Acquisition for the 21st Century

The F-22 Development Program

Michael D. Williams

with an introduction by
WILLIAM J. PERRY

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NATIONAL DEFENSE UNIVERSITY PRESS
Washington, D.C. 1999

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NDU Press publications are sold by the U.S. Government Printing Office. For ordering information, call (202) 512-1800 or write to the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

Library of Congress Cataloging-in-Publication Data
Acquisition for the 21st Century: The F-22 Development Program
Michael D. Williams
p. cm.
ISBN 1-57906-015-3
1. United States. Air Force--Procurement. 2. F-22 (Jet fighter plane)--Purchasing. 3. United States. Dept. of Defense--Procurement. 4. Defense contracts--United States. 5. United States--Armed Forces--Weapons systems--Production control. 6. New products--United States. I. Defense Acquisition University (U.S.) II. Title. III. Title:Acquisition for the twenty-first century
UG1123 .W55 1999
358.4'16212--dc21

98-33954
CIP

First Printing, March 1999

Dedicated to Lieutenant General Edward P. Barry, Jr., USAF, an outstanding leader, commander, and acquisition professional who taught a generation of Air Force officers the meaning of duty, honor, and country.

Contents

Introduction by William J. Perry

The Department of Defense has recently charted a new course to further improve the way in which it provides weapon systems for the warfighter. This path has seen a fundamental change in how members of the Government/industry acquisition team work together to develop America's arsenal for defense. These changes center around the use of Integrated Process and Product Development concepts and the use of empowered, multifunctional teams, called Integrated Product Teams. Integrated Product Teams have been used successfully in industry for a number of years. One particularly successful example has been the use of Integrated Product Teams on the Boeing 777 program. Now several programs in the Defense Department are operating under these concepts. The earliest, and the leader in these concepts, is the Air Force F-22 Advanced Tactical Fighter development program.

In this book, Lieutenant Colonel Michael D. Williams, USAF, first describes the principles and the concepts of the F-22 program. These thoughts and ideas are broad in nature and applicable to all weapons development programs. He then describes how the F-22 program implemented this theory. Here you will find detailed explanations of how the F-22 program operates and see practical examples of how the theoretical concepts can be applied in the real world. In the book's final section, Colonel Williams shows several examples of how we have successfully applied these concepts throughout the Department.

I believe that to truly improve the Defense Department's acquisition process we must do much more than reform rules and regulations. True change will come only from initiatives taken by the outstanding men and women serving in program offices, headquarters staffs, development laboratories, testing facilities, contractor plants, and throughout industry. This book explains successful program management initiatives that will improve the way the Department of Defense provides for its operational forces. This example can serve as a model and as an inspiration to all of us.

William J. Perry served as Secretary of Defense from 1994 to 1997.

Foreword

The F-22 development program has served as a flagship for defense acquisition reform. In this program, fundamental concepts such as integrated product development using integrated product teams were created, tested, refined, and fully implemented. These and other ideas from the F-22 program have propagated throughout the Department of Defense and defense industry. Examples abound in such programs as the Joint Strike Fighter, the New Attack Submarine, and the Landing Platform Dock (LPD)-17.

The F-22 management approach has yielded much nearer term benefits as well. Today, the Air Mobility Command operates the C-17 airlifter responding to missions that span the globe. In stark contrast to earlier predictions, the Boeing Company is delivering this airlifter below projected cost and ahead of schedule—all as a direct result of much hard work on the part of government and industry to implement management reforms flowing out of the F-22 program.

In *Acquisition for the 21st Century: The F-22 Development Program,* Lieutenant Colonel Michael D. Williams captures the elements which have spelled success for this new fighter program. However, this is much more than a documentation of history. Part I describes the theory behind the F-22 program acquisition innovations. Part II demonstrates how the program leadership applied this theory to the actual tools and techniques used to run the fighter development effort. Part III shows how the theory has been applied to several acquisitions throughout the Department of Defense, proving that the theory is applicable well beyond the F-22 program.

Acquisition for the 21st Century serves as both a history and an acquisition primer for successful program management. I commend it to Program Managers for their study. Perhaps most importantly, I commend it to the men and women in the program offices and defense suppliers throughout the Nation and the world who continue to develop the world's finest equipment for the world's best military.

Thomas M. Crean

Thomas Crean
President
Defense Acquisition University

Preface

The history of acquisition is characterized by dedicated individuals working within, and sometimes around, the system to provide weapons to the warfighter in the best way possible. Few outside our often-maligned defense procurement process know of the many success stories in the weapons developed by the United States. Admittedly, a few highly visible programs have fallen far short of being considered successful. The hallmark of every development effort is the desire of the program's management to learn from those who went before, capitalize on their lessons learned, and implement new procedures to improve the process of developing a system that meets the warfighter's needs. The development of America's next-generation air-superiority fighter—the Air Force F-22—is an example of a program that has done just that: capitalized on past successes, heeded warnings from past failures, created new tools and methods, and, as a result, developed a model acquisition program.

This account describes new methods and processes used in developing the F-22. What are these innovations, and why would readers want to know about them?

In 1986, General Larry D. Welch, the Air Force Chief of Staff, singled out the F-22—then called the Advanced Tactical Fighter (ATF)—program as an opportunity to improve the acquisition process. This book explains how leaders of the program have met that mandate; what they've done to improve the process of designing and developing a weapon system. But, again, why is it important for readers to know about the F-22 program?

By picking up this study you are obviously interested in acquisition. The F-22 system program office hosts more than 100 visitors every year; they, like you, share an interest in acquisition. The visitors have included program managers from within the Air Force, from other services, and from elsewhere within the Department of Defense (DOD) as well as congressional staffers, procurement officials from agencies outside the DOD (such as the National Aeronautics and Space Administration and the Federal Aviation Administration), and officials from other countries. All have wanted to know how the F-22 program operates.

Perhaps you're an acquisition official trying to see what all the hoopla is about. Perhaps you're trying to reform the acquisition process. Maybe you're a program manager merely trying to survive to see another sunrise. Whatever your position, this book tells how the F-22 program operates. More important, it shows *why* the F-22 program runs the way it does. Before diving in, however, you need to know the answers to several questions.

What Are the Book's Conventions?

The subject of this study has known two names—the ATF program and the F-22 program. In October 1986, to pursue a replacement for the F-15 fighter, the Air Force awarded two air vehicle design contracts for the demonstration/validation phase. This effort pitted Lockheed Aircraft Systems Company (teamed with the General Dynamics Corporation and Boeing Aircraft Company) against Northrop Aircraft Division (teamed with McDonnell Douglas Corporation) to conduct design and technology demonstrations in order to validate their weapon system approaches for the next-generation air-superiority fighter. These approaches stemmed from the previous concept development investigation phase. Lockheed's prototype, designated the YF-22A, and the YF-23A Northrop, were to fly and demonstrate their respective team's predicted performance. Simultaneously, the ATF program office took control of the ATF Engine program, previously called the Joint Advanced Fighter Engine program. This engine program similarly followed a competitive demonstration/validation prototype program in which General Electric Aircraft Engine Company vied with Pratt & Whitney Government Engine Business to see who would develop and produce the ATF's engine.

In April 1991, Secretary of the Air Force Donald B. Rice selected the Lockheed F-22 team to develop the weapon system (the fighter plus the training and support systems). He also selected Pratt & Whitney to design and build the ATF's F119 engine. (See appendix A for a brief history of the program.)

Following Secretary Rice's decision, the engineering and manufacturing development phase started on August 2, 1991. At that time the ATF program became the F-22 program. This account refers to the *ATF* program when discussing the early program (such as the demonstration/validation phase) and the *F-22* program when describing engineering and manufacturing development, the subsequent phase. Also, several of the main participants changed rank during the course of events. For example, James A. Fain, Jr., the Program Director from 1986 until 1992, started the program as a colonel and retired from the Air Force in 1995 as a lieutenant general. I refer to him as General Fain throughout the text.

Who Originated the Ideas in the Book?

The ideas, thoughts, and collective wisdom presented come from the founders of the ATF program: General Fain, Eric E. Abell, Colonel Wallace T. Bucher, and Jon T. Graves, whose positions in the program appear below.

These four leaders drew support from an able staff of some of the Air Force's and industry's finest personnel. The entire ATF/F-22 team had a hand in creating and shaping the concepts described. That team consists of members of the program office, representatives of the operational user (Air Combat Command, formerly Tactical Air Command), representatives of other Government organizations, and, significantly, members of the contractor community (the F-22 and F-23 aircraft teams and the F119 and F120 engine teams). Among this team, Colonel Robert Kayuha, Colonel William Buzzell, Michael Nock, Ronald Runkle, and Lieutenant Colonel Janet Bloom stand out as major contributors to the acquisition innovations now in use by the program.

The ATF Program Founders

James A. Fain, Jr.	Program Director	1986-1992
Eric E. Abell	Technical Director	1985-1993
Wallace T. Bucher	Deputy Program Director	1986-1991
Jon T. Graves	Deputy Program Director	1984-1996

What Is My Perspective?

I joined the ATF program as a project officer in January 1990, at the end of the demonstration/validation phase. In March 1991, I became General Fain's executive officer, gaining firsthand access to the program director and his staff. I left the program for 14 months but returned in September 1993 to head the Support System Integrated Product Team, one of the F-22's four major teams. In that position, I had to live or die with the tools and procedures described in chapters 7 and 8.

Thus, during my two tours with the F-22 program, I saw the program from the perspective of the program director and his key advisors and then participated in day-to-day program execution. Admittedly a biased observer, I've seen firsthand how the program operates. Moreover, I've worked with the team that laid the foundation for the program.

How Is the Book Laid Out?

Simply put, it's theory first, practice second, and other examples third. Don't bypass the theory, or what I call the *principles and methods*. Here's why: The way the F-22 program carries out its mission works well for the F-22. However, its solutions are system specific. They meet the unique needs of the F-22 program—or a similar program of its size and in the same environment. Nonetheless, the F-22's fundamental concepts should apply to most acquisitions in most environments. Thus, the section on theory (part I) gives *basic acquisition truths*—the really important material. Their application (part II) shows how the F-22 program operates and gives examples that help prove the value of the underlying theory. Part III describes several programs and activities within the DOD that are using these techniques today and the way the Department has mandated their use in all aspects of weapon acquisition for the future. For those who are especially hearty, more detailed discussion on some special topics follows in the appendixes.

How Best to Read This Book?

I suggest that you read the conclusion (chapter 11) first. It summarizes the entire book and includes the most important points. Then read the preface and the first page of each chapter. At the beginning of each chapter is an outline of that chapter, which you can scan to find the information you most want to read in more depth. Chapters 2 and 3, on principles and methods, present the heart of the basic acquisition truths, and chapter 9 describes the lessons learned from the use of these ideas on the F-22 program.

Acknowledgments

First, and most important, I want to thank my wife, Beth, and our two daughters, Kristin and Jacqueline, for their love and patience as I worked (and worked!) on this project.

Second, I want to thank the individuals who came up with the concepts captured on these pages and the men and women who have carried them out. Lieutenant General James A. Fain, Jr., USAF, Mr. Eric E. Abell, Colonel Wallace T. Bucher, USAF, Mr. Jon T. Graves, and their key staffs truly charted a new course for Department of Defense Acquisition. The men and women of the ATF and F-22 programs; from all of the contractors, vendors, and suppliers, the government program office, and the Air Combat Command warfighters, truly comprise one of the best examples of American aerospace excellence. These professionals successfully implemented the ideas described in this book and are well on their way to supplying the United States with a vital peacekeeping, and, if need be, war-winning capability.

Third, I wish to express my appreciation for the many people who gave up their precious time to pore over this manuscript and make many suggestions. I especially wish to thank my father, Colonel Dick Williams, USA (Ret.), and my classmate, Colonel Jack Pinnel, USAF, for their diligence in scrubbing this work.

Finally, I wish to thank the institution and the individuals that caused this manuscript to see the light of day. The Industrial College of the Armed Forces (ICAF) is the home of the Defense Acquisition University's Senior Acquisition Course. The course is the capstone in acquisition education and fosters scholarly research in the many fields of defense acquisition. This manuscript is but one small part of the research generated by this excellent program. While at ICAF I was privileged to work with four of the school's best research advisors. Dr. Joseph Goldberg, Captain Gerald Abbott, USN (Ret.), Colonel Michael Smith, USAF (Ret.), and my primary advisor, Colonel Joseph Rouge, USAF, all served to guide this document every step of the way. Following graduation, I had the pleasure to work with Colonel Stephen Thatcher, USA (Ret.) as we finalized the project. The fact that it has been published is completely due to his efforts.

Photo courtesy of Lockheed-Martin.

The YF-22 (foreground) and the YF-23 advanced tactical fighter prototypes in formation.

Acquisition for the 21st Century:

The F-22 Development Program

PART I

Theory

Because circumstances vary, there's some danger in assuming that the same procedures that have been successful in one weapon development program are appropriate for another. If the environment and all conditions are the same in both programs, such an approach may work. However, when the situations differ (as is usual), the unchallenged application of original prescriptions will likely fail. Part I examines basic acquisition truths that are appropriate for most conditions and environments. Twenty principles make up the first part of these truths (described in chapter 2). Two methods complement them (chapter 3). The Advanced Tactical Fighter (ATF) program's leadership used these concepts to conduct the ATF demonstration/validation phase and to establish the F-22 engineering and manufacturing development phase.

1

Setting the Stage

- Background: The Ugly Years of Weapon Development
- Congressional and DOD Reform
- The Charge: Create a Model Acquisition Program

Congress has warmly embraced well-disciplined, trim and fit, ready to fight programs such as the advanced tactical fighter (ATF), now known as the F-22.

Senator John W. Warner,
"Legislative Perspective,"
in *Military Project Management Handbook*

Congress, the Department of Defense (DOD) leadership and, most important, the Air Force warfighters view the F-22 development effort as a model acquisition program. It is instructive to remember that the first two groups have, in the past, frequently seen much to fix within the weapon development process. What have been the problems, and what role has the F-22 program played in helping improve the way America builds weapons?

Background: The Ugly Years of Weapon Development

Interest in improving the acquisition process for U.S. military weapons and supplies began with the founding of the Nation. However, since World War II, the executive and legislative branches have shown an exponentially increasing interest in military acquisitions.

Fear of the Soviet threat in the 1950s spurred U.S. development of weapons that would provide the Armed Forces a military edge. DOD acquired weapon systems with a strong focus on performance, at the expense of cost and schedule. In 1962, the Harvard Weapons Acquisition Research Project examined 12 major defense projects and found a tendency for cost and schedule overruns (costs averaged seven times more than initially estimated and development took 36% longer than originally scheduled). The Project recommended:

- Making cost equal in importance to performance and schedule
- Eliminating "gold plating" (developing performance and features well beyond that reasonably needed for effective military capability)
- Increasing competition at the start of a new project
- Reducing the number of cost-type contracts, particularly cost-plus-fixed-fee contracts.

By the mid-1960s, in an effort to improve the acquisition process, Robert H. Charles, the Assistant Secretary of Defense for Installations and Logistics, conceived of the *total package procurement* concept. His motivation was to

- Reduce cost overruns
- Instill greater competition
- Assign the contractor total responsibility for system design
- Prevent contractors from "buying into" programs by submitting artificially low bids.

Although the total package procurement concept had some limited success (the Air Force Maverick air-to-surface missile is the best example), it did not solve the traditional problem of cost overruns. In addition, programs continued to slip schedules and frequently did not meet their performance specifications. Programs that encountered problems under the concept included the Air Force C-5A cargo aircraft, the Army AH-56A Cheyenne helicopter, and the Navy DD-963 destroyer.

Congressional and DOD Reform

The problems on the C-5A, AH-56A, and DD-963 programs raised concern in Washington about the federal acquisition process and led to numerous studies, including that of the Commission on Government Procurement, established by Congress in November 1969. Also in reaction to the problems of cost, schedule, and technical performance, the Deputy Secretary of Defense, David Packard (the co-founder of the successful electronics giant Hewlett-Packard), initiated a host of efforts to reform the Department's method of developing and acquiring weapons. These included:

- Establishing a Defense Systems Acquisition Review Council (the predecessor of the current Defense Acquisition Board) to examine and assess a program's readiness to proceed to the next phase of its development
- Increasing competition through the use of prototype systems to decrease reliance on technically unreliable "paper" competitions
- Encouraging early testing and evaluation of a system to gauge its performance and limitations and thus its operational suitability as soon as possible
- Requiring formal Secretarial approval at three points in the weapon development cycle known as *milestones* (between the four phases of the cycle: concept formulation, validation, operational systems development, and production; see Figure 1-1).

Figure 1-1. Original Packard Weapon Development Phases, 1970

Concept Formulation	Validation	Operational Systems Development	Production

Milestones I II III

In 1972, following Packard's changes to DOD procurement, the Commission on Government Procurement released its four-volume report, which made 149 recommendations—82 requiring executive action and 67 requiring legislative action. Among the major recommendations were:

- Emphasize up-front competition on alternative system approaches
- Simplify the decision process by relying more on sound judgment and less on regulations and complicated contracts
- Reduce the layers of management and administration between policymakers and program offices
- Require more government reliance on the private sector and less on in-house facilities for procurement
- Give visibility to Congress so that it can exercise its responsibilities (i.e., provide Congress with the information it needs to make key program decisions and commitments).

DOD had already implemented many of the recommendations by the time the Commission released the report. One major change lay in the search for alternate ways to eliminate mission deficiencies. This resulted in a new milestone (termed *Milestone 0*, so that the existing milestones would not be renumbered) that required the approval of a need statement before the start of concept exploration.

The 1970s saw continued acquisition reviews and studies. In 1976, the Office of Management and Budget issued Circular A-109, which defined the federal acquisition process and aligned the majority of executive departments with the DOD phased procurement method (including Milestone 0).

In 1981, Frank C. Carlucci, the Deputy Secretary of Defense, directed changes to the acquisition system through his 31 Initiatives. His objective was to improve the acquisition system. His goals were to:

- Reduce cost
- Improve the efficiency of the acquisition process
- Increase the stability of weapon development programs
- Decrease the time it took to acquire military hardware.

In 1983, the spotlight again fell on federal and, specifically, DOD procurement. Kenneth L. Adelman and Norman R. Augustine, in *The Defense Revolution*, describe the times this way:

> Stories of wildly inflated prices for ordinary items [toilet seats, coffee pots, diodes, pliers, and hammers] first surfaced in the early years of the Reagan defense buildup when the then secretary of defense extensively publicized such incidents in an apparent effort to demonstrate that the Defense Department would be a scrupulous and tough manager of the increased funding it was seeking. Somehow the whole effort backfired. The public concluded that the department must be grossly incompetent to have paid so much money for everyday items and that the defense industry must be composed of crooks.

With the tortured history of weapon acquisition and the image of the infamous $400 hammer firmly in mind, President Ronald Reagan established his Blue Ribbon Commission on Defense Management. This Commission brought David Packard back to the center stage of DOD acquisition reform. The Acquisition Task Force (headed by William J. Perry), a subgroup of the Commission, released its initial findings and recommendations in *A Formula for Action: A Report to the President on Defense Acquisition* on April 7, 1986. The study found that cost and schedule overruns still existed. The task force summarized the issues as follows: "All too many of our weapon systems cost too much, take too long to develop, and, by the time they are fielded, incorporate obsolete technology." The key recommendations of the study included:

- Streamline the organization and procedures of acquisition
- Use technology to reduce the cost of acquisition (by stressing the importance of prototypes and demonstrations that prove the effectiveness of technology)
- Balance cost and performance (by encouraging early trade-offs to meet military needs at a lower cost)
- Stabilize acquisition programs
- Expand the use of commercial products
- Increase the use of competition in the acquisition process
- Enhance the quality of acquisition personnel
- Improve the nation's capability for industrial mobilization.

THE CHARGE: CREATE A MODEL ACQUISITION PROGRAM

The $400 hammer and the Packard Commission's report set the tone in the halls of the Pentagon in December 1986. The newly appointed director of the Air Force program to develop the next-generation air-superiority fighter, General James A. Fain, Jr. (then a colonel), was summoned to meet with General Larry D. Welch, the Air Force Chief of Staff. General Welch was quick and to the point in his charge to Fain:

1. Develop the Air Force replacement for the aging F-15 fighter
2. Create a model acquisition program and thereby set the standard for all future weapon developments.

General Fain had just served as the Director of the Low-Altitude Navigation and Targeting Infrared for Night (LANTIRN) program (he is credited with bringing it back from the brink of disaster). As such, he understood the first task, to lead the program that would develop and field an F-15 replacement. However, his second task, to create a model acquisition program, seemed daunting, perhaps even impossible. As he flew out of Washington on his way back to Wright-Patterson Air Force Base, Ohio, he decided he would tackle the comprehensible issue first. He'd figure out the model acquisition part later.

2

The 20 Principles of Acquisition

- THE PRINCIPLES OF ACQUISITION
- SUMMARY

It's not what *we did that's important. It's* why *we did what we did that people should remember!*

General James A. Fain, Jr.

When General Fain became the Director of the Advanced Tactical Fighter (ATF) development program, he brought with him a list of what he would avoid in managing an acquisition program. He had created the list from hard-won experience running the Low Altitude Navigation and Targeting Infrared for Night (LANTIRN) program. For example, on LANTIRN, he had become frustrated by its failure to integrate the cost-reporting system with the statement of work. Unable to track actual cost performance by task, he found the cost-reporting tool of little value. He vowed then never to run another program without properly integrating its various management tools.

Fain, and the principal members of his team, Eric E. Abel, Colonel Wallace T. Bucher, and Jon T. Graves, examined the successes of earlier weapon development programs, such as those for the F-15 and the F-16 fighters. They also looked at where these and other programs had run into trouble. Armed with the LANTIRN list and lessons learned from other programs, they drew on their accumulated acquisition experience to evolve a set of operating principles for managing the ATF/F-22 program. Using these operating principles as the foundation for their decisions and actions, they hoped to create a program that would successfully yield an air-superiority fighter responding to the needs of the Tactical Air Command. Figure 2-1 lists the operating principles they defined.

The Principles of Acquisition

1. Operate with Integrity — Integrity stands out as the conspicously most important principle. *Webster's New World Dictionary* defines *integrity* as "the quality or state of being of sound moral principle; uprightness, honesty, and sincerity." Defined for the

Figure 2-1. The ATF/F-22 Program's Principles of Acquisition

1. Operate with integrity.
2. Work as a team.
3. Use logic and common sense.
4. Involve everyone.
5. Integrate the entire system.
6. Ensure ownership.
7. Use a disciplined approach.
8. Understand what is really required.
9. Set realistic expectations and meet them.
10. Provide realistic options.
11. Take a long-term view.
12. Do it right the first time.
13. Have what you need for the effort.
14. Ensure everyone knows what it takes to meet the goal.
15. Use an event-based schedule with defined success criteria.
16. Define success and be able to measure it.
17. Reward success.
18. Focus on a win-win relationship.
19. Guarantee open communications.
20. Achieve success with a positive attitude and focus.

F-22 program, integrity went further. It demanded two things of every team member:

- Conduct all business relationships honestly
- Make sure the receiver understands one's message.

General Fain amplified the second point. On more than one occasion, he had seen those who would intentionally present factual details in such a way that the person receiving the information would incorrectly assume a certain condition to be true. Although knowing that the information could (and likely would) be misinterpreted, the presenters technically would not be lying. Fain required all members of the ATF/F-22 team to not only present—but also make sure that the receiver understand—the full, *true* story.

2. Work as a Team — Teamwork seems a somewhat obvious notion. Working together and sharing ideas and suggestions allow many brains to focus on a problem. Teamwork also draws individuals together, helps them bond, and helps commit them to the endeavor.

The program leadership recognized the enormous complexity, technical as well as managerial, of developing a supersonic, highly reliable stealth fighter. They realized that to succeed at this undertaking they had to constantly reinforce the idea of teamwork.

In designing the ATF, the attributes of stealth, aerodynamic performance, supercruise (the ability to fly faster than the speed of sound without using afterburner), integrated avionics, cost, reliability, and ease of maintenance could all work against one another. For example, a very low observable aircraft could be made by ridding the aircraft of most of the maintenance access doors, thus eliminating their cracks and gaps (which can reflect radar energy and make the aircraft easier to detect). But that would make the aircraft much more difficult to service, because the maintenance technician, with fewer access panels, would have a harder time checking fluid levels or getting to parts that need replacement. The goal, then, is to balance these attributes while designing a fighter that meets all requirements.

The way to reach a balanced design is to make sure that the various disciplines responsible for the attributes (such as reliability engineering, signature engineering, and manufacturing as well as those concerned with logistics, finance, and contracting) cooperate, that is, *work as a team*. Each discipline needs to understand the constraints imposed by other disciplines, and those responsible must coordinate and interweave their work to achieve a balanced design.

The ATF management team realized the need for teamwork from the beginning. So that everyone understood the requirements, the team saw that the government program office and the contractors worked closely with the operational users (the combat fighter pilots who create the requirements). At the same time, the team leadership made sure that the users saw firsthand what their requirements meant in terms of aircraft complexity and cost. Thus, teamwork applied to all levels and members of the team: the users, the contractors, and the program office.

3. Use Logic and Common Sense — General Fain had a deep-seated belief that the only reason for rules and regulations was to try to prevent people from repeating past mistakes. His view was that reasonable people, who were aware of the intended direction of the organization, would use their common sense and make the right decisions. In other words, he assumed they would make decisions logically, based on the facts and not on emotions. In his own words, "If something doesn't feel right, look right, smell right, it probably isn't right. Don't do it! Just use plain old everyday common sense in everything you do, and you'll do the right thing." He also encouraged each team member to take on "the system" to eliminate rules or regulations that failed the logic test.

4. Involve Everyone — As Principle 2 states, teamwork is important. But who makes up the team? Simply put, anyone who has a stake in the outcome belongs on the team. For the ATF program, the core, the everyday functioning team, consisted of representatives of the contractors, the program office, and the user—those working most closely with the program and thus having a greater stake in the outcome.

However, the program team also included those outside this immediate family. The program's leadership saw a need for each person who would come in contact with the ATF to be tied into the program so that everyone would understand the nuances of the program better. More importantly, the leadership wanted all team members to feel they had something to gain by the success of the ATF. In earlier programs, members of various staff groups and oversight agencies (most of the organizations outside the program office) created great turmoil through their questions and requests to review the program because they weren't intimately familiar with the programs. Many of their perceptions and beliefs were inaccurate. These groups did not necessarily share the desire to see the program succeed that the user, the program office, and the contractors did. The ATF program management knew that these groups formed a necessary part of fielding a weapon system successfully and focused on making them an active, contributing part of the ATF development team.

The program office achieved this involvement in many ways. For example, before release of the final request for proposal (RFP)—the document that tells the competing contractors what the Government wants them to offer to do—the program office called together 18 Air Force generals and Navy admirals involved in the ATF program. At this General Officer Review, the program office explained precisely what it was requesting of the contractors and consulted the flag officers for their advice and insights. Dissent by any member of this forum could have easily delayed or complicated the procurement. However, the program office had thoroughly prepared the RFP and the overarching acquisition strategy. Both proved to be examples of excellent coordination with, and involvement by, affected government agencies and competing contractor teams. For these reasons, there was no dissent, and each attendee agreed to the release of the RFP without major change. Moreover, since the review directly involved these senior officers they not only became part of the process but also readily bought into the effort.

5. Integrate the Entire System — In the LANTIRN program, General Fain had been concerned that the many management tools available (such as cost performance reports, work breakdown structures, and specifications) rarely related to one another. These tools frequently reported conflicting information and, as a result, often worked at cross-purposes. In addition, some information developed and used by the contractor personnel, such as internal cost-accounting information, did not follow the regulation-required government format. As a result, the contractor had to translate this information into that format. General Fain's intent was to coordinate and focus all of the tools in the acquisition "tool set" to deliver a high-performance, high-quality product on schedule and within cost. Ideally, the contractor and the Government would use the same information (thus eliminating the need for translation of data).

As the ATF demonstration/validation phase progressed, the principle of integration expanded. It was a driving force behind the creation of the acquisition strategy for the next phase, engineering and manufacturing development (EMD). The founding fathers ensured that all the elements of the acquisition strategy were tied together to support the overall goal of fielding the ATF. They described the concept as a stone wall. Just as fine New England stone walls are carefully crafted by interlocking each uniquely shaped stone to create great strength, all the elements of the ATF acquisition strategy had been carefully fitted. If one element (stone) of the strategy was taken out or changed, it would affect the entire strategy (wall). Change was allowed, but the integrated process had to recognize all the implications of any change. The F-22 integrated acquisition strategy "stone wall" is shown in Figure 2-2.

6. Ensure Ownership — As stated in the fourth principle, the program leadership wanted everyone involved to be committed to success of the F-22. Their logic was that, if all team members owned the program, all would want to see it succeed and would do what it took to develop a high-quality product.

The F-22 program office established ownership in many ways. At the unit level, the program office structured the government and contractor organizations around teams, called *integrated product teams* (see chapter 7), that focused on developing a specific product (for example, the cockpit team or the landing gear team). To drive ownership down to the individual level, the program leadership gave the team members ultimate responsibility for their product by allocating a budget, requirements, and a schedule—making them

Figure 2-2. The F-22 Integrated Acquisition Strategy

Integrity Programs	Integrated Master Schedule	System Support Concept	EMD and Production
Executable Program Schedule	Production Incentive Structure	Award Fee Plan	Integrated Master Plan
Military Prime Specifications	Executable Program	Contractor Generated Statement of Work	
Contract Type	Subcontract Management/ Competition	Demonstration/ Validation Data Base	Work Breakdown Structure

"mini–program directors" for their product. The leaders wanted all team members to know their product so well that they could describe its current status at a moment's notice (i.e., know the technical performance achieved to date, as well as the latest production cost and weight estimates.)

The management team also wanted to establish ownership among participants who worked at the various headquarters and associated organizations around the country primarily by involving them in the full program. As in the General Officer Review, members outside the program office, not traditionally viewed as members of acquisition teams, had an opportunity to become involved by casting their vote. The direct result was buy-in and greater ownership of the F-22. Pentagon staff officers were surprised and pleased that they were invited to attend F-22 reviews. Members of the Defense Plant Representative Offices were stunned to hear the Program Director say they were to be treated like members of the program office and that they were full members of the F-22 development team. Once they were convinced of this, ownership and its inherent desire for program success followed naturally.

7. Use a Disciplined Approach — Perhaps a disciplined approach to a program seems like common sense (and it is), but the founders had seen many earlier programs fail for lack of a structured method of management. Time wasted working on previously solved problems, uncontrolled schedule slips, inexplicable cost growth, and development of items not needed by the user were common in other programs. The founders realized that, to avoid these and similar problems and to implement the other principles they planned to use on this program, they needed to manage the effort tightly.

8. **Understand What Is Really Required** — A key failing of many acquisition programs is changing requirements. The most palatable reason is a change in threat. To counter the new threat, the program office must change the weapon. However, other reasons for a change in requirements can be much less palatable. The program's management, which had seen these problems before, wanted to make sure that the ATF's requirements matched user requirements and that the users understood the impact, including the cost, of changes they were asking for. For this understanding to develop, they found it was important to involve everyone who had a stake in the outcome of the fighter in the requirements process.

Tactical Air Command personnel, as the operational users, established the requirements. They worked their requirements iteratively with the program office to understand the impact on the cost, schedule, and performance of the fighter and then evaluated the operational benefit of these revised requirements (a disciplined, "bang-for-your-buck" analysis). The ATF program office also found it helpful to have the requirements coordinated at a level in the Air Force high enough that any change would require an argument good enough to sway the opinion of a senior decisionmaker (the Chief of Staff of the Air Force). See chapter 5 for a discussion of the definition and refinement of the ATF requirements.

9. **Set Realistic Expectations and Meet Them** — In talking to a group of budding program managers, General Fain explained, "The definition of a successful program is a program that never surprises the Beltway—you cannot allow mis-expectations!" The founders knew that the definition of success depended on (a) the individual judging you, and (b) that individual's expectation of what you would deliver.

As an example, in the General Officer Review the 18 flag officers had the chance to see what the program office was asking for in the EMD phase. This session *set their expectations* of what the ATF program would and would not do. For example, the expectation that the ATF was to be a single-engine aircraft would be reset as they learned that both team's concepts called for two engines. If they believed the ATF would fly with engine-thrust reversers (originally planned at the start of demonstration/validation), they would learn that the user and the program office dropped reversers for reasons of reliability, cost, weight, and complexity. The power of the General Officer Review was that it gave these key individuals the opportunity to voice disagreement with the plan and adjust the program's projected course. Because the General Officers all saw the projected program at the same time, they all shared the same view. Their expectations (by design) matched those of the program office.

The second part of the principle, *meet expectations*, has an important corollary. An individual who cannot do what was promised needs to explain the reason to the correct people and readjust their expectations. Timeliness is critical. As soon as a team member knows an event will not follow the original schedule, or that a performance point will not be met, that individual must reset everyone's expectations as fast as possible.

10. Provide Realistic Options — Life in a program office is spent answering questions. Frequently Pentagon program element monitors (the staff who budget the necessary funds) call the program office to find out the impact of a proposed change in future funding. Typically such questions need answers in a short time (minutes, hours, or days). These "budget drills" or "what-if exercises" often become reality, resulting in a change in the program's expected funding profile. The F-22 team policy was to answer every question with multiple (generally three) accurate, executable courses of action. Each answer had to explain the impact on cost, in both the affected years and over the total life cycle; on schedule; on the performance of the aircraft; and on opportunity costs. The program leadership found this approach critical to maintaining its credibility inside the Pentagon and helped the program office meet realistic expectations with the Air Force Headquarters and the user, Tactical Air Command.

11. Take a Long-Term View — Historically, program directors have occasionally caused problems by basing decisions on short-term expedients and failing to take into account long-term consequences. For example, the B-1B program's decision to delay developing support equipment hurt the initial readiness of the aircraft. Deputy Program Director Graves and the rest of the F-22 team vowed not to let that kind of problem happen in their program. In resolving all problems, the program office weighs how the solution will, in the long term, affect the operational user. The team calls this *life-cycle decisionmaking*.

Lockheed demonstrated this concept early in the design of the production aircraft when the fundamental design issue arose of how to attach the wings to the fuselage. One method would attach the wing sturdily and allow it to be installed and replaced relatively easily. The second method would keep the wing attached equally well but would make the wing harder to install and much more difficult to replace. The second type of wing was cheaper to manufacture and would yield a lighter airplane (both good news to a program director at the start of EMD). The team opted for the more expensive (at least initially) and heavier attachment method because the life-cycle decision clearly highlighted the problems the user would have, should a wing need replacement. If the program director had chosen Option 2, he would have committed the Air Force to a complex, and thus expensive, wing replacement process. The decision chose the method that cost more in the short term but would be much cheaper in the long term.

12. Do It Right the First Time — At the start of the demonstration/validation phase, Lieutenant General Thomas H. McMullen, who commanded the Aeronautical Systems Division (the higher headquarters of the ATF program office) was adamant about eliminating inefficiency in programs and improving the way the Government developed weapons. He wanted his people to accomplish a task correctly on the first try. To do otherwise meant coming back and redoing the task—clearly a waste of time and money. Thus, clearly guided by McMullen and Fred Rall, his director of Engineering, and reinforced by lessons learned from past programs, Fain and Abell set up ATF program operations with the power and procedures to "do it right" on the first pass.

Fain redoubled this effort toward the end of demonstration/validation, when the Pentagon directed a cost-type contract for the EMD phase. He was concerned that there would not be enough money in the budget to make errors on the first pass and accomplish a task on the second try. As the EMD phase of the F-22 program began, he reiterated that all members of the F-22 team were to "do it right the first time."

13. Have What You Need for the Effort — Abell did not want to start development of the aircraft until he knew what would work and what wouldn't. Having seen other programs work hard to discover or invent something before they could put their system into production, he knew that chasing technology could prove expensive in both time and money and resolved not to let the F-22 be held hostage to unprogrammed advancements. The ATF's primary focus in demonstration/validation was to refine requirements and mature technology for the EMD phase of the program. Only if the contractors could demonstrate a technology would Abell allow them to plan for its use in the development and production of the fighter.

14. Ensure Everyone Knows What It Takes to Meet the Goal — A powerful advantage of having a tightly run, highly integrated program structure is that the Program Director has better insight into how much money and time the contractor needs to complete a program. With a firm understanding of the expected costs, the program's leadership could credibly defend the F-22 budget. They made sure the acquisition leadership in the Pentagon as well as the leadership at Tactical Air Command (which requests the program's funding) knew what resources the program needed to be successful. Providing credible cost and schedule requirements to senior decisionmakers helped ensure that the F-22 program received its budgeted funding.

15. Use an Event-Based Schedule with Defined Success Criteria — This principle is the backbone of the F-22 management system, the integrated master plan (discussed in detail in chapter 8). While working on other programs, the F-22 management team had participated in many preliminary and critical design reviews that were held precisely on their scheduled date, even though the contractor and the program office were not ready. A review like this would generate many open-action items that had to be completed. In some cases, a second or third review took place months later. As the F-22 leadership knew, holding a critical review before everything is ready yields items that must be scrapped and reworked (clearly violating Principle 12, do it right the first time). As a solution, the management team devised a method in which the contractor defined intermediate checkpoints in the program with criteria for when an activity could be considered complete. The contractor sequentially arranged these events to establish an event-based schedule that clearly showed what had to be done and when. By instilling the concept that the F-22 would be an event-based program (i.e., the program wouldn't proceed until the event had successfully met its success criteria), the founding fathers helped ensure that major reviews would take place at the correct time—when the work was done and the program was ready to move on to the next step.

16. Define Success and Be Able to Measure It — In general, people want to do a good job, but frequently they don't know what job needs to be done, or they do not find out how they are doing so they can improve. The leaders of the program must define what needs to be done, and team members must know the leader's view of success. The F-22 program leadership believed that any activity that could be measured could also be improved. They envisioned this measurement process to be routine and standard, a normal part of doing business. Their goal was to measure and regularly track every major part of the F-22 program and focus on areas that exceeded certain predetermined limits. Fain and his directors defined these limits based on their agreed-on measures of success—technical performance measures (see chapter 8). Significantly, they chose the success criteria before the event.

17. Reward Success — The F-22 program has rewarded success at many levels. The current development effort uses a cost-plus-award-fee contract in which the Government awards the contractor its profit every 6 months based on how well it has performed. On a smaller scale, every Friday the program office picks the outstanding individual or team for that week. An old adage says that success breeds success, and a key to making that adage come true is identifying and acknowledging success. Having a standard measurement process that easily enables the leadership to evaluate program performance also enables the leadership to fairly identify success. Recognition serves to reinforce positive behavior by providing positive feedback to the winners and to all other members of the team.

18. Focus on a Win-Win Relationship — A popular program office saying was, "If the contractor wins, the Government wins. If the contractor loses, the Government loses." In the past, whether reviewing a specification or conducting a negotiation, the contractors and the Government often would be at odds. The program leadership realized that the Government/contractor team would be more effective if the members were working together to solve their problems. If the contractor developed a fighter system that met the user's stated needs within the planned budget, cost, and schedule, the Government would be satisfied—it would win. If the contractor delivered the weapon system as promised, it would win—that is, earn the full profit (awarded through the cost-plus-award-fee contract). The converse is true as well. If the contractor did not deliver a system that met the user's needs or was over budget, cost, or schedule, the Government would lose because it wouldn't be satisfied; so would the contractor, since its profit would be reduced. This idea encouraged all Government team members to join their contractor counterparts to form one unit that would develop a fighter weapon system that met warfighter needs.

19. Guarantee Open Communication — In earlier programs, problems that were hard to solve and expensive to fix had reached Fain. When he delved into them, he found that his people had known of them for some time but couldn't solve them at their level. He realized that if he had known of the problems at the time they occurred, he could have solved them easily and cheaply. Based on this observation, he wanted to establish an environment where a person finding such a problem could report it in a way that would help get the problem solved. Setting up a win-win relationship resulted in common trust and understanding and established the environment that Fain was looking for, one that supports open communication.

20. Achieve Success with a Positive Attitude and Focus — Another popular saying in the F-22 program office was "The key to success is positive attitude and focus." A team of people focused on the correct objective and with the right frame of mind could tackle any problem. The program's leadership ensured that the team stayed aimed in the right direction and at the right issues. They refused to let the team complain or worry about items over which they had no control (summed up with two other popular program office expressions: "no whining" and "no hand wringing").

SUMMARY

The 20 principles of acquisition in Figure 2-1 don't seem very revolutionary. They are simple and straightforward, born of common sense. However, they are effective. In some organizations, they also are fairly rare. How many of these principles have been violated in other organizations? How effective could those organizations have been if they had implemented all 20? These principles, which apply to almost any other acquisition program (and to most other situations as well), serve as the F-22 program's foundation. The two concepts in chapter 3 complete the basic acquisition truths.

Photo courtesy of Lockheed-Martin.

The fine lines of the YF-22 are displayed in this head-on view. The aircraft was designed for a reduced radar signature as well as the ability to cruise at supersonic speeds.

3

Risk Management and Concurrent Leadership

- **Risk Management**
  - Refine and understand the requirements
  - Manage the needed technologies
  - Use a product-based management system
- **Concurrent Leadership**
  - Traditional management
  - The ATF demonstration/validation phase leadership model
  - The F-22 concurrent leadership model
- **Summary**

Concurrent leadership is a new way of doing business. It is a new culture that relies on successful teaming. We have to have the right people. Law-and-order managers no longer cut it. Our team members must be functional experts but with a broader perspective. They must have a program view.

James (Micky) Blackwell,
Lockheed F-22 Program Director

Chapter 2 described the principles that form the foundation of the F-22 program. Expanding on these principles, the program founders embodied them in two central methods they used to manage the program. Serving as central themes for developing the program, one method centered on how to achieve program success by managing risk, the other on how to empower one's work force through concurrent leadership.

Risk Management

All weapon development programs seek to design and deliver a product that meets the operational user's needs within allocated resources (both time and money). From experience with earlier programs, the management team knew that the chief risks to successful performance lay in three areas. One area relates to problems stemming from lack of firm requirements or from misunderstood requirements. Another relates to problems stemming from immature or missing technologies. Both sets of problems negatively affect cost, schedule and performance. But after controlling these problem, programs can still get into trouble. A third area of risk centers on inadequacies in planning and tracking the overall effort.

From this assessment, the program office evolved the three-pronged approach to managing risk:

1. Refine and understand the requirements of the program
2. Manage the needed technologies
3. Use a product-based management system.

The ATF program implementation of these ideas is described in chapters 5 (requirements), 6 (technology), and 7 and 8 (the management system). Figure 3-1 serves as a "road map" of risk management.

