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Lessons Learned from the

# **F/A–22 and F/A–18E/F Development Programs**

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## Preface

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The process of acquiring new weapon platforms requires the U.S. military to invest substantial time and money in development, testing, and production. Two recent fighter aircraft programs, the Air Force's F/A-22 and the Navy's F/A-18E/F, illustrate the real difficulties and successes of this process. This report evaluates the historical information of these platforms to understand how costs and schedules had changed during the development. The study derives lessons that the Air Force and other services can use to improve the acquisition of such aircraft as the Joint Strike Fighter and such other hardware systems as unmanned aerial vehicles and missile programs.

This is one of a series of reports from a RAND Project AIR FORCE project, "The Cost of Future Military Aircraft: Historical Cost-Estimating Relationships and Cost Reduction Initiatives." The purpose of the project is to improve the tools used to estimate the costs of future weapon systems. It focuses on how recent technical, management, and government policy changes affect cost.

The project was sponsored by Lieutenant General John D. W. Corley, Principal Deputy Assistant Secretary of the Air Force for Acquisition, and conducted within the Resource Management Program of RAND Project AIR FORCE. The project technical point of contact was Jay Jordan, Technical Director of the Air Force Cost Analysis Agency (AFCAA). The observations of this study were mainly drawn from various cost and schedule reports including Selected Acquisition Reports, Contract Cost Data Reports, and Contractor Performance Reports. The historical data were supplemented

by additional information from the AFCAA and the Naval Air Systems Command's (NAVAIR) Cost Department.

This report should be of interest to the military aircraft acquisition community and defense acquisition policy professionals generally.

Other RAND Project AIR FORCE reports that address military aircraft cost-estimating issues include the following:

- In *An Overview of Acquisition Reform Cost Savings Estimates*, MR-1329-AF, Mark Lorell and John C. Graser used relevant literature and interviews to determine whether estimates of the efficacy of acquisition reform measures are robust enough to be of predictive value.
- In *Military Airframe Acquisition Costs: The Effects of Lean Manufacturing*, MR-1325-AF, Cynthia Cook and John C. Graser examined the package of new tools and techniques known as “lean production” to determine whether it would enable aircraft manufacturers to produce new weapon systems at costs below those predicted by historical cost-estimating models.
- In *Military Airframe Costs: The Effects of Advanced Materials and Manufacturing Processes*, MR-1370-AF, Obaid Younossi, Michael Kennedy, and John C. Graser examined cost-estimating methodologies and focused on military airframe materials and manufacturing processes. This report provides cost estimators with factors useful in adjusting and creating estimates based on parametric cost-estimating methods.
- In *Military Jet Engine Acquisition: Technology Basics and Cost-Estimating Methodology*, MR-1596-AF, Obaid Younossi, Mark V. Arena, Richard M. Moore, Mark Lorell, Joanna Mason, and John C. Graser presented a new methodology for estimating military jet engine costs and discussed the technical parameters that derive the engine development schedule, development cost, and production costs and presented quantitative analysis of historical data on engine development schedule and cost.
- In *Test and Evaluation Trends and Costs in Aircraft and Guided Weapons*, MG-109-AF, Bernard Fox, Michael Boito, John C.

Graser, and Obaid Younossi examined the effects of changes in the test and evaluation (T&E) process used to evaluate military aircraft and air-launched guided weapons during their development programs.

- In *Software Cost Estimation and Sizing Methods, Issues and Guidelines*, MG-269-AF, Shari Lawrence Pfleeger, Felicia Wu, and Rosalind Lewis recommended an approach to improve the utility of the software cost estimates by exposing uncertainty and reducing risks associated with developing the estimates.

## **RAND Project AIR FORCE**

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





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## Summary

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### **Two Multirole Fighter Aircraft Programs Emerged at the End of the Cold War**

From the late 1980s through the present, the U.S. Air Force and the U.S. Navy have been acquiring two multirole fighter aircraft platforms. The Air Force has pursued the F/A-22, the world's first supersonic stealth fighter, while the Navy has developed the F/A-18E/F, a carrier-capable fighter with air-to-air, interdiction, and close air support capability. Currently, the F/A-22 is in the late stages of development, while the F/A-18E/F is in full production and has already been deployed in Operation Enduring Freedom and Operation Iraqi Freedom.

The design of the F/A-22 includes advancements in all the major areas of the aircraft, including airframe, avionics, and propulsion. The airframe incorporates an advanced stealth design to lower its radar cross section and uses large amounts of advanced materials, such as composites and titanium. The integrated avionics suite of the aircraft brings together information collected from several sensors on the aircraft to be displayed to the pilot. The propulsion system features two high thrust, Pratt and Whitney, F119 jet engines to allow the F/A-22 to supercruise above the speed of sound without using the fuel-consuming afterburner. The airframe design, flight controls, and thrust vectoring are also used to improve the maneuverability of the aircraft.

The F/A-18E/F Super Hornet was designed to be an upgrade to the existing F/A-18A/B/C/D multirole aircraft fleet. The program

sought to increase the aircraft's range, payload, and survivability. The program was an outgrowth of a Secretary of Defense memorandum from July 1987, directing the Navy to investigate advanced versions of the F/A-18 for 2000 and beyond. The trade studies, known as Hornet 2000, led to a Milestone IV/II review in March 1992 to begin formal Engineering and Manufacturing Development (EMD) of the program in July 1992. The F/A-18E/F is 4.2 feet longer than the legacy platform, has a 25 percent larger wing area, and can carry 33 percent additional internal fuel. The airframe design was largely new with very little commonality with the original design. It incorporated some limited radar cross-section reduction techniques, such as new inlets and attention to door and panel edges. The avionics for the initial release of the F/A-18E/F incorporated the suite from the C/D model. Provisions were made for a series of avionics upgrades to be performed subsequent to the basic air vehicle development. The propulsion is provided by two General Electric F414 jet engines.<sup>1</sup>

## **These Programs Reflect the Challenges of Developing Major Weapons Platforms**

The F/A-22 program has experienced significant cost growth and schedule delays, whereas the F/A-18E/F program completed its development on cost and without any significant delays. As shown in Figure S.1, the F/A-22 program had exceeded its original schedule by more than 52 months as of the date of the last Selected Acquisition Report (SAR) examined (December 31, 2001), while the F/A-18E/F was virtually on time. The total cost of developing the F/A-22 grew by \$7.6 billion in Fiscal Year 1990 dollars, compared to the F/A-18E/F program, which met its original cost estimates. The schedule and cost overruns in the F/A-22 program have generated considerable

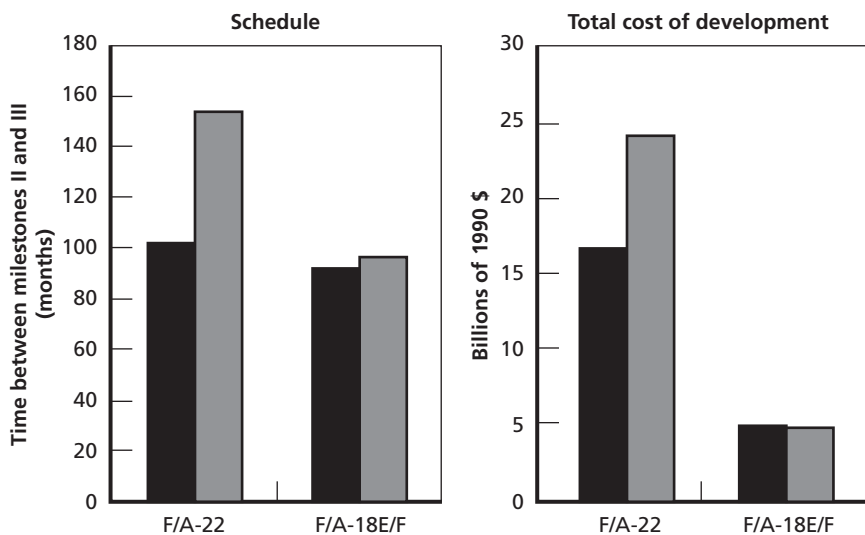
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<sup>1</sup> The information is from the F/A-18 Selected Acquisition Report (SAR), F/A-18E/F Cost Analysis Requirements Description, and the Naval Air System Command's Hornet hyperlink, available at <http://pma265.navair.navy.mil/Public%20Affairs/stores/shorner/shorner.html>, accessed February 2004.

concern from the Department of Defense and Congress, leading to close scrutiny of the program and reductions in the number of aircraft to be produced.

The office of the Assistant Secretary of the Air Force for Acquisition asked RAND Project AIR FORCE (PAF) to investigate the reasons behind the cost growth and schedule delay of the F/A-22 program and those contributing to the cost and schedule stability of the F/A-18E/F program during EMD. This report examines the acquisition strategies employed by the F/A-22 and F/A-18E/F programs from their inception through the demonstration and validation (Dem/Val) and EMD phases. The analysis is based of various cost and schedule reports available to PAF as well as data and information available in open sources. For instance, the SARs, Contract Cost Data Reports (CCDRS) and Cost Performance Reports (CPRs) were the

**Figure S.1**  
**F/A-22 Experienced Schedule Slips and Cost Growth, While the F/A-18E/F Completed Development on Time and on Cost**



\*Includes government costs.  
 SOURCE: Selected Acquisition Reports.

main sources of data for the cost and schedule growth analysis. Other documents, such as Cost Analysis Requirements Description (CARD), contractor's weight reports, General Accounting Office (GAO) reports, and published articles and reports were also examined. The purpose of this analysis is to derive lessons for improving future Air Force acquisitions.

## **Multiple Factors Contributed to Problems or Stability in Each Program**

The F/A-22 and F/A-18E/F programs pursued different approaches to securing contractors, encountered various technical challenges during development, and employed distinct methods to monitor contract performance data during the EMD phase. All of these factors contributed to the separate cost and schedule outcomes seen in Figure S.1:

- **Each program used different methods to solicit contractor proposals and to divide work among contractors during their development phase.** Concerns about the needed mix of technical expertise and other industrial base issues led the F/A-22 program to distribute the work equally among three contractor team members. This arrangement resulted in an artificial distribution of work during the EMD phase and may have contributed to the schedule and cost problems experienced. Other business base concerns with respect to the program teaming structure as well as a move from Burbank to Marietta may have contributed to the program's instability and ultimately to its cost growth and schedule delays. By contrast, the F/A-18E/F program drew on preexisting relationships and contractor expertise to minimize the technology risks involved in the project. The program also implemented a number of acquisition reform strategies designed to control costs and schedule, such as the principle of cost as an independent variable (CAIV). These

measures helped keep the F/A-18E/F program on schedule and within cost during EMD (see pp. 13–27).

- **Concurrent development of new technology created greater technical challenges for the F/A-22, while incremental improvements reduced technical risk in the F/A-18E/F.** The F/A-22 cost growth was mainly the result of design challenges in the airframe (arising from stealth requirements), the integrated avionics suite, and the new propulsion system. Some of these challenges were either assumed to be low risk or were not accounted for in the initial program cost estimates. Also, concurrent development and integration of all aspects of the F/A-22 may have compounded the cost growth and schedule slippage. In contrast, the F/A-18E/F requirement was met by incremental improvements with minimal stealth requirements, a mostly existing avionics system from its predecessor aircraft, and a derivative engine design. This low-risk approach may have contributed to the F/A-18E/F's stable cost and schedule (see pp. 29–46).
- **The programs allocated different portions of their budgets for management reserve.** Management reserve is a budget withheld for management control purposes and is mostly used to cover unknown problems in a development program. The F/A-22 program allocated only about 2 percent of its budget to management reserve. This reserve was depleted in about the first year of the EMD effort because of the technical challenges described above. By contrast, the F/A-18E/F program maintained a substantial management reserve, roughly 10 percent of contract value. As the program proceeded through its development and unforeseen problems arose, the amount of management reserves covered these problems and was decreased accordingly (see pp. 47–53).

This report provides the Air Force and other services with lessons learned to improve the acquisition of such future and current weapon systems as the Joint Strike Fighter and such other hardware systems as unmanned aerial vehicles and missile programs. Our major

lessons learned for the Air Force acquisition decisionmakers are the following:

- Early, realistic cost and schedule estimates set the program on the right path for the rest of the development program.
- A stable development team structure, proper team expertise, clear lines of responsibility and authority, and a lead contractor responsible for overall program progress are critical to program success.
- An experienced management team and contractors with prior business relationships help eliminate early management problems.
- Concurrent development of new technology for the airframe, avionics, and propulsion adds significant risk.
- Reducing the cost and risk of avionics should be a key focus of the concept development phase. Avionics is a considerable cost driver of modern weapon systems, and new concepts should be demonstrated along with the new airframe designs.
- Preplanned, evolutionary modernization of high-risk avionics can reduce risk and help control costs and schedules.
- Careful monitoring of airframe weight is important. Airframe weight instability is an early indicator of problems.
- Earned value management (EVM) data should be used to monitor and manage program costs at the level of integrated product teams (IPTs).

Appropriate use of management reserve can help address program cost risk and can mitigate cost growth.

## Acknowledgments

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# Abbreviations

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ACS	Advanced Crew Station
ACWP	Actual Cost of Work Performed
AESA	Active Electronically Scanned Array
AMC&D	Advanced Mission Computer and Displays
ASTE	Advanced Strategic and Tactical Expendables
ATA	Advanced Tactical Aircraft
ATD	Achieved to Date
ATF	Advanced Tactical Fighter
ATFE	Advanced Tactical Fighter Engine
ATFLIR	Advanced Targeting Forward-Looking Infrared (pod)
AWACS	Airborne Warning and Control System
BAC	Budget at Completion
BCWP	Budgeted Cost of Work Performed
BCWS	Budgeted Cost of Work Scheduled
BUR	Bottom-Up Review
BVR	Beyond visual range
CAIG	Cost Analysis Improvement Group
CAIV	Cost as an Independent Variable
CARD	Cost Analysis Requirements Description

CBB	Contract budget baseline
CBO	Congressional Budget Office
CCDR	Contract Cost Data Report
CMWS	Common Missile Warning System
CNI	Communication, Navigation, and Identification
CPR	Cost Performance Report
CTC	Contract Target Cost
DCS	Digital Communication System
Dem/Val	Demonstration and validation
DoD	Department of Defense
DoDD	DoD Directive
DOT&E	Director of Operational Test and Evaluation
DT	Development test
DTW	Design-to-weight
DVMC	Digital Video Map Computer
EMD	Engineering and manufacturing development
EVM	Earned Value Management
EW	Electronic warfare
FMS	Foreign Military Sales
FOTD	Fiber Optic Towed Decoy
FY	Fiscal year
GAO	General Accounting Office
IDECM	Integrated Defensive Electronic Countermeasures
ILS	Integrated Logistics Support
IOC	Initial operational capability
IOT&E	Initial operational test and evaluation
IPT	Integrated product team
JET	Joint Estimating Team

JHMCS	Joint Helmet-Mounted Cuing System
LO	Low observable
LRE	Latest revised estimate
LRIP	Low-rate initial production
NATF	Navy Advanced Tactical Fighter
NAVAIR	Naval Air Systems Command
OPF	Operational Flight Program
OSD	Office of the Secretary of Defense
OTB	Over-target baseline
P3I	Preplanned Product Improvement
PA&E	Program analysis and evaluation
PAF	Project AIR FORCE
PDR	Preliminary Design Review
PGMs	Precision-guided munitions
PIDS	Positive Identification System
PM	Program manager
QDR	Quadrennial Defense Review
RAM	Radar-absorbing materials
RAS	Radar-absorbing structures
RDT&E	Research, development, test, and evaluation
RFI	Request for information
RFP	Request for proposal
RO	Reduced observable
RUG I	Radar Upgrade (from APG-65)
RUG II	Radar Upgrade (from APG-73)
SAM	Surface-to-air missile
SAR	Selected Acquisition Report
SE/PM	Systems engineering and program management

SHARP	Shared Advanced Reconnaissance Pod
SLOCs	Source lines of code
SMS	Software management system
SPO	System Program Office
ST&E	System test and evaluation
STOL	Short takeoff and landing
T&E	Test and evaluation
T/R	Transmitter and receiver
TAMMAC	Tactical Air Moving-Map Capability
USD (AT&L)	Under Secretary of Defense (Acquisition, Technology, and Logistics)
VLO	Very low observable
VMS	Vehicle Management System
WBS	Work Breakdown Structure

## Introduction

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### **Two Multirole Fighter Aircraft Programs Emerged at the End of the Cold War**

From the late 1980s through the present, the U.S. Air Force and the U.S. Navy have been engaged in acquiring two new multirole fighter aircraft platforms. The Air Force has pursued the F/A-22, the world's first supersonic stealth fighter,<sup>1</sup> while the Navy has developed the F/A-18E/F, a carrier-capable fighter with air-to-air, interdiction, and close air support capability. Currently, the F/A-22 is in the late stages of development, while the F/A-18E/F is in full-rate production and has already been deployed in Operation Enduring Freedom and Operation Iraqi Freedom.

