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INSTITUTE FOR DEFENSE ANALYSES

WSARA 2009: Joint Strike Fighter Root Cause Analysis

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June 2010

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IDA Paper P-4612

Log: H 10-000647

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About This Publication

This work was conducted by the Institute for Defense Analyses (IDA) under contract DASW01-04-C-0003,Task AY-7-3223, "WSARA 2009: Root Cause Analysis of Programs in Nunn-McCurdy Breach," for the Director, Program Assessment and Root Cause Analyses (D, PARCA), Office of the Under Secretary of Defense (Acquisition, Technology and Logistics). The views, opinions, and findings should not be construed as representing the official position of either the Department of Defense or the sponsoring organization.

Acknowledgments

Stanley A. Horowitz, Christopher A. Martin, and James L. Wilson of IDA were the technical reviewers.

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EXECUTIVE SUMMARY

The Institute for Defense Analyses (IDA) was tasked by The Office of the Under Secretary of Defense (Acquisition, Technology, and Logistics) Director, Performance Assessment and Root Cause Analyses (PARCA) to identify and quantify the issues that led to the current Nunn-McCurdy breach of the Joint Strike Fighter (JSF) program. IDA's study of the JSF program found three major issues that contributed to the 2010 Nunn-McCurdy breach. The major quantifiable reasons for the breach are:

- Errors in the Milestone B estimate resulted in a 23 percent increase in the program average unit cost (PAUC). This category includes programmatic, technical, and basic cost estimating assumptions that later proved to be false. Three major estimating issues that IDA identified and quantified are:
  - Incorrect contractor fully burdened labor rates were used
  - The airframe unit weight estimate was too low
  - The contractor/subcontractor fee arrangement was not modeled correctly for the production estimate
- The redesign effort increased the PAUC by 26 percent. The redesign effort led to significant changes in the aircraft that impacted production, assembly, and design of the vehicle. The four significant issues related to the redesign effort are:
  - Change in materials manufacturing efficiency
  - Changes in non-recurring tooling and equipment
  - Design changes negated affordability and production efficiency plans
  - Additional design effort during System Design and Development (SDD)
- Changes in the buy profile led to a 5 percent increase in the PAUC. Over the course of the program the quantities have been reduced, the ramp rate to full production has been altered, and the combined Air Force, Navy, and Marine peak production rate has been reduced. The individual changes that IDA quantified are:
  - Change in the ramp rate to peak production
  - Combined impact of lower procurement rate and reduced Navy quantities

Errors in the Milestone B estimate are a root cause of the Nunn-McCurdy breach while the redesign effort and changes in the buy profile are only proximate causes of the breach. These three factors do not account for the entire 57 percent PAUC increase but they do account for a majority of the growth.

Numerous other contributing factors have been suggested, specifically:

- Lack of adequate systems engineering by the contractor early in the process
- Failure of the concept demonstration programs to provide design and technical maturity
- Lack of management discipline and the complexity of a global supplier program
- Slowness by the program in responding to the weight growth
- The difficulty in integrating designs for three aircraft
- Decreased part commonality between the three F-35 variants
- Lack of clear incentives by the program office through the award fee process
- Lack of affordability emphasis by the program office
- Adherence to aggressive schedules to meet Service needs

Some of these issues might be underlying causes of the cost growth. In the time available, however, we were not able to link any of them quantitatively to the redesign effort or changes in the JSF buy profile.

I. BACKGROUND

A. PROGRAM DESCRIPTION

The mission of the Joint Strike Fighter (JSF) program is to develop the next generation strike aircraft in order to replace Air Force, Navy, and Marine assets. The program encompasses three variants: Conventional Take-Off and Landing (CTOL), Short Take-Off and Vertical Landing (STOVL), and Carrier Variant (CV). The CTOL is designed to replace the F-16 and A-10 for the Air Force. The STOVL is designed for the Marine Corp and will replace the AV-8B and the F/A-18A/C/Ds. Finally, the CV is designed to complement the F/A-18E/F and to replace existing Navy F/A-18A/C/Ds. In addition to the three variants, the program also funds two interchangeable engines, the F135 by Pratt and Whitney (PW) and the F136 by General Electric (GE). The JSF program also incorporates international participation through agreements with the United Kingdom, Canada, Netherlands, Italy, and others.

The program was established as a model of acquisition reform and incorporated Cost and Operational Performance Trades (COPT). Additionally, the JSF program incorporated a technical maturation phase prior to development that required the two competing contractors, Lockheed Martin and Boeing, to build a concept demonstration aircraft in order to prove the feasibility of several technical and performance challenges. At the end of the concept demonstration phase, Lockheed Martin was selected as the prime contractor for the JSF System Design and Development (SDD) contract.

The JSF program is expected to span over 40 years with a peak production rate of more than 200 aircraft per year. The current estimated Tri-Service procurement purchase is 2443 aircraft. International partner nations are expected to acquire an additional 783 aircraft. Foreign military sales (FMS) are also anticipated.

B. TECHNICAL DESCRIPTION OF THE SYSTEM

JSF is a family of fifth generation strike aircraft. It incorporates several new technologies and capabilities that have either not been fielded or fielded in limited quantities. For example, the F-35 is a very low observable (VLO) aircraft that is intended to be more easily maintained and exportable. Previous VLO aircraft such as the F-22, F-117, and B-2 have not been exported. Also, the F-35 will be equipped with a novel vehicle diagnostic data management system, called the autonomic logistics system, which allows the ground segment to continuously monitor the vehicle health.

The JSF family is built around common interchangeable engines and mission systems. Unlike the F-18 and F-22 the JSF will have a single engine. The new engines for the F-35 will provide significantly more thrust than the F-16 engine. The STOVL shaft driven lift fan (SDLF) concept also represents a significant departure from previously fielded STOVL aircraft (AV-8B) that have used directional nozzles to provide lift. The mission systems for JSF are expected to incorporate 2–3 times more code than the F-22 and allow the pilot to access a wide range of information through the Helmet Mounted Display System (HMDS), Multi-Function Display System (MFDS), and the built in Electro-Optical Targeting System (EOTS).

C. TIME LINE OF MAJOR EVENTS

The JSF concept grew out of the 1993 Secretary of Defense Bottom Up Review. The Joint Advanced Strike Technology (JAST) Program Office, established in 1994 and changed to Joint Strike Fighter (JSF) in 1995, carried out a series of studies investigating the feasibility of developing a common aircraft to support Tri-Service requirements. The studies pointed to developing three variants of the aircraft with high commonality. In 1995 the United Kingdom signed a Memorandum of Understanding (MOU) extending their participation into JSF. In 1996, the Milestone I Acquisition Decision Memorandum (ADM) was signed and Concept Demonstration contracts were awarded to Lockheed Martin and Boeing to compete for the System Design and Development (SDD) contract. International participation increased in 1997 as Denmark, Norway, the Netherlands, and Canada joined the JSF program. Contractor flight demonstrations were carried out in 2000.

The Milestone B Defense Acquisition Board (DAB) was held in October 2001. The materials prepared for that DAB revealed cost estimates by the JSF Joint Program Office (JPO) and the Cost Analysis Improvement Group (CAIG).[1] In 2001 there was less than 5 percent difference between the CAIG and JPO estimates and the decision was made to fund the program to the JPO estimate.[2] (The JPO and CAIG estimates and the discussion that follows use BY2002$). The SDD contract was awarded to Lockheed Martin and Pratt and Whitney in October 2001 for the development of the F-35 aircraft and the F135 engine respectively. GE was also funded to continue work on its F136 engine.

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1 Due to the Weapon System Acquisition Reform Act of 2009 (WSARA) the CAIG has been replaced by the Office of Cost Assessment and Program Evaluation (CAPE).