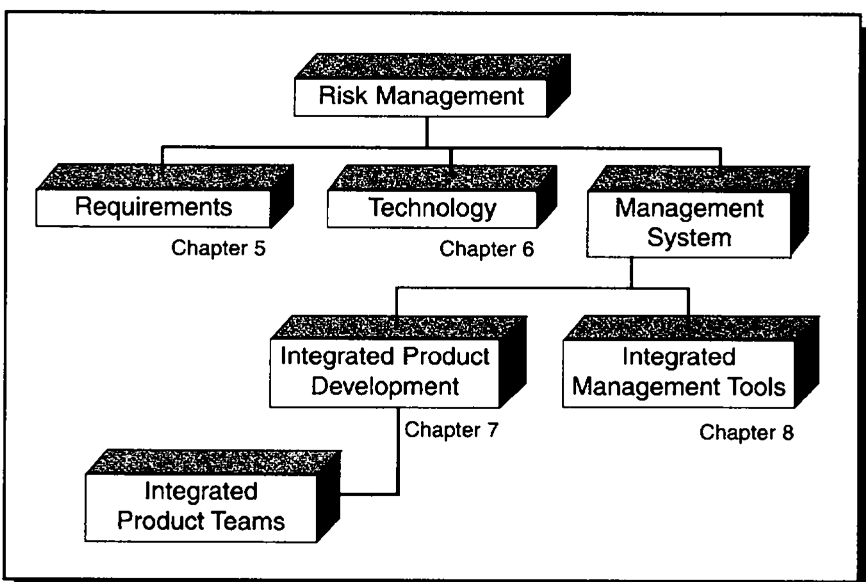
Refine and Understand the Requirements

It's a simple enough concept: build what the user needs. But program manager after program manager has found that doing so is not simple at all. The ATF founders discovered that they had to get all of the key players to agree on what was really required and on what they wanted to achieve. Several of the ATF/F-22 principles described in chapter 2 apply to requirements definition and refinement:

4. ***Involve everyone***
6. ***Ensure ownership***
7. ***Use a disciplined approach***
8. ***Understand what is really required.***

Involve everyone — Experience on the ATF program showed that the users will adjust their requirements if they understand the impact (for example, on the cost, reliability, or maintenance capability) of those requirements. To do that, they had to be fully involved. Likewise, if contractors understand why a user has a certain requirement, they can generate innovative ways to meet it. This process works best if all of the players (program office, user, contractors) are mutually involved and able to talk to each other.

Figure 3-1. Elements of Risk Management



Ensure ownership — As mentioned in chapter 2, people will commit to making something happen if they have bought into the concept—if they have ownership. Bringing all of the players together to define and refine the system's requirements gives them a vote in what is finally decided, which helps guarantee they will all support those requirements.

Use a disciplined approach — Reviews on a regular basis force all parties—program office, users, and contractors—to readdress the user's needs. The users revalidate their requirements. The contractors reaffirm their ability to meet them. If the weapon system won't meet a user requirement, the program must either fix the weapon (if possible) or amend the requirement. To adjust the requirement, the team, led by the user, must reexamine the weapon, threat, and other factors driving the requirement) to see if the requirement for change is valid or if it can be met in some other way (such as through a change in tactics). If there is a mismatch between the weapon system and the user's requirements, it is best to know early so the service can change one or the other.

Understand what is really required — Clear communication with the group that needs the product and a clear understanding within the user group of what it wants helps to ensure a successful program. By working as an integrated team and regularly reviewing the user's requirements and the contractor's ability to meet them, the program will establish a solid, achievable set of requirements, will greatly reduce scrapping and reworking of items, and will help ensure that the user gets a weapon that does what it needs to do.

Manage the Needed Technologies

The starting assumption behind this strategy is that the new system requires new technology. The F-22, a supersonic, highly maneuverable stealth fighter, clearly did. In other programs, such as the Army RAH-66 Comanche helicopter, the Navy SSN-21 Seawolf attack submarine, or the Marine V-22 Osprey tilt-rotor aircraft, the need for new technology is also obvious. However, the need for technology does not guarantee its availability. The program must focus on developing and proving the technology that is needed and appropriate to support the user's requirements. Given the current lengthy development cycles, developing and proving technology at the beginning of the program may mean entering production with something other than the latest technology. What is important is to enter into production not with the latest technology but with technology that works to meet the user's needs.

The ATF/F-22 principles that apply to technology development and definition are:

9. ***Set realistic expectations and meet them***
13. ***Have what you need for the effort***
14. ***Ensure everyone knows what it takes to meet the goal***
19. ***Guarantee open communication.***

Set realistic expectations and meet them — The Government relies on the contractor to develop a weapon to meet the user's requirements and deliver the weapon with the technology necessary to meet those requirements. In the past, some programs have oversold what new technology could do. Early promises served to set the user's expectations at an unreasonably high level, and the new weapon, although better than previous systems, may not have met the user's original expectations. Understandably, this resulted in dissatisfaction. Involving the user in proving what technology can actually do greatly helps in setting appropriate expectations.

Have what you need for the effort — As described in chapter 2, the program office wanted to make sure that the technology promised for ATF problems actually existed and worked. To bank on the successful application of an unproven technology would greatly increase the risk in the program. The program had to prove the technology through analysis, demonstrations, and other testing.

Ensure everyone knows what it takes to meet the goal, and guarantee open communication — During the demonstration/validation phase, the ATF development teams consisted of many different contractors. Each contractor had its own technology development laboratories staffed by hundreds of scientists and engineers knowledgeable about different materials and approaches applicable to challenges of designing a new fighter aircraft. Because the lead contractors (Lockheed and Northrop) clearly communicated the challenges and the approaches to each member of their team, each competing team could take advantage of a large body of knowledge, which solved many demanding problems. Whether an effort involves many contractors or just many people, open communication and clear statements of what it takes to meet the goals draws in everyone to help develop the needed technology.

Use a Product-Based Management System

Exceeding planned costs, not staying on schedule, and not meeting requirements has historically attracted a great deal of attention. As mentioned in chapter 1, during the 1950s and 1960s many programs had large cost overruns and schedule slips. Although the Department of Defense (DOD) has made large improvements in this area (a recent study shows the DOD controls costs much better than most other government agencies), tight management is essential to keep cost, schedule, and technical performance under control. The ATF management team wanted every person on the F-22 program to be as effective as possible. Workers at all levels needed to feel a strong commitment to their task and a sense of pride and ownership in what they did for the F-22. As a result, the management team wanted to develop a management system that focused workers at all levels on their product.

The key management system ATF/F-22 principles are:

5. ***Integrate the entire system***
6. ***Ensure ownership***
7. ***Use a disciplined approach***
8. ***Understand what is really required***
11. ***Take a long-term view***
13. ***Have what you need for the effort***
14. ***Ensure everyone knows what it takes to meet the goal***
15. ***Use an event-based schedule with defined success criteria***
16. ***Define success and be able to measure it***
17. ***Reward success.***

The length and depth of this list highlight the importance of the management system. To manage cost, schedule, and performance and follow the principles above, the F-22 program developed several management tools and procedures (discussed in chapter 8). These include an event-based schedule coupled with success criteria and measures of effectiveness, and a means to track performance, hold individuals accountable, and reward the performance of the team. The F-22 program organization empowered the lowest tier members of the team while it also ensured a well-balanced approach to the product (see chapter 7).

Integrate the entire system — The F-22 program introduced this powerful idea to the DOD. In the past, management teams used separate tools to look at cost, schedule, and technical performance. To be successful, the management system must tie together existing or newly created tools so that the management team can assess all aspects of performance. The most important benefit of such an approach is clarity of information. Management can easily and clearly see how the program is performing from the integrated views of cost, schedule, and performance. An integrated management system greatly improves team member—especially the program director's—situational awareness of the program.

Ensure ownership — The management system must be structured in such a manner that all members of the team, from program manager to line draftsman, believe the product they are working on is their personal responsibility. One way to do this is to carve the program into pieces, units, and subunits and assign individuals to work on the development of the products within them. The management system should hold individuals accountable for the development of their products and give them the authority to make those products work. As in the integrated management system mentioned above, the system should hold each team member, regardless of technical specialty, accountable for the cost, schedule, and performance of the product.

Use a disciplined approach — The management system of any complex endeavor—defense acquisition, automobile design and production, even home construction—must plot a rigorous, organized path to its next phase.

Understand what is really required — This idea applies to much more than the requirements of the end product. The team needs to think through all of the steps needed to design, develop, test, produce, and field the user's weapon system. The management system requires and, in fact, depends on a detailed up-front plan that takes the program from the current starting point to the next phase. In the ATF program, the competing contractors started their detailed planning as part of the preparation for the EMD phase in the last 2 years of the demonstration/validation phase, when the two sets of competing teams had a good understanding of the requirements and their design solution. However, the concept applies to any phase. What is important is to have a management system that forces the team to plan well in advance yet allows the flexibility needed to deal with unanticipated problems.

Take a long-term view — The management system must allow decisionmaking to focus on long-term considerations of delivering a product that meets the user's requirements. A detailed, long-range schedule helps workers at every level see the path to the end product. Tracking current product performance against the user's desired operational (delivered) requirements helps focus team members on the goal of user satisfaction.

Have what you need for the effort — To look at all aspects of cost, schedule, and technical performance for all products, as discussed above, the system needs a method of collecting data that assesses the status of each area. It's best to have one set of data that the entire team uses: Government team members should use contractor data in the format that the contractor normally uses. In fact, the ATF program office emphasized the efficient use of data: "Create data once—use it many times."

Using contractor data in the contractor's format saves money (the Government doesn't have to pay the contractor to translate information into a Government-required format). It reduces communication errors (bringing realism to the hackneyed expression, "let's all sing off the same sheet of music"). Having the contractor, program office, and user looking at the same sheet of paper with the same data encourages teamwork. The management system should get the necessary information in a way that uses the contractor's format, saves time that can be applied to improving the user's product, saves taxpayer money, and promotes teamwork.

Ensure everyone knows what it takes to meet the goal — As discussed above, the management system must force and facilitate detailed, up-front planning that drives the team to chart a clear path to the final product. The management system must also require that each team follow one overall plan so that each team member knows what activities must take place to meet the final objective and each team understands its relation to the overall program. For example, if the model department falls behind in building wind tunnel test models, the wind tunnel tests are delayed. If data from wind tunnel tests are delayed, aerodynamic load factors for the airframe design team don't arrive in time. If the design of the airframe is delayed, the construction of the first flying prototype will also be delayed. If the model makers can look at a single schedule and see the impact of their delays on their ultimate product (the flying prototype and, ultimately, the operational airplane), they will have a stronger motivation to find a way to get back on schedule.

Use an event-based schedule with defined success criteria — The management system must have a plan that shows intermediate events that need to occur to arrive at the final product and in what sequence they must happen. The plan must also define what constitutes successful completion of each event. Finally, the management system must tie the events to a calendar so that the program can be costed (to determine how much effort by year and thus how much money by year is necessary) and scheduled (to reserve test ranges and other facilities as well as schedule deliveries for materials). Even though events (for instance, budget reductions) may delay the program, the sequence usually does not change (the model maker must make the model before the wind tunnel can collect data, but it can happen in May instead of January).

A preapproved definition of success is important to support the original planning. For example, the airframe design team might determine it needs aerodynamic loads for the aircraft with flaps deployed and retracted, calling for two models. At the start of the program, the design team would define successful completion of wind tunnel testing as capturing data for an aircraft with flaps deployed and retracted. If, during the course of the program, the model maker fell behind and, to catch up, built a model that only simulated flaps retracted, the event of wind tunnel testing could not be completed because it requires data for both configurations. With a defined criterion for wind tunnel testing, the team focuses on capturing the data needed for completing the event, rather than meeting the schedule. In this manner, the management system encourages activities to support the quality of the product (in this example, a complete design using data for both flap configurations).

Emphasizing the quality of the product does not imply that the schedule is not important. As described above, the program holds each team accountable for meeting all aspects of performance, including schedule performance. However, unlike a calendar-based program schedule, the event-based schedule focuses on achieving the predefined activities according to the predefined criteria. Other portions of the management system (such as the award component) can motivate successful schedule performance. The key is not to trade product quality for schedule performance.

Some may fear that up-front planning locks the team into an unchangeable path. But new events (such as a destroyed wind tunnel or, perhaps, an improved, validated computational fluid-dynamics computer model that successfully predicts aerodynamic performance) will force a change in the sequence, success criteria, or event timing of the plan. If this occurs, it is important to change the plan in an integrated manner. If all players on the team (the model makers, the wind tunnel technicians, the airframe designers, and the flight test team) agree to the change and understand its impact, then the plan must be changed.

Define success and measure it — For a management system to hold an individual responsible for a product (really a subproduct of the final product delivered to the customer), the system must determine how well that product is progressing compared to the projected targets for cost, schedule, and technical performance. First, the system must define success—that is, define the product requirements in terms of cost, schedule, and technical performance. It's important to note that requirements for lower tier products (subproducts) are based on performance targets for higher level products (for example, the cost, schedule, and performance requirements of the cockpit must support the cost, schedule, and performance requirements of the overall airframe), which tie into the overall, top-level product requirements. The management system must track how the product is meeting its targets at each level.

Reward success — With success defined and measured, the next step is for the management system to reward members (both individuals and teams) for their performance. The rewards will vary. The challenge for the program leadership (both the contractor and the Government) is to develop rewards that motivate future high-level performance. The contractor, as a company or group of companies, can be rewarded financially through an award-fee or incentive-fee contract. The contractor could choose to allocate this award to key performers responsible for the team's success. Or the Government and contractor could recognize team members through a team awards program (for example, Outstanding Team of the Month, Best Team Member of the Quarter). Whatever methods one chooses, the key is to recognize and reward the performance of both individuals and teams.

Concurrent Leadership

Leaders know that mission success depends upon one's people. The challenge is to structure the organization so that people can accomplish the mission. Fain built upon pre-1990 Air Force IPD concepts by applying concurrent leadership, empowering teams to develop integrated solutions. As described in chapter 7, concurrent leadership is an essential element of the F-22 program management system. Some say it's the secret to the program's success.

General Fain explained the genesis of concurrent leadership during an interview with Donald Fujii of the Defense Systems Management College in July 1991, just before the start of the EMD phase of the F-22 program:

Fain: This is my equation for how to run a program. When I have a problem I get together the functional experts from contracts, finance, engineering, management, and test (if I need him). I sit them around this table; they're called the FOG [front office group]. I say, "This is what we need. Generate it." Each one of these guys has the capability to walk out of their functional stovepipe and generate a solution based on his expertise, but in a general way, taking into account the others' perspectives and constraints. When we first started this I got a strategy, for example, based on contracts, but it was a general strategy. After a couple of years of doing this, I started getting strategies that weren't based on contracts but were based on everything (engineering, finance, management, test, and contracts). That happened because they all sat around this table and watched each other and learned each other's functional constraints, issues, and limitations.

Fujii: They were thinking in an integrated fashion.

Fain: Right, right, right! That's the concept. [It is important] to have the functional expert deal with the functional raw data. For example, I don't know everything I need to know about the contractual raw data. But I've got someone who does. But I won't let him answer a question from a contract point of view. I let him answer it from a general point of view.... That is the secret to how we have run the ATF for the last 3 or 4 years. It has been very successful....

After I bring them into this room, when we get done sorting out the issue, we have a strategy that covers all aspects, an integrated approach. And then, you would be surprised how easy it [the solution] is to implement.

Fujii: You are sort of doing management concurrency. Like the design concurrency notion where you get designers and engineers and manufacturing all together.

Fain: Concurrent engineering? Yes. We are doing concurrent management. No, make that concurrent leadership.

The notion of concurrent leadership may be best shown by comparing three models of management—the traditional method of management, the model used during the ATF demonstration/validation phase described above, and the fully developed F-22 concurrent leadership model.

Traditional Management

Organizations with traditional program management (shown in Figure 3-2) tend to be focused along functional lines. Each specialty resides in its respective functional area, or stovepipe. Structural engineers, avionics engineers, and support equipment engineers all work in the engineering division. Manufacturing experts work in the manufacturing division. Finance and contracting professionals work in their respective departments.

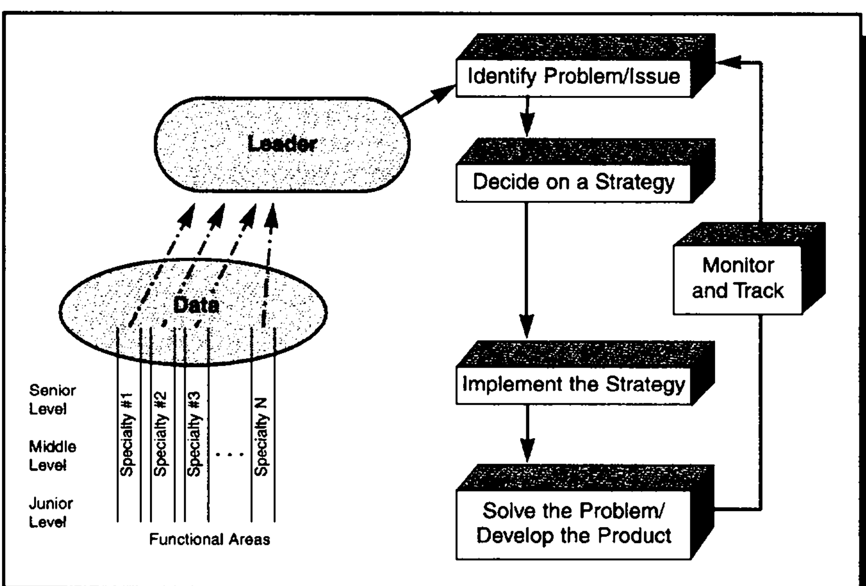
In the traditional model, experts tend to rise to ever-higher management positions in their functional stovepipes. As they move up in the organization, they tend to see more of other elements of the organization, gaining a perspective that allows them to deal with broader issues. When a problem surfaces in an organization, the leader goes to the functional chiefs and requests data. The appropriate specialists generate raw data, and the functional chiefs, with their broader perspective, make sure the data are in a form that the leader can use. The functional chiefs then present the data to the leader. The leader integrates the data and, alone or with the functional chiefs, decides on a strategy, implements a course of action, and produces a solution.

Admittedly, the example above is simplistic, but it serves to point out that in a traditional organization, the burdens of data integration and problem solving tend to rise to the leader's level.

The ATF Demonstration/Validation Phase Leadership Model

As Fain described, the ATF program office developed a different approach during the demonstration/validation phase. Relying on the principles of involvement and ownership, he created a Front Office Group (FOG), consisting of the ATF program office chief functional experts in finance (program control), contracts, engineering, manage-

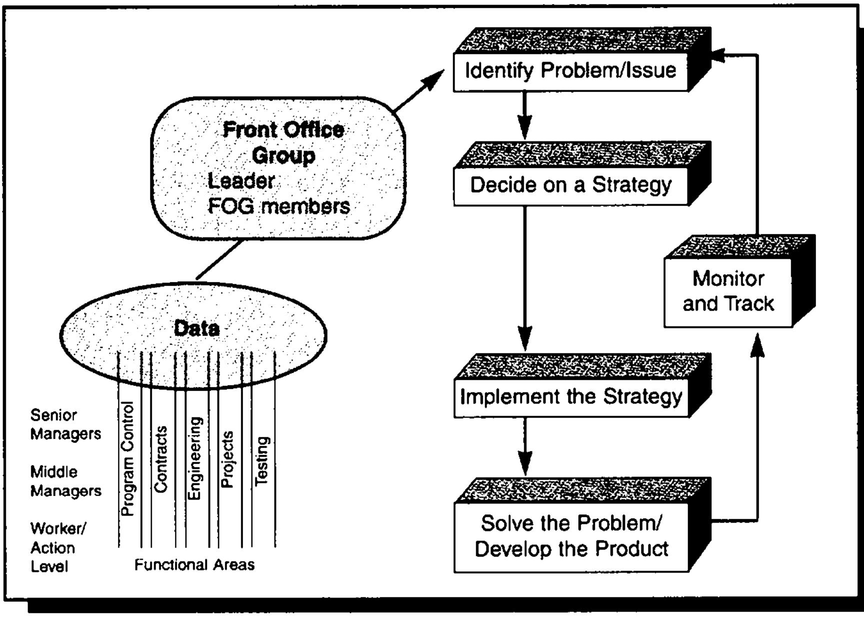
Figure 3-2. Traditional Management Model



SOURCE: "Acquisition Program Leadership for the 1990s," F-22 program office briefing (Wright-Patterson Air Force Base, OH, November 1992).

ment (projects), and testing. They formed an integrated team to address problems. This leadership model (shown in Figure 3-3) differed from the traditional model in that the chief functional experts did not just hand data to the leader but as a team worked through the data integration process, created the strategy to solve the problems, and then implemented the solution.

Figure 3-3. ATF Demonstration/Validation Phase Leadership Model

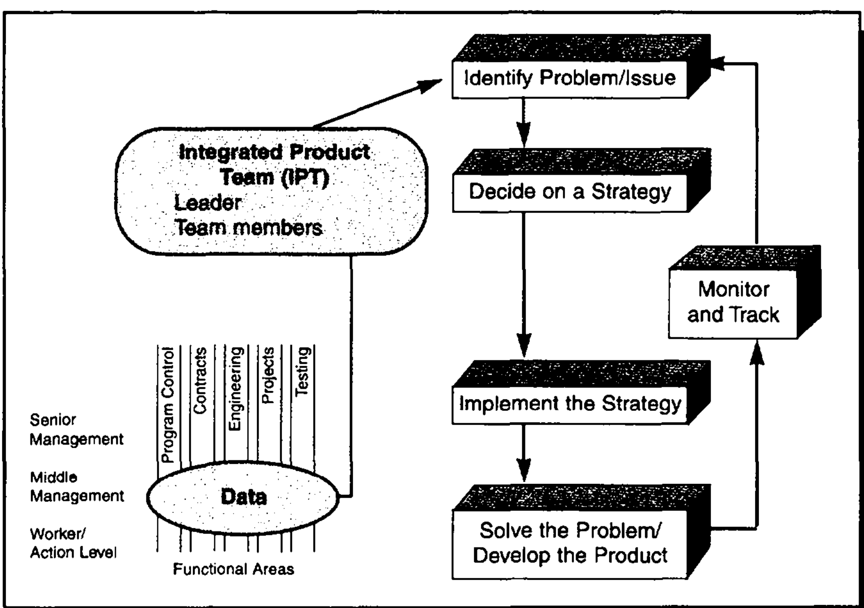


The F-22 Concurrent Leadership Model

The quality of the solutions that came out of FOG meetings impressed the group. As the group members prepared for the EMD phase, they concluded that the FOG's success should be replicated at lower, subunit levels of the organization instead of keeping the multi-functional team only at the highest level of the Government program office. The teams could consist of program office, user, and contractor personnel. Fain dubbed this leadership approach concurrent leadership, shown in Figure 3-4. (See chapter 7 for a detailed discussion of the implementation of concurrent leadership for the F-22 program via integrated product teams.)

In concurrent leadership, individuals at the worker/action level from different functional areas work together to identify problems and develop solutions. Their team focuses on a specific product, process, or issue. A multidisciplinary team manages an item based on a range of viewpoints, experiences, and expertise. Each functional area has its own requirements, constraints, strengths, and weaknesses. A great engineering solution may not be affordable, and the finance officer can rapidly identify that. A contractual solution proposed by a manager may violate the Federal Acquisition Regulations, which the contracting member of the team can point out. A manufacturing teammate can refine the design engineer's proposed solution to meet the performance requirements and still allow the part to be easily machined. An important aspect of concurrent leadership is that the roles of the team members differ from the roles found in the traditional leadership model.

Figure 3-4. Concurrent Leadership Model



The role of the team leader. Surprisingly, the biggest difference between concurrent leadership and the other two models lies not at the working level but at the management level. Concurrent leaders are not directors but facilitators and coaches. The leaders bring in the right people and functional disciplines to help solve the problem. They do not bring every member of their team in on every problem, only those whose expertise or responsibility is needed. Therefore, the team's emphasis will change depending on the problem to be addressed.

Another major difference is that the leader does not make the decisions. To do that would take ownership away from the team members. Instead, the leader's job is to make sure that the team makes a good decision.

The role of team members. The concept of concurrent leadership derives its strength from the power that each member brings to the team. Typically an individual on a team is the lone expert on that team in a particular field. Thus, all team members need to be proficient (ideally, experienced and well trained) in their specialty. However, the members must be able to grasp issues in ways that go beyond their narrow expertise. As in the ATF demonstration/validation phase leadership model (Figure 3-3), members must work out each problem from their teammates' viewpoint. The design engineer must think about the cockpit canopy from a maintenance technician's point of view. The program manager must see the issue as the financial member of the team would see it. This broad perspective is critical to ensure that a balanced solution emerges. The final responsibility of team members in concurrent leadership is to take ownership of each of the team's actions and outcomes and to actively contribute their expertise to the team's product.

Summary

The 20 principles of acquisition outlined in chapter 2 and embodied in the methods used to manage risk and to empower the work force through concurrent leadership underlie the success of the ATF/F-22 program. Part II describes how the program actually applied these ideas.

PART II

Application

The principles of acquisition embodied in the methods used by the ATF/F-22 program to manage risk and empower the work force apply to most weapon acquisition programs. Moreover, when adopted, they will make future programs much more successful. The challenge for any program manager is to apply these ideas in a way that makes sense for the program and the environment in which it will operate. Chapters 4–9 review how the ATF/F-22 program applied the principles and methods to satisfy the operator's need for a weapon system.

4

The Formation of the F-22 Team

- THE ENVIRONMENT
- IMPLEMENTATION: MULTIFUNCTIONAL TEAMS
- THE TEAM NORMS
  - Integrity
  - Teamwork
  - Logic
- PRODUCT ORIENTATION
- THE ROLES OF ORGANIZATIONS AS TEAM MEMBERS
  - The users
  - The program office
  - The contractors

The cost-plus environment requires a whole different strategy than what we've used in the past. The only solution in this cost-plus environment is teaming. It is the only way we are going to find out the information fast enough. And it's the only way in which we will be able to execute the program with any reasonable cost and schedule control.

General James A. Fain, Jr.

This chapter outlines how the F-22 program put the principles and methods described in chapters 2 and 3 into practice. The Government's Front Office Group (FOG) managed the program under certain constraints, both external and self-generated. To understand how the program applied the principles and methods, one must know what the environment was and how it drove the program structure, how the program office planned to implement the program, and, finally, how the leadership attempted to set the mores of the program—the norms for the F-22 team, their view of product orientation, and their definition of team member roles.

THE ENVIRONMENT

The ATF demonstration/validation phase began in an environment unlike anything that anyone connected to the program could remember. After the peak budgets of the Reagan administration, Department of Defense funding started to decline. As noted in chapter 1, acquisition reform dominated 1986. The Air Force initial Advanced Tactical Fighter (ATF) acquisition strategy called for a competition among three or four weapon system contractors and two engine contractors for demonstration/validation. In the next phase, engineering and manufacturing development (EMD), the Air Force would select one weapon system and one engine contractor to develop the ATF. Because of reduced funding, the Air Force encouraged the seven weapon system contractors that had competed in the original concept development investigation phase to form teams. In this way, the Air Force could maintain competition and maximize industry involvement but award only two weapon system demonstration/validation contracts (at a cost lower than that of the original three or four contracts). (See appendix A for a more thorough discussion of the history of the

ATF program.) The two teams competing for weapon system demonstration/validation were the Lockheed Aircraft Systems Company–General Dynamics Corporation–Boeing Aircraft Company F-22 team and the Northrop Aircraft Division–McDonnell Douglas Corporation F-23 team. Both Pratt & Whitney Government Engine Business (F119) and General Electric Aircraft Engine (F120) received contracts for the engine demonstration/validation.

For the demonstration/validation phase, the Air Force chose a fixed-price contract for each contractor because, in a competitive environment, a cost-type contract, which pays all of the contractor's costs, would encourage the contractors to spend ever-higher amounts to help secure more data and thus increase their chances of winning the development and then production contracts. Following the extensive risk reduction in demonstration/validation, the program office originally planned to award a fixed-price incentive fee contract for EMD. In 1988, the Department of Defense required all developmental contracts to be cost reimbursable, forcing a major change in the ATF acquisition strategy for the EMD phase.

A cost-type contract dramatically changed the relative roles of Government and contractor because it shifted the balance of risk. In a fixed-price contract, the contractor promises to deliver a product as defined in the contract, for which it is paid a certain amount of money, regardless of what the product costs the contractor to produce. The contractor pays for any cost or schedule overrun. To succeed, a contractor needs well-defined requirements, usually described in detailed specifications. As happened in the Air Force C-17 cargo aircraft and Navy A-12 attack aircraft programs, a fixed-price development contract has great potential to create an adversarial relationship between the contractor and the Government.

In a cost-type contract, the contractor promises its best effort in delivering a product for which the Government pays all allowable costs, including any overrun. The Government assumes all cost risk and responsibility. When the Government cannot tightly define the specifications and requires design trade-offs, cost-type contracts are best. One advantage of a cost-type over a fixed-price contract is that it reduces the potential for adversarial relationships and increases the potential to build a successful industry/Government team. A disadvantage is that the contractor, unless motivated in some other way (such as by an award fee), may be less inclined to tightly control costs.

Because the Government incurred the cost risk and did not want to see a cost overrun, the program leaders wanted the Government to take part in all decisions. The program office also realized that it needed to continue to balance cost, schedule, and performance with a structured, disciplined management approach in which the Government gave clear guidance. To be successful, the program office needed to rely on contractor and government working together to deliver the fighter that the operational user expected.

IMPLEMENTATION: MULTIFUNCTIONAL TEAMS

The F-22 program office needed to establish a way to allow the Government to participate but not to be a roadblock. Information had to flow quickly within the Government/contractor team to allow time-sensitive decisions to be made. The only way to accomplish these objectives was to depend on the working-level managers to provide data as well as make decisions.

The F-22 management team realized that the success of the F-22 rested on lower-tier members of the Government/contractor team. For them to succeed, the program leadership needed to empower them to make decisions in their areas while keeping higher levels informed. Each team had to understand their roles, their decision-making authority, and they had to understand when to elevate issues to higher level decisionmakers.

To define a team's decision space, the program used the concept of fenceposts. The F-22 FOG believed in empowering all members of the team to work on issues and make decisions appropriate to their position and individual capability. For example, the leader of the cockpit team should worry about the weight and the cost of the canopy and would be responsible for making the necessary trade-offs to meet the users' needs for a canopy and the team requirement to meet cost and schedule performance requirements. Fain established what decisions each of his team leaders should make and what decisions they should pass up to higher levels. Fain, James (Micky) Blackwell (Lockheed's F-22 program manager), and Walter Bylciw (Pratt & Whitney's F-119 program manager) approved a budget for each team, approved an allocation for weight (a critical parameter for an aircraft), and suballocated technical requirements when needed. They also approved the plan that each team was to follow. Thus each team had its own cost, schedule, and performance targets. In effect, each team was its own program developing its particular product, and each team leader served as that product's program director.

Fain, Blackwell, and Bylciw recognized that this empowerment would be a new experience for the lower tier workers. Applying concurrent leadership called for multifunctional teams, whereas the working-level personnel had traditionally focused on a specific expertise (such as electrical engineering, mechanical engineering, maintenance, or finance). They had never been trained to balance the design of a complete product; typically they had concentrated on perfecting their piece of the product. Under the new approach (discussed in more detail in chapter 7), the team members had to look at each problem from a higher level perspective, incorporating the functional concerns of other team members with those based on their own area of expertise. This new, broader perspective required training, much of which came from interaction with the other functional members of the teams.

To support the new team approach, the program needed a new set of integrated tools that would provide for a disciplined, well-planned, easily tracked program and allow the team members and program leaders to measure progress and success. Chapter 8 discusses these tools.

The Team Norms

Fain believed his role included establishing the norms, or mores, of the ATF/F-22 team for government as well as contractor personnel. At the start of the EMD phase, Fain traveled to each contractor and most subcontractors to personally explain his views on the program and the standards to which he would hold each team member. The bedrock of all of his thoughts, what he called his team philosophy, derived from his three personal pillars: "I am going to harp on three things: Integrity, Teamwork, and Logic."

Integrity

To Fain, integrity was clearly the most important tenet (and the reason it is the first principle of the 20 listed in Figure 2-1). Integrity in the F-22 program demanded that every team member conduct all business relationships honestly and ensure that the receiver of a message understands it. Fain made it very clear to all F-22 personnel, including those in his program office, at other Government locations, and at the contractors' or subcontractors' facilities, that he expected complete integrity from everyone involved in the F-22 development program.

Teamwork

Fain recognized that it was the combined efforts of thousands of individuals that made the demonstration/validation phase successful and that the engineering and manufacturing phase required the three weapon system team members (Lockheed, Boeing, and General Dynamics) to continue to work well together and with the engine contractor (Pratt & Whitney). As the new phase of the program started, each contractor would bring more people into the program. Fain did not want the successes of demonstration/validation and its hard-earned teamwork to fall away with the new workers. He emphasized three items.

First, he encouraged the continuation of open, timely, and effective communication between and among the contractors and all Government team members. Because the contractor organization divided major responsibilities among three large contractors spanning the country (Lockheed in Marietta, GA; Boeing in Seattle, WA; and General Dynamics in Fort Worth, TX), he knew that open and continuous communication was vital to successfully develop the weapon system.

Second, in keeping with his belief that a problem identified early was often a problem easily and cheaply solved, Fain directed each team to identify obstacles to its program quickly and then to report them as soon as the team members decided they could not overcome the obstacles themselves.

Third, Fain wanted all individuals to maintain close working relationships with their counterparts on other teams and be responsive to the users' needs. For program office personnel, this meant they should stay in close contact with their team members at Air Combat Command, the users. The program office needed to be responsive to user needs (which included the individuals who repair and maintain the system). Contractor personnel were to work closely with both program office team members (a contractor's traditional customer) and operational team members.

With this focus on teamwork, Fain attempted to smash an age-old paradigm. In the past, the contractor had designed a weapon system for the government inside the company and, as it went along, presented results to the government (usually just the program office). Fain understood the immense complexity of developing the F-22, especially with responsibility spread among four major contractors (including the engine contractor). He had to get the contractor team members to change the traditional way of doing their work and develop a team approach that included both the government program office and the user.

Logic

Fain's third pillar for the F-22 team was logic, or what he frequently called common sense. He shared his belief that rules and regulations were merely guidelines. In his view, the only reason regulations had been written was to try to correct some problem experienced in the past. Therefore, he wanted everyone on the F-22 program to let common sense, not rules and regulations, drive all their decisions.

PRODUCT ORIENTATION

To ensure ownership (Principle 6), the founding fathers focused the teams on tangible products, ideally a physical entity such as a piece of hardware (the software component as well as the physical hardware), like a radar, an engine turbine, a landing gear, a cockpit, or an avionics suite. To keep focused on the final objective, the weapon system, each team needed to understand how its subproduct related to the overall product (brakes, landing gear, airframe, and completed jet), what their product was to do, how it would be built, how it would be supported, and how the individuals using and maintaining their product would be trained.

THE ROLES OF ORGANIZATIONS AS TEAM MEMBERS

An important aspect of running a disciplined program is establishing clear roles and responsibilities for the members of a team as well as for the organizations that make up a team. The major organizations making up the weapon development team are the users, the program office, and the contractor.

The Users

The most important member of the development team is the user. The system exists to fulfill the users' need, and users define the requirements. To help ensure the best product, the users need to state their requirements in a functional manner. General George S. Patton, Jr. advised, "Never tell people how to do things. Tell them what to do and they will surprise you with their ingenuity." This holds true in acquisition. Users should state their requirements without specifying the solution. As part of this process, the users, with the help of intelligence specialists, such as the service intelligence experts and the Defense Intelligence Agency, define potential threats, determine likely scenarios in which they will use the new weapon system, describe where and how they will use it (which defines the operating environment), and define how they intend to maintain the equipment and what level of skilled technicians will repair it.

The users also need to work closely with the program office to understand available options to fulfill their requirements, to understand the affect of their requirements on the cost and complexity of the weapon system, and to be ready to adjust requirements to balance operational capability against weapon cost and complexity. The officer responsible for ATF requirements at Tactical Air Command during the demonstration/validation phase, Major General (then Colonel) David J. McCloud, described a good example of such a trade-off:

> It is easy to say, "We need a 9G aircraft" [able to turn at a speed that results in a pull on the plane of nine times the force of gravity]. The question gets much more complex when the program office asks, "Do you want 9Gs immediately after takeoff, or will you settle for 7Gs at takeoff and 9Gs when you get to altitude?" It turns out that the difference is 500 or 600 pounds of aircraft structural weight and a lot of engineering time that goes into beefing up the aircraft structure to give you the ability to pull 9Gs right after takeoff. The point is, we don't need 9Gs right at takeoff. Where we need 9Gs is in the fight arena.

The Program Office

The system program office has the responsibility to make sure the users get what they need. Its role is to form the acquisition team, establish the team environment, and work with the users as they identify their needs and define their requirements. The program office must then translate those requirements into terms and a structure that are meaningful to the contractor. In so doing, they must make sure the contractor fully understands what the users need.

The program office also needs to work with the contractor to develop and provide options to the users and to explain to them how long each option will take to deliver and how much each will cost. It should also provide an "80 percent" option that meets the most important user requirements but that can be developed in less time, for less money, or both. With a full set of options the users can determine the cost of meeting their requirements and decide which option is best, given the available government funding. The program office must also ensure that the contractor has laid out a sound program with an appropriate level of risk.

Finally, as the prime agent responsible for delivering the equipment, the most important role of the program office is to set and meet everyone's expectations. For the user to understand what is really possible, how much time the development will take, and how much it will cost, the program office must develop viable options with viable cost and schedule projections. For contractors to fully understand what users need, and to operate under a fair contract that encourages them to develop it, the program office must appropriately set contractor expectations about the work required and the method of contracting.

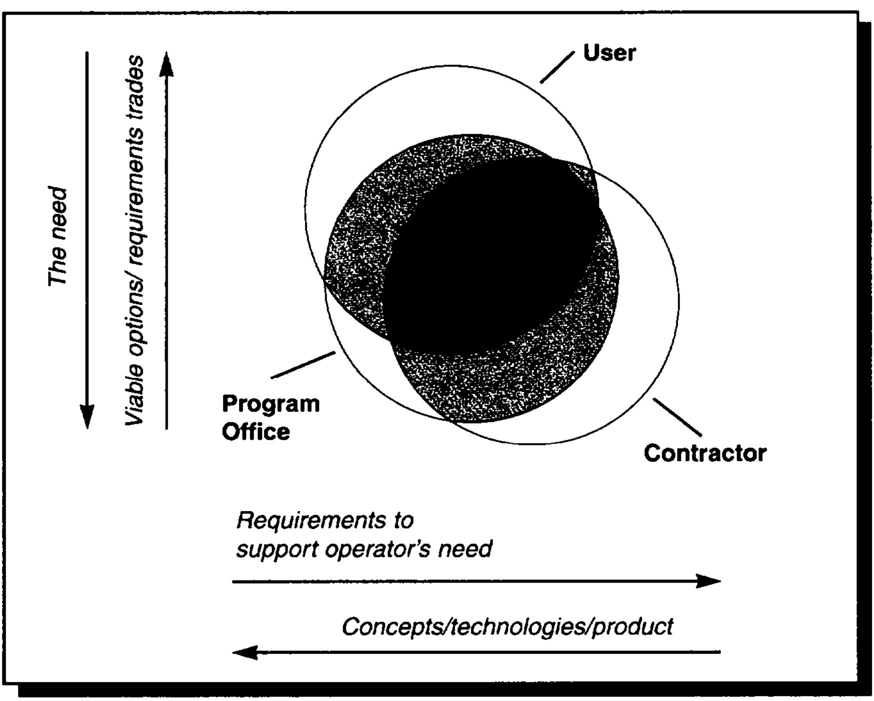
The Contractors

The contractors have the hardest job: to understand the user's requirements and generate the options to fulfill them. They must develop the ideas and find, or develop, the necessary technology to transform them into an actual weapon.

The contractor lays out a program to develop a system that will meet the operational requirements with the appropriate amount of risk, conducts the program, and produces the actual weapon system.

Figure 4-1 illustrates the roles and responsibilities of the operator, the program office, and the contractor on the weapon system development team. The circles represent the activity of each team member. The significant overlap of the user and program office circles represents the high amount of interaction that should take place between the two groups. All three circles overlap to a great extent, indicating that much of the activity requires the participation of all three teammates. The contractor and user circles do not have much overlap outside the program office circle. Program managers generally agree that program office attendance at discussions between the user and the contractor can help ensure that the Government (as the user) does not provide contractual direction to the contractor and that the contractor fully explains its information to the user.

Figure 4-1. Weapon System Development Team Member Roles



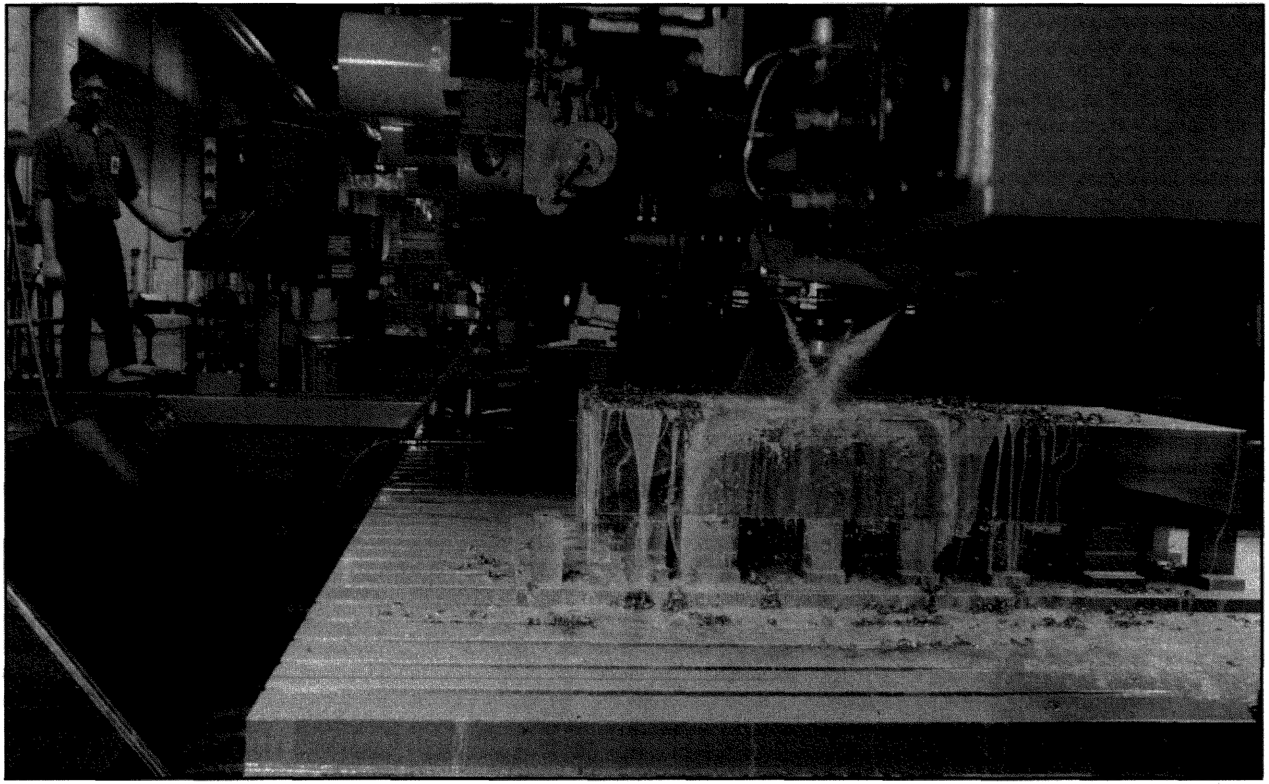


Photo by Randy O'Brezar, courtesy of Boeing Aircraft.