Although these aircraft entered the Engineering and Manufacturing Development (EMD) at approximately the same time, their missions and performance goals differ widely. These differences are shaped in part by changes in the threat environment following the end of the Cold War. The F/A-22 was originally designed to counter what was perceived to be the growing Soviet fighter threat. Specifically, the Air Force wanted a new air-to-air fighter capable of defeating improved Soviet Su-27 and MiG-29 aircraft. The Air Force postulated that these new Soviet aircraft would have the capability to detect and fire on enemy fighters at lower altitudes (known as “look-down, shoot-down capability”) and that they would be fielded in

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<sup>1</sup> The Lockheed F-117, the first stealth combat aircraft, is a subsonic attack aircraft used primarily for air-to-ground operations.

large numbers. Supported by a Soviet version of the U.S. Airborne Warning and Control System (AWACS), this new threat would require a technically superior U.S. fighter to counter it. Because the F-117 could perform the attack role, what was needed, according to the Air Force, was a new, sophisticated and stealthy air-to-air fighter to replace the aging McDonnell Douglas F-15 (Aronstein, Hirschberg, and Piccirillo, 1998, p. 41). This vehicle was known as the Advanced Tactical Fighter (ATF). When the postulated Soviet threat failed to materialize, however, questions were raised concerning the need for large numbers of a technologically advanced fighter dedicated solely to the air-to-air mission.<sup>2</sup> Perhaps in response to this criticism, in summer 2002 the Air Force, arguing that it needed to be able to counter a growing proliferation of surface-to-air missile (SAM) threats, added suppression of enemy air defenses to the new platform's list of missions and redesignated the aircraft the F/A-22. Thus, the F/A-22 has evolved into a multirole fighter.

The F/A-18E/F was not designed to counter a new threat or an improved Soviet capability. In fact, by the late 1980s the Navy had concluded that the threat to its battle group from enemy aircraft had diminished sufficiently that a replacement for the F-14 was not warranted. Consequently, the E/F program was initiated essentially to address the shortcomings of the F/A-18A/B and C/D models—specifically, limited bring-back capability<sup>3</sup> and less than desired range—that limited their ability to carry out missions associated with littoral warfare. As stated in the F/A-18E/F Cost Analysis Require-

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<sup>2</sup> In April 1995, the Defense Science Board F-22 Task Force final report alluded to looking at relaxing some F-22 requirements. Specifically, it recommended that “there are substantial margins throughout the F-22 specifications and a very capable aircraft would result even if performance fell somewhat short of meeting many or even all of these specs. It is therefore important that the [System Program Office] and [the Office of the Secretary of Defense] not take a rigid stance on meeting all specs but rather, as the program progresses, look at the overall performance, cost and schedule impacts on deciding which, if any, performance areas need further work.”

<sup>3</sup> “Bring back” is the ability of an aircraft to land on a carrier with a certain amount of unused ordnance and fuel. This is increasingly important with costly precision munitions becoming more the norm for combat ordnance.

ments Description (CARD),<sup>4</sup> “the objective of the F/A-18E/F program is to develop, test, produce, and deploy an upgraded F/A-18 with increased mission range, increased aircraft carrier recovery payload, additional growth potential, and enhanced survivability.” With the increased attention during Operation Desert Storm from the use of precision-guided munitions (PGMs), the F/A-18E/F was designed with a greater “bring-back” capability. Thus, from the beginning, the F/A-18E/F was designed as a multirole fighter to perform the same missions and counter the same threats as earlier models of the F/A-18 but with some incremental increase in capability.

Tables 1.1 and 1.2 illustrate the different performance goals as well as other metrics of each platform compared with the aircraft they were intended to replace.<sup>5</sup> The performance metrics are speed, payload, range, and engine thrust. We also compare the avionics weight as a proxy for complexity. Finally, we compare the stealth feature of each platform. Because of the classified nature of military aircraft stealth technology, we use a subjective method to provide the reader with a qualitative relative comparison. These qualitative categorizations are very low observable (VLO), low observable (LO), reduced observable (RO), and minimum treatment (MIN). VLO airframes

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<sup>4</sup> The CARD documents the ground rules and assumptions for a program at a specific point in time, typically at a major milestone decision point. It is required to be provided by DoDI 5000.2 at milestones B and C or when an economic analysis is required. The information in the CARD describes the physical, performance, and contract assumptions behind the program and should be used as the basis of the program office estimate. The program office or sponsoring agency is responsible for preparing the CARD in draft format at initiation of the independent cost activities and a final version prior to the milestone decision. Areas of information include a system overview, risk, operational concept, quantities, manpower requirements and activity rates, schedule, acquisition plan, development plan, facilities requirements, track to prior CARD, and Contract Cost Data Report (CCDR) plan.

<sup>5</sup> The information on these tables for the F-14, F/A-18A/B, F-16, and F-15A/D came from the Institute for Defense Analysis Report, *Military Tactical Aircraft Development Costs* (R-339), 1988. The values for the F/A-18E/F and the F/A-22 came from the CARDS, unclassified program office briefings, and other open source publications. One difficulty of this depiction is ensuring common definitions of performance across the platforms. Perfectly congruent definitions were not possible for comparing all these platforms because of the varied sources used and the visibility of performance characteristics.



**Table 1.1**  
**Comparison of Some of the F/A-22 Performance Gains over Legacy Aircraft**

Performance Characteristics	F/A-22	F-15C/D	F-16C/D
Speed (knots)	1,434 <sup>a</sup>	1,434	1,184
Payload (pounds) <sup>b</sup>	17,589	26,635	20,094
Range (nautical miles)	415	648	346
Avionics Weight (pounds)	1,891	1,250	1,045
Engine Thrust (pounds) <sup>c</sup>	35,000	23,840	23,840
Stealth <sup>d</sup>	VLO	MIN	MIN

<sup>a</sup>Mach 2 class.

<sup>b</sup>Payload is defined as the useful load, which equates to the weight that can be carried in stores (weapons, pods, and fuel tanks) and the weight of the internal fuel. It was generally calculated by subtracting the empty weight of the aircraft from the maximum (or gross) takeoff weight of the aircraft.

<sup>c</sup>Thrust is typically the maximum thrust of each engine.

<sup>d</sup>Stealth was given a subjective range judged by the authors to include the following points: MIN, RO, LO, and VLO.

**Table 1.2**  
**Comparison of Some of the F/A-18E/F Performance Gains over Legacy Aircraft**

Performance Characteristics	F/A-18E/F	F-14	F/A-18C/D
Speed (knots)	1,059	1,170	1,029
Payload (pounds)	35,436	31,663	28,850
Range (nautical miles)	520	521	363
Avionics Weight (pounds)	1,411	2,821	1,289
Engine Thrust (pounds)	20,832	20,900	17,775
Stealth	RO	MIN	MIN

include not only a significant amount of Radar-Absorbing Materials (RAM) used in the treatment of all airframe surfaces but also Radar-Absorbing Structures (RAS) and the overall shaping of the airframe. The use of RAM and RAS progressively decrease from LO to MIN.

As shown on Table 1.1, the F/A-22 was designed to provide significant performance gains over the F-15 and F-16 fighters. Most important was the inclusion of cutting-edge innovations in stealth and an integrated avionics suite. The F/A-18E/F, as shown on Table 1.2, was intended to provide some incremental improvements over the C/D model, especially in the areas of stealth, range, and payload capacity. However, it is important to note that the F/A-18E/F sought

lower performance in some areas compared with the F-14. As we discuss in Chapter Two, these lower performance goals were motivated by concerns about the platform's cost.

## **These Programs Performed Differently During Their Development Phases**

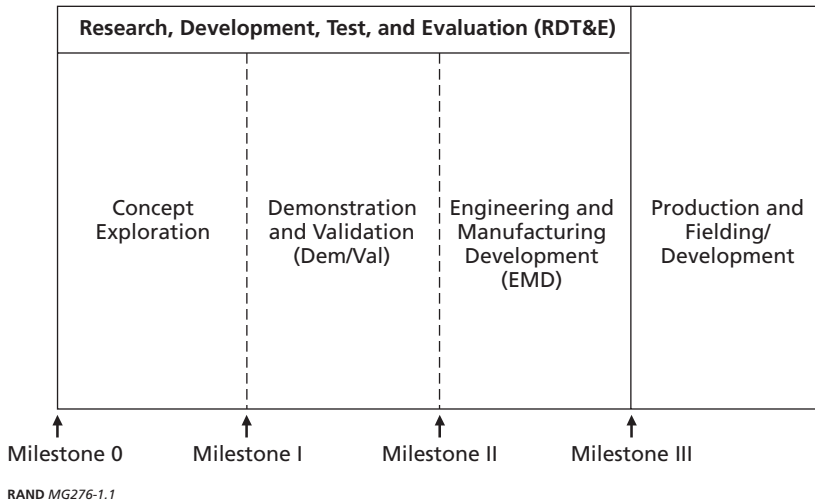
The acquisition of new combat aircraft is a lengthy process involving a series of milestones and approvals that must be obtained from the Department of Defense (DoD). This process is intended to ensure that a new platform can provide its promised technical capabilities in a timely and cost-effective way. The F/A-22 and F/A-18E/F acquisitions were modeled after the earlier version DoD instruction 5000.2.<sup>6</sup> Figure 1.1 illustrates this process. The old instruction divided the acquisition process into two distinct phases: the research, development, test, and evaluation (RDT&E) phase and the production phase. In the old instruction, RDT&E was broken down into the demonstration and validation (Dem/Val) phase and EMD phase.

The F/A-22 and F/A-18E/F programs are important examples of the stability or instability that new aircraft platforms may experience during the EMD phase. Figure 1.2 compares the schedule and cost planned for each program at the beginning of its development phase with the actual time and cost it took to complete this phase. As shown on the left, the F/A-22 has exceeded its original schedule by more than 52 months as of the date of the last Selected Acquisition Report (SAR) examined (December 31, 2001), while the F/A-18E/F was virtually on time. The total cost of developing the F/A-22 grew by \$7.6 billion in fiscal 1990 dollars compared to the F/A-18E/F program, which met its original cost estimates.

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<sup>6</sup> The current version has streamlined the acquisition process by eliminating unnecessary reports and reviews.

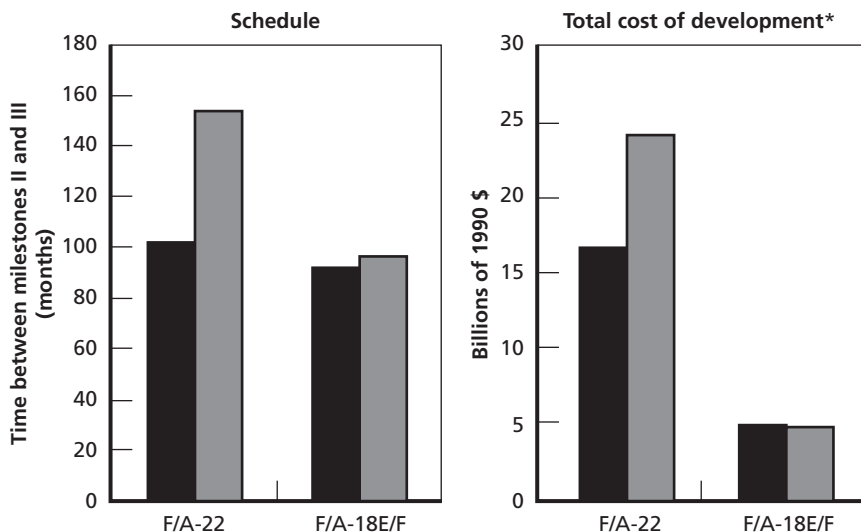
**Figure 1.1**  
**Acquisition Process for F/A-22 and F/A-18E/F Programs**



These differences represent gradual trends evident over the course of the development phase of each program. For example, Figures 1.3 and 1.4 display the estimated completion date of each step in the EMD phase (the y-axis) as reported in annual SARs (the x-axis). A flat line indicates that the program objective was met on the originally planned date, while a rising line depicts a slip in schedule. As shown on Figure 1.3, every major milestone of the F/A-22 development program slipped. For example, initial operational test and evaluation (IOT&E) and Milestone III completion dates slipped by more than two years. Moreover, we would like to emphasize that the test and evaluation (T&E) program is not complete and program development is not over; therefore further slippage might occur. In contrast, as shown in Figure 1.4, very few schedule slips occurred in the F/A-18E/F program, with the exception of the initial operational capability (IOC) date.

Similarly, Figure 1.5 depicts the estimated development costs for each program as reported in the annual SARs. As shown at the top, the F/A-22 RDT&E, which includes both Dem/Val and EMD,

**Figure 1.2**  
**F/A-22 Experienced Schedule Slips and Cost Growth, While the F/A-18E/F Completed Development on Time and on Cost**



\*Includes government costs.

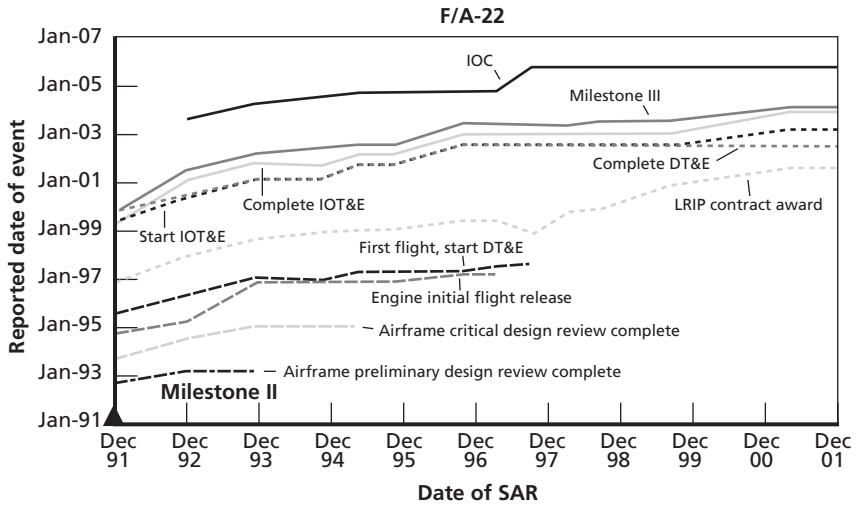
SOURCE: Selected Acquisition Reports.

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increased at a gradual rate. The F/A-18E/F, shown at the bottom, showed very little fluctuation during the entire development period.

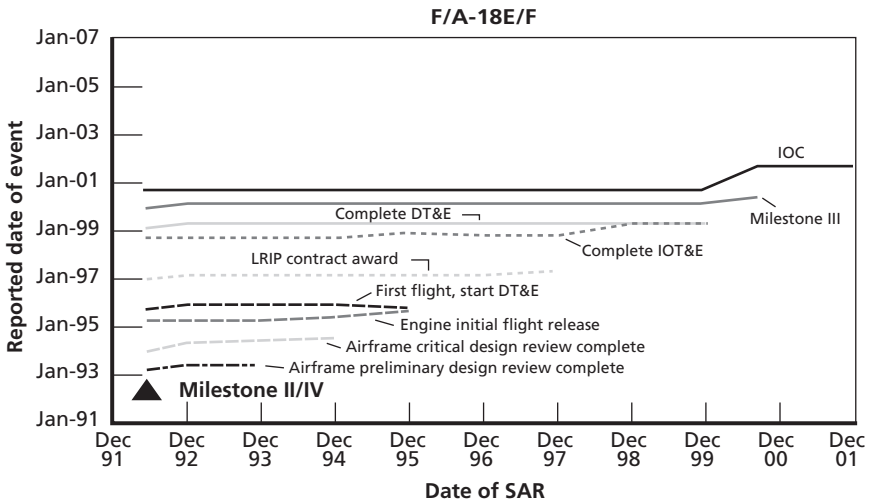
How do the F/A-22 and F/A-18E/F experiences compare with other Air Force and Navy tactical fighter programs in recent years? Historical experience suggests that such programs often take longer and cost more to develop than originally planned. However, the F/A-22 and F/A-18E/F represent exceptional cases. The F/A-22 cost and schedule is substantially higher than historical combat aircraft cost and schedule growth, and the F/A-18E/F is substantially lower than that average. Figure 1.6 shows how well previous fighter aircraft have met their estimated schedules for achieving first flight, first production, and IOC. A value of 1.00 indicates that the program met its schedule goal. As shown on the right, the degree of slippage in the F/A-22 schedule far exceeds that of previous tactical fighter programs.

