrennial Defense Review (QDR), the military departments have adopted a performance based logistics (PBL) strategy to increase weapon system readiness through the use of integrated logistics chains and public/private partnerships. To facilitate "best value" assessments of product support strategies on new and legacy systems, the office of the Undersecretary of Defense developed a set of consistent BCA guidelines to be used when assessing product support strategies. These guidelines were used in this assessment of the alternate engine program to support the Joint Strike Fighter. The BCA guiding principles applied in this study are listed below. (USD(AT&L), 2004)

- All BCAs will be based on warfighter-stated performance requirement(s), documented in Performance Based Agreements (PBAs).
- BCAs will be conducted to assess changes from existing product support strategies for legacy systems and to support the product support strategy for new weapon systems. Over time, BCAs will need to be updated or repeated to validate the approach taken to support future plans.
- BCAs will evaluate all services or activities needed to meet warfighter performance requirements using "best value" assessments. Best value is the expected outcome that, in the Department's consideration, provides the greatest overall benefit in response to requirements. The assessments will include cost per output, performance measures, life cycle costs, and risk management. The value added in terms of benefits and outcomes of all services and activities will be identified.

- BCAs will continue through the life cycle process with oversight to ensure reassessment at appropriate trigger points, including life cycle costs (LCC) updates; Reduced-Total Ownership Costs activities; and/or continuous improvements actions. The Military Services will evaluate product support strategy performance at appropriate decision points.

- The cost and performance baselines for legacy systems will be determined by historic experience and costs. The cost baseline will include all appropriate government and/or contractor costs, including indirect costs, overhead, and handling fees.

- BCAs will include risk assessment of expected performance, supply chain responsiveness, and surge capabilities. Consideration of performance and cost risk will explicitly consider contract versus organic risk management, financial accountability, and recovery actions. The risk assessment should address the probability of and confidence level of the following events occurring: poor performance, and cost growth.

- BCAs will be developed using information provided by all appropriate product support stakeholders, including government and industry providers. In order to maintain a competitive environment, industry participation will be determined in accordance with the Federal Acquisition Regulation (FAR).

- BCAs will be conducted using analytic tools approved by the Services.

II. LITERATURE REVIEW

A. INTRODUCTION

Sourcing strategy has been a frequent topic of research over the years. In examining these studies, the one clear conclusion is that there is not one clear answer. There is no panacea. But there does appear to be agreement that the most effective sourcing strategy is dependent on the characteristics and scope of the program, and the specific contractors involved. In this section, research comparing sole-source, multiple sourcing, and parallel sourcing strategies is presented in an attempt to draw out general trends and situational factors that may aid in the examination of sourcing for the JSF engine. But first, a real-world and particularly relevant example is presented regarding the first Great Engine War between GE and Pratt & Whitney. For all practical purposes, the competition strategy used in that engine program is considered a success, despite the fact that it has not been repeated in the acquisition of any other engine or major weapon system. The Great Engine War case study is juxtaposed with the JSF program to reveal the many similarities and lessons learned that should be useful in making the decision to adopt or cancel the JSF alternate engine program.

B. F-16 PROPULSION ACQUISITION–THE GREAT ENGINE WAR

1. Background

In March 1970, after a rigorous source selection process, Pratt & Whitney was awarded the contract to design, develop, and test the F100 engine for the Air Force's F-15 aircraft. Pratt & Whitney was chosen over GE in large part because it was felt the company had a better understanding of the engine/inlet compatibility phenomena that had been plaguing the F-111 at the time. Then in 1975, the Air Force selected General Dynamics to produce the F-16. Since the Air Force planned to power the F-16 with Pratt & Whitney's F100 engine, it found itself completely dependent on Pratt & Whitney for all of its high performance fighter engine needs. (Camm, 1993)

Initially the F100 engine was well received by pilots who particularly liked the maneuverability, acceleration, and rate of climb the F-100 engines afforded them. But as the flying hours accumulated, major problems began to arise. The two most significant were "stall stagnation" and short life-cycles with high maintenance costs. Stall stagnation occurred under certain operating conditions and required pilots to shut down and restart the engine in flight. While this was a danger in the two-engine F-15, it was a significant safety of flight issue in the single-engine F-16. Additionally, the engine's short cycle time between depot overhauls and high maintenance requirements drove up its operating costs. (Camm, 1993)

In his book, *The Air Force and the Great Engine War*, R.W. Drewes (1987) characterized Pratt & Whitney's reaction to the Air Force's attempts to get the problems with the F100 engines resolved as "stubborn resistance." The Air Force's perception was that Pratt & Whitney was "more interested in generating profits through contract changes than in making the engine perform properly." (Drewes, 1987, p.55) The company contended that they were under no contractual obligation to fix the problems since the F100 had been designed and qualified to the Air Force's specifications. If the Air Force wanted to add requirements to improve performance, those changes represented an additional tasking and were subject to additional charge. Although Pratt & Whitney did slowly improve the F100, it was still unreliable and costly to operate and maintain. Relations between the Air Force and Pratt & Whitney deteriorated quickly and the Air Force began looking for alternative solutions.

In a RAND study comparing the two engines, author F. Camms (1993) described the problems GE was facing during the same time period. It had lost out to Pratt & Whitney in the competitions to provide engines for the F-14, F-15, and F-16; leaving the company essentially locked out of the U.S. market for fighter engines. In 1975, in a last-ditch effort to get back in the market, GE used its own funds to develop a demonstrator engine called the F101X. The company hoped to use the engine to persuade the Navy to re-engine its F-14s, but the Navy was not interested. The Air Force, however, was interested. It was exactly what they were looking for—a possible alternative to the F100 and, more importantly, a potential threat they could use to get better performance out of Pratt & Whitney. (Camm, 1993)

The Alternate Fighter Engine competition was officially launched, once again pitting Pratt & Whitney against GE. Throughout the competition, according to Camms, Pratt & Whitney maintained is attitude of defiance, while GE strove to be a responsive as possible to the Air Force's needs. On February 3, 1984 the decision was announced—a split award, 75 percent (or 120 engines) to GE and 25 percent (or 40 engines) to Pratt & Whitney. In addition, this represented only the first year's buy. The Air Force would re-compete the contract each year, allowing contractors to improve the terms of their offers on a wide variety of factors.

In a press release, the Air Force stated that GE had offered "lower overall support costs, had ensured better procurement of spare parts through an outstanding plan for second sourcing and re-procurement of engine components, and had offered an excellent warranty. " (Drewes, 1987, p.126) In essence, GE had been more responsive to the Air Force's requirements. But even more significant was that both contractors' proposals brought substantial benefits to the engine program in the areas of engine operability, supportability, and performance. The new engines would be warranted to be twice as durable as the current F100, free from rapid-throttle-movement worries and from afterburner flameouts, and almost completely relieved from needing extensive ground trimming. In addition, support costs were expected to decrease by 50 percent. (Drewes, 1987)

Although typical development issues arose throughout the years, both development programs produced engines that operated as expected, on schedule, and without cost overruns. The annual competitions brought improvements in many areas, most notably a 30-50 percent reduction in cost per flight hour, maintenance man-hours, and engine removals per 1000 flight-hours. (Camm, 1993) Operational benefits included unrestricted throttle movement, improved war-time surge capability, improved thrust, and lower fuel consumption. Through the use of competition, the balance of power had shifted to the Air Force, allowing it to get many contractual changes at no cost to itself or to trade one change for another on more favorable terms.

2. Research Studies of the Great Engine War

In his Naval Postgraduate School master's thesis titled, "The Next Great Engine War: Analysis and Recommendations for Managing the Joint Strike Fighter Engine Competition", Karl Amick conducted a review of the research studies done in the years following the Great Engine War in an effort to apply the lessons learned to future engine competitions. His research centered on six representative studies. He found that while each study had a slightly different focus, they all concluded that competition was the "right thing to do." Amick highlights the following themes across the six studies:

- The competition was a great success
- Cost savings was not a factor in the success
- Competition improved manufacturer responsiveness
- Competition should be pursued in future acquisition programs

For the most part, the studies he examined were unanimous in all categories except cost savings. Amick's findings are summarized in Table 2. **Error! Reference source not found.**A complete description of his findings can be found in Amick, 2005.

Table 2. Summary of Research Studies on the Great Engine War

Summary of Studies									
Reports	Successful Competition?		Cost Saving?			Responsiveness?		Future Applications?	
	Yes	No	Large	Small	Inconclusive	Improved	Unimproved	Yes	No
Metamorphosis of Business Strategies and Air Force Acquisition Policies in the Aerospace Propulsion Industry: Case Study of the "Great Engine War" (Jon Steven Ogg)	√				√	√			√
The Air Force and the Great Engine War (Robert W. Drewes, Col, USAF)	√			√		√		√	
Analysis of the Air Force and the Great Engine War (Victoria Mayes)	√				√	√		√	
Alternate Fighter Engines Competition Study (Jeffrey A. Hoover)	√			√		√		√	
The Development of the F100-PW-220 and F110-GE-100 Engines: A Case Study of the Risk Assessment and Risk Management (Frank Camm)	√				√	√		√	
Fighter Engine Competition: A Study of Factors Affecting Unit Price (Brian R. Leginus)	√				√	√		√	

From: Amick, 2005.