2 October 26, 2001 ADM. Subject: Joint Strike Fighter (JSF) Program Milestone B Acquisition Decision Memorandum.

In 2002 the Navy reduced its total projected buy from 1089 to 680 aircraft, which was a 14 percent[3] cut in the program's total quantity. In the 2002–2004 timeframe the estimated weight of the design aircraft posed a threat to the Key Performance Parameters (KPP). This resulted in the formation of two weight reduction teams, the Blue Ribbon Attack Team (BRAT) and the STOVL Weight Attack Team (SWAT) in an attempt to control the design aircraft weight. The BRAT was initiated first and identified several weight reduction initiatives. Subsequently, the projected weight saving from the BRAT effort proved to be optimistic and SWAT was formed to identify additional design changes that could control the weight of the aircraft. The SWAT effort resulted in significant modifications to the design, fabrication, and assembly of the airframe. Specifically, the wing, bulkheads, and center fuselage were all redesigned, which moderated the weight growth. The redesign of these areas not only impacted the manufacturing of parts but also significantly altered the production and integration plans, which impacted the aircraft commonality.

In the 2003 Selected Acquisition Report (SAR) a "critical" PAUC and a "significant" Average Procurement Unit Cost (APUC) Nunn-McCurdy (N-M) breach on the current baseline were reported (see Appendix A). Subsequently, in March 2004, a new Acquisition Program Baseline (APB) was approved. Subsequently, the 2005 SAR reported "significant" N-M breaches in the PAUC and APUC on the original baseline. Following the N-M breaches a new APB was established in March 2007.

After the 2007 APB, several review teams were formed to assess the JSF program. Initially, the Joint Estimating Team (JET), led by Office of Secretary of Defense (OSD) CAIG, was formed to quantify the resources required in the FY 2010–2015 budget to adequately fund JSF. The JET reported its results in 2008. Subsequently, a JET 2 study was initiated to update the 2008 JET results for the FY 2011–2016 budget. During the same period the Independent Manufacturing Review Team (IMRT) also reviewed the JSF manufacturing and ramp up plan. Additionally, the F135 Joint Assessment Team (JAT) reviewed the F135 engine and found that additional investments would be required. As a result of these reviews an Acquisition Decision Memorandum (ADM) was signed by Under Secretary of Defense for Acquisition, Technology, and Logistics (USD(AT&L)) that ordered a DOD-wide review of the JSF program and established the JET 2 estimate as the cost estimate for the JSF program, resulting in a "critical" PAUC and APUC N-M breach against the original baseline.[4]

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3 Defense Acquisition Management Information Retrieval (DAMIR): 2001 and 2002 SAR. The quantity cut resulted in a reduction in aircraft from 2886 to 2457.

4 Feb 24, 2010, Subject: F-35 Lightning II Joint Strike Fighter (JSF) Program Restructure Acquisition Decision Memorandum (ADM).

II. NUNN-MCCURDY BREACH

A. COMPUTATION OF THE BREACH

1. Program Acquisition Unit Cost Breach

The Nunn-McCurdy PAUC breach is based on two factors, the Original APB and the subsequent growth in the unit cost. At the time of the 2001 APB estimate, the JPO and CAIG estimate differed by less than 5 percent and the decision was made to fund the program to the JPO estimate.[5,6] As of the 2009 SAR the JSF PAUC estimate has grown 57 percent from its initial October 2001 ABP value of $61.8 million to its current value of $97.1 million, resulting in a "critical" Nunn-McCurdy breach.

Following are the key features of the breach:

- Of the 57 percentage point growth in the PAUC estimate, 11 percentage points are associated with RDT&E and the remaining 46 percentage points are associated with Procurement (Recurring Flyaway, Non-Recurring Flyaway, Other support and Initial Spares).
- The single largest area of growth in the PAUC estimate is the Unit Recurring Flyaway (URF) estimate, growing from $40.5 million to $60.4 million and accounting for 32 points of the 57 percent PAUC growth.

Table 1 depicts the PAUC growth as it relates to the officially documented cost positions. As previously noted, the 2001 Original APB is very close to the initial JPO and CAIG estimates; therefore, a "critical" Nunn-McCurdy breach occurred relative to all three cost positions.

Table 1. JSF Cost Positions (BY 2002 $M)[7]

Documented Estimate	RDT&E ($M)	Procurement ($M)	Total ($M)	Total Units	PAUC ($M/Unit)	Growth in PAUC (%)
2001 Original APB	$32,300	$143,300	$177,100	2866	$61.793	0%
2004 Change 1 APB	$42,100	$149,500	$193,100	2457	$78.592	27%
2007 Change 2 APB	$42,100	$168,981	$212,581	2458	$86.485	40%
2009 SAR	$45,136	$193,005	$238,599	2457	$97.110	57%

5 The initial aircraft quantities were 2866, which included 14 RDT&E aircraft.

6 October 26, 2001, Subject: Joint Strike Fighter (JSF) Program Milestone B Acquisition Decision Memorandum.

7 The Total line includes $1,500 M in Milcon.

Table 2 summarizes the calculation of the PAUC breach. As seen in the table, the growth in Unit Recurring Flyaway cost ($19.9 million) accounts for more than half of the $35.3 million growth in PAUC and, without at least a $15.4 million increase in the URF, there would have been no Nunn-McCurdy breach. Furthermore, neither a single, nor any pair, of cost categories in and of themselves breach the N-M "critical" threshold.

Table 2. Calculation of Documented Nunn-McCurdy PAUC Breach (BY 2002 $M)[8,9]

	APB 2001		SAR 2009		PAUC	
	Total	$/Unit	Total	$/Unit	Delta $/Unit	% Change to Total APB
MILCON	$1,500	$0.523	$457	$0.186	$(0.337)	-1%
RDT&E	$32,300	$11.270	$45,136	$18.370	$7.100	11%
PROCUREMENT						
Recurring Flyaway	$116,094	$40.507	$148,353	$60.380	$19.873	32%
Non-Recurring Flyaway	$5,122	$1.787	$15,815	$6.437	$4.650	8%
Support						
Other Support	$15,404	$5.375	$15,542	$6.326	$0.951	2%
Initial Spares	$6,681	$2.331	$13,295	$5.411	$3.080	5%
Total	$177,100	$61.79	$238,599	$97.110	$35.317	57%

In summary, the 57 percent growth in JSF PAUC from the 2001 ABP to the 2009 SAR exceeded the 50 percent growth level required to trigger a "critical" Nunn-McCurdy breach. The growth was primarily in procurement, which in turn was driven by growth in the URF cost. No breach would have occurred without significant growth in URF cost. In addition to the growth in cost, the program also experienced a 14 percent reduction in quantities. While the growth in some subaccounts was relatively large (e.g., Initial Spares more than doubled), their contribution to the overall breach was relatively small.

2. Average Procurement Unit Cost Breach

The APUC estimate also experienced a "critical" Nunn-McCurdy breach, mirroring the PAUC. Although there are no additional insights into the cause of the breach beyond those discussed for the PAUC, the following data are presented for completeness. The basis of the Nunn-McCurdy APUC breach may be summarized as follows, where all cost estimates are

8 The original estimate included 2866 aircraft and the current estimate is for 2457.

9 The numbers of the table track to pages 16, 17, and 38 of the 2009 SAR.

reported in BY 2002$: the JSF APUC estimate has grown 57 percent from its ABP October 2001 value of $50.2 million to its current, December 2009 SAR value of $79.0 million, resulting in a "critical" Nunn-McCurdy breach.[10] Table 3 summarizes the calculation of the APUC breach. As seen in the table, the growth in URF cost ($20.0 million) accounts for nearly 70 percent of the $28.8 million growth in APUC.

Table 3. Calculation of Documented JSF Nunn-McCurdy APUC Breach (BY 2002 $M)[11,12,13,14]

	APB 2001		SAR 2009		APUC	
	Total	$/Unit	Total	$/Unit	Delta $/Unit	% Change to Total APB
PROCUREMENT						
Recurring Flyaway	$116,094	$40.706	$148,353	$60.726	$20.020	40%
Non-Recurring Flyaway	$5,122	$1.796	$15,815	$6.474	$4.678	9%
Support						
Other Support	$15,404	$5.401	$15,542	$6.362	$0.961	2%
Initial Spares	$6,681	$2.343	$13,295	$5.442	$3.100	6%
Total	$177,100	$50.245	$238,599	$79.003	$28.758	57%

In a similar vein to the PAUC calculation neither a single, nor any pair, of cost categories in and of themselves breach the N-M "critical" threshold for APUC, and the URF also represents the single largest contributor to the N-M breach.