**Figure 1.3**  
**F/A-22 Schedule Estimates Grew Throughout the Development Phase**



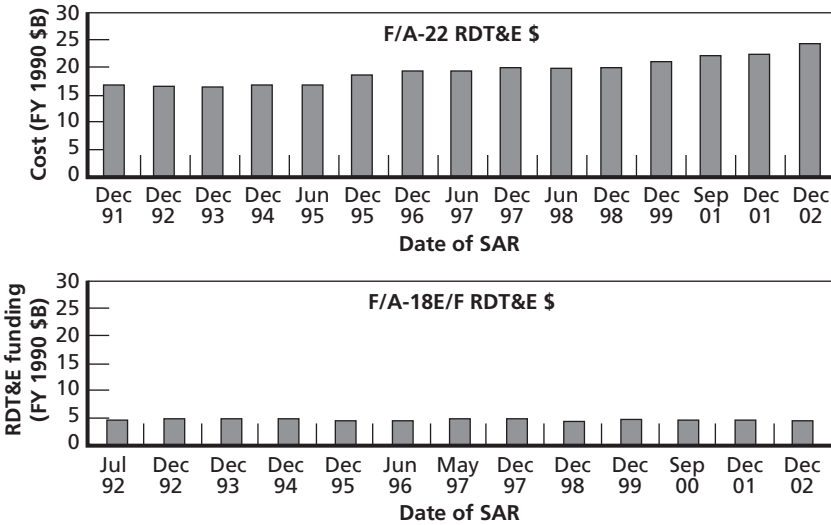
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**Figure 1.4**  
**F/A-18E/F Schedule Estimates Remained Steady Throughout the Development Phase**



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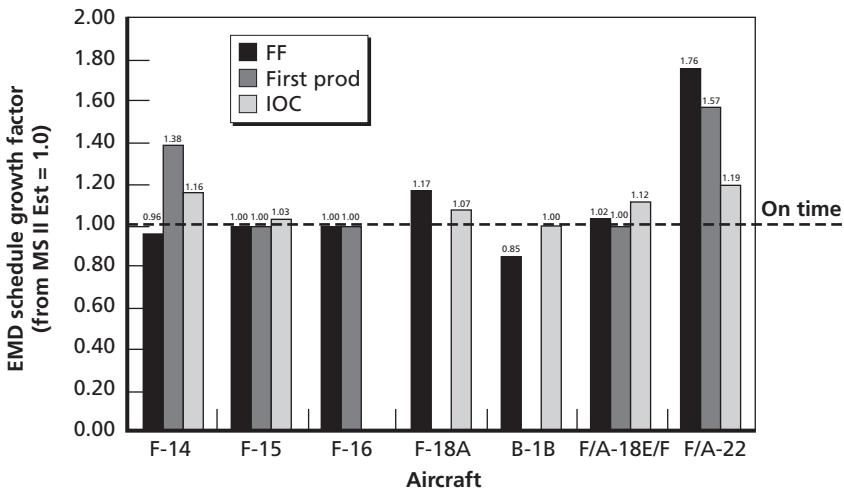
**Figure 1.5**  
**F/A-22 Costs Rose Steadily, While F/A-18E/F Costs Remained Stable**



SOURCE: Selected Acquisition Reports 1991–2002.

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**Figure 1.6**  
**F/A-22 Schedule Slippage Is Higher Than the Historical Average**



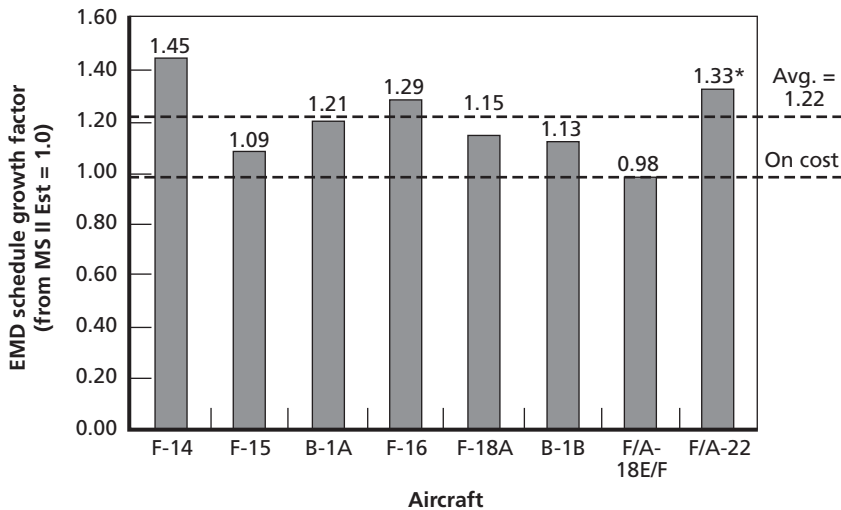
NOTE: Numbers on top of bars reflect current estimate.

RAND MG276-1.6

The F/A-22 program took 76 percent longer than estimated to achieve first flight and 57 percent longer to reach first production, and it is expected to take 19 percent longer to reach IOC. The next set of bars to the left indicate that the F/A-18E/F took only 2 percent longer than estimated to reach first flight, reached first production on schedule, and took only 12 percent longer to reach IOC.

The results are similar if we compare the cost growth figures for previous tactical fighter programs. Figure 1.7 displays cost growth (or reduction) as measured by dividing the last reported cost in the program SAR at the end of the program by the original cost estimate at Milestone II. A value of 1.00 represents no cost growth. As the figure shows, the F/A-22 cost growth is second only to that of the F-14, with the potential to continue growing until the development phase is complete. The F/A-18E/F is lower than the historical average and is the only program to complete its development under cost.

**Figure 1.7**  
**F/A-22 Cost Growth Is Higher Than the Historical Average**



\*Based on March 03 program office estimate.

## **Purpose of This Report**

The schedule and cost overruns in the F/A-22 program have generated considerable concern from DoD and Congress, leading to close scrutiny of the program and reductions in the number of aircraft to be produced. The office of the Assistant Secretary of the Air Force for Acquisition asked RAND Project AIR FORCE (PAF) to investigate the reasons behind the cost growth and schedule delay of the F/A-22 program and those contributing to the cost and schedule stability of the F/A-18E/F program during EMD. This report examines the acquisition strategies employed by the F/A-22 and F/A-18E/F programs from their inception through the Dem/Val and EMD phases. The analysis is based on various cost and schedule reports available to PAF as well as data and information available in open sources. For instance, the SARs, CCDRs, and Cost Performance Reports (CPRs) were the main sources of data for the cost and schedule growth analysis. Other documents, such as Cost Analysis Requirements Description (CARD), contractor's weight reports, General Accounting Office (GAO) reports, and published articles and reports were also examined. The purpose of this analysis is to derive lessons that the Air Force and other services can use to improve the acquisition of such future aircraft as the Joint Strike Fighter and such other systems as unmanned aerial vehicles and missile programs.

## **Organization of This Report**

Chapter Two discusses the acquisition strategies and industrial base issues that affected the performance of each program from inception through the EMD phase. Chapter Three analyzes the specific technology issues that surfaced during each program's EMD phase and discusses their effect on schedules and costs. Chapter Four evaluates the management approaches of each program to determine how schedules and costs were controlled during EMD. Chapter Five summarizes our conclusions and provides a list of lessons learned that the Air Force acquisition community should consider in developing



future weapon systems. Finally, Appendix A discusses the Department of Defense oversight and congressional interests in each program, some of which may have posed further challenges.

## **Acquisition Strategies and Industrial Base Issues**

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This chapter discusses the acquisition strategies employed by the F/A-22 and F/A-18E/F programs from their inception through their EMD phases. We examine the methods used by each program to solicit and evaluate contractor proposals during the Dem/Val phase and the division of work among contractors during the EMD phase. As we shall see, concerns about the needed mix of technical expertise and other industrial base issues led the F/A-22 program to distribute the work equally among the three contractor team members in the program, which resulted in an artificial distribution of work during the EMD phase. This strategy may have contributed to the schedule and cost problems experienced in the program. By contrast, the F/A-18E/F program drew on preexisting relationships and contractor expertise to minimize the technology risks involved in the project. In addition to having a team with historical ties, the program implemented a number of acquisition reform strategies designed to control costs and schedules.

### **The F/A-22 Program Sought to Maximize Participation by Multiple Contractors**

We begin with an overview of the F/A-22 program's acquisition strategy from the ATF program in the early 1980s to the Dem/Val and EMD phases.

### **The F/A-22 Represented an Important Opportunity for the Combat Aircraft Industrial Base**

In November 1981, DoD formally launched the ATF program.<sup>1</sup> As noted in Chapter One, this program was intended to produce a replacement for the McDonnell Douglas F-15, then the Air Force's premier air superiority fighter, with a supersonic stealth aircraft that would use state-of-the-art advances in aerospace technologies and capabilities.

Very soon, it appeared to the U.S. aerospace industry that the ATF would be the only opportunity to develop an all-new, cutting-edge-technology supersonic fighter for the next decade or more. This was because in 1983, because of budget constraints and competing priorities, the U.S. Navy put on hold its plans for procuring a new common fighter (labeled the VMFX) to replace both the Grumman F-14 fleet air defense fighter and the Grumman A-6 attack aircraft. The Navy replaced the VMFX program with a new program to upgrade existing F-14s and A-6s and to procure a new stealthy subsonic attack aircraft, called the Advanced Tactical Aircraft (ATA).<sup>2</sup> Thus, after 1983, U.S. contractors could expect at most only one major development program for an all-new supersonic air-superiority fighter—the ATF—and one other program for a subsonic attack aircraft—the ATA—at least over the following decade.

All nine then-active U.S. defense aerospace prime contractors hoped to compete for the ATF full-scale development effort: General Dynamics, McDonnell Douglas, Lockheed, Northrop, Boeing, Grumman, Rockwell North American, Vought, and Fairchild. As early as May 1981, the Air Force had issued a Request for Information (RFI) seeking conceptual design studies to all nine contractors.

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<sup>1</sup> The ATF program was the forerunner of the F-22 program, which later became the F/A-22 program. The Defense Resources Board first approved ATF program start-up on November 23, 1981. The most detailed unclassified history of the early period of the F-22 program through the end of the system demonstration and validation phase is found in Aronstein, Hirschberg, and Piccirillo (1988).

<sup>2</sup> In November 1984, two teams won preliminary design contracts for the ATA: McDonnell Douglas teamed on an equal basis with General Dynamics, while Northrop led a team that included Grumman and Vought.

At this early stage, competition among contractors was fierce. Every participant knew that many of the losers would ultimately have to withdraw as stand-alone prime contractors from the fighter-attack aircraft market sector. Indeed, the aftermath of the ATF and ATA competitions witnessed the beginning of a massive corporate consolidation and downsizing that transformed the very structure of the U.S. aerospace industry.

As was the case during the early stages of the F-X (F-15) program nearly two decades earlier, considerable debate existed initially within the Air Force and DoD regarding the most desirable mission focus and performance characteristics for the ATF. During 1982, a consensus began to emerge that a modified version of the F-15 or F-16 could perform the air-to-ground role, permitting the ATF to be optimized for air superiority.<sup>3</sup> By mid 1983, the ATF had clearly been defined as an F-15 air superiority fighter replacement.

Following the emergence of this consensus, the Air Force awarded concept development contracts in September 1983 to further refine the design concepts for the ATF. Nine months later, in May 1984, after numerous design iterations, the seven remaining participating airframe prime contractors concluded the ATF concept development phase by submitting their final reports.<sup>4</sup> At this time Air Force acquisition officials planned to select as many as four prime contractors late in 1985 to begin a 32-month concept Dem/Val phase.

By this time it was generally recognized that the extremely demanding ATF performance requirements being refined by the Air Force would pose substantial technological, design, engineering, and

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<sup>3</sup> General Dynamics and McDonnell Douglas developed prototypes of their competing modification proposals called F-16XL and F-15 Strike Eagle, respectively, which first flew in 1982. Two years later, the Air Force selected McDonnell Douglas's entry for full-scale development as the F-15E. The F-16XL and F-15E programs had an effect on the ATF program parallel to the decision to procure the LTV A-7 in the 1960s, a decision that permitted the F-X (F-15) requirement to focus on the mission of air superiority. See Lorell and Levaux (1998).

<sup>4</sup> Early in the concept development stage, Vought and Fairchild opted out, leaving the remaining seven contractors to compete for the contract.

manufacturing challenges for industry. For example, the Air Force decided to seek supercruise capability (the ability to cruise at supersonic speed without afterburner) and engines with vectoring nozzles for short takeoff and landing (STOL) capability and greater agility, combined with stealth and F-15/F-16-class maneuverability. Planners decided to require development of the first fully integrated fighter avionics system, and incorporate revolutionary new technologies into the fire control radar based on a solid-state active electronically scanned array (AESA) technology.

In recognition of the daunting technological challenges posed by the program, the Air Force soon funded technology development and risk-reduction programs applicable to the ATF, such as efforts to develop new materials applicable to stealth, antenna arrays for AESA radars, and the F-15 STOL and Maneuver Technology Demonstrator program (S/MTD or NF-15B). In September 1983, the government launched the joint Advanced Tactical Fighter Engine (ATFE) program by awarding contracts to Pratt & Whitney and General Electric to develop advanced technology engine demonstrators. During 1985, seven contracts were awarded for predesign studies on the integrated avionics program called Pave Pillar. As anticipated, the Air Force sent out requests for proposals (RFPs) for a Dem/Val phase for the ATF in October 1985.

### **The Packard Commission Led to a Two-Team Approach for Demonstration and Validation**

The F/A-22 program's Dem/Val phase was affected by changes brought by a Presidential Blue Ribbon Commission, also known as the Packard Commission. In 1986, the commission reviewed the Department of Defense's management and acquisition process and recommended a number of reform initiatives. Most important among these reforms were the requirements for two competing contractors to develop technology demonstration prototypes during Dem/Val, greater emphasis on performance specifications as opposed to detailed technical specifications, and contractor sharing in development costs. These initiatives were intended to reduce technological risk and to

maintain competitive pressures to promote cost savings and greater innovation throughout the early phases of development.

From the beginning, the ATF program was managed within the standard regulatory and organizational structure of traditional major Air Force acquisition programs. Nonetheless, the Packard Commission reforms led to important program innovations. The Air Force reorganized the ATF System Program Office (SPO) around government-industry integrated product teams (IPTs) and granted the competing contractors considerable control over the structuring of the prototype technology demonstration effort. IPTs are composed of a team of individuals representing various engineering and management functions. It is a key component of the integrated product development approach. The F/A-22 program was one of the first major acquisition programs to implement the IPT structure before DoD mandated its use in 1995.<sup>5</sup> These innovations led to a restructuring and extension of the Dem/Val program schedule by two years, with a slip of the anticipated Milestone II decision (for the full-scale development phase) from December 1988 to December 1990.<sup>6</sup>

The seven participating prime contractors all responded to the Dem/Val RFP with serious design proposals. Partly because of concerns over the future of the industrial base, the Air Force encouraged the prime contractors to team together so that broad industrywide participation could be maintained at least through the Dem/Val program. The Office of the Secretary of Defense (OSD) granted Milestone I (now A) approval and the Air Force selected Lockheed and Northrop in October 1986 to lead competing teams during a planned 54 month Dem/Val phase. Lockheed led a team composed of General Dynamics and Boeing, while Northrop teamed with McDonnell Douglas. Only one team, of course, would receive the final award for full-scale development at the end of the competitive

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<sup>5</sup> For a more detailed discussion of the IPT structure, see Cook and Graser (2002).

<sup>6</sup> In October 1989, the Defense Acquisition Board (DAB) slipped completion of the Dem/Val stage another six months to June 1991. DoD has since renamed the full-scale development phase twice for all major acquisition programs: first as EMD, then as the system development and demonstration (SDD) phase.

Dem/Val stage. GE and P&W received new contracts to continue technology development for the newly named ATFE program.

In mid 1990, the two ATF contractor teams began flight-testing their technology demonstrator prototypes: the Lockheed YF-22 and the Northrop YF-23. On April 23, 1991, more than five years after the beginning of the Dem/Val phase and following an extensive flight test program, the Air Force selected the Lockheed/General Dynamics/Boeing YF-22 for full-scale development as the next Air Force air superiority fighter, and designated it the F-22. In August, the Air Force awarded Cost Plus Award Fee EMD contracts to Lockheed and Pratt & Whitney. Despite the technical challenges, most observers consider the Dem/Val program to have been well managed and highly successful.<sup>7</sup>

### **The F/A-22 Program Created an Artificial Split in Workload**

Despite the successful completion of the Dem/Val phase, the division of work among contractors during the EMD phase proved to be a source of problems. One issue was the division of EMD work equally among the three major contractors. Lockheed Martin, the prime contractor, was clearly the leader in stealth aircraft design with F-117 experience. As team members, it chose General Dynamics for its fighter aircraft experience and Boeing for its innovative manufacturing approaches that had made it the industry leader. Both the contractors and the government justified the work split as a way to ensure that each contractor maintained its capability to remain competitive as prime contractors for future business.

This work split may have led to an artificial distribution of the development effort. As shown in Figure 2.1, the F/A-22 EMD work was divided among the three contractors in such a way that the major elements of the airframe, avionics, and support systems were given to different team members. For instance, although the F/A-22 avionics suite is a highly integrated system, various elements are managed and controlled by different team members. Other F/A-22 design features

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<sup>7</sup> For example, see Myers (2002) .

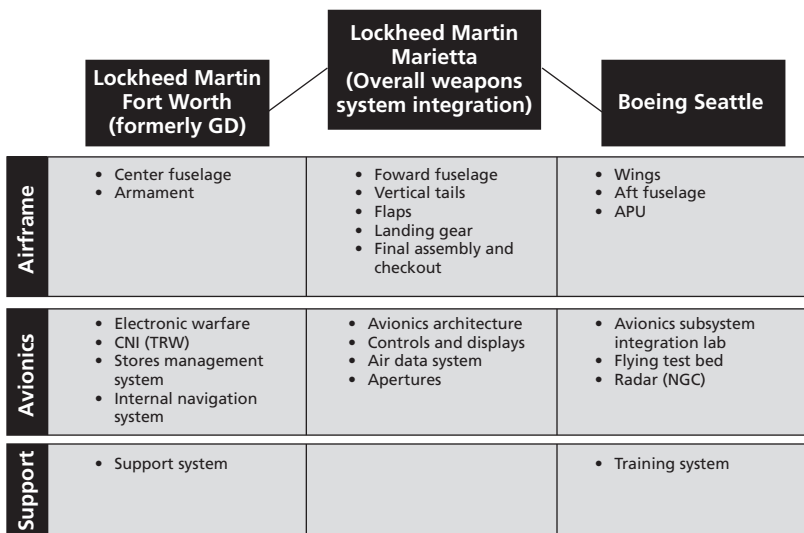
are highly integrated as well, and combining the systems developed by different team members has proven to be a challenge for the prime contractor, as discussed further in Chapter Three.