3. Lessons Learned and General Observations

The following lessons learned and general observations can be made regarding the Great Engine War between GE and Pratt & Whitney:

Maintaining competition, as the Air Force did in this case, may not always be possible. Competition will work best on programs with high total volume over the life of the program and high annual production rates. These factors are necessary in order to justify the fixed costs of supporting two manufacturers. The precise breakeven point, where the cost of single versus multiple sources is equal, will vary depending on the program and the contractors involved. (Drewes, 1987)

Competition shifts the balance of risk in a development program. In essence, it shifts the perceived risk away from the government and onto the contractors. With each contract competition, the government can redistribute market share among the contractors, thus increasing the contractors' risks while at the same time decreasing the government's risk by reducing its dependence of under-performing contractors. (Camm, 1993)

Competition can increase contractor responsiveness to government or military service needs. GE demonstrated this during the first year production competition. In addition, when unexpected events occur, the government can expect greater success in getting an attractive settlement, thereby reducing the probability and size of negative effects of contractor performance. (Camms, 1993)

Competition reduces the likelihood of opportunistic or exploitive behavior on the part of the contractor. This creates a lower risk situation for the government, thereby reducing the cost of monitoring contract compliance. While it does not completely eliminate the need for monitoring, it greatly simplifies it and allows for more flexible and creative program management. (Camm, 1993)

While the use of competition discourages opportunistic contractor behavior, it does not completely eliminate it. In the case of the Great Engine War, it became clear to the contractors that the Air Force valued competition enough that it was not willing to withdraw completely from its relationship with either GE or Pratt & Whitney. In effect, both contractors came to realize that they could engage in some opportunistic behavior without fear of the Air Force withdrawing entirely. An example of this occurred during the first year production competition when Pratt & Whitney priced its offer to strongly encourage the Air Force to buy all of its engines from Pratt & Whitney. It accomplished this by setting it pricing scale in such a way that any engines purchased from GE would significantly increase not only the cost of each Pratt & Whitney engine, but the warranty price too. In order to keep the competition going and keep both contractors under pressure, the Air Force ended up accepting the increase in price. (Camm, 1993)

Competition is not without costs. In the Great Engine War, full-scale development of two engines essentially doubled the cost to the government of creating the capability. While certain economies were created by the competition, they did not fully offset the costs incurred in developing two engines. The real financial benefits come during the production lifespan. (Camm, 1993)

4. Key Differences between JSF and F-16 Engine Acquisitions

Can the success achieved during the Great Engine War be repeated on the JSF program? The programs have many similarities. For example, both the JSF and F-16 programs have the advantage of high domestic and international sales volume. This contributes significantly to each programs' affordability. When it comes to choosing the most beneficial acquisition strategy for the JSF engine, however, decision makers should pay careful attention to the differences between the programs. In his master's thesis, Amick (2005) discusses the key differences between the programs and the potential positive and/or negative impacts of each. These are summarized below.

The Great Engine War was born out of dissatisfaction with Pratt & Whitney's performance on the F100 engine contract. The JSF engine competition, on the other hand, was congressionally mandated from the outset. Each contractor has been able to plan accordingly, and in the end, without the same motivations that drove the Great Engine War, contractor responsiveness to the services' needs may be lacking.

The JSF requirement is for engines that are physically and functionally interchangeable. This was not the case on the F-15 and F-16 programs. The net effect may be a reduction in number of performance gains as the two competitors no longer feel the "performance race" pressure they did during the Great Engine War. On the JSF program, the two competitors will need to cooperate with each other to extent much greater than they did in the past engine war. This will surely stunt performance growth over the lifetime of the program.

The development of the two JSF engines has been referred to as "Coopetition"--an amalgamation capturing the ideas of the *cooperation* of the two companies in design integration and then, later, the *competition* when production begins. This may have the net positive effect of reducing the development cost of the F136 since its design will be finalized after both the F135 and aircraft designs have been stabilized.

Since the two engines will be physically and functionally interchangeable, only one support system will be required to meet the customer's maintenance, supply, and training needs. In fact, all the Lockheed Martin flight-line support equipment is already designed to support both engines. This reduces the logistic impact of having two engines for the same aircraft. It also allows the customer (the government) to easily transition from one engine variant to the other. In essence this means there will be a little to no switching cost to go from one engine to the other.

The JSF engines will be the first with onboard Prognostic and Health Management sensors, allowing maintainers to predict engine component failure and react proactively. This capability will improve aircraft availability and help streamline maintenance efforts. This will have the positive effect of reducing the engines' development risk and support costs.

C. COMPETITIVE VERSUS SOLE-SOURCE PROCUREMENTS

1. Competing Points of View

The most obvious take away from the research comparing source strategies is that there is much disagreement regarding the advantages of competitive sourcing. When it comes to choosing a sourcing strategy, the tradeoff is between the benefits gained from competition and the costs associated with having multiple sources. The benefits of competition include the potential for lower price, improved quality, and competitive pressures that speed the learning process. On the other hand, the costs of utilizing multiple sources include tooling and start-up costs at the second facility, diminished economies of scale resulting from split purchases, and a possible slowdown in learning-curve effects due to a lack of competitive pressure.

W. Edwards Deming leads the group of practitioners advocating sole-source procurement. Point Four of Deming's celebrated Fourteen Points urges buyers to minimize total cost by working with a single supplier. He states that "a long-term, tightly integrated, relationship with a sole source is the route to improved quality and lower total cost." (Richardson and Roumasset, 1995, p.71) It has also been traditional Japanese practice to establish exclusive long-term relationships with a single supplier. They argue that the added cost of establishing these relationships of increased buyer-supplier coordination will be more than offset by the reduced costs of rework, scrap, and warranty claims and the added benefit of higher-quality products.

M. Porter leads the argument for competitive sourcing. He recommends competing multiple sources against one another to "assure low price, high quality, and the lowest total cost." (Richardson and Roumasset, 1995, p.72). Porter recommends the following:

- Increase the buyer's bargaining power by keeping the number of sources sufficient to ensure competition but small enough to be an important buyer to each source
- Select suppliers who are especially competitive with each other and divide purchases between them
- Vary over time the proportion of purchases awarded to suppliers to ensure they do not view it as an entitlement
- Solicit occasional proposals from new suppliers in order to test market prices and gather technological intelligence

Advocates of competitive sourcing claim the problem with investing so heavily in a sole source is that is increases the buyer's dependence on the supplier. The funds invested to establish the relationship are sunk costs which equate to switching costs that reduce the buyer's ability to threaten the supplier with a loss of business. With little or no competitive pressure, and without the threat of losing business, the suppliers can exert power over the buyer by way of increased prices, lower quality, and lower performance.

2. Competitive versus Sole-Source Procurements with Regard to Cost Savings

Over the years, there have been numerous studies on the benefits of competitive procurements with specific regard to cost savings. In his paper titled, "A Review of the Literature: Competition versus Sole-Source Procurements", W.N. Washington attempts to gather and compare the results of these studies in order to draw useful conclusions for modern day acquisitions. In researching the topic, he discovered two general categories of studies on the topic: simple comparison studies and multiple factor analyses. In the simple comparison studies, cost savings were consistently found associated with competition programs, although the amount of savings varied widely from 10 to 67 percent. Washington concludes that these studies are of limited value in assessing cost savings in competitive procurement because they "failed to take into account all the costs associated with the competition process, such as the cost of conducting the competition, setup costs for the new contractor, special tooling and government-furnished equipment, and the time value of money to set up the new contractor." (Washington, 1997, p.174) Even given these omissions, and the inconsistency of results between the studies, there did appear to be a general level of cost savings associated with competition, particularly, he found, regarding the procurement of spare parts.

The second category of studies Washington examined, multiple factor analyses, were more comprehensive in their handling of the factors affecting procurement costs. Many of the studies he examined were master's thesis from the Air Force Institute of Technology. Unlike the earlier, simpler studies, these studies were less eager to declare grand estimates of cost savings associated with competition. And in some instances, competition was not found to be beneficial. The general conclusion was that cost savings in competitive procurements was dependent on many factors, including the maturity of the technology or system being acquired, the number of qualified suppliers, the complexity and scale of the item being acquired, and the size of the government's purchase. The studies also discovered several industrial base issues influencing production costs that should also be considered in the decision to pursue sole or competitive sourcing, including production rate, production quantity, time required to stabilize design, capacity utilization, requirement for special production skills or facilities, and proprietary data rights. (Washington, 1997) In addition to these costs, the studies found several costs associated with competition that must be taken into account when determining if competitive sourcing will really save money. These include:

- Additional source selection costs incurred by both the government and the contractor
- Second source development costs, such as special tooling and test equipment, and the cost of transferring technical data to the new source
- Learning curve losses if quantities are split between several sources
- Increased contract administration costs
- Increased technical data administration costs incurred to maintain and update more than one source
- Company-funded research and development costs that must be recaptured by the original developer

Based on his research, Washington concluded the following. First, there appears to be some rationale supporting competitive sourcing, but not all competitive procurements produce savings; and those that do seem to produce less than 25 percent savings. Second, there are several factors that must be considered when choosing between sole and competitive sourcing. These include production quantity, item complexity, capacity utilization of the industry involved, the requirement for special skills, and the maturity or availability of data regarding the item being procured. Third, decision makers should perform a cost-benefit analysis before choosing competitive sourcing to determine if any real cost savings will result. Finally, Washington concluded that competition is "probably the best choice for acquisition of low-dollar-value spare parts required in considerable quantity, or for component parts and systems that are jointly and extensively used by private industry." (Washington, 1997, p.183)

3. The Effects of Sole-, Multiple-, and Parallel-Sourcing on Supplier Performance

In their paper entitled, "Sole Sourcing, Competitive Sourcing, Parallel Sourcing: Mechanisms for Supplier Performance," authors Richardson and Roumasset (1995) use an agency theory model to determine the conditions under which the three selected sourcing strategies appear to be superior. The first strategy is the traditional sole-sourcing strategy. To represent competitive sourcing, the authors differentiate between multiple and parallel sourcing. Multiple sourcing occurs when two or more sources compete against one another to supply the same item. Parallel sourcing, which originated from Japanese practice, occurs when a firm simultaneously maintains a relationship with more than one supplier producing the same or similar items. Normally only used by large buying firms, parallel sourcing's appeal is that it appears to provide coordination and quality control benefits normally attributed to sole sourcing, while maintaining competitive pressures comparable to multiple sourcing.