III. MAJOR COST VARIANCES REPORTED IN THE SARS

The SAR is an official report to Congress of a program's yearly performance and current status. The SAR provides data on the program's expected funding profile by account (RDT&E, Procurement, and Milcon), cost variances by explanation category (Economic, Quantity, Schedule, Engineering, Estimating, Other, and Support), as well as a change explanation for each

10 The initial aircraft quantity of 2852 was reduced to the current quantity of 2443.

11 Original Estimate is October 2001 Acquisition Program Baseline.

12 Current Estimate is the 2009 SAR.

13 Number of A/C = 2852 (Original Estimate) and 2443 (Current Estimate) and exclude the 14 RDT&E A/C.

14 Numbers track to pages 16, 17, and 38 of 2009 SAR.

variance (e.g., Adjustment for current and prior escalation). The SAR data provides an initial starting point for understanding how the program has changed since the original APB and where the of cost growth is reported. Unfortunately, the SAR does not contain enough data at a sufficiently detailed level to serve as the only basis for conducting a root cause analysis. For example, the SAR does not track assumptions made in the Milestone B cost estimate and it entangles numerous effects into a single cost change explanation (e.g., Increases in Propulsion estimate due to raw material prices, hardware/configuration changes, exchange rate updates, and higher than expected lift system hardware costs).[15] SAR data, however, were used to identify the significant areas of cost growth, calibrate IDA models, and compute the N-M breach by account.

A plot of PAUC growth by SAR year is shown in Figure 1. About 39 percent PAUC growth is reported in two SAR years: 2003 and 2009.[16] Using the SAR Change Explanations and Cost Variance Reports, we computed that the Navy quantity reduction of 409 aircraft resulted in 4 or 6 percent[17] PAUC growth, thus confirming that it is not the significant driver of the N-M breach.

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[15] 2009 SAR.

[16] The following are examples of SAR Explanations of PAUC Growth. In 2003, labor and OH rate increases; one year production delay; configuration update; MYP delayed. In 2005, configuration update; increased airframe materials cost; change in subcontractor manufacturing plan for wing; change in prime/subcontractor work share resulting in increased labor rates. In 2009, labor and OH rate increases; revision in air vehicle and propulsion estimate based on actual SDD and early LRIP costs; planned MYP delayed; production sustainment cost increases (based on changes in equipment costs); added risk funding due to JET assessment; change in production quantity and profile.

[17] The 4 or 6 percent value varies depending on if the SAR Change Explanation or Cost Variance report, respectively, is used. The difference is due to an accounting issue based on how costs associated with quantity reductions are accounted for between the Quantity and Support category in the explanation categories.

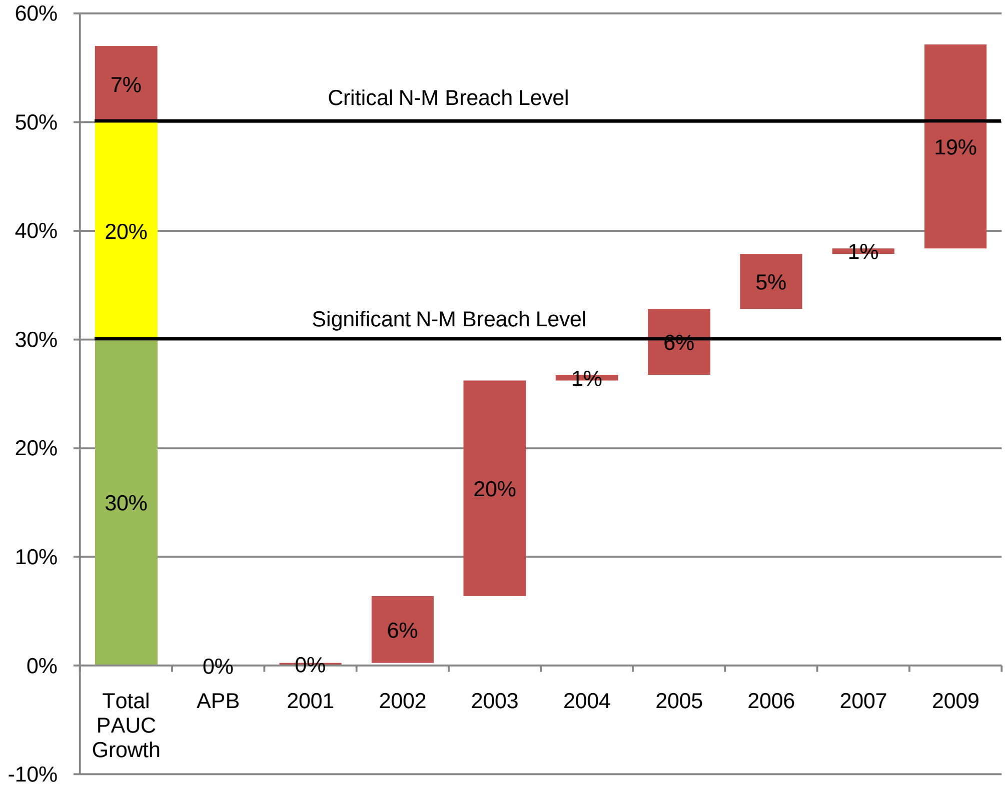

Figure 1. N-M PAUC Growth by SAR Year

The PAUC growth by SAR cost variance category, Figure 2, indicates that a significant majority of the cost growth is attributable to Estimating issues. The Estimating category covers cost model refinements or cost estimating assumptions not covered in any other categories. The Economic, Quantity, and Schedule variances are calculated automatically. Engineering is used to cover cost changes associated with a physical or functional change in the fully configured end item. Finally, Support covers cost changes not associated with flyaway costs. Based on these definitions the SAR indicates that very little of the cost growth is associated with changes in the aircraft or the associated change in quantity.

