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ROOT CAUSE ANALYSES OF NUNN-MCCURDY BREACHES

VOLUME 1

Zumwalt-Class Destroyer, Joint Strike Fighter,
Longbow Apache, and
Wideband Global Satellite

Prepared for the Office of the Secretary of Defense

Approved for public release; distribution unlimited

RAND NATIONAL DEFENSE RESEARCH INSTITUTE

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Preface

As a result of continuing concern with large cost overruns in a broad range of major defense programs, Congress enacted new statutory provisions extending the ambit of the existing Nunn-McCurdy Act, stipulating the review and reporting by the Department of Defense (DoD) of factors and issues in both specific and general terms. In accordance with the revised Nunn-McCurdy Act, the Performance Assessments and Root Cause Analysis (PARCA) office must provide its root cause explanation as part of a 60-day program review triggered when the applicable military department secretary reports a breach.

In March 2010, the newly created PARCA office within the Office of the Secretary of Defense (OSD), in view of staffing limitations, elected to rely on federally funded research and development center (FFRDC) support to help discharge its new responsibilities. It engaged the RAND Corporation to study the root causes of Nunn-McCurdy breaches in four of six major defense acquisition programs that had breached: the DDG-1000, the Joint Strike Fighter, the Longbow Apache, and the Wideband Global Satellite. RAND conducted its work within this 60-day window so that the PARCA office could use RAND findings in preparing DoD reports to Congress.

This monograph contains the findings from each of the program reviews conducted by RAND. Although the programs involved are different, the RAND analysis found many similarities, ranging from unrealistic expectations to contracting methods. The report details the specifics of the reported breaches and is intended for a general audience; however, it also used, in part, previously conducted RAND research on programs such as the Joint Strike Fighter and the DDG-1000. Selected publications that may be of interest about these programs and related acquisition processes are available at www.rand.org.

This research was sponsored by OSD PARCA and conducted within the Acquisition and Technology Policy Center of the RAND National Defense Research Institute, a federally funded research and development center sponsored by the Office of the Secretary of Defense, the Joint Staff, the Unified Combatant Commands, the Navy, the Marine Corps, the defense agencies, and the defense Intelligence Community.

For more information on the RAND Acquisition and Technology Policy Center, see http://www.rand.org/nsrd/ndri/centers/atp.html or contact the director (contact information is provided on the web page).

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Summary

Background and Purpose

As a result of continuing program cost growth and observations by the Government Accountability Office (GAO) placing defense acquisition on the high-risk target list, Congress continued to refine and expand on program execution controls. In this report, we focus on the mandates for root cause analysis and performance appraisal of major defense acquisition programs (MDAPs) and how RAND supported DoD (that is, the director of the PARCA office in the Office of the Under Secretary of Defense, Acquisition, Technology, and Logistics [OUSD AT&L]) as it executed its responsibilities for analysis and certification of MDAPs that had breached Nunn-McCurdy thresholds. The research and analysis performed by RAND and the conclusions it reached formed a foundation of the inherently governmental function of program certification required by statute.

In the face of six MDAP cost threshold breaches reported by several secretaries of the military departments, the PARCA director determined that he required support to execute his statutory responsibilities and turned to FFRDCs and academia to provide that support for the program execution status research and analysis. Along with the Institute for Defense Analyses (IDA), Center for Naval Analyses (CNA), and the University of Tennessee, RAND was engaged to perform analysis and provide recommendations. RAND was assigned sole responsibility for three programs: Wideband Global Satellite (WGS), Long Bow Apache Helicopter (Apache Block III), and *Zumwalt*-Class Destroyer (DDG-1000). In addition, RAND shared the analytic effort for a fourth program, the Joint Strike Fighter (JSF), with IDA and the University of Tennessee.

For RAND, these efforts were somewhat unusual on several levels. The time allowed under the statute from the moment the breach was announced to the need for certification was very short. The time limit drove the use of already available material held by the government to perform analysis. Research was conducted in concert with government offices (in point of fact, it could not have happened otherwise given the time available), often under the direction of DoD offices and officials. DoD officials used the results of RAND's research and analysis by performing their inherently governmental functions well before the production of even a draft report. As a consequence of the resulting approach to this shared set of responsibilities, the Secretary of

Defense was able to perform his certification responsibilities to allow program continuation. The materials found in Chapters Three through Six of this report represent the results of the RAND research and analysis efforts used by DoD in arriving at program certification.

As noted above, time did not allow for generation of fresh data. DoD made available to four RAND research and analysis teams (one for each of the designated programs) the cost, schedule, and performance data in existing DoD databases. The four RAND teams, each headed by a senior RAND researcher, performed data analysis, engaged both applicable contractor and appropriate government personnel in in-depth discussions on program status, and reviewed pertinent previous RAND efforts and documentation to distill program understanding.

Each program represented a different set of conditions and, as a result, required tailored approaches to produce the requisite material in support of the government's process. The fundamental questions to be answered were stipulated in statute, and the PARCA office established an approach to display the findings at a summary level. Both are discussed in greater detail in Chapters One and Two. Some of the causes identified, such as quantity changes and unfounded technical expectations, were found in most of the programs. Several unique findings led to an examination in greater depth of the metrics available to enable progress review. That, in turn, led to a finding that greater attention needs to be paid to the metrics currently in vogue because they do not appear to cover adequately some aspects of program execution. This issue becomes even more significant in light of another finding. To satisfy statutory demands fully, the root cause analysis and performance assessment processes need to be conducted on a continuum that examines and reports on the same issues over time, thereby requiring more than static metrics. Finally, given the state of the industrial base, a better understanding is required of the interrelationship of government and commercial lines of business within a defense contractor as well as the importance of the financial health of any contractor supplying goods and services to DoD.[1]

What is certain is that if DoD is to continue to perform the PARCA office functions as it did in the initial process, a better understanding of the full range of data available needs to be developed, and access to those data needs to be better enabled. Of particular interest and discussed further in Chapter Seven is greater access to the Defense Acquisition Management Information Retrieval (DAMIR) system and to service program briefings.

---

[1] Loren Thompson of the Lexington Institute emphasizes that latter point in his recent article on the financial travails of Oshkosh. See Loren B. Thompson, "Oshkosh Vote Shows Danger of Rewarding Aggressive Bids from Shaky Companies," *Lexington Institute Early Warning Blog,* September 3, 2010.

Results

Root Causes

Although our work on root causes identified several contributory factors, our analysis of the four programs indicates that three were common across all four programs: planning, changes in the economy, and program planning. Table S.1 provides a summary of the root cause analyses of the four programs reviewed, listing the causes in

Table S.1
Comparison Matrix of the Root Causes of Program Cost Growth

Category	Root Cause of Nunn-McCurdy Breach	WGS	Apache	DDG-1000	JSF
Planning	Underestimate of baseline cost	√	√	√	√
	Ambitious scheduling estimates			√	√
	Poorly constructed contractual incentives	√ √			√
	Immature technologies		√ √	√	√ √
	Ill-conceived manufacturing process			√	
	Unrealistic performance expectations			√	
	Delay in awarding contract			√	
	Insufficient RDT&E	√	√	√	√
Changes in economy	Increase in component costs	√ √	√	√	√
	Increase in labor costs		√		√
	Discontinued/decreased production of components	√			
	Decreased demand for similar technology in private sector (economies of scale)	√			
	Inflation	√	√	√	√
Program management	Production delays	√ √		√	√ √
	Change in procurement quantities				
	Increase	√	√ √		
	Decrease			√ √	√
	Unanticipated design, manufacturing, and technology integration issues		√ √	√	√ √
	Lack of government oversight or poor performance by contractor personnel			√	√
	Inadequate or unstable program funding	√	√	√	√
	Accounting artifact	√			

NOTE: √ = Root cause, √ √ = Significant root cause.

each of the three categories. A single check mark indicates a root cause, and double check marks indicate a significant root cause.[2] As the table shows, underestimation of baseline cost; increases in component costs; insufficient Research, Development, Test, and Evaluation (RDT&E); inflation; and increased, inadequate, or unstable program funding were identified as root causes in all four programs. For the WGS, the increase in component costs was a significant root cause. The prevalence of these same factors across four very different programs may indicate systemic root causes that warrant increased attention in future program planning.

Lessons Learned

Our analysis of the root causes of the Nunn-McCurdy breaches led us to draw the following lessons learned:

- Production delays increase exposure to changing private sector market conditions, which can result in cost growth.
- Acquisition flexibility (e.g., start-stop programs) comes with a cost.
- Cost estimates should be conducted independently of a program manager.
- Combining remanufactured and new build items causes complexity and can lead to cost growth.
- Greater planning of manufacturing process organization is required.
- Large reductions in procurement quantities can significantly increase per unit cost.
- Sufficient RDT&E is required to ensure the "produce-ability" of a program.
- Greater government oversight of the contractor is required in a technologically complex project.
- More "hedges" against risky elements of program are required.
- Additional collaboration is needed on design specifications and discussion of cost-performance trade-offs.

These lessons can help project managers avoid cost increases if they are attended to promptly in the early phases of the program. For example, when a program has obvious technical complexity, the program manager should take steps early in the project to ensure that the government has made adequate provision for oversight of the contractor.

[2] The discrimination between a root cause and significant root case was a qualitative assessment of the magnitude of the effect in contributing to the Nunn-McCurdy breach.

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The RAND team also enjoyed, and benefited from, informal collaboration with colleagues at the Institute for Defense Analyses and the University of Tennessee's National Defense Business Institute. Within RAND, we also received helpful support from colleagues familiar with the programs we studied.

We deeply appreciate the efforts of our two reviewers, colleagues Richard Hundley and Bruce Held. Their incisive comments helped make this report better.

Finally, we wish to thank those who provided administrative and technical assistance for the project. Jennifer Miller, Sabrina Hayes, Christine Galione, and Catherine Piacente all provided administrative support. Debbie Peetz worked with the team to collect data at the beginning of the analysis.

Abbreviations

AB3	Apache Block III
ACE	Army Cost Estimate
ADM	Acquisition Decision Memoranda
AFCAA	Air Force Cost Analysis Agency
AGS	advanced gun system
AIM	advanced induction motor
AMDR	advanced missile defense radar
APB	acquisition program baseline
APPN	appropriation
APUC	average procurement unit cost
ASTOVL	Advanced STOVL
AT&L	Acquisition, Technology, and Logistics
BES	Budget Estimate Submission
BMD	ballistic missile defense
BRAT	Blue Ribbon Action Team
BY	budget year
CAB	Combat Aviation Brigade
CAIG	Cost Analysis Improvement Group
CAIV	Cost as an Independent Variable
CAPE	Cost Assessment and Program Evaluation

CARD	Cost Analysis Requirements Description
CBO	Congressional Budget Office
CDP	concept demonstration phase
CDR	critical design review
CIGS	close-in gun system
CMRB	composite main rotor blade
CNA	Center for Naval Analyses
COPT	cost/operational performance trade
CPARS	Contractor Performance Assessment Reporting System
CTOL	conventional takeoff and landing
CV	carrier takeoff and landing
DAB	Defense Acquisition Board
DAES	Defense Acquisition Executive Summary
DAMIR	Defense Acquisition Management Information Retrieval system
DARPA	Defense Advanced Research Projects Agency
DBR	dual band radar
DD 21	Future Destroyer Program
DD&C	detail design and construction
DD(X)	Future Destroyer Program
DDG	guided missile destroyer
DoD	Department of Defense
DSCS	Defense Satellite Communication System
EDM	Engineering Design Model
ESSM	evolved Sea Sparrow missile
EVM	earned value management
FCR	fire control radar
FFP	firm fixed price

FFRDC	federally funded research and development center
FPIP	fixed price, incentive fee
FY	fiscal year
GAO	Government Accountability Office
GBS	Global Broadcasting System
HPSS	high performance shock strut
HR/MF	high-resolution multifrequency
ICE	independent cost estimate
IDA	Institute for Defense Analyses
IMRT	Independent Manufacturing Review Team
IOC	initial operational capability
IOT&E	initial operational test and evaluation
IPR	internal program review
IPS	integrated power system
IPT	Integrated Product Team
JAST	Joint Advanced Strike Technology
JET	Joint Estimating Team
JIRD	Joint Initial Requirements Document
JORD	Joint Operational Requirements Document
JPO	Joint Program Office
JROC	Joint Requirements Oversight Council
JSF	Joint Strike Fighter
KPP	key performance parameter
LM	Lockheed Martin
LRIP	low rate initial production
LRLAP	long range land attack projectile
MDAP	major defense acquisition program

MFR	multifunction radar
MS B	Milestone B
MSE	mission system equipment
NAVAIR	Naval Air Systems Command
NAVSEA	Naval Sea Systems Command
NGSS	Northrop Grumman Ship Systems
NRE	nonrecurring engineering
O&S	operations and support
OEF	Operation Enduring Freedom
OIF	Operation Iraqi Freedom
OPEVAL	operational evaluation
OIPT	Overarching Integrated Process Team
OSD	Office of the Secretary of Defense
OUSD	Office of the Under Secretary of Defense
PARCA	Performance Assessments and Root Cause Analysis
PAUC	program acquisition unit cost
PB	President's Budget
PLCCE	program life cycle cost estimate
PMAG	Program Manager's Advisory Group
POM	Program Objective Memorandum
PoPS	probability of program success
RCA	root cause analysis
RDS	rotorcraft drive system
RDT&E	Research, Development, Test, and Evaluation
RF	radio frequency
RHIB	rigid hull inflatable boat
SAF	Secretary of the Air Force

SAR	Selected Acquisition Report
SATCOM	satellite communications
SC 21	surface combatant for the 21st century
SCN	Ship Construction Navy
SDD	System Development and Demonstration
SETA	Systems Engineering and Technical Assistance
SRR	System Requirements Review
STOVL	short takeoff and vertical landing
SWAT	STOVL Weight Attack Team
TRL	Technology Readiness Level
TSCE	Total Ship Computing Environment
URF	Unit Recurring Flyaway
USAF	U.S. Air Force
USC	U.S. Code
USD	Under Secretary of Defense
VM	vulnerability matrix
VSR	volume search radar
VTUAV	vertical takeoff unmanned aerial vehicle
WGS	Wideband Global Satellite
WSARA	Weapon Systems Acquisition Reform Act

CHAPTER ONE

Introduction

Background

The U.S. Congress has become increasingly concerned with the rate of cost increases in major defense acquisition programs (MDAPs). This concern, combined with the prospect of shrinking defense budgets, led Congress to focus more of its senior policy-makers' attention on oversight of these programs.[1] The Weapon Systems Acquisition Reform Act (WSARA) of 2009[2] established a number of requirements that affected the operation of the Defense Acquisition System and the duties of the key officials who support it, including the requirement to establish a new organization in the Office of the Secretary of Defense (OSD) with the mandate to conduct and oversee Performance Assessments and Root Cause Analysis (PARCA) for MDAPs.[3] The act assigned the PARCA organization five primary responsibilities:

1. Carry out performance assessments of MDAPs.
2. Perform root cause analysis (RCA) of MDAPs whose cost growth exceeds the threshold as detailed in the Nunn-McCurdy Act.
3. Issue policies, procedures, and guidance governing the conduct of performance assessments and root cause analyses.
4. Evaluate the utility of performance metrics used to measure the cost, schedule, and performance of MDAPs.
5. Advise acquisition officials on performance issues that may arise regarding an MDAP.[4]

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1 U.S. House of Representatives, House Report 111-124 on S. 454, "Weapon Systems Acquisition Reform Act of 2009," May 20, 2009. U.S. House of Representatives, Committee on Armed Services, House Report 111-101 on H.R. 2101, "Weapons Acquisition System Reform Through Enhancing Technical Knowledge and Oversight Act of 2009," May 12, 2009.

2 Public Law 111-23, Weapon Systems Acquisition Reform Act of 2009, May 22, 2009.

3 Ashton B. Carter, Under Secretary of Defense, Acquisition, Technology, and Logistics, OUSD (AT&L), Directive-Type Memorandum (DTM) 09-027—Implementation of the Weapon Systems Acquisition Reform Act of 2009, December 4, 2009; Public Law 111-23, Section 103.

4 Public Law 111-23, Section 103.

Project Objective

PARCA's responsibilities are inherently governmental functions. However, recognizing the limited number of staff at its disposal, the PARCA office reached out to federally funded research and development centers (FFRDCs) to assist it with the analytic portions of these inherently governmental functions.

This report focuses on a key aspect—program research and analysis—of one of these responsibilities: the RCA process. 10 USC [U.S. Code] § 2433a stipulates that a root cause analysis be conducted by the director of the PARCA office when a major weapon system acquisition program incurs a critical cost growth breach, as detailed in the Nunn-McCurdy Act.[5] The WSARA requires that the Secretary of Defense conduct an RCA after consultation with the Joint Requirements Oversight Council (JROC).[6] The RCA assesses the underlying cause or causes of shortcomings in cost, schedule, or performance that may have contributed to the MDAP's critical cost overrun. The WSARA defined topics to consider as part of an RCA, including the role played, if any, of the following:

1. unrealistic performance expectations
2. unrealistic baseline estimates for the cost or schedule
3. immature technologies or excessive manufacturing or integration risk
4. unanticipated design, engineering, manufacturing, or technology integration issues arising during program performance
5. changes in procurement quantities
6. inadequate program funding or funding instability
7. poor performance by government or contractor personnel responsible for program management
8. any other matters.[7]

At the time this report was written, six ongoing major weapon systems programs had incurred critical Nunn-McCurdy cost growth breaches in 2010 and thus were subject to the provisions of current federal law described above. RAND was enlisted by the organization responsible for PARCA to support the RCA process for four of these MDAPs: the DDG-1000 *Zumwalt*-Class Destroyer, the Joint Strike Fighter (JSF or F-35), Longbow Apache Block III (AB3), and Wideband Global Satellite (WGS).[8] Given the time constraints mandated by the Nunn-McCurdy recertification process,

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5 The Nunn-McCurdy provision and definition of critical cost growth are described in greater detail in Chapter Two.

6 10 USC § 2433a, as specified in Public Law 111-23, Section 206.

7 Public Law 111-23, Section 103; Carter, 2009.

8 The RCA for the Joint Strike Fighter was performed in coordination with the Institute for Defense Analyses and the University of Tennessee.

RAND organized four teams to provide a "quick look" assessment of the major issues related to cost, schedule, or performance shortcomings.

Table 1.1 summarizes the cost growth breaches incurred by these programs. Chapter Two and the related Appendix A provide detail on the characteristics of breaches. Chapters Three to Six discuss the specific breaches of each program in detail.

Approach

Each team undertook two tasks in tandem: establishing the basic facts surrounding the program's Nunn-McCurdy breach and determining the contribution to unit cost growth from the eight RCA issues stipulated in the WSARA legislation and listed above. The time that elapsed between each program's completion of Milestone B (MS B) and the recognition of RCA issues applicable to each program was portrayed in a chart similar to that of Table 1.2, which illustrates the framework provided by the PARCA office. For each program under RAND's purview, this figure provided a temporal lens through which RCA issues could be viewed and the analysis informed. In addition to the findings for each program, a WGS-, AB3-, DDG-1000-, and JSF-specific version of this chart appears in subsequent chapters of this report.

The table arrays the issues specified in the Nunn-McCurdy legislation in the left column and the fiscal years of a notional program whose MS B occurred in 2001 across the top. X indicates the years in which the event occurred. Thus, unrealistic cost or schedule estimates occurred every year after MS B. The text under execution for 2002 is in place of an X, as the change represented in the text is large and warrants further explanation in the chart.

As mentioned above, the time line for reporting and certification provided in the statute restricted the amount of data gathering and analysis that could be performed. To meet PARCA needs, RAND relied on many documents through the course of the project. Not all were used through the course of the project, but the following list gives a good idea of the documentation that was available for the RAND team during the short window of work:

From Defense Acquisition Management Information Retrieval:

- SARs
- Defense Acquisition Executive Summary (DAES) reports
- Program Objective Memoranda (POMs)
- Budget Estimate Submissions (BESs)
- APBs
- earned value management (EVM) contract data.

Table 1.1
Current Programs Incurring Cost Growth Breaches in 2010 (FY $ Millions)

			Cost Growth Threshold Breaches							
Program	**Baseline Unit Cost**	**Current Estimate December 2009 SAR**	**Baseline Breached**	**Percentage**	**Amount**	**Level**	**Baseline Quantity**	**December 2009 SAR Quantity**	**Cause in SAR**	**SAR Explanation**
WGS FY 2001	APUC $294.160 2007 APB	APUC $374.186	Over current baseline (2007 APB)	APUC +27.20	+$80.026 FY 2001	Critical	5	7	Quantity change from 5 satellites to 7 satellites	Addition of two new satellites (WGS 7 and 8)
	PAUC $358.520 2007 APB	PAUC $424.457		PAUC +18.39	+$65.937 FY 2001	Significant	5	7		
	APUC $268.200 2000 APB	APUC $374.186	Over original baseline (2000 APB)	APUC +39.52	+$105.986 FY 2001	Significant	3	7		
AB3 FY 2006	APUC $9.600 2007 APB	APUC $12.591	Over current baseline (2007 APB)	APUC +31.16	+$2.991 FY 2006	Critical	639	695	Quantity change from remanufacture of 634 aircraft to building additional 56 new aircraft	56 new build aircraft significantly more expensive to build because they are 100% new versus 30% new for a remanufacture
	PAUC $11.139 2007 APB	PAUC $13.977		PAUC +25.48	+$2.838 FY 2006	Critical	634	690		
	APUC $9.225 2006 APB	APUC $12.591	Over original baseline (2006 APB)	APUC +36.49	+$3.366 FY 2006	Significant	597	690		
DDG-1000 FY 2005	APUC $2,323.470 2005 APB	APUC $2,901.967	Over current baseline (2005 APB)	APUC +24.90	+$578.497 FY 2005	Significant	10	3	Quantity change from 10 ships to 3 ships	Truncation of program from 10 ships in November 2005 APB to 3 ships in PB11
	PAUC $3,154.790 2005 APB	PAUC $5,882.500		PAUC +86.46	+$2,727.710 FY 2005	Critical	10	3		
	PAUC $3,154.790 2005 APB	PAUC $5,882.500	Over original baseline (2005 APB)	PAUC +86.46	+$2,727.710 FY 2005	Critical	10	3		

Table 1.1—Continued

Program	Baseline Unit Cost	Current Estimate December 2009 SAR	Cost Growth Threshold Breaches							
			Baseline Breached	Percentage	Amount	Level	Baseline Quantity	December 2009 SAR Quantity	Cause in SAR	SAR Explanation
JSF (F-35) FY 2002	APUC $50.245 2001 APB	APUC $79.003	Over original baseline (2001 APB)	APUC +57.24	+$28.758 FY 2002	Critical	2,852	2,443	Increases in procurement cost estimates	Historical increases and programmatic changes reported in previous SARs and estimated procurement cost increases
	PAUC $61.793 2001 APB	PAUC $97.110		PAUC +57.15	+$35.317 FY 2002	Critical	2,866	2,457	Increases in procurement cost estimates	Historical increases and programmatic changes reported in previous SARs and estimated procurement cost increases

SOURCES: Department of Defense, *Selected Acquisition Report WGS,* December 31, 2009; Department of Defense, *Selected Acquisition Report AB3*, December 31, 2009; Department of Defense, *Selected Acquisition Report DDG-1000*, December 31, 2009; Department of Defense, *Selected Acquisition Report F-35*, December 31, 2009.

NOTES: The numbers in red indicate the "speeding ticket" triggering root cause analysis by PARCA. Formulas and criteria used to generate the information shown here are specified in federal law and are shown in Chapter Two. APUC = average procurement unit cost; PAUC = program acquisition unit cost; APB = acquisition program baseline; SAR = Selected Acquisition Report; PB = President's Budget.

Table 1.2
PARCA Root Cause Matrix Framework

	Year from MS B and Fiscal Year					
	B 2001	+1 2002	+2 2003	+3 2004	+4 2005	+5 2006
Baseline issues						
Unrealistic estimates for cost or schedule		X	X	X	X	X
Immature technology; excessive manufacturing, integration risk		X	X	X	X	X
Unrealistic performance expectations		X	X	X	X	X
Execution issues						
Changes in procurement quantity	X	Change from 150 to 55				
Inadequate funding/ funding instability	X					
Unanticipated design, engineering, manufacturing, or technical issues	X					
Poor performance of government or contract personnel	X					

From Cost Analysis Improvement Group/Cost Assessment and Program Evaluation (CAIG/CAPE) documents on costs throughout the life of the program and Nunn-McCurdy breach:

- Latest acquisition strategy
- Congressional Budget Office (CBO) cost estimates
- The draft and final Cost Analysis Requirements Description (CARD)
- Acquisition Decision Memoranda (ADMs) post–Milestone B

Government and industry collaboration website:

- award fee
- cost estimates
- Contractor Performance Assessment Reporting System (CPARS)
- design reviews

- prime contractor contracts
- program documents.

Contractor monthly assessment reports.

Briefings from:

- prime contractor
- Program Office and Joint Program Office (JPO) on the System Development and Demonstration (SDD), System Requirements Review (SRR), and Unit Recurring Flyaway (URF)
- Overarching Integrated Process Team (OIPT) on Nunn-McCurdy breach
- deputy advisors working group
- Naval Air Systems Command (NAVAIR)
- Naval Sea Systems Command (NAVSEA)
- Program Office post–Milestone B.

Meetings with:

- prime contractors
- Program Office
- JPO
- CAPE
- Air Force Cost Analysis Agency (AFCAA).

Internal DoD memos from John Young, Aston Carter, Acquisition Executives.

"Notification to Congress" of the Nunn-McCurdy breach.

Some of this material and the program discussion process provided quantitative data and some provided program execution and management decisionmaking insights.

Analysis of each MDAP identified risk as a common denominator to all four programs. The teams investigated a wide variety of risk, ranging from the rather straightforward, such as insufficiency of program funding, to the more complex, such as reliance on the private sector to maintain the optimal technology configuration. As the risks encountered by each program were identified and assessed, sources of program vulnerabilities were collected and compared. The compilation of these vulnerabilities represents a key contribution of this work: the "vulnerability matrix." The vulnerabilities that were identified throughout the research, in addition to the time period or phase at which this vulnerability could potentially occur, are listed in Table 1.3. A more developed version of this table, populated in accordance with the findings of each team, appears in Chapter Seven. Several programs shared some vulnerabilities, whereas

Table 1.3
Program Vulnerabilities That May Contribute to Cost Growth

Type of Event	Time Period/Phase
Cost Events	
Cost increases began	Concept refinement
Cost increases began	Technology development
Cost increases began	System development and demonstration
Cost increases began	Production and deployment
Cost increases began	Operations and support (O&S)
Cost increases began	Additional blocks
Documented different estimates	Concept refinement
Documented different estimates	Technology development
Documented different estimates	System development and demonstration
Documented different estimates	Production and deployment
Documented different estimates	O&S
Documented different estimates	Additional blocks
Known Factors During Cost Estimation	
Unrefined design and performance requirements	All
Lack of previous similar work	All
No or bad past performance	All
Technology immaturity	All
Technical complexity	All
Complexity of system integration	All
Decision to employ parallel development rather than sequential	All
Insufficient number of government personnel to run the program	All
Unique contracting strategy	All
Ambitious system performance goals	All
Difficulties in negotiating major contracts (e.g., contract protests)	All
Internal Changes to Program	
Change of performance requirements	Concept refinement
Change of performance requirements	Technology development
Change of performance requirements	System development and demonstration
Change of performance requirements	Production and deployment
Change of performance requirements	Operations and support

Table 1.3—Continued

Type of Event	Time Period/Phase
Cost Events	
Funding instability	All
Change in quantity—increase	All
Change in quantity—decrease	All
Changes in program guidance/service mission	All
External Changes to Program Environment	
Increase/decrease in quantity of related program	All
Cancellation of predecessor program	All
Changes to external programs	All
Addition of new construction to an upgrade program	All
Change of technology direction	System development and demonstration
Changes to Operating Environment	
Increase in wage rates	All
Increase in cost of materials or equipment	All
Changes to industrial base	All
Change in government standards or regulations	All
Natural disaster/act of God	All
Significant congressional interest	All

others were specific to only one. It is important to note that this matrix is not definitive or all-inclusive; rather, it is a product that will evolve over time, as a perspective through which MDAPs can be monitored and evaluated.