Fabrication of the F-22 began December 8, 1993 as a milling machine operator used a five-axis milling machine to cut a block of titanium to form a forward boom keelson panel.

5

Defining and Refining the Requirements

- THE PACKARD COMMISSION VIEW
- THE ATF APPROACH
- THE SUMMIT PROCESS
- SUMMARY

Fundamental to the ultimate success of a new program is an informed trade-off between user requirements, on the one hand, and schedule and cost, on the other.

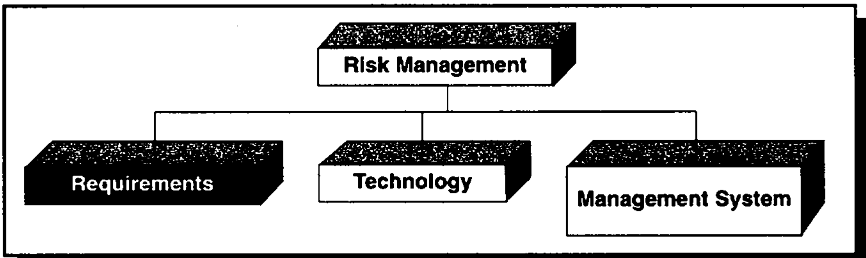
President's Blue Ribbon Commission on Defense Management, *A Quest for Excellence: Final Report to the President*

As described in chapter 3, the F-22 program leadership viewed managing risk as the key to program success. As depicted in Figure 5-1, managing risk required defining requirements, using proven technology, and using a management system that supported a disciplined development program. This and the next three chapters show how the F-22 program implemented these ideas.

The Packard Commission View

President Ronald Reagan's Commission on Defense Management, led by David Packard, identified establishing weapon system requirements as a fundamental acquisition problem. The Commission reported, "Problems with the present defense acquisition system begin with the establishment of approved 'military requirements' for a new weapon, a step that occurs before development starts." The report stated that the services typically define requirements in one of two ways, *user pull* or *technology push*. In user pull a user identifies the weaknesses of current systems against projected threats and generates the characteristics of future weapons—without fully understanding the likely affect of these requirements on cost, schedule, or maintenance.

Figure 5-1. Elements of Risk Management: Requirements



In technology push the research community develops a new technology and tries to convince users to make use of it. The downsides to technology push are that the technology may not fully meet the user's operational needs, may not be fully developed, or may lead to other problems (e.g., the jet engine greatly improved aircraft speed but was susceptible to damage from stones and other loose objects while the aircraft was on the ground with the engines running).

The Packard Commission correctly saw that the answer to the longstanding requirements problem was to balance performance and cost. However, the Commission's method of doing so violated the Advanced Tactical Fighter (ATF) principles of involving everyone and ensuring ownership. The final report stated:

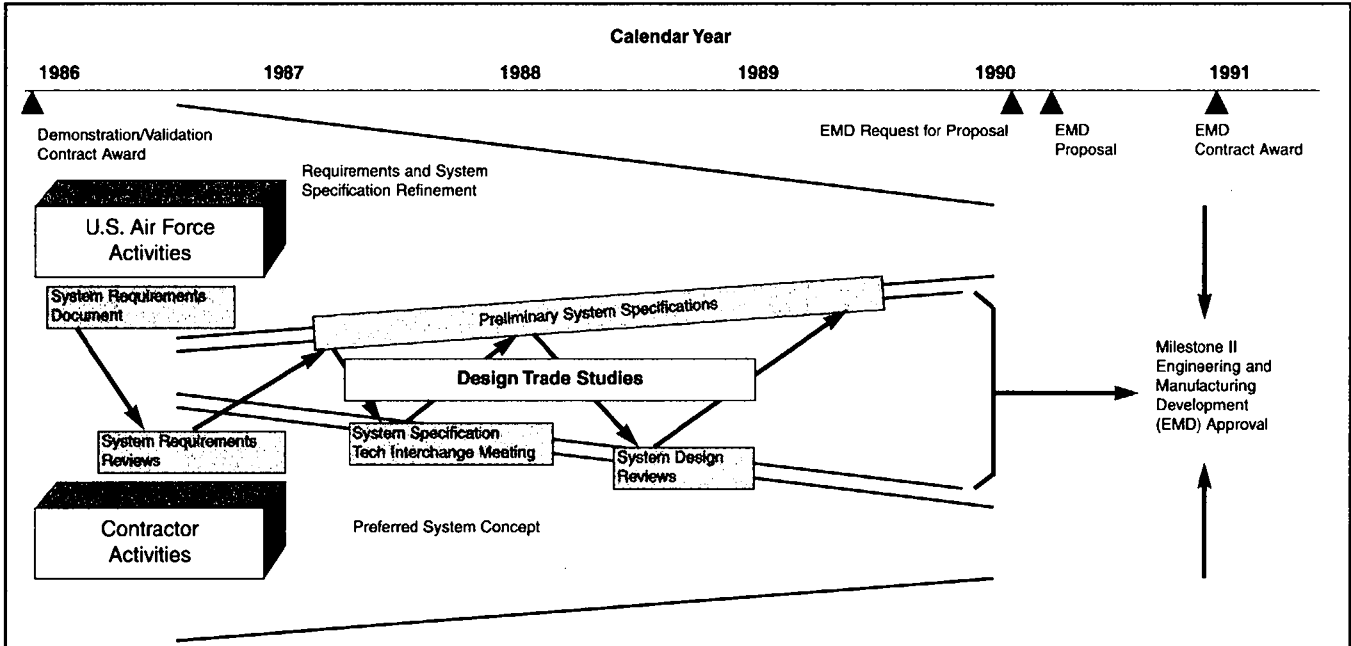
> Generally, users do not have sufficient technical knowledge and program experience, and acquisition teams do not have sufficient experience with or insight into operational problems, to strike this critical balance [between performance and cost]. It requires a blend of diverse backgrounds and perspectives that, because the pressures of goldplating can be so great, must be achieved at a very high level in DOD.... We recommend, therefore, that the JRMB [Joint Requirements Management Board] be restructured to make such trade-offs.... It should evaluate major trade-offs as a program progresses.

The ATF Approach

The ATF method of balancing cost and performance relied on the stakeholders cooperatively defining and refining both the requirements and the proposed solution. The ATF founders labored over longstanding problems with requirements. As ATF Technical Director, Eric E. Abell, said: "Our objective was to balance requirements against proven capability. Only then could you ensure that you really could do what the operator wanted and thus meet their expectations." Instead of relying on a distant headquarters group (the Packard solution) to conduct the necessary trade-offs and establish system requirements, the leaders formed an integrated team of operators from TAC, acquisition experts from the program office, and the competing Lockheed YF-22 and Northrop YF-23 aircraft teams and the competing Pratt & Whitney F119 and General Electric F120 engine teams. The ATF program system for defining requirements is shown in Figure 5-2.

The process started in 1986, following the award of the contracts for the demonstration/validation phase of the ATF program. Based upon the preliminary ATF system operational concept provided by the TAC, the program office drafted an initial list of the goals for the

Figure 5-2. The ATF Program's Process of Defining Requirements



Bottom Line: The process results in match of requirements and doable technologies to form the basis of an executable program at the start of the engineering and manufacturing development phase.

weapon system. The program office then worked closely with TAC to refine the list and form the system requirements document. The competing contractors used this document as a basis for their weapon system design (the jet as well as the support and training system), which would evolve and become known as their preferred system concept.

In a series of System Requirements Reviews, each contractor demonstrated how it would meet the Government's goals for the ATF. Initially the contractors felt that they could meet the diverse and demanding requirements established in the system requirements document. Abell made it clear that, before the specifications were finalized for the next development phase, engineering and manufacturing development (EMD), that the contractors must prove—by demonstration and analysis—that they could meet the requirements. As the program progressed each contractor discovered it could not meet all of the goals. During individual System Specification Technical Interchange Meetings, the contractors presented their engineering results and discussed with the Government program office/operator team how they planned to update their preferred system concept.

Following the system specification meetings, the program office and the users updated the preliminary ATF system specifications. These sessions exposed the TAC users to the pros and cons of each technology and the preferred contractor solutions. The users saw the projected cost, reliability, and complexity of each concept—thus fixing what the Packard Commission identified as a key failing of the acquisition requirements process. Also, through demonstrations and tests, the contractor proved the validity of the technology it planned to employ (answering the technology push concerns).

The preliminary system specifications became the functional specifications used in the Government's request for proposal (RFP) for the EMD phase. Each contractor's preferred system concept design became their aircraft design proposal. This iterative process of adjusting requirements based on proven technologies met the needs of the users, the program office personnel, and the contractors. All three groups set, and met, appropriate expectations and fully understood the reasons behind the requirements and the preferred solutions, because all three groups had helped build them.

The Summit Process

Based on negative experience with earlier programs (such as the B-1 bomber), Air Force Chief of Staff, General Larry D. Welch, wanted to ensure that the ATF requirements were updated on a regular basis. He required the Program Director to present the ATF requirements to the Commander of Tactical Air Command and himself annually so that the operational requirements document remained current. He hoped to preclude problems when the program came up for operational testing (such as having to test to requirements no longer needed by the users that the weapon system might not be able to meet). Welch also wanted the Program Director to understand what the user expected from the weapon system and find out, from the program office standpoint, if there were any problems in meeting those validated needs.

Toward the end of the demonstration/validation phase, after the users on the ATF team had approved the preliminary system specifications, the Program Director met with the Commander of Tactical Air Command and then the Air Force Chief of Staff, who formally approved the requirements. Both the ATF program office and the warfighting command found this process, later known as the Summit Process, immensely helpful in solidifying requirements and preventing unnecessary changes by members of the acquisition process outside of the TAC users.

Air Combat Command, in close coordination with the program office, continues to refine and update the requirements by comparing anticipated performance with operational needs. If there is a projected shortfall in fighter performance, Air Combat Command and the program office identify solutions to meet the user's needs. The results of these requirement reviews and updates continue to be briefed annually as part of the F-22's Summit Process.

SUMMARY

Allowing the user, program office, and contractors to work closely together in stating requirements and demonstrating the ability to meet them greatly improves the odds of developing a weapon that can carry out warfighter missions. An important benefit is that the users see the impact of their requirements on the cost and complexity of the weapon system and can then explore the possibility of refining their requirements to lower either element.

Major General David McCloud, the former chief of ATF requirements at TAC during the demonstration/validation phase, summed up the requirements refinement process:

> The general consensus of those involved is that the ATF program has been very successful especially in the very early part of the program when we were heavily involved in the requirements trade-offs.... The one thing that made the ATF program such a success was small organizations, tightly tied together, but willing to challenge each other and listen and argue and debate and come up with a reasonable answer.

6

Managing the Technology

- **The Packard Commission Recommendation**
- **The Demonstration/Validation Technology Program**
  - Prototype air vehicles
  - Full-scale radar cross-section pole models
  - Test engines
  - Avionics prototypes
  - Reliability, maintainability, and support
  - Materials
  - Modeling and simulation
- **Results**

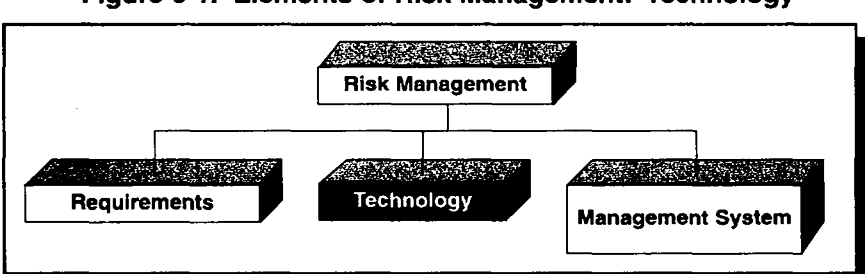
We've demonstrated all the technologies to be employed. There are no miracles required here. There are no technologies we don't have a handle on.

Colonel Wallace T. Bucher
at the start of the engineering and
manufacturing development phase

After defining the requirements of the weapon system, the second element of the Advanced Tactical Fighter (ATF) program approach to risk management was to develop and prove the technology required for the design and production of the weapon system (see Figure 6-1). Recalling the 13th principle, "Have what you need for the effort," the founders mandated that the contractors could not propose a solution for the engineering and manufacturing development (EMD) phase unless they had sufficiently proved the technology during the demonstration/validation phase.

The initial strategy for the ATF team demonstration/validation phase called for contracting with three or four of the seven airframe prime contractors who had participated in the initial concept development investigation phase. Tight funding required the contractors to apply the limited money to the areas with the highest risk. The plan called for the competing contractors to conduct Critical Technology Demonstrations aimed at the highest risk area, primarily avionics. The contractors were to use computer models to assess the aerodynamic performance of their proposed aircraft.

Figure 6-1. Elements of Risk Management: Technology



The Packard Commission Recommendation

In April 1986, in the midst of the demonstration/validation source selection, the program office plans suddenly, and historically, changed. The Acquisition Task Force of President Ronald Reagan's Blue Ribbon Commission on Defense Management submitted an interim report on improving the national acquisition process, *A Formula for Action.* One of the recommendations was to increase the use of prototypes in the early stages of development:

> We recommend a high priority on building and testing prototype systems to demonstrate that new technology can substantially improve military capability, and to provide a basis for realistic cost estimates prior to a full-scale development decision.

The Air Force responded to the Commission's report by amending its guidance in the *ATF Program Management Directive.* This new guidance directed the ATF program office to include the development, fabrication, and test of two prototype air vehicles in the demonstration/validation program. Each contractor was to "fabricate and demonstrate a ground-based prototype Avionics Integration Labora-tory, and conduct active sensor testing aboard an Avionics Flying Laboratory." (See appendix C for a discussion of the use of prototypes.)

Flying prototypes are in the short term more expensive than paper studies. To follow Air Force guidance and keep the program within the approved funding, the ATF program office took advantage of the information it had seen in the initial program phase by encouraging contractors to form two competing teams.

In October 1986, the Air Force awarded two ATF contracts, the YF-22 to Lockheed teamed with Boeing and General Dynamics, and the YF-23 to the team of Northrop and McDonnell Douglas. These 54-month, firm fixed-price contracts required their best effort in the initial design and testing of the ATF. Each contractor was to fly two prototype air vehicles, develop a ground avionics prototype (with an avionics flying laboratory), and develop initial system specifications.

The Air Force awarded General Electric and Pratt & Whitney competing contracts to develop prototype engines under the ATF Engine program. Support of the prototype air vehicle required each contractor to deliver six flight-qualified ATF-prototype engines (two for each of the YF-22s, two for each of the YF-23s, and two spares) plus a number of ground demonstrator engines (as originally planned under the previous Joint Advanced Fighter Engine, or JAFE, program).

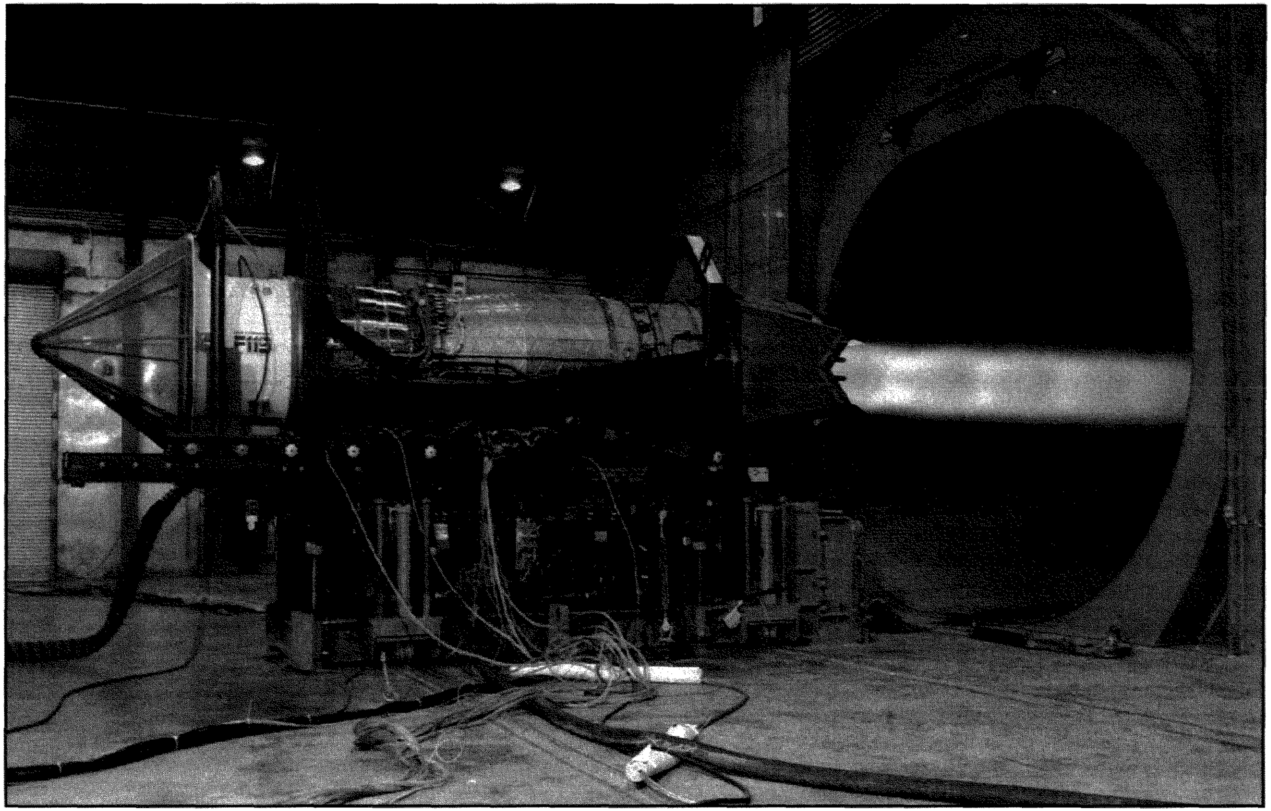


Photo courtesy of Pratt & Whitney.

An F119 engine prototype undergoes pre-flight tests.

The Demonstration/Validation Technology Program

Based on the initial airframe concepts and the technology in development at various Air Force laboratories, the ATF program office main technical concerns involved three components:

1. The aerodynamic performance of the fighter in a low-observable (stealth) platform
2. The advanced supercruise engine
3. The integrated avionics in the aircraft.

Aerodynamic Performance in a Low-observable Platform

Many Air Force and the Department of Defense leaders had serious doubts as to whether a stealth aircraft could be made maneuverable (in 1986 few people were cleared into stealth aircraft programs; those that were knew of the F-117 and the B-2—neither of which approached the maneuverability of an F-15). Many feared that the stealth constraints (such as leading- and trailing-edge alignment) would severely limit high-speed, "turn-and-burn" fighter performance.

Advanced Supercruise Engine

The capabilities of the new engines emerging from the JAFE (later renamed the ATF Engine) program would allow a fighter to cruise faster than the speed of sound for sustained periods. Until then, such speed required the use of fuel-consuming afterburners. Many in Washington and the aerospace community doubted that supercruise was possible, even with new technology.

Integrated Avionics

Technological improvements were rapid in the avionics (aircraft electronics) industry. The latest fighter, the Navy F/A-18, had the most electronically advanced cockpit and the most difficult and

Figure 6-2. Elements of the ATF Demonstration/Validation Phase

- Prototype air vehicles
- Radar cross-section models
- Test engines
- Avionics prototypes
- Reliability, maintainability, and support
- Materials

demanding set of controls of any aircraft flying. The ATF avionics suite had to be fully integrated to give the pilot situational awareness (an easy-to-understand view of the environment). The diversity and complexity of avionics and the poor performance of past avionics programs led the program office and contractors to view avionics as the technological area of highest risk.

Figure 6-2 shows the elements of the ATF demonstration/validation phase. This phase attempted to reduce the risk in the three areas of technical concern by developing and testing: prototype air vehicles, radar cross-section models, test engines, and avionics prototypes.

In addition, the ATF program needed to build the foundation for key technologies that would be used in the EMD phase. In particular, the program was seeking improvements in materials and in reliability, maintainability, and support.

The final element of the ATF demonstration/validation phase, which included a multitude of tasks from creating and refining operational requirements to detailing the ATF design, focused on modeling and simulation.

Prototype Air Vehicles

The purpose of building prototype air vehicles was to demonstrate the aerodynamic performance of the basic shape of the low-observable aircraft. Prime contributors to an aircrafts radar signature are its profile and planform. Both the Government and the contractors wanted to see how well the uniquely shaped ATF would fly. The test aircraft would also corroborate wind tunnel data and provide data with which teams could calibrate computer models. The prototypes had standard, current-generation flight controls and avionics and did not employ low-observable coverings or treatments. Nor did the prototype aircraft incorporate the internal subsystems that would form its operational configuration (which would be finalized with the other operational design elements during EMD).

The program philosophy for prototype air vehicle flight testing differed from that in other programs. Traditionally, the Government owned the test aircraft and, with the contractor, would determine what to test. Typically, competing aircraft would fly similar profiles to evaluate the performance of one against that of the others. In the ATF program, however, the contractor retained ownership of the air vehicles and determined what aspects to demonstrate. As the contractor's engineering and manufacturing program manager, Lockheed Vice President James E. "Micky" Blackwell, stated, "The sole contractual requirement for the prototype was that it had to take off."

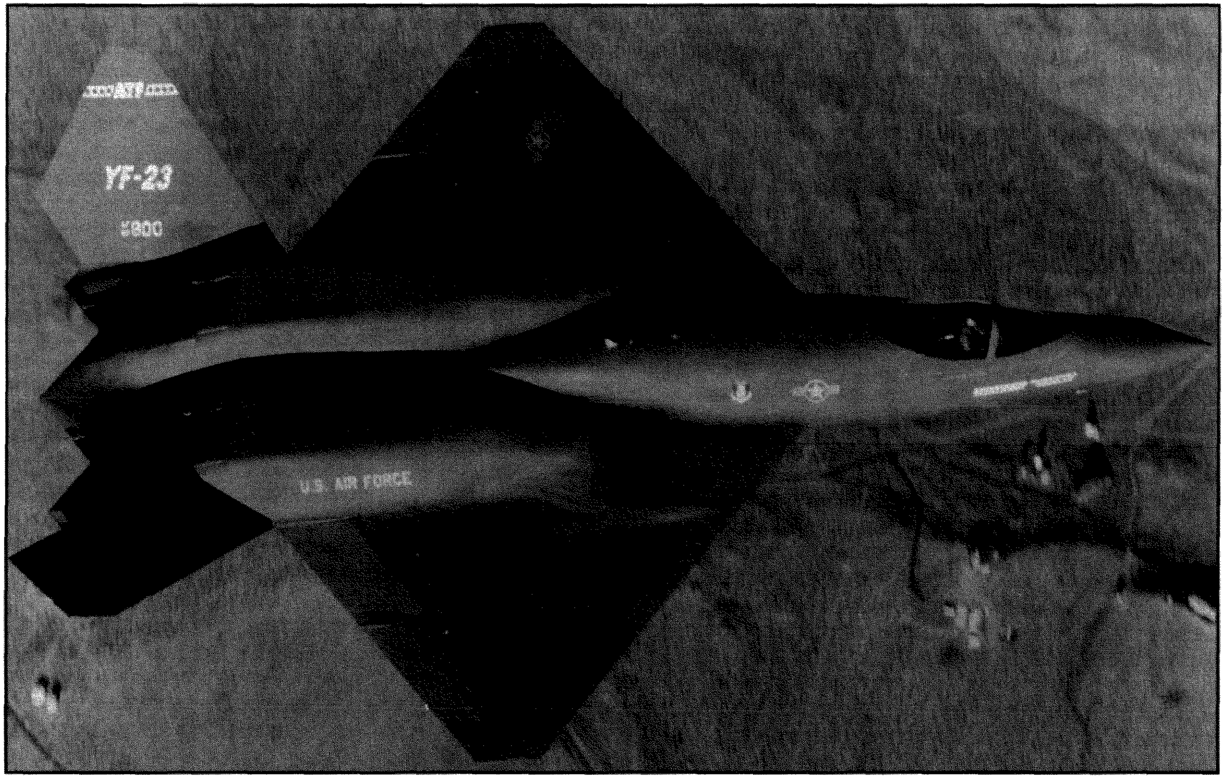


Photo courtesy of Northrup-Gruman.

Leading and trailing edge alignments are shown in the planform view of the YF-23. The alignments aid in reducing the aircraft's radar signature.

The four aircraft were flight tested from August 27 until December 28, 1990. As shown in Table 6-1, the Lockheed/Boeing/ General Dynamics YF-22 and the Northrop/McDonnell Douglas YF-23 successfully completed 124 sorties and logged 157.4 flying hours. During that time the competing contractors demonstrated handling qualities, performance at altitudes above 50,000 feet, and sustained supercruise of more than 1.3 Mach. Both the YF-22 and YF-23 demonstrated their maneuvering performance characteristics; the YF-22 achieved controlled flight at a 60-degree high angle of attack.

Some members of the Government were concerned about the location of the missile bays and the engine inlets of the YF-22. They feared that when a missile was shot from the aircraft, the aircraft engines would ingest smoke from the missile and flame out. To demonstrate that this would not happen, the Lockheed team launched an AIM-9 Sidewinder missile and an AIM-120 Advanced Medium Range Air-to-Air Missile (AMRAAM) from the missile bays of the the YF-22.

The competing contractor teams submitted data from flight testing to the Government as part of their proposal for the EMD phase on January 2, 1991. The flight testing of both the YF-22 and the YF-23 convincingly demonstrated high maneuverability in a low-observable fighter and the ability to achieve supersonic, level flight without the use of afterburner (supercruise).

Full-Scale Radar Cross-Section Pole Models

The ability to accurately model radar cross-sections (which produces an aircraft radar "echo") on a computer had not been satisfactorily verified. To prove the stealth features of their designs, both contractors developed a full-scale model aircraft based on their preferred system concept (the design the team would propose as the ATF operational configuration). The models (termed pole models because they

Table 6-1. ATF Prototype Air Vehicle Test Summary

Prototype	Sorties	Flight hours
YF-22 (Lockheed/Boeing/General Dynamics)		
1 (General Electric engine)	43	52.8
2 (Pratt & Whitney engine)	31	38.8
YF-23 (Northrop/McDonnell Douglas		
1 (General Electric engine)	34	44.4
2 (Pratt & Whitney engine)	16	21.4
TOTAL 124	157.4	

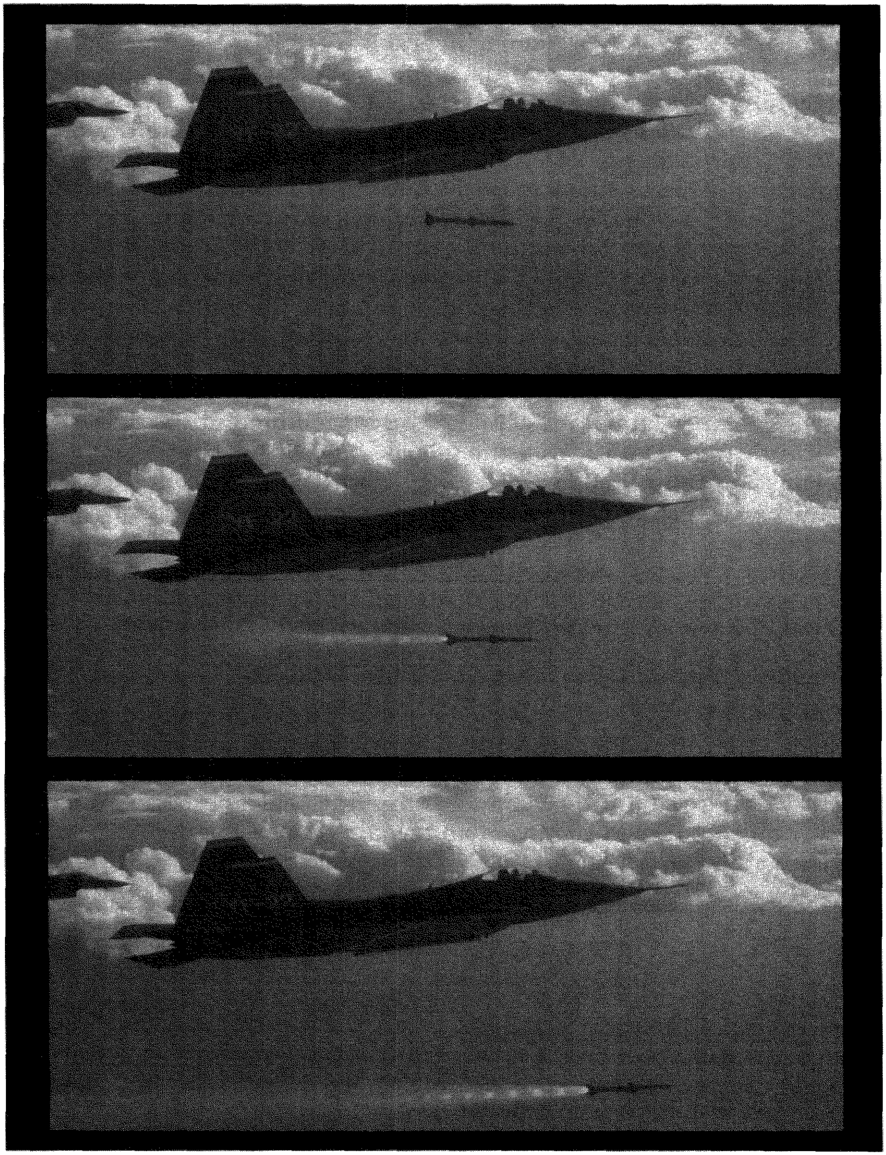


Photo courtesy of Lockheed-Martin.

A YF-22 launches an unarmed AIM-120 AMRAAM missile. The launch of the AIM-120, as well as an AIM-9 Sidewinder missile, proved that ingestion of the smoke from the missiles was not a problem for the YF-22 engines.

would be mounted on poles) included radar-absorbing structures and materials, antennas, simulated engines, simulated canopy, and the cracks and gaps caused by the aircraft flaps and other aerodynamic control surfaces. The contractors conducted more than 800 hours of tests on these models against various radar emitters, and the Government conducted an additional 400 hours of radar cross-section tests. The contractors also carried out 12,000 hours of radar range testing on model components. The tests verified that radar cross-section test results could be predicted—pretest predictions were usually very close to the actual results. The data from these ATF pole models gave the contractors and the Government high confidence that they could achieve the radar cross-section values for the operational aircraft.

Test Engines

Capitalizing on lessons learned from the F-15, F-16, and other jet aircraft programs, the Air Force knew that engine development had to precede airframe design and that the aircraft-engine inlet interface had to be designed early in the program. Work on what was to become the Pratt & Whitney F119 and the General Electric F120 officially got underway in 1983 when the Air Force propulsion program office awarded a contract to each engine company for what was initially called the JAFE program. The objectives of this program were increased thrust (with a goal of providing supersonic cruise without the use of afterburner), fuel efficiency, improved reliability, and ease of maintenance.

In the initial phase, both engine contractors conducted numerous component rig tests on key sections of the engine and tested two ground demonstrator engines. Under the renamed ATF Engine Program, both contractors produced six prototype engines to support the YF-22 and YF-23 flight tests, which completed over 4,000 hours of ground testing and accumulated over 300 hours of flight test. For the YF-22, which Lockheed had designed to use two-dimensional thrust vectoring (the direction of thrust can angle up or down 20 degrees, increasing the agility of the aircraft), the engines completed over 1,500 hours of ground testing with the thrust-vectoring nozzles.

Flight testing ultimately proved that the F119 and F120 engines could generate sufficient thrust to maintain supersonic flight without afterburner and verified the engines' improved fuel efficiency and greatly improved reliability.

Avionics Prototypes

In the mid-1980s the Air Force established several programs in its Avionics Laboratory to exploit the new technological capabilities of

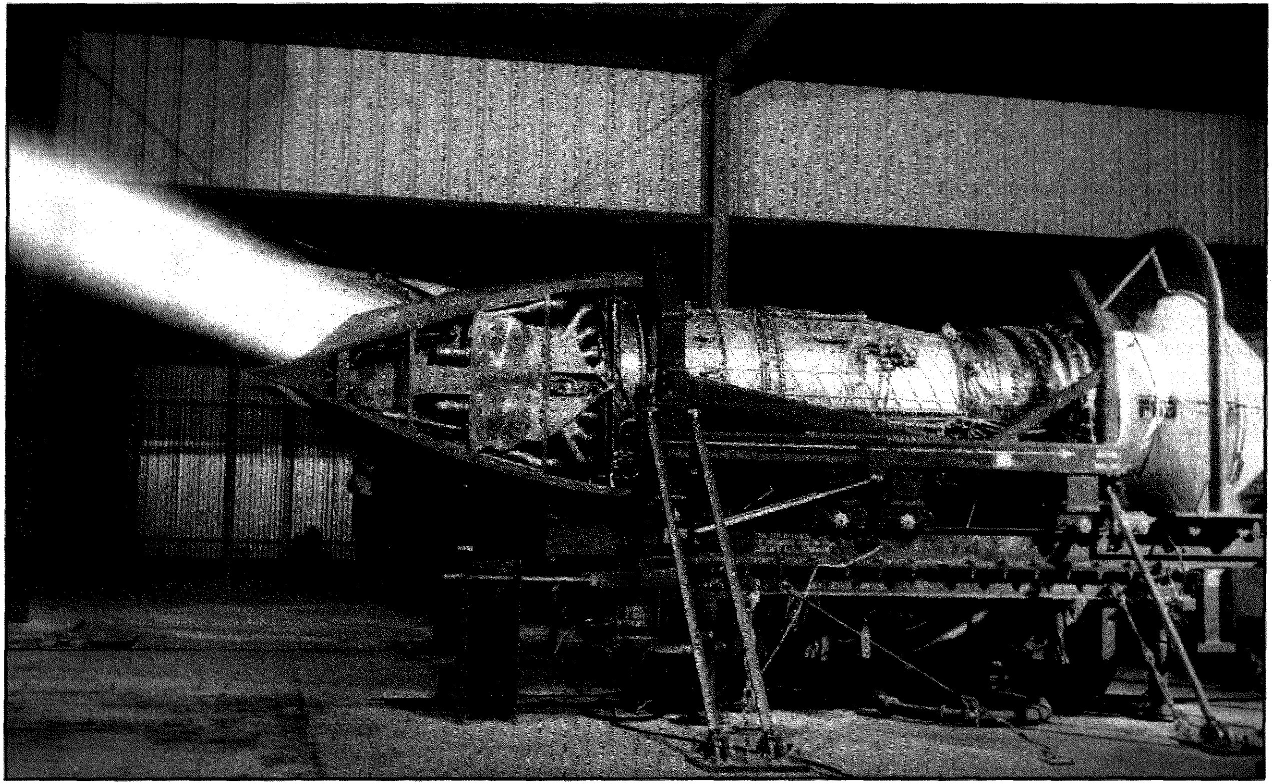


Photo courtesy of United Technologogoies/Pratt & Whitney.

A feature of the F119 engine is its ability to angle the thrust of the engine 20 degrees up or down. The high thrust, fuel efficient engine uses fewer and less complex parts than previous fighter aircraft engines.

aircraft electronics. The programs examined improved methods of designing radars, electronic warfare systems, communications systems, and overall avionics architecture for an aircraft. All of these greatly improved both performance and the fighter pilot's situational awareness. The Avionics Laboratory programs produced six components that proved critical in the development of the ATF. These components are described below:

Pave Pillar: An integrated system architecture that provides a common signal processor, data bus, and other avionics elements for functions such as communications and radar

Common Signal Processor: A computer module designed for the Pave Pillar architecture to provide computational power for multiple avionics functions including communications, electronic warfare, and radar processing

Ultra Reliable Radar: A phased-array radar with numerous, small transmit-and-receive modules coupled to improve radar performance and reliability

Very High Speed Integrated Circuits (VHSIC): Electronic components that support higher speed and more powerful microprocessors

Integrated Communication, Navigation, Identification Avionics (ICNIA): A highly integrated suite of avionics that provides a wide array of systems and functions, including radios (VHF/UHF), data links (such as the Joint Tactical Information Distribution System), identification friend or foe (Mk XII), and location (Global Positioning System)

Integrated Electronic Warfare System (INEWS): Similar in concept to the ICNIA and designed to operate within the Pave Pillar architecture; a laboratory system that analyzes enemy radio and radar signals to identify the type of threat and provide appropriate countermeasures.

> I can't think of a set of technology programs that has ever provided more bang for the buck than the Air Force is going to get from Pave Pillar, VHISC, ICNIA, and INEWS.
>
> Sherman Mullins, Lockheed ATF Program Manager
> in "The ATF: Hot and Stealthy," *Air Force Magazine*

The common thread of these technologies is the integrated manner in which they were to be designed and implemented. However, individual

Photo courtesy of Boeing Aircraft

This model of a Boeing 757 shows some of the modifications that converted the aircraft into an avionics flying laboratory used to develop the F-22's sensors/radars.

avionics developments were hard enough, and many believed integrated avionics would be extremely risky. To quantify and reduce the risk, the contractors developed an Avionics Ground Prototype and an Avionics Flying Laboratory, also known as the Flying Test Bed. The Avionics Ground Prototype incorporated brassboard hardware and commercial processors and test equipment to demonstrate key technologies. The primary objective of the Avionics Flying Laboratory was to test brassboard sensors and processors while airborne.

As part of the avionics testing, the contractors built and tested 30 major avionics module types and over 650 brassboard modules. As part of the effort, the contractors wrote over 1.4 million lines of Ada software code. To support software development, the contractors developed a prototype software development "environment" that provided standard equipment and tools and interlinked over 600 software programmers in six different states.

The contractor teams also tested additional types of hardware. Each team developed a prototype electrically scanned antenna array to prove new radar technology. As part of this effort, the radar subcontractors produced more than 2,000 transmit/receive models for component radar system testing. The communications subcontractor for each team developed a communications, navigation, and identification suite that simultaneously processed signals from the communications radios, radio navigation aides, Global Positioning System, Joint Tactical Information Distribution System, and Mark XII identification friend-or-foe system.

The competing teams integrated and demonstrated elements of the avionics test hardware in the Avionics Ground Prototype laboratory and then flew some components in the Flying Test Bed (a Boeing 757 for the YF-22 team, a BAC-111 for the YF-23 team). As part of the final ground prototype testing, both contractors used breadboard processors programmed with Ada software code to process information from signals captured by developmental antennas and processors carried by the flying test beds, resulting in an integrated presentation of data for the pilot. The YF-22 team also flew the breadboard processors and demonstrated in-flight operation of their integrated suite.

Reliability, Maintainability, and Support

From the beginning, Tactical Air Command emphasized that the ATF was to have significantly increased reliability and require less support than the F-15. Design for increased reliability and ease of maintenance started during the concept development investigation phase. The contractors verified the new design features and technology during the demonstration/validation phase.

Both contractor teams checked the installation and accessibility of both the F119 and F120 engines within a mockup of the aircraft engine bay, tested the ease of gaining access to major components installation and repair, and tested whether the air-to-air missiles (AIM-9 and AIM-120) would fit within the weapon bays. Both teams demonstrated the basic concepts of their integrated diagnostic systems and generated initial paperless (digital) technical orders for repair and maintenance of the aircraft.

The reliability engineers also conducted a continuing logistical support analysis that identified critical failure mechanisms. After discussion with the program office and the users, the contractor design engineers revised the aircraft and their component designs based on the analysis. As a result of reliability demonstration and analysis, the contractors incorporated over 1,000 design changes to improve the reliability and ease of maintenance of the weapon system.

Materials

In the early 1980s the aviation community held high hopes that advanced composite materials could replace much of the metal, primarily aluminum, in the aircraft. To measure the physical properties of advanced materials, including composites, and see how they would perform in different environments and configurations, the competing contractors conducted over 9,000 tests on various materials.

Materials testing had a high payoff. For example, one type of composite material, called thermoplastics, looked very promising at the start of demonstration/validation. Thermoplastics, formed under high-pressure heating, can be reprocessed again and again, making them a good choice for items requiring repair in the field. Another type of composite material, called thermosets, undergoes a one-time chemical change when it is heated and cured. This property makes manufacturing errors more significant (because the piece can't be reworked) and requires different repair procedures in the field. Lockheed predicted that thermoplastics would be the major type of composite for the production aircraft.

After 4 years of development and testing, both contractors determined that thermoplastics did not measure up to predicted performance and cost. However, advanced thermoset materials performed far better than expected. As a result, Lockheed will use thermoplastics only for a few specialty parts, such as those subject to impact with foreign objects (belly skins and removable panels) and will use advanced thermosets as the primary composite material. As a direct result, the Lockheed team entered the EMD phase with a known family of composites to use in the production aircraft.

Modeling and Simulation

Both contractor teams used computer modeling in every aspect of maturing the ATF technology. The models fall into two broad categories: design models and effectiveness models. The ATF teams used them to develop and refine requirements, assess the applicability of technology, and establish the weapon system design. The ATF program also used man-in-the-loop simulations to verify requirements and cockpit layout and to evaluate proposed capabilities and information presentation.

Design models. These models, which include aerodynamic, structural, and avionics models, predict performance and can extrapolate test results. Their output serves as input for the effectiveness models. The development teams used design models iteratively. Their initial use predicted performance, and, as testing yielded data, the teams updated, refined, and validated the design models. Once the models were validated, the design engineers could use them to extrapolate test results and predict a fuller range of performance for the weapon system.

Aerodynamic models: The design teams used aerodynamic models to predict such information as aircraft range, maneuverability, rate of turn, and external loads. The contractors used data from more than 30,000 hours of wind tunnel testing and 157 hours of flight testing to refine and validate the models.

Structural models: Component design engineers use structural models to predict the performance of a specific item, such as a spar. For example, these models can predict internal loads within the aircraft, which the engineering team can then use to size the spar. The models can predict the performance of the spar for various configurations and determine its ultimate strength and fatigue life. Important input variables for the structural models are the material's physical properties (such as shear strength, directional strength, and stiffness factor). The design teams used results from material coupon testing in the structural models to determine the type of material to use for a specific component.

Avionics model: Avionics engineers used models to predict the performance of such items as radars, radios, and antennas and the most effective location for antennas and other sensors.