**The F/A-22 Did Not Have a Stable Industrial Base**

Another source of problems during EMD was the F/A-22’s lack of an existing industrial base and members of a supplier network experienced in working with one another in fabricating, assembling, and producing the high-technology components necessary for the new aircraft. Three problems in particular delayed the project’s schedule and increased its costs.

First, the EMD program management and design oversight responsibilities were moved from Burbank, California, to Marietta, Georgia, in January 1991. Lockheed and the U.S. government publicized the move as a cost-cutting measure. The Marietta facility, mainly a production facility with transport aircraft (C-141, C-5, and C-

**Figure 2.1**  
**F/A-22 EMD Work Was Artificially Distributed Among the Contractors**



SOURCE: Lockheed Martin F/A-22 website.



130) experience, lacked an in-house design team that understood the technology and innovation required for a state-of-the-art air superiority fighter.<sup>8</sup> Less than 10 percent of the core team that had worked on the ATF during Dem/Val as well as the early stages of the EMD phase moved from Burbank to Marietta. Because the facility had no previous experience with fabricating high-technology aircraft or parts, it has taken longer than expected to assemble and deliver test aircraft during EMD. Moreover, in 1999, the program experienced problems fabricating the F/A-22's wings from composites. This problem forced Boeing to qualify a second supplier to speed deliveries, thereby exacerbating the cost and schedule problems. A machinists' strike in 2002 further delayed the delivery of test aircraft. This inability to attract engineers and managers who gain specialized experience during the early phase of development from Burbank to Marietta along with Marietta's lack of a design team capable of meeting the F/A-22's engineering challenges arguably may have been the root of many problems during development.

Second, the F/A-22 faced the problem of overcapacity in its production facilities when it entered production. The Marietta facility was expanded in 1992 to accommodate a production line capable of assembling 48 F/A-22s per year. Since the early 1990s, however, peak production has been cut to 32 per year. The likelihood of foreign military sales (FMS) to increase production rates is also dim. The F-22's high cost makes it an unlikely candidate for a significant number of FMS, and DoD and the State Department may be reluctant to release the advanced technology in the F/A-22 to overseas customers.

Finally, the GAO expects that lower-than-expected FMS of the C-130J, also assembled at Lockheed Martin's Marietta facility, will raise overhead costs at the plant. Some of these costs would ultimately have to be borne by the F-22 program (GAO, 2000, p. 16).

Concerns about the needed mix of technical expertise and other industrial base issues had led the F/A-22 program management to

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<sup>8</sup> According to press reports, Lockheed Martin decided to assemble the F-22 at its Marietta plant under pressure from then Senate Armed Services Committee Chairman Sen. Sam Nunn. See Grossman (2002).

distribute the work equally among the three contractor team members, which may have resulted in an artificial distribution of work during the EMD phase and potentially contributed to the schedule and cost problems experienced in the program.

## **The F/A-18E/F Program Drew on Preexisting Expertise and Contractor Relationships**

We turn now to an assessment of F/A-18E/F acquisition strategies and industrial base issues from the program's inception through the EMD phase.

### **The Navy Adopted a Cautious Approach to F/A-18E/F Acquisition**

As discussed in Chapter One, the U.S. Navy began pursuing plans to develop a new supersonic fighter/attack aircraft in the early 1980s. The Navy considered several options to meet this requirement. One option was to modify the existing F/A-18C/D design. The Navy examined at least seven major new configurations for the "Hornet 2000" conceptual design effort, including significantly more advanced designs incorporating totally new wing designs and avionics changes.<sup>9</sup> Another alternative was to modify and upgrade the Grumman F-14. A third option was to procure a variant of the ATF, which was then in the Dem/Val phase. Indeed, in September 1988, the Navy contracted with the ATF airframe and engine contractors to conduct design studies for a naval version of the ATF called the Navy ATF (NATF). The Navy established an NATF SPO collocated with the Air Force ATF SPO at Wright-Patterson AFB, Ohio.<sup>10</sup>

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<sup>9</sup> General Dynamics also continued to conduct modification and design upgrade studies of improved versions of the F-16 for the Air Force and for potential foreign customers.

<sup>10</sup> In March 1986, the Navy formally agreed to evaluate the ATF or a variant as a possible F-14 replacement and the Air Force agreed to evaluate the ATA as an F-111 replacement. This agreement and the later formal but brief Navy participation in the ATF (NATF) Dem/Val program were driven in large part by congressional pressure. See Aronstein, Hirschberg, and Piccirillo (1998).

Ultimately, the Navy chose to modify the F/A-18C/D. By and large, cost considerations drove this decision. In January 1988, the Navy had selected the McDonnell Douglas/General Dynamics team to develop the stealthy ATA, now known as the A-12. However, by mid-1990, the A-12 program was already at least \$1 billion over cost and 18 months behind schedule. In January of 1991, then-Secretary of Defense Dick Cheney canceled the program. The A-12 program proved to be a major embarrassment to the Navy. With the F/A-22 likely to evolve into a high-end, high-priced air superiority fighter optimized for Air Force requirements and smarting from the A-12 fiasco, the Navy preferred to pursue the lower-cost, lower-risk multi-mission design approach based on the Hornet 2000 studies.

The cancellation of the A-12 program in 1991 had a profound effect on the management of the F/A-18E/F program. Not wishing to meet the same fate, the E/F team of Navy managers and contractors was adamant that they would learn from the failure of the A-12 program. As a result, the E/F program office established a system for closely monitoring the contractor's cost and schedule performance. The program office sought to work closely with the contractors and did so by setting up a routine of daily phone calls between the Navy program manager and his counterpart from the prime contractor, McDonnell Douglas, and weekly video or teleconferences that also included representatives from Northrop and General Electric, the contractors responsible for the modified center and aft portions of the fuselage and the engines, respectively. The program manager also established a dedicated data line so that analysts in the program office would have the same access to cost and performance data as the contractors. Thus, although the A-12 cancellation did not affect the F/A-18E/F program directly, it motivated the program manager to take steps to tightly control cost and schedule performance.

The technology requirements for the aircraft were deliberately crafted to control technological risk and to constrain costs. The Navy directed McDonnell Douglas to undertake further risk-reduction studies throughout 1991, resulting in the rejection of some of the more radical contractor design modification proposals from the Hornet 2000 effort. In October of that year, the Navy formally requested

designation of the Hornet 2000 program, now known as the F/A-18E/F, as a major modification effort rather than as a new program start. Although the new F/A-18E/F design entailed major airframe modifications, the Navy intended to incorporate existing F/A-18C/D avionics and a derivative of the existing engine. While all new, the airframe design for the F/A-18E/F was aerodynamically similar to the F/A-18C/D.<sup>11</sup> Perhaps most important, the new aircraft design was burdened with far less demanding performance requirements than the F/A-22 was. For example, the F/A-18E/F eschewed such technologically challenging and potentially costly F/A-22 requirements as supercruise, full stealth capability, thrust vectoring, fully integrated new avionics, and AESA radar.<sup>12</sup> In addition to these acquisition strategies, the F/A-18E/F program employed a key acquisition reform concept later formalized as Cost as an Independent Variable (CAIV).<sup>13</sup> By early 1992, the senior Navy leadership had made it clear that the E/F program would not proceed unless the cost estimates for the development program and for the average unit flyaway costs remained under strict ceilings dictated by likely funding realities.<sup>14</sup>

In May 1992, OSD formally designated the F/A-18E/F program as a major modification program (Milestone IV/II approval),

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<sup>11</sup> Unlike the Hornet 2000 design proposals, which retained the basic F/A-18C/D fuselage and merely inserted plugs for greater length, the follow-on designs that evolved into the F/A-18E/F design were completely new and different from the F/A-18C/D design.

<sup>12</sup> Whether the F/A-18E/F design could most accurately be characterized as a major modification of the F/A-18C/D or as a totally new design remained controversial with Congress. Because of its designation as a “major modification” rather than a new start, the F/A-18E/F avoided a significant amount of programmatic documentation, oversight, and review requirements normally associated with the early phases of major DoD acquisition programs. Perhaps most accurately, the F/A-18E/F program could be characterized as a spiral development program or one following the acquisition philosophy of Preplanned Product Improvement (P3I). Thus, while no AESA radar or Forward-Looking Infrared (FLIR) systems were required for the initial variant, they were included in the engineering specification as planned upgrades for future variants.

<sup>13</sup> The basic concept of CAIV is that it raises cost goals to the same priority level as schedule, performance, and other key program and system goals during the design, development, and production phases of a weapon system.

<sup>14</sup> These were \$4.9 billion for R&D and \$39 million for unit flyaway cost (both in FY 1991 dollars).

enabling direct entry into EMD.<sup>15</sup> On July 20 of that year, the Navy awarded a sole-source contract for full-scale development to McDonnell Douglas. After award of the basic EMD contract, the Navy and industry completed a design review of the General Electric F414 engine intended for the fighter. The F414 was an evolutionary engine based on the F404 and used the F412 core, which was partially developed for the A-12 program. Thus the engine selection was also intended to reduce technological risks and costs.

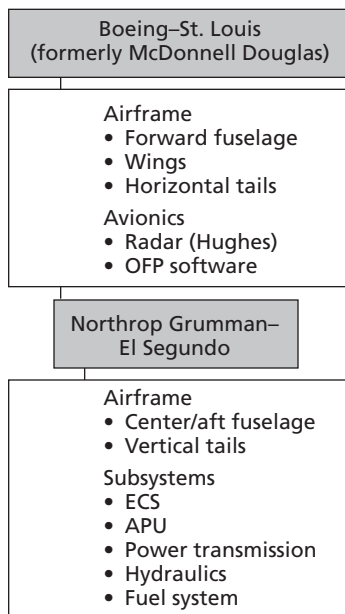
### **The F/A-18E/F Program Developed a Worksharing Agreement Based on Contractor Specialties**

Unlike the F/A-22, the F/A-18E/F used an existing workshare break-out based on the history of contracts on the F/A-18A/B/C/D development and production. McDonnell Douglas (now a part of Boeing) was considered the prime contractor, and Northrop (now Northrop Grumman) was a major subcontractor on the effort (as opposed to a partnership of equals in the F/A-22). The F/A-18E/F team of McDonnell Douglas and Northrop had substantial experience on the F/A-18C/D. Both contractors had experienced design teams in place and drew heavily from existing suppliers and industrial base. As shown in Figure 2.2, this workshare arrangement allowed the contractors to concentrate on their specialties from the predecessor program and to use their existing subcontractor industrial base. Similar to the F/A-18C/D, Northrop Grumman remained responsible for the aft fuselage section of the aircraft and the ultimate responsibility to integrate the entire weapon system rested on McDonnell Douglas. Major subsystem subcontractors, such as General Electric for the engine and Hughes for the radar, remained the same. Other avionics suite components remained common with the F/A-18C/D. Thus the program leveraged the existing vendor base to a large extent.

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<sup>15</sup> Although the program proceeded through a Milestone IV/II review, very little of the airframe was common between the F/A-18C/D and F/A-18E/F. The OSD (CAIG) memo from March 1992 states, "The F/A-18E/F will be a new aircraft. We estimated EMD costs based on a new airframe and engine, as did the Navy."

**Figure 2.2**  
**F/A-18E/F EMD Work Breakout Was Less Complex Than the F/A-22 and Had Historical Roots**



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### **The Use of IPTs Further Minimized Technical and Programmatic Challenges**

While the F/A-18E/F program was not free from serious technological and programmatic challenges, it progressed throughout the 1990s more or less in accordance with its original schedule estimates. One reason was that the program office adopted a variety of new acquisition reform strategies that promoted program stability and close cooperation between the Navy program office and the contractor.

One such strategy was the use of IPTs. The F/A-18E/F program was in effect an informal Navy and DoD pilot program for development of the IPT concept. In 1992, the Commander of Naval Air Systems Command (NAVAIR) commissioned a special study group to develop a new strategy for major system acquisitions. The team rec-

ommended moving away from functional “stovepipes” toward a product orientation approach, which fully integrated functional areas, including both government and industry sides. The Navy developed an implementation plan and selected the F/A-18E/F program as a pilot program for “proof of concept” of this approach. Thus the F/A-18E/F program management, like the F/A-22, was organized in accordance with IPT principles three years before the Department of Defense officially mandated IPTs (OSD, 1995). Of course by the time the F/A-18E/F development was undertaken, the lessons from the IPT implementation from the early implementers were learned and the implementation approach was certainly more mature than when it was initially implemented in the F/A-22 program. Many observers believe effective use of the IPT approach was one of the most important management initiatives promoting stability and effective management of technological challenges in the F/A-18E/F effort.<sup>16</sup>

Numerous technical challenges were identified during developmental flight testing, but none led to major restructuring of the program or significant cost growth. The first F/A-18E/F test aircraft (Aircraft Number 1) flew in November 1995, 32 days ahead of schedule. The second test aircraft first flew one month later. The formal developmental flight test program began early the following year at NAS Patuxent River, Maryland. One problem that attracted considerable public attention was the “wing drop” problem, discovered in 1996. During certain maneuvers, one wing of the aircraft would unexpectedly stall or dip, causing the aircraft to roll. The Navy and contractors worked together closely to develop fixes. This type of a problem is not uncommon during the development of a new airframe. Other technical and performance areas that caused some controversy during development included combat range and survivability. Most of these problems were either successfully resolved or dealt with by other adjustments.<sup>17</sup>

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<sup>16</sup> See Bailey (1998).

<sup>17</sup> For example, see GAO (1999). Also see F/A-18E/F SAR, December 31, 1997.

Thus, with more limited technical objectives, tighter management controls, and continuing success in maintaining cost and schedule performance, plus the fact that there were few other short-term options for USN carrier aviation, the F/A-18E/F progressed through EMD with greater ease than the F/A-22.

## Conclusions

The following major lessons can be gleaned from the acquisition approaches of these programs:

- The “equal” teaming and work share may have led to an artificial work distribution in the F/A-22 program and may have contributed to cost and schedule problems. In contrast, the F/A-18E/F contractor team was structured according to experience on the F/A-18 A/B/C/D programs. Lines of responsibility were clearly defined between contractors and subcontractors.
- The F/A-22 program team included subcontractors with limited prior working relationships. In contrast, the F/A-18E/F program drew upon preexisting expertise and relationships.
- The F/A-22 program was one of the first implementers of IPT management structure. In contrast, the F/A-18E/F implemented the IPT per DoD mandate and when some lessons had already been learned.





## Potential Contributors to Cost and Schedule Growth

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This chapter discusses the technical factors that may have contributed to the F/A-22's cost and schedule growth and to the relative stability in the F/A-18E/F program. We evaluate the cost data reports and technical documents from the F/A-22 and F/A-18E/F program provided by the Air Force and the Navy cost analysis agencies. The cost information is from SARs<sup>1</sup> ending with the December 31, 2001, version for each program. We also used Contract Cost Data Reports (CCDRs)<sup>2</sup> as well as the Cost Performance Reports (CPRs).<sup>3</sup> We

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<sup>1</sup> SARs are status reports provided to Congress required by Title 10, USC 2432 for Major Defense Acquisition Programs (MDAPs). They provide information that covers program background, schedule, performance characteristics, funding summaries, and top-level contract information on the program. The schedule shows major design milestones within the program as it progresses from development into production and fielding. The funding summaries show the yearly amount of funding for the various appropriations that are used for the program. Typically, SARs are produced at the beginning of development (Milestone B) and annually at the end of the calendar year but may be required more frequently for significant changes on the program.

<sup>2</sup> CCDR reporting is required for all major acquisition category (ACAT) level 1 programs by DoDD 5000.4M and generally uses a product-oriented work breakdown structure (WBS) to categorize costs. This WBS is somewhat common across different programs thus allowing for collection of costs for systems in the same commodity. The CCDR also separates the nonrecurring and recurring efforts typically associated with a contract. The reporting requirement is flowed down to supporting contractors who perform a significant portion of the work.

<sup>3</sup> The CPR is a management tool that uses cost information to measure progress on a specific contract. The Earned Value Management System integrates technical, cost, and schedule information on a contract to allow the contractor and the government to obtain insight into the program on a timely basis (reports are generally provided monthly). An overall con-

were able to collect the top-level costs from the monthly CPRs on the main air vehicle contracts for the length of the EMD effort on both programs. In addition, while we could collect all the available F/A-18E/F CCDR data for EMD, we could only obtain F/A-22 EMD CCDRs from September 1995 to September 2002. Thus our analysis does not include the detailed cost for development from earlier years.

## Comparison of the EMD Program Costs

EMD program costs are driven in part by the complexity of the major subsystems within a fighter aircraft. A comparison of EMD program costs for the F/A-22 and the F/A-18E/F shows that the more far-reaching innovations in the F/A-22's airframe, avionics, and propulsion contributed to the cost overruns in that program. By contrast, we find that the more incremental advances pursued by the F/A-18E/F program helped keep EMD costs stable.