Organization of This Report

This report contains seven chapters. The next chapter summarizes how Congress has used legislation to establish and increase its oversight of weapon system acquisition programs and discusses the requirements of Nunn-McCurdy legislation in more detail. Those familiar with the history of congressional oversight of defense acquisition programs and the provisions of Nunn-McCurdy may wish to skip that chapter. Chapters Three through Six report the findings of the RCAs performed by the RAND teams on each of the four programs under review in the following sequence: DDG-1000 *Zumwalt*-Class Destroyer, Joint Strike Fighter, Longbow Apache Helicopter, and Wideband Global Satellite. These chapters, idiosyncratic of the specific programs and independent analyses of the teams, reflect the reports that were sent to the PARCA office to be used to carry out its responsibilities and produce the materials necessary for the recertification decision process as required by the Under Secretary of Defense for Acquisition, Technology, and Logistics (USD AT&L), and, ultimately, the Secretary of Defense. The final chapter presents our conclusions and recommendations.

CHAPTER TWO

Congressional Concern with Growth in Program Costs

This chapter provides a synopsis of the history of congressional oversight of cost growth and oversight of program status. It begins with a discussion of how current federal law deals with cost growth, starting from early SAR reporting demands. It then traces the history of the legislation focused on containing the cost growth of major weapon systems.

Selected Acquisition Reports

Starting in the 1970s, when Congress expropriated the SARs to use for determining program status, Congress has continued to create mechanisms to gain insights into program execution. The SARs were initially designed as an internal DoD program status tool. DoD Instruction 7000.3 established SARs on February 23, 1968, with the following purpose:

> The SARs' initial purpose was to keep its sponsor, the Assistant Secretary of Defense (Comptroller), apprised of the progress of selected acquisitions and to compare this progress with planned technical, schedule, and cost performance. In February 1969, the Chairman of the Senate Armed Services Committee asked the Secretary of Defense to provide status reports on major weapons systems. The parties agreed in April 1969 that the SAR would be the vehicle to satisfy the committee's needs.[1]

However, SARs did not become a legal reporting requirement until 1975, with Public Law 94-106.[2] SARs summarize the latest estimates of cost, schedule, and performance status. These reports are prepared annually in conjunction with the President's

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1 U.S. General Accounting Office, "Comptroller General's Report to the Congress: 'SARs'—Defense Department Reports That Should Provide More Information to the Congress," May 9, 1980, p. 1.

2 Bob Leach, "Acquisition Reporting Overview," Office of the Under Secretary of Defense (Acquisition, Technology, and Logistics), June 12–13, 2002, pp. 9–11.

Budget and quarterly under certain conditions. Congress has continued to increase its oversight of weapon system acquisition programs that incur cost overruns.

History of Cost Growth Legislation

In 1981, Senator Samuel Nunn and Congressman David McCurdy introduced the Nunn-McCurdy amendment[3] to the Department of Defense Authorization Act of 1982.[4] The purpose of the amendment was to establish congressional oversight of defense weapon system acquisition programs that experience cost growth above limits specified in the amendment. The Nunn-McCurdy amendment defined two types of unit cost: total PAUC, which is the sum of development funding and procurement funding divided by units procured, and APUC, which is the procurement funding divided by units procured. Cost growth of a weapon system was measured by how much the unit costs in 1982 exceeded the same respective unit costs in the weapon system's SAR dated March 31, 1981. Hence, the amendment applied only to those major weapon systems with March 31, 1981, SARs. Greater detail and definition of terms is provided in Appendix A.

The original amendment required that the Secretary of Defense notify Congress when a major weapon system unit cost growth exceeded 15 percent. If unit cost growth exceeded 25 percent, the program was assumed terminated unless the Secretary of Defense submitted specific written certifications to Congress within 60 days of making the cost growth determination. These certifications survive in current law and are explained in detail below.

Congress made the provisions of the Nunn-McCurdy amendment permanent in the 1983 Authorization Act[5] by requiring that the secretary of each military department establish a baseline description of each major weapon system acquisition program under the jurisdiction of the secretary. The baseline description was to include a baseline estimate of the program cost. The permanent Nunn-McCurdy provisions measured unit cost growth by comparing the current unit costs against the same respective unit costs in the baseline estimate. The cost thresholds for notifying Congress and for program termination presumptions in the original Nunn-McCurdy amendment remained unchanged in the 1983 Authorization Act but have subsequently changed. The certifications required to be submitted to Congress also remain unchanged in current federal law.

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[3] The Nunn-McCurdy amendment is also known as the Nunn-McCurdy provision. See Nunn-McCurdy Amendment, Department of Defense Authorization Act, 1982, Report No. 97-311, November 3, 1981.

[4] Public Law 97-86, National Defense Authorization Act of 1982, December 29, 1981.

[5] Public Law 97-252, National Defense Authorization Act of 1983, September 8, 1982.

Congress's Continuing Concern with Program Cost Growth

Every two years since 1990, Congress has tasked the Government Accountability Office (GAO) with creating a list of issues considered to represent high risk. The issues on the high-risk list are those that require attention because they either are particularly vulnerable to mismanagement, waste, fraud, or abuse; or need transformation to address major economy, efficiency, or effectiveness challenges. The last high-risk list came out in January 2009, and Department of Defense weapon systems acquisition is on that list.[6] One primary reason weapon systems acquisition is on the high-risk list is because of large cost overruns. To be sure, cost overruns are hardly new to weapon systems acquisition. Indeed, weapon systems acquisition has appeared on every GAO high-risk list produced since 1990, and each time, large cost overruns have been a primary reason for its placement on the list.

The Department of Defense does not necessarily disagree with GAO's assessment. Shortly after the GAO issued its last high-risk list, Secretary of Defense Robert Gates testified before the House Armed Services Committee stating that chief among the department's concerns is acquisition.[7] Secretary Gates noted that acquisition problems have been persistent and difficult to resolve despite Congress's long involvement in trying to resolve them and the nearly 130 studies on various aspects of acquisition that also have not resulted in a comprehensive, effective, and permanent solution. He stated that the defense acquisition system cannot be reformed in a short period of time and that cost overrun problems have plagued defense acquisition since the first Secretary of War, Henry Knox, incurred cost overruns in building the nation's Navy.

Beginning with the passage of the Nunn-McCurdy amendment in 1981, Congress has repeatedly refined and increased its oversight of major defense weapon systems acquisition programs that incur cost growth breaches. When statutory provisions dealing with cost growth were first enacted, program personnel were very concerned about breaching cost growth thresholds. As the concept of incurring cost growth threshold breaches became more familiar, such breaches have caused less apprehension. Congress's latest attempt to increase oversight imposed more stringent actions, including a mandatory root cause analysis and program reassessment for programs incurring critical cost growth breaches. Whether Congress's latest legislative efforts to control cost growth prove to be effective remains to be determined.

What is clear, starting with efforts in the 1980s, is that Congress has been dissatisfied, if not alarmed, by DoD's acquisition performance, because defense acquisition constitutes a significant portion of discretionary spending for the United States. Secretary Gates's comments notwithstanding, Congress is not prepared to wait for

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6 U.S. Government Accountability Office, *High-Risk Series: An Update,* GAO-09-271, Washington, D.C., January 2009.

7 Robert M. Gates, Secretary of Defense statement submitted to the House Armed Services Committee, January 27, 2009.

acquisition performance to get better. The cost overrun experienced in DoD programs is particularly pernicious in the eyes of a Congress dealing with high unemployment levels where military projects represent well-paying jobs in home districts. The Nunn-McCurdy provisions have been Congress's way of doing due diligence on the one hand while forcing the Secretary of Defense to make tough decisions on programs central to the national security on the other.

As with all permanent legislation, the permanent provisions of the Nunn-McCurdy amendment were codified in the U.S. Code. The next section discusses the permanent provisions as they currently exist and notes changes that have occurred since the original Nunn-McCurdy amendment was enacted into law in the 1982 Department of Defense Authorization Act.[8]

Program Cost Growth and Certification Requirements

A weapon system acquisition program incurs a unit cost growth breach when the unit cost reaches or exceeds limits or thresholds specified in federal law. Such cost growth breaches are commonly known as Nunn-McCurdy breaches, in reference to the original Nunn-McCurdy amendment, though this term does not appear in federal law.

Unit cost growth breaches are computed using definitions, formulas, and thresholds provided in federal law. 10 USC §§ 2432 and 2433 provide the definitions of "program acquisition unit cost" and "procurement unit cost," formulas for computing unit cost growth, and thresholds for incurring significant and critical cost growth breaches. The concept of significant cost growth and critical cost growth were introduced with enactment of the Defense Authorization Act of 2006.[9]

A *significant* cost growth threshold breach is defined as

- a PAUC that is at least 15 percent over the program acquisition unit cost shown in the current baseline estimate for the program or
- an APUC that is at least 15 percent over the acquisition procurement unit cost shown in the current baseline estimate for the program or
- a PAUC that is at least 30 percent over the program acquisition unit cost shown in the original baseline estimate or
- an APUC that is at least 30 percent over the acquisition procurement unit cost shown in the original baseline estimate.

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8 The original Nunn-McCurdy amendment was not considered permanent law, because it applied only to March 31, 1981, SARs. Nonpermanent laws, such as the yearly congressional authorization amounts, are not typically codified in the U.S. Code. Permanent provisions are always codified.

9 Public Law 109-163, Department of Defense Authorization Act of 2006, Section 802, January 6, 2006.

A *critical* cost growth threshold breach is defined as

- a PAUC that is at least 25 percent over the program acquisition unit cost shown in the current baseline estimate for the program or
- an APUC that is at least 25 percent over the acquisition procurement unit cost shown in the current baseline estimate for the program or
- a PAUC that is at least 50 percent over the program acquisition unit cost shown in the original baseline estimate or
- an APUC that is at least 50 percent over the acquisition procurement unit cost shown in the original baseline estimate.

Table 2.1 summarizes the unit cost threshold definitions in federal law.

In addition, the Weapon Systems Acquisition Reform Act of 2009[10] imposes a root cause analysis process on programs that incur critical breaches. This action is required of the Secretary of Defense after consultation with the Joint Requirements Oversight Council.[11] The pertinent legal definitions appear in Appendix A.

Current law specifies that a program that incurs a critical cost growth breach is assumed to be terminated unless the Secretary of Defense provides specific certifications to Congress within 60 days of the SAR due date as specified in 10 USC § 2432(f).

Table 2.1
Breach Thresholds

Level	Unit Cost	Baseline	Threshold, %	Source
Significant	PAUC	Current	≥15	10 USC § 2433 (a)(4)(A)(i)
	APUC	Current	≥15	10 USC § 2433 (a)(4)(B)(i)
	PAUC	Original	≥30	10 USC § 2433 (a)(4)(A)(ii)
	APUC	Original	≥30	10 USC § 2433 (a)(4)(B)(ii)
Critical	PAUC	Current	≥25	10 USC § 2433 (a)(5)(A)(i)
	APUC	Current	≥25	10 USC § 2433 (a)(5)(B)(i)
	PAUC	Original	≥50	10 USC § 2433 (a)(5)(A)(ii)
	APUC	Original	≥50	10 USC § 2433 (a)(5)(B)(ii)

10 Public Law 111-23.

11 10 USC § 2433a, as specified in Section 206 of Public Law 111-23.

The certifications must state the following:

- The system is essential to the national security.
- No alternatives will provide an acceptable capability to meet joint military requirements at less cost; the new estimates of PAUC and APUC have been determined by the director of Cost Analysis and Program Evaluation to be reasonable.
- The program has a higher priority than programs whose funding must be reduced to accommodate the growth in cost of the program.
- The management structure for the program is adequate to manage and control the PAUC or APUC.

These certifications must be accompanied by a root cause analysis and assessment.

10 USC § 2433a stipulates that a root cause analysis be conducted by the director of the PARCA office when a major weapon system acquisition program incurs a critical cost growth breach. The root cause analysis assesses the underlying cause of the critical cost overrun. The office is responsible for producing a root cause report that must identify the role, if any, of the eight elements listed in Chapter One in causing the cost overrun.

Evolvement of Statutory Governance of Cost Growth Breaches

History indicates that if cost overruns are not controlled by Congress's latest efforts in the WSARA of 2009, further legislative actions may be in the offing. Indeed, Congress has stipulated that a new acquisition process be put in place for acquiring information technology to address the problems unique to such acquisitions. The National Defense Authorization Act of 2010 also mandates an assessment by the director of Cost Assessment and Program Evaluation on the wisdom of creating baselines for operation and support costs. In addition, GAO has been tasked by the same act to evaluate growth in these costs. These congressional requests indicate that Congress is considering legislative actions to control operations and support costs in addition to its actions to control procurement costs. These actions also indicate that Congress is determined to use its full authority to launch a multipronged attack to control defense acquisition cost overruns. The Weapons Acquisition Reform Act of 2009 passed with nearly unanimous votes in both houses of Congress. This strong support and the wide spectrum of recent congressional actions with respect to weapon systems acquisition taken together indicate that Congress is determined to continue the quest initially proposed by the original Nunn-McCurdy amendment to control cost growth overruns.

The next four chapters address the four programs assigned to RAND for analysis; similar information is available for the two programs assigned to the Institute for Defense Analyses (IDA). As noted above, the analysis responsibility for JSF was shared. Although decisions shared by DoD and the Congress are notable in the "speeding tickets" involved (quantity changes are pervasive, for example, in most of these programs), Congress looks to DoD to control costs. It is notable that all the programs received recertification.

CHAPTER THREE

Zumwalt-Class Destroyer (DDG-1000)

On February 1, 2010, the Navy notified OSD and Congress of a Nunn-McCurdy breach in the DDG-1000 program. The immediate cause of the breach was a reduction in the planned total number of ships from ten to three, which resulted in an 86 percent increase in PAUC and a 25 percent increase in APUC.[1] This chapter describes the DDG-1000 program, the Nunn-McCurdy breach, and the research approach taken to analyze the breach (including factors that limit that analysis).

Program Overview

The DDG-1000 program has its origins in a 1993 study of candidate system concepts for a surface combatant for the 21st century (SC 21). The DDG-1000 represents an entirely new ship system designed around a highly specialized mission: precision strike and volume fire support from the littoral against land targets. The system has both offensive and defensive capabilities designed to contribute surface, subsurface, and air battlespace dominance in the littoral.

The ship hull is a wave-piercing tumblehome configuration—a new design for a ship of this size (approximately 15,000 ton displacement). The integrated power system (IPS), also new on a Navy ship, consists of two main turbine generators, two auxiliary turbine generators, and two advanced induction motors (AIMs). The deckhouse is made of composite material rather than the traditional steel.

Mission systems include 80 advanced vertical launch cells placed around the periphery of the ship (as opposed to the center as on current ships) containing a mix of Tomahawk, evolved Sea Sparrow missiles (ESSMs), standard missiles, and the advanced gun system (AGS) 155-millimeter guns forward of the deckhouse with 600 rounds of the long range land attack projectile (LRLAP) developed specifically for this mission. There are two 57-millimeter close-in gun systems (CIGS) for self-defense. The aviation

[1] PAUC is calculated as the total Research, Development, Test, and Evaluation (RDT&E) and procurement (construction) costs divided by the planned total quantity. APUC is total procurement cost divided by total quantity.

contingent is designed to include two MH-60R helicopters or one MH-60R and three vertical takeoff and landing unmanned aerial vehicles (VTUAVs). Two seven-meter rigid hull inflatable boats (RHIBs) or two 11-meter RHIBs can be accommodated. The dual band radar (DBR) includes an S-band volume search radar (VSR) and X-band multifunction radar (MFR) for enhanced operations in the cluttered littoral environment. The high-resolution multifrequency (HR/MF) bow sonar arrays and a multifunction towed array provide subsurface operational capabilities.

PAUC Breach

The DDG-1000 program has only one development estimate and that is the APB approved on November 23, 2005.[2] This November 2005 APB, approved at Milestone B, is both the current baseline estimate and the original baseline estimate used to compute the PAUC and APUC in the DDG-1000 SARs.

The DDG-1000 December 2009 SAR shows three cost growth breaches for the DDG-1000 program.[3] Table 3.1 shows a significant APUC breach of more than 25 percent and a critical PAUC breach of 86 percent of the baseline. Since the original and current baselines for DDG-1000 are the same (November 2005 APB), according to the unit cost growth criteria, the APUC growth is a significant breach against the current baseline, and the PAUC growth is a critical breach against both the original and current baselines. The baseline quantity of ten ships was used to compute the baseline APUC and PAUC; a quantity of three ships was used to compute the December 2009 current estimate APUC and PAUC.

The two critical PAUC cost growth breaches are the "speeding tickets" that triggered the root cause analysis specified in the WSARA Act of 2009. The December

Table 3.1
DDG-1000 Unit Cost Growth Breaches (FY 2005 $ Millions)

	Baseline (November 2005)		Current Estimate (December 2009)		Difference	
	Cost	Quantity	Cost	Quantity	Cost	Percentage
APUC	2,323.5	10	2,902.0	3	578.5	24.9
PAUC	3,154.8	10	5,882.5	3	2,727.7	86.46

SOURCE: Department of Defense, *Selected Acquisition Report DDG-1000*, December 31, 2009.

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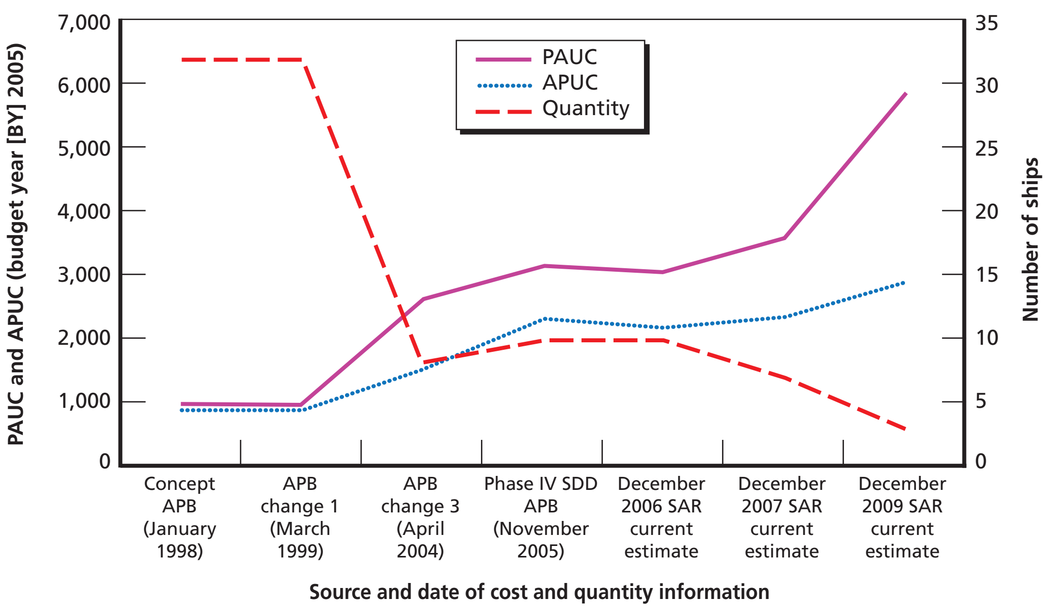
2 Department of Defense, *Acquisition Program Baseline (APB) DDG 1000*, November 23, 2005.

3 A schedule breach associated with an eight-day delay award of the detail design and construction contract is also documented in the December 2009 SAR. This breach is nominally unrelated to the cost growth and is not addressed here.

2009 SAR states that the quantity change from ten ships to three ships was the cause for breaches and further explains that truncation of the DDG-1000 program from ten ships in the November 2005 APB to three ships in the 2011 President's Budget caused the breaches.

Figure 3.1 shows the change in PAUC, APUC, and quantity since the original program conceptual baseline in January 1998. The November 2005 baseline was established at Milestone B and is the baseline from which the cost increases are calculated. The original program envisioned a 32-ship class, which dropped to eight in the middle of the technology development phase (Phase III in program terminology) as the ship design and technology was matured and as more realistic cost estimates were generated. A baseline quantity of ten ships was approved at Milestone B. Planned quantity was reduced to seven as part of the FY 2008 budget preparation; a revised APB was generated by the Program Office, approved up through the Navy Acquisition Executive, and sent to OUSD AT&L for approval. That revised baseline—with a quantity of seven ships—was never formally approved by OUSD AT&L because of questions at that time concerning the final quantity. Figure 3.1 also shows how sensitive PAUC is to changes in quantity.

Figure 3.1
Unit Cost and Quantity Changes Since Program Inception



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Research Approach and Caveats

The DDG-1000 is a complex program with a long history rich in details, unique attributes, and technical and programmatic accomplishments. This discussion is not intended to be a complete program history and so does not attempt to deal with every element of the program. Rather, we have attempted to identify aspects of the program that are relevant to the explanation of the Nunn-McCurdy unit cost breaches. For the most part, the focus is on the baseline established at Milestone B and on subsequent program execution.

The work documented here was done within the construct of the response to a critical Nunn-McCurdy breach, which requires either recertification or termination of the program within 60 days of informing Congress of the breach. The information contained here has been validated to the extent possible and draws heavily on official primary source documentation. Historical and recent documentation include the official ADMs, DAES, SARs, OSD CAIG memos, budget documents, and Program Office briefings dating from Milestone B to the present. We also draw on briefings that the Program Office gave to the Nunn-McCurdy Integrated Product Teams (IPTs) established to generate the information required for the determination of recertification or termination. Discussions with Program Office and OSD officials supplemented the primary source documentation.

We also draw heavily on prior RAND research, particularly on a case study sponsored by the future destroyer program (DD(X))/DDG 1000 Program Office that was conducted over the period March 2004 to December 2007. A final report describing the program in detail from the earliest studies through Milestone B awaits public release by the sponsor. A follow-on report covering program history through award of the dual lead ship construction contracts in February 2008 is ongoing. These separate research activities collected a considerable amount of program information (reports, briefings, oversight documentation, and notes from interviews with program officials), all of which was consulted in support of the root cause analysis when relevant.

Findings[4]

The DDG-1000 December 2009 SAR reported a critical PAUC Nunn-McCurdy breach (86.46 percent) due to a PB11 budget decision to truncate the program at three ships. The critical breach consequently required a root cause analysis by PARCA. The PAUC grew from a Milestone B baseline objective of $3,154.8 million to a current estimate of $5,882.5 million, largely as a result of spreading RDT&E costs across fewer ships.

[4] All dollar figures in this narrative are expressed in fiscal year 2005 dollars.

Our analysis confirms the Navy's explanation that the quantity change from ten to three was the main driver of the unit cost growth. The 86.46 percent increase in the PAUC is largely due to spreading total program RDT&E costs, which are not sensitive to changes in procurement quantity, over three ships rather than ten, as shown in Table 3.2. Of the $2,727.71 million difference between the November 2005 APB PAUC and the December 2009 PAUC, nearly 80 percent is from redistributing the RDT&E, and just over 20 percent of it is from increases in the Ship Construction Navy (SCN) account. Nonquantity-related cost growth (which, as of December 2009 was less than 8 percent over the November 2005 APB RDT&E figure) did not cause the Nunn-McCurdy breach. Table 3.2 shows the breakdown of differences between the SAR baseline APB of November 2005 and the December 2009 SAR.

To broaden our perspective on the effect of truncating DDG-1000 ship quantities, we created a cost estimate for a hypothetical "three-ship program at Milestone B," using baseline data from the 2005 SAR. Table 3.3 shows the result. Interestingly, the calculated PAUC estimate is higher than the current estimate that put the program in breach. RDT&E costs grew from the baseline amount of $8,313.2 million to $8,941.6 million in the current estimate (both in FY 2005 $) largely driven by the additional scope of the development effort, including additional funding for LRLAP low rate production to support round qualification, self-defense test ship support, next generation command and control processor, enterprise alternative to full ship shock trials, and line of sight/below line of sight installation. RDT&E growth is largely explained by the addition of subsystems to the scope of work, rather than to any technical problems encountered during development. In contrast, the procurement account (SCN) funding we estimated for a nominal three-ship program at Milestone B is higher than the current estimate SCN. Though only rough estimates, these results suggest that if adjusted for changes in quantity, DDG-1000 would not have experienced any growth in unit cost through the December 2009 current estimate. Unit cost growth is largely

Table 3.2
Breakdown of Differences Between SAR Baseline APB (November 2005) PAUC and Current PAUC Estimate in PB11 (FY 2005 $ Millions)

Category	SAR Baseline 2005 APB	Quantity	Current Estimate (PB11)	Quantity	Difference	
					Cost	Percentage
RDT&E	831.32	10	2,980.53	3	2,149.21	78.79
Procurement flyaway recurring	2,172.67	10	2,374.07	3	201.40	7.38
Procurement flyaway nonrecurring	150.80	10	527.90	3	377.10	13.82
Total (PAUC)	3,154.79	10	5,882.50	3	2,727.71	86.46

SOURCE: Department of Defense, *Selected Acquisition Report DDG-1000*, December 31, 2009.

Table 3.3
"Three-Ship Program" Cost Comparisons (FY 2005 $ Millions)

	APB MS B (Current APB Objective)	Estimate APB MS B	Current Estimate (New APB)
RDT&E	8,313.2	8,313.2	8,941.6
SCN	23,234.7	9,799.6	8,705.9
Total	31,547.9	18,112.8	17,647.5
Quantity	10	3	3
PAUC	3,154.79	6,037.6	5,882.5

SOURCES: Department of Defense, *Selected Acquisition Report DDG-1000*, December 31, 2005; Department of Defense, *Selected Acquisition Report DDG-1000*, December 31, 2009.

NOTES: The "three-ship program" cost estimate is calculated by summing advanced procurement, nonrecurring costs through the first three ships, and the budget lines for the first three ships, as shown in Table 15 of the December 2005 SAR. If the ramp-down in SCN costs in years after last ship is funded ($412.6 million) is included, total estimated PAUC = $6,175.13 million.

driven by a relatively small increase in RDT&E funds (7.5 percent) to cover additional work and the spreading of total program RDT&E funds over fewer ships (three ships rather than ten).

The statute that established PARCA provided a list of potential root causes for cost breaches. PARCA turned these into a matrix. The PARCA root cause matrix for DDG-1000 is shown in Table 3.4; subsequent paragraphs elaborate on each set of factors. It is useful to divide the discussion of program history and key events into two categories: establishing the baseline and program execution.

Baseline Issues

Unrealistic Baseline Estimates for Cost or Schedule. The DDG-1000 cost estimates at Milestone B were lower than the estimates produced by the CAIG, CBO, and GAO. They were also lower than historical experience would suggest, particularly when compared with the DDG-51. The differences in estimates related to the level of RDT&E required to mature critical technologies (i.e., the Engineering Design Models [EDMs]) and to integration of those technologies during ship construction, as well to the costs of procuring some subsystems, software development, and cost improvement curve effects (assumptions about first unit cost and the slope of the curve). Though the estimates in the Milestone B baseline were much more realistic than earlier estimates, they were still highly optimistic given the large uncertainty surrounding both technical and programmatic aspects of the program.

Table 3.4
PARCA Root Cause Narrative Matrix for DDG-1000

	Year from MS B and Fiscal Year					
	B 2005	1 2006	2 2007	3 2008	4 2009	5 2010
Baseline issues						
Unrealistic estimates for cost or schedule	X			X		
Immature technology; excessive manufacturing, integration risk	X					
Unrealistic performance expectations	X					
Execution issues						
Changes in procurement quantity		Change from 10 to 7		Change from 7 to 3		
Inadequate funding/funding instability		X	X	X	X	X
Unanticipated design, engineering, manufacturing, or technical issues	X	X	X			
Poor performance of government or contract personnel	X					
Other			X			

Table 3.5 shows the differences between the Program Office and the CAIG cost estimates at Milestone B, both for the initial plan proposed by the Navy and for the dual lead ship strategy eventually adopted.