The use of the avionics model in correctly sizing the radar antenna shows the complexity of the design process for an aircraft and the importance of models. Radar performance depends on many things,

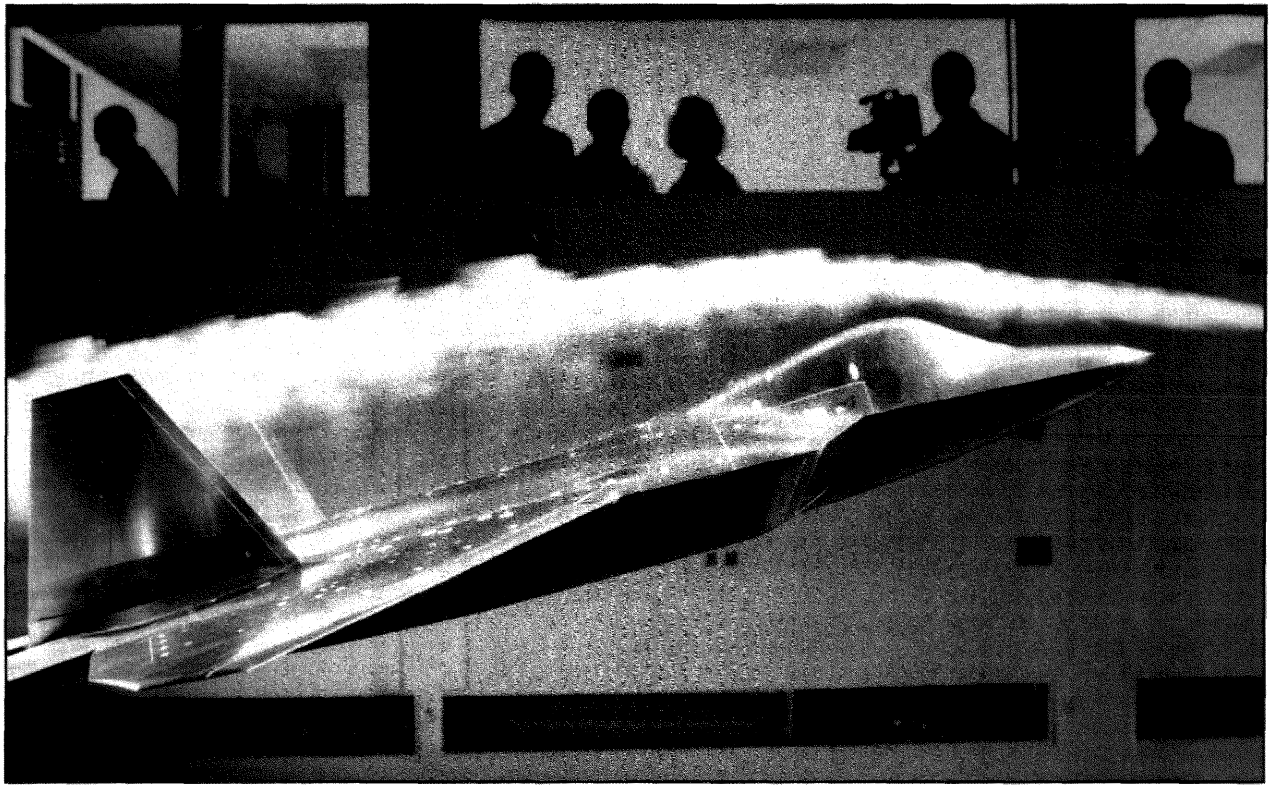


Photo courtesy of Lockheed-Martin.

Models of the YF-22 prototype were used in wind tunnel tests to predict wind resistance to the requirement that the aircraft be able to sustain supersonic cruising (supercruise) speeds.

including the ability of its transmitter and receiver as well as the shape and size of the radar antenna (in general, the larger the size, the farther away a radar can detect targets). Therefore, the radar engineer wants the antenna aperture to be as large as possible. However, the radar must be mounted on the front of the fighter (just behind the pointed radome). A large radar drives the diameter of the fuselage, and a wide fuselage increases the size, drag, and radar signature of the aircraft. Thus the airframe engineers and engineers concerned with the radar signature of the aircraft want to minimize the size of the fuselage.

To balance radar performance, aerodynamic performance, and low radar return, the design team used the respective models. The radar engineer computed the smallest shape of radar that could meet the requirements for identifying targets (like enemy aircraft) at a certain distance. The airframe designers and low-observability engineers computed the largest fuselage diameter that would still meet their requirements. This iterative process continued until the design team determined the optimum size for the fuselage. As test results came in from the radar laboratories and wind tunnels, the design engineers updated their models, refined their calculations, and, if needed, updated the preferred system concept for the radar and aircraft fuselage.

Effectiveness models. The program office, the contractors, and, in some cases, TAC used effectiveness models to set performance requirements and conduct trade-offs. Examples include: TAC BRAWLER, Enhanced Surface-to-Air Missile Simulation (ESAMS), and the Logistics Composite Model (LCOM).

TAC BRAWLER: This complex computer model predicts the outcomes of friendly versus enemy air engagement by modeling friendly fighters, the ATF, and enemy fighters. BRAWLER can model a single fighter against a single fighter, many fighters against many fighters, or a combination. During demonstration/validation the ATF program completed over 22,000 TAC BRAWLER runs to size the aircraft, establish its maximum radar cross-section, and ultimately evaluate the military effectiveness of the design. The team also used the model to establish such features as the number and type of air-to-air missiles the aircraft needed to carry.

Both contractors and the Government conducted evaluations and trade-offs using TAC BRAWLER. In fact, it is an understatement to say that the contractors defined the ATF design in large part based on the results of TAC BRAWLER runs. During the design process the contractor teams would change some aspect of their preferred system concept and submit the results of their TAC BRAWLER runs to the program office for evaluation. The program office would then run the changed design on their own version of BRAWLER to validate the contractor performance predictions. This procedure verified the accuracy of the program office and the contractor calculations, serving as a system of checks and balances for the modeling.

Because the contractors and the Government had to compare data from their separate runs, they had to use TAC BRAWLER models that were of the same configuration and that were validated. After the Air Force Office of Studies and Analysis had verified the TAC BRAWLER model and validated its accuracy, it provided a level playing field on which the Government could compare the predicted performance of one contractor design with the other. Both contractors submitted TAC BRAWLER data as part of their proposal for the EMD phase.

Enhanced Surface-to-Air Missile Simulation: The ESAMS model compared the ATF radar signature with enemy missile systems to determine the ability of a missile to acquire an ATF and shoot it down. The teams used ESAMS data to see how well the ATF could penetrate an integrated air defense system with current and projected surface-to-air missiles. This data helped finalize the ATF radar cross-section requirements. As it did with TAC BRAWLER, the Air Force validated and verified the ESAMS and used it to compare the contractor designs.

Logistics Composite Model (LCOM): The Air Force has traditionally used the LCOM to predict the manpower required to support a new weapon system. The Air Force modified the LCOM so that it could not only forecast manpower but also determine the likelihood of the aircraft being available to fly a mission. The LCOM also predicted failure rates for most aircraft subsystems and components. With these rates and known maintenance requirements, the development teams computed what supplies and equipment an operational fighter squadron would need for a period of time. That information and another model, the Computer-Aided Load Manifest (CALM) model helped the teams determine how many C-141 cargo aircraft it would take to airlift the needed supplies and equipment. The LCOM also predicted the sortie generation rate (the ability of the aircraft to fly missions).

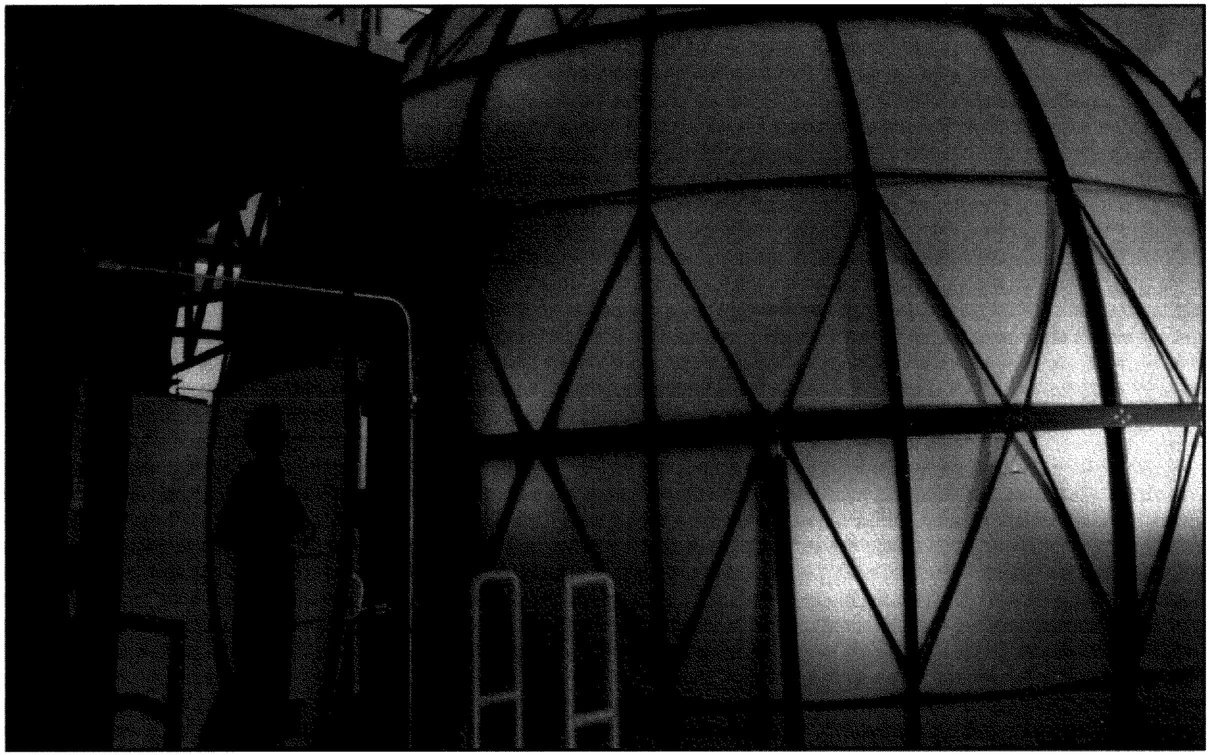


Photo by Eric Schulzinger courtesy of Lockheed-Martin.

Man-in-the-loop testing was essential in the F-22 demonstration/validation phase. Simulators, such as this domed system, allowed pilots to "fly" the F-22 before the YF-22 prototype was built. The simulations used the contractors system concept to determine what pilots really needed in the new weapon system, a step which was invaluable in developing the prototype.

Man-in-the-Loop Simulations. The ATF demonstration/validation phase was unusual among programs in the degree of user involvement. As part of the requirements iteration process, the users needed a tool to help them fully understand possible features and capabilities and determine their utility to the combat pilot. Both contractor teams established manned-flight simulators to allow TAC pilots to fly the aircraft that incorporated the contractor preferred system concept.

The simulators had the ability to model different types of avionics equipment (how useful is an infrared search-and-track system), types of aircraft performance features (how often does a pilot need speed brakes), and types and quantities of weapons (how often does a pilot of a stealth fighter need to fire a short-range infrared missile). During man-in-the-loop simulations the pilots began to develop new tactics that took advantage of the various features of the new fighter (including stealth, advanced avionics, and thrust-vectored and supercruise flight), which helped refine aircraft requirements and uncovered new requirements that maximized the fighter's capability against enemy aircraft and surface-to-air missiles.

As a result of more than 800 man-in-the-loop simulations, the users, the program office, and the contractors had a much better understanding of what the fighter needed to do and what it could do.

Results

The ATF program objective in the demonstration/validation phase was to mature and prove the technology needed to design the weapon system. Did it meet its objective?

The ATF program invested more than 4 years in demonstration/validation with two highly talented aerospace teams working out all aspects of technical risk. As a result of the rigorousness of the demonstration/validation phase, in more than 4 years of EMD, the F-22 program has not run into any significant technical problems—a remarkable accomplishment for a complex weapon system that incorporates a great deal of new technology.

Was the addition of the flying prototypes helpful to the program? The ATF founders say yes—but for different reasons. Fain believes that the benefit of having the contractors design and construct the prototype was that it forced them to predict the prototype performances and thus to validate their models, which improved their ability to properly design the production aircraft.

The other founders, Bucher, Abell, and Graves, see the benefit of the prototypes as being more procedural than technical. Making the multi-company teams design and build a test aircraft forced them to create a business and working arrangement that allowed multicompany design and construction to take place. This prototype process saved significant time in the EMD phase because the hard business decisions had already been made and the procedures had been developed and refined.

In Fain's view, thanks to the demonstration/validation effort, the F-22 program advanced technically in the areas of low observability, engine performance, and avionics. However, the program also learned that it could not go as far as originally thought in the area of aerodynamic performance. This outcome was acceptable, as the TAC BRAWLER model verified that the keys to mission effectiveness are low observability, supercruise, and advanced avionics.

7

Management and Integrated Product Development

- INTEGRATED PRODUCT DEVELOPMENT: A DEFINITION
  - The characteristics of IPD
  - The history of IPD
- INTEGRATED PRODUCT DEVELOPMENT IN THE F-22 PROGRAM
  - Team organization
  - The F-22 integrated product teams
  - IPD in action
  - A final note on IPTs
- RESULTS

I think the concept of integrated product teams . . . is a breakthrough. A breakthrough in breaking down the barriers between functional components to produce teamwork. It has prevented innumerable problems from creeping into the [F-22] program that would have taken months, if not years, to uncover had we not had the IPT process.

General John Michael Loh,
Commander, Air Combat Command

After defining the requirements and managing the technologies, the third element in managing risk is to set up a management system focused on the product. This chapter reviews the management approach, integrated product development (IPD), and the management structure, integrated product teams (IPTs) (see Figure 7-1). The next chapter reviews the F-22 management tool set.

INTEGRATED PRODUCT DEVELOPMENT: A DEFINITION

Within much of the DOD and defense industry the phrase "integrated product team" (IPT) is used for cross-functional, empowered work groups that support integrated product development (IPD).

The Air Force defines IPD as "a team approach to systematically integrate and concurrently apply all necessary disciplines throughout the system life cycle to produce an effective and efficient product or process that satisfies customer needs." In 1990, the ATF program office reviewed a study conducted at Wright-Patterson Air Force Base, Ohio, entitled *The Results of the Aeronautical Systems Division Critical Process Team on Integrated Product Development.* This report defined IPD as follows:

> IPD is an efficient process of bringing a product from user's needs to field operation. The basic principle is to iterate and integrate the design of a product and design of its manufacturing, operation, support and training processes with specific focus on achieving low-cost development, production, operations and support within the shortest schedule while achieving robust quality of products and services.

Fain's definition of IPD was more succinct:

IPD is nothing more than the right people, at the right time, focused on the right problems, to make the right decisions!

The Characteristics of IPD

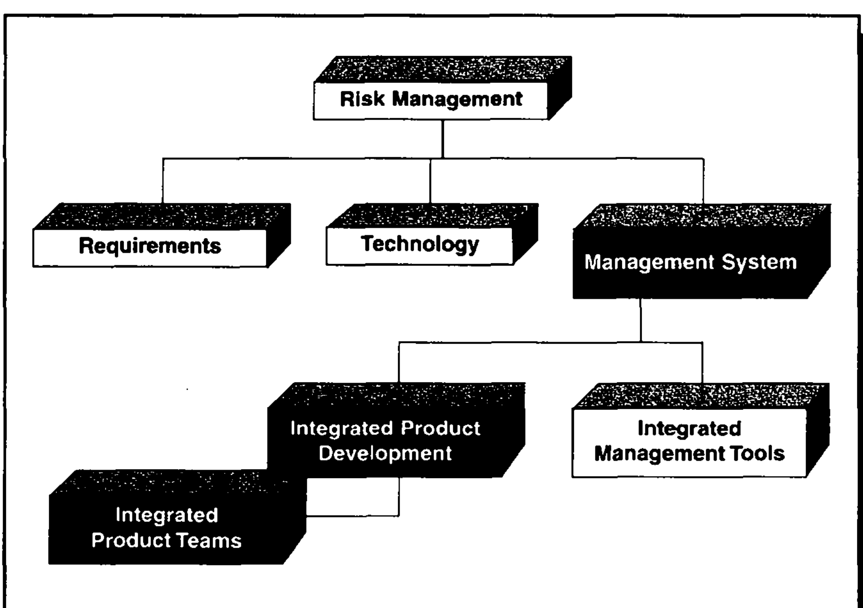
IPD has four major characteristics (Figure 7-2).

IPD is customer-focused. The reason any activity exists is to provide a product (or a service) to meet a customer's needs. IPD starts with understanding the customer's needs and working to meet them.

IPD is product-oriented. IPD redirects the old focus on functional expertise to the item that will meet the customer's needs—the product. The classic, pre-IPD approach to development also designed and produced products but emphasized an individual's functional expertise (engineering, manufacturing, logistics) rather than the product. The intent behind IPD is to have workers emphasize the product first and their technical specialty second.

IPD uses empowered, cross-functional teams. To develop a product that meets customer needs, IPD relies on a group of individuals who have the needed skills to ensure the product is "doable": one that manufacturing can affordably build and that meets the near- and long-term needs of the customer. IPD relies on all needed specialties

Figure 7-1. Elements of Risk Management: The Management System



making design decisions together to yield a high-quality product. Design engineers (e.g., electrical, mechanical, and aeronautical) work with financial and manufacturing personnel (to make sure the design can be built affordably) and logistics experts (to make sure the product will last and can be easily fixed) as well as test engineers to create a product that will do what the customer wants. To successfully build their product, these multidisciplinary teams must make decisions about the design and development of their product. Therefore, the organization's leadership must give the teams the responsibility and authority to make those decisions.

IPD takes a long-term view. The IPD teams must focus on the full needs of the customer. They must meet the immediate need for a product that does what the customer wants, but as mentioned above, it must be easy to fix when it breaks. The product should ideally be easy to modify and improve in the future to meet the evolving needs of the customer. This requires the design team to think about the product from delivery through modification to disposal.

Figure 7-2. Key Elements of Integrated Product Development

Integrated Product Development

- **Is customer-focused**
- **Is product-oriented**
- **Uses empowered, cross-functional teams**
- **Takes a long-term view**

The History of IPD

IPD traces its origins back to the engineering processes first used in the 1950s by the Japanese in their "lean production" method of automobile manufacturing (see Figure 7-3). The philosophy behind lean production was to deliver high-quality products and to continuously improve the processes used to develop those products. Japanese automakers achieved continuous improvement by using collocated, multifunctional teams that concentrated on designing for cost-effective production of products that met customer requirements.

In the 1970s, the term concurrent engineering emerged to describe a process similar to (and based on) Japanese lean production. Concurrent engineering called for a multifunctional team that considered design as well as manufacturing and affordability in the product initial design phase. In the 1980s, thanks in part to competitive pressure from Japan, several sectors of U.S. industry (most notably car manufacturers) adopted concurrent engineering design practices.

In 1988, the Institute for Defense Analyses studied the applicability of concurrent engineering to the weapon system acquisition process. Shortly after, the ATF program office decided to implement concurrent engineering in the engineering and manufacturing development (EMD) phase. In 1990, the Air Force Systems Command leadership, as part of its quarterly leadership Horizon conference, set the goal of implementing IPD. The Commander of Air Force Systems Command, General Ronald W. Yates, believed in the benefits of IPD but needed to figure out how to implement it command-wide.

INTEGRATED PRODUCT DEVELOPMENT IN THE F-22 PROGRAM

> Prior to the beginning of F-22 engineering and manufacturing development, the Air Force acquisition community had talked about integrated product development, that was a theme we had in the late 1980s. But we had not figured out how to implement it. We had not gotten down to the level of integrated product teams. That is something clearly pioneered by the F-22 and proven to be very valuable. As I sit here in 1995, just 5 years after the start of F-22 EMD, I am amazed how the IPT concept has spread. I met with a contractor this morning who explained his teaming arrangements for a new program. His team has all of the functionals, all from various companies, collocated in the same building. That was unheard of in the 1980s. That was unheard of in 1990. The success of the IPTs has spread throughout the industry and to all of the other major programs throughout the Air Force. That is all due to the F-22.
>
> Darleen A. Druyun, Principal Deputy
> Assistant Secretary for Acquisition Management

The implementation of IPD for the F-22 program evolved naturally from the founders' principles (such as teamwork, integration, ownership, and long-term view) and several experiences in the ATF demonstration/validation phase.

During demonstration/validation, the program office established working groups made up of personnel from the Air Force, the Navy, and the rest of the DOD to address a full spectrum of issues, including armament integration, security management, common avionics, and cost estimation. Following the fourth principle, involving every-

Figure 7-3. History of Integrated Product Development

1960–1970	1980	1990	1991	1993
Concurrent engineering develops out of lean production culture	U.S industry adopts integrated product development design practices	Institute for Defense Analyses publishes report on concurrent engineering	F-22 program office implements IPD	Air Force implements IPD
		Horizon conference sets IPD as goal	Air Force Materiel Command forms IPD steering committee	

one who has a stake in the outcome, these working groups included representatives from not only many organizations but also many disciplines. Through participation in these groups, the various organizations could raise their issues and debate the various suggestions from the others. The members knew and understood the reasons behind the decisions. Once given a chance to voice their opinions and thus be part of the decisionmaking process, they could effectively explain back at their home organizations why the ATF program (of which they were a part) had made a certain decision.

Another example of effective teaming during the demonstration/validation phase came in the form of *tiger teams*, which the program office set up when some part of the program ran into difficulties. These tiger teams consisted of the people with the right expertise to solve the problem. For example, the tiger team for a business problem might include individuals from contracts, finance, and program management. Often these teams had members from various Government groups as well as from the appropriate contractors. Because the tiger teams included people with the necessary expertise and a stake in the outcome, the solution usually fell within everyone's constraints and met everyone's expectations. Fain found that the tiger teams delivered highly successful strategies and solutions.

The example that convinced Fain that the concept of multifunctional teams had a high payoff came from the Lockheed YF-22 design effort. In 1987 and early 1988, the Lockheed-Boeing-General Dynamics team could not agree on the design for its prototype version of the ATF. To meet the scheduled flight date of 1990, the YF-22 team had to quickly finalize the design. After repeated failures to reach agreement, the Lockheed program manager, Sherman Mullins, brought the key design engineers and manufacturing personnel into one location, telling them that no one could go home until they reached an agreement. The process worked. The design team emerged several weeks later with a solid design that each company felt good about.

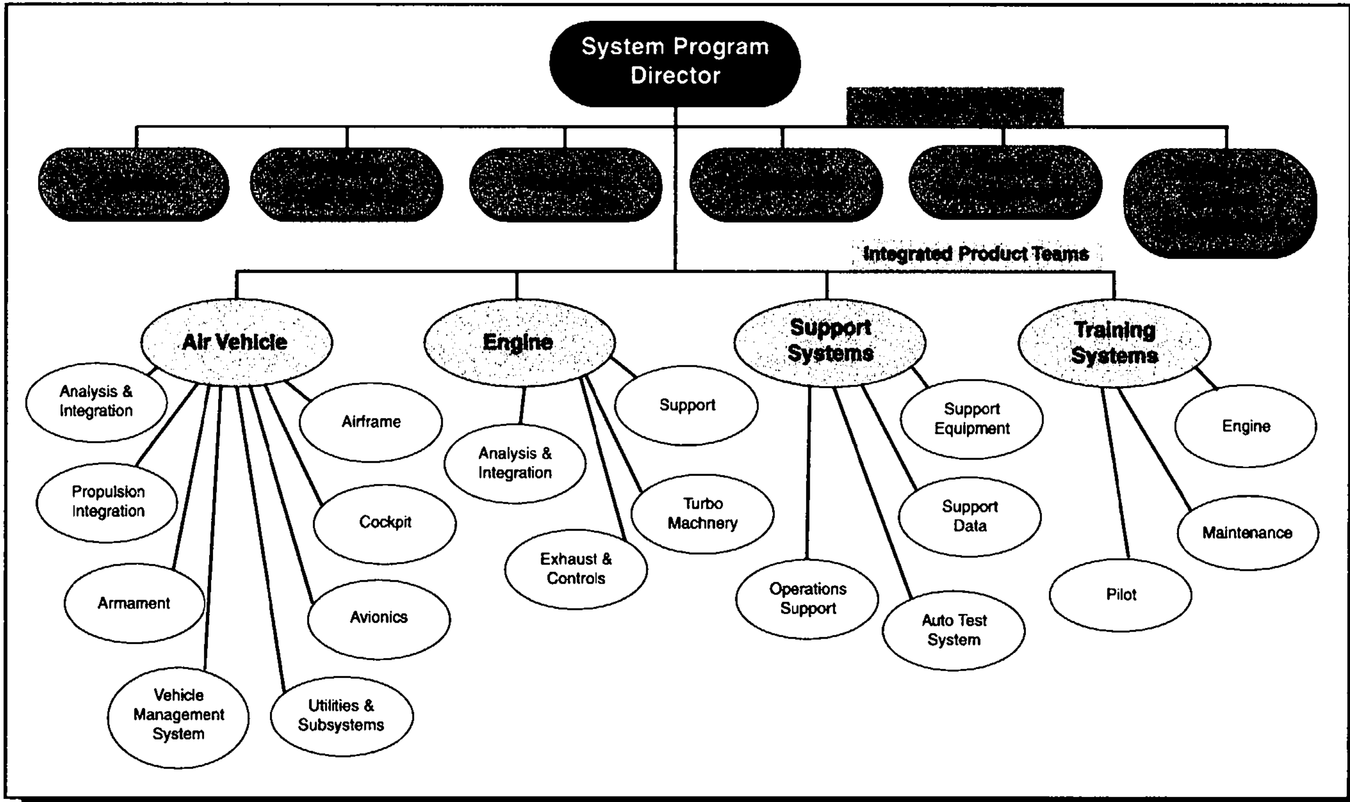
Late in demonstration/validation, as the founding fathers planned the EMD phase, Fain asked Abell, Bucher, and Graves a simple question: "Today we always use tiger teams when we get in trouble. For EMD, why don't we use permanent tiger teams?" As the founders considered the concept of permanent tiger teams, they discussed the evolution of the front office group (FOG) decision process, in which Fain would call his FOG together as a team to create a strategy and implement a solution that satisfied each member's functional constraints. The founders decided to push this concept to the lowest levels. The result, the concurrent leadership described in chapter 3, was the establishment of multifunctional teams (just like the FOG) as permanent tiger teams.

To remind the teams to maintain their focus on the product, the program office originally called these teams IPD teams. During one of the early organizational planning meetings, Colonel Peter Smith, Fain's program manager for the engine program, asked, "If we are focusing on the entire life cycle [a long-term view] and not just the up-front design, why do we put the emphasis on development? Shouldn't this team be around during production and perhaps even to support the jet?" Smith's logic hit home. Fain dropped "development" and changed the name to integrated product team.

Team Organization

Figure 7-4 shows the structure of the F-22 program office and the way it implemented IPTs. The program office has four major integrated product teams: Air Vehicle, Engine, Support System, and Training System, each with a number of subintegrated product teams that focus on lower level products. For example, the Air Vehicle team includes, among others, the Armament, Avionics, Cockpit, and Utilities and Subsystems IPTs. Because of the complexity of some of the products, each team is further broken down

Figure 7-4. The F-22 System Program Office



into smaller subintegrated product teams (for example, avionics subteams include Radar, Core Processor, and Offensive Avionics).

The program office also includes functional offices such as logistics, systems engineering, and test. However, the composition of these offices is much different than in a traditional program office. At the Air Force Aeronautical Systems Center, the Director of Engineering would typically direct around half of the program office, 150 people. In the F-22 program office, the engineers are located in the product teams (e.g., Air Vehicle, Engine). The Directorate of Engineering now has fewer than 20 individuals assigned. Clearly, the focus is on the product.

The contractors also adopted IPTs. As is shown in Figure 7-5, the Lockheed F-22 program and the F-22 program office have very similar organizational structures—by design. The program office emulated the contractor organization to support teamwork and communications. In fact, when the F-22 team members describe their IPT membership, they include people from the program office, the contractors, and Air Combat Command (ACC). Similar organizations make this one-to-one matching much easier.

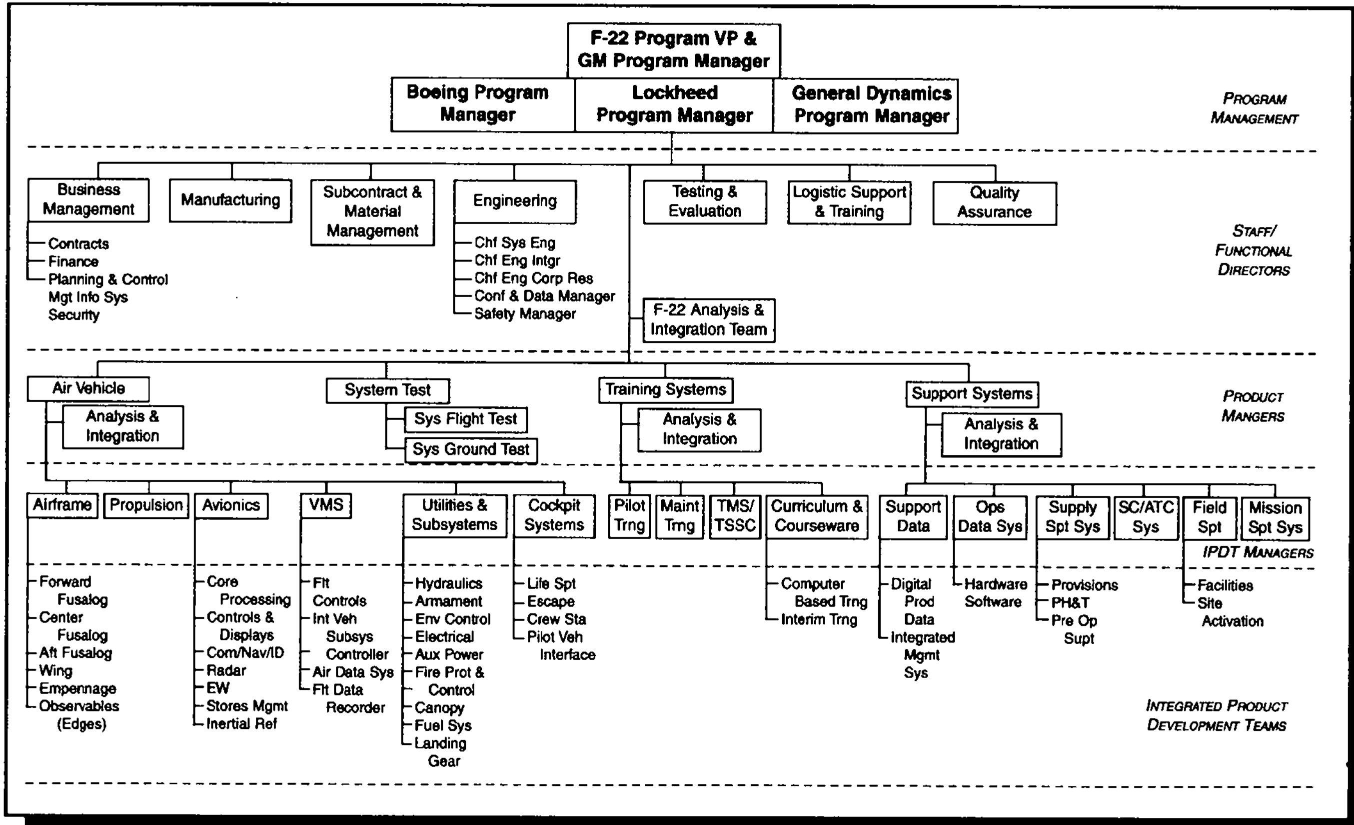
The F-22 Integrated Product Teams

Figure 7-6 shows one F-22 IPT, Support Data, and its lower tier IPTs. This team, as well as characteristics of IPD as they relate to such F-22 IPTs, are described below.

The Support Data IPT is one of four teams that make up the F-22's third major team, the Support Systems IPT. The Chief of the Support System IPT holds the sub-IPTs responsible for cost, schedule, and performance in the development of their products. The Chief of the Support Data IPT, Major Lowry, serves as a program director for all elements of his products. For example, he and his contractor counterpart are responsible for seeing that the Integrated Management Information System (a portable computer that flight-line technicians will use to display technical orders and diagnose problems with the aircraft) meets its performance requirements. They also see that the design team meets the schedule with respect to the rest of the F-22 program, meets its producibility cost targets, and does not exceed its annual development budget.

Note that the Support Data IPT has a diverse set of team members. The team includes managers, engineers, and logistics experts as well as a collocated representative from ACC, who helps ensure that the contractor and program office understand the needs of the command. Although located on the Support Data team, the ACC

Figure 7-5. The Lockheed F-22 Program: 1991



representative helps in all areas of the program office that require operational insight and skills (e.g., flightline maintenance).

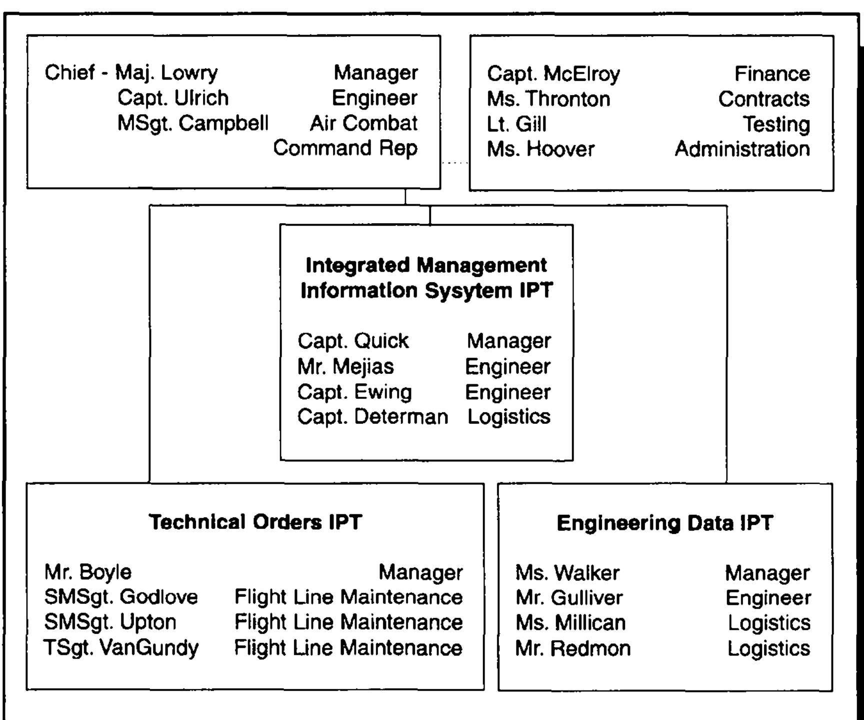
The F-22 IPTs, including the Support Data IPT, incorporate the characteristics of IPD previously discussed.

They are customer-focused. The F-22 IPTs are focused on their customer, Air Combat Command. Members of ACC are assigned to the program office to improve the communication among the program office, the contractor, and ACC.

They are product-oriented. The Support Data IPT is organized along its portfolio. The contractor side of the team has IPTs that focus on lower levels of indenture as well. In the ever-increasing tiers of teams, the F-22 Program Director has an IPT responsible for every element of the weapon system. Each is based on a product or group of products.

They are empowered, cross-functional teams. In an IPT, managers, design engineers, manufacturing engineers, logisticians,

Figure 7-6. The F-22 Program Support Data IPT
(Government Members Only)



and in some cases ACC representatives all work in the same physical area of the program office. A dedicated contracting specialist and a financial expert are also assigned to the team. In the largest teams (Air Vehicle and Engines), the finance specialists sit with their teams. The contractor representative and the team members maintain contact through frequent visits to each other's facilities and frequent communication by telephone, electronic mail, and F-22 dedicated video teleconferences.

They take a long-term view. Each team focuses on meeting the near- and long-term requirements of its product. In fact, each IPT includes members from the Sacramento Air Logistics Center, who service or update the aircraft when necessary.

IPD in Action

Does IPD work? The Commander of Air Combat Command believes that it does (and he has been involved in the program for more than 10 years). The F-22 program founders, as well as later program directors, such as Major General Robert Raggio, also have seen the great payoffs of an integrated, multifunctional, empowered work force.

The following memorandum is an actual IPD. Written by an Air Force maintenance officer assigned to the F-22 program office, it describes the trade-off process team members used to reach a balanced design in the F-22 lower tail section. In the memo, an expert in repairing and maintaining the aircraft reports on reaching the best overall solution to improve the quality of the product *(the italics in the memo are mine).* Captain Tinsler's example is but one of thousands of product-focused trade-offs that occur everyday in the F-22 program.

> 10 May 94
> Memo to: ASC/YFFV
> YFF
> IN TURN
>
> Subject: Trip Report, Boeing, 5 May 94
>
> 1. Purpose of visit: Aft boom redesign
>
> 2. Discussion: The objective of this meeting was to reach agreement on the best solution for the aft boom stiffness design. Four designs were considered:
>
> 1. Baseline design - A large contoured access panel on the bottom of the aft boom with zero tolerance holes, the panel is considered part of the stiffness loop. Problems with this approach are:
>
>   a. Zero tolerance holes of 0-.003 inches *difficult to control in manufacturing.*
>   b. *Difficult to produce* multi-contoured stress panel

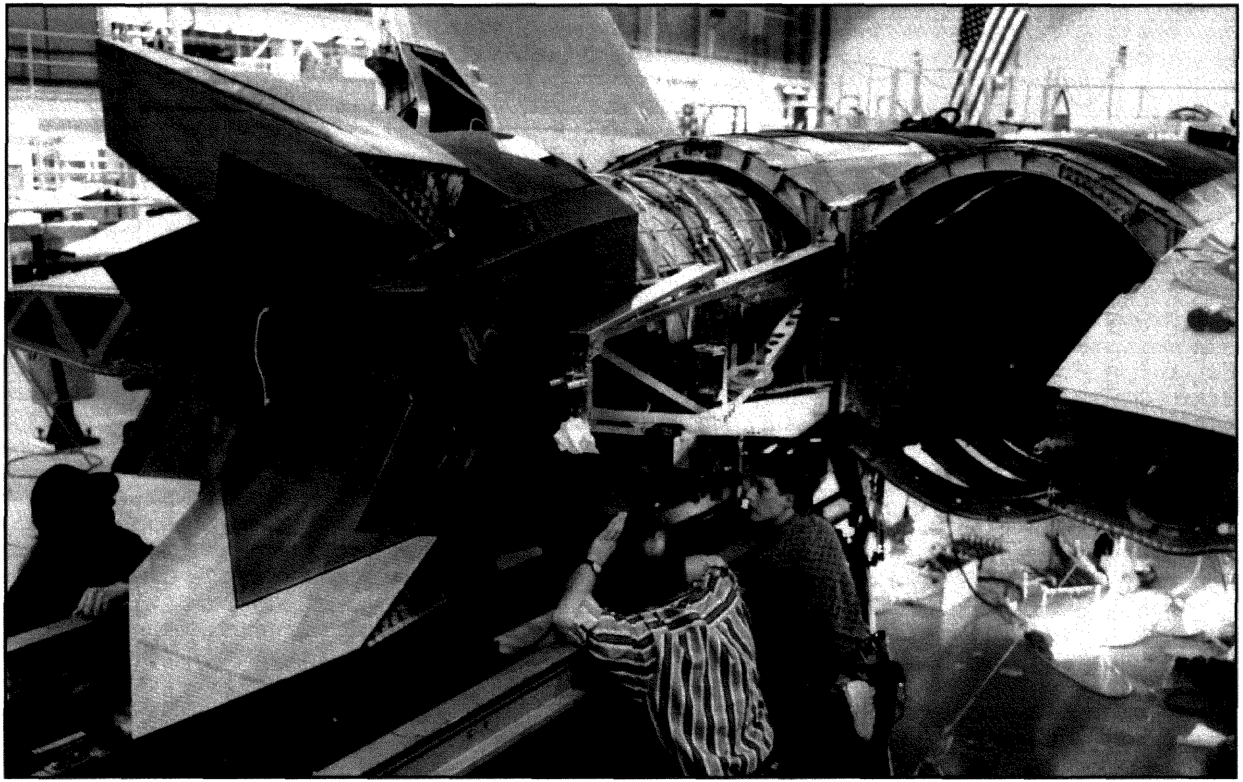


Photo courtesy of Lockheed-Martin.

Captain Tinsler's memo concerning the aft boom design was largely about the frequency and ease of engine replacement and nearby components. Here, workers are fitting an F119 engine into the aft boom area Tinsler mentions.

c. *Difficult to install* the panel
d. *Difficult if not impossible to drill* new panel to fit when replacing the panel
e. Requires load alleviation to install/ remove the panel

2. Gussets - Triangular shaped stiffeners that tie frames 1 and 3 to the sidewalls, panel is shaped same as baseline but is not part of stiffness loop. The problems referenced in 1b-e above apply with these additional concerns:

a. *Adds 30 pounds*
b. Installation/removal of actuator support pins extremely difficult due to gusset interference
c. Increases number of engines removed by 39.5 per squadron per year

3. Inverted Actuators - This involves flipping the actuator servo valve at the bottom of the cylinder. This design was not seriously pursued since the actuators have already passed CDR and this option involves redesigning the actuator (yuch).

4. Keelson Access - Bottom aft boom is permanent structure instead of an access panel, access to aft boom is through keelson panel. This is the cleanest solution for the stiffness problem and saves significant weight but requires an engine removal to gain access to the keelson panel.

Option 4, as originally proposed, required an engine removal to gain access to the horizontal tail actuator, actuator hydraulic lines,...fuel dump screen. Preliminary numbers showed this design would require an additional 44 engine removals per year per squadron, an idea the maintainers were adamantly opposed to. Despite our maintainability objections, Boeing vigorously pursued the idea since it was a good stiffness solution with a significant weight benefit. *Working closely with the program office and Air Combat Command maintainers, Boeing looked at how best to address our concerns* and presented their recommended solution at this meeting. Their recommendation was a modified option 4 approach. The highlights of this design are:

a. Small access panel on bottom of aft boom for fuel pump removal and limited hydraulic line B-nut access, the rest of the skin is permanent
b. Two keelson access panels behind the AM&S for access to the fuel dump valve and screen and access to the horizontal tail mount bolts: access to these panels gained by removing the AM&S
c. Large keelson access panel for actuator removal; access to this panel requires engine removal.

This modified option 4 reduces engine removals to 5 per year compared to 44, significantly improves access to the hydraulic lines on top of the actuator, saves the aircraft about 45 pounds, and reduces overall access time (based on comparing 90 minute engine remove and replace to load alleviation jacking and removal of coating and 300+ fasteners). Removing and installing the actuator is the only reason to remove the engine, *a tradeoff the program office and Air Combat Command maintainers agreed to based on the benefits listed above.*

Conclusions: *When Boeing originally proposed this idea to the maintainers, we told them we considered pulling an engine to gain actuator access a non-option. They listened to our concerns and in a two-week span came up with the modified option solution. To further convince us, they mocked up the aft boom complete with actuator, fuel pump, fuel dump valve and all associated tubing. Fundamentally we* *still dislike the idea of removing the engine to gain access to other components. However, I believe we made the right tradeoffs and came up with the best solution for the airplane.*

James A. Tinsler, Capt, USAF
Vehicle Management System Maintainer

A Final Note on IPTs

The F-22 program IPTs are successful at developing balanced solutions that have the commitment of the stakeholders who must carry them out. These Government/contractor teams fully engage the ACC customer-user. The user, being both part of the design cycle and the most important part of the decision process, fully supports the decision reached by the team. IPD is instrumental in user satisfaction.

It is perhaps obvious that, because IPTs implement IPD, the characteristics of a successful IPT echo the elements of IPD in Figure 7-2. However, as shown in Figure 7-7, there is an additional characteristic necessary for a successful IPT. Each team must know the limits of its decisionmaking authority, or fenceposts (as described in chapter 4). When the team understands what the constraints of cost, schedule, and performance are for its product and what decisions must be coordinated at higher (or lateral, or sometimes, lower) levels, it is fully empowered to manage its portion of the program.