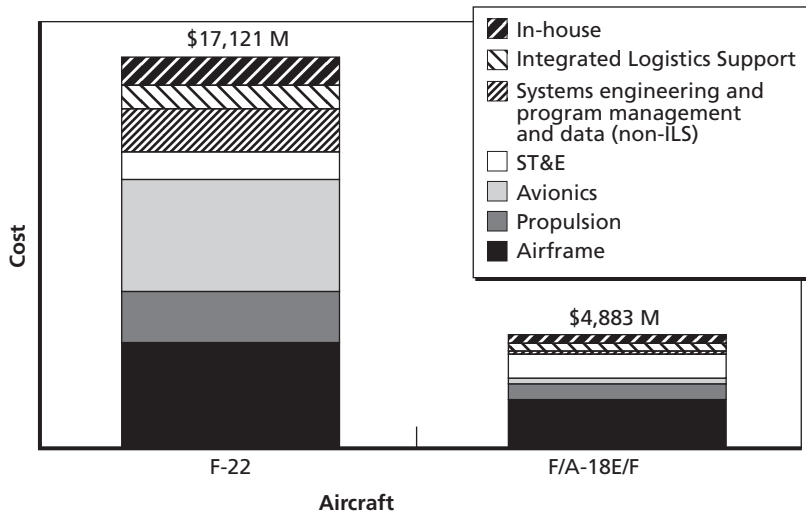
As discussed in Chapter One, the F/A-22 EMD effort includes advancements in all the major areas of the aircraft: airframe, avionics, and propulsion. A key objective of the airframe development efforts was to design a radar cross section that uses large amounts of advanced materials, such as composites and titanium. The integrated avionics suite of the aircraft brings together information collected from several sensors on the aircraft to be displayed to the pilot. The propulsion system features two high-thrust, Pratt & Whitney F119 jet engines to allow the F/A-22 to supercruise at speeds above the speed of sound without using the fuel-consuming after burner. The airframe design, flight controls, and thrust vectoring are also used to improve the maneuverability of the aircraft.

As can be seen in Figure 3.1, the F/A-22 EMD program was more than three times more costly than the F/A-18E/F EMD. Almost

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tract is broken down into smaller, specific work tasks with specific budgets and linkages to completing the overall contract. This assignment of budget to scheduled tasks on a contract is called a performance measurement baseline and is used as the benchmark for measuring schedule and cost performance.

**Figure 3.1**  
**F/A-22 and F/A-18E/F EMD Program Cost Drivers**



SOURCES: F/A-18E/F MSII Program Office estimate. F/A-22 March 2003 Program Office estimate and September 2002 CCDD used for WBS breakout.

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one-third of the F/A-22 program budget has been spent on the avionics—more than any other subsystem, including the airframe.

The F/A-18E/F's major cost element was the airframe, with far fewer dollars spent on the avionics.<sup>4</sup>

In our attempt to explore the main contributors of the cost growth, we examined the CCDD from 1995 through 2002 for the F/A-22 and from 1992 through 1998 for the F/A-18E/F, summarized in Figure 3.2 and 3.3. Most contractors engaged in a DoD-sponsored major development activity are required to submit CCDDs. The CCDD is a cost report prepared by the contractor that

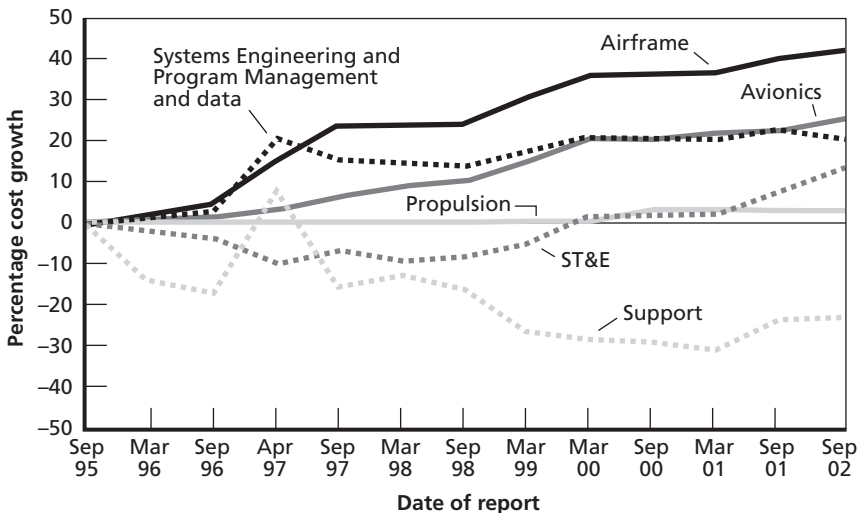
<sup>4</sup> We also note that about 23 more weapons were certified for the F/A-18E/F program than for the F/A-22. In terms of percentages, the E/F spent more money on system test and evaluation (ST&E) than did the F/A-22, albeit the F/A-22 test is not yet complete. The F/A-22 program certified only three weapon systems: the AIM-120C Advanced Medium-Range Air-to-Air Missile (AMRAAM), the AIM-9M Sidewinder missile, and the 1,000-pound GBU-32 Joint Direct-Attack Munition (JDAM), as defined in the April 2000 CARD.

shows the actual cost for the contract at various points during the program. They provide labor hours expended and other incurred cost information by WBS and functional labor categories, for example engineering, manufacturing, tooling, and quality assurance.

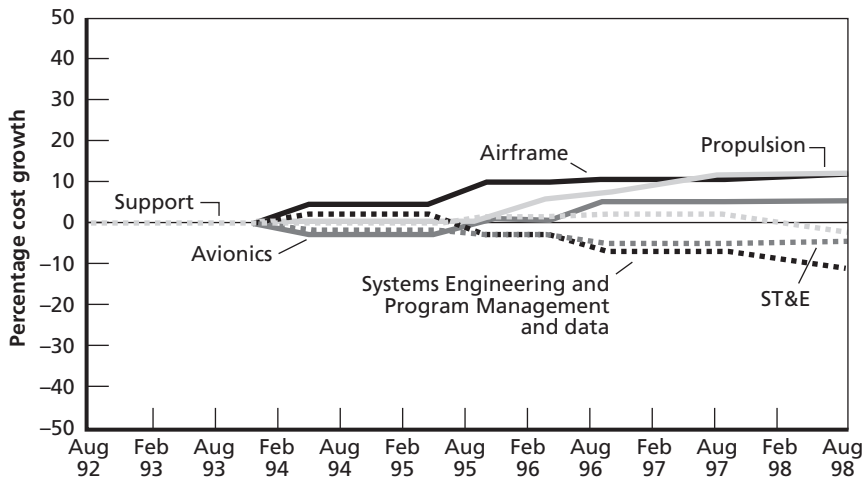
In Figures 3.2 and 3.3, the percentage change of the estimates to complete the development work from the initial report available to us are shown at semiannual points in the two EMD programs. However, since the period of performance is roughly the same for both aircraft and cost growth is the focus of the chart, not absolute cost, we elected to display the data as submitted by the contractors. In both F/A-22 and F/A-18E/F cases, the data capture the majority of the development EMD phase, but the early F/A-22 data (from 1991 until 1995) was not available in the F/A-22 case. Therefore, the F/A-22 information does not provide a complete picture of the cost growth of its major subsystems from those early years.

The F/A-22 airframe cost growth of 42 percent is much higher than any other subsystems, followed by the avionics at 25 percent as

**Figure 3.2**  
**F/A-22 Cost Growth Trends for Major Systems**



**Figure 3.3**  
**F/A-18E/F Cost Growth Trends for Major Systems**



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shown in Figure 3.2. However, as of the date of this report, the airframe design is almost complete, whereas significant amount of work remains to be done on the avionics, so that cost growth will likely increase. Other cost elements, such as propulsion development, system test, and support, indicated minimal or no growth during the examined timeframe. As with avionics development, the test program is far from completion. Recent information indicates that development test (DT) is scheduled for completion in December 2005 or June 2006 and Milestone III (approval for full-rate production) is scheduled for March 2005. Ironically, the support costs have decreased as a percentage of total costs.

In contrast, as we can observe from Figure 3.3, the E/F airframe cost grew by 12 percent. However, this growth was offset by the declines in other cost categories such as System Engineering and Program Management, System Test and Evaluation (ST&E) and support. In addition, adequate management reserve may have also played a key role in keeping costs under control. A more detailed discussion of management reserve occurs in the next chapter. The net result was

no growth. In the next section, we attempt to compare the major aircraft elements of the F/A-22 and F/A-18E/F and examine the reason for the cost growth of the F/A-22 program.

## **An Assessment of Cost Growth of Major Subsystems**

We turn now to a more detailed discussion of the specific subsystems that contributed to cost growth in the F/A-22 and stability in the F/A-18E/F. The scope of technological advance and the needed innovation to deliver the required performance differs greatly between these two aircraft programs and so has the magnitude of technological challenges facing them. We first discuss the F/A-22 cost growth in the airframe, then the avionics, and finally the propulsion systems. For comparative purposes, we also discuss the F/A-18E/F results in the same areas.

### **Airframe Cost Growth**

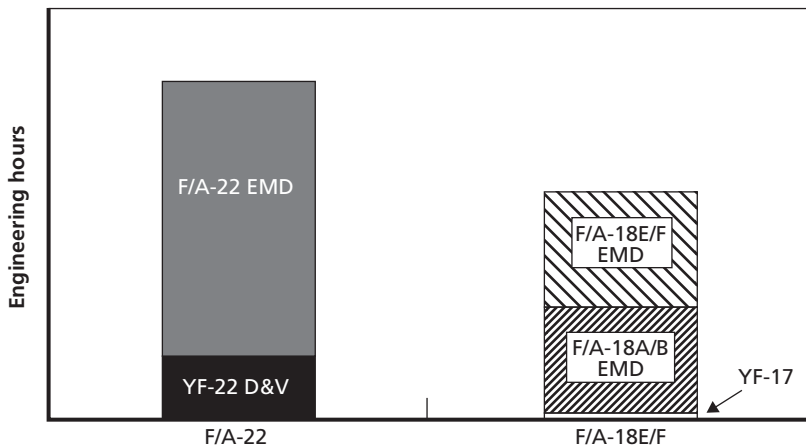
A major reason for the cost differences shown in Figure 3.1 is that each program had different requirements for airframe design. The F/A-22 airframe needed a large amount of composite materials to satisfy its stealth requirements and meet its weight constraints. Engineering these materials added time and manpower to the development phase. The F/A-18E/F had minimal stealth requirements and was able to use more traditional airframe materials, thus reducing the time needed for development. Moreover, the F/A-22 program encountered airframe design problems that required continual adjustment, leading to an overall rise in the expected airframe weight. The F/A-18E/F program maintained a relatively stable airframe weight, suggesting that design problems were solved with seemingly minimal effort. We explore these issues in more detail in the sections below.

**The F/A-22 Stealth Requirement Was a Challenge.** Stealth is a major feature of the F/A-22 airframe design. New radar-absorbing materials and structures along with internal weapon carriage capability allow for the exceptional low-observable (LO) characteristics of

the airframe. However, LO has been a major engineering challenge for the airframe designers during the development. All the LO design aspects, such as internal weapon carriage, further complicate an already challenging design problem. In contrast, the F/A-18E/F stealth requirement was minimal and internal carriage of the weapons is not required.

Figure 3.4 shows the amount of engineering hours required or forecast to design the F/A-22 Air Vehicle.<sup>5</sup> These hours are based on data from CCDRs from the YF-22 Dem/Val and the F/A-22 EMD efforts. When we compare the F/A-22 engineering hours to the F/A-18E/F air vehicle engineering hours, we can see that the F/A-18E/F hours are substantially less—that is, the F/A-18E/F EMD engineering hours are less than half of those of the F/A-22 EMD. Even if we include the entire engineering hours spent on the YF-17 and F/A-18A/B development contracts and compare that amount to the total

**Figure 3.4**  
**Comparison of the Air Vehicle Design Hours**



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<sup>5</sup> Air Vehicle design hours exclude design hours associated with the avionics and propulsion systems.

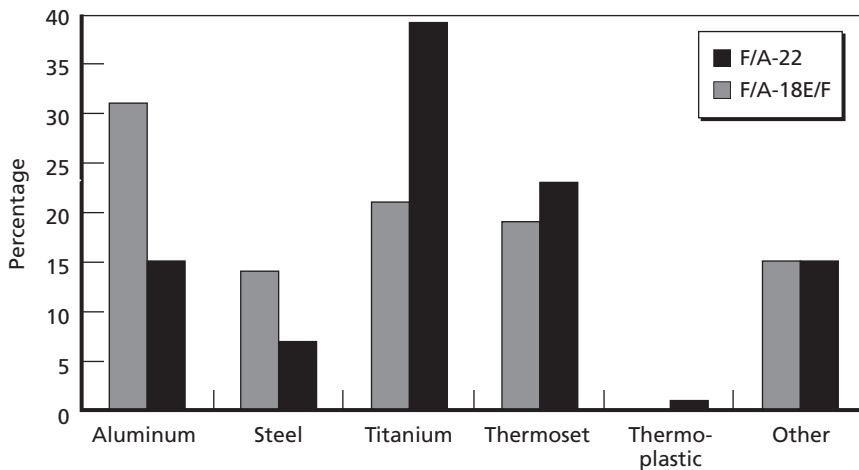


engineering hours expended on the YF-22 and F/A-22 development contract, the F/A-18 still shows significantly fewer hours. Also, it should be noted that the F/A-18A/B development effort was for essentially a new airframe design with no real commonality to the F/A-18E/F airframe design, as was previously mentioned in this report.<sup>6</sup>

As mentioned earlier, stealth requirements as well as differences in the material composition of the two airframes may account for some of the differences in the engineering hours.

This difference is illustrated in Figure 3.5. The F/A-22 airframe design includes 24 percent carbon epoxy composites and about 40 percent titanium. Composites, in addition to their low relative weight compared to metals, allow for LO features. Titanium structures provide strength and temperature control needed for LO air superiority

**Figure 3.5**  
**Airframe Material Distribution**



SOURCE: Younossi, Kennedy, and Graser (2001).

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<sup>6</sup> We excluded the F/A-18C/D effort from this analysis since most of the C/D effort was focused on avionics and was accomplished through a series of engineering change proposals.

fighters. Both these materials are more complex than aluminum, the traditional material used in airframe designs. Manufacturing of composites is more time-consuming than aluminum and steel. Titanium is an expensive metal and it is hard to machine.<sup>7</sup> In addition, design information of composite structures is not as mature as that of metal structures, so more engineering hours are normally needed for like structures. In contrast, the F/A-18E/F uses significantly more aluminum and steel in the airframe structure than the F/A-22—approximately 31 percent and 14 percent, respectively. Both of these materials have traditionally been the main structural material in airframe designs.

**Weight Instability Was an Early Indicator of Problems for the F/A-22.** Another airframe design feature linked with the complexity and stability of the airframe configuration is weight. Weight fluctuations as a result of redesign to meet requirement or to accommodate additional performance directly affects cost and schedule. Keeping the aircraft weight under control has historically been a challenge to aircraft designers. The F/A-22 airframe weight has been unstable and has grown during most of the EMD period. At the beginning of the F/A-22 EMD program, both the Design-to-Weight (DTW) and the parametric weight estimate were significantly lower than the current weight of the aircraft, or Achieved-to-Date (ATD) weight.<sup>8</sup> The F/A-22 DTW increased and grew more realistic and converged with the ATD as the program progressed. Figure 3.6 depicts the ATD weight from the beginning of the program until September 2002.

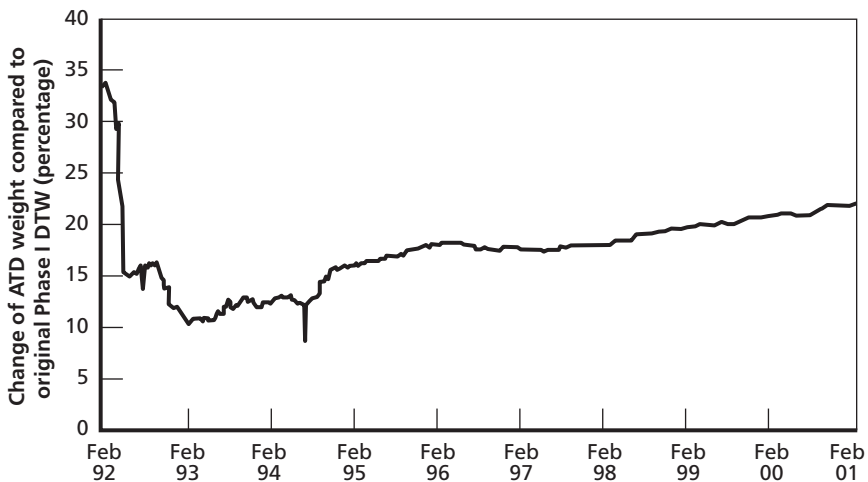
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<sup>7</sup> For more information on these materials and other advanced materials, see Younossi et al. (2001).

<sup>8</sup> The DTW is a weight goal for the program to achieve. The parametric weight estimate is generated using historical weight data from historical aircraft programs. It is allocated to an IPT that develops a “build-to” data package (engineering, material, planning, and tooling data). This target weight includes a decrement to the proposal weight, which allows for the growth that normally occurs during design development. The ATD weight reflects the weight of the aircraft by using the actual drawings of the aircraft design. The ATD weight is the weight that reflects the current drawings. It usually represents calculated or actual weight data but can include estimated weight. As a result, ATD weight reporting lags a design decision by a significant time, sometimes several months.