The schedule estimates were perhaps more realistic, but achieving them required actually receiving the planned resources. Several program restructures pushed back program milestones before the schedule at Milestone B was adopted. The Milestone B baseline schedule was based more on the need to maintain workload and financial stability at the two remaining U.S. shipyards[5] on estimates of when the program would be ready to proceed to subsequent technical engineering and contractual events. The detail design and construction (DD&C) contract was negotiated for nine months (November 2005 to August 2006) before it was awarded. Negotiations for the lead ship construction award began almost immediately after and required several Defense Acquisition Board internal program reviews (DAB IPRs); the contract was eventually awarded in February 2008, after a delay of 14 months caused by a Navy decision to revisit contract type for the lead ships. The extended contract negotiations resulted in pushing back out-year milestones associated with the DD&C awards—first ship

[5] Bath Iron Works, a subsidiary of General Dynamics, and Northrop Grumman Ship Systems, a division of Northrop Grumman.

Table 3.5
CAIG and Navy Cost Estimates at MS B ($ Billions)

	PLCCE		CAIG	
	Initial	**Updated**	**Initial**	**Updated**
Sunk	3.7	3.7	3.7	3.7
RDT&E	4.7	4.9	5.3	5.6
Procurement	24.4	24.4	30.1	30.0
O&S	17.2	17.2	19.5	19.5
Total	49.9	50.1	58.7	58.7

SOURCES: OSD CAIG Mmemorandum to OSD (AT&L), *Update to the OSD CAIG Report for Milestone B Defense Acquisition Board (DAB) of the DD(X) Program,* November 2, 2005, April 2005 and November 2005 (updated).

NOTE: All estimates are in FY 2005 base year dollars for a ten-ship program.

deliveries, operational evaluation (OPEVAL), initial operational capability (IOC), and Milestone C, all of which were breached.

Immature Technologies or Excessive Manufacturing or Integration Risk. The EDMs did much to mature key technologies and provided experience in both design and manufacture that increased confidence in achieving desired capabilities. However, the technology readiness scores of about half the EDMs were technology readiness level 5 (TRL 5) at Milestone B, and more than half were expected to be TRL 6 at ship installation. Thus, at Milestone B, significant risk remained in some major subsystems, including IPS, DBR, and AGS/LRLAP.

The manufacturing process envisioned at the time of Milestone B included having both shipyards participate in detail design for different zones in the ship construction plan as well as each yard having the ability to construct the ship. Each shipyard was also responsible for the construction of specific zones, which then would be shipped to the other yard for installation as required. This plan was intended to only maintain the viability of both yards. There was little historical precedent for managing this plan. The deckhouse was to be designed and constructed out of composites, which would entail both new manufacturing and materials handling processes, and it was to be manufacturing at Northrop Grumman Ship Systems (NGSS) for all ships in the class.

The CAIG noted that system integration was underestimated in the Navy cost estimates at Milestone B. A Navy Program Manager's Advisory Group (PMAG) reached the same conclusion in 2007. The Total Ship Computing Environment (TSCE) and the mission system equipment (MSE) were consistently identified as significant integration challenges before and after Milestone B. TSCE required a degree of integration of both ship and mission systems unprecedented in Navy ship programs. The relatively high level of automated functions on DDG-1000 (including firefighting, engine control, and gun-loading) relied on successfully integrating those functions within TCSE to realize the reduced manpower objective; reduced manning was critical to achieving reduced lifecycle costs.

Unrealistic Performance Expectations. The capabilities envisioned for DDG-1000 were very ambitious and required technologies that had not been previously demonstrated. The initial requirements for DD-21, the program from which the DD-1000 evolved, derived from several early studies and, together with a change in Navy focus from blue water to the littoral, required many new technologies and concepts that had never been applied to a large surface combatant. Not only did those technologies need to work individually, they also needed to be highly integrated to improve or enhance functionality and reduce potential conflict. There was only limited historical experience on which to judge technical feasibility, let alone cost or schedule. As a result, there was little evidence supporting the feasibility of achieving the desired performance, particularly under the cost and schedule constraints that were later imposed.

Execution Issues

Changes in Procurement Quantities. Changes in quantity are never the primary source of a change in cost. Rather, quantity changes are always driven by some other factor, such as a change in threat or mission, which changes the requirement, or technical problems, which increase costs and therefore affect affordability.

The initial reductions in planned quantities from the 32-ship class originally envisioned for DD-21 to the ten ships included in the Milestone B baseline were due to affordability. As the system design matured and experience was gained with the key technologies and subsystems through the EDMs, more realistic (higher) cost estimates were developed, which reduced both the production rate (number of ships approved for construction in a given year) and total quantity.

The baseline approved at Milestone B contained ten ships, but it was recognized at the time that this was a planning number rather than a hard requirement based on mission needs analysis. There were significant cost risks still at Milestone B, and the program was potentially underfunded (i.e., Navy compared with CAIG funding estimates). Those risks translated to an affordability concern, especially when considered in light of the Navy's force structure goal of 313 ships. Post MS B, planned total quantity changed from ten to seven and then from seven to three. The APB containing the planned seven-ship program was never formally approved by OUSD (AT&L).

The quantity change from ten to three that resulted in the critical Nunn-McCurdy breach to PAUC and the significant APB breach to APUC were due to perceived changes in the emerging threat and mission priorities. Navy leadership argued in July 2008 that the ballistic missile defense (BMD) mission had become higher priority than volume fire support from the littoral, and that the DDG-51 hull was more suitable for that BMD mission. The Navy actually proposed truncating the program at two ships (the two lead ships, one at each yard). A subsequent FY 2010 budget decision by the Secretary of Defense increased the number of ships to three and moved construction of all ships to Bath Ironworks while restarting the DDG-51 line at NGSS. A revised baseline in 2008 reflecting a quantity of seven was not approved by OUSD (AT&L) because of uncertainty in the total program quantity.

The FY 2011 budget decision to truncate the DDG-1000 program at three ships and restart DDG-51 production was largely due to a change in the perceived threat and mission priority by Navy senior leadership. Priority was placed on ballistic missile defense rather than the original DDG-1000 precision and volume fire support mission. The radar hull study recommended the DDG-51 hull form with a new advanced missile defense radar (AMDR) as more effective in the ballistic missile defense mission than DDG-1000. DDG-51 with AMDR was also assessed to have less cost risk.[6]

Inadequate Program Funding or Funding Instability. The Navy estimated a $600 million shortfall in FY 2006–2011 budgets at the time of Milestone B.[7] The CAIG estimated a much higher shortfall: $4.1 billion over the FY 2007–2011 budget period.[8] The difference was largely due to the differences in cost estimates. However, the fact that the Navy had a budget shortfall using its cost estimates for planning suggests inadequate program funding at the time of Milestone B.

OUSD (AT&L) instructed the Navy at MS B to fund to the Navy estimate, and it did in FY 2007. However, in subsequent years, the Navy did not fully fund to the program manager's estimate. This forced the program to either reduce or redistribute costs (and the associated work) across future years; contract negotiations and capability (e.g., the number of vertical launch tubes went from 128 to 80, the number of LRLAPs per gun went from 600 to 300) yielded some cost savings.[9]

Figure 3.2 shows that RDT&E funds have largely remained unchanged in the program. Projections of out-year budgets have been relatively stable both before and after Milestone B. The RDT&E growth that resulted from the increased scope discussed above can be seen in the difference between the projections in the December 2005 SAR and subsequent SARs in the period 2009–2013, but, relatively speaking, the difference is small. A stable RDT&E budget line facilitates effective execution of the development program and also indicates that few technical problems have been encountered that could not be handled within existing budget authority.

Figure 3.3 tells a very different story for SCN (procurement) funds. Each out-year projection of SCN funding has been different from that approved at Milestone B, and

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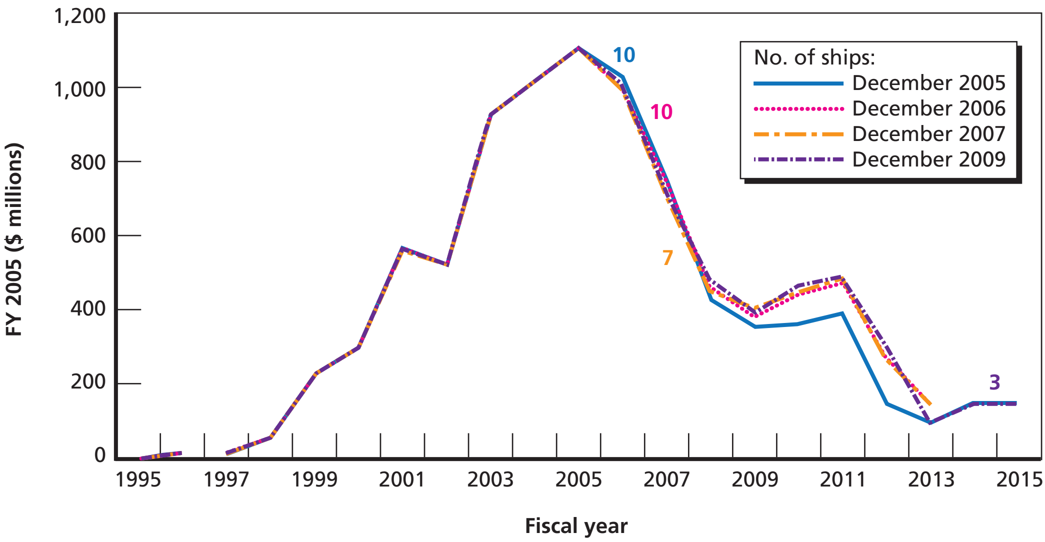
6 The DDG-1000 root cause analysis team has not reviewed the radar hull study and so cannot validate its results and implications.

7 OSD CAIG Memorandum to USD (AT&L), *Update to the OSD CAIG Report for Milestone B Defense Acquisition Board (DAB) of the DD(X) Program*, November 2, 2005, p. 3.

8 OSD CAIG Memorandum to USD (AT&L), 2005.

9 We have not yet been able to verify the specific budget changes in each year.

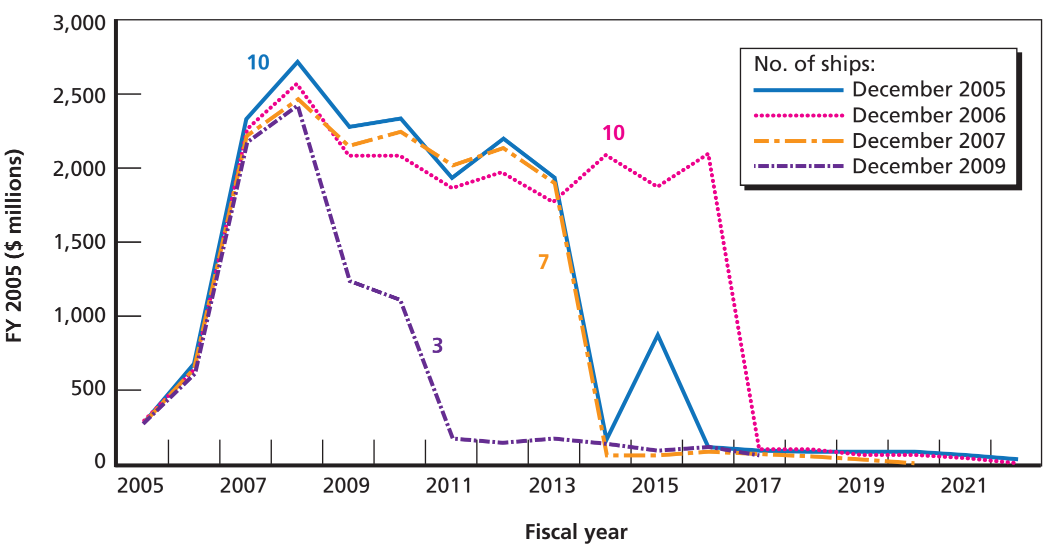
Figure 3.2
DDG-1000 RDT&E Funding



SOURCES: Selected Acquisition Reports, December 2005, December 2006, December 2007, and December 2009.

RAND *MG1171z1-3.2*

Figure 3.3
DDG-1000 Procurement (SCN) Funding



SOURCES: Selected Acquisition Reports, December 2005, December 2006, December 2007, and December 2009.

RAND *MG1171z1-3.3*

each has differed from the other. With the exception of the dramatic profile change in the 2009 projection that resulted from the quantity reduction from ten to three ships, the other differences in budget projections have been due to factors other than quantity. Some evidence suggests that budget instability was driven largely by Navy (as opposed to OSD or Congress) actions and that this instability adversely affected program execution, but we have not yet been able to verify this hypothesis independently.

Anecdotal evidence also suggests that the extended DD&C contract negotiations (for both detail design and lead ship construction) were due in part to disagreements on cost, with the Navy pushing the contractors to lower the price to accommodate the Navy's budget targets. Again, we have been unable to verify this claim.

Unanticipated Design, Engineering, Manufacturing, or Technology Integration Issues Arising During Program Performance. Some manufacturing techniques were new as was the planned relationship between shipyards, as noted above. In addition, materials were new, particularly the composite deckhouse, requiring completely new construction procedures. However, with only 20 percent of the lead ship completed to date,[10] many of these factors have not yet come into play.

Testing of the EDMs before Milestone B caused some required redesign work to improve performance, but there is no evidence that this adversely affected program cost or schedule. In fact, the purpose of the EDMs was to reduce risk earlier in the program, thus reducing the cost of any redesign work.

It is still too early in the lead ship construction process to determine whether the significant integration risks mentioned above will result in extended schedules or cost growth. However, those risks are real and remain a serious management and technical challenge.

That said, it is also important to note that the detail design for DDG-1000 was more mature when construction began than most other ship programs have historically seen. This factor might mitigate some of the manufacturing and integration challenges facing the program.

Poor Performance by Government or Contractor Personnel Responsible for Program Management. The program greatly benefited from the continuity of talented staff, both military and civilian, most of whom had extended tenure at the program. However, the official Program Office was smaller than other ship Program Offices, numbering fewer than 20 government officials, who drew on Systems Engineering and Technical Assistance SETA) support locally as well as on an extended network of support from other NAVSEA organizations. The small number of government staff resulted in heavy workloads given the complexity of the program. There is no direct evidence that this affected program execution or PAUC or APUC estimates, but it seems like a noteworthy and potentially contributing factor. The 2007 PMAG noted that the small staff size was one of its top three factors affecting program execution.

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[10] This figure is a rough estimate provided during Program Office conversations with the analysis team in 2007.

Other Factors Affecting Program Execution. The Secretary of the Navy's direction to reassess contracting strategy delayed the lead ship contract award for 14 months. According to the Program Office, this delay resulted in an increase of approximately $500 million to the lead ship; over that 14-month delay, the shipyards revised and increased many cost elements in their proposed contract value.

Acquisition Strategy and Execution-Related Observations

Although it may not be possible to tie any elements of the DDG-1000 acquisition strategy to the root cause of the Nunn-McCurdy breach, these elements did play a significant role in program execution, both positive and negative. The acquisition strategy and program history have many unique elements relative to past ship acquisition programs, including the following:

- The relative newness of the mission need and resulting requirements on ship design, driven largely by the shift of emphasis from blue water operations as part of a battle group to more independent operations in the littoral in support of ground troops. This change reflects in the difference between the precision and volume fire support capability requirements underlying the program and the ballistic missile defense capability requirement that resulted in the truncation of the DDG-1000 program.
- Teaming arrangements between shipyards and system integrators, and the relationships (contractual and technical) between teams.
- The reduced role of the Navy in the design of ship and mission systems and the increased responsibility and authority of industry.
- The use of EDMs as subsystem prototypes and test beds to reduce risk and refine ship and mission system design.
- The consistent underlying policy objective of maintaining the financial and technical viability of the two shipyards capable of constructing large surface combatants.

Conclusions

The original program baseline (January 1998) envisioned a 32-ship class and production rates of up to three per year. The cost estimate at the time—$750 million (in FY 1996 $; approximately $876 million in FY 2005 $) for the fifth ship—was grossly understated and was based more on a budget constraint and the need to maintain two viable shipyards than on any cost analysis.[11] Over time, the cost analysis was performed and a more realistic estimate was eventually adopted at Milestone B. It is interesting to note that unit cost increased between the January 1998 baseline and the November 2005 baseline by roughly a factor of three ($876 million to $3.2 billion, FY 2005 $) whereas the quantity included in the Milestone B baseline decreased by a factor of three (32 to ten). Unit cost is more sensitive to changes in quantity when procurement quantities are already low: Research and development, overhead, and other administrative costs are spread over a smaller base; and economies of scale (i.e., cost improvement curve effects) shrink.

In this case, total planned quantity was reduced by 70 percent (ten to three ships), which can be expected to only increase unit costs dramatically, all other things being equal. That quantity change explains upward of 80 percent of the PAUC increase; much of the rest is due to increases in scope (work content). Other factors such as technical difficulties, schedule slips, or poor performance by government or contractor personnel do not play a role here.

The quantity change resulted from the 2008 decision of senior Navy officials to truncate the program at two ships (with a third added back in later). That decision, formally incorporated into the FY 2011 President's Budget, was based on the perception of an emerging ballistic missile threat and the resulting change in mission priority from precision and volume fire support to ballistic missile defense. Remaining cost risk in the DDG-1000 program and affordability concerns contributed to the decision to base that ballistic missile defense capability on the DDG-51 platform rather than on the DDG-1000.

DDG-1000 program outcomes were driven largely by factors external to the Program Office. At Milestone B, there was a mismatch of desired performance (required capabilities) and resources, leading to chronic underfunding and affordability problems. The Milestone B ADM directed that the Navy fund the program to its cost estimate rather than to the CAIG estimate, which was $4.1 billion higher over the period FY 2007–FY 2011. In the FY 2008 and subsequent budgets, the Navy did not fully fund the program to the Program Office's cost estimate.

It is important to note that the DDG-1000 has been well managed by a small, dedicated government team with continuity. EDMs were used effectively to reduce risk. Detail design was largely complete (over 80 percent drawing complete) before construction began. The Program Office was aggressive in contract negotiations throughout, protecting Navy interests. Post-Milestone B metrics generally reflect good program execution, with relatively small variances in cost and schedule metrics to date.

Significant cost and performance uncertainty remains in the DDG-1000 program. Ship construction has been under way for only a little over a year, and there are limited cost data on which to base new estimates. The challenges and cost of system

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11 This observation was made by several officials involved in the early (DD-21) program.

integration, including both ship and mission systems, have yet to be determined. Other remaining risks include software development and integration, hull form sea-keeping and signature requirements, and IPS integration and test.

Next Steps

Given that the lead ship is still under construction with many significant integration challenges still to come, program execution and SCN funding should be carefully monitored. It would also be useful to verify the claim of budget instability and its effect on program execution.

CHAPTER FOUR

Joint Strike Fighter (F-35)

On March 26, 2010, the Air Force notified OSD and Congress of a Nunn-McCurdy breach in the JSF program. The immediate cause of the breach was an increase in the program's cost estimates, which had already grown substantially from the 2001 program baseline. The resulting 57 percent increase in PAUC and 58 percent increase in APUC triggered the Nunn-McCurdy breach and associated process.

Program Overview

An aging fleet of fighter aircraft and declining budgets prompted DoD to establish the Joint Advanced Strike Technology (JAST) program in January 1994. The program was created to mature technologies that could be used in the next generation of affordable tactical aircraft. In October 1994, Congress passed legislation that merged JAST with the Advanced Short Takeoff and Vertical Landing (ASTOVL) program managed by the Defense Advanced Research Projects Agency (DARPA). The program envisioned development of a demonstrator aircraft with the potential to meet the requirements of the services flying fighters: the Air Force, Navy, and Marine Corps.[1] The joint program would be managed by a JPO, with leadership rotating between the Air Force and Navy, and would seek international partners.

A concept demonstration phase (CDP) for the Joint Strike Fighter program began with a Joint Initial Requirements Document (JIRD) promulgated in August 1995. This JIRD was updated in 1997 and 1998 and a draft Joint Operational Requirements Document (JORD) was signed in March 2000. The JROC validated the JORD in April 2000. The CDP first flight took place in September 2000, and the flight test was completed in August 2001.[2]

1 See "The F-35 Lightning II History," web page, undated.

2 Chronology based on BG John L. Hudson (USAF), *JSF Program Update*, November 2001, and SARs.

SDD began in October 2001 with the approval of Milestone B by the Defense Acquisition Board and subsequent letting of an SDD contract to Lockheed Martin. We use the baseline that was adopted in October 2001 in our analysis.

JSF Technical and Integration Challenges

The JSF is inherently difficult to develop. It is the first aircraft to combine stealth signatures with supersonic flight and the ability to perform short takeoff and vertical landings (STOVL). Mission systems integration across the three platforms also poses new challenges, and the JSF contains an unprecedented level of sensor fusion, requiring development of large amounts of software code. Table 4.1 compares F-35 variants with other advanced aircraft programs. None has the breadth of the F-35.

The F-35 combines four, sometimes competing, characteristics among its three variants. Supersonic flight and stealth signature are required on all variants, with STOVL required for the F-35B and the capability to operate from aircraft carriers required for the F-35C. Only recently, with the development of the F-22A Raptor, did we see a supersonic stealth aircraft. Before the F-22, aircraft were designed for a particular mission, choosing one characteristic for primary design optimization. The F-117 and B-2 were primarily designed for stealth. The F-14, F-15, F-16, and F/A-18 were primarily designed for supersonic flight. The AV-8B was primarily designed for STOVL. Few aircraft are carrier-capable. Carrier aircraft operate in a very different flight enve-

Table 4.1
Historical Aircraft Characteristics

	Stealth	STOVL	Supersonic	Carrier Capable
F-14			X	X
F-15			X	
F-16			X	
F/A-18			X	X
AV-8B		X		
F-117	X			
B-2	X			
F-22	X		X	
F-35A	X		X	
F-35B	X	X	X	
F-35C	X		X	X

lope from other aircraft. The approach to a carrier landing must be much slower than landing on a hard-surface runway. This requirement entails different design for control surfaces, which must be larger than on other aircraft. They also require stronger (and therefore heavier) airframes and landing gear than aircraft that operate only from land-based runways. The upshot of these significant differences means that the carrier take-off and landing (CV) version of the aircraft will have much less commonality with the other variants and will likely have important cost implications.

The CAIG memo summarizing its independent cost estimate (ICE) for the JSF Milestone B decision in October 2001 acknowledged that the program was highly risky, from both a technological and a schedule perspective.[3] The SDD Milestone B program schedule, driven by the need to develop an affordable aircraft to replace aging combat aircraft, was aggressive and highly concurrent, with the first flight in the fourth quarter of 2005, just 48 months after the SDD contract award, and with over 600 aircraft procured by the end of initial operational test and evaluation (IOT&E) in March 2012.[4] This would amount to a concurrency of about 25 percent for the JSF.[5] Concurrency for the F-22, an equally challenging technology program, was 18 percent.[6] Figure 4.1 shows certain elements of this concurrency. Note the triangles indicating critical design review (CDR) and first flight and the steep ramp-up in production before the completion of IOT&E in 2012. Other high-technology programs may have had similar issues of concurrency (e.g., the F/A-18, F-22, DDG-1000, CVX (undesignated aircraft carrier), and Joint Tactical Radio System radios but, in the time allowed, we were unable to review or analyze them.

Affordability is also a critical element of the program, and the baseline cost estimates and acquisition strategy relied heavily on hypotheses about the benefits of acquisition reform to meet cost, schedule, and performance objectives. Affordability was to be achieved through a number of acquisition process improvements. Before Milestone B, Cost as an Independent Variable (CAIV) processes were used extensively to make cost and operational performance trades to maintain affordability. Commonality initiatives for the airframe, vehicle systems, propulsion, and mission systems were also expected to contribute to affordability. The program expected technology innovations, such as the use of streamlined testing and expanded use of simulation, to contain program costs. Design-to-manufacturing efficiencies were assumed in developing the program's cost and schedule. The steep ramp-up to high-quantity production also con-

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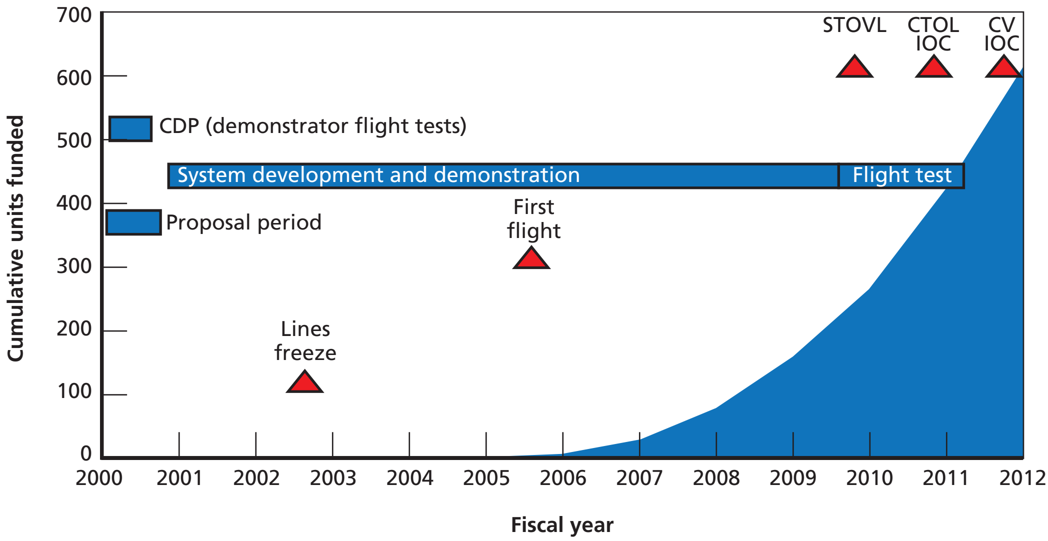
3 "CAIG Milestone B Independent Cost Estimate (ICE) for Joint Strike Fighter (JSF) Program," October 24, 2001. Not available to the general public.

4 CAIG Milestone B Independent Cost Estimate (ICE) for Joint Strike Fighter (JSF) Program, 2001.

5 Concurrency is generally defined as the amount of IOT&E completed before entering production of a system.

6 U.S. General Accounting Office, "Tactical Aircraft: Concurrency in the Development and Production of F-22 Aircraft Should Be Reduced," GAO/NSAID 95-59, Washington, D.C., April 1995.

Figure 4.1
Highly Concurrent Program



SOURCE: The figure is based on data compiled from JSF SARs.
RAND *MG1171z1-4.1*

tributed to affordability and was reflected in program cost estimates. Finally, stable program funding was identified as a key element of program affordability.[7]

Approach

RAND took a top-down approach to its JSF root cause analysis. It reviewed a number of the previous JSF program assessments to look for common themes or other critical factors driving cost and schedule performance. The team also reviewed a selection of articles discussing the JAST and JSF program histories. Access to data and officials familiar with the program was critical to identifying relationships and thus root causes. RAND analyzed data provided by many sources, though this report relies heavily on SAR data because these reports convey DoD's official public cost estimates for the program. In the end, as the team diagrammed the story, additional levels of complexity and causality were revealed. RAND's effort benefited from access to a wide range of JSF program materials provided by the JPO and Lockheed Martin, as well as from extensive conversations with Lockheed Martin and JPO staff. CAPE provided additional materials.

7 "CAIG Milestone B Independent Cost Estimate (ICE) for Joint Strike Fighter (JSF) Program," 2001.

The next section presents a program overview including the facts on JSF program cost and schedule from the baseline to the breach. That section is followed by an overview of the causes of this cost growth and schedule slippage and a more detailed discussion of key elements. This chapter on the JSF concludes with a description of root causes and identification of potential future cost and schedule concerns.