Results

Multidisciplinary teams, focused on meeting the short- and long-term needs of the customer-user, are a powerful tool in solving complex problems. To reap the full benefit of integrated, product-focused teams, the teams need a tool set that is also integrated. Chapter 8 describes the tools that support the F-22 program IPD.

Figure 7-7. Characteristics of Successful IPTs

Successful IPTs

1. Are customer-focused
2. Are product-oriented
   (Where a "product" can be an item, a process or an issue)
3. Are empowered, cross-functional teams, including
   - All stakeholders involved
   - All necessary disciplines/organizations (including the customer)
4. Take a long-term view
5. Understand the limits of their decisionmaking authority (fenceposts)

8

Management and the Integrated Tool Set

- BACKGROUND
- THE INTEGRATED MANAGEMENT FRAMEWORK
  - Requirements
  - Work breakdown structure
  - Statement of work
  - Integrated master plan
  - Integrated master schedule
  - Technical performance measures
  - Cost/schedule control systems criteria
  - Closure plans
  - Award fee
- THE IPT MANAGEMENT TOOL SET
- USING THE IPT TOOL SET
- SUMMARY

Everyone is lined up. They all know where they are within the contract, know what specs they are working to, what part they are working to, how many resources they have, and how much time they have to do it.

Colonel Wallace T. Bucher,
at the start of the engineering and
manufacturing development phase

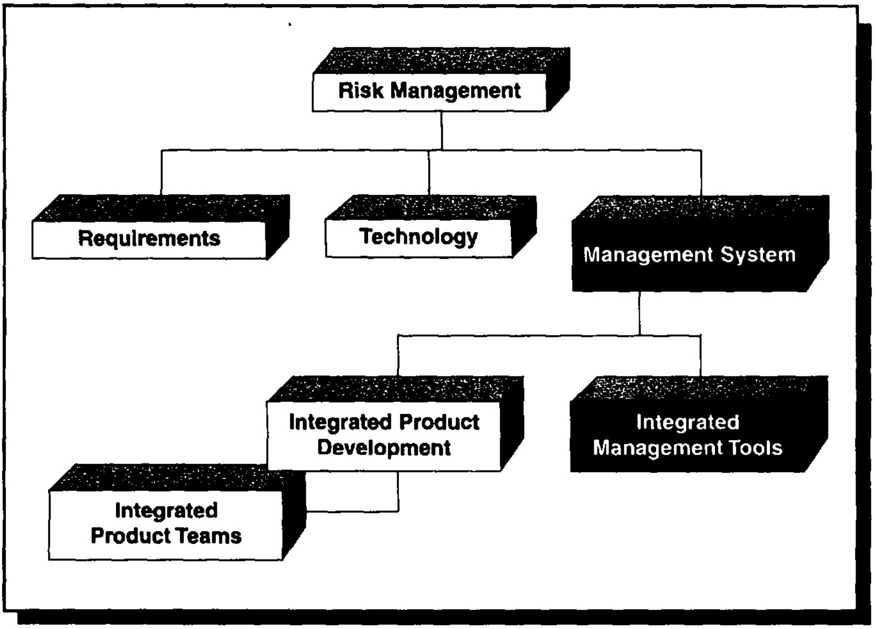
BACKGROUND

The first half of the F-22 management system, integrated product development (IPD, described in chapter 7) is supported by the second half, the management tools used by all levels of the program (see Figure 8-1). Everyone from the Program Director to the individual members of the integrated product teams (IPTs) use this integrated management framework for the day-to-day execution of the F-22 development effort.

The purpose of the demonstration/validation phase of the ATF program was to reduce risk. In addition to addressing the risks associated with requirements and technology, the ATF program office also actively worked to reduce risks by controlling costs and schedules, and by meeting performance expectations for the development phase. Early in demonstration/validation, the program office established an Acquisition Strategy Working Group to address the business aspects of the program, including the acquisition strategy and management framework for the engineering and manufacturing development (EMD) phase. This working group, led by the Deputy Program Director, Colonel Wallace T. Bucher, included finance and contracting personnel, engineers, managers, logistics experts, and test personnel from the program office and the contractors. They discussed such items as what types of contracts to award, how to motivate the contractors to perform, what type of data they would need, and how to track progress—every aspect of the program that was not technical.

The Acquisition Strategy Working Group had two primary objectives in developing the new management structure: first, plan and commit to an executable program—track and manage to their plan—and, second, decide how to evaluate and reward contractor performance.

Figure 8-1. Elements of Risk Management: The Management System



The working group prototyped and tested several techniques during the engine's second-phase demonstration/validation contracts. Armed with the lessons learned from the engine experience, the ATF program refined the concepts and created an integrated management framework.

THE INTEGRATED MANAGEMENT FRAMEWORK

The F-22 integrated management framework, shown in Figure 8-2, can be divided into three categories of management tools. The first category, planning tools, includes the requirements called for in the functional system specifications: the work breakdown structure, the statement of work, and the integrated master plan. The second category of tools focuses on tracking: the integrated master schedule, technical performance measures, cost/schedule control systems criteria and other financial tools, and closure plans. The final category includes the means of giving feedback to the team on performance, delivered through the award fee process.

Requirements

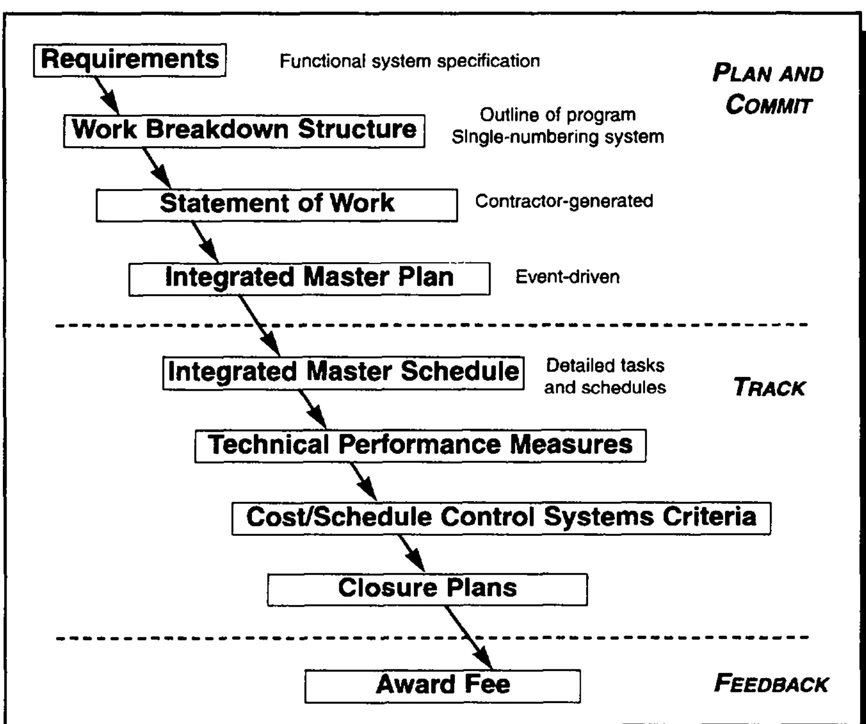
As discussed in chapter 6, the ATF program documented the requirements for the weapon system in the preliminary system specification. The bidding contractors submitted their version of the weapon system specification as part of their proposal for the EMD phase. The contractor chosen for EMD then allocated the top-level requirements from the weapon system specification to more detailed specifications for the major portions of the weapon system. These functional, "Type A" specifications covered 15 separate areas, including the weapon system, the air vehicle, the support system, the training system, and other major portions of the air vehicle (such as avionics). The engine contract includes three additional functional specifications for the engine and the engine's support and training systems.

Work Breakdown Structure

The work breakdown structure serves as a program outline. It graphically depicts the way in which the contractor intends to perform the work. As such, the F-22 (and the F119) work breakdown structure is tailored to the development and manufacturing process.

The work breakdown structure serves as the basis for the F-22 single-numbering system and is needed to ensure an integrated set of management tools. All specifications, as well as the statement of

Figure 8-2. The F-22 Program's Integrated Management Framework



work, integrated master plan and schedule, technical performance measures, and cost reporting, are arranged according to the work breakdown structure. Because it is organized primarily by products and their constituent subproducts, and because it is the main thread that runs throughout the management system, it reinforces team focus on the product. As a result, IPTs are also organized according to the work breakdown structure.

Statement of Work

The statement of work describes the minimal essential requirements of the program—that is, what the contractor must do. The following paragraph is an excerpt from the statement of work for the vehicle management system (VMS).

> **1500 VEHICLE MANAGEMENT SYSTEM**
> The contractor shall design, develop, integrate, test, qualify and prepare for production of a VMS that meets the Weapon System Specification, in accordance with the activities described in the IMP. The contractor shall analyze, verify, and document the design of each VMS configuration item and integrate them within the VMS. The contractor shall integrate the VMS with other ATF subsystem elements, the air vehicle, and the support and training systems. The contractor shall develop the requirements for, coordinate the use of, and control configuration of an integrated VMS test facility for the purpose of verifying and validating certain VMS requirements and the integration of the VMS with other subsystem elements.

The F-22 statement of work is different from those in earlier programs in that the contractor wrote it. In typical acquisitions the Government presents the contractor with a statement of work and a detailed specification, but for the ATF program the Government only supplied sample language for its minimum essential activities (like the Government test program). The ATF program leadership understood that the contractors knew how to develop a fighter much better than the Air Force did. Fain explained it this way:

> When you go out and build a house, you don't schedule the jobs and tell the general contractor what they're to do. You tell them to build you a house. The general contractor figures out how to build it—it's their job. They are the expert! To have the Government come in and tell the contractor how to build a weapon system by giving them a statement of work is just plain stupid!

Integrated Master Plan

The integrated master plan (IMP) is an event-driven planning document prepared by the contractor and used by the IPTs to manage the development effort.

Birth of the integrated master plan and integrated master schedule. Marcia Irvin of the F-22 program office described the evolution of the IMP and IMS as follows:

> Early in the process, the engineering community within the SPO [System Program Office] encouraged the use of a Systems Engineering Master Schedule (SEMS). The belief was that the contractor would surely need to use this or some similar planning tool to accomplish a program of this size. Hence, SEMS became the launching point for schedule.

One problem noted by the Acquisition Strategy Working Group, however, was that the SEMS included dates, and, as a contractual annex, would require contract modification each time the program schedule changed. The proposed solution was to create a solely event-based (no dates) planning document that could be incorporated into the contract and maintain a data item to provide the supporting schedules for the contractual plan. So, SEMS was reformatted somewhat and the dates were removed to create the event-based contractual plan. The supporting data item developed was known as the Systems Engineering Detailed Schedule (SEDS).

The one fallacy with SEMS and SEDS was that while they would easily have satisfied the engineering community, management would not have had any insight into functional processes necessary for program accomplishment. The intermediate solution was a "sister" set of schedules to SEMS and SEDS that would be process oriented, the Management Master Plan (MMP) and the Management Master Plan Schedule (MMPS). Trial application of this concept on the ATF engine second demonstration/validation contract, however, surfaced another problem. The gray area between the technical focus of SEMS/SEDS and management (process) focus of MMP/MMPS created an integration problem. Specifically, some items would either be duplicated on both sets of documents or they might not be included at all because it wasn't clear which set of documents was appropriate. Ultimately, the solution was to eliminate the gray area. SEMS and MMP were merged to become the Integrated Master Plan. The SEDS and MMPS were merged to become the Integrated Master Schedule.

As just described, the major difference between previous tools, such as the system engineering master schedule, and the IMP is that the IMP contains all program activity (not just engineering) and does not contain calendar dates.

The IMP is part of the contract so that no one can change the program activities without agreement between the contractor and the Government. It expands on the tasks in the statement of work and defines the milestones for both the products and the processes needed to design, test, and produce the F-22 weapon system. As described in the ATF request for proposal, the IMP is defined by four elements—events, significant accomplishments, accomplishment criteria, and detailed tasks—that describe the activity and define its successful completion. Their specific definitions follow:

- Event: The conclusion or initiation of an interval of major program activity
- Significant accomplishment: A desired result at a specified event that indicates a level of design maturity (or progress) directly related to each product or process
- Accomplishment criterion: A definitive measure or indicator that the level of maturity (or progress) has been achieved
- Detailed tasks: Detailed work to be completed in support of a specific significant accomplishment.

Figure 8-3 shows a portion of the work breakdown structure; Item 1500 of the IMP for the VMS. Note that the event is critical design review and that the significant accomplishment is completion of detailed design. Also note the single-numbering reference to the statement of work sections.

Because of the details provided by the contractors in the IMP, the program office prohibited use of all standard "specialty" plans (such as quality plans or configuration management plans). Presenting these specialty details in the IMP gave the teams a better appreciation for how specialty areas had to work with other parts of the program and has greatly helped reinforce integration.

Integrated Master Schedule

The IMS expands on the IMP by providing the tasking and timing of the work effort required to support the IMP events. The IMS is not part of the contract, which allows the IPTs the flexibility to manage their program without constantly changing the contract. The IMS lays the foundation for budget and schedule planning and links directly to the reporting of cost and schedule. Figure 8-4 shows the IMS for the VMS.

Figure 8-3. Vehicle Management System Integrated Master Plan

EVENT / Significant Accomplish / Accomplishment Criteria / Tasks	ACTIVITY NUMBER	SOW REF
VMS CRITICAL DESIGN REVIEW (CDR)	**J03**	**1500**
VMS DETAILED DESIGN COMPLETE	**J0306**	**1500**
VMS Computer Resources CDR complete for each CI	J030616	1500
MEDS Design review update (DRU) complete	J030616A	1520
PICC CDR complete	J030616B	1520
Power supply CDR complete	J030616C	1520
METS CDR complete	J030616D	1520
TPS CDR complete	J030616E	1520
TPS SW CDR complete	J030616F	1520
VMS VKS CDR complete	J030616G	1520
METS software baseline released	J030616H	1520
VKS CDR update complete	J030616I	1520
PICC Spec V&V plan complete and available	J030616J	1520
VMS Actuators CDR Complete for each CI	J030617	1530
VMS Actuator CDR complete for each CI	J0306171	1530
VMS Actuator design and analysis	J0306172	1530
VMS Actuator modeling analysis complete	J0306173	1530
VMS Actuator vendor test procedures complete	J0306174	1530

Technical Performance Measures

> Metrics motivate behavior. However, you must be very, very careful as to what you measure.
>
> Major General Robert Raggio

> Why did I invent TPMs? Because I wanted to put discipline into the technical aspects of the program.
>
> Eric E. Abell

Technical performance measures (TPMs) are a tool to track technical progress toward meeting the weapon system specifications. Abell, knew that in past programs the cost and schedule elements of risk could be tracked with metrics (such as the cost/schedule control system, or critical path charts to manage the schedule). He wanted a similar tool to allow him to track technical risk.

The F-22 program uses TPMs at all levels to display results-to-date along with projected results, to show the technical maturity of each product, and to present trends as well as projected performance that the IPTs expect their product to achieve. An important benefit of TPMs is that they provide an historical record of a product's performance.

Figure 8-4. Vehicle Management System Integrated Master Schedule

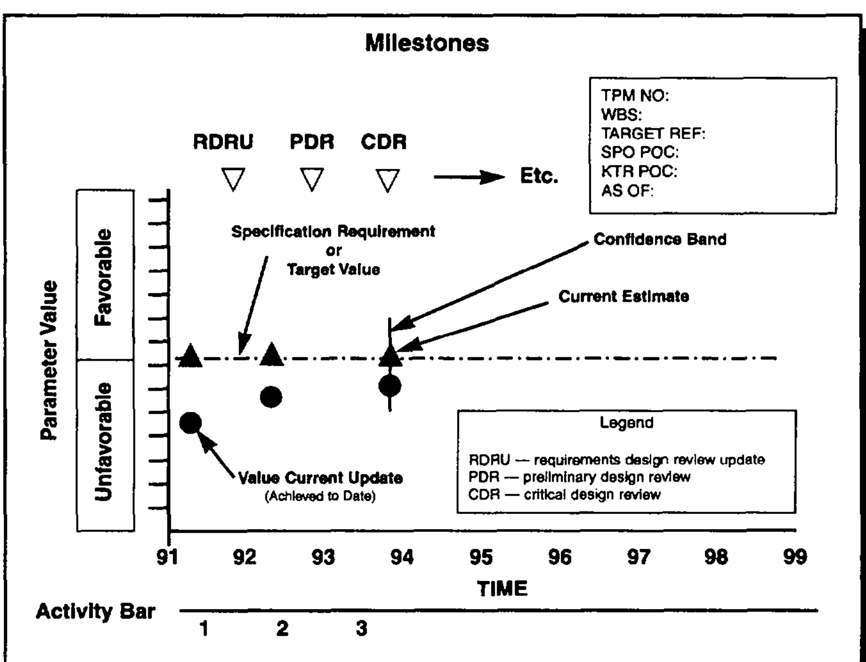
Activity Name	Activity Code	1993									1994											
		Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
VMS Critical Design Review	J03																				△	
VMS Detailed Design Complete	J0306																				△	
VMS Computer Resources CDR Complete	J030616																			△		
MEDS Design Review Update (DRU) Complete	J030616A					▲▲																
PICC CDR Complete	J030616B												△△									
Power Supply CDR Complete	J030616C																			△		
METS CDR Complete	J030616D	Completed 10/30/92																				
TPS CDR Complete	J030616E	▲				▲																
TPS SW CDR Complete	J030616F	▲				▲																
VMS VKS CDR Complete	J030616G					▲▲																
METS Software Baseline Released	J030616H																		△			
VKS CDR Update Complete	J030616I																△△					
PICC Spec V&V Plan Complete and Available	J030616J									▲		▲										

Figure 8-5 shows the standard TPM chart format. On the top of TPMs are the program milestones: requirements design review update (RDRU), preliminary design review (PDR), and critical design review (CDR). The information box in the upper-right corner shows the work breakdown structure reference, the TPM source for requirements (usually the specification), the contractor and Government owners of the product measured, and the date of the information. The graph plots performance against time. For classified TPMs the values are normalized to show differences from the classified requirement (usually making the TPM unclassified).

The target value, shown by the dashed line in the center, shows the specification value for the product. The round dot identifies the proven performance value as derived by development accomplishments by a certain date. The achieved-to-date value, based on initial lab tests or tests coupled with calculations, typically lies below the target line and increases as development progresses and the demonstrated performance of the product improves. Thus, over time, the value of the current update should approach the target value.

The current estimate, shown by a solid triangle, is the most

Figure 8-5. Technical Performance Measure Chart Format



recent forecast from the IPT on how it believes the product will perform when first produced. When this value strays below the target, the IPT (and its higher level IPTs) know to start corrective action.

Like any projection, the TPM chart includes assumptions. The confidence band shows the possible range of the current estimate for the best- and worst-case assumptions. In this manner, the reader of the chart understands the magnitude of the accuracy and maturity of the current estimate and the range of values for final performance.

The activity bar at the bottom of the graph identifies when the IPT generated new data for the TPM. An attached sheet (called the TPM summary) describes the estimates, the reasons values have changed from earlier information, the TPM measures, and any assumptions or additional information about the TPM.

The F-22 TPMs are tiered by product. Virtually every TPM on each product describes performance that supports the performance of a higher level item, which supports that of a higher level item, ultimately contributing to the overall performance of the aircraft, engine, or support or training system. The highest level TPMs track the F-22 critical characteristics (shown in Figure 8-6). By DOD regulation, failure to meet any of the critical characteristics allows the Secretary of Defense to review the program and assess whether it should continue. The F-22 Program Director reviews the TPMs relevant to each critical characteristic weekly.

Figure 8-7 shows the independent airlift TPM. The program office, the contractor, and the ACC members of the Support System IPT use this TPM to monitor how many C-141B equivalent loads they would need to deploy and maintain a squadron of 24 F-22s for 30 days. The requirement is to deploy with no more than eight C-141Bs, half of what is needed today for the F-15. This TPM is a good example of the power of metrics. Whenever the current estimate approaches the target, a great deal of management attention goes into finding out what has changed and what the IPT will do to lower the C-141 forecast.

Figure 8-6. F-22 Critical Characteristics

- Radar cross-section
- Supercruise
- Acceleration
- Maneuverability
- Payload
- Combat radius
- Radar detection range
- Independent airlift
- Sortie generation rate
- Mean time between maintenance

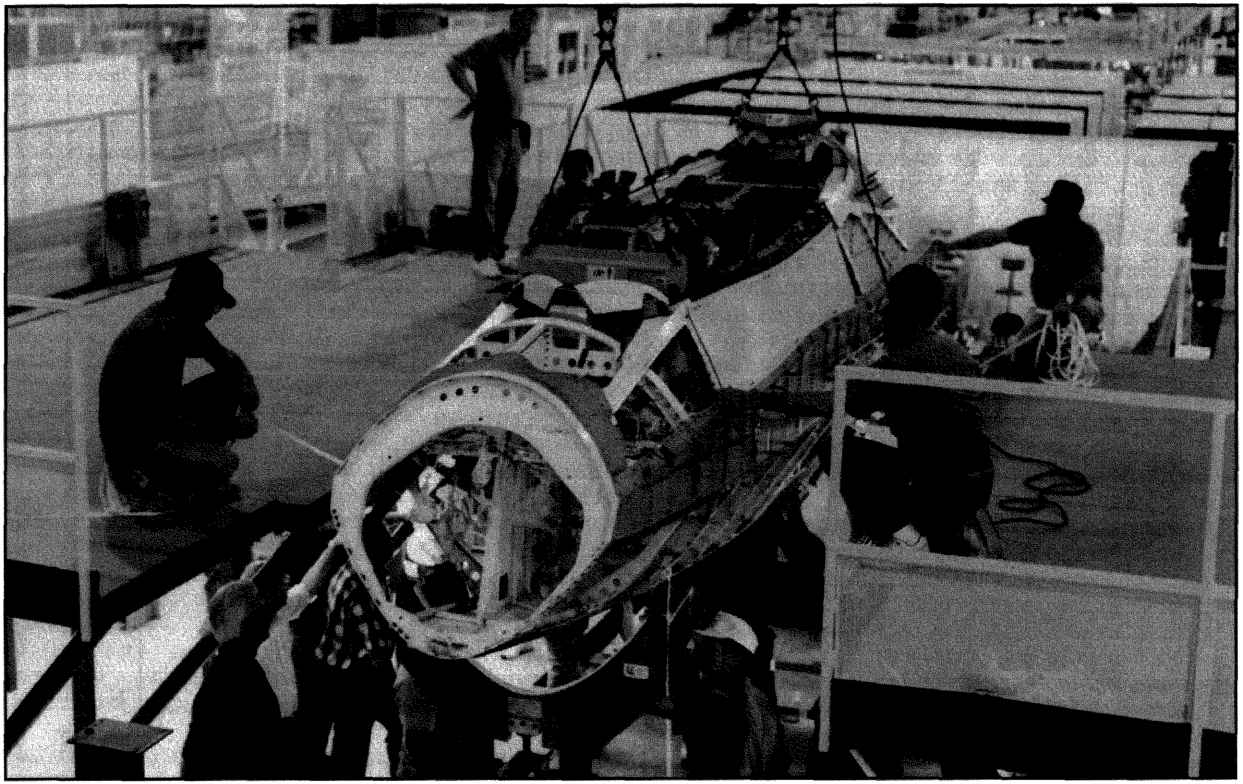


Photo by John Rossino courtesy of Lockheed-Martin.

The forward fuselage of the first F-22 is lowered into the fuselage mate tool. Later the mid and aft fuselage components will be added to this tool.

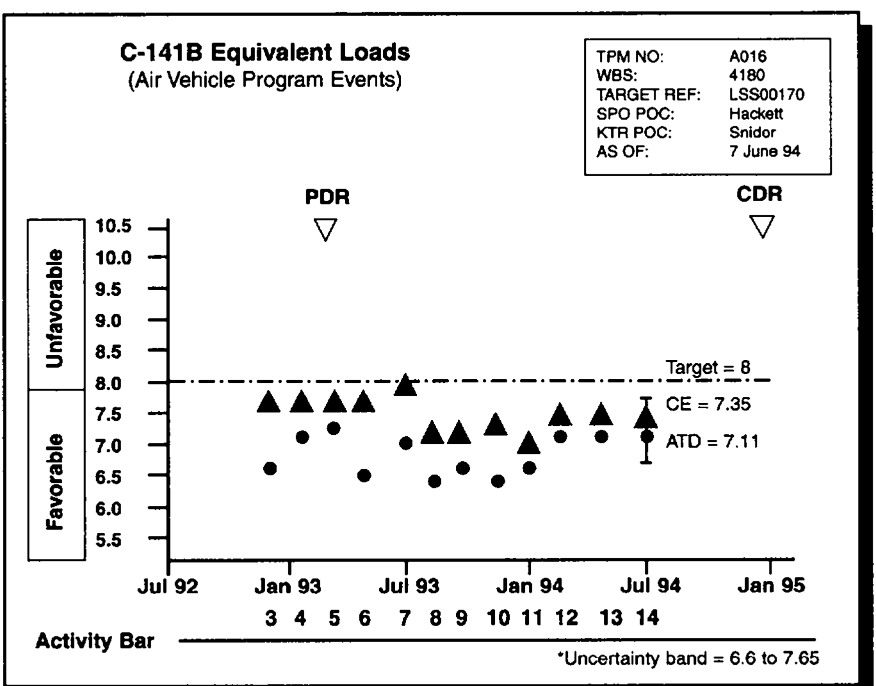
Cost/Schedule Control Systems Criteria

The F-22 program monitors cost performance in three ways: through the cost performance report, the overhead cost report, and the design-to-cost status report.

Cost performance report. The primary method of cost tracking comes from the contractor's internal cost control system as validated by the Government to meet defined cost/schedule control systems criteria. Each month, the contractors generate a cost performance report that shows their expenditures to date compared with their planned expenditures and, thus, their progress in terms of cost and schedule variance. The F-22 program office worked with both Lockheed and Pratt & Whitney to tailor a portion of the report to deliver a Format 2B, which shows the cost status by IPT. This information is extremely valuable to the IPTs in monitoring whether they are performing according to plan.

The Program Director (and the Government/contractor IPTs) receives a preliminary cost performance report, called a flash report,

Figure 8-7. Independent Airlift Technical Performance Measure



no later than 10 days after the contractor accounting month ends. This report is unaudited but serves to give the IPTs and the Government and contractor Program Directors early insight into cost and schedule issues. Both contractors deliver the final cost performance report 30 days after the close of the accounting month. In earlier programs, the cost performance report typically would not arrive until up to 90 days after the close of the accounting month—making the data very old and less useful. The program office insisted that the contractors deliver the cost performance report as soon as possible. It's important for future Program Directors to note that both contractors initially believed that a 10-day delivery of initial cost performance data was impossible.

Overhead cost report. During the source selection for EMD, the Secretary of the Air Force, Donald B. Rice, expressed concern about the potential for increased overhead rates for each of the contractors. With the reduction of defense contracts, the contractors would need to spread their fixed costs over a smaller number of ongoing contracts (such as the ATF weapon system and the ATF engine), directly increasing the costs allocated to the remaining contracts. Secretary Rice feared that the cost of the ATF program would increase greatly as a result of the projected increase in overhead rates. He directed the F-22 program to create a method of tracking overhead costs that would show clearly what he concluded would be the major financial challenge for the program.

Following their selection as F-22 contractors, Lockheed and Pratt & Whitney worked with the program office to establish a method of tracking and reporting overhead costs—called, cleverly enough, the overhead cost report. The contractors initially defined their overhead rates at the start of the EMD contract. Today, they submit the report only when their overhead rates change from this initial baseline to document what changed and why. The Government and contractors then together define actions to control and reduce the growth in overhead costs.

Design-to-cost status report. The founding fathers wanted all IPTs to focus on a life-cycle perspective. To make decisions properly the IPTs need to know the cost of the decisions, not just for the immediate future (the development cost), but also for downstream production. Through the use of design to cost, the IPTs establish production cost as another performance variable. The monthly design-to-cost status report allocates production cost targets and identifies critical areas and problems that may cause the IPTs to exceed their cost goals. The IPTs also prepare a TPM that tracks their product's projected production cost. The regular reporting of this TPM gives the IPTs a clear way to document the actions they've taken to reduce production costs.

Closure Plans

The fourth IPT tool for tracking progress and managing their program is the closure plan. The F-22 program current IMS contains over 30,000 items. As detailed as that may at first appear, sometimes it requires judgment to determine when an IPT can declare an item complete. The closure plan is simply a formal agreement between the contractor and the Government specifying actions that will occur before completion of an item. The Government and contractor team members jointly prepare and sign this plan to define their course of action. Closure plans give the IPTs the flexibility to manage their portions of the program within a formalized agreement.

Award Fee

At the end of the demonstration/validation phase, the program office (and the bidding contractors) wanted to ensure that the development contracts would be fair to both the Government and the contractors. The Government thus decided to use cost-plus-award-fee contracts in the F-22 and F119 development efforts. With this type of contract, the Government agrees to pay the contractors all of their allowable costs and to pay an award relative to how well they meet their cost, schedule, and performance requirements. Both the F-22 and F119 contracts specify a 4 percent fixed fee (to cover the contractor's unallowable but required costs) and a 9 percent award fee (a percentage of the contract value). The award fee establishes a pool of money available for the contractor to earn based on performance. As Raggio describes it, this contract allows an equal sharing of risk. The Government agrees to cover the costs to develop the F-22 (or F119), and the contractor agrees to put its entire award profits (the 9 percent) on the line.

The award fee is the primary (some say only) tool for motivating contractor performance. Meeting contractual requirements (including those for cost, schedule, and technical performance) results in an award of 100 percent of the award fee pool. The Government determines, and pays, the award fee every 6 months. Monthly, the IPTs record contractor performance, citing both strengths and weaknesses, and the IPT leaders pass the assessment directly to their contractor counterparts as feedback. Three months and 6 months into every period, the contractors and the Government award fee board meet to exchange views on contractor performance. In this way, the contractor gets regular information on how it is doing and where the

Government believes the contractor needs to improve. The objective of the Government is very clear: for the contractor to earn 100 percent of its profits, it must fully meet its cost, schedule, and performance requirements. It is important to note that the program office accomplishes award fee tasks on a daily basis using standard information (nothing is tracked just for award fee purposes).

A significant feature of the F-22 award fee process is that the program director determines the fee for the period, in contrast to other programs, in which the fee-determining official typically serves at a level above the program director. The conventional logic argued that the fee official needed to be somewhat removed from the program to ensure an objective decision. During the F-22 EMD Defense Acquisition Board review, the Assistant Secretary of the Air Force for Acquisition, John J. Welch, argued strongly that the program director should be allowed to determine the award fee because it is the primary motivator for the contractor. To take the award fee decision away from the program director leaves the the director with little influence over the contractor, for whoever decided the award fee amount would, in effect, be the real director. The fact that from 1991 to 1995 the contractors never protested the award shows that a program director can fairly determine it.

The program office designed the award fee process to be a win-win relationship, a vital part of the integrated management framework. The integrated tool set helps evaluate contractor performance objectively, and the award fee program promotes frequent communication, early problem identification and resolution, proactive management, and the teamwork needed to develop the weapon system and engine.

The IPT Management Tool Set

Every design engineer, program manager, logistics expert, maintenance expert, manufacturing engineer, and finance or contracting specialist serving on an IPT has a set of IPT management tools. The tool set begins with the identification of a work breakdown structure element (such as 1500 for the VMS), which has its own set of tools (Figure 8-8). The IPT member uses the appropriate statement-of-work tasks and IMP sections to define the work, the appropriate specification paragraph to define the requirements, and the budget, as allocated by the contractor team members, to define the resources available for the job.

The IPT tracks its performance against the IMS for the task, monitors and tracks the technical performance of its product through the correct TPMs, and appraises its cost performance by analyzing the Format 2b in the cost performance report. Finally, the contractor members of the IPT receive feedback through the award fee process.

Figure 8-8. IPT Management Tool Set

The IPT tool set includes:

Planning and Commitment Tools
- Task from the statement of work
- Integrated master plan section
- Specification paragraph
- Budget

Tracking Tools
- Integrated master schedule section
- Technical performance measures
- Cost performance reports

Motivating Tools
- Award fee

Using the IPT Tool Set

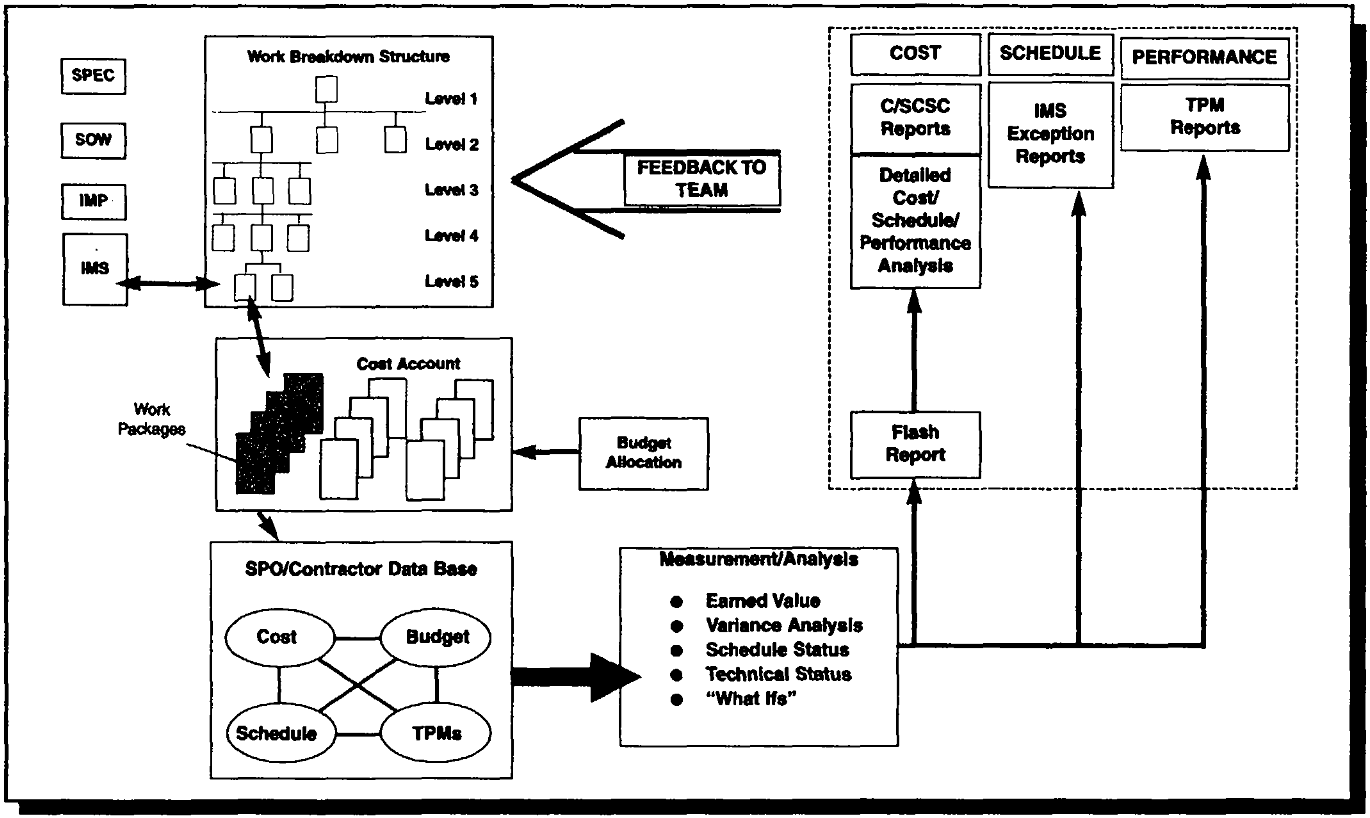
Figure 8-9 gives a graphic representation of how the IPTs use the tool set to track and manage the development of their product.

Using the work breakdown structure and the IMS for their product, the contractor members of the IPTs build the work package and allocate funds to the task. The teams capture their progress through the cost performance report and the TPMs in the contractor's data base (to which the Government program office has full access). The IPTs then record their development status on the flash reports and subsequent cost performance reports, which show the team's cost and schedule variances; document progress against the schedule through regular reporting of IMS activities; and describe technical progress according to the technical performance measures for their product. In addition to day-to-day conversations, the contractor receives feedback through the award fee process.

Summary

The ATF founders designed the integrated tool set to support their objectives of integration, focus on the product, and early up-front planning. The principles of successful program management (shown in chapter 3) indicate that the integrated tool set supports them. IPD is a powerful concept but the team has to have the right tools. The F-22 integrated management framework provides the tools and empowers IPTs to successfully develop the F-22 fighter and F119 engine.

Figure 8-9. Using the Integrated Tool Set to Track a Product



9

The F-22 Program: How's It Working?

- **The Operator's View**
  - Customer satisfaction
  - The F-22 program as a model
- **The View From Air Force Acquisition**
  - Customer satisfaction
  - The F-22 program as a model
- **The Program Director's Perspective**
  - Integrated product teams
  - Integrated management tools
  - Legacy of the F-22 program
- **Visible Advantages of the F-22 Program**
  - Improved design maturity
  - User involvement in design solutions
  - Improved management flexibility
- **Lessons Learned**
  - The program
  - Integrated product development
  - Integrated product teams
- **Summary**

The F-22 program has been deliberately paced. Its foundations, including the competitive prototyping and risk reduction, are admirable. It is reaching the development milestone with a management pedigree for success.

Aviation Week and Space Technology
(April 29, 1991, Page 68)

The F-22 acquisition effort entered the engineering and manufacturing development (EMD) phase in 1992. How well are these tools and methods working today? Is the F-22 program really a model acquisition program, as former Secretary of Defense Richard Cheney, Under Secretary of Defense John M. Deutch, Senator Sam Nunn, and others claim? To answer the question this chapter includes the views of the program customers—Air Combat Command (ACC), the operational user, for whom the program office is designing the weapon system, as well as the leadership of Air Force Acquisition. The chapter also includes the perspective of the program office after 4 years experience with integrated product development (IPD) and the integrated management system. The chapter concludes with a review of the advantages of the F-22 program structure and the lessons learned from the F-22 program as of mid-1996.

THE OPERATOR'S VIEW

The warfighting customer perspective of the F-22 program can be assessed through the views of General John Michael Loh, Commander of Air Combat Command from 1991 until his retirement in 1995. Loh was closely, and continuously, involved with the ATF program since the early 1980s (he wrote the first ATF requirements document). As the ATF program progressed through the demonstration/validation phase and its subsequent requirements refinement, he served as the Air Force Director of Operational Requirements when that responsibility resided with the Deputy Chief of Staff for Research and Development at Headquarters, Department of the Air Force. Loh also served as the commander of the Aeronautical Systems Division, the parent organization of the F-22 program office, as the program completed demonstration/validation. With his extensive experience

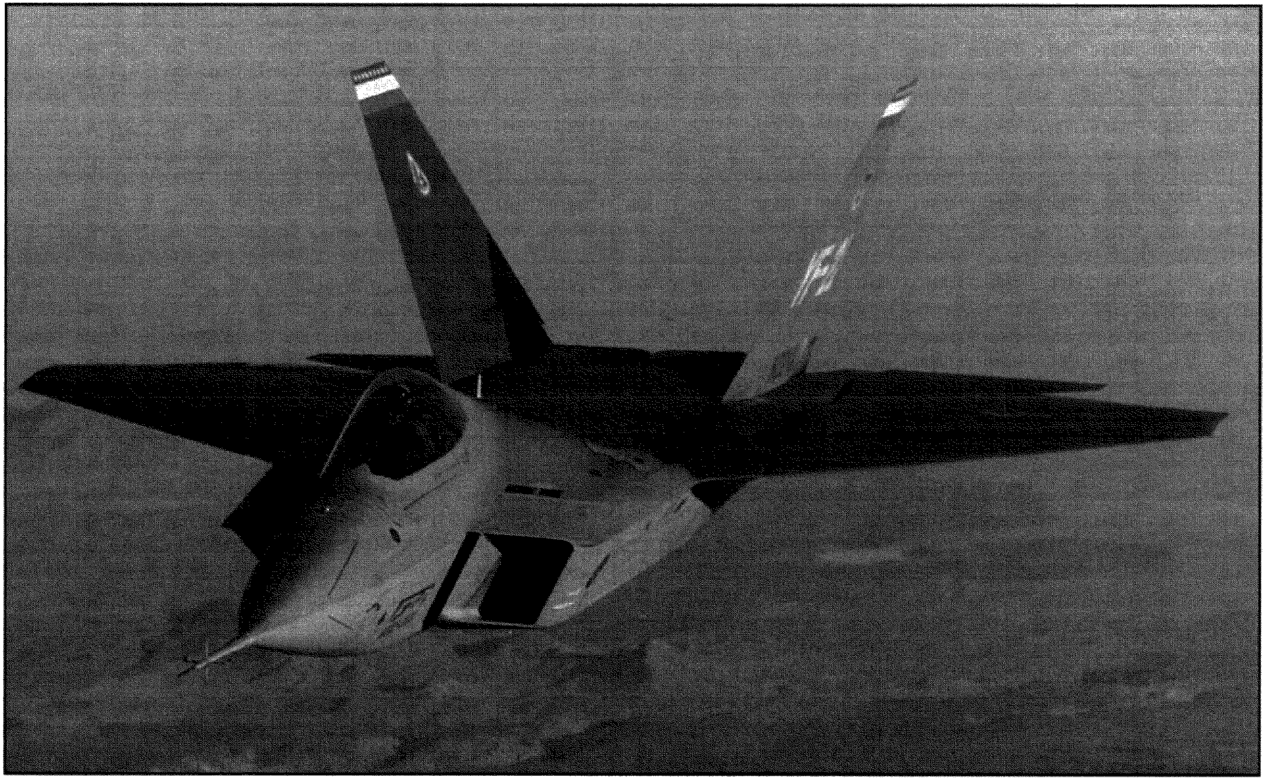


Photo courtesy of Lockheed-Boeing Team.

The YF-22 prototype is 44'-6" wide, 62'-1" long, and 16'-5" in height. Use of the prototype will lead to an advanced tactical fighter with a balanced design of low observability, agility, supercruise, and advanced offensive and defensive avionics.

and multiple points of view, Loh provides an important and valuable perspective on the F-22 development program.

Customer Satisfaction

Query: From Air Combat Command's standpoint, are you, the customer, satisfied with what you are seeing on the F-22 program?

Loh: Oh yes, I'm satisfied that we are going to get the airplane that we signed up to...that the management of the program is excellent...that we, the customer, have a direct input into the program as part of the integrated product teams [IPTs,] and that our voice is heard all of the time. I have no problem whatsoever in the way the interaction between customer and supplier is being handled today, or ever, in the F-22 program. That has been a more open process than any other program I can recall. It continues to be a very open process and I attribute that to the fact that we do have this IPT process. We are members of the IPT. The SPO [System Program Office] is very open and candid about problems....