In their study, Richardson and Roumasset analyzed each sourcing strategy using agency cost theory. This theory asserts that firms will organize in such a way as to minimize total agency costs. In the realm of buyer-supplier relationships, agency costs refer to the costs associated with activities undertaken to ensure supplier performance, as well as the costs incurred if the supplier performs badly. These activities include investment in the buyer-supplier relationship, monitoring performance, and administering rewards and penalties. In their analysis, Richardson and Roumasset define the superior sourcing strategy as the "one that provides the lowest total agency costs and therefore the greatest profit to the buyer." (Richardson and Roumasset, 1995, p.74) Adjustable parameters in their model included: labor price, unit production cost, cost of coordination, cost of inspection, fixed setup cost, other setup costs, cost of handling returns, and fixed production costs.

Richardson and Roumasset concluded that the best sourcing strategy depends on the situation and that increased buyer-supplier coordination combined with competition appears to be the most cost-effective mechanism for achieving high supplier performance. They found that no one method works in all circumstances, but they were able to make some general observations (Richardson and Roumasset, 1995):

- When the priority is supplier performance (e.g. quality), parallel sourcing is superior to sole sourcing. If setup (switching) costs are also high, multiple sourcing is also superior to sole sourcing. In general, when poor supplier performance is even modestly costly, either parallel sourcing or multiple sourcing provides a higher level of supplier performance at a lower total cost.
- The added costs of coordinating with more than one supplier are offset by the increased effectiveness resulting from competitive pressure. Coordination combined with competition seems to be the most cost-effective mechanism for achieving high supplier performance.
- In general, parallel sourcing is superior to multiple sourcing. This is because parallel sourcing provides improved buyer-supplier coordination while still retaining the credible threat of lost business (i.e. switching to another supplier).
- If high fixed setup costs cannot be avoided, the advantage may shift to sole sourcing. This is because the high cost of setting up parallel or multiple suppliers may outweigh the advantages to be gained from competition. The authors point out, however, that supplier performance (e.g. quality) in this sole sourcing scenario is unlikely to be superior to parallel or multiple sourcing.

Although they seem to favor the competitive sourcing strategies, the authors pointed out three factors that, if present, would help ensure high quality performance from a sole source. The first is "reputation effects" where a supplier may value a good reputation and as a result provide high performance in order to increase business with this or other potential buyers. The second is a situation where the supplier is in a highly concentrated industry where they are extremely dependent on the buyer's business. Finally, the sole-source supplier is likely to provide high quality performance if there is a situation of mutual dependence where the supplier's performance strongly affects the buyer's competitiveness, which in turn strongly influences the supplier's business. In other words, "if the supplier's fortunes are strongly tied to the buyer's, there may be an incentive for better performance." (Richardson and Roumasset, 1995, p.81)

D. CHAPTER SUMMARY

From the research reviewed in this section it is clear that competition has the potential to yield significant benefits in the acquisition of defense weapons systems. The magnitude of the benefits, however, is highly dependent on several variables regarding the particular type of program, the political situation at the time, the state of the supplying industry, the contractors themselves, and the size and duration of the acquisition. The conclusion drawn from the research that is more applicable here is that a cost-benefit analysis should be conducted to assess the real savings that can be obtained from the use of competitive sourcing.

III. METHODS AND ASSUMPTIONS

A. ALTERNATIVE SOLUTIONS AND DATA

Two primary solutions are considered in this business case analysis. The first is a sole-source scenario in which Pratt & Whitney is awarded a sole-source contract for the duration of the JSF program. The second is a competitive scenario in which contracts will be awarded based on an annual competition approach starting in 2012. Furthermore, since learning curve cost savings can be a significant factor in production costs, and since the amount of learning curve cost savings is dependent on the number of units produced, the specific competitive scenario evaluated is the “worst case” scenario of 50:50. In other words, Pratt & Whitney produces an average of 50% of the aircraft engines and GE/Rolls-Royce the other 50%. In the Sensitivities, Risks, and Conditions chapter, the competitive scenario of 70:30 is evaluated to determine the impact a learning rate advantage would have on the results. The following table summarizes the scenarios examined in this analysis.

Table 3. Summary of Production Scenarios Considered

Scenario	Description	Percentage of Production	
		Pratt & Whitney	GE/Rolls-Royce
1	Sole-Source	100	0
2	Competition – 50:50	50	50
3	Competition – 70:30	70 30	30 70

B. SCOPE OF THE CASE

Data used in the computation of life-cycle costs was obtained from the JSF Joint Program Office (JPO) and from studies performed by the General Accounting Office (GAO), Institute for Defense Analysis (IDA), and Cost Analysis Improvement Group. At the time of this study, the JSF JPO was preparing for LRIP contract negotiations with GE and Pratt & Whitney. Due to the proprietary nature of the data used in the negotiations, the program office could not provide updated cost or learning curve estimates. Where necessary, reasonable assumptions are made (e.g. the learning rate was estimated at five percent). All assumptions are conservative in nature and are in keeping with those used in other studies. All assumptions are clearly annotated. The comparison of life-cycle costs offered here attempts to present the data in an unbiased manner using reasonable assumptions of industry and market behavior.

C. FINANCIAL METRICS

1. Life-Cycle Cost Analysis

The production scenarios included in this analysis are compared using life-cycle cost (LCC) analysis. LCC includes the total cost of the system and any relevant supporting activities throughout the system's planned life cycle. In the case of the alternate engine program, this includes all future costs associated with research, design and development, engine production, aircraft fielding, operation and support, and retirement and disposal. Since the purpose is to compare the alternatives, rather than calculate a total cost, the cost factors that would be the same under either scenario are eliminated. As a result, the scenarios are compared based on the following cost factors:

- Remaining system development and demonstration costs
- Production costs – including all recurring unit fly-away costs
- Initial standup costs – including spares, training, manpower requirements, and depot standup

2. Learning Curve Savings

The basic concept behind the learning curve is that as the total volume of units produced doubles, the cost per unit decreases by a constant percentage. These cost reductions occur for several reasons, such as increased familiarization with production procedures, improvements in work flow, and improved tooling. Although there are several conditions and situational factors that may affect the rate of learning, and hence the amount of cost savings generated, in general the more units that are produced, the more efficient production becomes. In terms of the JSF engine program, in a sole-source arrangement one contractor will produce all of the engines. By having all of the production activity, that contractor will achieve the highest achievable learning rate. The more production is split between two contractors, the fewer number of engines each will produce, and hence the fewer number of engines each can "learn" from. To represent these learning rate improvements in the life cycle cost comparison, a conservative five percent learning rate is used.

3. Net Present Value

The net present value of the life-cycle costs is computed to reflect the time value of money. A discount rate of seven percent is used based on Office of Management and Budget (OMB) guidance on conducting benefit-cost analysis of Federal Programs. (OMB, 2006) Discount periods are in years to reflect the annual contract competition.

D. MAJOR ASSUMPTIONS

The following assumptions are made during the calculation and comparison of life-cycle costs:

- Sunk costs are not included in the comparison. Most notably this includes monies already spent on system development and test. Sunk costs are defined as those costs incurred through FY2007.
- Calculated costs reflect U.S. only costs but include the production quantity benefits of the anticipated foreign military sales. Production costs and

learning rate savings are calculated based on 3089 engines. This includes 2443 engines for the U.S. aircraft, and 646 engines for the aircraft sold via foreign military sales. Initial spares are included under initial standup costs.

- For ease of comparison with other studies, dollar amounts reflect fiscal year (FY) 2002 dollars.
- The engine production cost is $10.569 million in FY2007 dollars. (SAF/FMB, 2006) When adjusted to FY2002 dollars, this amount is $9.12 million. This figure is used for both the F135 and F136 engines.
- Initial standup costs include initial spares (assumed to be 15 percent), training, manpower, and depot standup.
- The engine competition and its anticipated cost benefits begin in FY2012.
- The percentage of savings due to competition was applied only to production costs.
- For net present value calculations, a discount rate of seven percent is used.
- Sustainment costs required to maintain fielded aircraft are based on engine flight hours costs and usage rates. Sustainment costs are not considered because the number of aircraft and cost per flight hours would be the same under either scenario.

IV. BUSINESS IMPACTS

A. LIFE-CYCLE COST COMPARISON

The DoD's argument for cancelling the alternate engine program centers around an immediate cost savings of $1.4 billion, which is the approximate amount remaining on the SDD contract for that engine.[1] However, when comparing the two production alternatives in terms of cost, the true additional cost of the alternate engine is higher than $1.4 billion. In addition to the increased RDT&E costs associated with developing two engines rather than one, there are numerous other cost increases that would occur under the two-engine scenario. Fielding one engine will require training, manpower, manuals, and the standup of maintenance depot(s) and an associated logistics supply line. Fielding two engines will increase all of these cost elements. Even if executed in the most streamlined and efficient manner, the increased cost of fielding two engines rather than one will be unavoidable. To accurately compare the sole-source and competition scenarios, therefore, a life-cycle cost comparison is needed.

While there are many cost factors to be considered when calculating a program's life-cycle cost, for example RDT&E, production, initial standup, operation, sustainment, and disposal, the life-cycle cost comparison in this evaluation focuses on only those costs that will differ under a two-engine scenario. Specifically, the cost elements included in the comparison are SDD, production, and initial standup costs. Given that the number of aircraft and the cost per flight hour are the same under each scenario, differences in operation and sustainment costs should be inconsequential and are therefore not included. Similarly, disposal costs are not considered since the same number of engines will exist under each scenario.