The figure shows the contractor responsible weight<sup>9</sup> changes over time. After the initial drop of 21 percent, the weight has grown by 11 percent since the program's preliminary design review (PDR) in April 1993. The data also indicate that considerable efforts may have been made to bring down the F/A-22 airframe weight estimate before the PDR because the weight dropped about 5 percent in the six months preceding PDR. The figure also shows that, after this initial drop, the weight steadily increased ever since. It is interesting to note that the weight dropped just before and increased right after both the PDR and critical design review. Significant weight decrease just before a major design review reflects unstable airframe design. In contrast to the F/A-22, the F/A-18E/F airframe weight has remained relatively stable, with a minor 2 percent growth during EMD. Figure 3.7 shows the F/A-18E/F DTW over time. Even though the F/A-18E/F program experienced notable weight stability, the contractor weight estimates did fall before both design reviews

**Figure 3.6**  
F/A-22 Airframe Weight Changes over Time



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<sup>9</sup> Contractor responsible weight is the aircraft empty weight minus the engine weight.

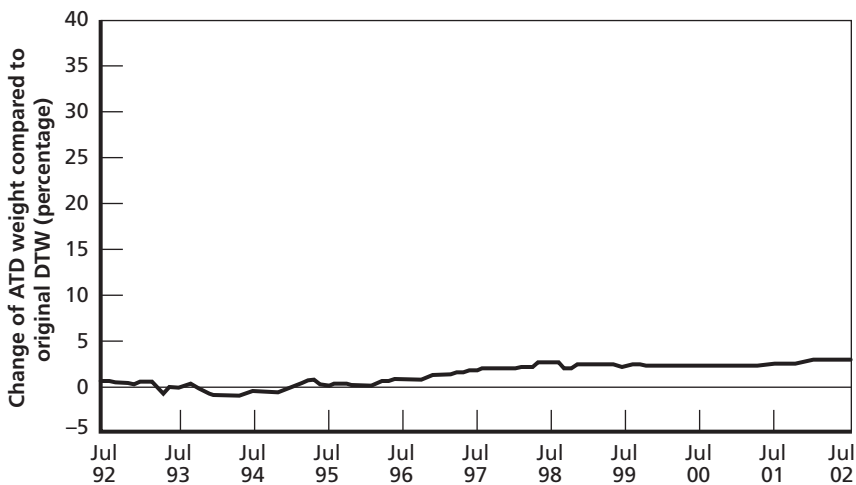
and increased after the reviews, but in the 1 to 2 percent range. Although the overall weight of the F/A-18E/F grew substantially less than the F/A-22, the weight data still show the same phenomena of weight drops prior to the design reviews (June 1993 and June 1994), albeit at a much smaller magnitude.

A major contributor to the airframe weight instability may have been some key airframe components of the F/A-22 airframe, such as the wings and vertical and horizontal stabilators. The program has also encountered design problems that required some airframe redesign. In contrast, the F/A-18E/F airframe problems were solved with seemingly minimal effort.

### Avionics Cost Growth

Another contributor to the cost growth has been the F/A-22's avionics suite, which is far more challenging than any other fighter electronics system to date. The integrated avionics suite fuses information collected from several sensors on the aircraft to be displayed to the

**Figure 3.7**  
F/A-18E/F Weight Estimates over Time



pilot. In contrast, the F/A-18E/F avionics for the initial release of the F/A-18E/F incorporates the suite from the C/D model. Provisions are made for a series of avionics upgrades to be performed subsequent to the basic air vehicle development during the EMD program. These separate approaches account for a large portion of the cost differences depicted in Figure 3.1. We examine each issue in detail below.

**The F/A-22 Program Embraced a Challenging Avionics Design.**

The F/A-22's integrated avionics system uses new technology electronically scanned radar, which uses transmit and receive modules, and Beyond Visual Range (BVR) weapons control. In addition the avionics suite includes a state-of-the-art electronic warfare (EW) system and communication, navigation, and identification (CNI) suites.

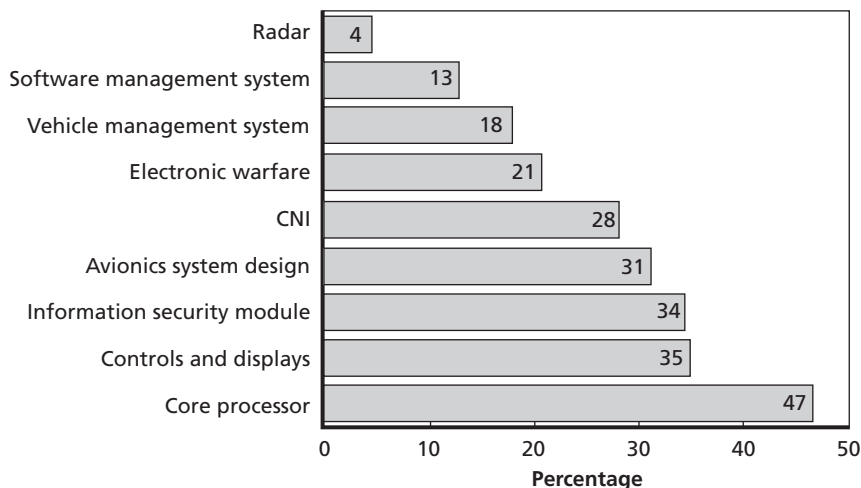
The avionics suites on most previous fighter aircraft used federated components—that is, separate avionics boxes provide information to the pilot independent of information from various other systems. In the F/A-22, a central core processor fuses information from many sensors and electronics and presents an integrated picture to the pilot. Thus, the processing capability requirement is huge. The new approach integrates all the information from numerous subsystems, and therefore these components need a significant processing capability—somewhere on the order of 250 million instructions per second for data processing, and more than 100 times that—10 billion instructions per second—for signal processing. Also, each aircraft must be capable of extensive sensor fusion from several active and passive organic sensors as well as harmonizing data from two or more other F/A-22s during a mission. These extensive demands on the computing systems in the aircraft caused system lock-up during test flights, (GAO, 2003b). According to the F/A-22 Program Office, the issue of avionics software stability was solved prior to the start of IOT&E in April 2004. Finally, the radar being developed for the F/A-22 is based on new technology with modules that both transmit and receive. These modules have neither been used previously in the space-constrained environs of a fighter aircraft nor have they ever been produced in the large quantities that will be needed to support the F/A-22 program.

To discover where the cost growth occurred in the avionics, we examined CCDR information from the September 1995 and September 2002 reports. The largest growth occurred in the core processor followed by the EW and CNI modules. Surprisingly, the radar, the traditional cost and risk driver, experienced the least amount of growth by percentage.

Figure 3.8 shows the F/A-22 EMD avionics costs broken out by the major parts of the avionics suite.<sup>10</sup> The entire avionics development was funded as part of the EMD program. As can be seen in the figure, the CNI, EW, radar, and core processor account for about 80 percent of the total avionics development cost with the core processor being the most expensive and the one with the most cost growth. These data were current as of September 2002.

Problems with developing, testing, and correcting deficiencies in the ambitious avionics in the F/A-22 have caused program stretch-

**Figure 3.8**  
**F/A-22 Avionics Cost Growth by Component**



RAND MG276-3.8

<sup>10</sup> These costs are from the F/A-22 EMD Team CCDR. The numbers indicated estimated cost at completion and include both hardware and software costs.

outs and delays. The EMD portion of the F/A-22 program is now more than 10 years old. The program has been in development for 20 years since the contract for concept development was awarded in September 1983. This extended development period has led to several analyses that find some of the components of the F/A-22 obsolete or will be obsolete by the time the aircraft actually enters the force. In 1998, then–Under Secretary of Defense for Acquisition, Technology, and Logistics Jacques Gansler said that “the F-22 . . . is not yet into production but, with electronic products becoming obsolete in as little as 18 months, [it] already contains outdated parts” in congressional testimony (Gansler, 1998). A later quote from a DoD analyst stated that “the avionics for the F-22 was obsolete before the plane even went into production” because the chips in the processors were outdated in 1992 (Cockburn and St. Clair, 2001). Finally, in September 2002 Brig. Gen. William Jabour, arguing for introduction of an upgraded radar starting with Lot 5 aircraft, stated that “the current radar . . . is the best radar flying right now. It is, however, ten-year-old technology” (Colarusso, 2002). The cutting edge of technology, it seems, moves faster than the DoD acquisition process.

Also, the current modernization program plans to implement a series of spiral developments to improve the F/A-22’s air-to-ground capability significantly. This modernization effort occurs concurrently with the EMD activities. Because the avionics design is still not completed, it may further exacerbate cost and schedule problems.

**Software Growth May Have Contributed to the F/A-22 Avionics Program Cost Growth.** Another contributor to the avionics cost is software. The overall size of the air vehicle software and the increase in the number of source lines of code (SLOC) may have been contributors to the cost growth. The F/A-22 SLOC grew by 565,000 lines of code, approximately 34 percent, between October 1993 and April 2000. Although the F/A-22 data are relatively old, they do show a significant growth in the number of lines of code between 1993 and 2000.<sup>11</sup> These SLOC counts are based on each program’s CARD.

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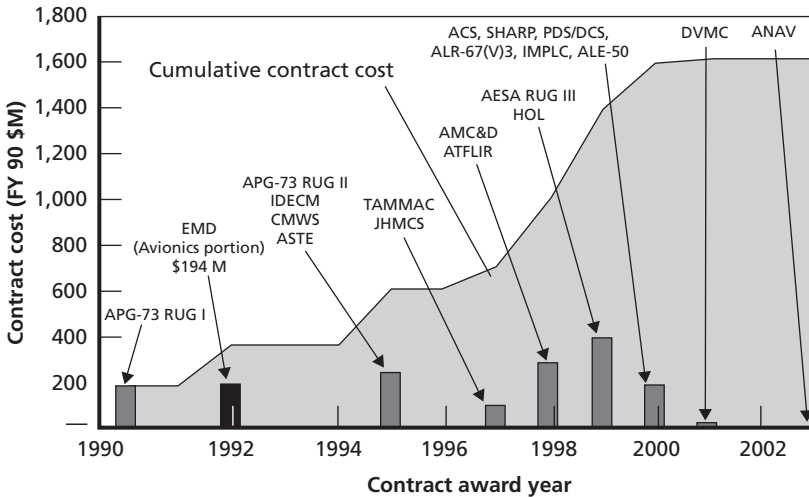
<sup>11</sup> The F/A-18E/F SLOC count comes from the Milestone II (dated 1992) and Milestone III (dated October 1999) CARDS. The F/A-22 SLOC count comes from the F-22 Weapons

Similarly, the F/A-18E/F SLOC grew by 405,000, or about 40 percent. Although this growth seems sizable, most of it was attributable to upgrades outside the F/A-18E/F EMD program. The E/F's initial baseline capability was equivalent to the C/D's. However, during the E/F's development, upgrades were made to the common C/D and E/F Operational Flight Program (OFP) and therefore the OFP at the conclusion of EMD included additional upgrades. Hence, the reported costs may not reflect all of this additional effort.

**The F/A-18E/F Avionics Development Reflect an Evolutionary Process.** As previously mentioned, the F/A-18E/F program was a major modification of an existing aircraft with only modest upgrades to the F/A-18C/D avionics as part of its EMD program. During the EMD, the program did not encounter many significant technology problems. More than 90 percent of the E/F's electronics in the initial production aircraft are common to the F/A-18C/D. Some upgrades to the subsequent production aircraft were included as preplanned product improvements from the beginning of the program. These include improved cockpit instrumentation, a new and improved forward-looking infrared (FLIR), and an electronically scanned array for the radar. Other improvements have been added to the program during the past several years, including a reconnaissance pod, a helmet-mounted cueing system, and some integrated electronic defensive countermeasures. Figure 3.9 shows the F/A-18E/F avionics development effort. None of these significant improvements in avionics over the C and D models was part of the EMD phase of the F/A-18E/F program, and so did not raise any concerns or cause any delays during development. The modernization to the avionics was, and continues to be, funded separately in relatively small packages. Because the avionics system is a federated system, these upgrades are easily incorporated when available, without any significant effect on the overall weapon system availability. Each avionics upgrade, being a smaller and separate program, has the advantage of having the exist-



**Figure 3.9**  
**The F/A-18E/F Avionics Development Program<sup>12</sup>**



NOTE: Figures reflect F/A-18 cumulative total since 1990 \$1.6 B (FY 90 \$)

RAND MG276-3.9

ing system in place in case problems are encountered with the upgrade system. This approach provides a backup solution such that the entire aircraft program can move ahead. It also has the added benefit of removing the external scrutiny from the main program. That is, the program manager can keep attention on the main program and incorporate the new systems as they become available without affecting the program’s critical path.

<sup>12</sup> The APG-73 RUG and E/F EMD data are from CCDRs and CPRs. Tactical Aircraft Moving-Map Capability (TAMMAC), Joint Helmet-Mounted Cueing System (JHMCS), Advanced Mission Computers and Displays (AMC&D), Advanced Targeting Forward-Looking Infrared (ATFLIR), Active Electronically Scanned Array (AESA), Advanced Crew Station (ACS), Shared Advanced Reconnaissance Pod (SHARP), and Digital Video Map Computer (DVMC) data are from CPRs and CSSRs. R-3 exhibit from February 2000 was used for the following programs: Integrated Defensive Electronic Countermeasures (IDECM), Common Missile Warning System (CMWS), Advanced Strategic and Tactical Expendables (ASTE), ALR-67(V)3, Integrated Multiplatform Launch Controller (IMPLC), and ALE-50. And the Navy Budget R-2 exhibit from February 2003 was used for Higher-Order Language (HOL), Positive Identification System/Digital Communication System (PIDS/DCS), and Accurate Navigation System (ANAV).

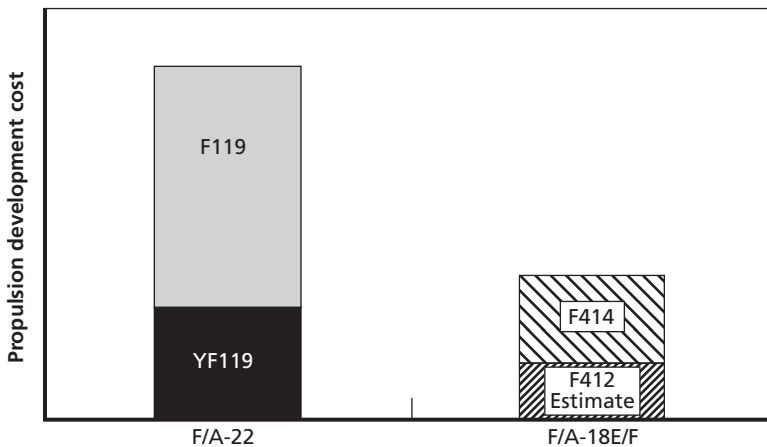
### Propulsion System Cost Growth

The third major cost area is the propulsion system development cost. The F/A-22 propulsion system features two high thrust, Pratt & Whitney F119 jet engines to allow the F/A-22 to supercruise at speeds above the speed of sound without using the fuel-consuming afterburner. This development effort was relatively costly because it required a new core engine. In contrast, the F/A-18E/F propulsion system is provided by two General Electric F414 jet engines that produce about 20 percent more thrust than the engines from the original design. As a derivative design, this system was easier and less costly to develop.

Figure 3.10 summarizes the cost of the F119 and F414 development costs. The F/A-22 propulsion system, the F119 engine, provides the aircraft with supercruise capability without the use of afterburners. The F119 new engine core development effort is significantly more difficult than the derivative development approach of the F414 engine used in the F/A-18E/F.

The F119 development was about two times more expensive than the F414 development. During ground testing, the engine expe-

**Figure 3.10**  
Development Cost Comparison of the F119 and F414 Engines



rienced some problems with blade failure stemming from overheating and variability in material properties (Druyun, 1999). Although these problems have apparently been corrected, they indicate some initial challenges in developing an engine capable of meeting the stringent requirements in the F/A-22 program. Conversely, the F/A-18E/F has a derivative engine that uses the core developed for the F412 engine, which was planned to power the A-12 aircraft. The F414 engine also benefited from previous experience on the F404, which powers the F/A-18C/D.

The increased development cost for the F/A-22's new core engine is consistent with RAND's recent study on engine costs, which suggests that an engine with a new core design is significantly more costly than one that includes a derivative design (Younossi et al., 2002). The analysis of the historical engine development costs in that study suggests that a new core development is much more costly than a derivative approach.

## Conclusions

The scope of technological advance and the innovation needed to deliver the required performance differed greatly between the F/A-22 and F/A-18E/F aircraft programs and so has the magnitude of technological challenges facing each. As shown previously, the F/A-22 cost growth was mainly the result of design challenges in the airframe arising out of the stealth requirements, the integrated avionics suite, and, finally, the new propulsion system. In contrast, the F/A-18E/F airframe requirement was met by incremental improvements with minimal stealth requirements, using mostly the existing avionics system from its predecessor aircraft, and a derivative engine design. Concurrent development and integration of all aspects of the F/A-22 may itself have contributed to the cost growth and schedule slippage, whereas the incremental improvements in the airframe, use of mostly existing avionic components, and a derivative engine may have facilitated the F/A-18E/F cost and schedule control.