My only complaint about the program is the length of the development program, which is not the fault of the SPO but...of the manner in which we [the U.S. Government] allocate resources to it year by year. It is extending the development program year by year beyond a most efficient level. And of course we continually have to look to the future and see what is out there for us to face. The flexibility and potential of the F-22 program to spin off other derivative aircraft using the technology we've developed in the F-22 is quite high.

The F-22 Program as a Model

Query: Many people say that the F-22 is a model acquisition program. Would you agree with that?

Loh: It is as model as you can get. I attribute that to the fact that we have had the IPT process from the very beginning and that includes not just ourselves [Air Combat Command] and the SPO but also the contractor team. And I attribute it to the fact that we used lessons learned from the past.... When we put the program together we didn't encourage excessive risk. I attribute where we are today as a manifestation of all that, in that we have a program that is not in trouble technically, it is not in trouble from a schedule standpoint, we understand its costs, and there is no excessive cost growth in the program. It is a well-managed program and [is] well put together. So if that is the measure of a model program; that the F-22 is on cost, on schedule, and meeting our essential performance needs, it is indeed a model program.

The View From Air Force Acquisition

Air Force acquisition views on F-22 development are expressed by the Principal Deputy Assistant Secretary for Acquisition and Management, Darleen A. Druyun, a senior leader in Air Force acquisition who also had firsthand experience with the F-22 program. During the 1980s and early 1990s Druyun became intimately involved in the development of the acquisition strategy for the ATF EMD phase in the Directorate of Contracting at Headquarters Air Force Systems Command. In the first half of 1991, she participated in the ATF source selection for EMD. In her current role as the Principal Deputy to the Air Force Acquisition Executive she observes the progress of the program monthly. Her long history with the program and her senior position within Air Force acquisition, makes Druyun ideally suited to assess the Air Force acquisition view of the F-22 development program.

Customer Satisfaction

Query: From the perspective of Air Force Acquisition, has the F-22 program been successful?

Druyun: The program itself has been successful and continues to be successful in terms of how we are implementing it. However, it has not been as successful as I had hoped with respect to the budget because we just don't have budget stability. Every single year it seems that we trim $100 million here or $200 million there on the F-22 and it becomes a bill-payer for other requirements in the Air Force. We tried to take all of the lessons learned in structuring the EMD contract so that we could have the contractor come up with his IMP [integrated master plan] and IMS [integrated master schedule] and have him stick to that schedule. As we have taken the money out of the program we have caused that program to stretch, stretch, and stretch. It is there where we have not been successful.

The basic structure that was laid in place to manage that program is working exceptionally well. The cost and schedule status reports show we are within about 3.5%

[of] cost and about 2% within schedule. This is with around 33% of the program complete. If we were going to have problems on this program, you would have seen them very early, and they haven't shown up. It is a very successful program and extremely well managed.

The F-22 Program as a Model

Query: Many have called the F-22 acquisition a model acquisition program. Do you agree?

Druyun: I felt back in 1990 and 1991 that the F-22 was a model program because General Fain came up with the idea for an integrated master plan and integrated master schedule. You take all of the documents that the contractor gives you in source selection and use them. You have them numbered the same way. That is now a common way of doing business in the Air Force. You see that in any major weapon system we are procuring. Even the way the F-22 contractor submits their cost and pricing data is in the same manner as how they write their statement of work. It is all linked together.

The F-22 became the pathfinder for how to do acquisition in the future. All of the programs now in the Air Force are using the ideas developed by the F-22. Today, I choose to call the F-22 program a pathfinder, as opposed to a model, because it really sets the key principles firmly in place.

The Program Director's Perspective

Major General Robert F. Raggio succeeded General Fain as F-22 Program Director on July 1, 1992. At that point, the EMD phase was not yet a year old. The implementation of the integrated management framework had clearly started but had not yet matured. Raggio explains how the IPTs and integrated tool set evolved and how well they worked.

Integrated Product Teams

Query: How have IPTs worked out? What changes have you made to the original IPT concept?

Raggio: First get it straight—IPTs are nothing more than a tool for integrated product development. IPTs gave us a straightforward way to successfully implement integrated product development.

IPTs have been incredibly successful. Each team has taken a balanced approach to their product design considering all of the elements, such as: design, manufacturing, near-term cost as well as ownership costs, ease of repair, etc.

IPT leads, both on the contractor side and the Government side, have typically come from an engineering specialty. As a result, they have easily focused on the technical issues. We [both Raggio and Gary Riley, the current Lockheed Program Manager] initially had to force them to focus on the cost and schedule part of their programs. We have worked hard to make the IPT leads into mini–program directors.

For IPTs to work, they need buy-in from the very highest levels on both the Government and the contractor sides. The F-22 program could not have implemented IPTs unless Mr. [Daniel] Telep, Mr. [Frank] Shrontz [Lockheed and Boeing chief executive officers], General [Ronald] Yates [Commander of Air Force Materiel Command], and General Loh were sold on IPTs. A functional [specialty] could have slow-rolled it—but that never happened since the corporate leadership agreed with the concept.

We found that we had to work carefully with the functionals. Some felt that IPTs would reduce their power base and importance to the organization. In fact, we have found that the role of the functionals in a program using IPTs gets greater, not less.

A problem that we identified early on was that some IPTs became independent rather than integrated. We found that once they were empowered to design their product, they did a great job, except they designed it at the expense of other products. In the old system, before IPTs, you had to integrate functional specialties efforts in designing a product. Under IPTs, we have to integrate the product team efforts with other parts of the weapon system.

We originally established analysis and integration [A&I] teams to...make sure that each product design meshed with the rest of the weapon system. We initially set them in the organization at the same level as the IPTs. This was not sufficiently effective. We adjusted the integration level; now our A&I teams are a half-notch higher than the IPTs, so that they can direct their activities and balance the teams.

I had a similar problem with my functionals [e.g., Engineering, Contracting, Finance] and my product teams [e.g., Air Vehicle, Support System]. I set up a weapons system A&I team made up of my four lead IPTs and all of my functional chiefs. I now get a balanced perspective on all issues.

The key is that integration must be balanced. If you force integration into the product teams, the decisions at the lowest levels get better, and developing the product becomes much easier.

Integrated Management Tools

Query: How has the integrated tool set worked out? What changes have you made to the original concepts?

Raggio: The tool set has been a high payoff. The program captures and tracks the information the IPTs need. Generally, management above the individual IPT reviews just summary data from the IPTs. Again, the key is that these tools are integrated. All data mutually support other data.

Work breakdown structure. Establishing the work breakdown structure to accurately reflect how Lockheed and Pratt & Whitney are designing the weapon system, and then matching the organization to align with the work breakdown structure along IPT lines, has allowed full integration across the program.

Having this type of work breakdown structure allows cost performance reports to flow through IPTs. In fact, cost performance reports *must* flow through the IPTs. The adaptation of the standard cost performance report to include a report based on IPTs [the Format 2B] was a great idea. This report shows the funding by product and not by the standard functional shred.

Early on we thought the hardest thing to do was get the engineers melded with the program managers. That happened pretty quickly. It has been a bigger leap to get the engineers and program managers to meld with the financial experts. The two major rephases on the F-22 (driven by Office of the Secretary of Defense or congressionally reduced budgets) have better forced this meld.

Integrated master plan/integrated master schedule. If the cost performance report were perfect, there would not be a need for an IMP or an IMS. Since the cost/schedule control system has, unfortunately, evolved over the years into a tool typically used by the financial community, and not so much by program managers, nonfinance personnel don't use it and don't put the effort into the plan that's required. We used IMP/IMS to force the planning and networking of relationships. It was critical to have this when we set up our critical paths.

Technical performance measures. We have rediscovered that metrics motivate behavior. The careful selection of metrics has allowed each level of IPT to focus on the things that really matter. Many TPMs [technical performance measures], such as product weight or design-to-cost, roll up to higher levels of indentures, like an antenna is a part of the higher level avionics system. In this way, we have solid visibility into overall aircraft parameters, like weight. These types of metrics give us an excellent bottoms-up prediction of performance.

An obvious but critical lesson we learned is that you need to ensure that you are gathering quality data for the technical performance measure and that one understands what the data really mean. I also want to make sure that, if at all possible, every metric fits the standard metric format [shown in Figure 8-5]. If it does, one can quickly determine if performance is good or bad.

Legacy of the F-22 Program

Query: What do you feel will be the legacy of the F-22 development program?

Raggio: The F-22 program has proven beyond a shadow of a doubt that given three things: (a) requirements stability, (b) careful up-front planning of the structure of the program, and (c) funding stability, then, you can deliver on your promises. The problem is that we have enjoyed the first two, but not funding stability.

We've enjoyed requirements stability because General Loh has personally worked to make sure that the requirements did not vary significantly. We have had a well-developed plan due to the work carried out in demonstration/validation. Funding stability is our Achilles' heel.

The main problem in Government acquisition is systemic of our type of government. A contractor writes a contract with the executive branch, not the legislative branch. The legislative branch must approve funds for that contract on a year-to-year basis. If we were serious about acquisition reform, we would figure out a way to get the legislative branch to buy into the same plan as the

> executive branch over 20 years, or at least 5 to 6 years.
>
> The technical problems that have occurred on F-22 are well in control. They have been handled well by our system, the IPTs with the integrated tools, and our people.
>
> You can see the payoff of a well-structured, carefully planned, carefully executed program in how we are doing in our cost and schedule performance as tracked by the C/SCS [cost/schedule control system]. Mr. Gary Christle [the Office of the Secretary of Defense official responsible for tracking the cost and schedule performance of all Department of Defense contracts] told me that the F-22 program is doing exactly what he has always wanted—lay in cost performance report data in detail down to the lowest level of the program. Gary says he's not seen another program like this. We are an $11.2 billion cost contract that is around 33% complete, and we are under 2% schedule variance and under 3.5% cost variance. And what is amazing, if we had had stable funding, we could have done even better! [See Figure 9-1 for a history of Lockheed's cost and schedule variance on the weapon system contract and for Christle's views on the F-22 program.]

A drawback of a very tightly planned program, as tightly planned as the F-22 program is, is that the program cannot adjust very easily to changes in funding levels. A conclusion on the F-22 program may be that if the system wants a well-structured program, it may not be able to take the current sloppy funding process.

Visible Advantages of the F-22 Program

Raggio believes that IPD, IPTs, and the tools and procedures of the integrated management framework are powerful components of a well-run program. He cited three tangible results of the F-22 program method of operation: improved design maturity, increased user involvement in design solutions, and improved management flexibility.

Improved Design Maturity

The F-22 program framework of IPTs using integrated tools results in a more balanced design because the perspectives of not only design engineers, but also systems engineers (who look at the entire weapon system), manufacturing engineers, and maintenance and logistics personnel (who assess the ease of repairing and supporting the weapon system) influence the initial design. For example, in December 1993, Lockheed developed and introduced a new tool and method for computing the aircraft radar signature. The initial results showed that minor changes in the aircraft design from the full-scale signature pole model used in demonstration/validation resulted in greater increases in signature than previously assessed. If this problem was not addressed, the aircraft would not fulfill some signature requirements. The F-22 development team responded by asking all sub-IPTs whose products contributed to the aircraft overall radar signature to revisit their product design to see if they could lower their contribution to the aircraft radar signature. In trying to solve the problem, each team assessed the effect of their solution not just on signature reduction but also on the ability to manufacture the product, the ease of maintaining the product or overall aircraft, and the overall life-cycle cost of the product. Because of the IPT process, a potentially major problem was solved by means of a balanced design that met the challenges of radar signature reduction while maintaining the other weapon system requirements (for example, ease of maintenance, producibility). Creating a balanced design early reduces the need to change the design later in the program. In earlier programs, manufacturing engineers typically had to adjust the design to build the product; they don't need to in the F-22 program because they helped in the initial design. As a result, the balanced design of the F-22 is also a mature design that will require fewer changes at production.

User Involvement in Design Solutions

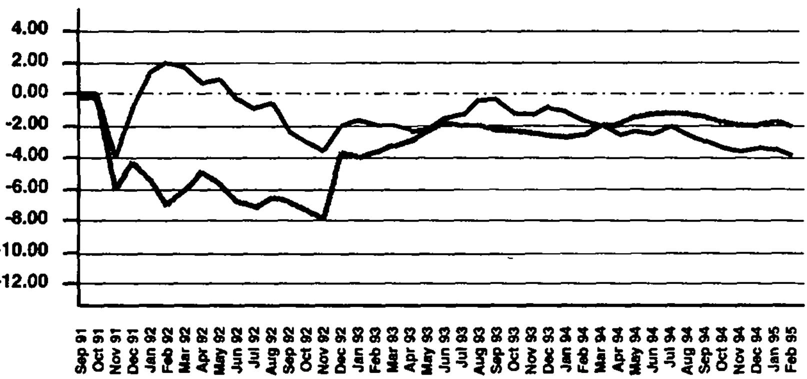
The power of teaming is that all the participants understand each other's constraints. The F-22 EMD phase (like the demonstration/validation phase) has exposed the operational user to the real-world limitations of design and production. Every major design trade-off and refinement (and most minor ones) have involved the members of Air Combat Command. As a result, the participants understand the issues and thus understand why the team had to change some aspect of the design. As Loh commented, user involvement results in very high user satisfaction. Air Combat Command is pleased with the product now under development.

Improved Management Flexibility

A major reason for establishing IPTs was to identify problems earlier than in previous programs. Three of the benefits Raggio has identified are

- Earlier identification of problems
- Faster agreement on solutions
- Better response time in contingencies.

Figure 9-1. Cost and Schedule Variance for the Lockheed F-22 Weapon System Contract



Source: F-22 Program Office

Mr. Gary Christie on Cost/Schedule Control System

We have an acquisition initiative to reform the way the Department of Defense's programs implement the earned value portion of the cost/schedule control system. We stress three things:

1. Earned value is a program management tool, not just a financial tool,
2. The program must be planned out in thorough detail down to the cost account level, and
3. The program must have integrated schedules, and other management tools, which are integrated vertically (up and down the organization) and horizontally (with other product teams or other specialties....)

...**I think with their IMP/IMS and other integrated tools, the F-22 is doing what we think they ought to be doing to run a successful program.** I am not ready to say you should 'cookie cutter' the F 22 approach for every program, but the two keys are there: It's got a detailed plan and it's integrated.

The F-22 is executing unusually well.... We generally consider the two best executing development programs in the Department today are the F-22 and the F/A-18E/F. If you look at the F/A-18E/F program, you will see they have implemented many concepts from the F-22, such as integrated product teams, integrated schedules, and a tight tracing system for earned value."

Gary Christie, Office of the Secretary of Defense, interview by author, tape recording, Washington, DC, May 16, 1995

Collocating multifunctional experts in product-focused teams and empowering them to manage all aspects of their product results in strong product ownership. The teams are motivated to find problems that are hindering the successful design and production of their product and work hard to find the best solution that falls within everyone's constraints. Higher level IPTs and, ultimately, the Program Director must ensure the IPTs understand all of the higher level constraints they must consider (the purpose of the analysis and integration teams).

By identifying problems earlier, getting rapid agreement for the right course of action, and responding rapidly to changing conditions, IPTs have given the F-22 program management much greater flexibility to respond to problems and other unforeseen challenges.

Lessons Learned

The history of acquisition is characterized by dedicated individuals who learn from earlier programs. After 4 years of experience with the new tools and methods, what can be learned from the F-22 program? The following observations come from the program office, various studies, and my own work in the program office and research. Figure 9-2 summarizes the lessons learned.

The Program

1. Full teamwork, among the operator, the program office, and the contractor, improves overall program performance. In the demonstration/validation phase the requirements refinement process provided the best example of teamwork. Today, as demonstrated by Captain Tinsler's memo reproduced in Figure 7-7, the day-to-day actions of the IPTs epitomize teamwork.

2. Integrated, detailed planning before the start of the program helps reduce start-up time and supports a well-managed program. For example, the program office required the competing contractors to submit their proposed IMP and IMS as part of their proposals for EMD (see appendix D), and the contractors invested great amounts of time and thought into developing the IMP and IMS because they were part of the evaluation process. Unlike typical programs, which take the first 6 to 12 months to plan and get organized, the F-22 and F119 teams went immediately to work.

3. Integrated management tools support a disciplined management process. The integrated management framework provides coherent information for all team members, including the program leadership. The IMP and IMS provide a detailed yet flexible map for the program to follow. These tools, coupled with strong leadership, result in a disciplined development program.

4. Tightly managed programs can deliver on their promises but suffer greatly from unstable funding. As Raggio pointed out, funding instability has been the F-22 Achilles' heel. Reductions in such a well-scheduled, well-structured program leave the program director two options: reduce performance or delay the delivery of the weapon system. The Air Force has chosen the second option. However, slipping the program creates a great deal of turbulence. In 1994 and 1995, as a result of budget reductions, many of the program office personnel and senior contractors spent over half of their time rescheduling program work to match the budget—time that the team could not spend improving the quality of the product.

Integrated Product Development

5. Successful implementation of IPD requires complete senior-level support and encouragement from all key players. IPD is sufficiently different from the classical, functional way of oper-

Figure 9-2. Lessons Learned From the F-22 Program

Program

1. Full teamwork improves program performance.
2. Integrated planning reduces start-up and supports a well-managed program.
3. Integrated management tools support a disciplined process.
4. Tightly managed programs suffer greatly from unstable funding.

Integrated Product Development

5. IPD requires complete senior-level support.
6. IPD requires a cultural change.
7. Classic functional organizations may initially resist IPD.

Integrated Product Teams

8. IPTs naturally accomplish IPD.
9. IPT members are motivated, are involved, and have ownership.
10. Every IPT requires training.
11. IPTs take leadership commitment from all groups.
12. IPTs should have experienced and empowered members
13. The I in IPT can easily become independent instead of integrated.
14. IPTs need to know their fenceposts.
15. Program leadership must ensure integration across the IPTs at every level.
16. Communication and software tools help integration.
17. IPT managers should be in charge of personnel and budget resources.
18. Both leadership and teams must set and track IPT objectives.
19. The right people must be in the right jobs at the right time.

ating that senior management must commit to and direct the change. Moving individuals from their traditional functional organizations toward integrated teams requires the sanction of top management.

6. Successful implementation of IPD requires a cultural change, which does not occur overnight. To make the transition from thinking about an item from a functional perspective to thinking about it from an integrated product perspective requires that individual workers look at the development process in a new way. Part of this change comes with focusing on the product and part from focusing on life-cycle requirements. To fully implement IPD requires a fundamental change in individual and organizational perspectives.

Such a cultural change is not without its costs, as not all individuals are comfortable with the IPD philosophy. The F-22 program leadership needed to move several mid-level managers, both Government and contractor employees, to other programs because they did not adapt to IPD.

7. Classic functional organizations may initially resist IPD. This problem requires top-level attention. In some locations, functional leaders tended to resist the implementation of IPD. Firm backing and guidance from the highest Government and corporate leadership eliminated this issue.

Integrated Product Teams

8. IPTs, when given the focus of working life-cycle issues, naturally accomplish IPD. IPTs exist solely to support IPD. Collocating the necessary individuals with the required skills and perspectives and giving them the task of developing a long-term solution leads to IPD.

9. When the program leadership assigns individuals to teams and holds them responsible for the successful development of the product, the result is strong worker motivation, involvement, and ownership. A survey conducted in 1993 of more than 70 percent of Government F-22 program office personnel found that the great majority of the members of IPTs believed that they personally made a difference in the development of their product. Over 80 percent believed that the quality of the F-22 weapon system would be improved through the use of the product team approach. One respondent concluded, "There is inherently more buy-in by those responsible for the product due, in part, to the higher degree of accountability."

10. Every level of IPT requires training. Initially the F-22 program indoctrinated each team member, Government and contractor, with the concepts of concurrent leadership and IPD to help guarantee that they all knew what was expected of them. In addition, the program senior leadership from the primary contractors and the Government initially met for 4 days to discuss communications, expectations, and methods of operation, which helped the different segments of the team understand the concerns of the other team members and work together. Individual IPTs met as well to discuss a multitude of issues including the teaming environment, intragroup dynamics, and the way the contractor/Government teams could best use the integrated tools. This training, which the program regularly repeats for new members, has helped greatly to establish the needed cultural change to support IPD and high-performance integrated teams.

11. Establishing IPTs takes commitment from the top on the part of the Government and contractor. As mentioned above, management must support IPD. To organize IPTs requires management to support taking experts out of their traditional functional offices. One can find literally hundreds of barriers to stop IPTs. Senior management commitment is the fastest, most effective way to eliminate these barriers.

12. IPTs should have experienced and empowered members. This is the potential shortcoming of IPTs. In traditional organizations, experts sit with other experts in the same function. New members learn from these experts and, when confronted with something new, can easily ask someone from the office. In IPTs, because the functional member of the team will frequently be the only person from that specialty, that person needs the experience and knowledge to resolve the problem without calling back to the functional office. For specialists to be truly effective, the team, as well as the functional office, must empower the IPT members to use their judgment on their product.

13. The *I* in IPT can easily become *independent* instead of *integrated*. The first lesson of the F-22 EMD phase was that empowered teams with allocated requirements, budget, and schedule tended to create their own optimized product—at the expense of the rest of the weapon system. The program leadership responded to this problem by strengthening the role of the analysis and integration team, whose missions changed seemingly overnight from primarily one of analysis to product integration. As Raggio mentioned, he further strengthened these analysis and integration teams by raising their stature to be a half-notch higher than the product teams they integrate.

14. IPTs need to know their fenceposts. IPTs need to understand what decisions they can make and what decisions they must pass to a higher level IPT or even the program director. If the IPT higher level management properly sets the team decision space, the chance of "independent" IPTs is reduced.

15. The program leadership must ensure integration across the IPTs at every level. Integration across IPTs prevents "independent" product development and helps ensure efficient, system-level weapon development.

16. A network of communication and software tools that ties together all team members improves integration. The F-22 program implemented a teamwide management/technical information system that allows both Government and contractor team members to access the same data bases (to look at, for example, TPMs, cost status, and document revisions) and to communicate through electronic mail. Standardized software products allow team members to transfer files between locations, and an encrypted video teleconference facility allows teams at the various contractor and Government sites to conduct a meeting from up to four different locations.

17. IPT managers should have authority over personnel and budget resources. As in any organization, a leader needs to have control over the people and resources that make up the team.

18. The program leadership and the teams themselves must jointly establish and track IPT goals and objectives. Typically the teams set goals and objectives based on the allocated requirements, budget, and program schedule. The IPT, and higher level management, tracks its performance through the use of TPMs. To ease this process, the leadership must

- Ensure that the appropriate team members participate in the appropriate decisions so that their expertise flows into the decision and the team member comes away from the decision with a stronger feeling of ownership of the outcome.
- Develop meaningful metrics. A famous program office saying goes: "What gets tracked, gets done." TPMs are a powerful tool, and the IPT leadership must make sure the metrics support their key activities and key requirements.

19. The program leadership should put the right people in the right jobs at the right time. Everyone has strengths and weaknesses. The challenge of the leader is to place individuals in positions that make full use of their strengths and minimize exposure of their weaknesses. To do so, leaders must:

- Appoint and train leaders. As is true of any organization, training for IPT leaders must stress the skills needed for teamwork and problem solving.
- Replace leaders who don't or can't lead. Not all individuals are comfortable with IPTs. The best technical product expert may not

be the best leader. The interesting twist to IPTs is that the best IPT leader may be a contracting expert, a finance specialist, or a logistics expert. Traditionally, individuals from these and other fields would never get a chance to lead a product development. Under IPTs, they can.

Summary

Has the F-22 program been successful? According to major customers of the program, it certainly has been successful. Has the use of the F-22 integrated management framework and IPTs been a panacea? Certainly not. However, these tools and the integrated development approach support a disciplined, well-managed program.

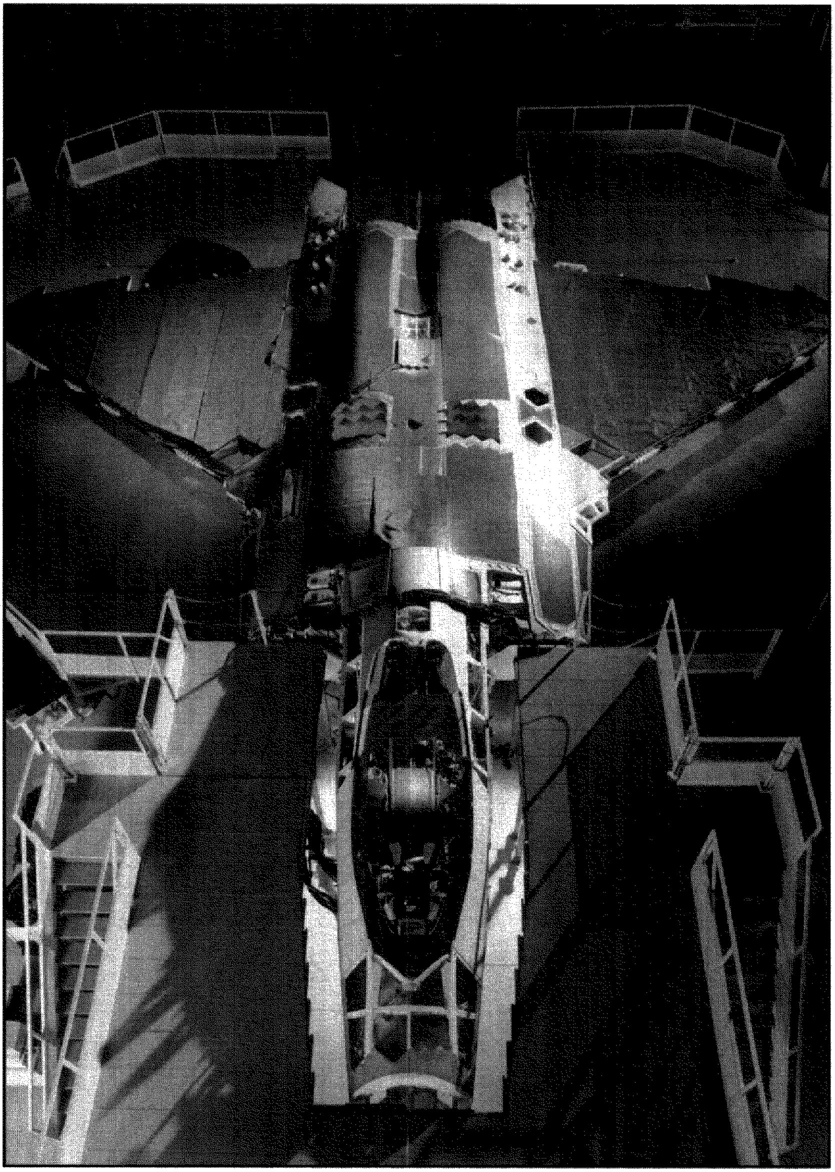


Photo courtesy of Lockheed-Martin.

The forward, mid, and aft fuselages, with wings, have been joined in the mate tool in construction of the first F-22.

PART III

Beyond the F-22

One of the ongoing challenges for the F-22 program managers (both at the program office and at contractor sites) is to explain the process they use to run the program. The F-22 Program Director and his industry counterpart speak on this issue annually to the Program Management class at the Defense Systems Management College. The F-22 program also supports Pentagon conferences on how to improve the process of acquiring military hardware. Since 1991, the F-22 program leadership has presented explanations of integrated product development through the use of integrated product teams, user/acquirer-refined requirements, event-based schedules, measurement of technical progress through metrics, and the other topics discussed in these pages. Thus, these concepts have spread and been refined and adapted to other programs and purposes. Chapter 10 shows how the concepts have been applied outside the F-22 program. Chapter 11 reviews the major points of the previous chapters.

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The Impact of the F-22 Initiatives

- THE JOINT ADVANCED STRIKE TECHNOLOGY PROGRAM
- THE C-17 PROGRAM RECOVERY
- NAVY INTEREST
- THE AIR FORCE REQUIREMENTS OVERSIGHT COUNCIL
- A NEW PROCESS FOR DOD ACQUISITION
  - Reengineering acquisition oversight
  - Can overarching IPTs really work?
- SUMMARY

I am directing a fundamental change in the way the Department acquires goods and services. The concepts of IPPD [integrated process and product development] and IPTs [integrated product teams] shall be applied throughout the acquisition process to the maximum extent practicable.

William J. Perry,
Secretary of Defense

The F-22 principles and concepts (the basic acquisition truths) apply to other acquisition efforts. Darleen A. Druyun of the Office of the Assistant Secretary of the Air Force for Acquisition has commented that Air Force weapons development programs are using the ideas developed by the F-22. Integrated product development (IPD) (including the use of integrated product teams, IPTs), product performance metrics (such as technical performance measures, TPMs), and the use of an event-based schedule with success criteria are common on new Air Force programs such as the Air Force Joint Direct Attack Munition, the Spaced-Based Infrared System, and the Enhanced Expendable Launch Vehicle. But do the F-22 basic acquisition truths apply elsewhere? Where have the F-22 program principles and concepts migrated? The F-22 program ideas have spread to more than just new acquisition programs: they are in use in a technology program (JAST), an existing program (C-17), all Navy programs, and the Air Force Requirements Oversight Council. The Department of Defense (DOD) plans to use several of these ideas to help improve its acquisition process.

The Joint Advanced Strike Technology Program

The Joint Advanced Strike Technology (JAST) program, now the Joint Strike Fighter Program, is a joint Air Force/Navy/Marine Corps research and development effort that is exploring affordable technology and approaches for next-generation tactical attack aircraft. Lieutenant General George K. Muellner, the Director of JAST, worked closely with the F-22 program when he served as the Deputy Director of Requirements at Tactical Air Command. As he established the JAST program, Muellner looked at the F-22 program for lessons learned. In his view, the key points of the F-22 program included its disciplined process, its focus on the effectiveness of the weapon system (as opposed to a focus on meeting a certain parameter, like speed), and its use of IPTs to implement IPD. He noted that all JAST contractors use integrated teams. According to Muellner, the use of IPTs is now the common way of doing business throughout the aerospace industry. In addition, two specific elements of the F-22 program that Muellner brought to the JAST effort were modeling and performance tracking.

Muellner saw firsthand that the ATF program modeling approach allowed a fair comparison between competing solutions (i.e., the Lockheed F-22 and the Northrop F-23) that could successfully stay focused on top-level performance. As in the ATF program, he structured the JAST program to require all competing teams to use a standard version of the tactical performance model, TAC BRAWLER (described in chapter 6). In fact, the JAST program has expanded on the concept of benchmarked, standardized modeling and simulation to forecast and compare values other than tactical performance.

The JAST program has also used the F-22 concept of performance monitoring. It has tracked progress on established key variables of performance using metrics similar to TPMs. These metrics allow the JAST program office to monitor the technical performance of the various competing portions of the program and assess technical progress.

The JAST program studied the F-22 program (as well as less successful programs like the Navy A-12) and tailored many of its concepts and their use to the specific JAST application. The JAST example shows that, as well as working with new programs, the F-22 program ideas also work for technology development efforts.

The C-17 Program Recovery

Could an established program, already well into development, put the F-22 program ideas into practice? In February 1993, the Assistant Secretary of Defense for Acquisition and Technology, John M. Deutch, wanted to assess whether the troubled C-17 airlifter program could be saved. The C-17 was to improve the Air Force ability to move cargo, especially outsized cargo that can usually only fit in the belly of a C-5, and help reduce a serious shortfall in U.S. airlift. One of the many improvements the C-17 was to bring to the Air Force airlifters was its ability to land on small, remote airfields. The program, started in the early 1980s, had run into many problems. In fact, the situation became so tense that the contractor, McDonnell-Douglas Aircraft, and the Government were preparing a number of major claims to file against one another. Faced with a critical military requirement for airlift, Deutch wanted to see if, and how, DOD could recover the C-17 program.

Deutch established a Defense Science Board Task Force to see what the problems in the C-17 program were and whether they could be solved. On the Task Force he wanted to have a mix of experts in the world of acquisition from industry, civilian government, and the military. Appointed as co-chairs for this study were Robert A. Fuhrman, previously president of Lockheed Aerospace and program manager for the original C-5 program, and Lieutenant General Fain, Commander of the Aeronautical Systems Center, and a former F-22 program director. Also serving were Edward C. "Pete" Aldridge, chairman of the Aerospace Corporation and former Secretary of the Air Force; Oliver C. Boileau of the Northrop Corporation; and Malcolm R. Currie, previously of Hughes Aircraft Company. Nora Slatkin, who was then serving as Deutch's special assistant, was to work with this group and follow its progress.

Looking back to his experience on the F-22 program, Fain suggested to Fuhrman that they establish multifunctional teams to study seven critical aspects of the C-17 program:

1. Systems engineering and operational requirements
2. Supportability
3. Production transition and manufacturing processes
4. Ground and flight testing
5. Financial management
6. Contracting
7. Program management.

Each team included members from the Air Force, the appropriate Office of the Secretary of Defense (OSD) functional area, the DOD Inspector General staff, and the Defense Contract Management Command. These teams were, in fact, IPTs.

After a detailed 2-month review, the Task Force found that the C-17 program was critical for the Nation and that the program could and should be saved. Among many recommendations, the Program Management team recommended several features that resembled the F-22 program. These recommendations included:

- Introduce IPD with a new organization based on multidisciplinary teams focused on products
- Create an integrated tool set that included an event-driven master program plan, a tiered, integrated master schedule, and standardized metrics with TPMs.

These and other measures became part of the agreement between McDonnell Douglas Aircraft and DOD to save the C-17 program.

In 1996 the C-17 reached initial operational capability, and Air

Mobility Command uses the new aircraft regularly to fly airlift missions. McDonnell Douglas has increased the delivery rate of C-17s and is actually delivering them early. At a follow-up meeting of the Task Force to assess the progress of the C-17 recovery, the Commander of the Defense Plant Representative Office at Douglas Aircraft, Colonel James Klutter, expressed his amazement that the C-17 Government/ Industry team had turned into a high-performance team. There are many reasons for this great success, but clearly the use of empowered, multifunctional IPTs using integrated tools, like an event-driven master plan with a tiered, integrated master schedule, has been a great help. Note that the basic acquisition truths applied to the C-17 program, even though the program had been underway for over 10 years, and that the principles of IPTs, also applied to the Defense Science Board review process itself.

NAVY INTEREST

In February 1994, a year following the start of the C-17 Defense Science Board review, the Assistant Secretary of the Navy for Research, Development, and Acquisition, Nora Slatkin, formerly Deutch's special assistant, arranged for Fain to explain his view of the acquisition process, primarily the concepts and ideas developed when he led the ATF/F-22 program, to all of the Navy program executive officers and program managers. On February 15, 1994, Fain explained the concepts he had seen work so well: a requirements evolution, as led by the operational user; the importance of maturing technology to match the requirements; the value of IPD using IPTs; and the use of an integrated tool set, including metrics.

In Navy programs such as the New Attack Submarine and the new amphibious assault ship, the Landing Platform Dock 17, the use of IPTs is standard. Many of the other concepts Fain presented are also being institutionalized throughout Navy acquisition, showing that the basic acquisition truths of the F-22 program apply to other services as well.

THE AIR FORCE REQUIREMENTS OVERSIGHT COUNCIL

The Air Force has used the IPT concept to improve its requirements process. In mid-1996, Major General David McCloud, the Director of Operational Requirements for the Air Force, was responsible for coordinating and reviewing all requirements for Air Force weapon systems. A recent major change in the Air Force requirements process came directly from his experience on the ATF program.

Late in the demonstration/validation phase, then Colonel McCloud led the Tactical Air Command division responsible for establishing ATF requirements. The essential task was to successfully challenge operational requirements and understand their cost. Individuals from the program office and from McCloud's office would cloister themselves in a conference room, debate the merits of the requirements, and discuss the various designs necessary to reach those requirements. As a result of this healthy challenge-and-debate cycle, the Air Force developed very solid requirements for the ATF that balanced operational need against platform complexity and cost. McCloud, who recognized the merits of this process, has now formalized this method for Air Force requirements.

He established the Air Force Requirements Oversight Council (AFROC), chaired by the Director of Operational Requirements, to look at every Operational Requirements Document sent to the Air Staff for review. The AFROC includes representatives from the various Headquarters, Air Force offices, including Logistics; Acquisition; Command, Control, and Communications; and Test and Evaluation, as well as from organizations outside of the Pentagon, such as the Air Force Operational Test and Evaluation Center, Air Force Materiel Command, and the major command sponsoring the requirements. The stakeholders of the requirements process serve as members of the AFROC. In effect, the new AFROC is an IPT for Air Force requirements.

One of the side benefits of the new review process is that more of the Air Force leadership learns about the various needs of the service. For example, in the past, some officers never learned of the need for space-based sensors or improved communication satellites. Now they understand the requirements and can better weigh the merits of future investment decisions. Not only does the new AFROC process result in a better requirements document, one that identifies true operational needs, but it also results in the "corporate Air Force" buying into what the Air Force needs to invest funding in.

The new AFROC process captures an important feature of the F-22 program—refining requirements to address the basic operational needs in a way that gives the contractor and program office the flexibility to explore, and propose, cost-effective solutions. Due to the AFROC, this requirements concept is being disseminated throughout the Air Force and will have a major positive impact on future Air Force programs.

A New Process for DOD Acquisition

Recent actions by DOD will ensure that many of these concepts receive a wider audience. On May 10, 1995, Secretary of Defense William J. Perry announced a fundamental change in the way the Department will acquire weapon systems. In a memorandum, he described the use of integrated product and process development (IPPD) and the implementation of IPTs:

> The IPPD concept has been successfully used by the private sector and by the Services on selected programs to reduce product cost and to field products sooner.
>
> IPPD is a management technique that simultaneously integrates all essential acquisition activities through the use of multidisciplinary teams to optimize the design, manufacturing, and supportability processes. . . .
>
> IPTs are the key to making IPPD work.
>
> IPTs include representatives from all appropriate functional disciplines working together to build successful programs and enabling decision makers to make the right decisions at the right time. IPTs are currently being used by many industry and government program managers. . . .
>
> *I am directing a fundamental change in the way the Department acquires goods and services. The concepts of IPPD and IPTs shall be applied throughout the acquisition process to the maximum extent practicable. . . .*
>
> Effective immediately, the Department shall: *Perform as many acquisitions functions as possible, including oversight and review, using IPTs, in a spirit of teamwork,* with participants empowered and authorized to the maximum extent possible to make commitments for the organization or functional area they represent. (italics added)

Perry's memo included a list of 10 IPPD tenets (see Figure 10-1). Each of Perry's tenets is captured in some aspect of the F-22 principles (see Figure 2-1), and several—early and continuous life-cycle planning, event-driven scheduling, multidisciplinary teamwork, and seamless management tools—are exactly the same. The memorandum and the accompanying IPPD tenets institutionalize the concepts proven in the F-22 program.

Reengineering Acquisition Oversight

As the memorandum states, Secretary Perry's goal was to use these concepts at all levels of acquisition in as many areas as possible. An innovative application of IPTs is in the realm of oversight and review.

A chief complaint of program managers had been that the Pentagon headquarters staff is a bureaucratic roadblock to successful development of a weapon system. In moving forward to secure a milestone decision, which allows a program to move from one development phase to another (such as from demonstration/validation to engineering and manufacturing development), program directors had to get the approval not only of their own service and the various offices in their service headquarters (such as logistics, test and evaluation, personnel, and operational requirements), but also of the OSD and its various offices. This process, known as Defense Acquisition Board review and approval, could be time consuming and painful. Program directors would take 6 months to get approval and might have to brief more than 50 individuals or groups. The directors found that the headquarter staff, especially the OSD, found it easy to veto program approval until certain conditions were met (such as rewriting test and evaluation master plans or expanding cost and operational effectiveness analyses). The headquarters staff seemed to be the real enemy.

The Under Secretary of Defense for Acquisition and Technology, Dr. Paul G. Kaminski, has a plan to improve the DAB process: "Overarching IPTs" will "structure and tailor functionally oriented IPTs to support the program manager, as needed, and [aid] in the development of strategies for acquisition/contracts, cost estimates, evaluation of alternatives, logistics management, etc." Each major program will have an overarching IPT that will include the program manager, the program executive officer, and staff principals from the OSD and the appropriate services. The appropriate former DAB Committee Chair (e.g., the former Strategic Systems Committee, Conventional Systems Committee) will lead the IPT. Under Secretary Kaminski described the overarching IPT process.

Figure 10-1. The Defense Department's 10 Tenets of Integrated Process and Product Development

1. Customer focus
2. Concurrent development of products and processes
3. Early and continuous life-cycle planning
4. Maximum flexibility for optimization and use of contractor-unique approaches
5. Encouragement of robust design and improved process capability
6. Event-driven scheduling
7. Multidisciplinary teamwork
8. Empowerment
9. Seamless management tools
10. Proactive identification and management of risk

> In this new approach, the user, the program manager, the program executive officer, the service component staff, the DOD staff and related decision makers, and the contractor involved will all share ownership in their programs, and they'll have a stake in making the program successful. . . .
>
> This new IPT approach is different in that it involves early Service and OSD staff involvement at the start of the program—three to four years before we've gotten to this milestone decision. It involves teaming with the program manager and the program executive officer to develop a quality program strategy and plan. It involves a joint determination of the program review and milestone decision requirements; and a joint determination of the functional IPT requirements and the documents—as opposed to a one-size-fits-all approach: that is, the same stamp-it-out approach for every acquisition program that we're taking. And it involves early and joint issue identification and resolution as opposed to OSD finding fault in the late stages of the program.
>
> The idea behind this overarching IPT approach is to have Service and OSD staff working together to identify and resolve issues early in the program.
>
> I think the result of this process will be to provide the best possible equipment to our warfighters in a more efficient and cost effective manner.

The overarching IPT concept allows the program manager to tap into a knowledgeable staff's accumulated experiences in a non-threatening way. The OSD and service staffs understand what the constraints of the program are early on and learn why the program manager, or user, made certain key decisions. Overarching IPTs should improve communication, provide a forum for setting realistic expectations, ensure ownership, and foster a win-win relationship. In short, the overarching IPT provides the forum for implementing the principles of the ATF/F-22 program.

Can Overarching IPTs Really Work?

Not surprisingly, as soon as the DOD leadership announced the concept, the debate immediately started as to whether overarching IPTs could really work. At an initial meeting to discuss the implementation of IPTs, many program managers questioned how a small program office could work with a larger, overarching IPT containing members from many parts of OSD (who might outnumber the personnel in the program office). Others questioned the role of members from the OSD Comptroller's Office. Would their interest lie in success of the program or in finding additional ways to fund budget reductions? Still others wondered how members of the OSD staff could support many IPTs for many programs.

The characteristics of successful IPTs, described in chapter 7 and repeated here in Figure 10-2, form the basis for answers to these and other concerns. The most important characteristic of overarching IPTs is the third, that they are empowered, cross-functional teams. The members of the overarching IPTs must feel they have a stake in the successful outcome of the program. If they can't add value to the program and don't need to be involved in it, they should not be part of the overarching IPT. This will immediately reduce the potential membership of the overarching IPTs.

The second important characteristic of overarching IPTs is their commitment to the customer (typically the warfighter in the field) and their focus on the product—on meeting warfighter needs through successful development and fielding of the weapon. Another important point is that the overarching IPT needs to take a long-term view of the program. Of all characteristics, this may very well be the hardest to instill in the new teams.