[1] Following SASC hearings in March 2006 regarding the cancellation of the alternate engine program, Congress added $408 million to the FY2007 budget to continue the program for another year. (CRC RL33405, 2006) At the time of the hearings, $1.8B remained on the SDD contract for that engine. In this evaluation, monies spent through FY 2007 are considered sunk costs and not included in the analysis.

Table 4. shows the estimated SDD, production, and initial standup costs for each scenario. Again, the competition scenario is based on each engine team winning an average of 50 percent of the contract awards. Tables showing the derivation of the production costs for each scenario are provided in Appendix A.

Table 4. Comparison of Costs between the Sole Source and Competition Scenarios

Cost (FY02$B)	F135 Sole-Source	Competition (50:50)
SDD (left to go)	1.00	2.40
Production	16.77	17.65
Initial Standup Costs	3.20	3.33
TOTAL:	20.97	23.38
DIFFERENCE:		+ 2.41 (or 10.31%)

It is often the case that investments made early in a program's life-cycle result in savings many years, or even decades, later. The F-35 engine, which has production currently planned out to 2034, will no doubt follow a similar pattern. For that reason, a net present value (NPV) calculation is included to account for the time value of money. A comparison of the NPVs for each scenario is shown in Table 5.

Table 5. Comparison of Net Present Values (NPVs)

NPV (FY02$B)	F135 Sole-Source	Competition (50:50)
SDD (left to go)	0.85	2.03
Production	6.94	7.31
Initial Standup Costs	2.60	2.70
TOTAL:	10.39	12.04
DIFFERENCE:		+ 1.65 (or 13.70%)

As shown above, the competition alternative will cost approximately $2.41 billion more than the sole-source alternative. The difference in SDD costs is directly related to the fact that two RDT&E efforts are required, one for each engine. The increase in production costs stems from a loss of learning curve benefits if engine production is split between the companies. Although the same number of engines will be produced under each scenario, in the sole-source arrangement Pratt & Whitney will produce every engine, thus allowing the company to maximize the cost savings possible through learning rate improvements. The more engine production is divided, the less each company can save through learning rate improvement. This topic is discussed more under Non-Quantitative Costs. Finally, the initial cost of standing up two engines will increase due to a requirement for two training programs, two sets of manuals, two depot standups, etc.

Simply concluding, however, that the sole-source scenario will save the government $2.41 billion over the competition scenario, is not an accurate cost comparison of the two solutions. As demonstrated during the Great Engine War, competition often leads to savings, particularly in the area of production. Under the pressures of competition, each company will seek ways to reduce production costs in order to make itself more attractive in the next round of contract awards. Therefore, to more accurately evaluate the two alternatives, some amount of savings must be incorporated into the computations. It is particularly illustrative to calculate the percentage of savings necessary for the two solutions to breakeven.

A breakeven analysis is shown in Appendix B. In the analysis, a fixed percentage of savings is applied to each year's production costs, then that amount is adjusted to account for the time value of money using a net present value calculation. To find the breakeven point, the percentage of savings is adjusted to find the amount of savings required for the NPV of the competition solution to equal that of the sole-source solution.

The result of the breakeven analysis is that a 26.45 percent savings is required for the two scenarios to be equal in terms of net present value. According to interviews conducted with defense and industry experts by the Government Accountability Office, 26.45 percent is at the top of the reasonable range of potential savings achievable through competition. (GAO-07-656T, 2007) For comparison, Table 6. shows how the results vary for different percentages of savings.

Table 6. The Effect of Savings Percentage on the NPC Comparison

Percent Savings (%)	NPV($FY02B)[2] Sole-Source	Competition (50:50)	Difference ($B)
0	10.39	12.04	1.65
5	10.39	11.73	1.34
10	10.39	11.41	1.02
15	10.39	11.10	0.71
20	10.39	10.79	0.40
25	10.39	10.48	0.09
26.45	10.39	10.39	0.00

The takeaway from the life-cycle cost analysis is that an additional investment of $2.41 billion may be required as a result of the alternate engine program; however this investment can be largely, if not completely, recouped through the savings to be gained by the competition.

B. NON-QUANTITATIVE BENEFITS

1. International Relations

To help achieve the JSF program goal of "affordability", international participation and foreign military sales have been an integral part of the program from the beginning. The eight international partners have pledged $4.6 billion towards the development of the JSF aircraft. This equates to 10 percent of the total development costs. The U.K., who is a level one partner on the program, has invested $2 billion of that international contribution, or 8 percent of the total development costs. Israel and Singapore have both signed letters of intent to join the program and contribute $50 million, while Poland is reportedly considering a foreign military sales investment of $75 to $100 million in the JSF program. (Bolkcom, Apr 2006)

a. International Alliances

The importance of maintaining a good relationship with our international partners is particularly significant in today's defense environment. The continuing trend

[2] Includes SDD, production, and initial standup costs

towards downsizing in the U.S. industrial base means increased reliance on foreign technology in the future; the same holds true for our partners. The JSF program offers opportunities to advance our alliances, most notably by awarding work on the F-35 to foreign companies.

Some friction already exists between the DoD and several of the JSF foreign partners over the quality and quantity of work that has been awarded to their companies; in particular Denmark, Italy, the Netherlands, Norway, and Turkey have expressed their dissatisfaction. (Bolkcom, Apr 2006) Not surprisingly, the U.K. is upset over the proposed cancellation of the F136 alternate engine which is being co-produced by GE and the British company, Rolls-Royce.

The U.K. is dissatisfied with canceling the second engine for a few reasons. First, although they are a level one partner on the program and have contributed $2 billion, they were not consulted about the engine decision. (Procurement, 2007) Second, the F136 engine, which is three years behind the Pratt & Whitney engine in development, will likely have greater thrust. This would be particularly beneficial in the short-takeoff, vertical landing JSF models the U.K. will be buying. Finally, the GE/Rolls-Royce partnership could be worth billions of dollars in sales for British companies over the 20 year production run. (Procurement, 2007)

U.K. officials expressed their frustration to the Senate Armed Services Committee in March 2006. Lord Peter Drayson, the U.K. military procurement chief, even went so far as to warn that his country “would not buy any of the aircraft unless it had the technology the British needed to fight on their terms.” (Cahlink, 2006) This highlights an issue relevant to all the partner nations--namely that they have invested their money in the program and expect in return an aircraft that will meet their unique needs and allow them to fight on their own terms. Providing a choice of engines is one clear way to do that.

b. Foreign Military Sales

The benefits of an engine competition also extend to foreign military sales. This is evidenced by the fact that 20 years after the great engine war, competitive pressures still exist and are influencing sales of F-15 and F-16 engines in the international market. For example, although U.S. F-15s are powered by Pratt & Whitney F100 engines, in 2002 South Korea selected the GE engine to power its F-15 fleet, and in 2005 Singapore followed suit, selecting the GE engine over the Pratt & Whitney model. Similarly, while GE engines power a large proportion of U.S. F-16s, Pratt & Whitney has dominated engine sales to international F-16 customers. (Bolkcom, Apr 2006)

The benefits of having more than one engine source are threefold. First, international customers reap the same competitive benefits, reduced operational risk, increased performance, improved readiness, and lower costs. This makes the aircraft more attractive and therefore more exportable. Second, the foreign customer has the ability to choose the engine that best suits the mission and operational scenario in which they will utilize the aircraft. This again makes the aircraft more attractive to potential customers. Finally, both the U.S. industrial base and DoD continue to benefit as the advantages gained through competition are perpetuated thanks to foreign sales.

2. Industrial Base

While in the past there existed four or five major U.S. producers capable of providing aircraft and engines, today only Pratt & Whitney and GE manufacturer fighter aircraft engines. If the alternate engine for the JSF is cancelled, Pratt &Whitney will receive a sole-source contract that could be worth over $100 billion over the life of the JSF program. (DeWine) Moreover, the cancellation would effectively create a “winner take all” scenario, not only for the JSF program, but potentially for any future tactical aircraft engine program. Reducing the industrial base to only one supplier may have long-term effects on both the industry and national security.

GE currently dominates in the commercial aircraft engine market, with 50 percent of the market share. It also has current and future engine opportunities in cargo and tanker aircraft, helicopters, and large unmanned aerial vehicle programs. In other words, the company will not go out of business if the alternate engine program is cancelled. However, when it comes to tactical aircraft engines its prospects are much more limited. The company currently builds and maintains engines for the Navy's F/A-18E/F, and supports the F110 engine series for domestic and international F-15 and F-16 customers. However, production in these fighter engine programs is on the decline.

For all practical purposes, there is only one fighter engine program now and for the foreseeable future—the JSF engine program. Before very long, if a company is not involved in the JSF engine program, it will not be involved in the fighter engine business. And while commercial engines have some similar qualities with fighter engines, they are very different. For example, commercial engines are generally designed for fuel efficiency, not performance. They do not use afterburners and their thrust-to-weight ratios are very different from fighter engines. Therefore, to produce and maintain a fighter engine requires a team of engineers and scientists tailored for that purpose. If the F136 engine is cancelled, there is no rationale for GE to sustain the unique capabilities and resources needed to design, develop, test and produce high-performance fighter engines; a fact they expressed to the Senate Armed Services Committee in March of 2006.

If the alternate engine program were cancelled, and then sometime in the future the DoD requested GE to design and build an alternate engine for the JSF, GE would face many challenges and incur much expense to reinstate the program. The F136 engine program currently trails the F135 engine program by three years. This lead would grow with every year that GE was out of the business. (Bolkcom, Apr 2006) GE also has no other engine in the same thrust class from which to pull resources and expertise. Essentially, it would have to rebuild the team of engineers and resources, at great expense to the DoD.