Nunn-McCurdy Breach

Nunn McCurdy breaches are calculated based on cost growth subsequent to the Milestone B baseline program. The JSF breach was triggered by cost growth of 58 percent in APUC and 57 percent in PAUC. The program's schedule delays also triggered a Nunn-McCurdy breach that resulted from delays in carrier (CV) first flight, delayed delivery of the first production aircraft, and a slip in the date for completing IOT&E.[8]

Costs Grew in Both Development and Procurement

The program is still in development and the early phases of low rate initial production (LRIP). As of May 2010, fewer than a dozen aircraft had been produced, and thus JSF unit cost is a mix of actual costs and estimates. Of the total estimated development cost of roughly $45 billion, 77 percent, or almost $35 billion, had been funded through FY 2009. Of the total estimated procurement cost of $193 billion, only 3 percent, or $6 billion, had been funded through FY 2009, with the remaining program costs based on estimates of future procurement costs. Figure 4.2 shows the relative amounts of incurred and estimated costs in constant (BY 2002) dollars.

Although just 3 percent of the procurement budget has been spent, procurement costs represent about 80 percent of the total cost growth from the program baseline estimate, with 20 percent attributed to RDT&E. That is, although the program has spent the majority of its budgeted RDT&E funds in its almost ten-year RDT&E program, the *anticipated costs* of procuring roughly 2,400 aircraft over more than 20 years dwarf RDT&E costs.

JSF Costs Rose in Two Main Spurts

The Nunn-McCurdy breach did not occur in one jump. As can be seen by the trend line in Figure 4.3, the program had two big jumps that bookend a period of more modest growth.[9]

The first growth spurt occurred in the first three years of the program and is shown in both the blue and pink lines. This growth reflects a reduction of 400 in the

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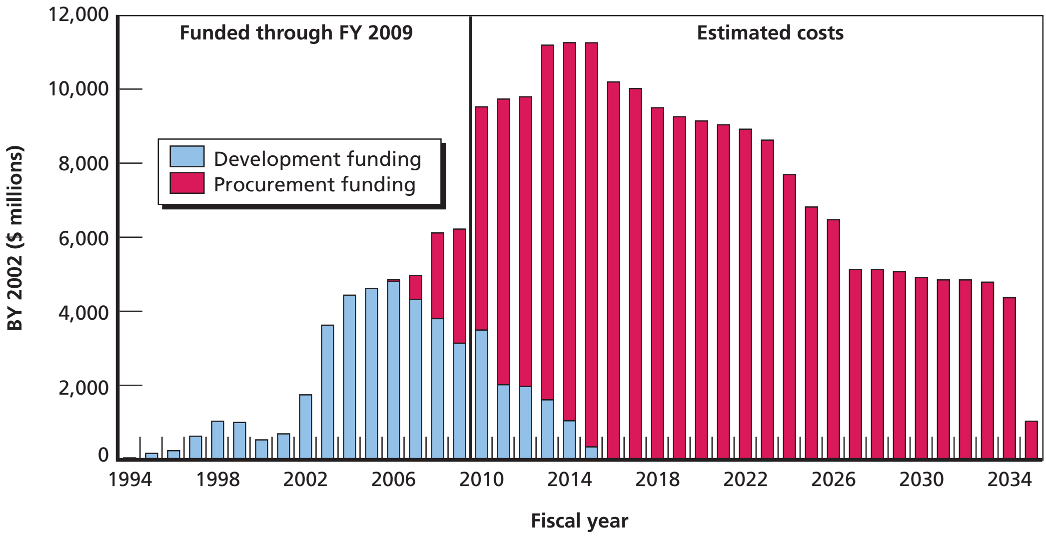
[8] Michael B. Donley, Secretary of the Air Force, Memorandum to the Honorable Carl Levin, "APUC, PAUC and schedule data from SAR dated December 31, 2009," March 25, 2010, pp. 4–5 (unit cost) and p. 8 (schedule).

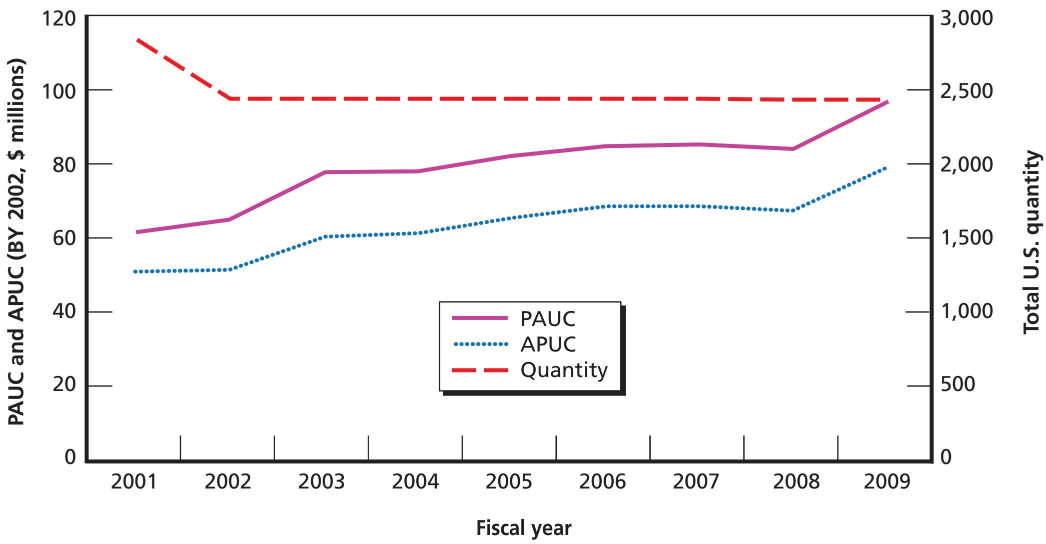
[9] Data for this section come from the F-35 SARs unless otherwise stated.

Figure 4.2
F-35 Acquisition Funding



SOURCES: SAR data, 2001–2009.
RAND *MG1171z1-4.2*

Figure 4.3
Cost Changes from Baseline



NOTE: SARs were not published in 2008; value is POM position.
RAND *MG1171z1-4.3*

quantity of aircraft being purchased by the Department of the Navy (red line) and a serious weight growth and design issue that was discovered as the first prototype was built. After this initial change, U.S. quantity remained stable with changes in ones and twos as test aircraft were canceled to pay for program cost growth.

However, weight and design issues continued to affect the program. In 2002 through 2003 and 2004, Lockheed Martin (LM) engaged in a Blue Ribbon Action Team (BRAT) and subsequent 18-month STOVL Weight Attack Team (SWAT) effort to address critical weight and design problems that cascaded into other issues including parts design and the propulsion system. After the major aspects of the weight and design issue were addressed, in roughly 2004, the program's costs grew more modestly until a second big jump in 2008–2009. This second jump reflects changes in the official DoD estimate of expected program costs and, more specifically, anticipated future cost growth.

Estimated Cost Changes[10]

RAND obtained four sets of data showing different categories of cost growth. The data are not comparable; each organization binned costs differently and some presented the data as program costs whereas others showed only unit costs. However the data do provide some explanatory value. Here we discuss the SAR data; the data from the other organizations appear in Appendix D.

Figure 4.4 provides SAR cost variance data in six categories: estimating, economic, schedule, engineering, quantity, and support. These data, which are *not* presented in terms of unit costs but rather in terms of total program cost, identify *schedule* delays as the primary driver of cost growth in RDT&E (77 percent for *schedule* individually) followed by *estimating* and *engineering* (6 and 30 percent, respectively). For procurement, which is a far larger figure than RDT&E, *estimating* accounts for 94 percent of the cost growth. The next largest factor driving cost is *quantity;* this refers to the 400 aircraft reduction in the Navy's program. *Quantity* is actually assigned a negative effect on cost growth equal to about one-third the effect of estimating growth because it reduced the overall cost of procurement. *Engineering, support,* and *schedule* are the remaining drivers of procurement cost growth, though much smaller in scale than *estimating* or *quantity*.

Data from the other cost estimates appear in Appendix D. Although the data do not lend themselves to comparison, they do convey a common message, summarized in Table 4.2. They generally agree that program cost growth was driven in large measure by optimistic cost and schedule estimates, program weight and design issues, problems with design control and parts production, and growth in labor rates and raw material costs. It is also true that the reduction of 400 aircraft in the Navy Department buy affected unit costs and thus the APUC and PAUC calculations.

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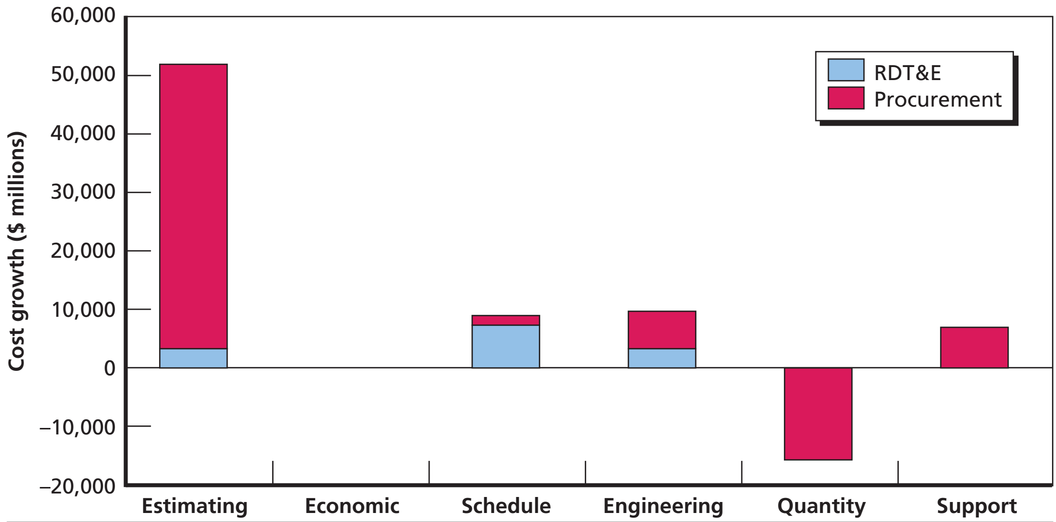
10 The organizations are CAIG/CAPE, Lockheed Martin, JPO, and AFCAA.

Figure 4.4
Explanations of Cost Growth from SARs, 2001–2009 ($ millions)



	Estimating	Economic	Schedule	Engineering	Quantity	Support
RDT&E	3,159	–139	6,779	2,815	131	0
Procurement	48,699	0	2,018	6,645	–16,249	6,753
Total	51,858	–139	8,797	9,459	–16,119	6,753

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Table 4.2
Identified Cost Growth Drivers

	Estimating	Navy Quantity Reduction	Weight and Design	Cost of Materials	Rates	Propulsion System	Schedule Delays
SAR	X						
LM			X	X		X	
JPO		X	X	X	X		
CAIG	X						X

SOURCES: SARs, December 31, 2002 through December 31, 2009; LM, JPO, and CAIG briefings to the PARCA team in April and May 2010.

JSF Program Schedule Slipped Repeatedly

The program schedule slipped repeatedly after 2001, with average milestone delays of two years through first flight. A key early delay resulted from aircraft weight growth and design problems that delayed CDR by about two years. During the ensuing design review, the STOVL variant was identified as the critical design challenge, and both conventional takeoff and landing (CTOL) and STOVL variants went through CDR together in February 2006. Table 4.3 shows the schedule slippage calculated from data

Table 4.3
Current Estimate Dates from 2001 SAR Compared with 2009 SAR

Critical Design Review	December 2001	December 2009	Slip (Years)
CDR CTOL	April 2004	February 2006	1.8
CDR STOVL	October 2004	February 2006	1.3
CDR CV	July 2005	June 2007	1.9
First flight CTOL	November 2005	December 2006	1.1
First flight STOVL	April 2006	June 2008	2.2
First flight CV	January 2007	May 2010	3.3
U.S. Marine Corps IOC	April 2010	March 2012	1.9
U.S. Air Force IOC	June 2011	March 2013	1.8
Completed IOT&E	March 2012	April 2016	4.1
U.S. Navy IOC	April 2012	March 2015	2.9

in the December 2001 and December 2009 SARs. The scheduled first flight of the CV variant occurred in June 2010,[11] illustrating the point that much of the schedule has yet to be completed and thus has the potential to slip further. Although the average major milestone schedule slip to date is slightly under two years, the slippage of IOT&E—the date that SDD will be considered complete—has already reached four years and with additional delays in first flight seems likely to grow.

These schedule delays affected the production schedule. Program affordability depended on a quick ramp-up to a high rate of U.S. production (Figure 4.1) (almost 200 aircraft per year) within six years of first flight. As of the December 2009 SAR, the ramp-up in U.S. production will take ten years, until 2016, and reach only 130 U.S. aircraft per year.[12] Figure 4.5 shows the shift in the U.S. procurement plan from 2001 to 2009—slower ramp-up and lower production levels. The dark blue line shows the 2001 baseline program and the dark red line shows the 2009 SAR-reported program. The other lines trace the incremental annual shifts in schedule and quantity.[13]

International procurement will improve the speed of the ramp-up in production but will not bring it back to the original plans. As of 2009, peak production including international production will occur in 2019, at over 200 aircraft per year.[14] Figure 4.6

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11 First flight was previously scheduled for May 2010 and occurred on June 7, 2010, instead. See Lockheed Martin, "Press Releases for F-35 Lightning II," various dates.

12 SARs of 2001–2009.

13 SAR schedules.

14 Annual cost estimating files are from the JSF collaboration website. U.S. data are from 2001 and 2009 SARs. International data are from Lockheed Martin presentations to Gary Bliss, April 23, 2010.

Figure 4.5
Procurement Plan Changes Through Each SAR

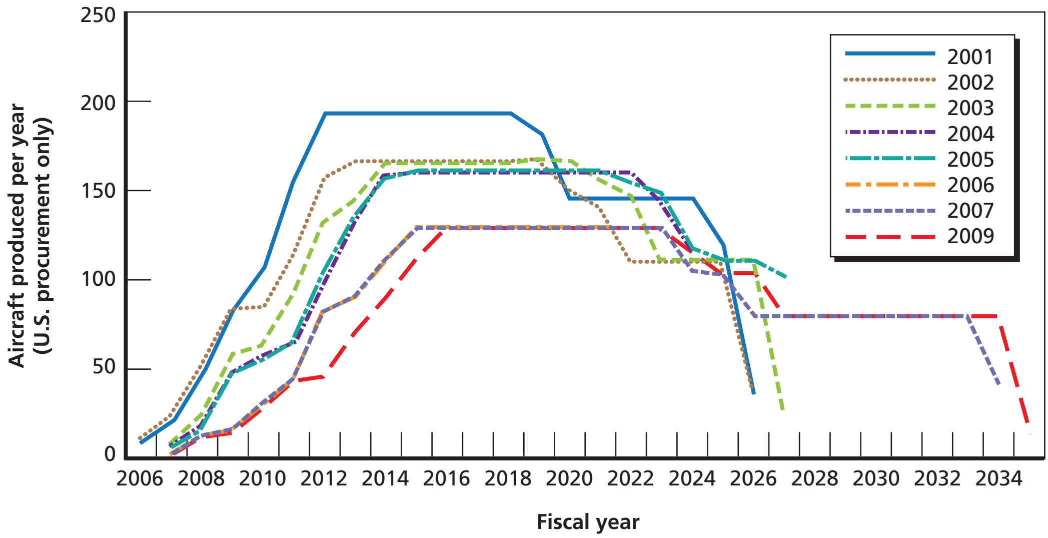

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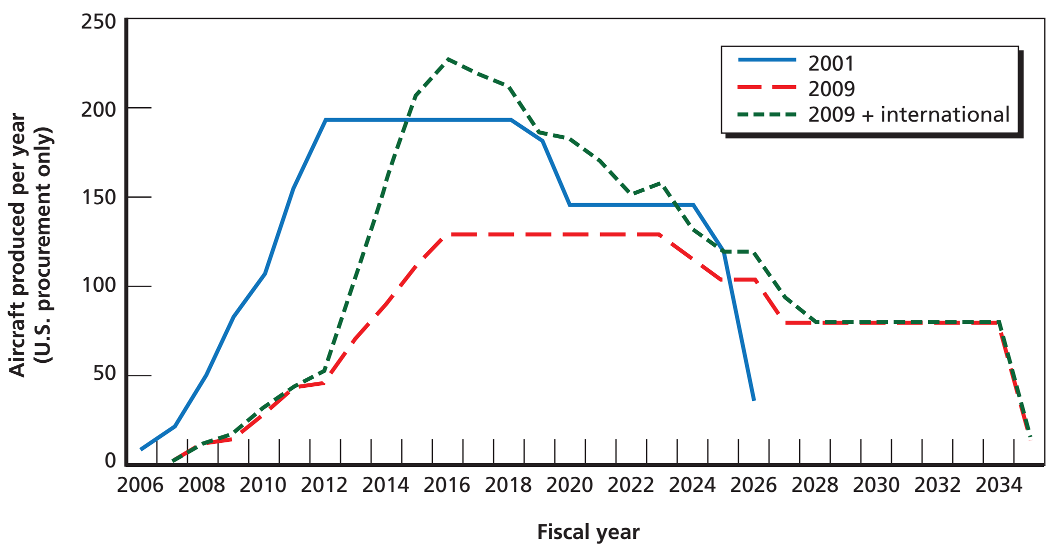
Figure 4.6
Procurement Plan with International Procurement Added



SOURCES: Annual cost estimating files are from the JSF collaboration website. U.S. data are from 2001 and 2009 SARs. International data are from Lockheed Martin presentations to Gary Bliss, April 23, 2010.
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shows the production schedule. The blue line shows the original U.S. buy. The red line shows the current, stretched out, U.S. buy, and the green line shows additional foreign aircraft as of May 2010.

These international sales are not included in the Nunn-McCurdy calculations of PAUC and APUC, which focus only on the U.S. element of the program. It is likely that inclusion of planned international procurement would change the PAUC calculation. Although the increase in production quantities should be good for efficiency and for reducing unit costs, such an increase assumes that Lockheed Martin can successfully manage the complexity of the program including the steep ramp-up for international production, the integration of many foreign manufacturing entities, and the production of an additional 6–12 variants as each country's model is slightly different. The effect of changes in U.S. airframe commonality standards and the further influence on commonality cost savings from the multiple variants remains to be seen.

In response to cost growth and schedule slips, the program was re-baselined twice, once in March 2004 and a second time in March 2007.[15] At both these points the schedule was also re-baselined. It is anticipated that another re-baseline will occur in the wake of the Nunn-McCurdy breach.

Findings Narrative

The PARCA law specifies a set of criteria to be assessed in DoD's program review following a Nunn-McCurdy breach. These divide into baseline issues and execution issues. For the JSF, the RAND team further divided these elements into issues related to development and issues related to procurement. In Table 4.4, the reader will find that blue shaded cells speak to problems in RDT&E and green shaded cells relate to procurement.

The reader should remember that this analysis is focused on root causes, so this review does not capture all the issues that may have come up in the program. We used the SARs to determine dates, though it is hard to be precise about them, in part because root causes can lag manifestation of a problem.

Baseline Issues

As noted in the research approach, RAND's analysis built on a number of prior and ongoing studies on JSF cost and schedule issues. In response to Lockheed Martin's early problems with JSF weight growth and design configuration and in response to

[15] SARs of December 2004 and December 2007 report APBs as follows: APB March 17, 2004, and APB March 30, 2007.

Table 4.4
PARCA Root Cause Narrative Matrix for the JSF

	Year from MS B and Fiscal Year								
	B 2001	**1 2002**	**2 2003**	**3 2004**	**4 2005**	**5 2006**	**6 2007**	**7 2008**	**8 2009**
Baseline issues									
Unrealistic estimates for cost or schedule	Acquisition strategy; concept demonstrator			X			X		APB breach
Immature technology, excessive manufacturing, integration risk	Integration challenges			X			X		
Unrealistic performance expectations	Systems engineering for weight; commonality			X			X		
Execution issues									
Changes in procurement quantity	X	U.S. Navy reduced ≈ 400	X	X	X	X	X	X	X
Inadequate funding/ funding instability									
Unanticipated design, engineering, manufacturing, or technical issues		Engine	Aircraft weight growth; common parts; schedule; rates	Changed support estimate; test program delays	Materials; wing; support	Production	Tooling; test manufacturing; lift fan	X	Rates; manufacturing plan; materials; spares
Poor performance of government or contract personnel		CAIV process	X	X	X	EVMS issue	X	X	X

subsequent concerns, DoD conducted a number of its own investigations into JSF cost growth and schedule slippage. These included the following:[16]

- Joint Estimating Team (JET 1) in 2008
- Joint Estimating Team (JET 2) in 2009
- Independent Manufacturing Review Team (IMRT) in 2009.

These studies variously identified problems with weight and design, quantity changes, materials costs, labor rates, and engineering as the drivers of cost and schedule performance issues. RAND explored a number of these findings to get a better understanding of the root causes of these problems.

Unrealistic Baseline Estimates for Schedule and Cost. The requirement to replace aging fighters, the need for affordability, and the belief that significant cost savings would be realized from implementation of acquisition reform practices all contributed to an overly optimistic schedule and cost estimate.

The JSF Schedule Was More Aggressive Than the F-22 Schedule. Table 4.5 compares the JSF baseline schedule to those of other fighters. Although the JSF baseline program schedule allowed more time than most aircraft between contract award and first flight, and between contract award and IOC (March 2012), these time periods were less than those for the F-22. The original schedule for STOVL from contract award to IOC was tighter than for both F/A-18E/F and F-22.

Milestone B cost estimates of both the JPO and the CAIG understated program costs.[17] These estimates were based on legacy aircraft data including both the F/A-18E/F and the F-22. However, only a few F-22 development units had been built at the time of the cost estimate in 2001, and thus these estimates did not have the benefit of meaningful knowledge about F-22 procurement costs. More recent CAPE estimates incorporated actual cost data from the F-22 program, contributing to an increase in the JSF procurement cost estimate.[18]

A key contributor to the understated estimates is insufficient margin for weight growth. The Milestone B CAIG estimate included a 6 percent margin for aircraft weight growth based on legacy aircraft experience.[19] JSF actual weight growth differed depending on the variant.[20] This is important because parametric cost estimating is based on aircraft weight, and thus an underestimate of the aircraft weight carries over into all aspects of the cost estimates.

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16 Joint Estimating Teams were composed of cost estimating experts from CAIG, OSD, and the other services.

17 These estimates were within 3 percent of each other per Milestone B estimates.

18 Christine H. Fox, Director Cost Assessment and Program Evaluation, OSD, testimony before the U.S. Senate Committee on Armed Services, March 11, 2010.

19 "CAIG Milestone B Independent Cost Estimate (ICE) for Joint Strike Fighter (JSF) Program," 2001.

20 SARs, 2001–2009.

Table 4.5
Comparison of Legacy Aircraft Program Months to First Flight and IOC

Aircraft	Contract Award	First Flight	DT&E End	IOC	Months from Contract Award to First Flight	Months from Contract Award to IOC
A-10	March 1973	February 1975	June 1977	October 1977	23	55
F-14	January 1969	December 1970	September 1974	December 1973	23	59
A-6	December 1957	April 1960	October 1963	February 1963	28	62
F-111	November 1962	December 1964	July 1972	April 1968	25	65
F-16	January 1975	December 1976	January 1979	June 1980	23	65
F-15	January 1970	July 1972	March 1976	September 1975	30	68
AV-8B	August 1979	November 1981	December 1984	August 1985	27	72
F/A-18A/B	January 1976	November 1978	March 1982	March 1983	34	86
F/A-18E/F	June 1992	November 1995	April 1999	September 2001	41	111
JSF/AF baseline	October 2001	November 2005	March 1912	June 2011	49	117
JSF/AF current	October 2001	December 2006	April 2016	March 2013	62	137
F-22	August 1991	September 1997	December 2005	December 2005	73	172

SOURCES: Program SARs and Institute for Defense Analyses (IDA), "Assessing Acq. Schedules," P-2105, February 1989.

Immature Technology, Excessive Manufacturing and Integration Risk.

Technology integration experience was immature. Although the key structural technologies—stealth, supersonic, STOVL, and carrier-capable—used on the JSF had all been demonstrated on other aircraft, integration of the STOVL and carrier-based elements with stealth and supersonic elements was new and complicated. Trade-offs are always necessary when designing aircraft, but combining different characteristics, as was the case with the F-35, creates countervailing trades. In a traditional aircraft, for example, if weight increases, designers can take several measures to mitigate the increase, including increasing engine thrust, speed required for takeoff, the rotation angle, and the wing area (which also increases weight).

All of these methods can be traded off against each other to achieve an optimal design. Unlike a conventional aircraft that has more options to overcome weight, the only characteristics a STOVL aircraft can balance is weight and thrust. So the only option that designers have to overcome an increase in weight is to increase engine thrust. However, generating more thrust with a given engine size requires more airflow, which requires larger engine inlets. This action conflicts with stealth measures, which limit the size of engine inlets to reduce aircraft signature. Table 4.6 shows some of the challenging design characteristics that an aircraft like the F-35 must overcome.

Manufacturing and integration risks were acknowledged but not accounted for. The government acknowledged at Milestone B that the JSF was a risky program with an aggressive schedule. The CARD at Milestone B highlighted the complex integration challenge facing Lockheed Martin and its concern about the company's ability to address these challenges. Indeed, the draft CARD supporting the Milestone B decision laid out 185 risk issues with 50 rated low, 89 medium, and 46 high. The list included four risk issues that are now quite familiar:

- engine operability—high risk
- EDM schedule milestones—medium risk
- weight assessment risk—medium risk
- weight definitions and loss of growth—medium risk

It is clear in hindsight that the contractor was not ready to address the program's manufacturing and integration challenges. Two factors identified as contributors to Lockheed's inability to address the program's challenges stand out:

Table 4.6
Design Trades and JSF Characteristics

	Stealth	STOVL	Supersonic
Engine inlets	As small as possible to reduce signature	Large to allow as much airflow as possible	Specific shape for supersonic shockwaves
Fuel storage	All internal to keep signature small	As little weight as possible to allow STOVL operations	As much fuel as possible for afterburning engines
Aircraft shape	Specific shape for reduced signature	Shape dictated by weight distribution	Shape dictated by supersonic flight and speed regime transitions
Materials	Allow for aircraft skin to assist in stealth operations	Light skin to allow for vertical operations	Strong skin to allow for sub-, trans-, and supersonic flight transitions

- the fact that a concept demonstrator was not an adequate basis for SDD
- a sequential approach to aircraft design, focused on the CTOL version, that reduced emphasis on other variants notwithstanding the fact that parts commonality was a critical element of affordability.

We discuss these two points below.

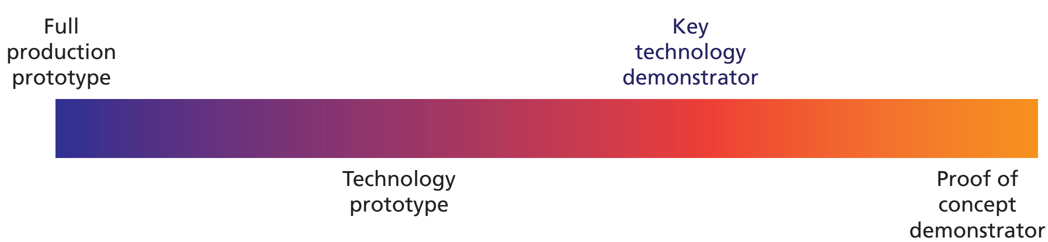
A concept demonstrator may not have been sufficient preparation for executing SDD. The theoretical debate around demonstration versus prototype can be thought of as a scale with full production prototype on the far left and proof of concept demonstrator on the far right. Figure 4.7 shows where different types of preproduction aircraft can fall.

- **full production prototype:** aircraft built using procedures, equipment, and technology as would appear on a full production model
- **technology prototype:** aircraft built to use the production technology but not produced in the same way as the full production models would be produced
- **key technology demonstrator:** aircraft built to show key pieces of technology in operation, though the aircraft itself would not represent a production model; only key technology would be tested
- **proof-of-concept demonstrator:** aircraft that does not represent the technology intended for use in a production model but that demonstrates that operational concepts are possible.

The YF-16, which was eventually developed into the F-16 Fighting Falcon, falls on the prototype side of the scale. The X-35, which was developed into the F-35 Lightning II, falls on the demonstrator side of the scale, close to the proof-of-concept demonstrator. By building an YF-16 prototype, General Dynamics/Lockheed Martin learned about what could and could not be done in the manufacturing phase.