Finally, the overarching IPTs need to understand their boundaries—which decisions to make, which to refer to higher levels (such as the Defense Acquisition Executive), and, perhaps more important (at least from a program director's perspective), which to keep at the program director level. The IPTs must also understand how their program fits into the overall joint warfighting architecture. With this perspective the overarching IPTs can help guide the program toward its goal of fully meeting the Joint Task Force warfighting needs. Because of this final characteristic, I believe that user representation, especially from the Joint Requirements Oversight Council, will be very important on all overarching IPTs.

As in any endeavor, a major ingredient in the success of IPTs will be the strength of the leadership at the OSD and service levels in ensuring that the overarching IPTs actually support the program director. The team efforts should produce value-added results that will lead to a successful program.

Will overarching IPTs really work? With good leadership in and above the overarching IPTs, yes, they will. It will take time, and no one method of implementation will work for all occasions. But the concepts of teamwork, integration, and support of the customer will result in an improved acquisition process that will directly benefit the men and women who defend the interests of the nation.

Figure 10-2. Characteristics of Successful IPTs

Successful IPTs

1. Are customer-focused
2. Are product-oriented
   (Where a "product" can be an item, a process or an issue)
3. Are empowered, cross-functional teams, including
   - All stakeholders involved
   - All necessary disciplines/organizations (including the customer)
4. Take a long-term view
5. Understand the limits of their decisionmaking authority (fenceposts)

SUMMARY

The F-22 program has served as an outstanding, successful example for the acquisition community as well as for other parts of DOD. The tools and methods crafted in this fighter program have yielded results all over the Department. Overarching IPTs hold the promise of greatly improving the review and oversight process and, more broadly, should result in the implementation of IPD in large and small programs throughout all of the services. Kaminski was not overstating the case when he referred to Perry's May 10, 1995 memorandum as "fundamentally changing the way we undertake our processes in acquisition."

11

Conclusion: Meeting the Challenge of Complexity

- **The Challenge of Complexity**
  - Complex weapon systems
  - Complex weapon development
  - Controlling complexity
- **Risk Management**
  - Requirements control
  - Technology control
  - Management system
- **Principles**
- **Lessons Learned**
- **Final Words**

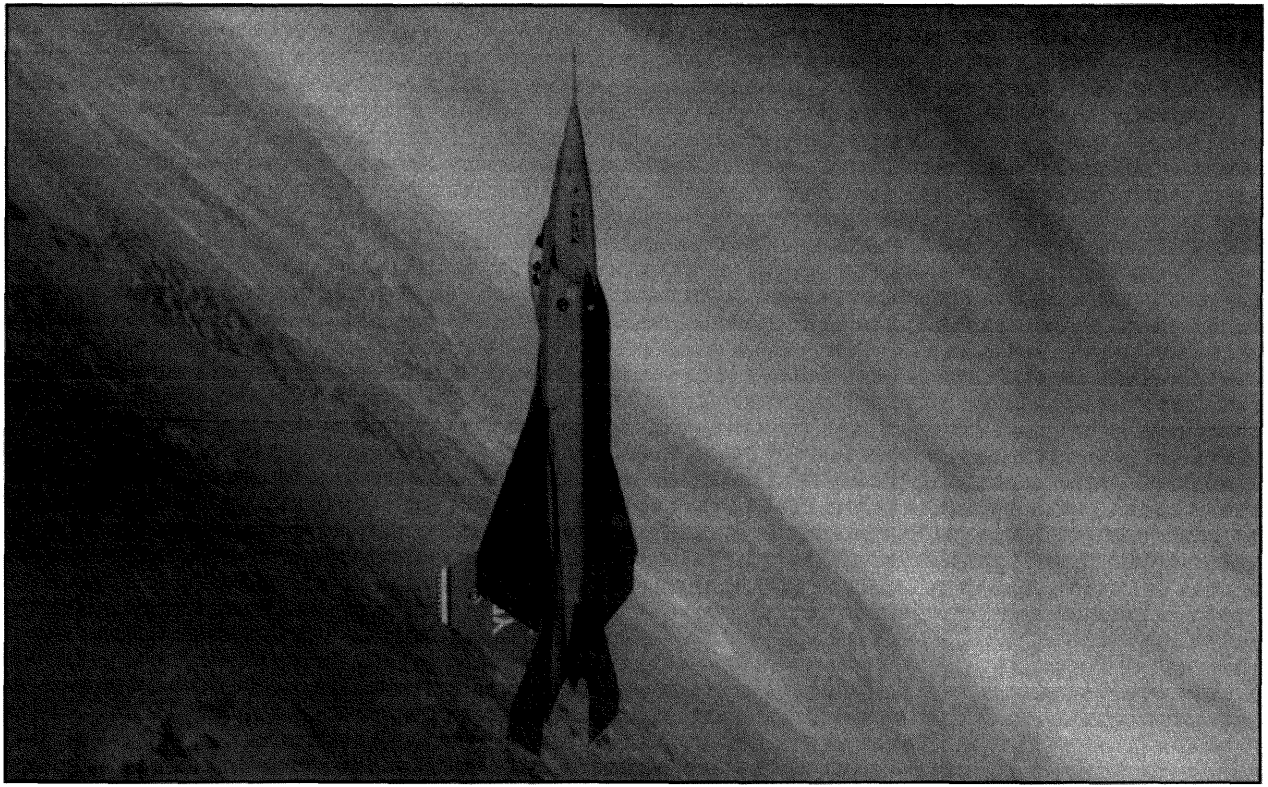


Photo courtesy of Lockheed-Martin.

A YF-22 rockets skyward in an aerial loop. When the advanced tactical fighter was first conceived some people doubted that an ATF could combine stealth, supercruise, and agility.

"Integrated" is a word threatened with overuse in the F-22 programme, but integration is what sets the aircraft apart from previous fighters. The F-22 will be developed according to an integrated master plan, which sets out what has to be done, and an integrated master schedule, which says when it has to be done. Work packages will be handled by integrated product teams which bring together all the disciplines required.

Flight International
(October 1, 1991, Page 32)

With perhaps teamwork running a close second, the word "integrated" certainly is the most prevalent word used to describe the F-22 program. And rightly so; integrated teamwork captures the essence of the development program. This chapter shows how the F-22 program approach to managing risk, with integrated teamwork at its core, helps control the complexity of a weapon development program.

THE CHALLENGE OF COMPLEXITY

Chapter 1 reviewed some of the historical problems with the defense acquisition process: staying within projected cost, meeting the advertised schedule, and performing as originally required. The main reason for the longstanding theme of overruns, delays, and worse-than-expected performance in weapon development is complexity.

As the military-industrial complex developed the first supersonic fighter, radar-controlled surface-to-air missile, computer-driven destroyer with phased-array radars, and hundreds of other weapon systems, it ran into problems both never encountered before (mostly technical) and familiar (like changes in requirements, the use of incompatible parts, or miscommunication). The reason is that weapon systems are complex and their development is complex.

Complex Weapon Systems

Weapon systems themselves are complex because they are generally made up of a vast array of smaller, highly interrelated components. For example, the F-22 weapon system is made up of the aircraft and its engine, the support equipment, and the information needed to repair the aircraft, as well as the system to train the pilots and maintenance personnel. The aircraft includes a vast array of items, including the avionics, which includes a radar, flight control systems, hydraulically controlled actuators, flight control surfaces, and the pilot ejection seat. A great number of components (and subcomponents) must all work together correctly to allow fighter pilots to successfully complete their mission of air superiority.

Complex Weapon Development

The process of developing a weapon is also complex. To develop a weapon system, designers are faced with three challenges. First, they must understand exactly what the product must do (in the case of the F-22, to detect and shoot down enemy aircraft) and the many constraints on the system, such as the size and projected cost of the system or the equipment the system must work with (such as the Airborne Warning and Control System, AWACS).

The second challenge is to create an initial solution to meet the requirements. That solution generally divides up the tasks necessary to meet the top-level requirements and assigns these sub-requirements to various pieces of hardware. This process of allocating requirements to ever-lower levels of indenture continues until the designers reach the most basic requirements. For example, in some parts of the F-22 aircraft, the subcomponent requirements nestle down 14 levels of indenture.

Finally, the designers develop the specific solution to meet each subrequirement, applying technology to best meet each subsystem need. As the designers, or design teams, develop their particular subsystem, they must be aware of how it relates to other components, and the design solutions they reach must allow their component to support and work with—that is, must be compatible or congruent with—other components of the overall system developed by other teams. For example, the aircraft radar cannot easily pass information in 32-bit words to an avionics computer designed to receive 16-bit words.

The three-part process—understand top-level requirements, allocate requirements to lower levels, and develop solutions to lower-tier requirements with the correct application of technology—sounds, and is, difficult.

Requirements. Guaranteeing that the designer fully understands the requirements is hard—not just because of communication challenges but, more important, because the designer needs to make sure the group setting the requirements knows what it really wants. Pinning all of the requirements down is frustrating but essential. The designers must capture the user expectations or the user will never be satisfied with the final product. This process alone drives the complexity of weapon development.

Technology. Making sure that new, unproven technology used for a solution works the way the designer thinks it will is also hard. Banking on a technology that turns out not to meet the expected (and planned for) characteristics causes great turmoil in a development program. Having to come up with alternate solutions because of problems with technology affects previously made, congruent decisions. The consequences of using unproven technology are usually increased cost, a delayed schedule, and, frequently, degraded performance. New, unproven technology thus adds to the complexity of development.

Congruence. Ensuring that teams that may be spread across the country make congruent decisions at all levels is hard as well. There is usually more than one right answer for each problem or question, but overall each answer must relate successfully to the answers to other questions. For example, the radar team decision must match that of the avionics computer team. The greater the number of and the interrelationships among these decisions, the greater the complexity of the development.

Controlling Complexity

Logically, the way to successfully develop a weapon system is for the program manager to control complexity by managing the three elements of the process above: requirements, technology, and a management system that aids in making congruent decisions. The program manager must establish a process to determine the user's real requirements, eliminate surprises from technology, and minimize the risk of noncongruent decisions.

Risk Management

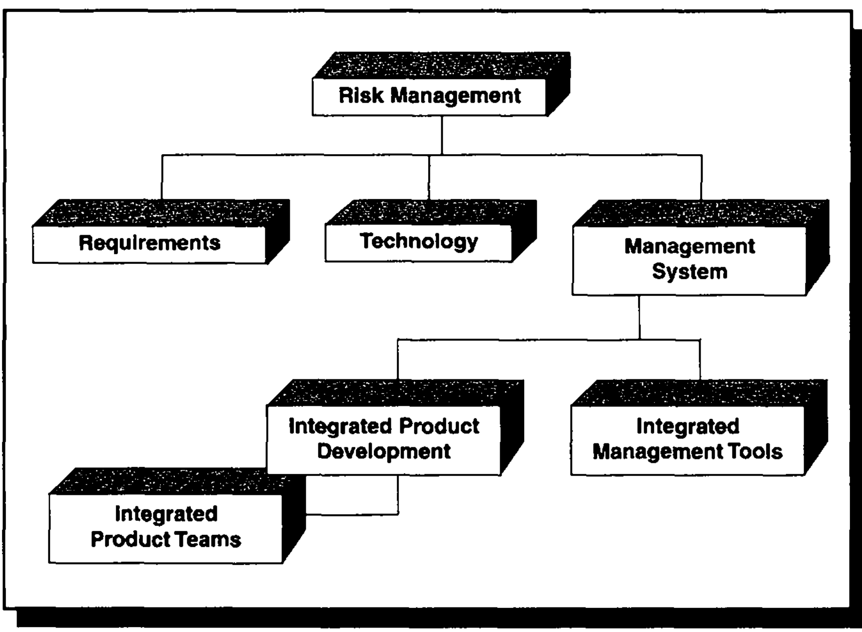
The leadership of the F-22 program created an approach to risk management that has successfully controlled the risks involved in establishing requirements, managing technology, staying on schedule, meeting performance expectations, staying within budgeted cost, and, most important, meeting warfighter expectations.

As outlined in chapter 3, the F-22 program approach to risk management includes three elements: requirements control, technology control, and the use of a proper management system to help ensure congruent decisions. Figure 11-1 shows this structure.

Requirements Control

The ATF program iterated requirements development process brings the warfighter (the user) together with the competing contractors (see chapter 5). The warfighter sets the requirements, and the contractors work toward meeting the requirements under the constraint to use only proven, or at least attainable, technology. Some requirements will be easily met; others will be more challenging. By being intimately involved in this early phase of development, the users see the complexity and cost of meeting their stated requirements and can reanalyze them to see if there is another way to carry out the mission of achieving air superiority and reducing the cost of the weapon system. Having the user who sets the requirements directly involved in the early phases of a program helps control complexity by ensuring that the designers know exactly the final requirements to design to.

Figure 11-1. Elements of Risk Management



Technology Control

In the ATF/F-22 program the contractors could not propose a solution unless they had demonstrated that the desired technology actually worked (see chapter 6). This explains why each team conducted numerous demonstrations and tests, including a flight test program using full-scale flying prototypes, in the demonstration/validation phase of the program. By essentially prohibiting unproven technology from the program, the F-22 program leadership shielded the program from the disturbance and complexity caused by technological surprises.

Management System

The management system should provide a disciplined way to run the program with the ultimate goal of ensuring that the designers make the right, congruent decisions. The first element of the product-focused management system consists of a management approach called integrated product development (IPD) implemented through the use of multifunctional, integrated product teams (IPTs). The second element of the management system is an integrated tool set that supports a well-structured, disciplined program.

Integrated product development. All of the experts that participate in developing a complex weapon system apply their expertise to resolve myriad issues in order to produce a product that meets the customer's mission requirements. IPD causes these experts to focus on a specific portion of the overall weapon, a particular product, and mutually create a solution that satisfies the issues of each specialty (see chapter 7 and Figure 11-2). IPD requires input from all the specialties (engineering, logistics, finance, contracts, etc.) required to design a specific part or component. To produce a product that will satisfy its customers, the team of experts must understand both their immediate and their long-term needs. By meeting the logistical, engineering, and manufacturing challenges of a product early in the design phase, the team greatly reduces later problems during the product's lifecycle.

A successful method of implementing IPD is to gather the experts associated with a particular product into a dedicated, product-focused team—an IPT. Most IPTs in the F-22 program revolve around hardware products, such as the landing gear. However, the concept of IPTs also applies to nonhardware products such as processes or issues. An important lesson learned early in the F-22 program was that an IPT with the responsibility to design and deliver a product is highly moti-

Figure 11-2. Key Elements of Integrated Product Development

Integrated Product Development

- **Is customer-focused**
- **Is product-oriented**
- **Uses empowered, cross-functional teams**
- **Takes a long-term view**

vated and determined to create the best design for the product. If team constraints (such as interfaces with other systems, maximum power available, allowed costs) are not clearly defined, the IPT will produce an excellent product that may not work correctly in the overall system. Therefore, each IPT needs to understand all of the design constraints and to know which decisions to make and which to pass to a higher level of IPT—that is, the IPT fenceposts. Figure 11-3 shows the characteristics of a successful IPT.

Integrated management tools. IPD is a powerful idea, but it needs the correct tools (see chapter 8), which make up the second element of the management system. The integrated management framework, developed towards the end of the ATF demonstration/validation phase, provides the features needed to properly control the program (see Figure 11-4). The elements of the framework (a) plan the actions and commit the participants of the program, (b) monitor and track the actual execution of the program, and (c) provide feedback to the members of the team. Many of these tools were used for earlier programs, but the significant difference is that the F-22 program coordinates these tools by focusing them on the various parts of the weapon system, supporting the team focus on the product. The F-22 program leadership also mandated a single numbering system, making it easy to see the relationship between program elements; for example, between the cost and schedule of a particular item under development. The integration of the management tools greatly increases the usefulness of the information available to the teams and supports a disciplined development

Figure 11-3. Characteristics of Successful IPTs

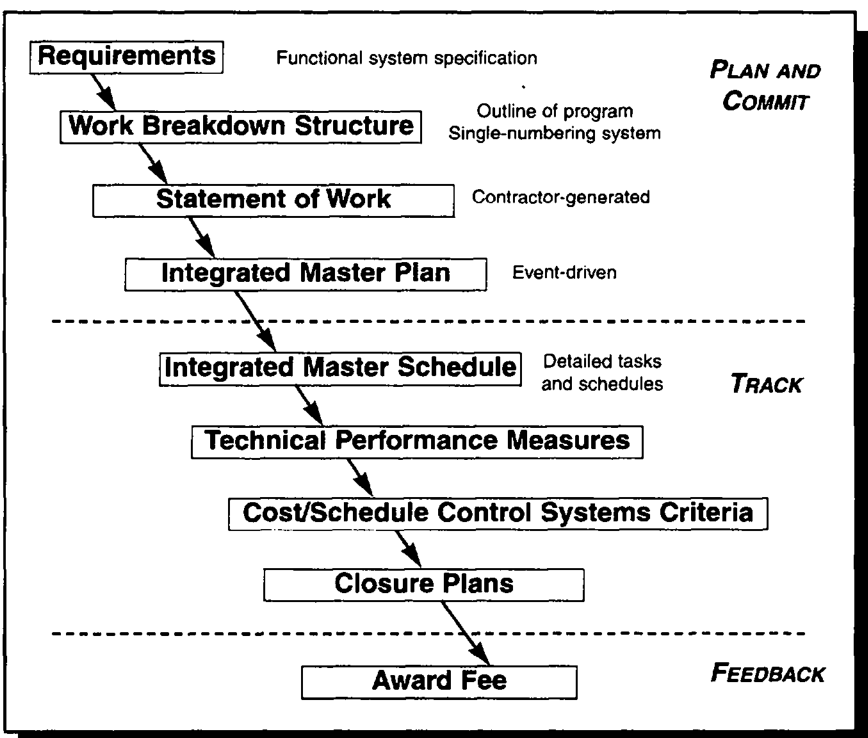
Successful IPTs

1. Are customer-focused
2. Are product-oriented
   (Where a "product" can be an item, a process or an issue)
3. Are empowered, cross-functional teams, including
   - All stakeholders involved
   - All necessary disciplines/organizations (including the customer)
4. Take a long-term view
5. Understand the limits of their decisionmaking authority (fenceposts)

process, greatly reducing the complexity of weapon development. The tools are:

Plan and commit: As stated, the process starts with requirements (called functional system specifications) that are iteratively developed with the warfighter and the contractors and then stated in mission terms without mandating a specific solution. The contractor then designs the program along product lines. The single-numbering system applied here is then used throughout other portions of the program (integrated master plans, technical performance measures, cost/schedule reports, etc.), resulting in a structure called the work breakdown structure. As the expert at designing, building, and testing a weapon system, the contractor (with review by the Government) prepares the statement of work and, finally, determines the events that need to occur to complete the statement of work and meet the product requirements. The contractor prepares this detailed plan of the events, called the integrated master plan (IMP), before work

Figure 11-4. The F-22 Program Integrated Management Framework



begins. Ideally, the Government program manager arranges for the IMP to be created during the competitive phase of the program and then use it as part of source selection. Requiring the IMP to be placed on contract results in contractor execution of the proposed program.

Track: While the IMP is an event-driven plan, which shows the sequence the program shall follow, the integrated master sche-dule (IMS) provides calendar-based tasks in much greater detail than the IMP does. Because program schedules can often change, the IMS is not put on contract (otherwise every change would require a contract change). The IMS serves to flesh out the IMP and provides the detailed planning necessary to coordinate team actions and track progress. The technical performance measures—the product-focused metrics used to track technical performance—show the performance goal for the product, the projected performance and the current performance achieved to date, and a history of achieved and projected performance. The cost accounts are designed to report along work breakdown structure lines, and, because the work breakdown structure is organized along product lines, the cost reports are directly comparable to the IMS and the technical performance measures. By working closely with the contractors, the F-22 program office receives initial "flash reports" on cost/schedule information 10 days after the contractors close their monthly accounting books. But as detailed as the IMS is, the Government and the contractor must still have a closure plan, an agreement stating the decisions the teams must make to determine when an item can be declared completed.

Feedback: The F-22 engine and weapon system engineering and manufacturing development contracts are cost-plus-award-fee contracts. This means that a Government team (program office and other stakeholders) reviews the contractor performance every 6 months. The award fee official, the Air Force F-22 Program Director, then determines the amount of the available award fee the contractor will receive. This award fee, the contractor profit, is the Program Director's most important (really, only) tool for rewarding success. Carefully structuring the criteria by which the contractor will earn that award fee allows the Government and the contractors to simultaneously achieve their goals (for the Government, to design, build, and field a reliable jet; for the contractor, to make a profit). With the integrated tracking and reporting tools, documenting the performance necessary to determine the every-6-month award fee is straightforward and requires very little overhead.

The F-22 management system relies on IPD and uses integrated management tools. Both elements combine to form a disciplined system that relies on the core principle of integrated teamwork within and among product teams to create a complex weapon system.

PRINCIPLES

The tools and techniques developed by the F-22 program all have a common underpinning in the central beliefs or principles held by the ATF/F-22 leadership. The ATF/F-22 program 20 principles of acquisition (see Figure 11-5), discussed in chapter 2, were not set down in stone and delivered at the first program staff meeting. Instead, they evolved during the early phases of the program.

The principles accurately capture the most important goals that the F-22 program leadership wanted the Government/contractor team to reach. A review of the list shows that there is nothing amazing or new about these principles. They are reasonable and straightforward. The challenge is to implement them so that they support one another and the mission of the organization.

LESSONS LEARNED

As the F-22 program implemented the ideas described in this book, the program refined its approach and learned about the

Figure 11-5. The ATF/F-22 Program Principles of Acquisition

1. Operate with integrity.
2. Work as a team.
3. Use logic and common sense.
4. Involve everyone.
5. Integrate the entire system.
6. Ensure ownership.
7. Use a disciplined approach.
8. Understand what is really required.
9. Set realistic expectations and meet them.
10. Provide realistic options.
11. Take a long-term view.
12. Do it right the first time.
13. Have what you need for the effort.
14. Ensure everyone knows what it takes to meet the goal.
15. Use an event-based schedule with defined success criteria.
16. Define success and be able to measure it.
17. Reward success.
18. Focus on a win-win relationship.
19. Guarantee open communications.
20. Achieve success with a positive attitude and focus.

Figure 11-6. Lessons Learned From the F-22 Program

Program

1. Full teamwork improves program performance.
2. Integrated planning reduces start-up and supports a well-managed program.
3. Integrated management tools support a disciplined process.
4. Tightly managed programs suffer greatly from unstable funding.

Integrated Product Development

5. IPD requires complete senior-level support.
6. IPD requires a cultural change.
7. Classic functional organizations may initially resist IPD.

Integrated Product Teams

8. IPTs naturally accomplish IPD.
9. IPT members are motivated, are involved, and have ownership.
10. Every IPT requires training.
11. IPTs take leadership commitment from all groups.
12. IPTs should have experienced and empowered members
13. The I in IPT can easily become independent instead of integrated.
14. IPTs need to know their fenceposts.
15. Program leadership must ensure integration across the IPTs at every level.
16. Communication and software tools help integration.
17. IPT managers should be in charge of personnel and budget resources.
18. Both leadership and teams must set and track IPT objectives.
19. The right people must be in the right jobs at the right time.

challenge of implementing some of the new methods. The 19 lessons learned (see chapter 9) are reiterated in Figure 11-6. Overall, the F-22 program assessment is that these techniques are extremely powerful and that they work. Initial start-up and acceptance of the techniques takes senior leadership support. I believe these lessons learned also show that what we have all heard from the earliest time in our careers, namely, that people are the group's most important resource, is absolutely true. People make it happen.

Final Words

The F-22 program application of principles—focused on a disciplined process, in an environment of integrity, teamwork, and logic—has worked well to meet the challenge of weapon system complexity. The value of these basic acquisition truths lies in the fact that they work. They greatly help control the risks of a complex weapon development effort.

This book has described how to manage risk. The approach developed by the F-22 program works well; its customer, Air Combat Command, is pleased; and the principles and concepts work for other programs and in other areas as well.

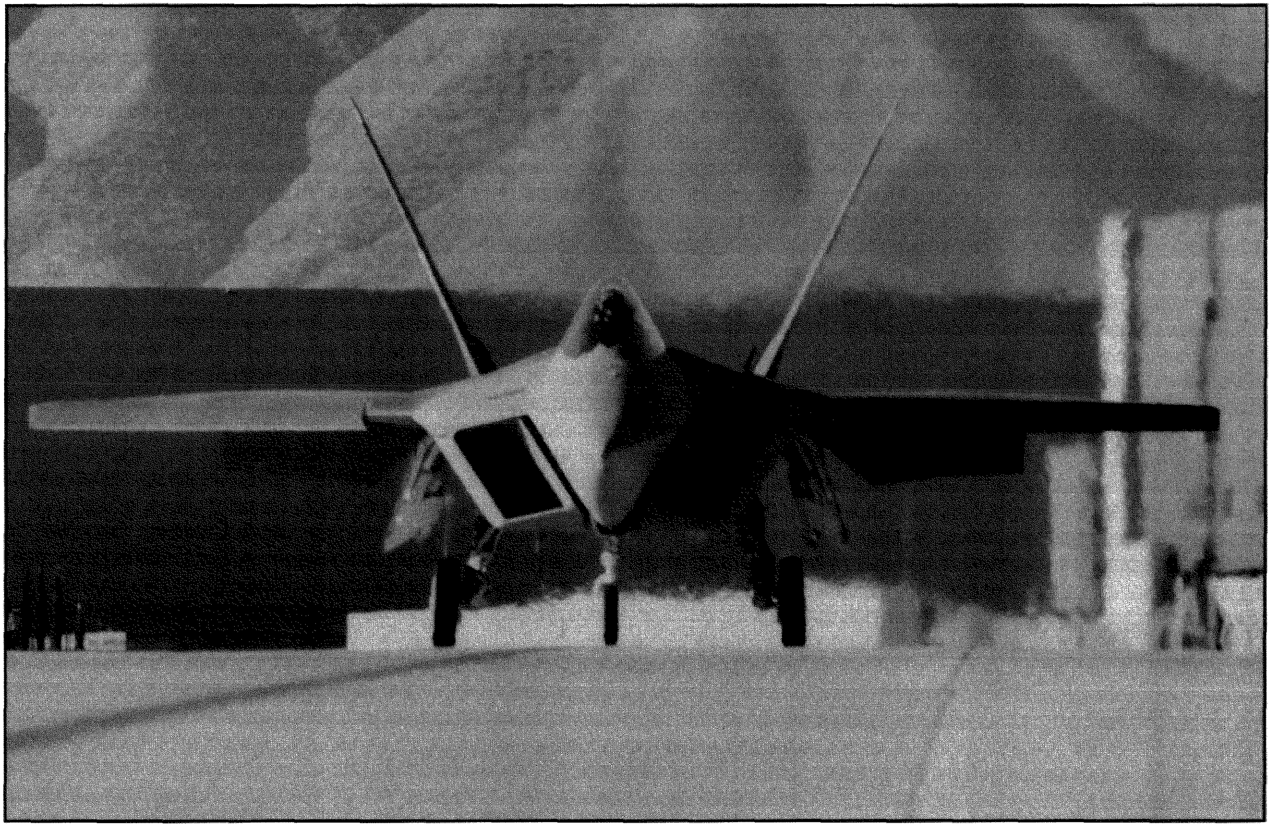


Photo courtesy of Lockheed-Martin.

Another test flight of the YF-22 begins as a pilot taxis the aircraft.

Appendixes

Appendix A

A Brief History of the Advanced Tactical Fighter

- The Genesis of the Advanced Tactical Fighter
- The Demonstration/Validation Phase
- The Engineering and Manufacturing Development Phase

The roads we traversed were dusty and crowded. Vehicles moved slowly, bumper to bumper. Fresh out of West Point, with all of its courses in conventional procedures, I was offended at this jamming up of traffic. It wasn't according to the book. Leaning over Dad's shoulder, I remarked, "You'd never get away with this if you didn't have air supremacy." I received an impatient snort, "If I didn't have air supremacy, I wouldn't be here."

Second Lieutenant John Eisenhower,
Normandy, France, June 1944

In more than 40 years, no U.S. ground soldier has been killed by enemy aircraft. The fundamental lesson to be learned from the history of aerial warfare is the importance of protecting the skies over friendly troops. This condition, called air superiority (or in its full measure, air supremacy) allows ground and naval forces freedom of movement, prevents disruption of their activities, and protects their lines of supply. Air superiority also provides freedom of action for friendly air forces. The U.S. Air Force has the primary responsibility for this demanding task. To ensure control of the skies for the Joint Forces Commander, the Air Force in the late 1960s developed the F-15 air-superiority fighter. By the year 2000, the F-15 will be more than 25 years old and will be outmatched by sophisticated surface-to-air missiles, such as Russia's SA-10 and SA-12, and newer foreign fighters, such as France's Rafale. To maintain its air superiority, the Air Force is developing the F-22 Advanced Tactical Fighter (ATF).

The Genesis of the Advanced Tactical Fighter

One can trace the start of the ATF to Headquarters, Tactical Air Command, Langley Air Force Base, Virginia, in the late 1970s. The Air Force was well along in fielding the F-15 when it looked ahead to the ever-improving Soviet fighters and surface-to-air missiles. Given the long lead time for development, the Langley planners knew that the planning and design of a new generation air-superiority fighter needed to start. In 1981, Colonel John Michael Loh, later the Commander of Tactical Air Command, wrote the first Tactical Air Force Statement of Need for the next-generation air-superiority fighter.

In 1981, the Defense Resources Board approved a mission element need statement that directed the Air Force to begin development of a

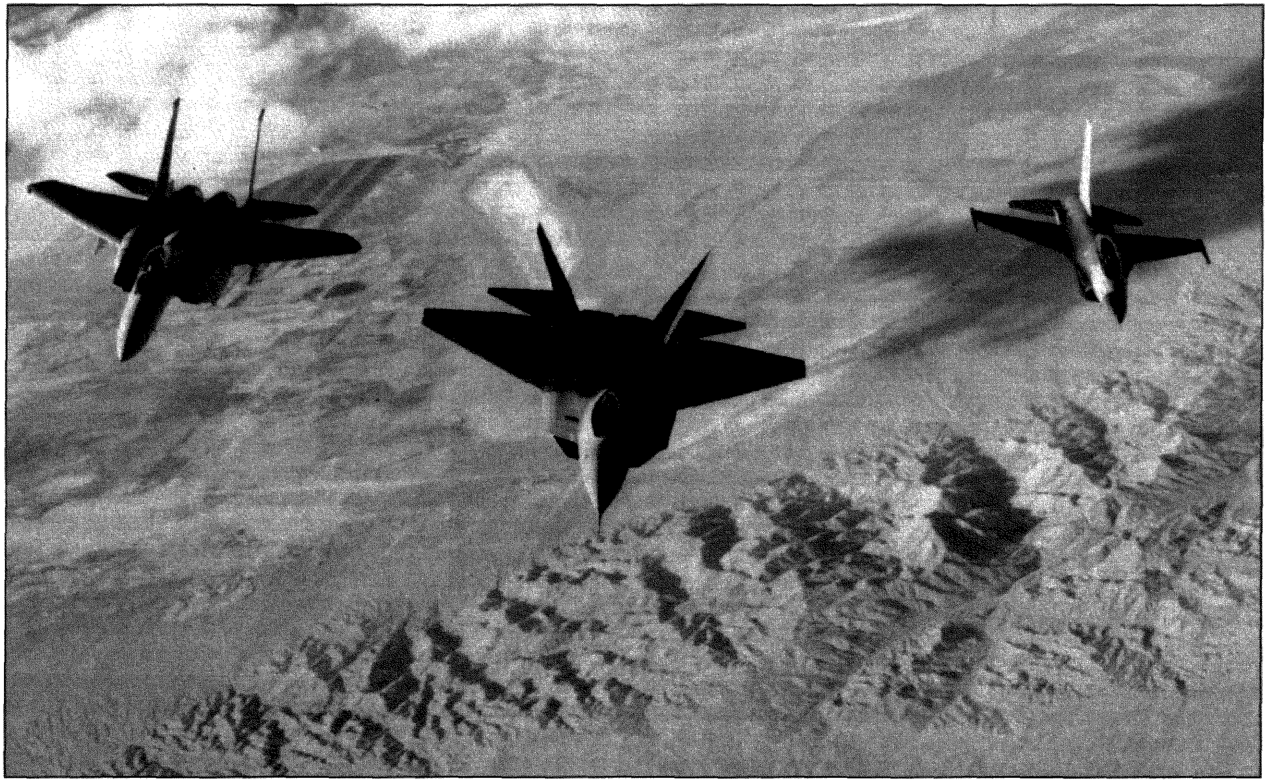


Photo courtesy of Lockheed-Martin.

The ATF purpose is to replace the aging, but highly successful F-15 in the air superiority role. Here an F-15 (left) flies formation with the YF-22 (center) and an F-16 (right).

manned air-to-air fighter with funding authorized in fiscal year 1983. Air Force Systems Command commenced work on a host of technologies to support this future fighter: new approaches to avionics, jet propulsion, flight controls, and airframe materials. The Aeronautical Systems Division, the Air Force Systems Command organization responsible for aircraft development, began working on the ATF when it issued a request for information from industry on possible future fighter concepts. The submitted concepts ranged from small, agile fighters to large, supersonic-cruising YF-12-like aircraft. The Air Force's Scientific Advisory Board Summer Study recommended that the service pursue an F-15-size, supersonic-cruising, low-observable aircraft, and the Air Force organized the initial system program office for the ATF in 1983. In September of that year, the program office awarded contracts to seven aerospace companies for the concept development investigation phase: Boeing, General Dynamics, Grumman, Lockheed, McDonnell Douglas, Northrop, and Rockwell International. These $1 million firm-fixed-price contracts directed the contractors to deliver conceptual designs in May 1984. The purpose of this phase was to provide the information necessary to select the design options for the ATF and to focus the needed technologies to be explored in the next phase, demonstration/validation. The proposed characteristics of the ATF included supersonic persistence (later termed supercruise—cruise above the speed of sound without using afterburner), increased combat radius and lethality, improved maneuverability, and improved supportability.

In parallel to the airframe concept development, the Propulsion program office at Aeronautical Systems Division ran the Joint Advanced Fighter Engine (JAFE) program, which the Air Force had started in recognition that it took longer to develop jet engines than to develop the airframes they would power. In September 1983, the Propulsion program office awarded firm-fixed-price contracts to General Electric and Pratt & Whitney to build two demonstrator engines incorporating innovative approaches that would meet the demands of decreased engine size, higher temperature materials, increased engine thrust, and greatly improved overall performance. The Propulsion program office changed the name of the program to the ATF Engine (ATFE) program to highlight its ultimate objective. The ATF program office subsequently assumed control of the ATFE program to give the ATF Program Director complete responsibility for both Government efforts (the ATF weapon system and the engine) necessary to the success of the fighter development program.

The Demonstration/Validation Phase

In May 1986, in the midst of source selection for the demonstration/validation phase, the Air Staff updated the ATF's program management directive to include the development, fabrication, and testing of two flying prototype aircraft, called Prototype Air Vehicles. In October 1986, the Defense Acquisition Board gave the ATF program approval to enter the demonstration/validation phase. The ATF program office awarded two firm-fixed-price airframe contracts to two teams of contractors: Lockheed Aerospace Systems Corporation (the first prime contractor), located in Burbank, California, teamed with General Dynamics Corporation of Fort Worth, Texas; and Boeing Military Aircraft, of Seattle, Washington. Northrop Aircraft Division, of Hawthorne, California (the second prime contractor), teamed with McDonnell Douglas Corporation of St. Louis, Missouri. The Lockheed prototype would be called the YF-22; the Northrop plane, the YF-23. Each contractor team would build two of their prototype aircraft, one powered by the General Electric prototype engines and the other, by Pratt & Whitney engines.

The ATF program office then modified the engine contracts with General Electric Aircraft Engine Company of Cincinnati, Ohio, and Pratt & Whitney Government Engine Business of West Palm Beach, Florida, to support ATF demonstration/validation. This modification required delivery of six ATF prototype engines from each of the ATF engine contractors, four to power two prototypes (the YF-22 and the YF-23 would both be two-engine aircraft) and two to remain on hand as spares. The Pratt & Whitney engine would be known as the F119; the General Electric engine, the F120.

From 1986 until 1990, the Air Force and the contractors conducted an intensive requirements trade-off and risk-reduction process. The prototypes flew in 1990, providing valuable input to the contractors' proposals for the engineering and manufacturing development phase (previously known as full-scale development). On April 23, 1991, after an intensive Air Force evaluation of both airframe and engine proposals, Secretary of the Air Force, Dr. Donald Rice, selected the Lockheed Aeronautical Systems Corporation to develop the F-22 aircraft and Pratt & Whitney Government Engine Business to develop the F119 engine. (See appendix D for more information about this source selection.)

The Engineering and Manufacturing Development Phase

On August 2, 1991, the respective contractors and members of the program office signed the cost-plus-award-fee contracts for engineering and manufacturing development. As befit the decision, the ATF program office became the F-22 program office.

The following week, senior personnel from the F-22 program office met off-site with personnel from the principal companies involved in the development of the F-22 and the F119 and key members of Tactical Air Command, the Air Staff, and the Office of the Secretary of Defense. The new Commander of Tactical Air Command, General Loh, explained his expectations for the new F-22. This meeting set the tone for the F-22 program. The emphasis was on cooperation and problem solving. The members of the team explained their perspectives and their concerns about the program, and the group assigned action items to resolve these concerns. This off-site meeting started the engineering and manufacturing program off on the right track—with an attitude of open communication, trust, and cooperation.

In December 1991 the Air Vehicle team held a Requirements/Design Review Update, allocating all upper-level requirements down to the lowest levels to allow detailed design to begin. In June 1992, the Air Vehicle team held the Design Review Update, marking the completion of the first of a three-phase design cycle and the transition from parametric weight tracking to detailed design weight tracking.

In July 1992, the F119 engine completed its Critical Design Review and its Initial Production Readiness Review, which completed 39 separate component reviews. The team validated the design maturity of the F119 and approved the engine's advancement into the next development phase, engine test.

In April 1993, the Air Vehicle team conducted its Preliminary Design Review. Because of the F-22 program's commitment to event-based schedules (instead of calendar-based schedules), the program had delayed this review from its originally scheduled date in January to allow the team to work out critical issues such as design-to-cost, weight reduction, configuration definition, wind tunnel testing, structural development testing, material selection, loads definition, and common integrated processor maturation. Completion of this review signaled the end of the second phase of aircraft design and the beginning of the third, and final, phase in the design of the F-22 air vehicle.

In March 1995, the Air Vehicle team completed its design and conducted the last major review, the Critical Design Review. Construction of the first flying aircraft based on the final design is underway. When it enters the inventory around 2003, the F-22 will help ensure that future joint forces commanders will enjoy air superiority well into the 21st century.

Appendix B

The F-22 Test Process

Iterative Modeling and Testing

The Ultimate Test—Flight Testing

If we see something out of the ordinary in the test flight we can go back into the lab and recreate the event to try to isolate the problem . . . rather than the usual fly, fix, fly.

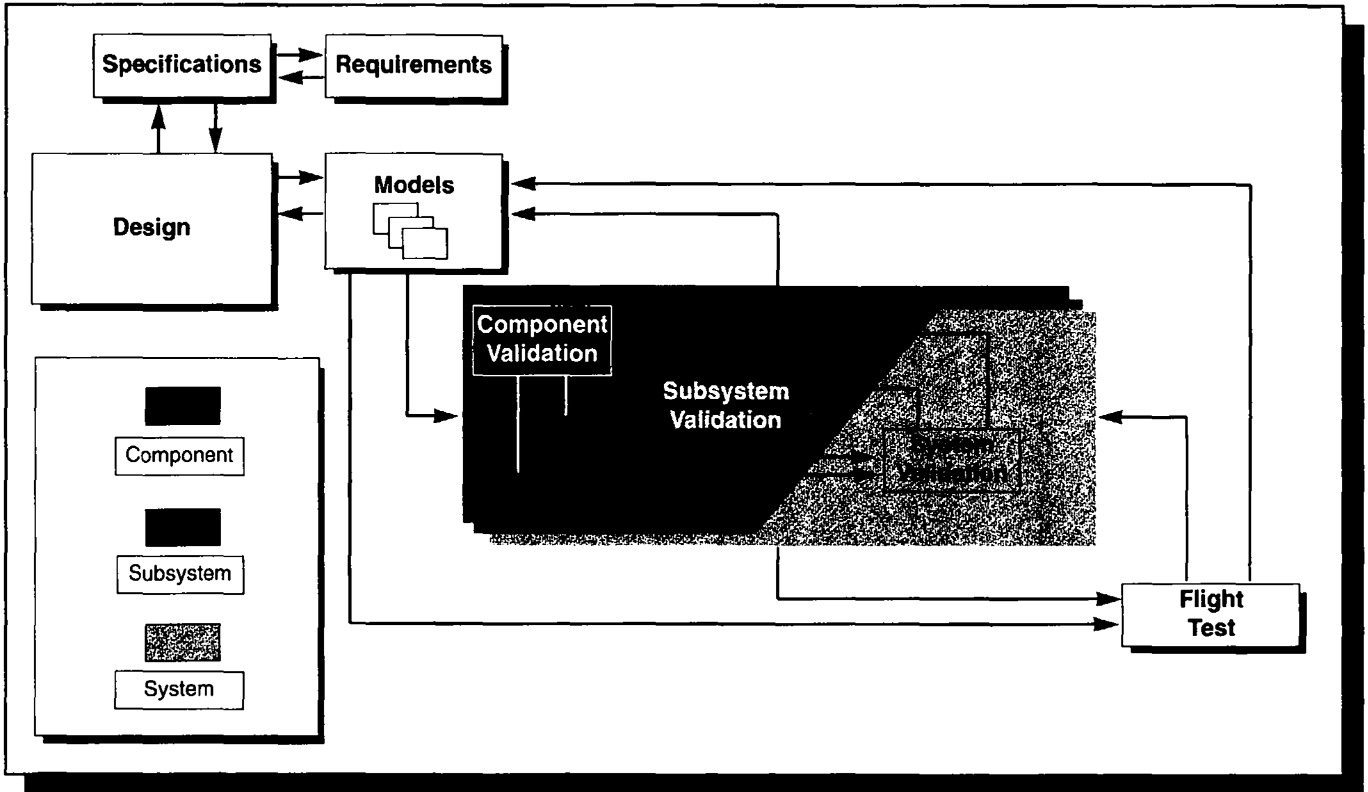
John W. Pieper,
Lockheed F-22 Chief of Test

As mentioned in chapter 2, General James A. Fain, Jr., ATF Program Director from 1986 to 1992, strongly believed that all elements of the ATF development program needed to be integrated. As a former test pilot, he saw the need to tightly integrate development and testing. The program's Government and contractor test managers therefore worked closely together to develop the F-22 integrated test approach, shown in Figure B-1.

The test process starts with requirements, in the upper middle of the figure. As described in chapter 5, the operators set their initial requirements, which led to functional specifications, which in turn led to the contractor's preferred system design. The contractor (and in some cases the Government) then "flew" its aircraft design through a group of developmental and effectiveness models, which showed the performance of the contractor design. Based on these data, the contractor revised its design (shown by the two-way arrow between Design and Models in the figure). When the contractor identified requirements that could not be met in a balanced, cost effective way, the program office, the operational user, and the contractor together refined and updated the requirements. This occurred thousands of times in the demonstration/validation phase and has continued during the engineering and manufacturing development phase.