## Use of Cost Performance Data

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Contractor cost performance data are extremely valuable for the program manager to gain insights into the financial and schedule health of a program. They provide specific metrics that the program manager uses to track the performance of work described and required under the contract. This chapter provides insight into the use of cost performance data collected by the F/A-22 and F/A-18 programs.

### **Different Methods of Measuring Progress Affect the Management of Program Costs and Schedule**

One method used by the government and contractors to manage both the F/A-22 and F/A-18E/F programs was Earned Value Management (EVM). EVM is a tool that provides insight into technical, cost, and schedule progress on development contracts. The EVM data from the contractor is documented in Cost Performance Reports (CPRs), which are then provided periodically to the government. A good EVM system ensures that the program manager has access to the accurate, valid, and timely cost and schedule information on a regular basis. The data reflect time-phased budgets for specific contract tasks and indicate work progress against planned schedules and costs. The data reported to DoD should be similar to the data used by the contractor to manage the work under contract. A WBS is used to allocate the contract's Statement of Work effort to lower-level work packages. The EVM common metrics are Budgeted Cost of

Work Scheduled (BCWS),<sup>1</sup> Budgeted Cost of Work Performed (BCWP),<sup>2</sup> and Actual Cost of Work Performed (ACWP).<sup>3</sup> In the next sections, we will show EVM data in a cumulative fashion as the F/A-22 and F/A-18E/F contract work was accomplished from contract award date until November 2002.

### **The F/A-22 Program Used Contract Performance Goals to Measure Progress**

Rebaselining strategy is used when contract costs grow and program schedules slip for various technical or contractual reasons. At times, the government clients allow contractors to rebaseline so their cost variance is readjusted to zero and their contract performance is measured against a new baseline.

Figure 4.1 depicts the monthly CPR data for the F/A-22 Air Vehicle EMD contract.<sup>4</sup> The lower portion of the figure indicates several cost and schedule overruns during the EMD program. The program has experienced four specific rephasings of the budget where at each point the program schedule and scope was modified. For instance, cost variance, which is the difference between the BCWP and the ACWP, increased through April 1995 until it was zeroed by a rebaseline of the program in December of 1995, when the variances disappeared. Another similar rebaseline took place around February 1997, after the Joint Estimating Team (JET) review.<sup>5</sup> The cost variance continued to grow until the present report to \$490 million. The

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<sup>1</sup> The BCWS is the sum of all the budgets from all the actual and estimated work as well as planning packages for future work.

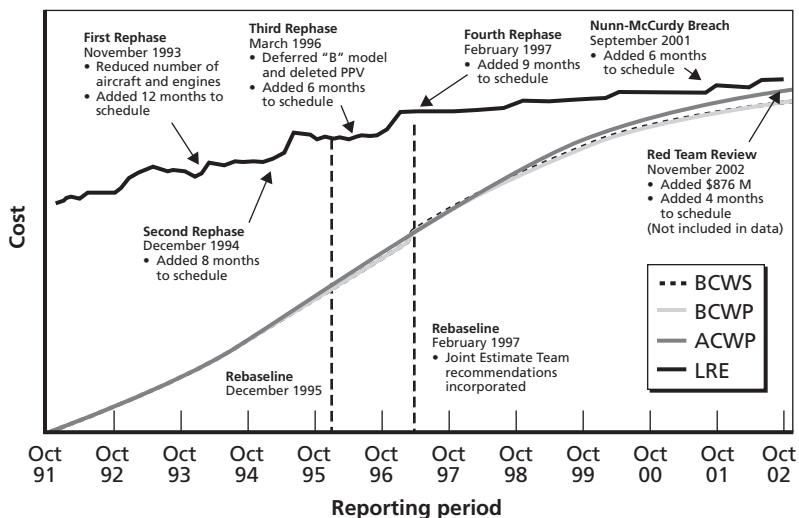
<sup>2</sup> The BCWP is the earned value of the sum of the completed work packages and completed portion of the open work packages.

<sup>3</sup> The ACWP is the actual cost for completing the work in the time period.

<sup>4</sup> CPRs track the cost and schedule progress of various key indicators on the program.

<sup>5</sup> The JET was a panel of high-level government and contractor personnel assigned to review the program plans during the end of 1996 and into 1997 in response to the Defense Science Board (DSB) Task Force review of the program in 1995. The JET's findings concluded that the EMD program plan required additional funding and time to complete and recommended restructuring the program and moving the Milestone III date.

**Figure 4.1**  
**The F/A-22 Program Used Contract Performance Goals to Measure Progress**



RAND MG276-4.1

program experienced a Nunn-McCurdy SAR breach in September 2001.<sup>6</sup>

Also, we can see that Budget at Completion (BAC), the sum of contract's work package budgets, grew from \$9.2 billion in October 1991 to \$13.4 billion. Similarly, the Latest Revised Estimate (LRE), the contractor's estimate of the cost to complete the contract, grew from \$8.9 billion to \$13.7 billion. In November 2002, an Air Force-led Red Team reviewed the entire program and recommended additional funds and time to complete the development phase.

### The F/A-22 Contractor Allocated Little for Management Reserve

Figure 4.2 depicts the use of management reserve in the F/A-22 program. Management reserve is a budget withheld for management control purposes, and it is mostly used to cover future unknown

<sup>6</sup> A Nunn-McCurdy (named after Sen. Sam Nunn [D-Ga.] and Rep. Dave McCurdy [D-Okla.]) unit cost breach occurs when a major defense acquisition program experiences a unit cost increase of at least 15 percent.

problems. The figure shows management reserve as a percentage of LRE. According to the EVM Implementation Guide,<sup>7</sup> management reserve is to be used to enable project managers to adjust for uncertainties on a contract and should not be used as a contingency fund to absorb the cost of contract changes. The guide also states that the total allocated budget may exceed the contract budget baseline (CBB) resulting in an over-target baseline (OTB) that can allow for replanning of future work to provide a more realistic amount for performance measurement than is currently indicated on the program.<sup>8</sup> In other words, once a program is behind on cost or schedule, a new baseline for reporting should be established to allow assessment of future work as it progresses. Otherwise, prior negative variances can hide new problems. As Figure 4.2 shows, only a relatively small amount of management reserve was allocated at the onset of the F/A-22 program and was used up quite rapidly. The management reserve was totally exhausted from May 1995 through February 1997. However, as a result of the JET recommendations the Air Force increased the program funding and the contractor allocated another sum of money to management reserve that was also quickly consumed.

### **The F/A-18E/F Program Used EVM Data to Measure Progress**

In contrast to the F/A-22 program, the F/A-18E/F Air Vehicle EMD contract CPR data, as shown in Figure 4.3, reflect a smoother accomplishment of work performed without any noticeable rebase-lines of the EVM metrics. Also, the management reserve was targeted to be approximately 10 percent of the remaining work as measured by the difference between the BAC and the BCWP.

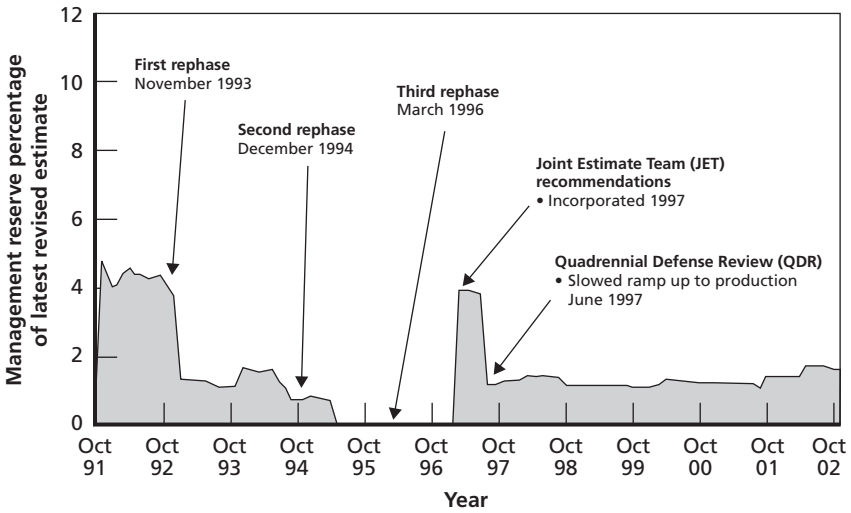
Figure 4.4 shows the total management reserve as a percentage of LRE. The figure shows that the contractor had set aside a healthy

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<sup>7</sup> The Earned Value Management Implementation Guide, Defense Contracts Management Command (DCMC), available at <http://www.acq.osd.mil/pm/currentpolicy/jig/evmigl.htm>.

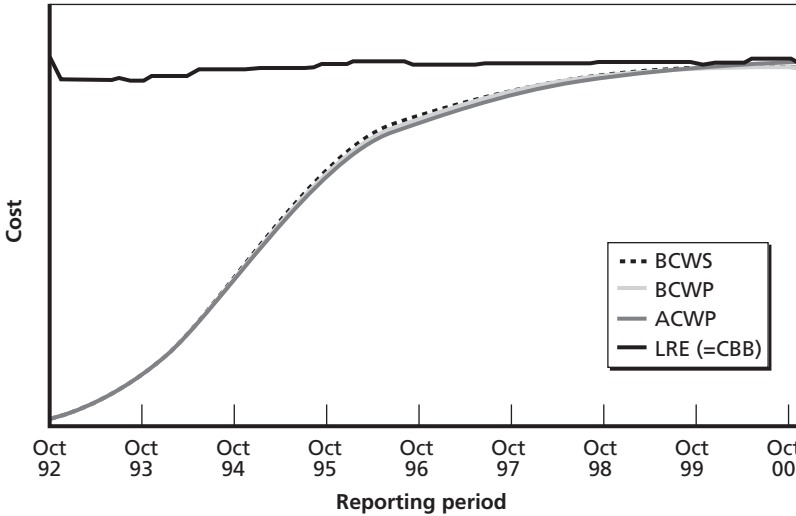
<sup>8</sup> When total budget allocated to work exceeds CBB, replanning future or current work and adjusting variances may be necessary. When implementing OTB, baseline budget changes must be documented and traceable. Establishing management reserve in OTB is acceptable.

**Figure 4.2**  
**The F/A-22 Contractor Allocated Small Amounts of Management Reserve**



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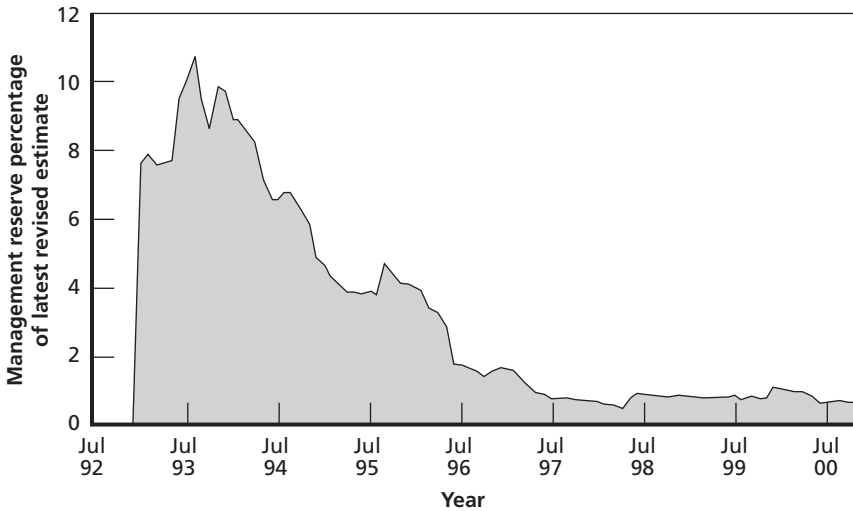
**Figure 4.3**  
**The F/A-18E/F Used EVM Data to Measure Progress**



RAND MG276-4.3



**Figure 4.4**  
**The F/A-18E/F Maintained a Large Management Reserve**



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sum of management reserve and, as the program progressed during the EMD and encountered unforeseen challenges, the management reserve funds were used. This budget was planned early to allow the program manager the capability to adjust for uncertainties of the program and was mostly expended as the contract reached completion.

## Conclusions

The EVM method was used by the government and the contractor in the management of both the F/A-22 and F/A-18E/F programs. The EVM data provided insight into technical, cost, and schedule progress on the development contracts. The F/A-22 data indicate cost and schedule trouble as early as October of 1992, whereas the F/A-18E/F data show a program that was virtually on cost and schedule throughout the entire development phase. One of the major contributors to the F/A-18E/F program's cost and schedule stability may have been the existence of a substantial management reserve. As the

program proceeded through its development and unforeseen problems arose, the amount of management reserves covered these problems and was decreased accordingly. In contrast, only a small amount of management reserve (about 2 percent) was allocated for the F/A-22 program, which was depleted in about the first year of the EMD effort.



## **Conclusions and Lessons Learned**

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This chapter summarizes our conclusions about the factors that contributed to either growth or stability in the F/A-22 and F/A-18E/F programs. We further aggregate these findings into a set of lessons that the Air Force and other DoD services may apply in their acquisition of future military platforms. Certainly, many of these findings are not unique to these programs, but have been evident in other DoD acquisition programs as well.

### **Conclusions**

Table 5.1 summarizes the major factors contributing to the F/A-22 program's schedule slippage and cost growth in the EMD phase and the major factors contributing to the stability of the F/A-18E/F program during the EMD phase.

### **Lessons Learned for the U.S. Air Force**

The process of acquiring new weapon platforms requires the U.S. military to invest substantial amounts of time and money in development, testing, and production. The lessons derived in this study from an evaluation of the F/A-22 and F/A-18E/F programs provide the Air Force and other services with ways to improve the acquisition

**Table 5.1**  
**Summary of Lessons Learned from Each Program**

	Lessons from the F/A-22 Program	Lessons from the F/A-18E/F Program
Technology Development	The F/A-22 program pursued revolutionary technologies and performance improvements over the legacy systems.	The F/A-18E/F program used the same technologies or pursued only evolutionary technology and performance improvements.
Cost and Schedule Estimates	The initial cost and schedule estimates seem to have been unrealistically low.	Cost and schedule estimates were relatively accurate and stable.
Contractor Teaming	“Equal” teaming and work-share may have led to an artificial work distribution and may have contributed to cost and schedule problems. The move from Burbank to Marietta led to the loss of most of the core design and management teams from the Dem/Val phase.	The contractor team was structured according to prior experience on the F/A-18A/B/C/D programs. Lines of responsibility were clearly defined with a designated prime contractor ultimately responsible for contract performance.
Development Concurrency	The concurrent development of high-risk technologies in airframe, engine, and avionics within the same contract was a high-risk endeavor.	The Navy took an evolutionary development approach for the moderately risky avionics technologies, which was funded outside of the EMD program. The existing F/A-18C/D avionics was always available as a backup solution.
Airframe Weight	The airframe weight data show significant fluctuations, which indicate airframe design instability.	The airframe weight had only minor increases, reflecting a stable design.
Management Reserve	Very little management reserve budget was allocated to cover design risks.	Sufficient budget and the contractor allocated sufficient management reserve to cover unforeseen problems.

of such airframe platforms as the Joint Strike Fighter and such other hardware systems as unmanned aerial vehicles and missile programs.

Here is the summary of our major lessons learned for the Air Force acquisition decisionmakers:

- Early, realistic cost and schedule estimates set the program on the right path for the rest of the development program. These estimates must be adjusted over time.
- A stable development team structure, proper team expertise, clear lines of responsibility and authority, and a lead contractor responsible for overall program progress are critical to success.
- An experienced management team and contractors with prior business relationships help eliminate early management problems.
- Concurrent development of new technology for the airframe, avionics, and propulsion adds significant risk to the program, not only from the risk of the individual component development but also from the integration of three significant, technically challenging, concurrent activities.
- Reducing the cost and risk of avionics should be a key focus of the concept development phase. Avionics is a considerable cost driver of modern weapon systems, and new concepts should be demonstrated along with the new airframe designs—that is, during early development rather than after Milestone II/B.
- Preplanned, evolutionary modernization of high-risk avionics can reduce risk and help control costs and schedules. It is important to recognize the speed of developments in the electronics industry, especially compared to the airframe or engine industry, and to develop a plan to stay current during development.
- Careful monitoring of airframe weight is important. Airframe weight instability is an early indicator of problems.
- EVM data should be used to monitor and manage program costs at the level of IPTs.
- Appropriate use of management reserve can help address program cost risk and can mitigate cost growth.



## DoD and Congressional Oversight

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The Department of Defense and U.S. Congress have been keenly interested in the F/A-22 and F/A-18E/F programs. These programs account for a significant share of the tactical air forces acquisition budget. This appendix describes in detail the extent of congressional oversight in both programs. It also outlines the OSD involvement.

### Congressional Oversight

Congress, through its control of the purse strings, can influence the execution of DoD programs. Four Congressional committees, the Armed Services and Appropriations Committees in the House and the Senate have direct jurisdiction over acquisition programs and can approve all, part, or none of the funding requested by DoD for its programs, or they can recommend the withholding of funds until specific conditions are met. The recommendations of the committees, if enacted in the authorization or the appropriations bills, carry the force of law. Even if the requests and recommendations of the committee are not signed into law, ignoring them puts DoD at its peril.