Lockheed Martin demonstrated its ability to perform supersonic flight and vertical landing within a stealth aircraft and demonstrated plans related to commonality, modularity, and affordability. It did not demonstrate its ability to translate these

Figure 4.7
Scale of Prototype to Demonstrator



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capabilities into a production aircraft.[21] In fact, although the aircraft did demonstrate capabilities, it did not do so using key technologies. Additionally, the simplified wing box that was flown on the X-35 had to be redesigned.

A prototype, on the other hand, would have required that Lockheed Martin build an aircraft that was as much like a production model as possible, with more elements integrated so that more cost and performance trade-offs would have been done in advance of SDD. In fact, it appears that two-thirds of the design was finalized after SDD contract award.[22] It is not clear that building a prototype would have avoided the weight and design issues, but it is clear that a demonstrator does not provide much guidance on produceability.

In the case of the JSF, the tenets of acquisition reform, the press for affordability, and the drive to replace aging aircraft led the government to use a technology demonstration approach to identifying its JSF prime contractor. Had a good prototype effort been undertaken before Milestone B, perhaps two years of post–Milestone B delay would have been avoided. At the time, however, the need for a new replacement fighter led DoD to move quickly and use a concept demonstration approach. Cost avoidance is more difficult to ascertain as there would have been additional costs associated with a prototype and a subsequent redesign, along the lines of those associated with the current program's SWAT program.

Engineering Strategy Focused on CTOL. The initial concept of developing a STOVL aircraft for the U.S. Marine Corps, then simply taking out the lift fan and adding an additional fuel tank for the USAF CTOL variant, was abandoned when the CTOL variant was chosen for development first. The strategy of starting with the CTOL variant—a result of a focus on the need for an F-16 replacement rather than on engineering feasibility—may also have contributed to a lack of focus on aircraft weight. Standard engineering practices usually lead to the development of the most difficult system first. Engineering principles dictate that the more challenging STOVL aircraft should have been designed first, with limits relaxed if possible for the CTOL and CV variants.[23]

By focusing on the less complex CTOL system before the more complicated difficult STOVL one, Lockheed Martin did not fully tackle the most difficult systems engineering challenges first. This may have contributed to delays in addressing weight, which grew so much that a complete redesign effort was required. In this redesign process, the more restrictive requirements for STOVL weight were addressed, but had the STOVL been the initial focus of attention, the weight issues might have been dealt with sooner.

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[21] F-35 Joint Program Office, "JPO Cost Growth Summary," JSFSDD-#152864, January 8, 2009.

[22] Telephone conversation with JPO representative, May 11, 2010.

[23] The United States also had the least experience with the STOVL design, as STOVL Harriers previously manufactured in the United States were originally designed in the United Kingdom and adapted for the U.S. market.

Unrealistic Performance Expectations. In a corollary to the point made above regarding the lack of appreciation of the difficulties of technology integration, there appears to have been excessive optimism as to the feasibility of, and savings to be gained by, commonality of design and parts and utilization of new methods for manufacturing and testing. These production-focused issues had implications for aircraft performance as well as for program execution. Implications for performance appeared primarily in the weight growth and subsequent efforts to cut weight to maintain a viable STOVL variant. Implications for program execution are discussed in the following sections.

Execution Issues

Quantity Reduction. Addressing the first of the execution issues, quantity, is straightforward. The U.S. Navy cut its procurement quantity by 400 in the first year of the program. Although the JPO assigns this action as contributing 4 percent to the 38 percent cost growth, the crisis over weight growth and the size of the overall anticipated fleet make this a point to note but not a driver of cost growth.[24] As noted above, the Nunn-McCurdy breach is calculated just on the U.S. buy and thus misses any implications for Lockheed's unit cost resulting from foreign sales. This is likely to be a significant omission for the JSF, which is expected to have a large foreign sales component.

Program Funding Stability. One affordability factor that the CAIG MS B estimate identified as critical[25] and that DoD was able to control was program funding stability. Despite turbulence in other dimensions, funding as measured by the difference between the President's Budget request and the appropriation was remarkably stable, with the biggest differences related to funding for a second engine program that DoD frequently deleted and Congress restored. Figure 4.8 shows the program funding from FY 2002 through FY 2010. The FY 2005 reduction is due to re-planned schedule changes, the FY 2006 reduction is due to excessive risk before CDR, and the FY 2007–2010 net increase is due to congressional funding for the F-136 alternative engine development. Unfortunately, funding stability was not enough to prevent schedule delays and cost growth.

Unanticipated Design, Engineering, Manufacturing, or Technical Issues. Many technical and integration problems were encountered in executing the SDD program. As described above, the program faced an aggressive schedule and keen focus on affordability, and successful SDD required a clean and efficient transition from concept demonstration to test and production. Several factors impeded this clean and efficient transition: A strategy focused on the CTOL variant has already been discussed; other factors included insufficient engine capability, insufficient attention to weight

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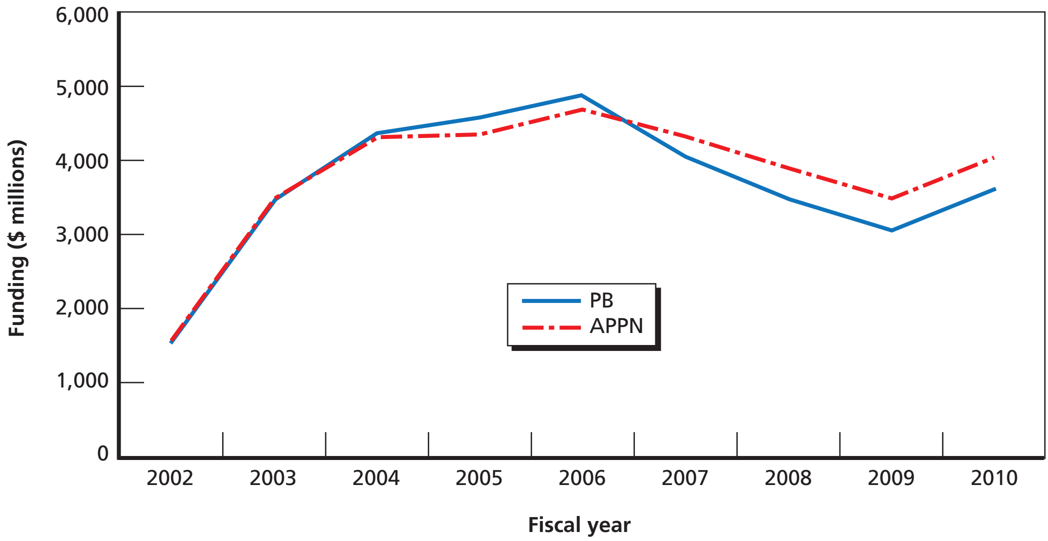
24 "JPO Cost Growth Summary," 2009.

25 "CAIG Milestone B Independent Cost Estimate (ICE) for Joint Strike Fighter (JSF) Program," 2001.

Figure 4.8
Program Funding



SOURCES: Data are for SARs, 2001–2009, and JPO annual Congressional Summaries, provided by JPO, May 2010.

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growth and design control, reductions in design commonality, incomplete capture of efficiencies from design-to-manufacture initiatives and the planned test program, and cascading manufacturing and production issues resulting from the weight and design problems and consequent schedule delays.

Engine Issues. Changes in the engine contributed to the weight growth of the JSF. Original plans called for JSF to use the same engine as the F-22—the F-119 engine. However, the F-119 proved to be underpowered for the performance desired of the F-35, so the F-119 engine was altered to generate more thrust and became the F-135 engine. By enlarging the F-119 engine into the F-135 engine, engineering issues such as shaft length and efficiency had to be dealt with. However, the increase in thrust also lead to an increase in the engine size by a reported 1.5 inches in diameter. This small change in the engine generated a need to redesign the airframe, which in turn changed everything from aerodynamics to stealth signature, all of which needed to be re-baselined. This engine issue also indicates lack of integration across the major contractors, which was Lockheed's responsibility as the prime contractor.[26]

[26] The project team did not interview Pratt & Whitney and therefore all information was received by the project team secondhand. Engine information was obtained through meetings and discussions with Lockheed Martin on April 23, 2010, with JPO on April 20, 2010, and with AFCAA on April 16, 2010. Those discussions did not yield much insight into the engine issues that were experienced by Pratt & Whitney.

Insufficient Attention to Weight Growth and Design Control. Aircraft design execution problems and weight growth caused a substantial direct growth in RDT&E costs with residual impacts on procurement costs. Lack of attention to design and manufacturing integration led to weight growth in the CTOL variant. This became apparent in 2002–2003 and was the focus of a BRAT and subsequently an 18-month redesign effort SWAT.

Commonality Reduced in Airframe. Commonality is another area in which cost savings were not as robust as initially anticipated and may have generated considerably more friction in the process than expected. As stated in the CAIG ICE memo at Milestone B, maintaining commonality was considered critical to affordability.[27] The expectation behind use of common parts is that they can reduce the costs of design and production as well as long-run support costs. Common parts need only be designed once, need only one set of tooling, and, through application of quantities of scale, can reduce O&S costs. However, the three variants proved different enough that, particularly with the airframe, design of common parts proved less practicable than originally planned. The uniqueness or commonality of parts is measured by the weight of the aircraft in the tradition of parametric cost estimating. The greatest growth occurred during the period Lockheed Martin worked to resolve the weight growth and design issues, during which time commonality was given less priority than simply designing an aircraft that could meet performance specifications.[28] Once the weight issue was under control (roughly 2004), the share of unique parts as a percentage of airframe unit weight stayed high through the fifth year of the program (2006), presumably as the program was resolving design issues for component parts. However, since about 2006, Lockheed Martin has identified opportunities to increase commonality slightly.

Commonality in other areas of the aircraft, such as in propulsion and mission systems, has largely remained as expected, at least to date. The impact of changes in airframe commonality in procurement and O&S accounts is largely still to be determined because only a few aircraft have been produced so no actual costs are available on production manufacturing or on O&S where significant savings are expected.

Incomplete Capture of Efficiencies from Design-to-Manufacture Initiatives and the Planned Test Program. Streamlined design-to-manufacturing initiatives were not all realized. For example, Lockheed Martin intended to use a new unitized wing that would reduce production costs by reducing labor required, but in light of the weight growth, the wing had to be redesigned and produced "the old fashioned way." Lockheed Martin and its partners used different versions of their design tools, complicating their ability to rapidly integrate designs.[29] The early weight growth of the aircraft may have been a symptom of both the program's integration complexities and the difficulty

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[27] "CAIG Milestone B Independent Cost Estimate (ICE) for Joint Strike Fighter (JSF) Program," 2001.

[28] Telephone conversation with JPO representative, May 11, 2010.

[29] Discussion with Lockheed Martin, April 23, 2010.

in managing or controlling design elements without a truly common system. Lockheed Martin had planned a five-month assembly plan through the use of design-for-manufacturing assembly methods, advanced manufacturing processes, and assembly simulation processes. Lockheed Martin may yet reach this target; thus far, it takes about 30 months to produce one aircraft.[30] Design for manufacturing was rated a medium risk in the CARD of 2000.[31]

The baseline estimate for Milestone B was based on anticipated savings through streamlined structural and flight testing with fewer ground test articles—four rather than seven—and leaner test operations.[32] Lockheed Martin claims that many of these design issues are behind them. However, the test program is still in its early stages, and additional design refinements may be necessary. Lockheed Martin's estimate to complete the test program has increased by 50 percent, and DoD's CAPE is looking for ways to add flight test articles and flying hours to the program.[33] It is not clear whether the move to increase the test program is driven by experience or by lack of confidence (or risk avoidance) on the part of the government, which may feel that it cannot afford a failure (crash) at this point in the program.

Weight Growth, Design Changes, and Schedule Slippage Had Cascading Effects on Other Program Costs. The problems associated with the weight growth and aircraft redesign effort were not entirely cleared up by the 2004 re-baselining or even by the 2007 re-baselining. The changes in manufacturing described above led to delays in producing definitive design specifications for second- and third-tier suppliers and changes to these designs, delays in the test program, and increases in the cost of parts and labor because of changes in plans and the stretch in the schedule.

These execution problems drove increases not just in RDT&E costs but also in procurement. The JSF acquisition strategy depended on a quick ramp-up to high production rates to achieve affordability. Schedule delays have led to a slower ramp-up, lower rates of production, and an extension of production ten years beyond that of the Milestone B program. Figure 4.9 shows the implications of the shift in production, with the red and green bars showing the 2001 SAR program and the red and purple bars showing the December 2009 SAR program. Procurement costs, even in constant dollars, rise with the stretching out of production costs. In addition cost increases also result from differences in actual and estimated labor rates. Actual rates have been in the 4–5 percent per year range whereas the DoD rates used to estimate the costs of the program are at 2.1 percent.

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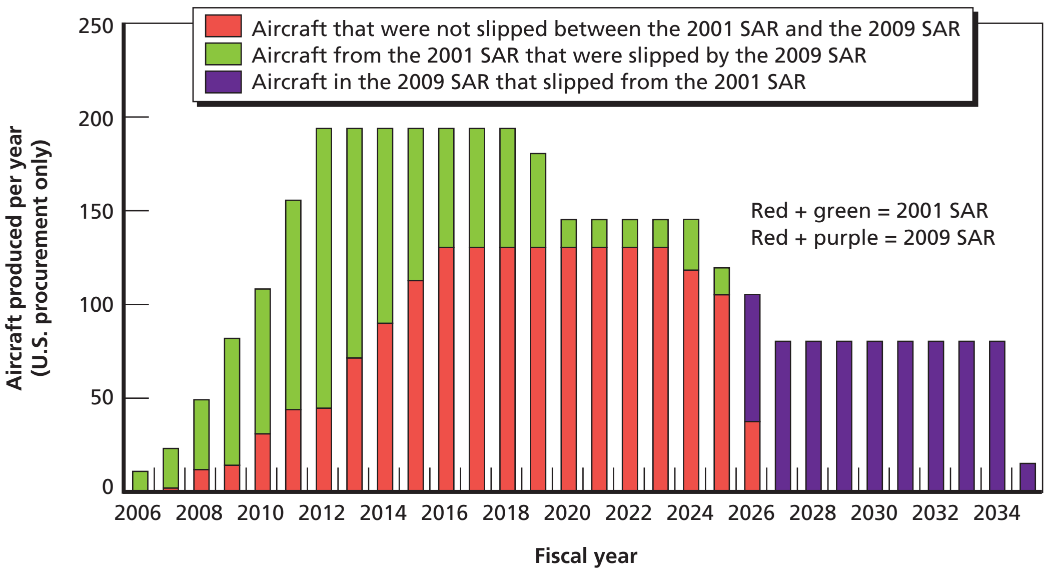
30 Discussion with Lockheed Martin, April 23, 2010.

31 F-35 Joint Program Office, *Joint Strike Fighter Cost Analysis Requirements Description*, July 2001, p. 11-8.

32 Presentations to PARCA team by Lockheed Martin, April 23, 2010.

33 Presentations to PARCA team by Lockheed Martin, April 23, 2010.

Figure 4.9
Comparison of 2001 SAR Plan to 2009 SAR Plan



NOTE: 409 aircraft were canceled between 2001 and 2002 and therefore do not appear in the 2009 SAR.
RAND *MG1171z1-4.9*

Poor Performance of Government or Contract Personnel. Some of the systems used in earlier phases of the program, or intended to be used during SDD as a way to manage or oversee the effort, seem not to have been implemented fully in the SDD phase. The use of CAIV processes and implementation of an EVM system both seem to fall into this category. Although we do not have good visibility into how cost-design trades were made after MS B, interviews with participants as well as the program's difficulties indicate that the process that proved useful before Milestone B was not effective afterward. EVM issues were studied by IDA and thus are not addressed here.

Formal CAIV Dropped After SDD Contract Award. Some of these acquisition reform initiatives, such as the use of cost/operational performance trades (COPT) (implementation of CAIV), were extensively employed in the development of requirements and seen as successful. However, these efforts were not continued during the competition or after contract award, when extensive additional design decisions were made. In fact, a discussion with requirements officials in the JPO suggested that about two-thirds of the aircraft design decisions were made post–MS B and were not included in the contract. That is, in the name of acquisition reform and in an effort to reduce redundant government oversight, the government lost a voice in key design decisions where trades were made. Contract incentives were put in place to guide Lockheed

Martin, but, in hindsight, JPO officials do not think these achieved the desired strategic goals.[34]

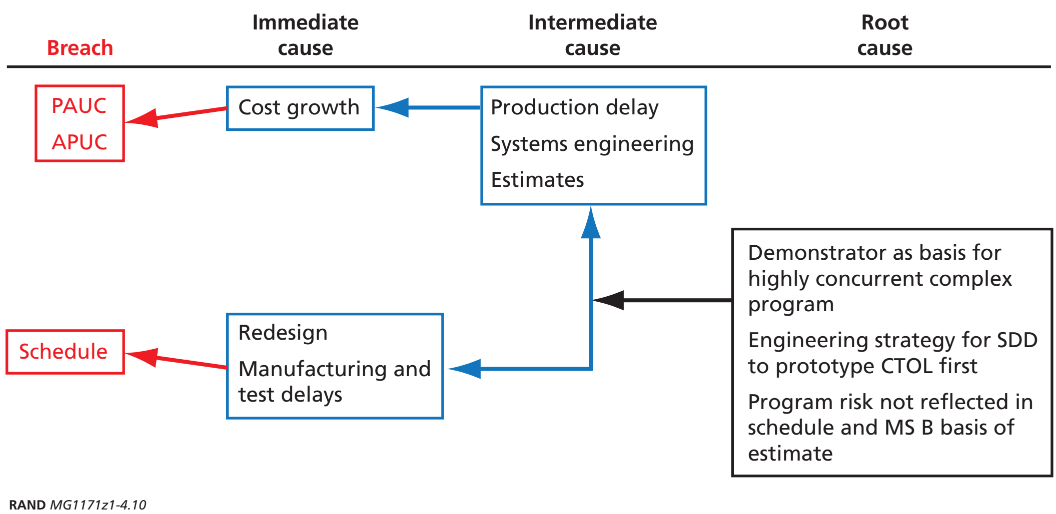
Complicating the use of CAIV/COPT was the services' continuing alteration of the design requirements. These changes did not affect the key performance parameters (KPP) and therefore did not raise any red flags. Each service had the ability to request design changes, which, because of the goal of commonality, affected all three variants of the aircraft. It seems that the design changes were made without trade studies to justify the changes.[35]

Conclusions

Figure 4.10 traces the immediate causes of cost growth to intermediate causes and finally, on the far right, root causes. Root causes are those factors that, if not present (or absent), might have resulted in a different outcome.

The immediate cause of the breach is APUC and PAUC cost growth of over 50 percent in the most recent government estimate. The government's Nunn-McCurdy

Figure 4.10
Root Cause Analysis Flowchart



[34] Telephone conversation with JPO representative, May 11, 2010.

[35] A good example of this involves the evolution of the internal weapons bay storage. Following the initial designs, the CV variant's weapons bay was increased in size to allow it to carry 2,000 lb bombs. The STOVL and CTOL variants had weapons bays only large enough to carry 1,000 lb bombs, but for commonality, all three were redesigned with larger weapons bays. This redesign caused the STOVL variant weight and balance issues and was eventually redesigned again with the smaller weapons bay.

estimate was driven by a program history of schedule slippage and substantial cost growth in the RDT&E account. This resulted in government estimates of future procurement cost growth. The path to the government's estimate is understandable given the program's history, and the root cause discussion revolves around how this history might have been more successful.

The root cause lies in some measure in an overly optimistic baseline estimate of the influence of acquisition reform and produceability initiatives. Though difficult to quantify, belief in these initiatives combined with the imperative to produce a replacement fighter for the F-16 enabled OSD to undertake a technologically complex, highly concurrent F-35 program. Whether a prototype would have helped keep the program on track will never be known, but the program's experience suggests that the concept demonstrator was not a sufficient basis for implementing this program. The lack of time and incomplete implementation of processes to refine design elements, insufficient design and systems integration control, and the focus on CTOL rather than STOVL led to significant problems in execution, requiring that the program essentially start over two years in. These problems in design and manufacturing execution—not funding instability, changes in quantity, or unreasonable performance expectations—led to the schedule slippage and cost growth that resulted in a Nunn-McCurdy breach.

Lessons from this program that might help to avert similar situations in the future include the important warning that technology demonstration does not equal produceability. If produceability is a concern for a program, and it often is, then additional time, trade studies, and negotiation are likely to be useful early in the SDD phase. Parametric estimates for fighters are based largely on weight, but as components have become smaller and integration has taken a prominent place in fighter production, it may be important to consider other metrics as drivers of cost. Furthermore, although acquisition reform precepts are indeed likely to result in greater cost savings over traditional approaches, such savings may not accrue in the first few programs as there will be a cost improvement curve in the implementation and application of such techniques as CAIV, design-to-production, and incentive contracts. Given the technical complexity of the JSF and the program complexity with so many subcontractors, the savings through implementation of design-to-production or other such manufacturing process techniques may not be as scalable as believed by OSD. Those who watch the auto industry, for example, note that the JSF is orders of magnitude more complex than designing and building a new car. This raises another point not captured in the cost estimates, and that is risk. It is true that the CAIG built in an allowance for 6 percent weight growth, but that was not enough. For a program that all acknowledged was risky, there were not enough hedges against risk or explicit incremental checkpoints.

Both the JPO and Lockheed Martin claim to have been surprised at the lack of an SDD manufacturing planning phase during which there might have been more collaboration on design specifications and discussion of the trade-offs to be made between cost and commonality and performance. Although none of the KPPs changed significantly during the execution of SDD, this dog that didn't bark should perhaps have been a signal that not enough collaboration was going on. As retold by the JPO, Lockheed Martin made a substantial number of important design decisions (as much as two-thirds of the design decisions by one estimate) on their own with only informal government participation and with no contractual record holding Lockheed Martin to those specifications. This devolution of responsibility to Lockheed Martin is a logical outgrowth of the tenet of acquisition reform that wanted to remove the government from its role as micro-manager, but in this case the JPO might say that the pendulum swung too far in the other direction.

Finally, what seems to have been inadequate control of systems integration allowed such substantial weight growth that the aircraft had to be substantially redesigned. Imperfect implementation of CAIV after Milestone B and a lack of trade studies also contributed to weight growth. Even after the major elements of the design were finalized, there were ongoing changes to subcomponent designs that led to delays in production and testing. Increases in rates for labor, materials, and other factors were compounded by schedule slippage. Whether the estimates that pushed the program into the Nunn-McCurdy breach will be borne out remains to be seen.

Next Steps

Significant cost and schedule uncertainties remain in the JSF program. Lockheed Martin claims that its actual costs since 2006 show very limited cost growth and downward curves are anticipated. However, much technical and production uncertainty remains in the program. Flight test is still in the early stages and has relied heavily on simulation. Thus far, this approach seems to be successful although there has been an increase in the use of traditional testing approaches. Regardless of the test method, findings from these tests will have to be integrated into the program. Mission systems have yet to be produced, integrated, and tested, and many account these to be more complex than the airframe tasks completed thus far. As noted above, the complete effect on cost of reductions in commonality between the variants remains to be seen because they will affect production and O&S costs into the future. The company states that international suppliers will not affect program schedule, but there may be added risk as some new suppliers are brought into the program, and certainly there will be added integration complexity.

If the CAPE-revised estimates are indeed only through 2015, then even the impact of inflation rates alone will result in significant increases to program costs. These inflation factors will continue to contribute to cost growth until the program moves to a fixed-price contract where the contractor must absorb this risk.

CHAPTER FIVE

Longbow Apache Helicopter (Apache Block III)

This chapter discusses the program to upgrade all of the AH-64 Apache attack helicopters to the Apache Longbow Block III (AB3) configuration and add additional AB3 helicopters. It begins with a brief overview of the program, our research approach to the issue, and a discussion of the nature of the Nunn-McCurdy breach.

Program Overview

The AH-64 Apache Longbow is an armored attack helicopter designed to attack enemy tanks at extended ranges. Its weapons currently include Hellfire antitank missiles, a 30-mm chain gun, and free-flight rockets. It can operate at night, in adverse weather, and in the presence of obscurities such as smoke. The Longbow radar gives the aircraft higher lethality, better survivability, and reduced maintenance requirements. The program involves retrofitting the current Apache fleet with the Longbow Block III upgrades and buying 56 new AB3 aircraft. The Block II improvements add several technologies to the aircraft, including digital and communications improvements.[1] Many of these technologies were added in anticipation of the helicopter operating in conjunction with the Future Combat System, the equipment component of which has been canceled.

Research Approach

Our research effort focused on the following elements:

- understanding the evolution of the AB3 program from Milestone B to the present
- understanding the differences in the costs of (1) the 48 new build aircraft for the 13th Combat Aviation Brigade (CAB), (2) the eight new build aircraft for the training base, and (3) over 50 new build aircraft manufactured to replace Apache

1 "AH-64D Longbow Block II/Extended Block II," GlobalSecurity.org, undated.

helicopters lost in combat in Operation Enduring Freedom (OEF) and Operation Iraqi Freedom (OIF)
- obtaining a breakdown and understanding of the other program costs reflected in the cost increases cited above.

The initial steps in this effort focused on obtaining the SARs and relevant POMs and other official documents that could provide details about the various increases in program cost and associated explanations. These materials provided an initial set of cost numbers but failed to provide cost breakdowns at a level of specificity that permitted the kind of assessment that was being sought by means of the seven statutory root cause factors reflected in the PARCA root cause narrative matrix (see below). To rectify this shortfall in information, RAND, in concert with the PARCA AB3 assessment leader, contacted the AB3 Program Office and initiated a sequence of exchanges that clarified the cost increases of interest (as described below). Of particular interest in this regard was the increase in costs associated with the multiple technology improvements that constituted the principal rationale for the AB3 program.

Nunn-McCurdy Breach

This section provides the details for the "speeding ticket" for the AB3 program—as summarized in Table 5.1. The AB3 breach was triggered by the 31 percent increase in the APUC and the nearly 26 percent increase in the PAUC.

The major contributors to the unit cost growth that resulted in the AB3 program Nunn-McCurdy breaches summarized in Table 5.1 were as follows:

The December 31, 2006, SAR increased the number of AB3 remanufactured aircraft by 37—from 597 to 634—and stretched out the annual procurement for FY 2010–2024 by shifting more of the production to later years. This increased program cost by $578.7 million (+10.5 percent). Software maintenance and system engineering/program management costs derivative of the increase in aircraft quantity and stretch-out of the procurement also contributed to this cost increase. The June 2007 APB reflected these program changes and established a new (current) baseline, which reflected in the December 31, 2007, SAR.

The final version of the December 31, 2008, SAR reflected a decision to buy new airframes (competitive in cost and increasing projected airframe life compared with refurbishing older/original Apache airframes) and also included an increase in nonrecurring engineering (NRE) costs reflecting experience and information gained in the period after Milestone B. These changes added $89.0 million (BY $) and $136.0 million (BY $), respectively, to the program cost.[2] The NRE costs included inter alia retooling costs unanticipated at Milestone B and a decision to include existing older

2 Information provided by the AB3 Program Office, May 10, 2010.

Table 5.1
AB3 Nunn-McCurdy Breach Summary (Costs in FY 2006 $ Millions)

		Cost Growth Threshold Breaches							
Baseline Unit Cost	**Current Estimate (December 2009 SAR)**	**Baseline Breached**	**Percentage**	**Amount**	**Level**	**Baseline Quantity**	**Quantity (December 2009 SAR)**	**Cause in SAR**	**SAR Explanation**
APUC 9.600 2007 APB	APUC, $12.591	Over current baseline (2007 APB)	APUC +31.16	+ $2.991	Critical	639	695	Quantity change from remanufacture of 634 aircraft to building additional 56 new aircraft	56 new build aircraft significantly more expensive to build because they are 100% new versus 30% new for a remanufacture
PAUC 11.139 2007 APB	PAUC, $13.977		PAUC +25.48	+ $2.838	Critical	634	690		
APUC 9.225 2006 APB	APUC, $12.591	Over original baseline (2006 APB)	APUC +36.49	+ $3.366	Significant	597	690		

SOURCE: Department of Defense, *Selected Acquisition Report AB3*, December 31, 2009.