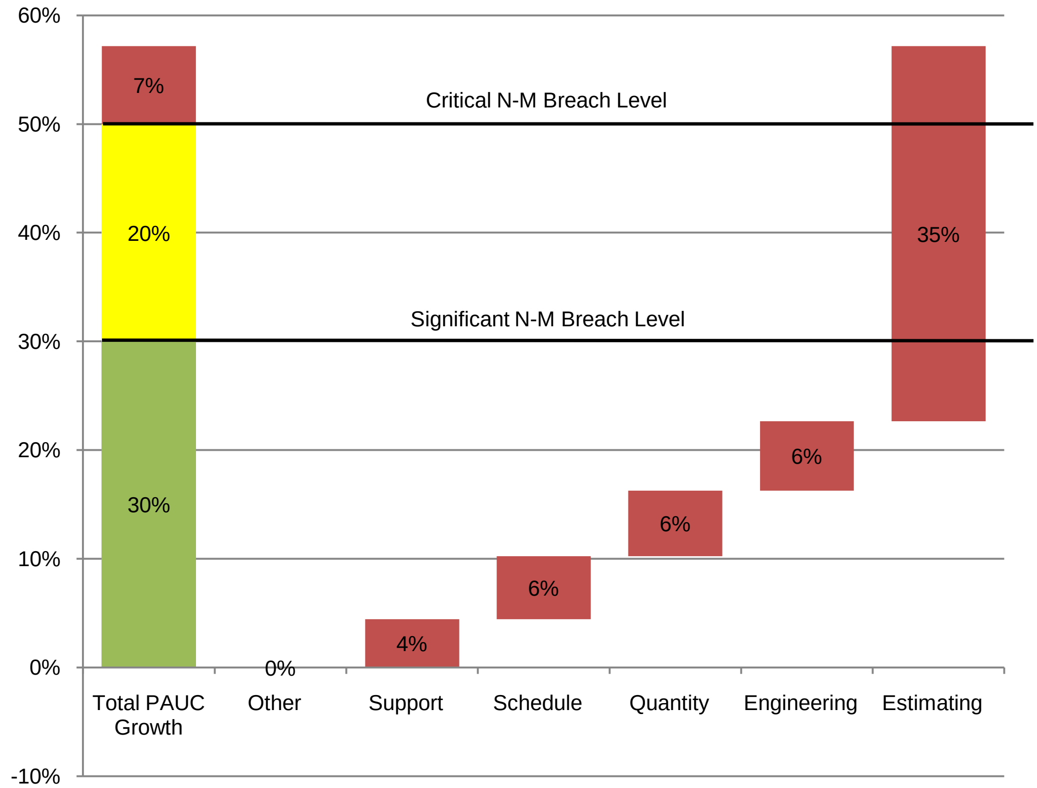

Figure 2. JSF PAUC Growth by SAR Cost Variance Report

Combining the PAUC cost breach calculation (Table 2) and the SAR cost variance explanations we can correct for the change in quantity to identify which accounts still exhibit "significant" PAUC growth. Figure 3 shows that taking into account the 14 percent reduction in units does not significantly change the results of the breach calculation. The URF cost remains the single largest contributor to the N-M breach. Without accounting for quantity changes, RDT&E is responsible for an 11 percent increase in the PAUC; however, when quantity changes are included in the calculation, RDT&E only accounts for an 8 percent increase in the PAUC.

In summary, the SAR data indicate the following:

- Reductions in quantity are not a significant driver of the N-M breach
- The increase in the Procurement URF cost is the single largest contributor to the N-M breach
- The 2003 and 2009 SARs had the two largest changes in PAUC (20 percent and 19 percent, respectively)

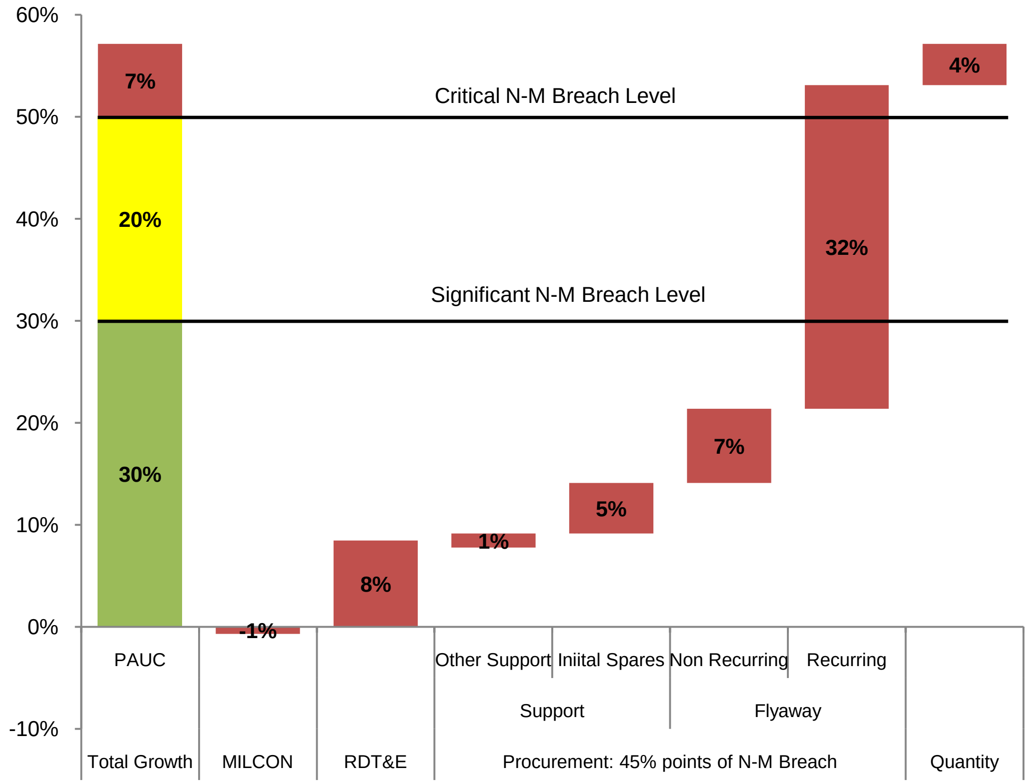

Figure 3. PAUC Growth by SAR Funding Category Corrected for Quantity Effects

IV. PROXIMATE ROOT CAUSE ANALYSIS OF COST GROWTH

A. GROUND RULES, DATA, AND ASSUMPTIONS

A multifaceted approach was used to understand the cost growth observed between the Milestone B and 2009 SAR estimate. In conducting the analysis, we used SAR data, JPO Milestone B documentation, historical IDA data, and contractor-provided information.

A top-down approach using the SAR data was employed to understand and quantify the cost growth associated with the major funding categories (e.g., RDT&E, Milcon, and Procurement) and the schedule and production profiles. This approach led us to initially focus on the single largest contributor to the N-M breach, the URF.

In conjunction with the SAR data, a bottom-up approach was employed that scaled up the Milestone B estimate to account for programmatic and technical changes that have occurred post Milestone B. This required increasing the various Milestone B URF subcategories (e.g., manufacturing, QA, tooling, materials) in order to compute the first order cost impact on the PAUC. IDA estimated the change in the PAUC by modifying key technical parameters and assumptions to match the current state of the program. Using a top-down and bottom-up approach allowed IDA to evaluate the accuracy of the Milestone B assumptions in the light of subsequent events. This approach yields a direct link between specific estimating assumptions and the growth over the Milestone B estimate.

B. MAJOR CAUSES OF THE COST GROWTH

IDA concluded that JSF PAUC growth can be grouped into three broad categories: errors in the Milestone B estimate, the redesign effort, and changes in the buy profile. The PAUC growth associated with each of these categories is depicted in Table 4.

Table 4. Gross JSF PAUC Growth Accounted for by Analyses

Errors in the Milestone B Estimate	
Aircraft Weight Growth	6%
Escalation Rates	14%
Fee-on-Fee	3%
	23%
Redesign	
Change in Materials Manufacturing Efficiency	6%
Changes in Non-recurring Tooling and Equipment	7%
Design Changes Negated Affordability and Production Efficiency Plans	6%
Additional Design Effort during System Design and Development	7%
	26%
Change in Buy Profiles	
Ramp Delay to Peak Production	2%
Lower Procurement Rate and Reduced Quantity	3%
	5%

1. Errors in the Milestone B Estimate

- Aircraft Weight Growth (6 percent): The Milestone B estimate used an estimate of the Airframe Unit Weight (AUW) for each variant, which included a 6 percent margin for growth, to compute the URF costs. The actual AUW turned out to be 10 to 21 percent[18] higher than the Milestone B estimated AUW. The direct effect of the growth was to increase procurement costs for manufacturing and engineering labor, materials, quality assurance (QA), and tooling.

- Escalation Rates (14 percent): DOD cost estimators are required to use escalation rates provided by the Office of the Under Secretary of Defense (Comptroller) (OUSD(C)) in making cost estimates used for budgeting of major systems. The Milestone B JPO estimate followed these rules. However, at the time of Milestone B, the Defense Contract Management Agency (DCMA) and Lockheed Martin had already agreed to a Forward Pricing Rate Agreement (FPRA) that increased rates more than the OUSD(C) escalation indices. We found that Lockheed Martin's actual rates closely matched the rates forecasted in their FPRA; therefore, the fully burdened labor rates turned out to be significantly higher than those used in the JPO Milestone B. In addition, changes in prime/subcontractor workshare added to cost growth. IDA did not perform an independent estimate of the impact[19] but did verify the error through the JPO milestone B documentation and the 2001 FPRA.
- Fee-on-Fee (3 percent): The Milestone B estimate was predicated on the application of a single fee to the sum of all costs, prime and subcontractor. This assumption remained valid through SDD. However, beginning with Low Rate Initial Production (LRIP) 1, the contractor teaming arrangement changed such that each contractor applied a fee to its own costs, while the prime contractor also applied a fee to the subcontractor costs and subcontractor fees. This led to cost growth since additional loading was not anticipated in the Milestone B estimate. We used LRIP 1 contractor cost data reports (CCDR) and the JPO Milestone B documentation to estimate this cost growth.