The bottom-line is that relying on a sole engine supplier for the JSF aircraft, which is a single-engine airplane designed for multiple missions for use by multiple services and nations, creates undesirable risk both for the DoD and the industrial base.

Investing a relatively small amount now in an alternate engine may reap large benefits in the future and help guarantee a healthy and competitive industrial base capable of providing the DoD with the competitive benefits of lower costs, increased performance, reduced operational risk, improved readiness, and increased foreign military sales.

3. Reliability and Performance

In addition to cost savings, the great engine war is credited with increasing engine reliability, improving performance, and increasing military value. Many critics have argued that while there were benefits of the F-16 engine competition, the industry and technological factors that existed at that time, which made the competition successful, are not present today. One area, in particular, that is frequently cited as the reason that competing the engines is unnecessary is reliability and performance. Specifically, that engine reliability and performance in general have improved significantly from what they were back then. In fact, the F-16 mishap rate has dropped from ten per 100,000 hours in 1996 to one per 100,000 hours is 2006. (SASC, 2006) Given this, they argue that any gain to be achieved through competition with regards to reliability and performance will be small and therefore not worth the investment. In this section, that argument is analyzed and ultimately refuted.

a. Sole-Sourcing Will Create Unprecedented Vulnerability

The F-35 program has been hailed as the largest DoD acquisition program to date, both in terms of dollar value and number of participating services and partner nations. With the planned U.S. purchase at 2458 aircraft, and foreign sales already predicted over 2150 aircraft, there is the potential for F-35 production to top 5000 aircraft. This far exceeds production quantities of all other U.S. aircraft platforms. Table 7. shows production quantities for several recent aircraft programs. Only the F-16 comes close to the production magnitude of the F-35 program and only after all four F-16 variants and foreign F-16 sales are combined.[3] The F-35 program is often compared to

[3] According to the Lockheed Martin website, over 4000 F-16s have been produced in total. This figure includes all versions of the aircraft and both U.S. and foreign military sales.

the F-22 program, but in fact the size of the two programs (2458 versus 183 aircraft) is vastly different. While critics argue that any reliability and performance gains will be small compared to those during the great engine war, when taken in proportion to the size of the F-35 program, those gains may result in billions of dollars of savings over the life of the program.

Table 7. Aircraft Production Quantities

Aircraft	Production Quantity (for U.S. Only)
F-35	2458
F-16 C/D	1421
F-16 A/B	795
F/A-18E/F	494
C-130 AMP	465
F-15 C	408
F-15 A/B	360
F-15 E	203
C-17	190
F-22A	183
F-15 D	61

From: 1. GAO-06-391, 2006. 2. www.fas.org/man/dod-101/sys/ac/f-16.htm. 3. Bolkcom, 2007. 4. www.fas.org/man/dod-101/sys/ac/f-15.htm. 5. Bolkcom, 2007. 6. www.fas.org/man/dod-101/sys/ac/f-15.htm.

Traditionally, the U.S. and its allies have relied on several aircraft platforms to meet their tactical airpower needs. A benefit of that approach is that if a problem is encountered that results in the grounding of a particular fleet of aircraft, there are other platforms available with similar capabilities that could, at least temporarily, fill the void. This may not be possible to the same extent under the JSF and F-22 programs. Collectively, the two aircraft have been designed to replace several aircraft types, including the F-16, F-15, F/A-18, A-10, A-6, and AV-8B. By 2030, the JSF and F-22 will represent 85% of U.S. and allied tactical airpower. (SASC, 2006) This creates a vulnerability that is unprecedented. Since both the F135 and the F-22's F119 engine are currently produced by Lockheed Martin, cancelling the F136 program will leave the U.S. and its allies dependent on one engine source. Further, since the F135 engine is a derivative of the F119 engine, a problem in the basic engine design could potentially affect both fleets. Competing the F135 and F136 engines greatly reduces this risk. Given the magnitude of the consequences of failure, spending $1.8 billion to develop an alternate engine seems well worth the expense.

b. Too Early to Forecast F135 Reliability

To help ensure and predict an engine's reliability, aircraft programs conduct many thousands of hours of ground and flight testing. Based on the testing conducted to date, DoD officials have asserted that the reliability of the F135 engine has now been sufficiently demonstrated and the operational risks reduced to the extent they can reasonable predict the success of the F135 engine, and defend the decision to cancel the alternate engine program. However, looking more closely at the amount of testing that has been conducted on the F135 engine it is too early to forecast the engine's reliability. At the time of DoD's decision to cancel the alternate engine program, the F135 engine had undergone 4,600 hours of ground testing, which is roughly one-third of the planned ground test hours. In addition, at the time of the decision, the F-35 aircraft had not yet flown. The first dedicated operational testing that will accurately measure the JSF aircraft's operational effectiveness and suitability is not even planned until 2011. (Sullivan, 2006) Figure 1. shows that propulsion performance flight testing does not start in earnest until 2009. Based on this it can be concluded that placing a high level of confidence in the F135 at this point, based solely on the testing conducted to date, is premature.

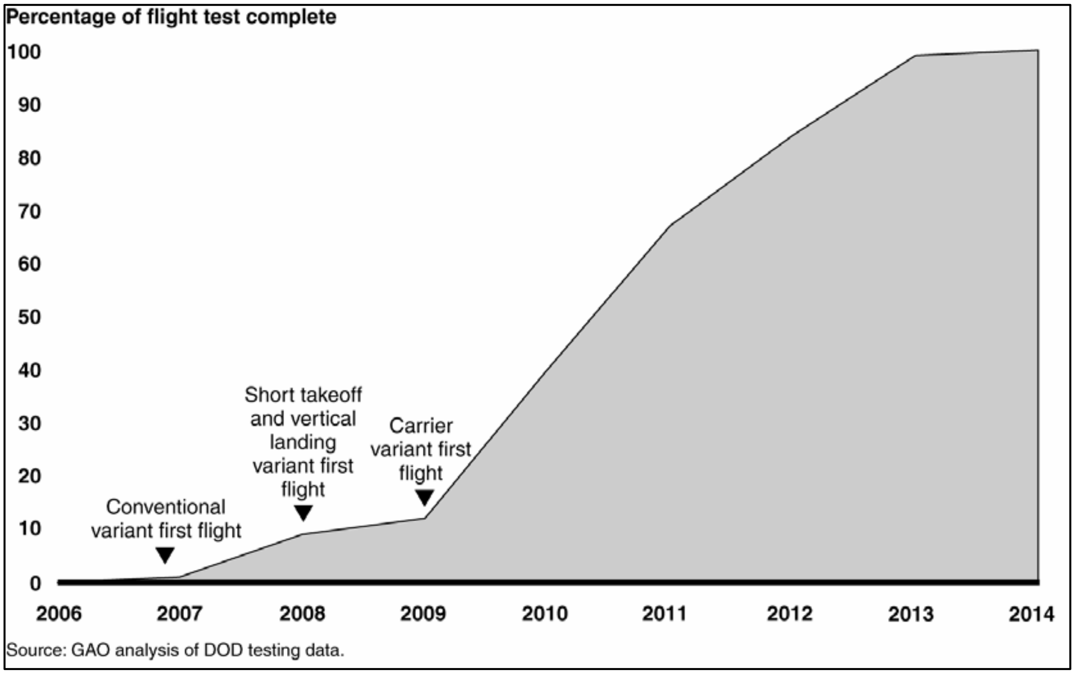

Figure 1. Planned Propulsion Performance Flight Testing and First Flight for the Three JSF Variants (From: GAO-06-391, 2006)

c. Comparisons to F-22 Engine of Limited Value

The predicted reliability of the F135 engine is frequently based on comparisons with the F-22's F119 engine, of which it is a derivative and shares up to 70% commonality.[4] Proponents of a sole-source scenario point out that in 12 years, the F119 engine has undergone 42,000 hours of ground and flight testing, and 16,000 hours of operational time with no engine-related losses and no groundings due to engine-related problems. (SASC, 2006) They further predict that the F135 propulsion system will have a 30% to 50% improvement in reliability and safety compared to the F119. (England, 2006) Comparisons with the F119 engine, however, are premature and possibly

[4] Lockheed Martin claims 70% commonality between the F119 and F135 engines; however officials at Rolls-Royce, who is co-producing the F136 engine with GE, disagree with this assessment claiming instead that it is more like a new engine than a derivative. They feel this is corroborated by the fact that Lockheed Martin is spending $4 to $5 billion to develop the F135 engine, versus $3.7 billion by GE/Rolls-Royce to develop the F136. (SASC, 2006)

misleading for two primary reasons. First, the F119 engine has not yet reached maturity, and second, the two engines will be used under different operational scenarios.

DoD officials have argued that the good performance of the F-22's F119 engine has sufficiently reduced the risk that would be incurred in relying on a single source for the F-35's engine. Even if the claim of 70% commonality between the two engines is accepted, the F119 engine has not yet reached maturity. The F-22 has completed approximately 20,000 operational engine hours, which represents only 10% of the 200,000 hours typically considered sufficient for system maturity. (Sullivan, 2006) As a point of comparison, when the great engine war commenced, the Pratt & Whitney F100 engine had already accumulated 2,000,000 hours of operational service (100 times more than the F119). (Bolkcom, 2006) Moreover, even with this extensive number of hours, numerous improvements in engine reliability and performance were attained during the 25 year competition.