NOTE: The numbers in red indicate the "speeding ticket" triffering root cause analysis by PARCA.

software in the 51 LRIP aircraft when it became clear that some of the AB3 software anticipated to be included in LRIP aircraft would not be available.

In August 2009, the AB3 Program Office[3] estimated that there would be additional recurring procurement material costs associated with (1) increased cost of the improved drive system ($97.2 million, BY $), (2) increased cost of the composite main rotor blade ($21.4 million, BY $), and (3) a range of LRIP enhancements ($86.4 million, BY $). The last of these increases was due primarily to a (previously anticipated) decision to equip the AB3 with high performance shock struts ($80.7 million, BY $). This addition is a direct consequence of the growth in aircraft weight from the Apache A to the Apache D as a result of the weight that went along with enhanced mission packages. This generated a perceived need to reestablish prior standards for the AB3 to allow aircraft landings under difficult conditions with no damage to the aircraft.

The December 31, 2009, SAR reflected the above cost increases and also included costs associated with directed changes to the program (RMD 700 and RMD 802), which added, respectively, 48 new build AB3 for a 13th CAB ($1,925 million, BY $) and eight new build AB3 for the training base ($225.9 million, BY $). This SAR also reflected increases in labor rates ($18.2 million, BY $). These changes and those noted in the August 2009 POM increased the total program cost by $2,597.3 million (BY $) and the procurement cost by $2,602.0 million (BY $) from the current (June 2007) APB baseline. As noted in Table 5.1, the additional 56 new build aircraft were the principal source of the cost increases that led to the Nunn-McCurdy breach.

After the closing date for input to the December 31, 2009, SAR (in preparation for Milestone C and in part a consequence of the Nunn-McCurdy breach), reexamination of cost estimates for many of the technology improvements to be incorporated in post-LRIP production has raised major questions about the validity of the original AB3 cost estimates for these improvements. As a consequence, it is clear that a new set of AB3 cost estimates that increase the costs of the program beyond those summarized above and shown in Table 5.1 will shortly emerge. The sources for these additional costs will include (1) increases in RDT&E costs as technical improvements are brought to the stage where they meet operational requirements and (2) more realistic cost improvement curves associated with the large amount of touch labor (that is, hands-on labor) required in the remanufacturing process.

Findings Narrative

Table 5.2 provides the AB3 version of the PARCA root cause narrative matrix, reflecting the program changes described above. The cell entries correspond to the fiscal year in which the changes were made.

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[3] Information provided by the AB3 Program Office, May 10, 2010.

Table 5.2
PARCA Root Cause Narrative Matrix for the AB3

	Year from MS B and Fiscal Year					
	B 2006	1 2007	2 2008	3 2009	4 2010	5 2011
Baseline issues						
Unrealistic estimates for cost or schedule	Technology development and cost improvement curve issues	X	X	X	X	X
Immature technology; excessive manufacturing, integration risk		X	X	X	X	X
Unrealistic performance expectations		X	X	X	X	X
Execution issues						
Changes in procurement quantity	X	Upgrade all aircraft; stretch production			New build of 56 aircraft	
Inadequate funding/ funding instability	X					
Unanticipated design, engineering, manufacturing, or technical issues	X			Buy new airframes; NRE costs		
Poor performance of government or contract personnel	X					
Other	X					

Observations on each of the cell entries follow (in chronological order).

Unrealistic Cost Estimate (Milestone B: Technology Development Issues). Any program that incorporates a large number of cutting-edge technologies such as the AB3 must of necessity depend on past technology development programs to estimate the eventual costs of a technology developed for military application—an inherently challenging undertaking considering military performance standards. When a new program incorporates as many technologies as the AB3 (15 by Army accounts; more by others), this problem is magnified, and the statistical probability that a number of these technologies will manifest unanticipated development problems correspondingly increases. In circumstances such as this, program proponents tend to be optimistic about eventual technology development and insertion costs, and thus DoD acquisition management must take a cautious if not a contrary approach. The AB3 program appears to manifest such a situation as already reflected in the increase in estimated cost of the improved drive system ($97.2 million, BY $) on a Milestone B base cost estimate of $235.4 million (BY $)—a 41 percent increase on a major technology insertion. In comparison (and somewhat in contrast), the increase in cost of the composite main rotor blade is estimated at $21.4 million (BY $) on a base of $204.0 million (BY $)—a 10 percent increase over original estimates. (See the final section of this chapter for a further discussion of the cost estimation challenges for these technology insertions.) A further broad overall complication in the costing for the AB3 occurred at Milestone B in June 2006 when the Army Cost Estimate (ACE) was chosen as the program baseline in spite of a significantly higher estimate by the OSD CAIG.

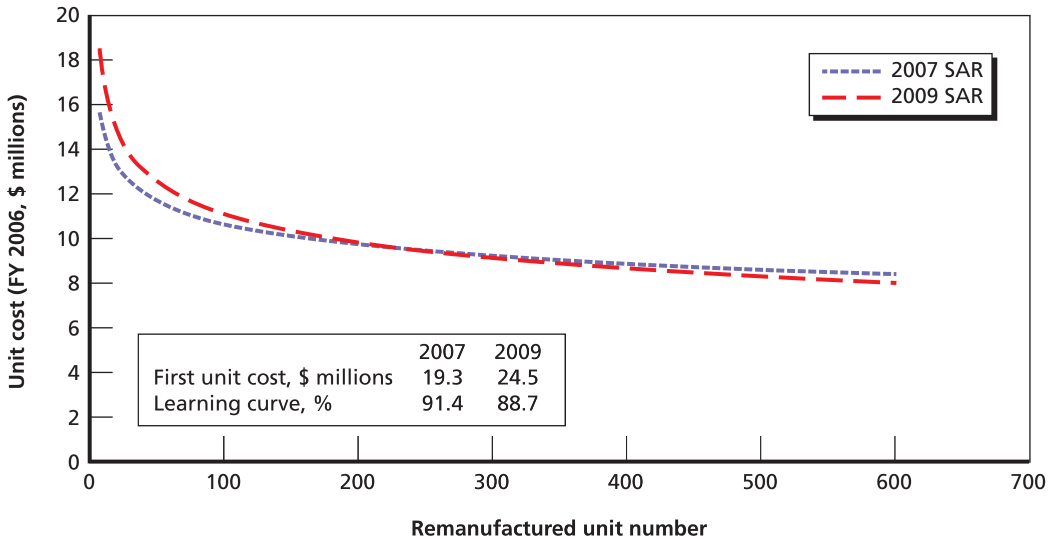
Unrealistic Cost Estimate (Milestone B: Cost Improvement Curve Issues). As with the eventual costs of a cutting-edge technology military system, substantial uncertainties also surround the actual costs of incorporating such systems along with many others in the actual manufacturing process. Here, there is the challenge of estimating just how fast those technicians who must perform the actual insertion of the finished product into a complex military system such as a heavily armed helicopter equipped with multiple sensors can achieve an efficient production process. In this case, it is already clear that the manufacturing costs for the LRIP aircraft will be substantially greater than originally anticipated. In these circumstances, it can be expected that there will be a strong temptation to be optimistic about the so-called cost improvement curve. As with development and procurement costs, in these circumstances DoD acquisition management must take a skeptical view of such optimism. This situation is manifest in the AB3 where the downstream make-up in the cost improvement curve for the remanufacturing process (see Figure 5.1) appears to some experienced observers as unduly optimistic, although actual experience in this regard remains to be seen.

Changes in Procurement Quantity

Year 1: Upgrade All Aircraft; Stretch Production. The decision in the December 2006 SAR to increase the number of AB3 remanufactured aircraft by 37 aircraft from 597 to 634 and to stretch the annual procurement buy profile for FY 2010–2024 followed on the heels of Milestone B. In consideration of the timing, the decision appears to manifest an early recognition that the Milestone B assessment was premature, and there needs to be a more realistic baseline program as reflected in the June 2007 DAB decision to establish a new APB for the program.

Year 4: Add 56 New Build Aircraft. Based on available information, it appears that the decision to add 56 new build aircraft to the AB3 program instead of creating a new line item for these aircraft was in part a decision made in consultation with DoD legal and comptroller representatives. This decision alone, independent of other program cost increases, would by inspection (i.e., back-of-the-envelope calculations) have assuredly produced a Nunn-McCurdy breach at the time of the next program SAR.

Figure 5.1
Meeting 2009 Production Estimate Requires Realization of Greater Learning



RAND *MG1171z1-5.1*

Although the discussion above indicates that there was about to be unanticipated cost growth in the program, this decision alone could be characterized as the flagship root cause for the breach.

Unanticipated Manufacturing Issues

Year 3: Buy New Airframes. Apparently as a result of unanticipated levels of damage to aircraft returning from OEF and OIF and going through the Apache Block II upgrade program, it became clear that it was more cost effective in the long run (e.g., projected aircraft longevity) to purchase new airframes rather than repair existing ones.

Year 3: Acknowledge NRE Costs. As discussed above, the challenge of estimating development and insertion costs for cutting-edge technologies is well recognized, as is the tendency for system proponents to underestimate such costs.

AB3 Technology Issues

As emphasized in the above assessment of the contributors to the AB3 Nunn-McCurdy breach, it is clearly important to understand those increased costs associated with major technology issues, in particular the three major technology contributions to the relevant cost increases:

- improved drive system
- composite main rotor blade
- high performance shock struts (HPSS).

Acquisition Issues

As argued above, a number of lessons can be derived from the AB3 experience that are relevant to the acquisition process:

- Using the program manager's cost estimate in the SARs introduces bias into the system; CAPE should carefully review the SAR inputs.
- Cutting-edge technology development and insertion costs are harder to predict; there is a high likelihood that unit cost will grow as a function of the number of advanced subsystems being incorporated (i.e., at least one subsystem out of a large batch of unproven subsystems is bound to present a problem).
- Combining remanufactured and new build items in the same program will increase the risk of cost growth.
- The balance between capability requirements and payload is very delicate.
- When there are many technical insertions, some of which depend on others, predicting the cumulative effect on program timing becomes very difficult.
- If significant engineering design changes made after the baseline unit cost at Milestone B have been estimated (e.g., in the AB3 case replacing the airframe with a new one), then the unit cost will surely increase—possibly implying a need to include contingency dollars to cover such after-the-fact design changes.

AB3 Technology Assessment

Fifteen key technologies associated with the Apache Longbow Block III (AB3) aircraft were initially identified as potential critical technologies.[4] These 15 technologies are listed in Table 5.3 along with the Army's assessment of their TRLs for two time periods—April 2004 and March 2006. (See Appendix C for a definition of the nine TRL levels.)

Army analysis subsequently concluded that only one was indeed a critical technology—the improved drive system; the remaining technologies were not critical. Note that the TRL rating for the drive system improvements was designated as level 6 in both years. (TRL 6 means that a representative model or prototype system

[4] U.S. Government Accountability Office, *Defense Acquisitions: Assessments of Selected Weapon Programs,* GAO-07-406SP, March 2007, p. 106.

Table 5.3
Assessment of AB3 Technologies

	Technology Insertions	TRL April 2004	TRL March 2006
1	Open system architecture	5	6
2	Composite main rotor blade (CMRB)	6	7
3	Modernized signal processor unit	7	7
4	Instrument flight rules/meteorological	9	9
5	Multimode laser	5	7
6	Radio frequency interferometer (RFI) frequency extension	6	7
7	Image fusion	5	8
8	Aided target detection/classification	5	8
9	Modified 7700-GE-701D engine	8	8
10	Level 4 unmanned aerial vehicle control	6	6
11	Improved drive system	6	6
12	Fire control radar (FCR) maritime targeting mode	5	6
13	FCR range extension	6	6
14	RFI passive ranging	5	6
15	Cognitive decision aiding system	6	6

that is well beyond the breadboard level has been tested in a relevant, nonoperational environment.)

Other potential technology insertions that could result in developmental delays, cost increases, or both are (1) the modified T700-GE-701D engine, (2) the CMRB, and (3) the HPSS advanced landing gear.

The 701D engine was given a high TRL rating (8) in both years. The CMRB, while based on a proven experimental design, received TRL ratings of 6 and 7 in April 2004 and March 2006, respectively. Early on, concerns had been expressed that the composite blade might lead to a cost growth. Finally, the decision to add the HPSS advanced landing gear was apparently an afterthought. It was not considered in 2006 and probably would not have been on the advanced technology list because shock struts are a mature technology. However, their incorporation into the LRIP units raises the unit cost of the aircraft.

Each of these four technologies is assessed below in terms of its potential developmental delays or cost growth.

Drive System Improvements

The drive system improvements consist of the Rotorcraft Drive System of the 21st Century (RDS-21) face gear transmission. The RDS-21 with its split torque capability allows significantly more torque to be transferred to the rotor by combining the output torque of the two engines into a single power torque transmission. This is to be accomplished without any increase in transmission weight. The RDS-21 technology was transferred to the Apache program manager in 2006. It has completed qualification testing and is now slated to enter LRIP in 2011. The estimate at Milestone B was based on the V-22 transmission cost (with a similar power rating) plus the addition of a complexity factor. The cost growth estimated as of August 2009 by the Apache Longbow Block III Program Office is $97.2 million (BY $).

701D Engine

The T700-GE-701D engine rating of TRL 8 in March 2006 means that, at that time, the actual system was completed, and it was flight qualified through test and demonstration. The first flight of a 701D-powered Apache Longbow Block III was successfully made in August 2008. The 701D engine, rated at 1,449 shaft horsepower,[5] features improved hot-section components that increase the durability and provide greater power than the current T700- GE-701C engine.[6] The empty weight of the Block III aircraft has increased approximately 6 percent over the Block II aircraft to 12,530 lb, and the shaft horsepower generated from each engine has increased a comparable amount. The performance specification of the Apache Longbow Block II aircraft requires that the aircraft hover with a 3,400 lb payload at 6000 ft altitude at 95°F temperature.[7] The 701D engine will also be used to upgrade the Army's fleet of UH-60A and UH-60L Blackhawk helicopters to the new UH-60M configuration. As a result, the engines are being furnished to the contractor as government-furnished equipment.

Composite Main Rotor Blade

With more aerodynamically efficient airfoil shape and a higher overall twist rate, the CMRB was designed to provide additional lift and thus improve aircraft performance, some of which was lost on account of the weight differential between the Apache A and D models.[8] In 2003, Boeing reported that the CMRB would cost 25 percent less

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5 Personal communication from Paul T. Keil, contractor, Apache Longbow Block III Program Office, May 12, 2010.

6 The 703D improvements include horse power improvement of 5.5 percent at standard-day sea level; hot temperature increase of 70°C; improved thermal cooling in the hot section rotors and stators; gas generator cooling holes and slots; reduced pressure loss internal blade channeling; blade aluminum oxide coating; and hot section airfoil redesign to reduce dovetail stress. See Apache Program Office, *AH-64D Longbow Apache Block III, Draft Procurement Objective Cost Analysis Requirements Description (CARD)*, February 2010.

7 Personal communication with Paul T. Keil, May 12, 2010.

8 Graham Warwick, "Team Player," *Aviation Week & Space Technology*, February 16, 2009.

than the current blades and would have twice the operational life, implying an even greater reduction in total O&S cost.[9] In March 2006, the CMRB was given a TRL rating of 7, indicating that a prototype had been sufficiently demonstrated in an operational environment. However, the cost estimate methodologies used at MS B for the composite blade were based on analogous calculations of an older blade (presumably not composite?), which may partially explain why concerns were expressed early that the CMRB might contribute to cost growth. The Program Office now knows much more about the blade and expects that the increased operational lifetime of the blades will offset at least partially the cost growth experienced thus far.

High-Performance Shock Strut

The HPSS advanced landing gear was scheduled to enter LRIP in 2010 and to provide the aircraft with hard landing capabilities. It improves on the struts used in the Apache Longbow Block II aircraft, which were facing obsolescence and not performing to standard in the field. The HPSS was also developed to address the gross weight increase of the Apache D model, for which the old shock struts were no longer optimal. Consisting of a new valve design that can be retrofitted onto the aircraft, this technology restores the helicopter's ability to meet its crash performance requirements. Since the new shock strut was not included in the MS B baseline, its incorporation in LRIP units raises the unit cost of the aircraft.

Conclusion

The key contributor to the cost growth in the AB3 program was the decision to combine 58 new build aircraft with the MDAP baseline remanufacturing program and include them in the PAUC/APUC calculations of the ongoing AB3 remanufacturing program rather than to open a new production MDAP reporting line. The Army has subsequently separated the new build aircraft from the remanufactured ones for purposes of program reporting. Compounding this decision were cost increases engendered by the improved drive system and the decision to add the high-performance shock strut, which was not in the MS B baseline. Exacerbating these problems were unrealistic cost and schedule estimates, unrealistic expectations for cost improvements, and inclusion of several cutting-edge technologies.

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[9] The Boeing Company, "Apache Longbow Flies Toward Future with New Composite Rotor Blades," December 3, 2003.

CHAPTER SIX

Wideband Global Satellite

This chapter presents the final of four case studies. It begins by briefly describing the program and then the specific nature of the Nunn-McCurdy breach that occurred along with the sources of that breach. It then presents the root cause analysis.

Program Overview

To meet DoD's ever-growing demand for military satellite communications (SATCOM), the WGS program was funded in 2001 (originally known as the Wideband Gapfiller Satellite program) to acquire an unprotected wideband SATCOM capability by using a commercial off-the-shelf satellite bus and Ka-band technology. WGS provides both X-band communications compatible with the older Defense Satellite Communication System (DSCS) platforms and Ka-band broadcast capability like the Global Broadcast System (GBS). In addition to DSCS and GBS capabilities, WGS is also capable of point-to-point Ka-band broadband connections and has a cross-linked communication bus that allows signals to be received on X-band and retransmitted in Ka-band and vice versa. Throughput for each satellite is estimated at over two gigabits per second.[1]

The program consists of two phases or "blocks." Block I of WGS comprises three satellites, the last of which was placed in orbit in December 2009. WGS Block II consists of three additional satellites, two contracted for the United States to replace aging DSCS and GBS satellites and a third wholly purchased by Australia in exchange for a percentage of global WGS bandwidth. Block II satellites are essentially the same as Block I with a high-bandwidth bypass feature for aerial intelligence, surveillance, and reconnaissance platforms.[2] With the delays and eventual cancellation of the Transformational Satellite Communications System, DoD decided to procure the seventh and eighth WGS satellites, Block II Follow-on (IIf), with a planned total buy of 12 WGS satellites to meet future broadband communication requirements.

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1 U.S. Air Force, *The Air Force Handbook*, Washington, D.C., 2007.

2 "Block 1 of WGS Constellation Completed," *Aviation Week & Space Technology*, March 8, 2010, p. 16.

Nunn-McCurdy Breach

The unit cost to the government of WGS Block II was roughly 50 percent more expensive than Block I ($377 million compared with $239 million), and Block IIf is again roughly 50 percent more expensive than Block II ($574 million compared with $377 million). (See Table 6.1.) This increase, we will argue, is largely due to the stopping and restarting of the production line and the fact that the commercial market no longer supports WGS systems, which have not changed in the decade since initial design. Such increases in the cost to the government resulted in a Nunn-McCurdy breach reported to Congress in March 2010.

Table 6.1, which shows the APUC in constant BY 2001 dollars, illustrates the Nunn-McCurdy breach. The 27 percent increase between the current estimate and the current APB (third column) exceeds the 25 percent threshold for a "critical" breach (the 40 percent increase [fourth column] between the current estimate and the original APB represents a "significant" but not "critical" Nunn-McCurdy breach).

The averages, in turn, permit calculation of a unit cost for Block I (WGS 1-3), Block II (WGS 4 and 5), and Block II follow-on (WGS 7 and WSG 8)—but not in a straightforward manner.[3] In real (BY 2001 $) terms, the PAUC of the WGS satellite

Table 6.1
WGS APUC (Exclusive of Launch Costs)

	Original APB	Current APB/ Original APB	Estimate/ Current APB	Estimate/ Original APB
Block	I	I & II	I, II, & IIf	I, II, & IIf
Satellites	1–3	1–5	1–8[a]	1–8[a]
Contract type	FFP	FPIF	FPIF	FPIF
APUC, $ millions	268	294	374	374
Unit cost[b], $ millions	239	377[c]	574	574
% Δ APUC, %	—	110	127	140
% Δ unit cost, %	—	158	152	240

SOURCE: Secretary of the Air Force (SAF) briefing charts.

NOTES: APUC costs are in constant BY 2001 dollars. FFP = firm fixed price; FPIF = fixed price incentive fee.

[a] WGS 6 was purchased for Australia and does not show up in U.S budget accounts.

[b] That is, cost to the government.

[c] Cost claims currently made by Boeing suggest that the true cost of the first three satellites was roughly $377 million. We discuss this in Appendix E.

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[3] Note that the original APB was $268 million (fifth row) per satellite, but the unit cost is now estimated to be $239 million (fourth row). The difference between the two is accounted for by the fact that other government costs ended up $29 million per satellite lower than estimated.

rose 58 percent between Block I and Block II (from $239 million to $377 million). Unit costs between Block II and Block II follow-on (IIf) are projected to rise 52 percent (from $377 million to $574 million). Table 6.2 indicates when each WGS satellite was ordered, when each was delivered, and the difference in years; Figure 6.1 indicates the interval during which the USAF-purchased WGS satellites were built and launched. The table indicates a large gap between WGS Block I and WGS Block II and a smaller gap between WGS Block II and WGS Block IIf. However, the time between program approval and launch for WGS Block I was five to seven years, and the expected cycle-time for WGS Block II is shorter, four to five years. If current launch dates for Block IIf prove accurate, then the gap between Block I and Block II will be somewhat smaller than the gap between Block II and Block IIf.

Sources of Nunn-McCurdy Breach

The WGS cost breach has two components: the increase in unit costs between Block I and Block II satellites and the increase in unit costs between Block II and Block IIf satellites. The first difference was ascribed[4] to "what proved to be an artificially low cost for the original three vehicles under a firm fixed-price contract." This section focuses

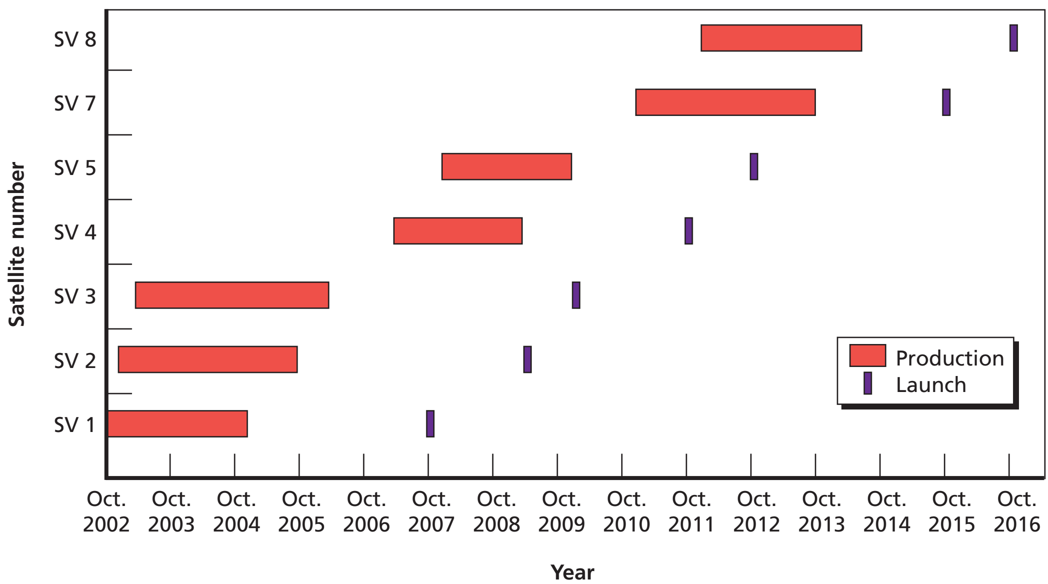
Table 6.2
WGS Order and Launch Years

	Satellite	Budget Year	Launch Year	Difference in Years
Block I	1	2002	2007	5
	2	2002	2009	7
	3	2003	2009	6
Block II	4	2007	2011a	5[a]
	5	2008	2012a	4[a]
	6 (Aus.)	2009	2013	4[a]
Block IIf	7	2011	2016	5
	8	2012	2017	5

[a] These are the launch dates taken from the 2012 President's Budget and are one to two years later than expected launch dates were at the time of our study in April 2010.

4 Letter from the Secretary of the Air Force to the Chairman, Senate Committee on Armed Services, March 8, 2010.

Figure 6.1
WGS Production/Launch Periods



NOTES: Launches do not include MexSAT-1 and MexSAT-2. Launch dates will follow MexSAT-3.
RAND *MG1171z1-6.1*

on the latter cost increase, largely because it is the current one and thus far more relevant to decisions to be made on the WGS program.

Examination of Unit Cost Increase Between Block II and Block IIf

Table 6.3, whose numbers were generated by the Program Office (note that these are Program Office estimates, not Boeing's actual cost proposals) in then-year dollars, shows both blocks in terms of target and ceiling costs. The latter includes margin sufficient to account for the possibility of cost overruns on the FPIF work (combining advanced procurement, base procurement, and launch support costs).

Table 6.3
Program Office Unit Cost Breakdown (Current Year, $ Millions)

	BY	Target	Ceiling
Block II	2007	355	410
Block IIf	2011	—	555

How do $555 million and $410 million (in current dollars) compare with the aforementioned $574 million and $377 million (in BY 2001 $)? Table 6.4 illustrates the difference.

Several features merit note. First is that storage and factory restart costs were very small in going from Block I to Block II but substantial in going from Block II to Block IIf, even though the gap before restarting production was four years for Block II and only two-and-a-half years for Block IIf. We could not explain this difference in the time allotted for the study. Second, in both cases, other government costs (estimated using data from the Program Office and SAF) are fairly large but roughly the same. These costs include contracting office and engineering costs; it was estimated by subtracting known cost components from total cost components and checked for overall reasonableness and consistency.

Third, and most important, the bottom line unit price figure for the Block II satellite is $355 million rather than the $410 million ceiling price. The reason for this is that the $355 million represented the contracted, hence targeted, price of the satellites; if Boeing costs were higher than $355 million, then, under the terms of the contract, the federal government would reimburse Boeing only for 80 percent of those additional costs. The $410 million was the ceiling price; Boeing would have to absorb all costs in excess of that amount. Building the current APB APUC (for Blocks I and II) out of the contract price but building the expected APB APUC (for Blocks I, II, and IIf) out of the ceiling price essentially compares apples and oranges. In effect, the WGS Program Office built a 15 percent hedge factor into the price. We cannot explain the programmers' motivation for doing so, particularly because it led to a critical Nunn-McCurdy breach that otherwise could have been avoided. Whether or not this difference represents their lack of confidence in the estimate can only be a matter of speculation. Were this 15 percent removed, then the unit cost of Block IIf would have been $516 million (in current dollars) rather than $574 million, yielding an APUC of $357 million, or an

Table 6.4
Relating Base Year and Current Year Costs ($ Millions)

	Block II	Block IIf
Unit cost, BY 2001 $	377	574
Inflation factor to current costs	1.14 (BY 2007)	1.207 (BY 2011)
Unit cost current year dollars	430	693
Less storage and factory restart	4	73
Subtotal	426	620
Less other government costs	71	65
Subtotal (from Table 6.3)	355	555

increase of 22 percent rather than 27 percent (that is, a "significant" rather than "critical" breach).

Nevertheless, $555 million is still a substantial increase over $355 million—and needs to be explained. Table 6.5 lists the various factors.