2. Redesign

- Changes in Materials Manufacturing Efficiency (6 percent): IDA used the Milestone B materials weight statement and the 2008 commonality database to identify changes in the material, price, estimated increases in the buy-to-fly[20] ratio, and additional labor in manufacturing the material relative to the Milestone B estimate. These changes led to growth relative to the original Milestone B estimate.
- Changes in Non-Recurring Tooling and Equipment (7 percent): The increases in non-recurring tooling and equipment results directly from the redesign effort. IDA did not break down the details of the increase but used the SAR estimate.

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[18] The actual AUW growth was beyond the 6 percent weight margin in the Milestone B estimate. The AUW estimate used in IDA's analysis was from the 2008 commonality database provided by Lockheed Martin. The Milestone B AUW estimate was from the JPO Milestone B briefing. The contractor AUW estimate at Milestone B was below the Government estimate.

[19] Cost impact taken from 2001–2009 SARs.

[20] Buy-to-fly refers to ratio of weight of the material in the finished part vs. the amount of material purchased to manufacture the part. It is used as a measure of manufacturing efficiency.

- Design Changes Negated Affordability and Production Efficiency Plans (6 percent): The Milestone B estimate included several affordability factors associated with increased productivity. For example, a manufacturing cost reduction factor of 20 percent was used to account for this additional productivity. Other factors were also applied to tooling and quality assurance. However, that plan was based upon the initial airframe design. The redesign effort negated the implementation of these affordability initiatives, resulting in cost growth. The removal of the affordability factors returned the JSF labor productivity estimate to that of the F-22 (as of the JSF Milestone B).
- Additional Design Effort during System Design and Development (7 percent): The RDT&E cost increased from the Milestone B estimate. IDA did not break down the details of the RDT&E increase, but took the SAR estimate minus the estimated fixed costs due to the delay in the start of production. The largest increase in RDT&E occurred in the Dec 2003 SAR, which indicated that the cost increase was due to "SDD schedule extension for additional design maturation and known and unknown risks."[21] The SDD schedule change between the 2002 and 2003 SAR was only one year, indicating that this was primarily a design issue.

3. Change in Buy Profiles

- Ramp Delay to Peak Production (2 percent): IDA estimates a ramp delay to peak production of three years. However, it is difficult to measure the delay precisely and one could reasonably estimate from two to four years for the delay (see Appendix B).
- Lower Procurement Rate and Reduced Quantities (3 percent): This estimate reflects a six-year procurement delay and the reduction in procurement units. In addition, the reduction in procurement units also changed the variant mix. Since the new variant mix was weighted more towards less expensive planes, this offsets part of the cost growth associated with lower production rates and reduced quantity (see Appendix B). The SAR reports that quantity reductions account for 4 or 6 percentage points of the N-M breach.

In terms of caveats and limitations to the study, two issues potentially qualify IDA's findings. First, IDA's estimate of the 54 percent PAUC growth represents the sum of the above factors, each of which (except for quantity reductions) individually resulted in positive cost growth. In contrast, the 57 percent cost growth indicated in the 2009 SAR is the net result of all factors, including not only those resulting in positive cost growth but also those resulting in negative cost growth. Therefore, the 54 percent IDA estimate and the 57 percent SAR estimate are not precisely reconcilable without detailed analysis of every individual cost that changed during the period of interest. However, the 54 percent and the 57 percent are entirely comparable in terms of baseline, major factors considered, and characterization and understanding of the Nunn-McCurdy breach.

[21] 2003 SAR.

Second, the factors IDA assessed were assessed on an individual basis and not in the context of a fully encompassing and integrated cost model. Therefore, it is theoretically possible that there are correlations among the factors which, if not accounted for, would cause the 54 percent to be biased. However, IDA found no indication or evidence of factor correlation or bias, certainly not on the scale that would alter the conclusions.

Therefore, neither issue presents a significant qualification to IDA's findings. Although IDA's assessment does not account for the entire growth in PAUC, it does capture the great majority of that growth. It identifies nearly all of the major individual factors, quantifies their impact in a highly transparent way using official Government and contractor data, and links those impacts to root causes. The second order effects relating to potential correlations between factors were not apparent in the data and analysis, and impose no qualifications on the results. Neither omitted factors nor second order effects can significantly alter or qualify the main conclusions of the study.

V. COMMENTS ON ROOT CAUSE

If one steps back from both the specific root causes defined in WSARA and the detailed, individual factors identified in IDA's assessment, it is possible to obtain a broader and more fundamental view of the nature of the JSF Nunn-McCurdy breach. At the most basic level, the question is whether the cost growth resulted primarily from the actions of the Government or from the actions of the contractor. Was it poor cost estimation and poor Government management or was it poor execution by the contractor team that led to the cost growth? Although IDA did not address the issue specifically in that way, IDA's results provide insight into the issue and quantitatively bound and constrain the discussion. Approximately 40 percent of the growth (i.e., 23 of the 57 percentage points of growth) is traceable to an unrealistically low cost estimate at Milestone B. An additional 9 percent (i.e., 5 of the 57 percentage points) of the growth is traceable to changes in quantity and schedule. Thus, about half the growth can be linked directly to Government actions. Further, if the redesign effort can be linked to the poor initial weight estimates by the Government and the contractor, then part of that cost impact also is traceable to Government actions. It is clear that, at the most fundamental level, Government actions were significantly more important in driving the cost growth than contractor execution problems.

WSARA[22] requires a root cause analysis with respect to a major defense acquisition program including an assessment of the underlying cause or causes of shortcomings in cost, schedule, or performance of the program, including the role, if any, of the following seven classifications:

- Unrealistic performance expectations
- Unrealistic baseline estimates for cost and schedule
- Immature technologies or excessive manufacturing or integration risk
- Unanticipated design, engineering, manufacturing, or technology integration issues arising during program performance
- Changes in procurement quantities
- Inadequate program funding or funding instability
- Poor performance by government or contractor personnel for program management

IDA identified and quantified the major reasons underlying the cost growth in the JSF program; however, IDA did not map the root causes IDA identified to WSARA root causes. In addition to quantifying the causes of PAUC growth, IDA also reviewed documentation of a number of recent studies. The most significant documentation includes the following reports:

A. SARs for 1997 through 2009
B. F-35 Joint Estimate Team I (JET I), September 9, 2008
C. F-35 Joint Estimate Team II (JET II), October 2009
D. F-35 IMRT Report, October, 20 2009
E. Naval Air Systems Command Risk Assessment, May 5, 2010

Table 5 categorizes a number of comments excerpted from the above documents to a root cause.

22 Public Law 111-23.

Table 5. JSF Assessments and Comments Categorized by Root Cause

Comment	Source
Unrealistic performance expectations	
Lack of strong Systems Engineering rigor and overall discipline	E
Multi-block software development plan leading to lab gridlock	E
Unrealistic baseline estimates for cost or schedule	
Engineering staffing ramp down too optimistic	B, C
Software/ Mission systems schedule too optimistic	B, C
SDD aircraft manufacturing span times too short	B, C
Flight test schedule too optimistic	B, C
Rates – Estimates of labor and OH rates	A, C
Immature technologies or excessive manufacturing or integration risk	
Analogy method for airframe design weights was inadequate	A
Unanticipated design, engineering, manufacturing, or technology integration issues arising during program performance	
Weight of the initial SDD airframe designs	A
Loss of commonality impacting material costs	A
Initial CV keel design inadequate for carrier launches	
Material changes and costs	A
Changes in manufacturing plan for wings	A
Increased manufacturing span times/shortage of parts	D
Propulsion (added thrust changes and materials)	A
Changes in procurement quantities	
Equipping all Navy aircraft with Electro Optical Tracking System	A
Reduction of 409 Navy aircraft	A
International aircraft additions	A
Inadequate program funding or funding instability	
Funding process within DOD does not support a complex large scale international partner, global supplier program	D
Poor performance by Government or contractor personnel responsible for program management	
Government unable to independently assess technical maturity	E
Lack of consistent DCMA engagement across the contractor's sites	D
Non-Compliant Earned Value Management	E
Disciplined Technical Review Processes not evident	E
LM must assume a more aggressive leadership role	D
Planned capability not aligned to an executable schedule	D, E
Inability to plan and execute against a plan	D, E
Mission systems integration and software development not under control	E
Realistic program baseline not in place	E
Risk reduction management process and funding not credible	A, D, E
Integrated cost and affordability improvement program not being execute	D
Parts shortage and production line workarounds	D

VI. SUMMARY OF FINDINGS

The IDA analysis concludes that errors in the Milestone B estimate accounted for about 23 percent PAUC growth. These errors were associated with the underestimation of airframe unit weight, the use of faulty labor rates, as well as the move to a contract structure based on a prime and sub relationship instead of a teaming arrangement with a shared fee pool. The root cause of these factors is an unrealistic Milestone B cost estimate.