In addition, while performance of the F119 has been good, the engine is not currently meeting several reliability goals. For example, the engine's mean time between maintenance actions was expected to be 100 hours at its initial service release in 2002. However, as of April 2006, the engine was averaging only 60 hours between maintenance actions. The performance requirement at system maturity in 2010 is 200 hours mean time between maintenance actions, however F-22 program engine officials predict the engine will achieve only 100 hours between maintenance actions--50% of the performance requirement. (Sullivan, 2006)

Comparing the F-22 and F-35 engines is also misleading because the two aircraft have distinctly different missions and will be flown under different operational scenarios. First, there are three versions of the F-35, each with different operational concepts. Second, the F-35 is being designed to rapidly transition between different air-to-surface and air-to-air missions while still airborne. Conversely, the F-22 will primarily serve as an air-to-air platform, flying at high speed and high altitude. Based on what is known about engine operation, the operational environment of the F-22 will put considerably less stress on its engine. Therefore, comparisons of the two aircraft engines must be qualified to put the association in proper context.

d. Lessons Learned from Other Aircraft Programs

Comparisons made between the F-35 and the F-22 and F/A-18E/F, both of which have only one engine source, may also be inappropriate because the latter aircraft are equipped with two engines, while the F-35 will have one engine. History has shown that single engine aircraft are inherently subject to higher risk than two-engine aircraft. For example, between FY1990 and FY2004, the single-engine F-16 experienced 80 Class A engine-related mishaps. That equates to a mishap rate of 1.31 per 100,000 flight hours. The two-engine F-15, on the other hand, experienced 21 Class A engine-related mishaps during that same period, for a rate of 0.64 per 100,000 flight hours. (Bolkcom, Apt 2006)

Adding to the complexity, the F-35's STOVL variant will be capable of short and/or vertical takeoff and landings. To achieve this, the F-35 engine will be augmented with a lift fan, roll posts, drive shaft, and three bearing swivel module. The engine will be subject to different operational stresses and conditions. Its nearest equivalent is the AV-8 Harrier, which has one of the highest mishap rates of all military aircraft. Moreover, unlike most aircraft types where mishaps are most frequently related to human error, two-thirds of the Harrier's mishaps have been related to aircraft failures. (Bolkcom, Apr 2006)

e. Engine Maturity Reflected in Contract Type

The DoD's confidence and the prime contractor's assurance that the F135 is little more than a derivative of the F119 engine, are belied by the choice of contract type being used for the acquisition. Specifically, the initial production F-35 engines will be purchased using a cost reimbursement type contract. According to FAR Subpart 16.3, cost reimbursement contracts are "suitable for use only when uncertainties involved in contract performance do not permit costs to be estimated with sufficient accuracy to use any type of fixed-price contract." (FAR 16.3)

f. F136 Design Changes Easier to Incorporate

In any program involving the design and development of a product or system, it is generally accepted that changes to the system's design are easier and less expensive to incorporate when they are made early in the program. The later design changes are made in the life of a program, the most costly they become, both in terms of dollars and schedule delays. This time-tested fact is another advantage of the F136 engine, whose development is approximately three years behind the F135 engine. Based on lessons learned from the F135 engine, program managers may desire to make changes in hopes of increasing thrust or improving operational reliability. Similarly, if weight growth continues to be an issue for the F-35's STOVL variant, the DoD may wish to counter it with increased engine/propulsion capabilities. Relatively speaking, accommodating changes in the engine's design will be easier and less expensive with the F136 engine than with the F135.

4. Cost Control

Considering the magnitude of the JSF program, where the engine procurement costs alone may exceed $100 billion over the life of the program, failure to control costs could be devastating to the nation's purse strings and negatively affect Congress's ability to fund the programs necessary to provide adequately and effectively for the nation's defense. History has shown that when competition exists, contractors put significant energy into reducing and controlling costs. This is a fact that has not gone unnoticed in Washington. During the March 2006 Senate hearings on the alternate engine program, Senator John Warner, the senior Republican member of the Senate Armed Services Committee, stated that, "a competitive environment is essential in the judgment of many of us to the Government's ability to control costs, especially in a program of the magnitude of the JSF." (SASC, 2006)

Many believe that the cost savings to be gained through competition of the F-35 engines could range from 10 to 20 percent. (Sullivan, 2007) Taking the conservative savings estimate of 10 percent still yields a total savings on the order of $10 billion over the life of the program. Even Pratt & Whitney, an obvious supporter of a sole-source arrangement, publically disclosed that they believe there were $3 billion saved during the Great Engine War as a result of the competition. (SASC, 2006) The bottom-line is that even by the most conservative estimates, the savings that can be gained on a program of this great magnitude more than overcomes the short-term investment required to develop a second engine.

C. NON-QUANTITATIVE COST

1. Logistics Support

The F135 and F136 engines are specifically designed to have identical external interfaces to the JSF aircraft, making them interchangeable in terms of form, fit, and function. Internally, however, the two engines differ significantly and have many unique parts, including fans, turbines, combustors, and compressors. As a result, supporting and maintaining two engines will require more resources and funding, than supporting only one. Two separate spares pipelines will be required, along with two separate maintenance depot capabilities. Additional training, engine manuals, tools, and test equipment will also be required to maintain two engines. Future configuration changes to the aircraft and/or engine will be more complex and may involve compromises in the design solution to accommodate both engines. Finally, the costs of engineering and software support will be higher. All in all, in the area of logistics support, a sole-source arrangement has the advantage both in terms of the amount of resources required for support and maintenance, and the simplicity of life-cycle management.

D. ANALYSIS OF ALTERNATIVES

Table 8. provides a summary comparison of the quantitative and qualitative advantages of the sole-source and competition scenarios.

Table 8. Summary Comparison of the Sole-Source and Competition Alternatives

ITEM	ADVANTAGE:		QUICK-LOOK EXPLANATION
	SOLE-SOURCE	COMPETITION	
Life-Cycle Costs	√		An additional investment of $2.41 billion may be required as a result of the alternate engine program, however this investment can be largely, if not completely, recouped through the savings to be gained by the competition.
International Alliances		√	The U.K. is a level one JSF partner and has contributed 8% of JSF development costs. There is the potential for billions of dollars in sales for British companies via the GE/Rolls-Royce partnership on the F136 engine.
Foreign Military Sales		√	Having a choice of engines makes the aircraft more attractive to foreign customers who will be able to choose the engine that best suits their operational needs and doctrine.
Industrial Base		√	The JSF engine is the only tactical fighter engine program planned for the foreseeable future. Cancelling the second engine reduces the number of tactical engine suppliers to one. This creates an undesirable level of risk given the magnitude of the JSF program.

ITEM	ADVANTAGE: SOLE-SOURCE	ADVANTAGE: COMPETITION	QUICK-LOOK EXPLANATION
Reliability & Performance Risk		√	The JSF program is of unprecedented size. Relying on a sole-source increases the reliability and performance risk of the engine. The F135 engine is based on the F-22 engine which is still immature and not meeting its reliability goals. Comparisons to F-22 and F/A-18 aircraft also invalid due to differing missions and number of engines per aircraft.
Cost Control		√	When the magnitude of the JSF program is put in proportion, poor cost control could be devastating and negatively affect Congress's ability to fund other programs necessary for national security. History has shown that cost control is most effective in a competitive environment.
Logistics Support	√		Supporting and maintaining two engines is more complex and requires more resources and funding. In a sole-source scenario, only one logistics pipeline and deport maintenance capability is required; one type of tools and manuals; one type of training; one type of test equipment; etc.

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V. SENSITIVITIES, RISKS, AND CONTINGENCIES

One clear conclusion from this and the other studies of its kind is that the financial advantage of one solution over another can change depending on the factors considered and assumptions made. Some of these factors include the learning rate, the cost of producing the engine, discount factors and inflation rates, and the number of engines included in the computation. In this study, all of those factors were based on open-source data, dictated by DoD mandates regarding BCA analysis, or chosen to facilitate comparison with other studies.

One factor that is particularly difficult to predict, and is therefore worthy of additional analysis, is the net percentage of contract awards each engine team will ultimately win. This study has thus far examined the 100:0 case in which Pratt & Whitney produces 100 percent of the engines (i.e., the sole-source scenario), as well as the 50:50 case in which each engine team averages 50 percent of the contract awards. To examine the sensitivity of this factor, the 70:30 case is useful. The life-cycle cost, NPV, and breakeven results for the 70:30 case are provided in Table 9. . Two sets of results are provided: one for the case that Pratt & Whitney produces 70 percent of the engines (labeled Competition 70:30), and one for the case that the GE/Rolls-Royce team produces 70 percent (labeled Competition 30:70). Data from the sole-source and 50:50 cases are included for reference.

Table 9. Total Cost and NPV Data for each Production Scenario

Case	Total Cost ($B)*	NPV ($B)	Savings Required to Breakeven (%)
Sole-Source (100:0)	20.97	10.39	n/a
Competition (50:50)	23.38	12.04	26.45
Competition (PW 70:GE/RR 30)	23.29	12.00	26.00
Competition (PW 30:GE/RR 70)	23.31	12.01	26.15
Average of competition results:	23.33	12.02	26.20
Variance of competition results:	0.0022	0.00043	0.053
Standard deviation of competition results:	0.047	0.021	0.23

*Total cost = Sum of remaining SDD, production, and initial standup costs

As shown in Table 9. , there is little variation between the 50:50 case and the two 70 percent scenarios. Based on this limited analysis, it can be reasonably predicted that the percentage of engine production awarded does not significantly impact the comparison of life-cycle costs and breakeven savings requirements until it approaches the sole-source scenario. Similarly, it is implied that the magnitude of learning rate savings is not significantly affected until the sole-source case. In other words, the “competition scenario” is adequately represented by either the 50:50 or 70 percent scenarios.