We start with the unit price of $355 million. Next we add the current cost overrun of 3 percent ($11 million) (although the final cost overrun may be higher or lower, we presume that cost overruns experienced to date establish a new baseline for what it really costs to build a WGS): hence, $366 million. The next adjustment, line 4, factors in four years of inflation at 3.5 percent per year (as calculated by the Program Office based on historical experience in satellite component and manufacturing costs);[5] hence, the $420 million in line 5. Next comes $2 million for additional tests not required for Block II, $35 million (as calculated by Boeing) to pay for three critical components that might otherwise go out of production,[6] and $25 million (also as calculated by Boeing) for cost increases in other components at risk in the supply chain; hence, the subtotal of $482 million in line 9. The last adjustment arises from the accounting artifact noted above—the difference between contract costs used to calculate Block II prices and the ceiling cost used to calculate Block IIf prices. This brings us to the $555 million that the Program Office uses to calculate unit costs for Block IIf.

Table 6.5
Cost Increase Between Block II and IIf (Current Year, $ Millions)

	Increase Component	Block II
1.	Unit cost, BY 2007 $	355
2.	3% cost overrun	11
3.	Actual unit cost, BY 2007 $	366
4.	Four years of inflation at 3.5 percent per year	1.147[a]
5.	Expected unit cost circa 2011	420
6.	Extra tests	2
7.	Higher component prices for three items	35
8.	Higher component prices overall	25
9.	Subtotal	482
10.	Risk premium of 15 percent	555

[a] 1.035 × 1.035 × 1.305 × 1.035 = 1.147 × $366 million = $420 million.

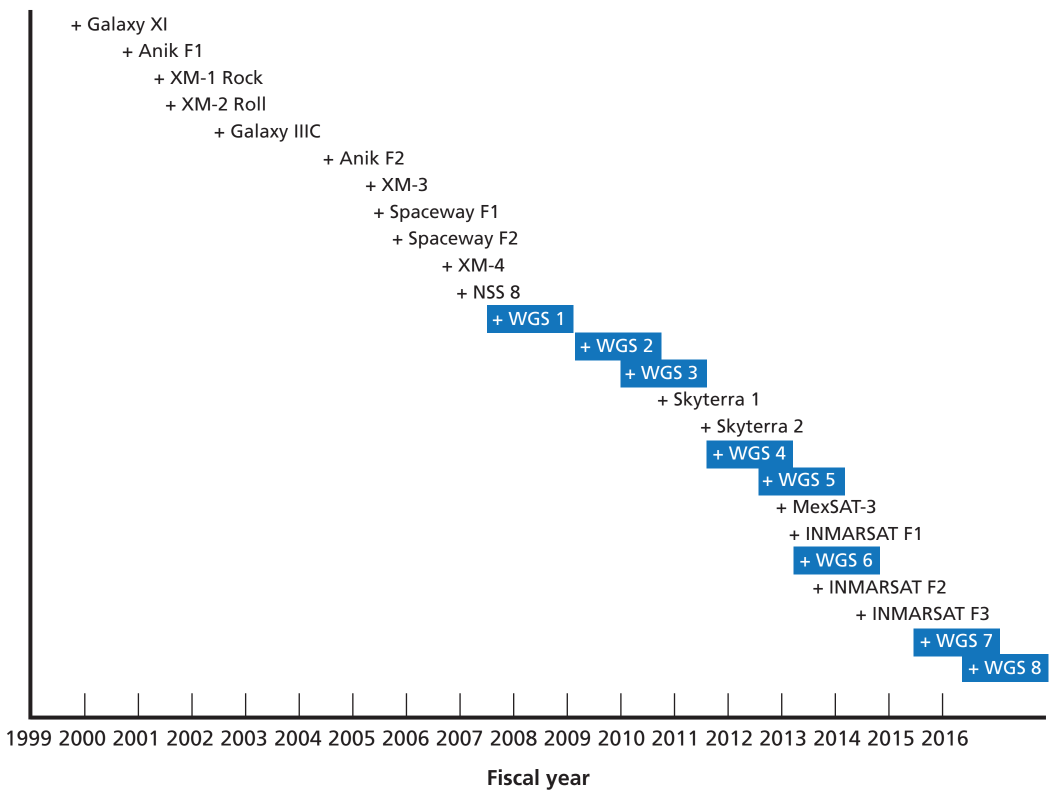
[5] Note that this 3.5 percent exceeds the 1.8 percent used as an overall price deflator by OSD to convert constant into current dollars.

[6] The xenon ion propulsion system, certain transponders, and a crypto box.

Explaining the Cost Differences

The $60 million in component cost inflation (over and above the normal 3.5 percent a year) shown in rows 7 and 8 of Table 6.5 requires further explanation. Reflecting a general shift in market requirements, Boeing shifted its commercial satellite offerings from its HS702HP (high-power) bus to its HS702MP (medium-power) bus. This shift has left WGS supporting the production of parts that no longer have much commercial demand, thereby raising the cost of these components. That noted, Boeing also claims that the cost ratio between bus and payload is expected to remain constant and that the cost ratio between component costs and Boeing's costs is also expected to remain constant. Both imply that its internal costs have also risen more or less proportionately with component costs. This may be reflected in the charges associated with the cold factory restart noted above. Figure 6.2 indicates a sharp decline in commercial satellite production at about the same time that WGS production started. Although the pace of

Figure 6.2
Launch Dates for Boeing-Produced Satellites



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satellite construction has recovered, it has not returned to earlier levels that characterized the first few years of this century.

Component cost inflation also reflects a broader phenomenon—the growing divergence between WGS and its civilian counterpart. Commercial products change constantly; military products change infrequently (but in relatively large chunks) and, in the case of military specification products, may not change at all precisely because product qualification is both torturous and tortuous. In effect, the WGS, born as a modification to a commercial business line, has evolved to a program that is primarily military. As noted, the WGS satellite bus has diverged from its civilian counterpart. The payload of the WGS satellite consists of Ka-band transponders and X-band transponders and channelizers to switch between the two. X-band is primarily military to begin with. The commercial market flirted with Ka-band ten years ago, but the trend toward terrestrial (fiber optics and cell phones) rather than satellite-based communications has put a damper on the industry's interest in exploring different spectra whose primary virtue is that it is largely unclaimed. Furthermore, the global business of U.S. satellite manufacturers has been dampened by increasingly stringent application of International Traffic in Arms Regulations rules starting ten years ago. Components that once could be supported from both WGS and commercial sales increasingly rely on the WGS market, and suppliers must be paid a premium to remain in the market. Similarly, former WGS workers who could count on transferring their skills into very similar commercial work when gaps appear in WGS face a harder transition. The days are gone when commercial sales could buoy the resources put into the WGS program between one buy and the next. The economics of WGS increasingly depend on the pace and scheduling of WGS buys alone.

Boeing and the Commercial Satellite Market

This section examines some of the background trends in the commercial satellite business together with Boeing's position within the market.

Aviation Week & Space Technology estimated that military satellite orders for both Lockheed Martin and Boeing over the next ten years would be for 29 satellites for \$11.7 billion for Lockheed Martin and 25 spacecraft for over \$5 billion for Boeing.[7] This suggests that manufacturing military satellites will cost between \$200 million and \$400 million each. This is well below the WGS Block IIf unit costs, although satellites, it should be cautioned, differ widely in their individual capabilities.

Ka-band satellite transmission growth rate has slowed over the past few years, as evident in Table 6.6, declining from some 40 percent to about 2 percent.

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[7] John S. Edwards, "Military Space Becomes Increasingly Important as Capabilities Mature," *Aviation Week & Space Technology*, January 25, 2010, p. 122.

Table 6.6
Ka-Band Transponder Recent Trends

Fiscal Year	Number of Transponder Equivalents[a] Launched	Number of Ka-Band Transponder Equivalents Launched	Percentage of Ka-Band Transponder Equivalents Launched
2007	~730	~300	41
2008	~750	~100	13
2009	~850	~20	2

SOURCE: "Futron Satellite Telecommunications 2009 Year-End Summary," *Aviation Week & Space Technology*, undated.

[a] A proxy measure for communications throughput.

However, "Both Hughes [Boeing] and ViaSat have ordered large new Ka-band satellites to keep up with demand. ViaSat-1 is scheduled for launch in February 2011, with Hughes' [Boeing's] Jupiter satellite scheduled for launch in 2012."[8] Space Systems/Loral is constructing both systems. ViaSat-1 is estimated to cost $300 million for construction, launch, and insurance.[9]

XTAR is providing commercial X-band service to Spain, Denmark, Germany, the U.S. State Department, and Defense Information Systems Agency.

In a 2003 review of geosynchronous commercial satellite buses, Futron found "Boeing's BS601 and BS702 performance complexity and problems along with declining levels of customer support cited consistently as causing their low ratings."[10] Additionally, "DirectTV in 2004 ordered three Boeing 702 model satellites for 25 percent of the year's market (along with options for a fourth satellite). The timing probably kept Boeing Satellite Systems [BSS] in business. Its struggles stemmed from on-orbit problems with its 601 and 702 series satellites, but since those problems were identified, Boeing's hard work to restore confidence in its manufacturing unit paid off."[11]

Ultimately, however, rather than the commercial market supporting Boeing's 702 bus, it appears that government business has been supporting the system.

> In its 10-year history, the Boeing division's main platform, the 702, has commonly served big commercial requirements, such as the three current orders for DirecTV and two for Sky Terra. But the platform also has been used for many of the compa-

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8 Peter de Selding, "ViaSat Bullish on Ka-band, Might Order 2nd Satellite This Year," *Space News*, February 9, 2010.

9 Typical launch and insurance costs of a communication satellite are roughly $100 million; WGS costs listed do not include launch costs.

10 Futron, *GEO Commercial Satellite Bus Operations: A Comparative Analysis*, August 13, 2003.

11 John S. Edwards, "Waiting for Rebound," *Aviation Week & Space Technology*, January 16, 2006, p. 161.

> ny's major government programs, most prominently the Wideband Global Satcom (WGS) network of six spacecraft that replaces the Defense Satellite Communications System. . . . WGS and two other major government programs—the Global Positioning System IIF and GOES N-P series—have provided 90 percent of Boeing's recent work. To redress that imbalance, the company began looking for new commercial market entries four years ago and concluded it could take advantage of the 702's flight software, avionics and power management systems to develop a smaller bus.[12]

Root Cause Analysis

Table 6.7 provides the WGS version of the PARCA root cause narrative matrix ("X" indicates that the category is relevant for that year but there is nothing to report on; the text gives more detail in place of an "X"; blanks indicate that the category is not relevant for that year).

The 52 percent increase between Block II and Block IIf unit pricing is primarily due to the first three factors listed in Table 6.8. Such results are necessarily limited by the 60-day window allowed for investigation under the Nunn-McCurdy legislation that curtailed RAND's ability to question subcontractors and analyze many of the cost claims that had to be accepted as valid over the course of the analysis.

The largest factor—almost one-third of the increase—is an accounting artifact where the Block IIf prices, as calculated by the Program Office and as thereby displayed for the purposes of making a Nunn-McCurdy presentation, include a 15 percent risk premium, whereas Block II unit costs do not (because they largely reflect expended rather than projected costs). This results in an apples and oranges comparison. Inasmuch as the Block IIf is practically identical to the Block II units that Boeing is already building, Boeing can be realistically expected to produce the satellites at near the target cost, which is 15 percent below the ceiling cost—although Block II is running 3 percent over target. But the ceiling price is what was reported. Next, Boeing is charging for storage and restart costs for the 2.5 year hiatus between Blocks II and IIf. On the surface, the cause appears to be the interruption in production, but the four-year hiatus (measured, as noted, in terms of when satellites were ordered, not when they launched) between Block I and Block II had a cost of only $3.5 million, or less than 7 percent of the current estimate. One explanation is that significant aspects of WGS production are no longer supported by the commercial market and therefore require storage and restart expenses during production breaks. Finally, key components of WGS that are no longer supplied to the commercial market will have greatly increased procurement costs accounting for another 26 percent of the cost increase. The second and third fac-

12 Michael Mecham, "Hosted Payloads Growth Eyed by U.S. Satellite Makers," December 7, 2009, p. 66.

Table 6.7
PARCA Root Cause Narrative Matrix for the WGS

	Year from MS B and Fiscal Year										
	B **2001**	**1** **2002**	**2** **2003**	**3** **2004**	**4** **2005**	**5** **2006**	**6** **2007**	**7** **2008**	**8** **2009**	**9** **2010**	**10** **2011**
Baseline issues											
Unrealistic estimates for cost or schedule	BSS claims losing $ on Block I (WGS 1-3)	X	X	X	X	BSS re-prices Block II (WGS 4, 5)	X	X	X	X	BSS expected to re-price Block IIf (WGS 7, 8)
Immature technology; excessive manufacturing, integration risk		X	X	X	X	X	X	X	X	X	X
Unrealistic performance expectations		X	X	X	X	X	X	X	X	X	X
Execution issues											
Changes in procurement quantity	X					WGS 4, 5 added					WGS 7, 8 added
Inadequate funding/ funding instability	X										
Unanticipated design, engineering, manufacturing, or technical issues	X										
Poor performance of government or contract personnel	X										
Other											

Table 6.8
Primary Factors for Block II to Block IIf Unit Cost Increase (BY 2001 $ Millions)

Factor	Increase Amount	Percentage
Risk premium accounting artifact	60	30
Storage and restart costs	57	29
Increased component costs	51	26
Other (e.g., SATCOM industry inflation, cost overruns)	29	15

tors support the argument that the root causes of the breach are changes in the commercial market without corresponding changes in the WGS design and procurement.

Despite these large cost increases, the WGS program is essentially healthy and relatively well managed. The satellites work; three of them are already on orbit serving customers. These customers are generally happy, which is part of the reason that the currently planned WGS constellation is larger than the one originally planned (more often, total buys decline over the life of a contract). There is no reason to expect that the cost of subsequent satellites after WGS 8 will increase; quite the contrary. Boeing's bid proposals for WGS 9 through 12 suggest that they will run $100 million less than WGS 7 did (once due account is taken of the baseline inflation in the satellite industry). Thus, although the cost increases in what should be a stable program may appear startling (and remain somewhat startling even after explanation), this is no indicator of a program facing technological or production problems that cannot be reasonably solved.

The broader lesson learned for this program is that when DoD procurement piggybacks on a commercial base, notably the commercial base of a particular company and its ecosystem, it takes a certain risk. The base may shrink, leaving it with less capacity to cover total overhead costs. Even if the base does not shrink, it will evolve. If DoD requirements do not evolve in parallel—and there is no inherent reason why they should—the divergence between DoD's requirements and the market's requirements means that either the requirements are compromised (admittedly, this may be acceptable in some circumstances) or, eventually, such programs have to stand on their own feet. They can no longer be free riders, so to speak. This suggests that a certain procurement discipline is called for, or DoD will pay the difference. Start-stop programs are costlier than steady-state programs (i.e., when buys are consistent from one year to the next), which, in turn, are somewhat more costly than total buy programs (e.g., we want six satellites, deliver them when you finish them). Although DoD cannot necessarily commit to even procurements for a variety of reasons (e.g., changing requirements, risk management, congressional politics), everyone concerned should understand that there are costs entailed in maximizing acquisition flexibility.

Conclusions

Three primary factors contribute to the Nunn-McCurdy breach: an accounting artifact, increase in the cost of component parts, and storage and restart costs. Each contributes to about one-third of the cost increase between Block II and IIf. An underlying factor of the increase, particularly with respect to the storage and restart costs, is the change that occurs in the commercial product base that affected the WGS costs. The government incurred additional costs because the commercial base of Boeing no longer supported the WGS. This probably would not have occurred if all Boeing had to do was pull parts from an active commercial line. Thus, when the government links one of its programs to a company's commercial base, it assumes an additional measure of risk.

CHAPTER SEVEN

Conclusions

This report addresses program specifics, but some common observations can be made about the analysis performed. At a minimum, three fundamental elements are required to perform the analysis in a fashion that meets the congressional demands and expectations discussed in Chapter Two. These are (1) access to adequate sources of raw data on programs, (2) access to individuals in both government and industry to gain the fullest possible understanding of both data and program execution, and (3) adequate numbers of informed and experienced research staff to allow the effort to be completed in time and consistent with the needs of the Secretary of Defense to comply with the law. These three elements also form the basis of our recommendations.

As was apparent in the program-specific chapters, each of the four programs investigated by RAND had different execution specifics, reflecting diverse complexities. However, at summary levels, RAND's root cause analysis identified several common causes of threshold breaches. Table 7.1 displays how each program analyzed reflected the three basic summary causes for breach: planning, changes in economy, and program planning. The comparison matrix lists several subcategories; the list is not exhaustive but it contains the best that could be constructed as general categories, given the level of detail in the data available.

Access to Data

The data that underpinned the analysis that supports these comparisons came from the breach notifications, SARs, acquisition strategy, and decision documents and briefings that relate to each program. These source materials were discussed in greater detail in Chapter One. Although they were sufficient to complete this first root cause analysis, going forward, more thought and effort will be required to ensure that appropriate detail and relevant material are available at the start of the analytic effort, given the short time allowed by the statutorily imposed deadlines. In that context, the approach developed by the government to perform the root cause analysis has great significance for the necessary advance planning and determinations necessary to best extract the

Table 7.1
Comparison Matrix of Root Causes of Program Cost Growth

Category	Root Cause of Nunn-McCurdy Breach	WGS	Apache	DDG-1000	JSF
Planning	Underestimate of baseline cost	√	√	√	√
	Ambitious scheduling estimates			√	√
	Poorly constructed contractual incentives	√ √			√
	Immature technologies		√ √	√	√ √
	Ill-conceived manufacturing process			√	
	Unrealistic performance expectations			√	
	Delay in awarding contract			√	
	Insufficient RDT&E	√	√	√	√
Changes in economy	Increase in component costs	√ √	√	√	√
	Increase in labor costs		√		√
	Discontinued/decreased production of components	√			
	Decreased demand for similar technology in private sector (economies of scale)	√			
	Inflation	√	√	√	√
	Production delays	√ √		√	√ √
	Change in procurement quantities				
	Increase	√	√ √		
	Decrease			√ √	√
Program management	Unanticipated design, manufacturing, and technology integration issues		√ √	√	√ √
	Lack of government oversight or poor performance by contractor personnel			√	√
	Inadequate or unstable program funding	√	√	√	√
	Accounting artifact	√			

NOTE: √ = Root cause, √ √ = Significant root cause.

nature of the research capability value from the supporting FFRDC or academic participants in the analysis and certification process.

The level of effort reflected in Chapters 3–6 and the similar effort at other FFRDCs and the University of Tennessee were deemed by the PARCA director from the outset to exceed what the government could do in the time available. Because of the inherently governmental nature of the effort, the use of FFRDCs in particular was an effective strategic approach for the PARCA director and appears to be one that will continue to be used. Going forward, participants' efforts in performing these first program assessments required by the statute should be used to strengthen the demand to make more data available. For example, some internal decision material not normally releasable would be useful in performing analysis. Given the nature of the relationship between the government and FFRDCs, these data should be released, because such release will both speed the analysis and improve its quality. A notional listing of desirable data is shown in Table 7.2.

The following list includes document types that RAND and other FFRDCs would request from the PARCA office at the beginning of each study and the reason for each request. Each item would be used in the analysis and would provide insight into the program from different points of view.

We will need additional documents as the project progresses:

- program and service briefings from the preceding year to give an idea of the state of the program over the past year or so
- OIPT briefings from all five teams
- program manager briefings to the IPTs.

As long as the FFRDCs have access to the DAMIR system, they will download their own copies of the following:

SARs
- official description of the information history of the program, *as reported to Congress*

DAES
- current "official" program status.

Table 7.2
Data Source Needs

Document Type	Reason
Notifications to Congress	This will allow the FFRDC to study exactly why the Nunn-McCurdy Act was breached, as it was reported to Congress
Latest signed acquisition strategy	Foundation of what the current strategy is so that the team has an up-to-date starting point
DAB and IPR materials	Support materials from these will assist in showing the decisions that affect the program throughout its life
ADMs	Description of the official parameters that govern a program
Program deviation reports	Record of spending deviations from the original program plan
Nunn-McCurdy OIPT kick-off briefing	Strategic guidance and issue resolution for cost issues and management issues
All previously signed acquisition documents	This will allow the team to see how the program has evolved over time

This additional material, in conjunction with greater access to program, government, and contractor managers, would enable a fuller examination of the issues identified in Table 1.2, which are more expansive than those represented in the comparison matrix in Table 7.1.

These additional data would also give greater fidelity to the identification of issues, for both the RCA and performance assessment elements of the statutory requirements. As RAND examined metrics-based approaches to supporting the PARCA director in his full range of reporting responsibilities, we found the current approaches being considered to be incomplete. The gap analysis we performed and shared with the PARCA director and his staff can be found in Appendix B. We believe that subsequent analysis efforts will identify further gaps. As DoD appears committed to using a standardized metrics approach to enable better understanding of program execution, we believe that it is necessary to develop a comprehensive set of metrics to give transparency to program execution, avoid subjective judgment, and avoid the wasting of time in both executing commands and in oversight offices. This is consistent with the fundamental recommendations of the Packard Commission and Secretary Robert Gates's initiative to eliminate inefficiency and waste.

Examples of the kind of data gaps that have become apparent are those company financial status/strength and business base (commercial and international) issues that we saw in play on both the satellite and aircraft/ship platform programs. In the summary of this report, we refer to Loren Thompson's observation on Army trucks being produced at Oshkosh. Looking to the smaller ship builders such as Marinette Marine and Austal on the littoral combat ship, one has to consider the effect of quantity reductions, such as those of the DDG-1000, on their financial viability. Line-of-businesses considerations by the satellite manufacturers played a large role in the WGS root cause analysis and was driven by commercial business decisions. The challenges reported on the Advanced Extremely High Frequency 1 launch and stationing on August 14, 2010,[1] reveal the uncertain nature of a business. Although Lockheed clearly has a more robust business base, even it can be affected in a manner that leads to unavoidable cost increases and schedule delays in government programs. Similar to commercial market implications is the significance of international sales on a contractor's ability to maintain cost and schedule targets. For example, in our review of the JSF, we noted that although international sales had not been entered into the threshold calculations, these sales represented a potentially large segment of Lockheed's business base going forward and could produce volatility. Since our quick look in early summer 2010, both the Dutch and British governments have experienced difficulty with maintaining levels of defense spending. If sales to these countries do not materialize as scheduled, there is the potential of a threshold breach in the JSF program. When coupled with the potential technical and production slippages addressed by Lockheed Martin CEO Robert

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1 "Military Satellite Relying on Backup to Save Itself," *Spaceflight Now*, August 30, 2010.

Stevens in September 2010, the implication for program cost and schedule could be significant.[2]

The point of all this is to say that some higher-order tools may need to be used and metrics developed to gain better insights. And, in the process, an evaluation of contractor efficiency in applying labor and capital to deliver a product may provide important insights and warnings. To assess the relative performance of major weapon systems producers, defense officials can apply data envelopment analysis—a quantitative technique that relies on linear programming that has been applied in numerous manufacturing and service industries to compare the relative efficiency of firms converting inputs (e.g., labor, capital, and raw materials) into outputs.

Access to Government and Contractor Personnel

More transparent and meaningful discussions with government and contractor officials are an important second step. The better these individuals understand the queries and specific aspects of the basis of questions, the more useful these discussions will be. As noted in Chapters Three through Six, all members of the RAND team found exchanges of views and understanding to be critical to our ability to fully support DoD in performing its inherently governmental function. Clearly, government and contractor team time is valuable. The IPT process used in the first round of these RCAs was an effort to limit repetitive visits and questions from multiple sources, all intended to illuminate the same issues. If that activity is deemed to be successful and is repeated in future RCAs, every effort should be made to regularize IPT activity and allow full engagement by all parties as appropriate if that becomes the principal path for gaining greater understanding of project/program activity. Clearly, a lot of activity had to be packed into a few weeks to meet the Nunn-McCurdy time lines. The more that systematic approaches for inquiry can be developed, the better the opportunity for success.

Adequate Research Staff

The RAND team found that being able to assemble and mobilize a group of experienced researchers with some knowledge of the technical disciplines involved quickly paid great dividends. Our first experiences showed that maintaining that type of capability over time will take continuing commitment and active cooperation between the government and its FFRDC and academic partners. Engaging the RAND analyst team in the continuing performance assessment process is proving to be of great benefit to having available knowledgeable cadres that can respond quickly to emerging issues.

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2 "Lockheed CEO: F-35B 'Re-phasing' Possible," *Aviation Week & Space Technology*, September 13, 2010.

The application of gaming theory to gauge manager responses and value propositions should provide more insights on areas that need to be better understood.

Findings and Recommendations

Table 7.3 summarizes the root causes of the Nunn-McCurdy breaches for the four programs in the second column. The middle column refers to issues that the research teams thought might be influential but lacked the time to research thoroughly. These issues warrant additional research. The right column contains the lessons learned from each case.

Each root cause analysis differs somewhat from others as indicated in this table. Although quantity changes appear to lead the pack, the table reveals multiple causes and, with further time and effort, RAND could develop a more complete view of root causes. Potentially, after we perform a number of these analyses, some common threads will appear and we may see some consistency. However, in the meantime, Table 7.3 summarizes what has been gleaned to date.

Table 7.3
Summary of Root Cause Analysis

Program	Root Cause of Nunn-McCurdy Breach	Issues Requiring Further Investigation	Lessons Learned
Wideband Global Satellite	Unanticipated increase in procurement quantity Unstable program funding Underestimation of baseline cost Increase in component costs Production delays leading to: (a) storage and restart expenses (b) cessation of commercial market support for production aspects Change in private sector market conditions Poorly constructed contractual incentives for contractor (distorted reporting of incurred costs) Accounting artifact	Role of commercial business reorganization and accounting cost-shifting in fueling significant increases in storage and restart expenses Estimation of baseline cost for Block I program (not required to be reported to DoD)	Production delays increase exposure to changing private sector market conditions Acquisition flexibility (e.g., start-stop programs) comes with a cost
Longbow Apache	Increase in procurement quantity Underestimation of baseline cost (training and technological development) Immature technologies Unanticipated redesign and technology integration costs Increase in component costs Increase in labor costs		Cost estimates should include “contingency dollars” for unanticipated design changes and technological integration issues Cost estimates should be conducted independently of program manager Combining remanufactured and new build items cause complexity and cost growth

Table 7.3—Continued

Program	Root Cause of Nunn-McCurdy Breach	Issues Requiring Further Investigation	Lessons Learned
DDG-1000	Decrease in procurement quantity Inadequate program funding and funding instability Underestimation of baseline cost and scheduling Immature technologies Unanticipated manufacturing process complexity and technology integration issues (lack of precedent or prior experience) Unrealistic performance expectations Small government staff size to monitor program Production delays Delay in awarding contract	Small government staff size to monitor program Funding instability (and its effect on program execution) caused by: (a) Navy pressuring contractors to lower price to fit target budget (b) Navy actions (as opposed to OSD or Congress) Effect of integration risks on production delays and cost growth	Greater planning of manufacturing process organization required Large reductions in procurement quantities can significantly increase per unit cost
Joint Strike Fighter	Decrease in procurement quantity Underestimation of baseline cost and scheduling Production delays Immature technology Unanticipated design issues Unanticipated manufacturing process complexity and technology integration issues Lack of government oversight and poor performance by contractor personnel Increase in component costs Increase in labor costs Insufficient RDT&E Poorly constructed contractual incentives for contractor	Use of common parts and suppliers to reduce cost Engine redesign issues	Sufficient RDT&E required to ensure produceability of program Greater government oversight required in a technologically complex project More hedges against risky elements of program required Additional collaboration needed on design specifications and discussion of cost-performance trade-offs

The initial effort on the first handful of Nunn-McCurdy breaches was a great start in arriving at a systematic, efficient, and economical approach to doing the necessary research and analysis to support the Secretary of Defense in his Nunn-McCurdy Act reporting and certification responsibilities. We recommend the following additional steps:

- the establishment of a comprehensive set of material to be used for analysis and the identification of and access to that material for all engaged parties
- the establishment of a clear understanding of the type of dialogue needed between all engaged parties doing research for the government's purposes and program

personnel to limit waste of time and duplication of effort; using new analytic tools or decisions games tailored to the effort at hand may better inform that effort
- use of research and analysis personnel to engage on MDAP potential fault lines across both RCA and PA in a continuum of effort to establish knowledgeable and capable cohorts in both the process of breach reporting and certification as well as the technologies involved in MDAP programs to be scrutinized and assessed.