IDA concludes that the redesign effort led to 26 percent growth over the Milestone B estimate, based on reductions in materials manufacturing efficiency, increase in non-recurring tooling and equipment, negation of affordability plans, and the increase in RDT&E effort. We do not have a clear hypothesis to offer as to the root cause of these factors, although the initial error in estimating aircraft weight clearly is implicated.

IDA concludes that the delay in ramp up to peak production, the lowered procurement rate, the overall reduced quantity accounted for 5 percent growth relative to the Milestone B estimate. Some would include these sources of PAUC increase with the consequences of the redesign. Others would argue that they reflect a lack of realism in the ramp rates assumed in the Milestone B estimate, inadequate attention to affordability at Milestone B, or the result of DOD budget policies. We have no persuasive hard evidence to offer on this disagreement.

APPENDIX A:
ACQUISITION TERMS OF REFERENCE

Average Procurement Unit Cost = Procurement Costs / Procurement Quantities

Program Average Unit Cost = Total Program Costs / (Procurement + RDT&E Quantities)

There are eight possible Nunn-McCurdy breaches, four for the APUC and four for the PAUC. The breach calculation is performed by measuring the percentage growth in the APUC or PAUC. A “significant” N-M breach occurs if the average unit costs have increased by >15 percent of the Current APB or >30 percent of the Original APB. A “critical” breach occurs when the average unit costs have increase by at least 25 percent against the Current APB or 50 percent against the Original APB. The Original APB is the APB that is established during the Milestone B decision (formerly Milestone II).

The Nunn McCurdy breach is reported in the Selected Acquisition Report (SAR). The SAR maintains an official record of the projected costs for a program by funding categories (e.g., RDT&E, Procurement, and Milcon). In addition to tracking total program costs, the SAR tracks the year-to-year change in costs and provides an explanation for the changes. Furthermore, each cost variance reported in the SAR is then attributed to one of six categories: Other, Support, Schedule, Quantity, Engineering, or Estimating. While providing insight, the SAR categories and program offices’ explanation of cost growth are not necessarily root causes as defined by IDA, PARCA, or WSARA.

APPENDIX B:
MODELING COST IMPACT OF SCHEDULE AND PROCUREMENT RATE CHANGES

A. BACKGROUND

IDA developed an analytic tool to estimate the JSF procurement costs; assuming a lot fixed cost, a unit cost curve that is driven by learning, and the theoretical first unit cost T_1 for each variant. The purpose is to capture how changes in the buy profile, schedule, and quantities affect the average unit cost. The total estimated impact of these changes is a 5 percent increase in the PAUC. The calculations were calibrated to the 2001 SAR,[1] which provided the earliest official record of the BY 2002 $ costs aligned with the JSF production profile.

B. BUY PROFILE CHANGES

The current plan for F-35 procurement extends procurement for nine years beyond the date reported in the 2001 SAR (see Figure B-1); the last procurement funding year slipped from FY 2026 to FY 2035.

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1 The 2001 SAR procurement costs are slightly larger than the 2001 APB, due to changes in labor and overhead indices issues. In order to account for the difference between 2001 APB and the 2001 SAR the final results were scaled down by the ratio of the 2001 APB to the 2001 SAR.

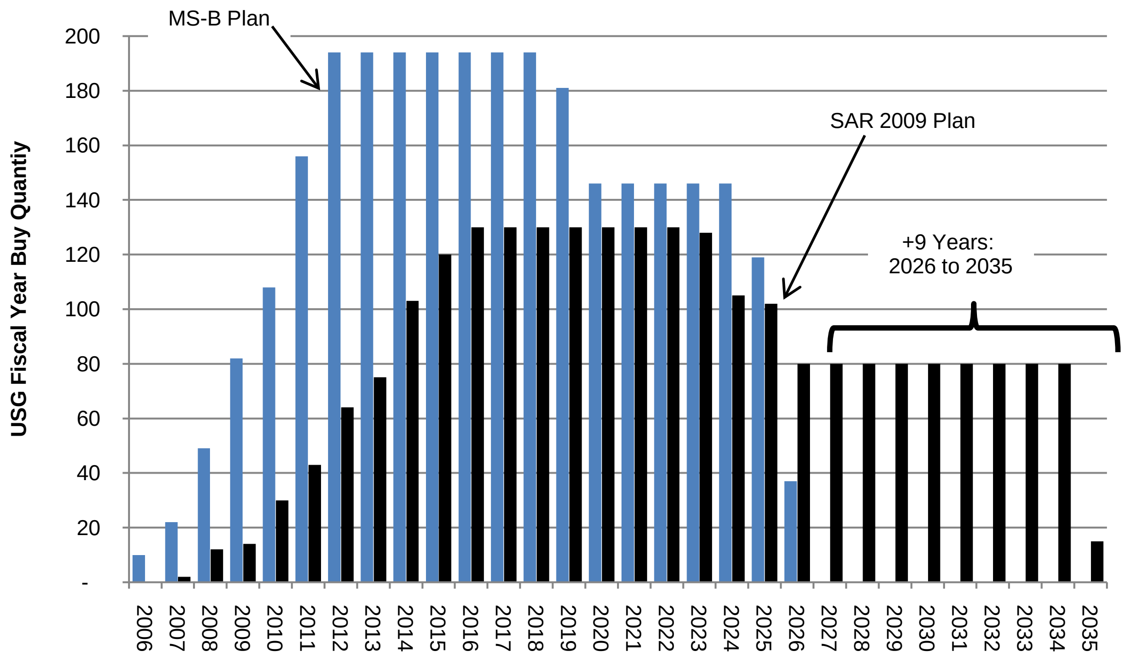

Figure B-1. Comparison of MS-B and SAR 2009 Procurement Plan

We estimated the cost impact of the change in the procurement profile using Equation 1.

$$UC_i\left(q_i,\ q_i^{USAF}, q_i^{USN}, q_i^{USMC}, Q_i\right)$$
$$= \boldsymbol{F}\frac{1}{q_i} + .95^{MYPi}\left(\boldsymbol{T_1^{USAF}}\frac{q_i^{USAF}}{q_i^{USG}} + \boldsymbol{T_1^{USN}}\frac{q_i^{USN}}{q_i^{USG}} + \boldsymbol{T_1^{USMC}}\frac{q_i^{USMC}}{q_i^{USG}}\right)Q_i^{\boldsymbol{\beta}}$$

Equation B-1. IDA model used estimate schedule, quantity, and production rate impacts

UC_i: unit cost in BY02 dollars for lot *i* as reported in the 2001 SAR.

q_i: total lot quantity for all aircraft including international customers,

q_i^{USG}: lot quantity bought by the the US government, where $q_i^{USG} = q_i^{USAF} + q_i^{USN} + q_i^{USMC}$,

Q_i: cumulative quantity for all aircraft (with SDD and international units) at the midpoint of lot *i*.