VI. RECOMMENDATIONS AND CONCLUSIONS

The recommendation of this BCA is to continue to fund and execute the alternate engine program for the Joint Strike Fighter. This recommendation is based on the quantitative and qualitative analysis performed in this study, which is summarized below.

This study finds that the alternate engine program requires an additional investment of $2.41 billion over the sole-source scenario. This investment, which includes the remaining RDT&E work, production costs, and initial standup costs, can be largely recouped, however, through the savings that can be gained during the course of competition. As demonstrated during the Great Engine War, competition is most effective on programs with high total volume over the life of the program and high annual production rates; a depiction that perfectly characterizes the F-35 engine program.

Beyond the comparison of life-cycle costs, there are several key qualitative factors that must be considered to fully assess the value of the alternate engine program. These include the following:

- International Alliances and Foreign Military Sales: Unlike most other DoD programs, the JSF program relies on several key international alliances. Competition strengthens these alliances, without which the program could lose valuable development funding and foreign military sales.

- Industrial Base: The JSF engine is the only tactical fighter engine program planned for the foreseeable future. Cancelling the second engine reduces the number of tactical engine suppliers to one, creating undesirable risk given the magnitude of the JSF program.

- Reliability and Performance: The JSF program is of unprecedented size. Relying on a sole engine producer increases the reliability and performance risk of the engine. Moreover, the F135 engine is based on the F-22 engine which is still immature and not meeting its reliability goals. Therefore, basing decisions to cancel the F136 engine on comparisons to the F-22 engine is not prudent.

- Cost Control: History has shown that cost control is most effective in competitive environments. Considering the magnitude of the JSF program, poor cost control could be devastating and negatively affect Congress's ability to fund other programs required for the nation's defense.

The bottom line is that even though the alternate engine requires an additional investment of $2.41 billion, most of that investment will likely be recouped, and the benefits to be gained through increased engine reliability and performance, increased foreign military sales, strengthened international alliances, a strengthened industrial base, and improved cost control more than outweigh the arguments against the alternate engine program. If executed carefully, using proper oversight and keeping in mind lessons learned from the Great Engine War, the F-35 engine program can be both effective and affordable in a competitive acquisition environment.

APPENDIX A: LIFE-CYCLE COST COMPARISON

Sole-Source Production Scenario

Fiscal Yr	2008	2009	2010	2011	2012	2013	2014	2015	2016
Year	1	2	3	4	5	6	7	8	9
# Engines Produced	DATA MASKED						126	127	126
Cumulative # of Engines	(Annual LRIP production levels are for official use only)						557	684	810
Cost ($Million)	96.89026	344.4375	385.9241	452.1073	631.7687	796.1696	726.2554	719.7282	704.2996
Discounted Cost ($Million)	90.55165	300.845	315.029	344.9105	450.4423	530.5214	452.2753	418.8883	383.0923

Fiscal Yr	2017	2018	2019	2020	2021	2022	2023	2024	2025
Year	10	11	12	13	14	15	16	17	18
# Engines Produced	127	126	127	126	127	126	127	126	127
Cumulative # of Engines	937	1063	1190	1316	1443	1569	1696	1822	1949
Cost ($Million)	701.7064	689.2399	688.609	677.824	678.3563	668.6578	669.9531	661.0161	662.8467
Discounted Cost ($Million)	356.7119	327.4529	305.7506	281.2728	263.0783	242.3523	226.9363	209.2608	196.1124

Fiscal Yr	2026	2027	2028	2029	2030	2031	2032	2033	2034
Year	19	20	21	22	23	24	25	26	27
# Engines Produced	126	127	126	127	126	127	126	127	126
Cumulative # of Engines	2075	2202	2328	2455	2581	2708	2834	2961	3087
Cost ($Million)	654.4744	656.6986	648.7625	651.2869	643.6985	646.4581	639.1539	642.102	635.0347
Discounted Cost ($Million)	180.9676	169.7034	156.6846	147.004	135.7862	127.447	117.7636	110.5671	102.1964

TOTAL PRODUCTION COST ($Billion) =	16.77346
NPV ($Billion) =	6.943604

Data Source: LRIP engine quantities obtained from 461 FLTS F-35 Capabilities Brief (2006)

50:50 Competition Production Scenario

Pratt & Whitney (50%)

Fiscal Yr	2008	2009	2010	2011	2012	2013	2014	2015	2016
Year	1	2	3	4	5	6	7	8	9
# Engines Produced	DATA MASKED						64	63	63
Cumulative # of Engines	(Annual LRIP production levels are for official use only)						310	373	436
Cost ($Million)	96.89026	344.4375	198.5856	232.0257	326.8823	411.066	384.8864	373.1341	368.4827
Discounted Cost ($Million)	90.55165	300.845	162.105	177.0113	233.0625	273.9106	239.6879	217.1674	200.4302

Fiscal Yr	2017	2018	2019	2020	2021	2022	2023	2024	2025
Year	10	11	12	13	14	15	16	17	18
# Engines Produced	63	63	64	63	63	63	63	64	63
Cumulative # of Engines	499	562	626	689	752	815	878	942	1005
Cost ($Million)	364.5539	361.1579	363.8335	355.4661	353.0673	350.884	348.8818	352.5279	345.2918
Discounted Cost ($Million)	185.3207	171.5835	161.5464	147.5058	136.9256	127.1765	118.1783	111.6013	102.1594

Fiscal Yr	2026	2027	2028	2029	2030	2031	2032	2033	2034
Year	19	20	21	22	23	24	25	26	27
# Engines Produced	63	63	63	64	63	63	63	63	64
Cumulative # of Engines	1068	1131	1194	1258	1321	1384	1447	1510	1574
Cost ($Million)	343.6935	342.1963	340.7885	344.8383	338.1842	336.9928	335.8596	334.7792	339.0367
Discounted Cost ($Million)	95.03412	88.43002	82.30488	77.83455	71.33891	66.437	61.88185	57.64747	54.56131

P&W TOTAL PRODUCTION COST ($B)=	8.988424
P&W NPV ($B)=	3.812239

COMBINED PRODUCTION COST ($B) =	17.65373
COMBINED NPV ($B) =	7.305257

Data Source: LRIP engine quantities obtained from 461 FLTS F-35 Capabilities Brief (2006)

50:50 Competition Production Scenario (continued)

GE / Rolls-Royce (50%)

Fiscal Yr	2008	2009	2010	2011	2012	2013	2014	2015	2016
Year	1	2	3	4	5	6	7	8	9
# Engines Produced	DATA MASKED						64	63	63
Cumulative # of Engines	(Annual LRIP production levels are for official use only)						249	312	375
Cost ($Million)	0	0	220.9383	247.2215	339.8822	428.0025	392.0368	378.6189	372.9726
Discounted Cost ($Million)	0	0	180.3514	188.6041	242.3313	285.1961	244.1408	220.3596	202.8724

Fiscal Yr	2017	2018	2019	2020	2021	2022	2023	2024	2025
Year	10	11	12	13	14	15	16	17	18
# Engines Produced	63	63	64	63	63	63	63	64	63
Cumulative # of Engines	438	501	565	628	691	754	817	881	944
Cost ($Million)	368.3481	364.4387	366.7634	358.0368	355.3862	352.9949	350.8178	354.3424	346.949
Discounted Cost ($Million)	187.2495	173.1422	162.8473	148.5726	137.8249	127.9416	118.8341	112.1757	102.6497

Fiscal Yr	2026	2027	2028	2029	2030	2031	2032	2033	2034
Year	19	20	21	22	23	24	25	26	27
# Engines Produced	63	63	63	64	63	63	63	63	64
Cumulative # of Engines	1007	1070	1133	1197	1260	1323	1386	1449	1513
Cost ($Million)	345.2394	343.6445	342.1503	346.1429	339.399	338.1455	336.956	335.8245	340.0507
Discounted Cost ($Million)	95.46157	88.80426	82.63377	78.12901	71.59516	66.66424	62.08386	57.82746	54.72449

GE/RR TOTAL PRODUCTION COST ($B)=	8.665303
GE/RR NPV ($B)=	3.493017

COMBINED PRODUCTION COST ($B) =	17.65373
COMBINED NPV ($B) =	7.305257

Data Source: LRIP engine quantities obtained from 461 FLTS F-35 Capabilities Brief (2006)

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APPENDIX B: BREAKEVEN ANALYSIS

BREAKEVEN ANALYSIS (50:50 Scenario)

SOLE SOURCE	Cost ($B)	NPV ($B)
SDD	1	0.85
Production	16.77346	6.943604
Initial Support Cost	3.2	2.6
TOTAL	20.97346	10.3936

Goal: NPV Sole Source = NPV Competition (50:50)
By changing the percentage of savings achieved during production due to competition.

SAVINGS REQUIRED TO BREAKEVEN = 0.25

INTIAL Competition (50:50)	Cost ($B)	NPV ($B)
SDD	2.4	2.03
Production	17.65373	7.305257
Initial Support Cost	3.33	2.7
TOTAL	23.38373	12.03526

BREAKEVEN Competition (50:50)	Cost ($B)	NPV ($B)
SDD	2.4	2.03
Production	13.57532	5.75381
Initial Support Cost	3.33	2.7
TOTAL	19.30532	10.48381

BREAKEVEN ANALYSIS (P&W 70 : GE/RR 30 Scenario)

Sole Source	Cost ($B)	NPV ($B)
SDD	1	0.85
Production	16.77346	6.943604
Initial Support Cost	3.2	2.6
TOTAL	20.97346	10.3936

Goal: NPV Sole Source = NPV Competition (70:30)
By changing the percentage of savings achieved during production due to competition.