In the entire process, greater understanding must be reached of what really matters in program execution and what risk areas most deserve attention on a continuing basis.

Legal Definitions Applicable to Unit Cost Growth Breaches

A unit cost growth breach occurs when unit cost growth, as computed by formulas defined in U.S. law, reach or exceed thresholds also specified in federal law. The thresholds are expressed in terms of the legal definitions of "program acquisition unit cost" and "procurement unit cost."

Definition of Program Acquisition Unit Cost

10 USC § 2432 defines the term "program acquisition unit cost" with respect to a major defense acquisition program as the amount equal to (a) the total cost for development and procurement of, and system-specific military construction for, the acquisition program, divided by (b) the number of fully configured end items to be produced for the acquisition program.

Showing the interrelationships of the various tools that Congress has mandated in its efforts to effect better acquisition management, SARs have adopted the acronym "PAUC" for program acquisition unit cost.

Definition of Procurement Unit Cost

10 USC § 2432 defines the term "procurement unit cost" with respect to a major defense acquisition program as the amount equal to (a) the total of all funds programmed to be available for obligation for procurement for the program, divided by (b) the number of fully configured end items to be procured.

SARs have also adopted the acronym "APUC" for acquisition procurement unit cost. By performing the computation used in the formulas specified in 10 USC § 2432, the APUC in the SARs is the same entity as the procurement unit cost defined in 10 USC § 2432.

Breach Thresholds

10 USC § 2433 defines two thresholds for unit cost growth. These are a significant unit cost growth threshold and a critical unit cost growth threshold.

A significant cost growth threshold breach is defined as

- a PAUC that is least 15 percent over the program acquisition unit cost shown in the current baseline estimate for the program or
- an APUC that is least 15 percent over the acquisition procurement unit cost shown in the current baseline estimate for the program or
- a PAUC that is at least 30 percent over the program acquisition unit cost shown in the original baseline estimate or
- an APUC that is at least 30 percent over the acquisition procurement unit cost shown in the original baseline estimate.

A critical cost growth threshold breach is defined as

- a PAUC that is least 25 percent over the program acquisition unit cost shown in the current baseline estimate for the program or
- an APUC that is least 25 percent over the acquisition procurement unit cost shown in the current baseline estimate for the program or
- a PAUC that is at least 50 percent over the program acquisition unit cost shown in the original baseline estimate or
- an APUC that is at least 50 percent over the acquisition procurement unit cost shown in the original baseline estimate.

Table A.1 summarizes the unit cost threshold definitions in federal law.

Table A.1
Breach Thresholds

Unit Cost	Baseline	Threshold, %	Level	Source
PAUC	Current	≥15	Significant	10 USC § 2433 (a)(4)(A)(i)
APUC	Current	≥15	Significant	10 USC § 2433 (a)(4)(B)(i)
PAUC	Original	≥30	Significant	10 USC § 2433 (a)(4)(A)(ii)
APUC	Original	≥30	Significant	10 USC § 2433 (a)(4)(B)(ii)
PAUC	Current	≥25	Critical	10 USC § 2433 (a)(5)(A)(i)
APUC	Current	≥25	Critical	10 USC § 2433 (a)(5)(B)(i)
PAUC	Original	≥50	Critical	10 USC § 2433 (a)(5)(A)(ii)
APUC	Original	≥50	Critical	10 USC § 2433 (a)(5)(B)(ii)

Certifications to Congress

Current law specifies that a program that incurs a critical cost growth breach is assumed to be terminated unless the Secretary of Defense provides specific certifications to Congress within 60 days of the SAR due date as specified in 10 USC § 2432(f). The certifications must state the following:

- The system is essential to national security.
- There are no alternatives that will provide acceptable capability to meet joint military requirements at less cost.
- The new estimates of PAUC and APUC have been determined by the defense director of Cost Analysis and Program Evaluation to be reasonable.
- The program is a higher priority than programs whose funding must be reduced to accommodate the growth in cost of the program.
- The management structure for the program is adequate to manage and control the PAUC or APUC going forward.

These certifications must be accompanied by a root cause analysis and assessment (described in following section).

- 10 USC § 2433a stipulates that a root cause analysis be conducted by the director of PARCA when a major weapon system acquisition program incurs a critical cost growth breach. The root cause analysis assesses the underlying cause of the critical cost overrun. As described in Chapter One, the office is responsible for producing a root cause report that must identify the role, if any, of the eight items stipulated.

Root Cause Analysis

10 USC § 2433a stipulates that a root cause analysis be conducted by the director of PARCA when a major weapon system acquisition program incurs a critical cost growth breach. The root cause analysis assesses the underlying cause of the critical cost overrun. The root cause report must identify the role, if any, of the following elements in causing the cost overrun:

- unrealistic performance expectations
- unrealistic baseline estimates for cost or 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 responsible for program management
- any other matters.

APPENDIX B

Vulnerability Matrix

Independent of program, program analysis and root cause analysis of cost and schedule overruns may show common themes. RAND studied four programs during the root cause analysis project: Joint Strike Fighter, DDG-1000, Wideband Global Satellites, and the Longbow Apache Helicopter. Although each program breached the Nunn-McCurdy Act for different reasons, it is useful to look for any common themes in the breach and common themes in overall risk that could help lawmakers identify potential breaches earlier.

Table B.1 shows a compiled list of potential risks and events that could lead to a Nunn-McCurdy breach, along with the four programs that were studied as part of

Table B.1
Vulnerability Matrix with Program Findings

Vulnerability Matrix: Type of Event	JSF	DDG-1000	WGS	Apache
Cost increases—concept refinement		x		
Cost increases—technology development		x		
Cost increases—systems development and demonstration	x	x		x
Cost increases—production and deployment				
Cost increases—operations and support				
Cost increases—additional blocks			x	
Documented different estimates—concept refinement	x	x		
Documented different estimates—technology development	x	x		
Documented different estimates—systems development and demonstration	x	x		x
Documented different estimates—production and deployment	x			
Documented different estimates—operations and support				
Documented different estimates—additional blocks			x	

Table B.1—Continued

Vulnerability Matrix: Type of Event	JSF	DDG-1000	WGS	Apache
Known Factors During Cost Estimation				
Unrefined design and performance requirements	x			x
Lack of previous similar work	x	x		x
No or bad past contractor performance	x			
Technology immaturity	x	x		
Technical complexity		x		x
Design flaws	x			
New manufacturing methods	x	x		
Integration of system is complex		x		x
Decision to employ parallel development rather than sequential	x	x		
Insufficient number of government personnel to run the program		x		
Unique contracting strategy		x		
Ambitious system performance goals		x		x
International participation	x			
Difficulties in negotiating major contracts (e.g., contract protests)		x		
Internal Changes to Program				
Change of performance requirements—concept refinement		x		
Change of performance requirements—technology development		x		
Change of performance requirements—systems development and demonstration		x		
Change of performance requirements—production and deployment				
Change of performance requirements—operations and support				
Change of performance requirements—additional blocks				
Funding instability		x		
Funding insufficiency				
Optimistic development schedule	x			
Schedule delays and extension	x			
Change in quantity—increase	x		x	x
Change in quantity—decrease	x	x		

Table B.1—Continued

Vulnerability Matrix: Type of Event	JSF	DDG-1000	WGS	Apache
External Changes to Program Environment				
Increase/decrease in quantity of related program	x	x		x
Cancellation of predecessor program	x	x		
Program restructured				
Reliance on private sector to maintain technology configuration		x	x	
Changes in program guidance/service mission		x		
Changes to external programs		x		
Addition of new construction to an upgrade program				x
"Special interest" program				
Change of technology direction				
Changes to Operating Environment				
Increase in wage rates	x	x		x
Increase in cost of materials or equipment	x	x	x	x
Changes to industrial base		x	x	
Program decisions heavily influenced by industrial base concerns				
Change in government standards or regulations				
Natural disaster/act of God		x		
Strong advocacy for program in OSD	x	x		
Strong advocacy against program in OSD	x	x		
Strong advocacy for program in Services	x	x		
Strong advocacy against program in Services	x	x		
Strong advocacy for program in Congress	x	x		
Strong advocacy against program in Congress	x	x		
Significant congressional interest	x	x		

this effort. It is important to note that this matrix does not only represent the reasons for the Nunn-McCurdy breach of the four programs. It also represents a broader look at the risks that programs could potentially encounter. Better understanding of factors that programs can encounter as they head toward a Nunn-McCurdy breach could help lawmakers and Program Offices more quickly identify at-risk programs so that adjustments could be made.

Table B.2 compares the vulnerability matrix (VM) to two other lists of warning signs. First is the DoD probability of program success (PoPS) factors. Second is a list

Table B.2
Vulnerability Matrix Mapped to PoPS and Young's Memo Findings

Vulnerabilty Matrix: Type of Event	Mapping Adequacy	Generic PoPS		Young's Memo
Cost increases—concept refinement	Y	Program execution:	Cost/schedule performance	Development issues
Cost increases—technology development	Y	Program execution:	Cost/schedule performance	Development issues
Cost increases—systems development and demonstration	Y	Program execution:	Cost/schedule performance	Development issues
Cost increases—production and deployment	Y	Program execution:	Cost/schedule performance	Development issues
Cost increases—operations and support	Y	Program execution:	Sustainability risk	Development issues
Cost increases—additional blocks	Y	Program execution:	Cost/schedule performance	Development issues
Documented different estimates—concept refinement	Y	Program execution:	Cost estimating	Low estimates
Documented different estimates—technology development	Y	Program execution:	Cost estimating	Low estimates
Documented different estimates—systems development and demonstration	Y	Program execution:	Cost estimating	Low estimates
Documented different estimates—production and deployment	Y	Program execution:	Cost estimating	Low estimates
Documented different estimates—operations and support	Y	Program execution:	Cost estimating	Low estimates
Documented different estimates—additional blocks	Y	Program execution:	Cost estimating	Low estimates
Known Factors During Cost Estimation				
Unrefined design and performance requirements	Y	Program requirements:	Program scope evolution	Flawed design process and knowledge base
Lack of previous similar work	O	Program execution:	Technical maturity	
No or bad past contractor performance	Y	Program execution:	Contractor performance	

Table B.2—Continued

Vulnerabilty Matrix: Type of Event	Mapping Adequacy	Generic PoPS		Young's Memo
Technology immaturity	Y	Program execution:	Technical maturity	Inadequate prototypes, immature technology, too little understanding of the design, risky technology
Technical complexity	Y	Program execution:	Technical maturity	Exquisite technology
Design flaws	Y	Program execution:	Technical maturity	Design flaws
New manufacturing methods	Y			Invalid remanufacture assumptions
Integration of system is complex	O	Program execution:	Program risk assessment	
Decision to employ parallel development rather than sequential	R			
Insufficient number of government personnel to run the program	G	Program resources:	Manning	
Unique contracting strategy	R			
Ambitious system performance goals	Y	Program execution:	Software	
International participation	G	Program advocacy:	International	
Difficulties in negotiating major contracts (e.g., contract protests)	O	Program requirements:	Program scope evolution	
Internal Changes to Program				
Change of performance requirements—concept refinement	Y	Program requirements:	Program scope evolution	Changing requirements, new systems and capabilities added, excessive requirements
Change of performance requirements—technology development	Y	Program requirements:	Program scope evolution	
Change of performance requirements—systems development and demonstration	Y	Program requirements:	Program scope evolution	
Change of performance requirements—production and deployment	Y	Program requirements:	Program scope evolution	
Change of performance requirements—operations and support	Y	Program execution:	Sustainability risk	

Table B.2—Continued

Vulnerabilty Matrix: Type of Event	Mapping Adequacy	Generic PoPS		Young's Memo
Change of performance requirements—additional blocks	Y	Program requirements:	Program scope evolution	
Funding instability	Y	Program resources:	Budget	Fluctuating budgets
Funding insufficiency	G	Program resources:	Budget	Underfunding
Optimistic development schedule	Y	Program execution:	Cost/schedule performance	Optimistic schedule
Schedule delays and extension	Y	Program execution:	Cost/schedule performance	Extended schedule
Change in quantity—increase	R			Quantity increased
Change in quantity—decrease	R			Reduced annual quantities, precipitous drop in quantity, reduced annual production rate
External Changes to Program Environment				
Increase/decrease in quantity of related program	O	Program "fit" in capability vision	DoD vision—inter-operability	
Cancellation of predecessor program	O	Program "fit" in capability vision	DoD vision—inter-operability	
Program restructured	R			
Reliance on private sector to maintain technology configuration	R			
Changes in program guidance/service mission	Y	Program "fit" in capability vision	Service vision—current force	Fluid program strategy
Changes to external programs	R			
Addition of new construction to an upgrade program	R			
"Special interest" program	R			
Change of technology direction	R			
Changes to Operating Environment				
Increase in wage rates	R			

Table B.2—Continued

Vulnerabilty Matrix: Type of Event	Mapping Adequacy	Generic PoPS		Young's Memo
Increase in cost of materials or equipment	R			
Changes to industrial base	Y	Program execution:	Industry/company assessment	
Program decisions heavily influenced by industrial base concerns	Y	Program execution:	Industry/company assessment	
Change in government standards or regulations	R			
Natural disaster/act of God	R			
Strong advocacy for program in OSD	G	Program advocacy:	OSD	
Strong advocay against program in OSD	G	Program advocacy:	OSD	
Strong advocacy for program in Services	G	Program advocacy:	Service secretary	
Strong advocacy against program in Services	G	Program advocacy:	Service secretary	
Strong advocacy for program in Congress	G	Program advocacy:	Congress	
Strong advocay against program in Congress	G	Program advocacy:	Congress	
Significant congressional interest	Y	Program advocacy:	Congress	Congress reversed DoD decision

of items discussed in the January 30, 2009, memo from Under Secretary of Defense John Young (OUSD AT&L) to Secretary of Defense Robert Gates regarding his own reasoning for cost changes in large acquisition programs.

Table B.3 shows what additional data and manpower might be needed if all the VM factors were to be recorded and acted on.

Ability of DoD to Identify Programs at Risk

Common causal factors emerged during the Nunn-McCurdy root cause analysis. These factors might help identify additional programs at risk for cost or schedule problems. Yet, it appears PARCA might not receive this information in easily recognizable formats. RAND identified metrics that might highlight critical factors in potentially vul-

Table B.3
Increased Manpower and Reporting Needed to Adequately Report VM Items

Vulnerability Matrix: Type of Event	Increased Manpower	Additional Reports from Program Office	Additional Reports from Contractor	Should Already Be Recorded
Cost increases—concept refinement				x
Cost increases—technology development				x
Cost increases—systems development and demonstration				x
Cost increases—production and deployment				x
Cost increases—operations and support				x
Cost increases—additional blocks				x
Documented different estimates—concept refinement				x
Documented different estimates—technology development				x
Documented different estimates—systems development and demonstration				x
Documented different estimates—production and deployment				x
Documented different estimates—operations and support				x
Documented different estimates—additional blocks				x
Known Factors During Cost Estimation				
Unrefined design and performance requirements	x			
Lack of previous similar work	x		x	
No or bad past contractor performance	x		x	
Technology immaturity			x	
Technical complexity			x	
Design flaws				
New manufacturing methods			x	

Table B.3—Continued

Vulnerability Matrix: Type of Event	Increased Manpower	Additional Reports from Program Office	Additional Reports from Contractor	Should Already Be Recorded
Complex integration of system			x	
Decision to employ parallel development rather than sequential			x	
Insufficient number of government personnel to run the program	x			
Unique contracting strategy			x	
Ambitious system performance goals			x	
International participation				x
Difficulties in negotiating major contracts (e.g., contract protests)				x
Internal Changes to Program				
Change of performance requirements—concept refinement	x		x	
Change of performance requirements—technology development	x		x	
Change of performance requirements—systems development and demonstration	x		x	
Change of performance requirements—production and deployment	x		x	
Change of performance requirements—operations and support	x		x	
Change of performance requirements—additional blocks	x		x	
Funding instability				x
Funding insufficiency				x
Optimistic development schedule				
Schedule delays and extension				
Change in quantity—increase				x
Change in quantity—decrease				x

Table B.3—Continued

Vulnerability Matrix: Type of Event	Increased Manpower	Additional Reports from Program Office	Additional Reports from Contractor	Should Already Be Recorded
External Changes to Program				
Increase/decrease in quantity of related program				x
Cancellation of predecessor program				x
Program restructured				x
Reliance on private sector to maintain technology configuration			x	
Changes in program guidance/ service mission				x
Changes to external programs				x
Addition of new construction to an upgrade program				x
"Special interest" program				
Change of technology direction	x		x	
Changes to Operating Environment				
Increase in wage rates			x	
Increase in cost of materials or equipment			x	
Changes to industrial base			x	
Program decisions heavily influenced by industrial base concerns			x	
Change in government standards or regulations			x	
Natural disaster/act of God				x
Strong advocacy for program in OSD				
Strong advocacy against program in OSD				
Strong advocacy for program in Services				
Strong advocacy against program in Services				

Table B.3—Continued

Vulnerability Matrix: Type of Event	Increased Manpower	Additional Reports from Program Office	Additional Reports from Contractor	Should Already Be Recorded
Strong advocacy for program in Congress				
Strong advocay against program in Congress				
Significant congressional interest				x

nerable programs. These metrics were compared to the PoPS criteria possibly received by PARCA. RAND identified those metrics PoPS might not identify but should given previous root cause results.

All three services use the PoPS metrics.

- Army: "The probability of program success initiative is designed to improve the Army's ability to accurately assess a program's probability of success, and clearly/concisely represent that success probability to Army leadership. The probability of program success will be calculated monthly. The report to senior leadership will occur quarterly during the following months: January, April, July, and October. The senior leadership report can be generated more frequently, if required."[1]
- Navy: PoPS provides a "holistic view of overall program health and readiness to proceed."[2]
- Air Force: "The probability of program success initiative is designed to improve the Air Force's ability to accurately assess a program's probability of success (ability to succeed), and clearly/concisely represent that success probability to Air Force leadership. To that end, each program spiral (including software spirals) will be evaluated independently utilizing the probability of program success criteria."[3]

PoPS gives the Program Office the ability to display a large amount of data in a standardized format to facilitate senior leadership decisionmaking. The standardized format allows for quick comparisons across programs and for historical analysis of program performance.

However, PoPS does not quickly identify aspects of change throughout the lifecycle of a program. For example, PoPS does not highlight change in the quantity of a related program, which we found to be a major factor in Nunn-McCurdy breaches.

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1 U.S. Army, *Probability of Program Success Operations Guide*.

2 U.S. Navy, *Naval Probability of Program Success (PoPS) Executive Brief*, June 2009.

3 U.S. Air Force, *Probability of Program Success (PoPS) Spreadsheet Operations Guide*, July 2007.

PoPS represents a snapshot of a program as it exists at a point in time, which limits its utility for predicting future breaches. Table B.2 ranks the mapping of PoPS to the VM from red to green, with green being a good match and red meaning that PoPS does not identify the issue at all. The following list shows what PoPS does well and what it does not do well.

PoPS Covers Some Potential Root Cause Factors

- internal factors
  - sufficient government personnel to run a program
  - funding sufficiency
- external factors
  - international advocacy and participation
  - program advocacy for a program from OSD, services, and Congress.

Some Criteria in PoPS Can Be Altered Slightly to Highlight the Impact of These Critical Factors

- internal factors (program incongruency)
  - different cost estimates as a program progresses
  - changes in performance requirements
  - funding instability (different from funding sufficiency)
- internal changes (program ambition understanding)
  - ambitious system engineering goals
  - technical immaturity or complexity
  - cost increases as program progresses
- external factors
  - congressional interest (different from advocacy)
- external changes
  - new manufacturing techniques
  - changes to the industrial base.

PoPS Only Tangentially Addresses the Impact of Some Critical Factors

- internal factors (program process decisions)
  - source selection decisions:
    - lack of previous similar work at a contractor
    - integration of a complex system, even if system is made up of noncomplex parts
  - contract negotiation concessions

- external changes
  - increase or decrease in related program quantity
  - cancellation of a predecessor program.

PoPS Is Missing Potentially Critical Parameters

- internal changes
  - changes in quantity: decreases or increases
  - changes to material, equipment, or manpower costs
  - restructuring of a program
- impact of internal factors (program process decisions)
  - parallel development vs. sequential development
- external changes
  - changes to external programs
  - changes to commercial sector for which program dependent to maintain a technology
  - changes in government standards or regulations
- external factors
  - special interest programs involvement
  - natural disasters/acts of God.

PoPS contains some criteria that can be helpful to identifying potential cost and schedule overruns that lead to Nunn-McCurdy breaches. However, most criteria need to be adjusted to better highlight potential root causes. Some RCA indicators identified by RAND do not exist in PoPs criteria. PoPS does not account for the changes in cost or schedule, just gives a snapshot in time. Therefore, those who look only at PoPS do not see changes that have occurred in the program.

Programs Are in Danger for Similar Reasons

In the course of the study, we found that all four programs sometimes shared risk factors that lead to cost increases and schedule slips. Table B.1 shows the types of events that each program experienced. Forty-five percent of the vulnerability matrix factors were experienced by more than one program. Some important factors that affected three or more programs are those listed below:

- lack of previous similar work
- increased cost of material
- increase in wage rates

- increase in quantity
- cost increases and documented cost estimate differences during system development and demonstration.

Other notable factors include:

- reliance on the private sector to maintain technology configuration
- strong advocacy for or against programs
- complex system integration
- insufficient number of government personnel on the program.

By studying the vulnerability matrix, we can see that unique programs share the same warning signs that can lead to a Nunn-McCurdy breach. (See Tables B.2 and B.3.)

APPENDIX C

Technology Readiness Levels

Table C.1 presents the definitions of the technology readiness levels used in DoD acquisitions.

Table C.1
Definitions of DoD Technology Readiness Levels

Technology Readiness Level	Description
1. Basic principles observed and reported	Lowest level of technology readiness. Where scientific research begins to be later translated into applied research and development. Examples might include paper studies of a technology's basic properties.
2. Technology concept or application formulated	Invention begins. Once basic principles are observed, practical applications can be invented. The application is speculative and there is no proof or detailed analysis to support the assumption. Examples are still limited to paper studies.
3. Analytical and experimental critical function or characteristic proof of concept	Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.
4. Component or breadboard validation in laboratory environment	Basic technological components are integrated to establish that the pieces will work together. This is relatively "low fidelity" compared to the eventual system. Examples include integration of ad hoc hardware in a laboratory.
5. Component or breadboard validation in relevant environment	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so that the technology can be tested in a simulated environment. Examples include "high-fidelity" laboratory integration of components.
6. System/subsystem model or prototype demonstration in a relevant environment	Representative model or prototype system, which is well beyond the breadboard tested for TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in a simulated operational environment.
7. System prototype demonstration in an operational environment	Prototype near or at planned operational system. Represents a major step up from TRL 6, requiring the demonstration of an actual system prototype in an operational environment, such as in an aircraft, a vehicle, or space. Examples include testing the prototype in a test bed aircraft.

Table C.1—Continued

Technology Readiness Level	Description
8. Actual system completed and flight qualified through test and demonstration	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications.
9. Actual system flight proven through successful mission operations	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. In almost all cases, this is the end of the last "bug fixing" aspects of true system development. Examples include using the system under operational mission conditions.

SOURCE: Department of Defense, DODI 5000.2 Acquisition System Guidebook, 2004.

APPENDIX D

Cost Estimates from Other Organizations

Chapter Four showed the cost estimates in the SAR. This appendix shows the cost estimates from Lockheed Martin, JPO, and the Air Force Cost Analysis Agency.

Lockheed Martin

Lockheed Martin provided a chart explaining URF cost growth in the RDT&E phase. Extrapolating from the chart, it appears that Lockheed attributes approximately $20 billion (roughly one-third) of RDT&E cost growth to the weight and design issues that were identified and addressed between 2001 and 2004. Other factors contributed to another $20 billion in the air system contract with another $20 billion occurring in the propulsion systems contract.[1]

JPO

The JPO provided RAND with an estimate of the factors contributing to APUC, which is the procurement account only. Table D.1 shows the JPO assessment. The JPO allocates almost 30 percent of cost growth to three factors: design/weight issues, cost of materials, and labor rates. Another 7.4 percent is allocated to propulsion system costs. Finally, the JPO allocates 6.3 percent of the cost growth to OSD inflation changes.

CAIG/CAPE

A fourth set of data comes from the CAIG, now CAPE, which redid its estimate in 2004–2005 in the wake of the re-baselining of the program after the weight and design issues arose. However, these numbers, which describe URF cost growth, were not used as the program estimate until 2008, when the update was calculated through 2015.

[1] Authors' interpretation of Lockheed Martin chart provided April 23, 2010.

Table D.1
JPO Track of Average Procurement Unit Cost Growth (APUC Only, MS B to SAR 2009)

Cost Growth Factor	Percentage
Design change/weight	11.0
Cost of materials	9.0
Labor rates	8.5
Propulsion update	7.4
OSD inflation changes	6.3
Aircraft reduction and multiyear shifts	4.5
Production support update	3.1
Airframe update	2.8
Rate tooling	2.0
CAPE estimate	1.3
Other	0.9
Systems update	0.7
Total	57.5

SOURCE: Data provided by JPO to PARCA JSF teams meeting, April 23, 2010.

The CAIG estimate is yet another breakout of the program, providing some overlap with categories reported by Lockheed Martin and the JPO, but it is not a clean match. These data are portrayed in Table D.2.

Table D.2
CAPE Track of CTOL Unit Recurring Flyaway Cost Growth (FY 2002 $ Millions)

	Cost	Percentage Change
Milestone B estimate	36.3	
Updated avionics from F-22 actuals	5.5	15
Weight growth	5.1	14
Updated labor rates	3.8	10
Fee and fee-on-fee	3.5	10
Updated propulsion from F-22/F119 actuals	2.5	7
Quantity reduction	1.0	3
Change in estimate since Milestone B	(21.3)	59
Updated URF estimate	57.6	

SOURCE: "URF Cost Comparisons from Milestone B," draft/pre-decisional briefing slide provided by CAPE to PARCA team on April 28, 2010.

APPENDIX E

Effect of Low Original WGS Baseline Costs

The SAF letter explaining the WGS Nunn-McCurdy breach argued that Boeing's failure to price Block I satellites correctly meant that the original and the current APB were below the true cost of building satellites (thus, a reversion to correct costs appears to be a cost increase). It is not clear what Block I satellites should have cost, since Boeing's FFP contract did not require that it submit cost data at the time, and recently released cost data had yet to be thoroughly audited at the time of this writing. The cost claims currently made by Boeing suggest that the true cost of the first three satellites was roughly the same as the next two satellites, despite higher-than-normal inflation in the satellite industry and the extra features present in Block II, which is both unusual and counterintuitive.

Were such a claim nevertheless true, then the unit cost for satellites 1–3 would have been $377 million rather than $239 million, and APUC for the current APB would be $377 million (rather than $294 million). In comparison, the projected APUC increase would have been 15 percent (five satellites at $377 million and two at $574 million for a total of $2,998 million for seven satellites or an APUC of $428 million). The $428 million APUC is 14.5 percent higher than the $377 million projection. It still qualifies as a significant cost growth threshold breach, albeit borderline. In light of USAF plans to buy WGS 9 through 12, however, a critical cost growth threshold breach would occur by WGS 11 as illustrated by the red-shaded cells of Table E.1 (if the last four satellites in the Block II follow-on series had the same unit cost as the first two). In other words, regardless of whether or not Block I prices reflected actual costs, the 52 percent increase in unit costs warrants explanation.

Table E.1
WGS Eventual Nunn-McCurdy Breach

Satellite	8	9	10	11	12
APUC, $ millions	433	451	464	475	484
Increase over APB, %	15	20	23	26	29

NOTE: Assuming that WGS APUC for Blocks I and II should be $377 million.

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