Over the past 20 years, Congress has paid close attention to the progress of the F/A-18E/F and F/A-22 programs. This section describes in detail specific congressional actions that have affected the two programs.

The F/A-22 program, from the early stages when it was known as the ATF program until the present, has been the focus of much



congressional interest and concern, particularly with regard to the program's cost, technical challenges, and schedule.

### **Congress Questioned the F/A-22 Cost Estimates and Acquisition Strategy**

Congress and its agencies have questioned the affordability and feasibility of the F-22 from the very beginning of the program. The Congressional Budget Office (CBO), in its April 1985 review of Air Force tactical budget issues, stated that cost estimates related to the ATF could be unrealistically low (CBO, 1985, p. 56). This was in part because the \$30 million price tag quoted by Air Force officials in "informal conversations" with CBO was not much higher than the \$15 million and \$25 million flyaway unit costs of the F-16 and F-15 at that time. Three years later, GAO issued a report that highlighted the schedule risks associated with initiating low-rate production before completing tests of prototype aircraft equipped with a fully integrated avionics system as well as the risk associated with having parallel development of the airframe, engine, and avionics (GAO, 1988).

Congress itself voiced its concerns regarding the planned acquisition strategy. In 1989, the House Appropriations Committee cut all funding for the ATF from its version of the fiscal year (FY) 1990 appropriations bill (Aronstein, Hirschberg, and Piccirillo, 1998, p. 130). This drastic action was taken because the committee felt that the ATF program combined "both an unacceptable degree of concurrence or parallel activities between development and production with a highly unrealistic assumption of substantial outyear funding levels" (Cooper, 1996). Although full funding for the ATF was eventually restored for FY 1990, the congressional interest kept all of the issues at a high level of visibility as the program prepared to enter EMD.

Congressional interest continued after the program entered EMD in mid-1991 and intensified as the program experienced problems attaining its cost and schedule goals and the projected threat from Soviet fighters faded. In 1992, 1993, and 1994, Congress did not appropriate the full amount of funds requested for EMD, reduc-

ing annual requests of about \$2 billion by \$200 million, \$163 million, and \$119 million in the three years, respectively. At roughly the same time, GAO testified before a subcommittee of the Senate Armed Services Committee regarding the lack of urgency for a replacement for the F-15 (GAO, 1994). Although GAO's testimony did not convince Congress to stop funding development of the F-22, it did reflect questions being raised by some members of Congress.

Starting in 1995, the F-22 program received additional annual scrutiny by Congress and was often subject to congressionally imposed restrictions. In April 1995, GAO issued a report that questioned the degree of concurrent development that existed in the F-22's acquisition strategy, particularly in light of the F-22's dependence on significant technological advances (GAO, 1995). The Senate Armed Services Committee reflected these concerns in its report accompanying the Senate's version of the FY 1996 authorization bill, stating that it would have serious concerns about any program that involved an inappropriately high level of concurrency that possesses high risk (Senate Report, 1995, p. 159). The committee made no finding on the level or risk of concurrency in the F-22 program. It did, however, direct the Secretary of Defense to submit a report to Congress that addressed its concerns on concurrency, weight, and specific fuel consumption.<sup>1</sup>

The following year, the Senate Armed Services Committee raised concerns, reflected in the authorization bill passed in September 1996, about the cost of the program.<sup>2</sup> Congress directed the Secretary of Defense to charge the Cost Analysis Improvement Group (CAIG) to conduct a new independent cost review and to submit a report to Congress by March 30, 1997, that compared the new cost estimate with the only previous independent cost estimate of production costs conducted by the CAIG in 1991.

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<sup>1</sup> Specific fuel consumption is the ratio of the fuel flow rate to the thrust.

<sup>2</sup> Public Law 104-201, *National Defense Authorization Act for Fiscal Year 1997*, September 23, 1996, Section 217.

In January 1997, CBO released a report that examined the Administration's plans for tactical air forces through 2020 and the associated costs. The report highlighted several issues concerning the F-22, including the unlikelihood of the Air Force meeting its cost goals and the high level of concurrency in the F-22's schedule. In November of the same year, the authorization bill for FY 1998 passed by Congress required GAO to conduct annual reviews of the F-22 program (CBO, 1997). It also set a cap—equal to the estimate reported by the Joint Estimating Team (JET)—of \$18.7 billion on total expenditures for EMD and a cap of \$43.4 billion on the total amount to be obligated or expended for F-22 production.

The next major congressional constraints were imposed in 1999 attached to funding for FY 2000. The authorization bill required the Secretary of Defense to certify that the testing plan in the EMD phase of the F-22 program was adequate for determining the operational effectiveness and suitability of the F-22 and that the projected total costs of EMD and production would not exceed the caps set by Congress the previous year, after adjustment for inflation<sup>3</sup> before the Air Force could award a contract for low-rate initial production (LRIP). The appropriations bill echoed these sentiments and added additional restrictions. Specifically, it provided funds for additional test aircraft, but it did not provide any funds for LRIP aircraft.<sup>4</sup> Instead, the bill restricted award of the LRIP contract until after the first flight of an F-22 test aircraft equipped with Block 3.0 software; the Secretary of Defense certified that the test plan was adequate and that the cost for EMD would not exceed the inflation adjusted cap; and the Director of Operational Test and Evaluation (DOT&E) reported that the test plan was adequate to measure and predict the performance of the F-22's avionics, stealth, and weapon delivery systems.

Congress was less restrictive in 2000 and 2001. The authorization bill for FY 2001, passed in October 2000, loosened the EMD

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<sup>3</sup> Public Law 106-65, *National Defense Authorization Act for Fiscal Year 2000*, October 5, 1999, Section 131.

<sup>4</sup> Public Law 106-79, *Department of Defense Appropriations Act for Fiscal Year 2000*, October 25, 1999, Section 8146.

cost cap, allowing the Secretary of the Air Force to raise it by 1.5 percent if the DOT&E determined that the additional funds were needed to support adequate testing.<sup>5</sup> The Appropriations Act for FY 2001 confirmed the prerequisites set in the previous year's Appropriations Act—that before a fully funded contract to begin LRIP of ten aircraft could be awarded, the requirements set forth in the Appropriations and Authorization Acts for FY 2000 had to be fulfilled (GAO, 2001, p. 9). In December 2000, Congress passed separate legislation providing the Air Force with authority to obligate up to \$353 million of the FY 2001 production appropriation if award of the full LRIP contract for ten aircraft was delayed beyond December 31, 2000, because the program could not satisfy congressional prerequisites (GAO, 2001, p. 9). In 2001, the cap for EMD was eliminated in the defense authorization bill for FY 2002, although the production cap and the requirement that GAO report annually on the progress of the F/A-22 program were retained (GAO, 2002, p.5).

In 2002, congressional concerns resurfaced, however, because of problems experienced during F/A-22 testing. While providing funds for 23 production F/A-22s, the Senate Appropriations Committee accepted assurances that recent problems with the aircraft's tail section and avionics would not cause delays or additional structural changes. If, however, future events proved otherwise, the committee expected the Air Force to cover additional costs from within planned funding levels (Senate Report, 2002, p. 147). The House Appropriations Committee was less sanguine in its acceptance of Air Force assurances. In its report, the House Appropriations Committee provided funding for the 23 production aircraft requested by the Air Force, but prohibited the Air Force from ordering more than 16 F/A-22s until the Under Secretary of Defense for Acquisition, Technology, and Logistics (USD (AT&L)) certified that the costs for any retrofits discovered during developmental and operational testing would be absorbed within the current total program cost (House Report, 2002, p. 167). It also required the USD (AT&L) to submit—also

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<sup>5</sup> Public Law 106-398, *National Defense Authorization for Fiscal Year 2001*, October 30, 2000, Section 219.

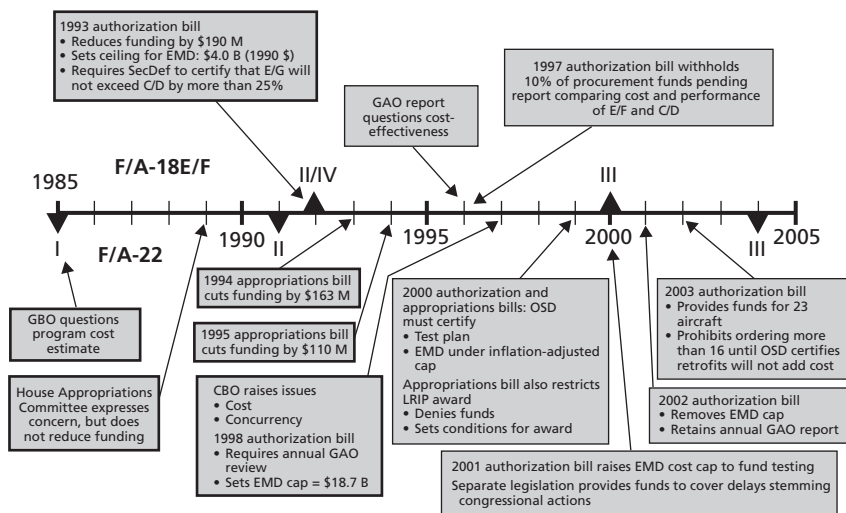
before purchasing more than 16 F/A-22s—a cost–benefit analysis comparing the cost advantages of increasing aircraft production in 2003 to the potential cost of retrofitting production aircraft once the operational test and evaluation had been completed. The appropriations bill for FY 2003 that was finally passed in October 2002 provided funds for 23 F/A-22s but prohibited obligation of funds for more than 16 production aircraft until the USD (AT&L) submitted to the congressional defense committees a formal risk assessment of the costs associated with increasing F/A-22 production rates before operational testing and certified that the current production plan was less risky and costly than a revised plan.<sup>6</sup> DoD submitted the risk assessment and certification in December 2002, but subsequent events have raised additional congressional concerns.

Since passage of the FY 2003 appropriations bill in October 2002, the F/A-22 program announced additional schedule delays and cost increases in its EMD and production programs. In response to these events, GAO issued a report in February 2003, and, as required by Congress, an annual assessment of the F/A-22 program in March 2003 (GAO, 2003a, 2003b). In these reports, GAO recommended that the Secretary of Defense provide Congress with documentation regarding the potential for growth in production costs if current cost reduction plans did not work as planned and the likely number of aircraft that could be purchased within the congressional production cost cap. The March report included additional recommendations that DoD delay increases in the production rate until after completion of operational testing and provide Congress with an update of the risk assessment and certification submitted in December 2002. It is too early to know if the Congress will act on any of GAO's recommendations but given recent congressional concern, Congress will likely place some additional constraints or requirements on the program for FY 2004. Figure A.1 summarizes these actions.

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<sup>6</sup> Public Law 107-248, October 23, 2002, Section 8119.

**Figure A.1**  
**Timeline of Congressional Actions**



RAND MG276-A.1

### The F/A-18E/F Effectiveness Endured Congressional Scrutiny but Not Its Cost Estimates

The F/A-18E/F faced its own share of criticism from the GAO and some members of Congress for not providing improvements in capability commensurate with the investment needed to attain them (GAO, 1996). Nevertheless, specific limitations of funding for the F/A-18E/F were imposed only twice from 1990 to 2002. The defense authorization bill for 1993, passed in October 1992, authorized \$944 million for the F/A-18E/F program, \$190 million less than requested. The same bill also set several conditions that had to be met before any of the funds could be obligated. Two of these required the Secretary of Defense to certify that management systems were in place to ensure that total EMD costs would not exceed \$4.88 billion (in 1990 dollars) and that the cost of the E/F model would not exceed 123 percent of the flyaway cost of the C/D model unless the Navy demonstrated that the higher flyaway costs would produce greater war-fighting effectiveness (House Report, 1992). In 1996, congressional

concern flared again. In June, GAO issued a report questioning the cost-effectiveness of the F/A-18E/F program (GAO, 1996). Later that year, Congress passed the bill authorizing defense appropriations for FY 1997. The accompanying conference report withheld 10 percent of the procurement funding authorized for 1997 pending a report to Congress from the Secretary of Defense on the cost and performance of the E/F model compared to the C/D model (House Report, 1996). In the years since 1996, Congress has placed no additional significant restrictions on the F-18E/F program.

### **Both Programs Received Substantial DoD Oversight**

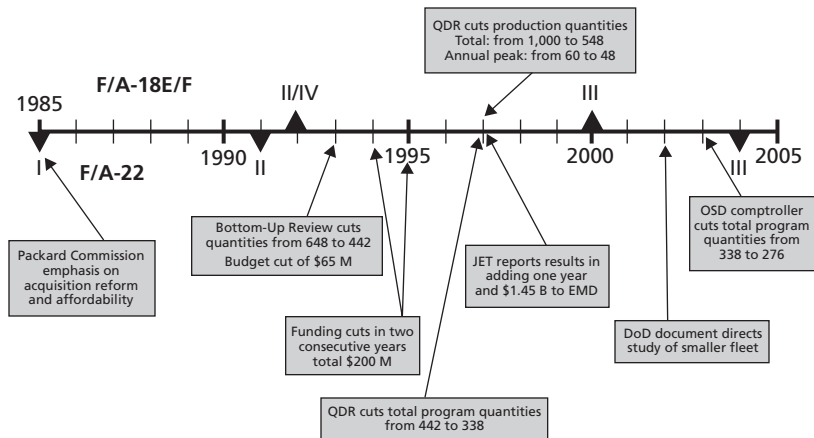
DoD reviews major programs at several levels and in various forums during a program's life. Programs undergo both service and OSD reviews of planned funding each year during the annual budget review process. In addition, OSD reviewed the need for a status of all major programs during the Quadrennial Defense Reviews (QDRs) conducted in 1996 and 2000. Finally, OSD and the services can request reviews of individual programs when problems or questions arise.

In part because the F/A-22 program was more ambitious in its development than most programs, it has experienced much more intervention from DoD during its acquisition phases (see Figure A.2).

The F/A-22 was affected indirectly early on by events outside the program. As mentioned earlier in the report, the emphasis of the 1985 Packard Commission on acquisition reform encouraged the services to eliminate uncommercial-like processes. According to a study by ANSER (Aronstein, Hirschberg, and Piccirillo, 1998), this led the Air Force, in an effort to make the F/A-22 a model for Air Force acquisition ingenuity, to assign an initial flyaway cost goal of \$35 million (in FY 1985 dollars), \$10 million below the program office's original cost goal (Aronstein, Hirschberg, and Piccirillo, 1998). That artificially low goal would come back to haunt the Air Force and the F/A-22 program years later.

The Bottom-Up Review (BUR) of the nation's defense forces conducted by then-Secretary of Defense Les Aspin in 1993 addressed

**Figure A.2**  
**Timeline of DoD Actions**



RAND MG276-A.2

the size and composition of U.S. theater air forces. The report issued in October 1993 recommended proceeding with development and procurement of the F/A-22 (Aspin, 1993, p. 37). Nevertheless, the size of the production was decreased following the review from 648 to 442 aircraft to reflect a reduction in the number of Air Force tactical air wings.

During the mid-1990s—from 1993 to 1995—the F/A-22 program experienced annual decrements to its budgets during the annual review cycles. Although these cuts were small compared to the program’s total annual funding—\$65 million to \$100 million was cut from annual budgets of roughly \$2 billion—the reductions did require the program office to adjust the development schedule.

The QDR conducted in 1996 led to another decrease in the size of the F/A-22 program. To be consistent with the F/A-22’s enhanced capability compared to the F-15 that it was replacing and with a slightly reduced Air Force force structure, then Secretary of Defense William S. Cohen decreased the total procurement of the F/A-22 from 438 to 339 aircraft (Cohen, 1997, p. 45). He also reduced peak annual production from 48 to 36 aircraft and slowed the initial ramp-



up to maximum production to decrease concurrency in development of key subsystems in the program.

During the same time period, the Assistant Secretary of the Air Force for Acquisition formed a JET composed of personnel from the Air Force, OSD and private industry to address the potential for cost growth that had been identified in management reviews of the program (GAO, 1997). In response to the JET's findings, the Air Force proposed adding one year and \$1.45 billion to the F/A-22 EMD phase to reduce risk before entering production. The USD (AT&L) approved the proposed restructuring in February 1997.

In the FY 2004 defense guidance documents issued in May 2002, Secretary of Defense Donald Rumsfeld directed the Air Force to study the implications of a much smaller F/A-22 fleet (Thompson, 2002, p. 1). Specifically, the document directed the Air Force to compare the performance of a smaller fleet of F/A-22s with the then-planned fleet of 339 aircraft, as well as alternative means for achieving national security goals, including the F-35 Joint Strike Fighter, unmanned aerial vehicles, naval strike systems, space systems, and various applications of information technology. In fall 2002, the Air Force vigorously and successfully defended its planned fleet of more than 300 F/A-22s. However, four months later in January 2003, the OSD Comptroller proposed and got approved a cut in the planned total production to 276 F/A-22s because of cost overruns projected during EMD (Butler, 2003).

Another DoD action that shaped the F/A-18E/F program was the QDR conducted in 1996. As a result of that review, the Navy was directed to reduce the total size of the F/A-18E/F program from 1,000 to 548 aircraft. The peak annual production was also cut from 60 to 48 aircraft, and the ramp-up to full production was delayed by two years (Cohen, 1997, p. 45).

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