SAVINGS REQUIRED TO BREAKEVEN = 0.260048

INTIAL Competition (70:30)	Cost ($B)	NPV ($B)
SDD	2.4	2.03
Production	17.5564	7.267615
Initial Support Cost	3.33	2.7
TOTAL	23.2864	11.99762

BREAKEVEN Competition (70:30)	Cost ($B)	NPV ($B)
SDD	2.4	2.03
Production	13.33938	5.6636
Initial Support Cost	3.33	2.7
TOTAL	19.06938	10.3936

BREAKEVEN ANALYSIS (P&W 30 : GE/RR 70 Scenario)

Sole Source	Cost ($B)	NPV ($B)
SDD	1	0.85
Production	16.77346	6.943604
Initial Support Cost	3.2	2.6
TOTAL	20.97346	10.3936

Goal: NPV Sole Source = NPV Competition (30:70)
By changing the percentage of savings achieved during production due to competition.

SAVINGS REQUIRED TO BREAKEVEN = 0.261535

INTIAL Competition (30:70)	Cost ($B)	NPV ($B)
SDD	2.4	2.03
Production	17.57569	7.280031
Initial Support Cost	3.33	2.7
TOTAL	23.30569	12.01003

BREAKEVEN Competition (30:70)	Cost ($B)	NPV ($B)
SDD	2.4	2.03
Production	13.32952	5.6636
Initial Support Cost	3.33	2.7
TOTAL	19.05952	10.3936

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APPENDIX C: ANALYSIS OF SEVENTY PERCENT PRODUCTION CASE

70:30 Competition Production Scenario

Pratt & Whitney (70%)

Fiscal Yr	2008	2009	2010	2011	2012	2013	2014	2015	2016
Year	1	2	3	4	5	6	7	8	9
# Engines Produced	DATA MASKED						89	88	89
Cumulative # of Engines	(Annual LRIP production levels are for official use only)						384	472	561
Cost ($Million)	96.89026	344.4375	198.5856	232.0257	456.7803	576.4227	527.4156	512.5928	511.2434
Discounted Cost ($Million)	90.55165	300.845	162.105	177.0113	325.678	384.0948	328.4479	298.3337	278.0825

Fiscal Yr	2017	2018	2019	2020	2021	2022	2023	2024	2025
Year	10	11	12	13	14	15	16	17	18
# Engines Produced	88	89	88	89	88	89	88	89	88
Cumulative # of Engines	649	738	826	915	1003	1092	1180	1269	1357
Cost ($Million)	499.6086	500.203	490.2033	491.8547	482.8548	485.1619	476.8395	479.5883	471.757
Discounted Cost ($Million)	253.9757	237.6428	217.6561	204.1022	187.2594	175.845	161.522	151.8254	139.5759

Fiscal Yr	2026	2027	2028	2029	2030	2031	2032	2033	2034
Year	19	20	21	22	23	24	25	26	27
# Engines Produced	89	88	89	88	89	88	89	88	89
Cumulative # of Engines	1446	1534	1623	1711	1800	1888	1977	2065	2154
Cost ($Million)	474.8205	467.3628	470.66	463.4968	466.9731	460.0488	463.6655	456.9392	460.6686
Discounted Cost ($Million)	131.2918	120.7754	113.6705	104.6173	98.50651	90.69706	85.43	78.68288	74.13556

P&W TOTAL PRODUCTION COST ($B)=	12.0191
P&W NPV ($B)=	4.972362

COMBINED PRODUCTION COST ($B) =	17.5564
COMBINED NPV ($B) =	7.267615

Data Source: LRIP engine quantities obtained from 461 FLTS F-35 Capabilities Brief (2006)

70:30 Competition Production Scenario (continued)

GE / Rolls-Royce (30%)

Fiscal Yr	2008	2009	2010	2011	2012	2013	2014	2015	2016
Year	1	2	3	4	5	6	7	8	9
# Engines Produced	DATA MASKED						38	38	38
Cumulative # of Engines	(Annual LRIP production levels are for official use only)						174	212	250
Cost ($Million)	0	0	220.9383	247.2215	204.3339	256.6354	238.6027	234.7569	231.6536
Discounted Cost ($Million)	0	0	180.3514	188.6041	145.6872	171.007	148.5898	136.6306	126.0042

Fiscal Yr	2017	2018	2019	2020	2021	2022	2023	2024	2025
Year	10	11	12	13	14	15	16	17	18
# Engines Produced	38	38	38	38	38	38	38	38	38
Cumulative # of Engines	288	326	364	402	440	478	516	554	592
Cost ($Million)	229.0574	226.8289	224.8792	223.1477	221.5917	220.1799	218.8883	217.6987	216.5966
Discounted Cost ($Million)	116.4412	107.7648	99.84904	92.59836	85.9371	79.80331	74.14504	68.91784	64.08312

Fiscal Yr	2026	2027	2028	2029	2030	2031	2032	2033	2034
Year	19	20	21	22	23	24	25	26	27
# Engines Produced	38	38	38	38	38	38	38	38	37
Cumulative # of Engines	630	668	706	744	782	820	858	896	933
Cost ($Million)	215.5704	214.6104	213.7091	212.8597	212.0569	211.2959	210.5727	209.8839	203.7286
Discounted Cost ($Million)	59.607	55.45942	51.61354	48.04525	44.73275	41.65628	38.79785	36.14106	32.78612

GE/RR TOTAL PRODUCTION COST ($B)=	5.537298
GE/RR NPV ($B)=	2.295253

COMBINED PRODUCTION COST ($B) =	17.5564
COMBINED NPV ($B) =	7.267615

Data Source: LRIP engine quantities obtained from 461 FLTS F-35 Capabilities Brief (2006)

30:70 Competition Production Scenario

Pratt & Whitney (30%)

Fiscal Yr	2008	2009	2010	2011	2012	2013	2014	2015	2016
Year	1	2	3	4	5	6	7	8	9
# Engines Produced	DATA MASKED						38	38	38
Cumulative # of Engines	(Annual LRIP production levels are for official use only)						236	274	312
Cost ($Million)	96.89026	344.4375	198.5856	232.0257	195.8521	248.6021	232.7282	229.9651	227.6136
Discounted Cost ($Million)	90.55165	300.845	162.105	177.0113	139.6398	165.6541	144.9314	133.8418	123.8067

Fiscal Yr	2017	2018	2019	2020	2021	2022	2023	2024	2025
Year	10	11	12	13	14	15	16	17	18
# Engines Produced	38	38	38	38	38	38	38	38	38
Cumulative # of Engines	350	388	426	464	502	540	578	616	654
Cost ($Million)	225.5694	223.7632	222.1468	220.6849	219.3514	218.1261	216.9933	215.9403	214.9569
Discounted Cost ($Million)	114.668	106.3083	98.63582	91.57639	85.06826	79.05894	73.50313	68.36116	63.59799

Fiscal Yr	2026	2027	2028	2029	2030	2031	2032	2033	2034
Year	19	20	21	22	23	24	25	26	27
# Engines Produced	38	38	38	38	38	38	38	38	37
Cumulative # of Engines	692	730	768	806	844	882	920	958	995
Cost ($Million)	214.0348	213.167	212.3476	211.5717	210.835	210.1339	209.4652	208.8261	202.7424
Discounted Cost ($Million)	59.1824	55.0864	51.28472	47.75452	44.47499	41.42719	38.59378	35.95891	32.62742

P&W TOTAL PRODUCTION COST ($B)=	5.877356
P&W NPV ($B)=	2.625555

COMBINED PRODUCTION COST ($B) =	17.57569
COMBINED NPV ($B) =	7.280031

Data Source: LRIP engine quantities obtained from 461 FLTS F-35 Capabilities Brief (2006)

30:70 Competition Production Scenario (continued)

GE / Rolls-Royce (70%)

Fiscal Yr	2008	2009	2010	2011	2012	2013	2014	2015	2016
Year	1	2	3	4	5	6	7	8	9
# Engines Produced	DATA MASKED						89	88	89
Cumulative # of Engines	(Annual LRIP production levels are for official use only)						322	410	499
Cost ($Million)	0	0	220.9383	247.2215	473.6396	589.0555	535.393	518.5825	516.114
Discounted Cost ($Million)	0	0	180.3514	188.6041	337.6985	392.5125	333.4159	301.8197	280.7318

Fiscal Yr	2017	2018	2019	2020	2021	2022	2023	2024	2025
Year	10	11	12	13	14	15	16	17	18
# Engines Produced	88	89	88	89	88	89	88	89	88
Cumulative # of Engines	587	676	764	853	941	1030	1118	1207	1295
Cost ($Million)	503.6269	503.6846	493.2106	494.5525	485.2495	487.3578	478.8242	481.436	473.4487
Discounted Cost ($Million)	256.0184	239.2969	218.9914	205.2217	188.1881	176.6409	162.1943	152.4103	140.0764

Fiscal Yr	2026	2027	2028	2029	2030	2031	2032	2033	2034
Year	19	20	21	22	23	24	25	26	27
# Engines Produced	89	88	89	88	89	88	89	88	89
Cumulative # of Engines	1384	1472	1561	1649	1738	1826	1915	2003	2092
Cost ($Million)	476.413	468.835	472.0576	464.7986	468.2172	461.2145	464.7857	457.994	461.6865
Discounted Cost ($Million)	131.7322	121.1559	114.0081	104.9112	98.76896	90.92688	85.63638	78.8645	74.29939

GE/RR TOTAL PRODUCTION COST ($B)=	11.69834
GE/RR NPV ($B) =	4.654476

COMBINED PRODUCTION COST ($B) =	17.57569
COMBINED NPV ($B) =	7.280031

Data Source: LRIP engine quantities obtained from 461 FLTS F-35 Capabilities Brief (2006)

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