MYPi has the value of 1 for lots with multi-year procurement savings and 0 otherwise

Parameters estimated:

F, the fixed cost associated with each lot;

$\boldsymbol{T_1^{USAF}}, \boldsymbol{T_1^{USN}}$ and $\boldsymbol{T_1^{USMC}}$ are first unit costs of the variants for each military service

β is the learning parameter

The MYP basis value (.95, a 5 percent savings) is per JPO assumptions

We decomposed the nine year delay into the portion associated with the delay in the production ramp-up and the portion driven by the decrease in the peak production rate.

1. Procurement Delay Due to Slowed Procurement Ramp-Up

To calculate the ramp delay we created a hypothetical production profile where all of the characteristics of the plan reported in the 2001 SAR were preserved except for the ramp-up to full rate production (see Figure B-2 below). While the current plan takes four years longer to reach full rate production, the calculated total procurement period delay is only three years. Our assumption for the hypothetical plan was that the peak production rate would be sustained for eight years, as is the plan reported in the 2009 SAR.

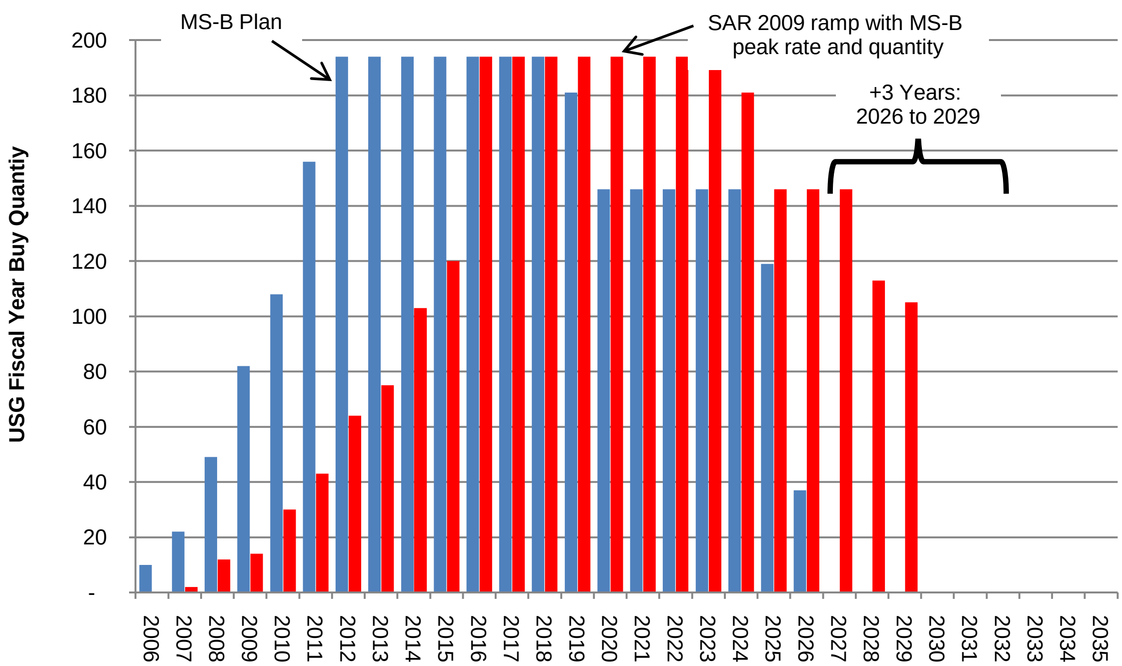

Figure B-2. Production Ramp Impact on Production Delay

2. Procurement Delay Due to Reduced Production Rate

The current 2009 SAR plan shows a peak annual procurement rate of 130 for U.S. government buys, down from 194 in the 2001 SAR. The reduction in rate accounts for the remaining six year production delay and the decrease in total procured quantity. Note that in all cases the USAF buy is the "critical" path in the completion of the procurement schedule. Thus the primary driver of the procurement stretch is the decrease in the USAF rate from 110 to 80 aircraft per year. The decrease in USMC and USN production rates was accompanied by decreases in the USMC and USN total procured quantity. Figure B-3 compares the 2001 SAR plan with the hypothetical plan.

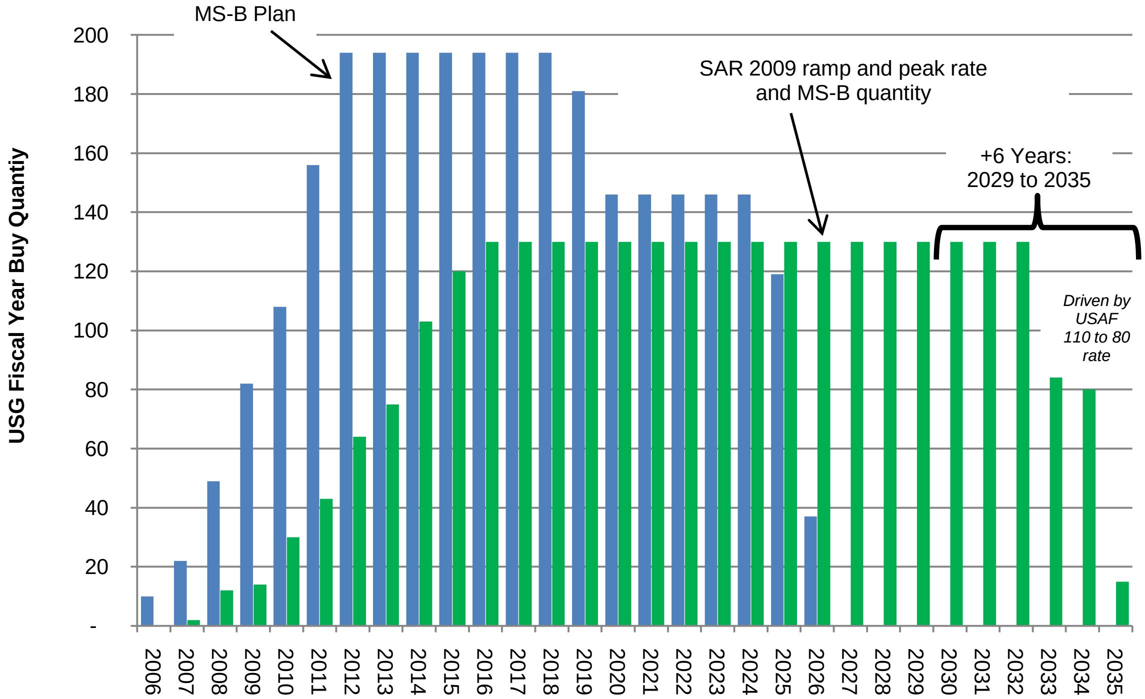

Figure B-3. Production Ramp and Peak Rate Impact on Production Delay

Note that the decomposition of the nine year delay into ramp-up and production rate effects does not change the resulting cost estimate, only its allocation between the two categories.

3. Cost Model Specification and Estimation

Equation B-1 was fit to the 2001 SAR procurement data using nonlinear least square with multiplicative errors. The unit costs are associated with the U.S. government buy; however, the model captures the learning and fixed costs associated with international purchases. We assumed the fixed portion of total lot costs would never be less than 8 percent and that $\frac{T_1^{USN}}{T_1^{USAF}} = 1.29$ and $\frac{T_1^{USMC}}{T_1^{USAF}} = 1.24$, based on information provided by the JPO.[2]

The fit resulted in an annual fixed cost of \$914 million, the USAF T_1 of \$202 million, the USMC T_1 of \$250 million, and the U.S. Navy T_1 of \$261 million, and a learning slope of 86 percent ($\beta = 0.23$). All costs reported are in BY2002\$.

2 The values to calculate the ratios were taken from "JSF Cost Brief to IDA", Mike Clark, Joint Strike Fighter Program Office, June 23, 2006.

Figure B-4 shows the fit of the model to the 2001 SAR data.

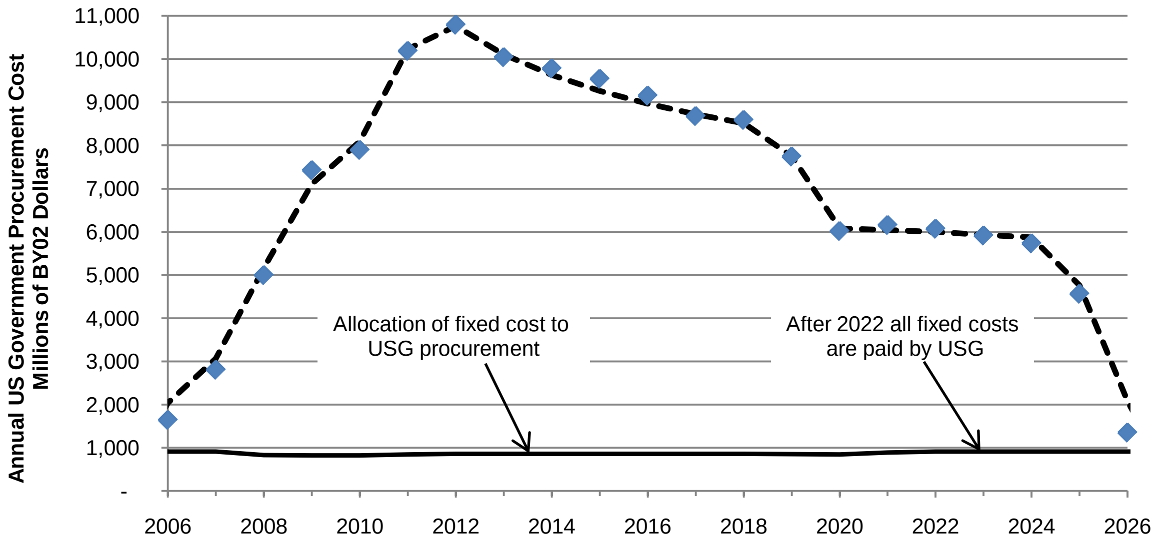

Figure B-4. Model Fit to 2001 Data

The resulting estimated parameters fit the data very well. The first two lots and the last lot were not used to estimate the parameters because they had low procurement rates. Fixed costs are allocated to all aircraft purchases (U.S. and international). Fixed costs associated with the procurement delays were allocated to the U.S. aircraft because there were no international purchases in those years.

4. Calculation of PAUC Growth Due To Ramp, Rate, and Quantity Changes

The results of the PAUC calculations are presented in two steps shown in Table B-1: first, the changes from the ramp delay to peak productions, and second, lower procurement rate and reduced quantities. The net result is a 5 percent increase in PAUC with 2 percentage points of the PAUC growth associated with the 3-year Ramp Rate change and the remainder (3 percentage points) increase associated with the program stretch and peak production rate reduction and associated total quantity cut.

Table B-1. Calculation of Final PAUC Adjustments

	Milestone B	3-year Ramp Rate Delay	Peak Production Delay and Quantity Cut
US Govt Quantity	2866	2866	2457
RDT&E, BY02$ B	$32,300	$32,300	$32,300
Procurement, BY02$ B	$143,300	$146,007	$126,279
Milcon, BY02$ B	$1,500	$1,500	$1,500
PAUC, BY02$ M	$61.793	$62.738	$65.152
% Increase in PAUC	0	2%	5%

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Period 11 Award Fee - Debrief to Lockheed Martin on the JSF Air System Contract		
Period 12 Award Fee - Debrief to Lockheed Martin on the JSF Air System Contract		
Period 13 Award Fee - Debrief to Lockheed Martin on the JSF Air System Contract		
Period 14 Award Fee - Debrief to Lockheed Martin on the JSF Air System Contract		
Period 15 Award Fee - Debrief to Lockheed Martin on the JSF Air System Contract		
Period 16 Award Fee - Debrief to Lockheed Martin on the JSF Air System Contract		

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Contractor Performance Assessment Record (CPAR)	11/01/2003 - 10/31/2004	February 23, 2005
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ABBREVIATIONS

ADM	Acquisition Decision Memorandum
APB	Acquisition Program Baseline
APUC	Average Procurement Unit Cost
AT&L	Acquisition, Technology and Logistics
AUW	Airframe Unit Weight
BRAT	Blue Ribbon Attack Team
CAIG	Cost Analysis Improvement Group
CAPE	Office of Cost Assessment and Program Evaluation
CCDR	Contractor Cost Data Report
COPT	Cost and Operational Performance Trades
CTOL	Conventional Take-Off and Landing
CV	Carrier Variant
DAMIR	Defense Acquisition Management Information Retrieval
DOD	Department of Defense
EOTS	Electro-Optical Targeting System
FMS	Foreign Military Sale
FPRA	Forward Price Rate Agreement
GE	General Electric
HMDS	Helmet Mounted Display System
IDA	Institute for Defense Analyses
IMRT	Independent Manufacturing Review Team
JAST	Joint Advance Strike Technology
JAT	Joint Assessment Team
JPO	Joint Program Office
JSF	Joint Strike Fighter
KPP	Key Performance Parameters
LRIP	Low Rate Initial Production
MFDS	Multi-Function Display System

MOU	Memorandum of Understanding
N-M	Nunn-McCurdy
OSD	Office of Secretary of Defense
PARCA	Performance Assessment and Root Cause Analyses
PAUC	Program Average Unit Cost
PW	Pratt & Whitney
QA	Quality Assurance
RDT&E	Research, Development, Test and Evaluation
SAR	Selected Acquisition Report
SDD	System Design and Development
SDLF	Shaft Driven Lift Fan
STOVL	Short Take-Off and Vertical Landing
SWAT	STOVL Weight Attack Team
URF	Unit Recurring Fly away
USD(AT&L)	Under Secretary of Defense (AT&L)
VLO	Very Low Observable
WSARA	Weapon System Acquisition Reform Act of 2009

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
xx-06-2010

2. REPORT TYPE
Final

3. DATES COVERED *(From - To)*
Mar - Jun 2010

4. TITLE AND SUBTITLE
"WSARA 2009: Joint Strike Fighter Root Cause Analysis"

5a. CONTRACT NUMBER
DASW01-04-C-0003

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

5d. PROJECT NUMBER

5e. TASK NUMBER
AY-7-3223

5f. WORK UNIT NUMBER

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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8. PERFORMING ORGANIZATION REPORT NUMBER
IDA Paper P-4612

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
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3620 Defense Pentagon
The Pentagon, Room 5A1082
Washington, DC 20301-3620

10. SPONSOR/MONITOR'S ACRONYM(S)
D, PARCA

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited. (September 6, 2011).

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Growth in unit cost estimates for the Joint Strike Fighter program, from the initial estimate in 2001 to the current estimate in the 2009 Selected Acquisition Report (SAR), has led to a "critical" Nunn-McCurdy breach and a subsequent recertification effort in FY 2010. The 2009 SAR reported a 57 percent increase in both the average procurement unit cost (APUC) and the program acquisition unit cost (PAUC), compared to the initial 2001 program estimates. To understand the reasons for the growth, Director, Performance Assessments and Root Cause Analysis asked IDA to provide a determination and assessment of the root causes of the Nunn-McCurdy Breach. IDA's analysis identified and quantified three major categories of growth: errors in the original 2001 Milestone B cost estimate, redesign of the aircraft in 2003, and changes in the buy profile (slipping the schedule and reducing the total quantity), together accounting for a growth of more than 50 percent over the initial unit cost estimates. Due to constraints of the Nunn-McCurdy recertification process, IDA did not have time to address other areas of potentially significant growth, such as growth in the propulsion cost estimates and a change in the estimating approach.

15. SUBJECT TERMS
Critical; Significant; Breach; PAUC; APUC; JSF; Milestone B Estimate; Nunn-McCurdy; Program Average Unit Cost; Average Procurement Unit Cost; Joint Strike Fighter; F-35; F135; F136

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES
Unclassified	Unclassified	Unclassified	Same as Report	58

19a. NAME OF RESPONSIBLE PERSON
Bliss, Gary, R.

19b. TELEPHONE NUMBER *(Include area code)*
571-256-0646

Reset