After fabricating and testing the initial breadboard components, the contractors used the data to validate and refine their model. For example, having fabricated the first very high frequency radio antenna, the communications subcontractor tested its performance, applied the results to the antenna propagation model, and adjusted the model to produce results that matched the laboratory data. The process continued for the next level of indenture, in this example, the communications subsystem, which might include the antenna, the antenna interface unit, the cable, and the transmitter/receiver brassboard

Figure B-1. F-22 Test Process



module. The next level of model included transmitter and receiver efficiencies, cable line loss, and other important aspects of the subsystem's performance. Ultimately the contractor fabricated a full avionics system, which then provided data used to refine and validate the top-level avionics performance models. Through this iterative process, new top-level performance requirements might emerge, causing the contractor/program office/operator team to reexamine the specification and perhaps even the operational requirements.

The greatest benefit of this evolutionary testing process, from basic component modeling and testing to complex system modeling and testing, lies in risk reduction and cost control. A problem caught during component testing is not only easier to find than it would be during higher level testing (since the component is less complex than a higher level system) but is also easier and much cheaper to fix. Once the component passes its modeling and testing, the program can move up to the next level of subsystem.

After modeling and testing components through system hardware comes the final test—the flight test. In the past, when programs did not perform rigorous system/subsystem testing, test pilots would catch many problems during the flight test. In a process called fly-fix-fly, the aircraft would stand down flight operations while the contractor and program office found a solution to the problem. After the contractor fixed the test plane, flight operations resumed. Not only did this delay the flight test schedule and waste the resources of the flight test program, but it was very expensive (relative to a laboratory environment) to find these problems in this phase of the program. The F-22 program has found that lower level testing evolving into higher level testing saves time (by catching problems early on) and ultimately costs less than finding routine development problems in the flight test.

Appendix C

Prototypes

- **The Tool of Prototypes**
- **ATF Prototype Air Vehicles**
- **Sealed Envelope: The Importance of Modeling**
- **Sealed Envelope Predictions**
- **Summary**

If we had gone, as was the original plan, directly into a full-scale development program from a paper demonstration/validation program [without the prototyping effort] we probably would have a pretty big schedule and cost problem on our hands.

Sherman H. Mullins,
ATF Program Manager, Lockheed,

I always get asked about prototypes. Use prototypes only when needed to reduce risk.

General James A. Fain, Jr.

Many people look at the ATF program use of flying prototypes and draw what may be the wrong conclusions. Major-scale prototypes are expensive, and their inappropriate use can waste critical resources that could be better applied elsewhere. However, prototypes can reduce risk and save millions of dollars. This appendix defines prototypes and reviews the reasons for them, the way the ATF program used them, and, most important, the reasons the ATF program used them.

THE TOOL OF PROTOTYPES

Prototypes are a tool that the program manager can use to reduce the risk in the program. A February 1993 Defense Science Board Task Force on Aircraft Assessment defined a prototype in this way:

> A prototype is a representative model used:
> 1. to reduce technical risks in a new system or subsystem
> 2. to answer design questions to some degree, and
> 3. to provide necessary confidence before moving to the next phase of a system acquisition with better technical, schedule, and cost information and estimates for the system.

In discussing prototypes and the ATF program, many people tend to think exclusively about the YF-22 and YF-23 flying prototypes. However, the ATF program used many types of prototypes, for example, the ground test engines in each engine company and the radar cross-section pole models (described in chapter 6). Because of the initial high level of risk in avionics, the ATF's Avionics Ground Prototype and the

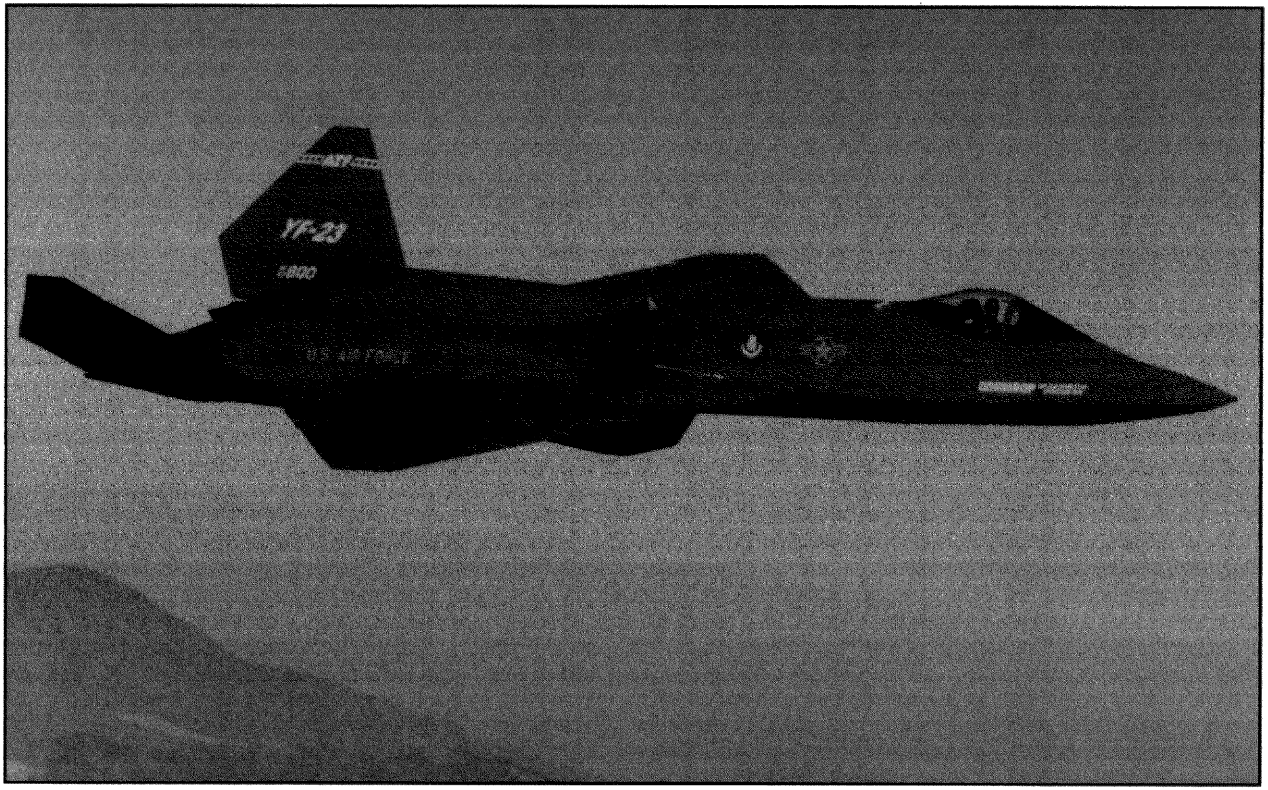


Photo courtesy of Lockheed-Martin.

Prototypes were essential in the validation/demonstration phase as competing firms sought to establish the qualifications of their aircraft. The most noticible feature of the Northrop and McDonnell Douglas YF-23 is its slanted tail stabilators.

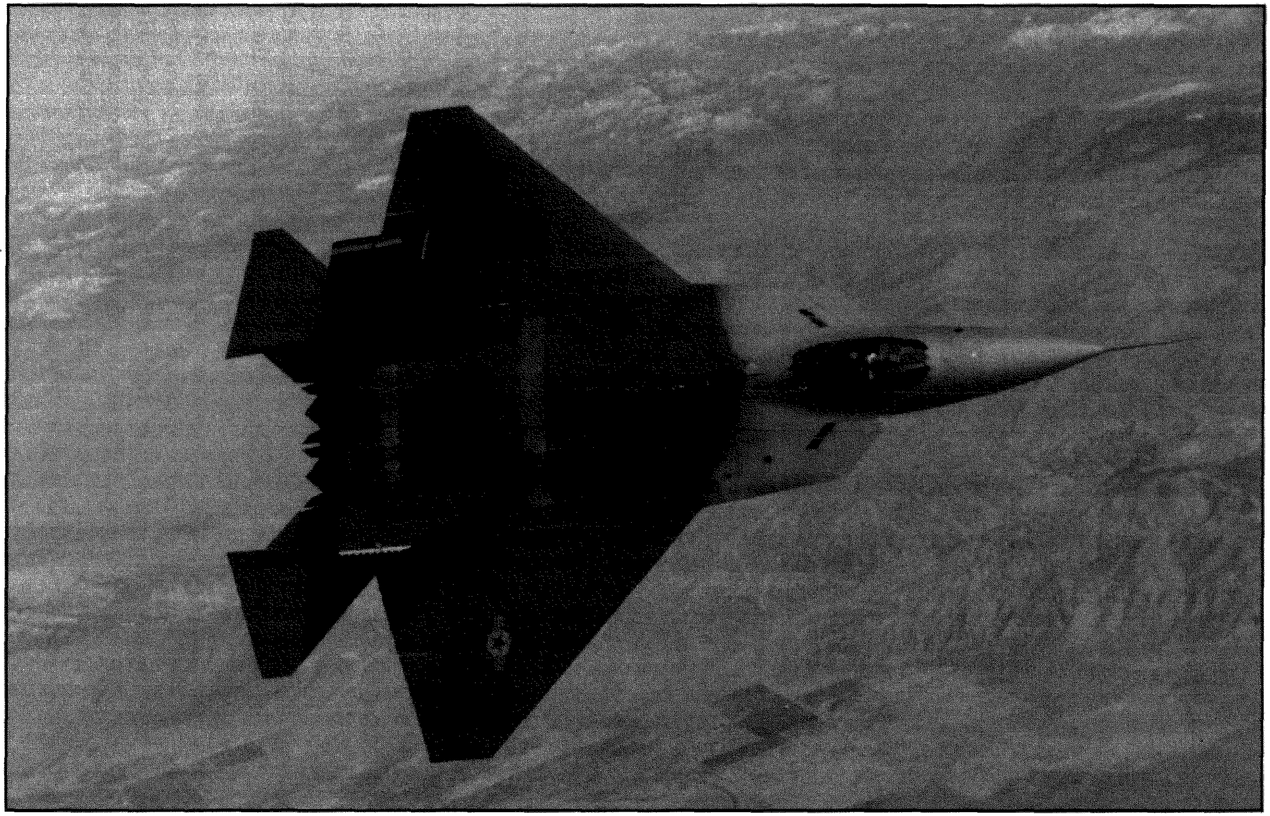


Photo courtesy of Lockheed-Martin.

The planform view of the Lockheed-General Dynamics-Boeing YF-22 prototype displays its twin tail stabilizers and wings.

avionics Flying Test Bed (integrated brassboard avionics systems that demonstrated key performance capabilities) were perhaps the most important prototypes in the demonstration/validation phase.

Prototypes can be more than just hardware. The computational fluid dynamics model of an aircraft, the "flying" model, can be viewed as a prototype. The engine program explored the most innovative prototype of the ATF's demonstration/validation phase—the integrated master plan and the integrated master schedule (see chapter 8).

The 1993 Defense Science Board, in an analysis of the F-22 program, said that:

> Both ground and flight prototype testing in the Dem/Val phase reduce the technical risk of a program, thereby reducing the schedule and cost risks in proceeding to E&MD [engineering and manufacturing development] (and production). Prototyping does not eliminate technical, schedule, and cost risk—that is why there is an E&MD. Prototypes cost money and take time—sometimes they are justified and sometimes not, depending on the degree of technical advance sought in a system or subsystem, the nature of the technical risks and the costs of risk reduction at various stages of an E&MD program.

Clearly, then, one should use prototypes to reduce technical as well as cost and schedule risks.

ATF Prototype Air Vehicles

As a result of the Packard Commission's Acquisition Task Force recommendation to increase the use of prototypes (see chapter 6), Headquarters Air Force directed the ATF program office to include flying prototypes in the demonstration/validation phase. The program office fought to keep the requirements for the prototypes simple. In fact, the only Government requirement was that the prototype actually take off. The basic concept called for the contractors to use their prototype to demonstrate their risk areas. The contractors would then submit the data from their flight tests as part of their engineering and manufacturing development (EMD) proposal to substantiate their performance projections for the production aircraft.

In an interesting sidelight, a key member of the Acquisition Task Force who later visited the program office to review the program was surprised to see that the program included flying prototypes. He believed that the original plan of testing the high-risk avionics and engines was sufficient and that aeroperformance risk could have been adequately addressed by modeling and simulation.

From the perspective of the ATF's Technical Director, Eric E. Abell, although the flying prototypes did help validate the computational fluid dynamics models and provide data unavailable from modeling, such as testing smoke ingestion by the engines from a missile launch, the cost of the prototype air vehicles did not justify their use on technical risk-reduction grounds. However, the flying prototypes did serve a valuable purpose in convincing a large body of experts that one could design and fly a high-performance aircraft designed to meet low-observable, stealth requirements. An unanticipated benefit was that the design and construction of the prototype air vehicles proved that a multicompany team could design and produce parts of an aircraft in different locations, bring them together on time, and conduct a highly successful flight test program. Sherman H. Mullins, Lockheed's ATF Program Director, summed up this result:

> We have not just prototyped an airplane or avionics system. We have prototyped a technical integration system that clearly demonstrates that you can make these teaming arrangements work in a technical sense.

Sealed Envelope: The Importance of Modeling

To build and fly a test aircraft during the demonstration/validation phase required the contractors to finalize their aircraft's design well before all of the operational requirements could be determined. From the outset, the ATF program leaders recognized that they would not take the demonstration/validation phase's Prototype Air Vehicle design unaltered into the EMD phase. However, beyond using the original flying prototypes for model verification, they wanted to ensure that the contractor could successfully predict performance and thus deliver on the predicted performance of the production aircraft. To meet this objective, the program office used sealed-envelope predictions. According to General Fain,

> Unless your requirements are firm, if you use prototypes, your requirements will change. Thus you must implement the sealed-envelope approach. You must establish the contractor's ability to predict and verify his predictions so that when you go into the next phase (engineering and manufacturing in our case) your models can predict performance.

Sealed Envelope Predictions

Before each flight test, or major ground test, the ATF program office required the contrator team to submit a prediction of what the test data would show at the conclusion of the test. The program office wanted specific values, such as: speed at altitude for sustained supersonic cruise, angle of attack, roll rate, or for avionics testing, perhaps the number of targets acquired and processed by radar. The contractor submitted this data in a sealed envelope. Following the test, members of the program office opened the envelope and examined the contractor's predictions.

The use and high visibility of sealed-envelope pretest predictions helped ensure that the contractors developed and validated their models, captured needed test data, and thoroughly thought through the test process before conducting the test.

Summary

The ATF/F-22 program has shown that prototypes can be a very effective tool in reducing technical as well as cost and schedule risk. However, prototypes can be much more than just flight-qualified hardware: Some programs may use hardware, others may use validated computerized simulations. The ATF program also showed that the real value of flight hardware and flight testing may not be in measuring aeroperformance but in assessing contractor teaming performance.

Another major lesson learned is that future program managers should ensure that the contractor can successfully predict test results. Confirming a model's accuracy and predictive capability can greatly improve the chances of developing a final product that will meet the operational user's requirements.

Appendix D

Source Selection: Concepts and Lessons Learned

- CONCEPTS LEARNED FROM SOURCE SELECTION
- THE MECHANICS OF ATF SOURCE SELECTION
- SUMMARY

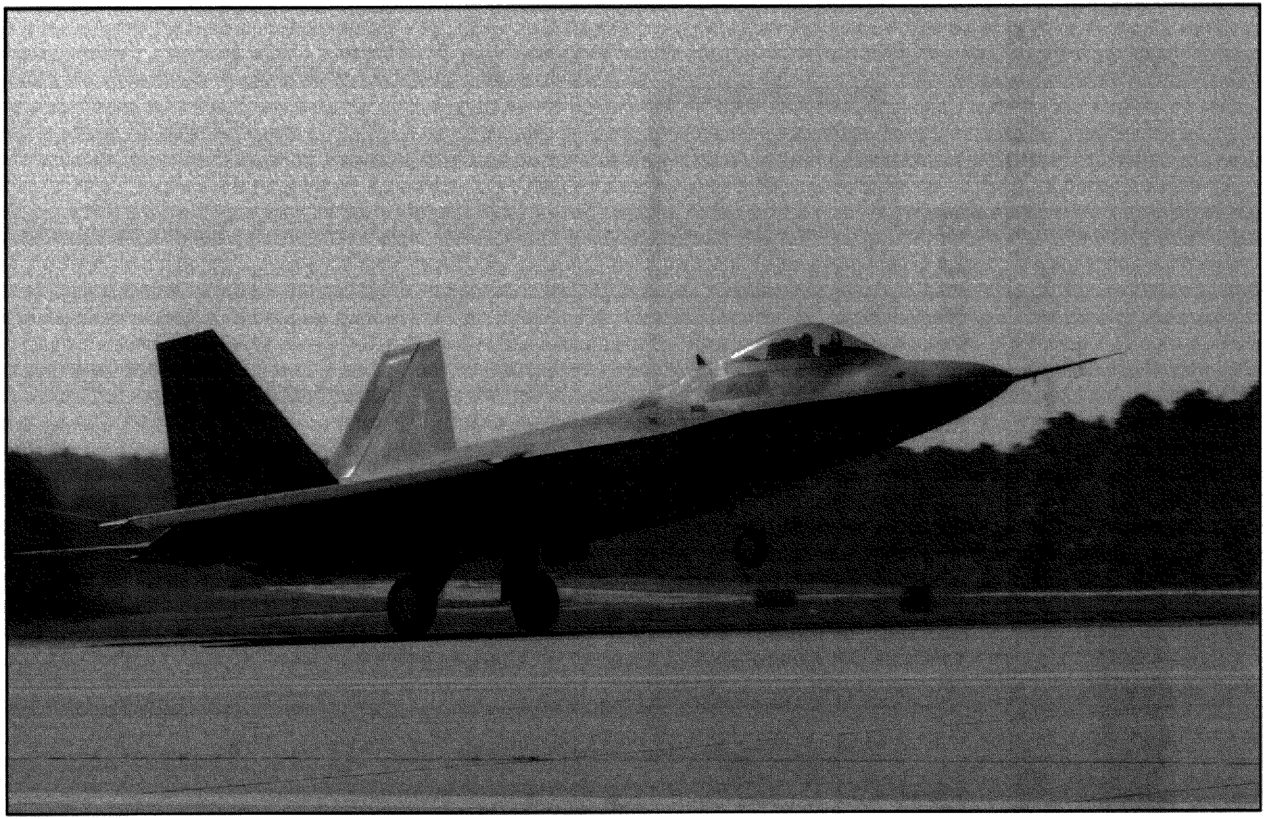


Photo courtesy of Lockheed-Martin.

Raptor 01, the first developmental F-22, takes off on its maiden flight.

We had an evaluation to make of two competing contractor proposals and two teams. Both of them met the requirements; either of them could have been chosen in the sense that they complied with what the Air Force had asked for, so we had to do the evaluation based on looking in depth into the way they proposed to go about it, into their management plans, into the technical risk reduction plans that they presented. We went through all of that in quite a lot of detail. There were many factors where there were differences between the two teams, no one of them determinant in its own right, but, on balance, we concluded that the Government would get the best value by proceeding with the Lockheed team in combination with the Pratt & Whitney engine manufacturer.

Donald B. Rice,
Secretary of the Air Force

The selection of the contractor to develop the Advanced Tactical Fighter (ATF) occurred in record time compared with earlier weapons competitions. Source selection evaluation officially began for the engineering and manufacturing development (EMD) phase when the Air Force released its request for proposals (RFP) on November 1, 1990. The four competing contractors (Lockheed and Northrop for the ATF weapon system and Pratt & Whitney and General Electric for the ATF engine) submitted their proposals to the ATF program office on January 2, 1991. The Government completed its evaluation and Secretary of the Air Force, Donald B. Rice, announced his decisions on April 23, 1991. Following this rapid award of one of the largest DOD cost-plus-award-fee contracts ($11.2 billion for weapon system development), many agencies asked what lessons had been learned from this highly successful source selection. The following information comes from two unpublished papers written by Mr. James D. Schairbaum, the manager of ATF source selection; and, Colonel Wallace T. Bucher and myself.

The first section of this appendix reviews the background and the concepts of the ATF's source selection, which are applicable to many other acquisition source selections. The next section, The Mechanics of ATF Source Selection, discusses the details of the source selection and the lessons learned that support the concepts.

Concepts Learned From Source Selection

The ATF commitment to integrated teamwork extended throughout the preparation for the EMD phase. In April 1989 the ATF's Acquisition Strategy Working Group created and released a preliminary acquisition package that laid the groundwork for what would eventually become the ATF RFP. The contractors scrutinized this document and suggested many revisions that would improve how the Government asked for proposals. The working group released the first draft of the RFP in August 1989 and the second in April 1990. Following each release, the contractors met individually with the Government program office and suggested improvements, which the program office screened to ensure that they added value to the program and did not simply assist one of the contractors. Ultimately, the draft RFP process resulted in over 1,000 proposed and 700 accepted changes—greatly improving the quality of the Government's RFP and giving each contractor unparalleled visibility into the final RFP.

The goal of the Acquisition Strategy Working Group was to develop and explain the concept of integrated master plans (IMPs) and integrated master schedules (IMSs). The working group's strategy was to have the contractors do actual, detailed up-front planning by requiring the IMPs to be part of the contract (submitted as part of the

Figure D-1. ATF Source Selection Concepts

1. Make sure the leadership is thoroughly familiar with all parts of the request for proposal (RFP)
2. Have a clear and agreed-to understanding of the requirements.
3. Understand the contractors' program and ensure that it has the appropriate level of risk.
4. Be totally prepared for source selection before it starts.
5. Guarantee that source selection participants have been involved in the preparatory activities to source selection and are stakeholders in the outcome of the evaluation and the ultimate decision.
6. Take the necessary steps to get a high-quality proposal.
7. Ensure that all high-level, special-interest groups (which are backed by law) and other mandatory exterior groups are adequately represented and involved prior to the RFP release.
8. Tailor the RFP and source selection process to meet the program's particular needs.
9. Have all Government evaluators conduct a "sealed-envelope" evaluation of the RFP, including the contractor's predicted response, prior to the release of the final RFP.

proposal). The Government's source selection team thus could evaluate the contract, which would be in force once the contractor was selected, as opposed to the contractor's proposal, which merely states the contractor's intentions.

The ATF program office learned nine key concepts as a result of the ATF source selection (see Figure D-1).

1. Make sure the leadership is thoroughly familiar with all parts of the RFP.

One final authority must ensure that all parties have included the appropriate requirements in the RFP and that all elements of the RFP have the correct, common focus. This individual, perhaps supported by a core group, prevents a stovepiped, functional specialist mentality and guarantees that all appropriate parties (including the user) have participated in the RFP process (see Concept 7).

2. Have a clear and agreed-to understanding of the requirements.

Both the system program office (SPO) and the contractors must clearly understand the user's functional requirements. The competing contractors must also thoroughly and correctly understand the SPO's additional requirements for the weapon system and for submitting the proposal.

3. Understand the contractors' program and ensure that it has the appropriate level of risk.

The key to evaluating the quality of a contractor's approach is to understand its development program as laid out in its proposal. Because risk is the major issue in evaluating a proposed program, Government management must understand the contractor's proposed level of risk and evaluate whether it is appropriate and acceptable.

4. Be totally prepared for source selection before it starts.

From all standpoints, the Government team must be fully ready when the offerors' proposals arrive. This includes knowing who is on the evaluation team, what each person is responsible for, and how the team is organized. It is also critical to fully train evaluation personnel in how source selection will operate, how they will do their job, and how they will report and document their portion of the evaluation. A detailed schedule should include everything from preparation details to interim evaluation submissions and contingencies (such as a period for contractor discussions).

5. Guarantee that source selection participants have been involved in the preparatory activities to source selection and

are stakeholders in the outcome of the evaluation and the ultimate decision.

In the best of all possible worlds, the people who make up the source selection team will be same people who wrote the draft RFP, discussed it with the contractors, and will have to live with the chosen contractor. This involvement really supports teamwork, clear communication, and an understanding of the other's view.

6. Take the necessary steps to get a high-quality proposal.

Obviously one can't conduct a high-quality source selection without a high-quality proposal. The problem is identifying the way to get one. The contractors must know that they must submit their best offer first and that there will be no discussions.

7. Ensure that all high-level special-interest groups (which are backed by law) and other mandatory, exterior groups are adequately represented and involved prior to the RFP release.

In general, the program should involve every stakeholder before the RFP release—especially those who have the ability to retard progress. If not involved up-front, they can slow down source selection. The key is to involve them, give them a vote in the contents of the final RFP, and ensure that they don't change their vote.

8. Tailor the RFP and source selection process to meet the program's particular needs.

Some in the source selection process are reluctant to modify and adapt all portions of an RFP to support the unique needs and conditions of the program. The RFP, especially Section L, Instructions, Conditions, and Notices to Offerors or Quoters, and Section M, Evaluation Factors for Award, can and should be tailored to the program.

9. Have all Government evaluators conduct a "sealed-envelope" evaluation of the RFP, including the contractor's predicted response, prior to the release of the final RFP.

If required to see the RFP (or, first, the draft RFP) from the offeror's perspective and develop an estimate of what the contractor will propose to do or is capable of doing, the evaluators will prepare a better, more realistic RFP. Forcing the Government evaluators to answer their own words shows them whether what they are asking for is reasonable.

The nine global concepts above, which were the keys to the program office's success in source selection for the ATF's engineering and manufacturing development phase, are applicable to most other programs.

THE MECHANICS OF ATF SOURCE SELECTION

The goal of this section is to capture the important details of the lessons learned from the 1991 ATF source selection. It describes how the ATF program office performed the tasks of source selection (and how one might do them better). Below are the source selection concepts with examples from the ATF source selection. The specifics described here may or may not fit other programs, depending upon their particular situations.

1. Make sure the leadership is thoroughly familiar with all parts of the RFP.

The Program Director served as the final authority for all items going into the RFP. The Program Director and the Deputy Program Director, Assistant Program Director, Technical Director, Director of Contracting, and Director of Program Control reviewed the draft and final RFPs to guarantee that the items requested were reasonable and needed. During the draft RFP phase, they also reviewed the feedback from the offerors. The Program Director personally made sure that the data items and the required specifications were reduced to the smallest number possible. During source selection, this team served as the key leadership of the Source Selection Evaluation Board.

2. Have a clear and agreed-to understanding of the requirements.

a. Open discussions during demonstration/validation. During the 2 years of demonstration/validation prior to the RFP release, the program office, Tactical Air Command (TAC), Air Training Command (ATC), the Air Logistic Centers (ALCs), other Government agencies, and the contractor teams frequently and openly discussed every facet of the RFP and the EMD phase of the program. It was only through these discussions that the SPO was able to communicate to the contractors and other Government agencies their intentions, requirements, and procedures for conducting source selection.

b. Draft RFPs. The ATF program office started the draft RFP process 2 years prior to the release of the final RFP and had four complete draft RFPs (the first two were actually called Preliminary Acquisition Packages and contained sections of the RFP) that they reviewed with the offerors. As part of this process, the SPO, TAC, the ALCs, ATC, and the National Security Agency honed the requirements to reflect what they really needed and phrase them adequately and clearly. As a result, the contractors easily saw what the Government was requesting. A key part of this process was the detailed follow-up to each draft RFP. Following the release of the first two draft RFPs, a representative of each Government entity and a contractor representative separately discussed the RFP and reviewed the contractor's suggestions for improvement. Following the third and fourth (final) draft RFPs, each contractor's work breakdown structure group formally and separately submitted final comments for improvement to the SPO. Also, the SPO and the contractors conducted monthly in-process reviews to formally analyze each section of the RFP. During this process, the contractors provided over 1,000 documented comments to the final RFP. In addition, more formal acquisition strategy working groups met to resolve program-level issues. As a result of the four iterations of draft RFPs, the contractors had few or no exceptions to the RFP, the Government included no surprises in the final RFP, and the contractors included no surprises in their proposals. Because they forced the Government and the contractors to communicate clearly and understand the requirements, the draft RFPs greatly reduced areas requiring discussion and assisted in shrinking the time necessary to conduct the source selection.

3. Understand the contractors' program and ensure that it has the appropriate level of risk.

a. Proposal "maps" and cross-references. For the ATF program, the key to understanding a complex, multivolume proposal was to prepare a map of the proposal and an in-depth matrix cross-referencing the requirements to sections in the proposal. A standardized proposal structure (e.g., volume-numbering schemes) would also have aided in the evaluation. Requiring such review aids in the RFP will help ensure thorough proposal evaluations, which will lead to an understanding of the contractor's proposed program and proposed level of risk.

b. Evaluation of the offeror's management approach. An extremely helpful procedure was to evaluate how each team would manage its activities to develop and produce the ATF weapon system. This evaluation extended to the contractor's management philosophy as well as its organizational relationships with teammates and key suppliers. To get the data to conduct this evaluation, the program office tailored RFP Section L, Instructions, Conditions, and Notices to Offerors or Quoters.

4. Be totally prepared for source selection before it starts.

a. Factor team schedules. Prior to the receipt of proposals, the factor chiefs had to state the seating space requirements for their team (based on the number of evaluators on the factor team) and their plan for reviewing the proposals. Each factor schedule had to support the overall area schedule of a quick-look review within 2 weeks after proposal receipt and a detailed review by each team within 1 month following receipt. To prepare a realistic schedule, most factor chiefs jointly worked out the required events with their factor teams. As a result, the factor evaluators were not only educated in what would be expected of them during source selection but were also personally part of building the factor schedule and thus had high ownership of the process. With this advance planning and organization, each factor team was ready to go on the first day of source selection .

b. Training. Formalizing the SPO teams that had been working on particular areas during the draft RFP process for the previous 2 years, 3 months prior to the receipt of proposals the SPO leadership identified each member of each factor evaluation team, each item, and each area and trained these individuals on the source selection process, their particular job, and expectations of them. In this way, all evaluators knew what factor teams they were on, who their factor "boss" was, where they would sit, and what they would do during source selection.

c. Forms. A critical part of the planning and preparation was creating all of the forms needed to document the source selection process (e.g., Analysis Worksheets, Item Summaries). Before source selection, all of the players involved (evaluators, factor chiefs, team chiefs, area chiefs, and administrative personnel) should design, review, and finalize the forms so that they cover all aspects of the source selection (initial as well as final analysis) The purpose and use of these forms should be taught during source selection training prior to the start of source selection.

d. Briefing charts. Careful study of the types of briefings required during source selection could have saved a great deal of preparation and translation time (transfer of information from one format to another). The approved format for the "master" configuration chart should be finalized prior to the start of source selection so that working-level charts for factor and team reviews can transfer more easily into top-level briefing charts.

e. Notebooks. Source selections are heavily bureaucratic (by necessity to force a structured, well-documented, fair selection process). The source selection leaders (factor chiefs and higher) each were given a notebook that contained all of the information they needed to perform the evaluation, such as the source selection regulations, the source selection plan (SSP), the source selection procedures document (SSPD), a cross-reference matrix, the standards and sections of the RFP that applied to that item or factor, and all of the products that team members would complete during the source selection process (e.g., analysis worksheets and item summaries along with instructions on how to fill them out). Most factor chiefs also added to their notebooks their factor team's schedule and other pertinent information. The evaluation team found these notebooks invaluable in organizing and streamlining how they worked.

f. Labeling and packaging of the proposal. To minimize the administrative time required to receive the proposals and shelve them so that evaluators have easy access to them, the RFP should instruct the offeror how to label and package the proposal, thereby eliminating the administrative nightmare of unpacking and marking the proposals for inventory purposes. To ease distribution, the RFP should include instructions to have the offeror label each copy of each volume (i.e., copy 1 of 25, etc.), and to have the offeror provide a clear and logical invoice, stating the specific contents of each box. Additionally, offerors should be instructed to submit updated copies of the model contract or other proposal volumes, if required, in binders of a different color than the binder for the original submittal and to appropriately annotate the changes made within each volume.

g. Provide for all contingencies. For several years prior to RFP release, the clearly stated objective of the ATF source selection was to conduct the selection without discussions. The SSP and the SSPD followed that philosophy and did not include provisions or procedures for discussions. When, ultimately, the program office did require discussions with the contractor, a great deal of effort and coordination was needed because the procedures had not previously been thought through. The lesson is to prepare for the worst-case scenario when creating the SSP and SSPD.

h. Evaluator checklists. All evaluators should develop checklists based on their standards and RFP instructions and have them approved by their factor chief. Factor chiefs can provide initial generic checklists to each evaluator for them to build upon.

5. Guarantee that source selection participants have been involved in the preparatory activities to source selection and are stakeholders in the outcome of the evaluation and the ultimate decision.

Key players—before, during, and after. In the ATF source selection, the quality of the proposal, the best understood contractor approach, and the highest quality (most complete) evaluation resulted when one person, or group of people, wrote the RFP section, reviewed it with the contractor counterparts (both teams) during the multidraft RFP process, created the standards for that area's proposal evaluation, and chaired (or evaluated) that factor during source selection. In many cases these individuals were to work on the same area in the EMD phase and were thus highly motivated to thoroughly understand the contractor's program, and involving them in source selection greatly helped in clear communication and understanding of requirements. Conversely, it took a great deal of time to educate evaluators new to the factor being evaluated or, worse, people new to the program on what it was trying to accomplish and how the program was trying to accomplish it. Their evaluations were not as complete and did not contain nearly the same understanding of the offerors' proposed approach as did the evaluations written by those who had been involved in the source selection process before, during, and after proposal receipt.

6. Take the necessary steps to get a high-quality proposal.

a. No discussions. The clearly advertised concept in the demonstration/validation phase was to conduct a no-discussions EMD source selection to convince the contractors of the sincerity of the Government's requirements and to engender the philosophy of "do it right the first time." However, the Government cannot control the requirement for discussion. An offeror merely needs to place unreasonable requirements in, for example, the Government Furnished Equipment list, and discussions would be required.

b. No return of proposals. As a way of reducing the repacking and administrative control of the offeror's proposal after the submittal, the RFP should instruct the offeror that the proposal and related documents will not be returned unless specifically requested. Although no one requested them back, due to the large number of volumes and copies, it could have been an administrative and cost burden.

c. Restrictive markings. The RFP for the ATF program should have instructed the offerer not to put any restrictive marking on any documents in the proposal that are to be included in the resulting "model contract." By not giving guidance to the offeror in this area, the RFP created a potential discussion item. Through oral discussion and clarification requests (CRs), the offerors had to be instructed to remove the markings so contract award could be made using the offeror's submittals. This process could have also been an administrative burden.

d. Point of contact for government-furnished property (GFP). The RFP should have instructed the offerors to identify the location and applicable contract and to provide a point of contact for all GFP. The information necessary to track requested GFP had to be obtained through CRs and caused additional oral discussions. A more specific RFP might have avoided this problem and decreased the time spent running down GFP.

e. Standards that reflect the RFP. The evaluators should prepare their section of the RFP and then prepare the evaluation standard. This helps force the evaluators to ensure that if they want something evaluated, it must be in the RFP.

7. Ensure that all high-level, special-interest groups (which are backed by law) and other mandatory, exterior groups are adequately represented and involved prior to the RFP release.

As mentioned above, all groups (e.g., Small Business Office, Independent Cost Analysis, Independent Technical Analysis) that may or may not add value (but can't be avoided) should be involved early, if for no other reason than to ensure that they do not retard the program's source selection schedule. Also, all groups and reviews should be identified well ahead of RFP release so that the necessary data for the reviews can be requested or generated and the roles and methods can be defined.

8. Tailor the RFP and source selection process to meet the program's particular needs.

The "standard" Section M did not specifically address the contractor's organizational structure and efficiency within the specific criteria. Without modifications to Section M, the Government could not have fairly evaluated the contractors' integrated product team implementations. The program office modified the ATF RFP to give better insight into the offeror's organizational relationship. The teaming relationship is likely to be a fact of life for the foreseeable future, and organizational efficiency is critical to the success of the program; both deserve special emphasis during the evaluation.

9. Have all Government evaluators conduct a "sealed-envelope" evaluation of the RFP, including the contractor's predicted response, prior to the release of the final RFP.

SPO estimates, which require much time and coordination within the SPO, and expectations provide a basis for reviewing the contents of the proposals. The SPO should define the estimates and expectations prior to RFP release to ensure that the requirements in the RFP are sufficient and to familiarize source selection participants with these documents prior to the beginning of source selection. SPO expectations to develop include software development schedules, expected performance values (based on the contractor's design approach), software sizing and timing estimates, and aircraft weight, performance, and reliability. All SPO estimates (e.g., overall schedule, software sizing, software schedules) and expectations (e.g., performance and schedule) should be defined prior to RFP release. These Government estimates will be very helpful in independent cost assessments as well as provide a technical check against what is proposed as part of the factor evaluation.

Other Lessons Learned

Below are other items that may be helpful to other programs as they suffer through the source selection process.

1. **Think through the discussions process.** If discussions turn out to be needed, the written discussion process Clarification Requests (CRs) and Modification Requests (MRs) must include a thorough review process with sufficient feedback to originators.

a. CRs and MRs required numerous reviews before their ultimate release, often with significant changes to the original meaning. In the CR/MR review process, when an evaluator originated a CR or MR, it was reviewed by the evaluator's factor chief, item captain, and area chairperson, and then went to the Source Selection Evaluation Board for approval with release on the day of approval. The CRs/MRs could be sent back to the originator for rewrite anytime during this process. This process worked extremely well; however, in some instances CRs/MRs required numerous rewrites, in part because too many individuals did not understand the CR/MR generation process prior to the beginning of source selection and wrote insufficient and incomplete CRs/MRs. CR/MR training could reduce the need for extensive review. Another cause of CR/MR rewrites was the similarity between two or three CRs/MRs, sometimes from different areas of the source selection. Upon identification, these duplicative CRs/MRs were returned to the originators to be combined into a single document. How well the originators communicated with each other determined how much of the original information remained in the resulting single CR/MR.

b. The source selection team did not provide sufficient feedback to the CR/MR originators. Some were unaware of the status of CRs/MRs, especially when they involved a combined Technical/Program Structure Area input. To alleviate this problem, a computer-generated tracking system database should be established that would allow everyone in source selection access to the day-to-day status of the release of CRs/MRs and the receipt of the offeror's response.

2. **Organize the Past Performance Risk Analysis Group early.** The Past Performance Risk Analysis Group (PPRAG)'s mission is to look at the previous performance of the offerors. Its tools include three contractor performance assessment reports (databases from Headquarters Air Force Materiel Command, Aeronautical Systems Center, and the Defense Plant Representative Office), defense acquisition executive summary reports, questionnaires, and interviews. A

team should be created well before RFP release to gather the information, sort and cross-check it, and start the past performance evaluation prior to the receipt of proposals.

3. Create an administrative group. The ATF program office created this group to handle all of the paperwork and administrative support (e.g., setting up local computers, unloading and shelving proposals, creating forms, tracking CRs/MRs). This group was invaluable.

SUMMARY

The ATF source selection for the EMD phase was remarkable in its efficiency and thoroughness. It was also remarkable that, with so much on the line, neither losing bidder protested the award. It is hoped that these lessons learned will help future programs to progress toward successful contractor selection as well.

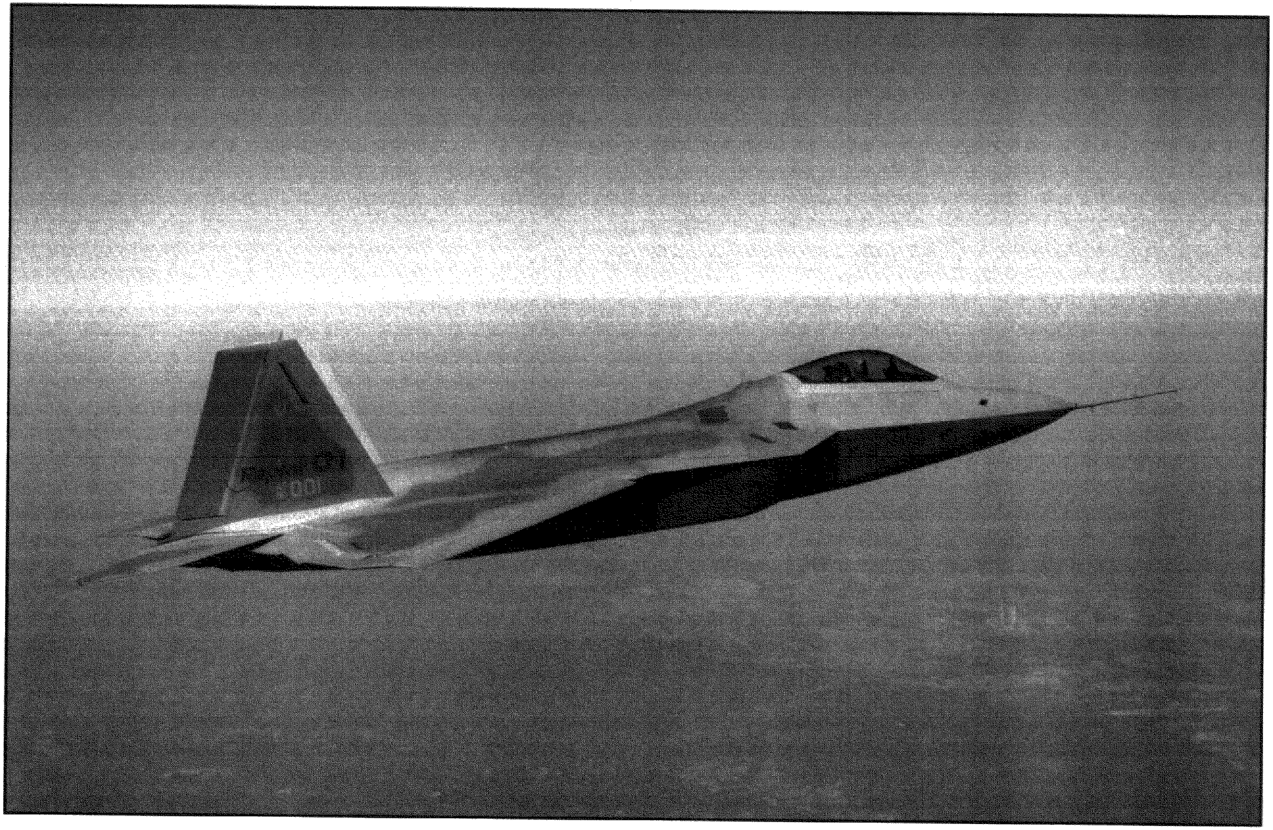


Photo courtesy of Lockheed-Martin.

The first developmental F-22, Raptor 01, during its first flight.

About the Author

Lieutenant Colonel Michael D. Williams, USAF, has extensive acquisition experience and helped manage the development of the Peacekeeper Intercontinental Ballistic Missile and the Small Missile. He has served in the Office of the Assistant Secretary of the Air Force for Acquisition as the Program Element Monitor for Combat Identification Systems, including the Mk XV Identification Friend from Foe system. In addition to helping lead avionics development on the Advanced Tactical Fighter program, he recently served as Chief of the F-22 Support System Integrated Product Team. He is a Level III Program Manager.

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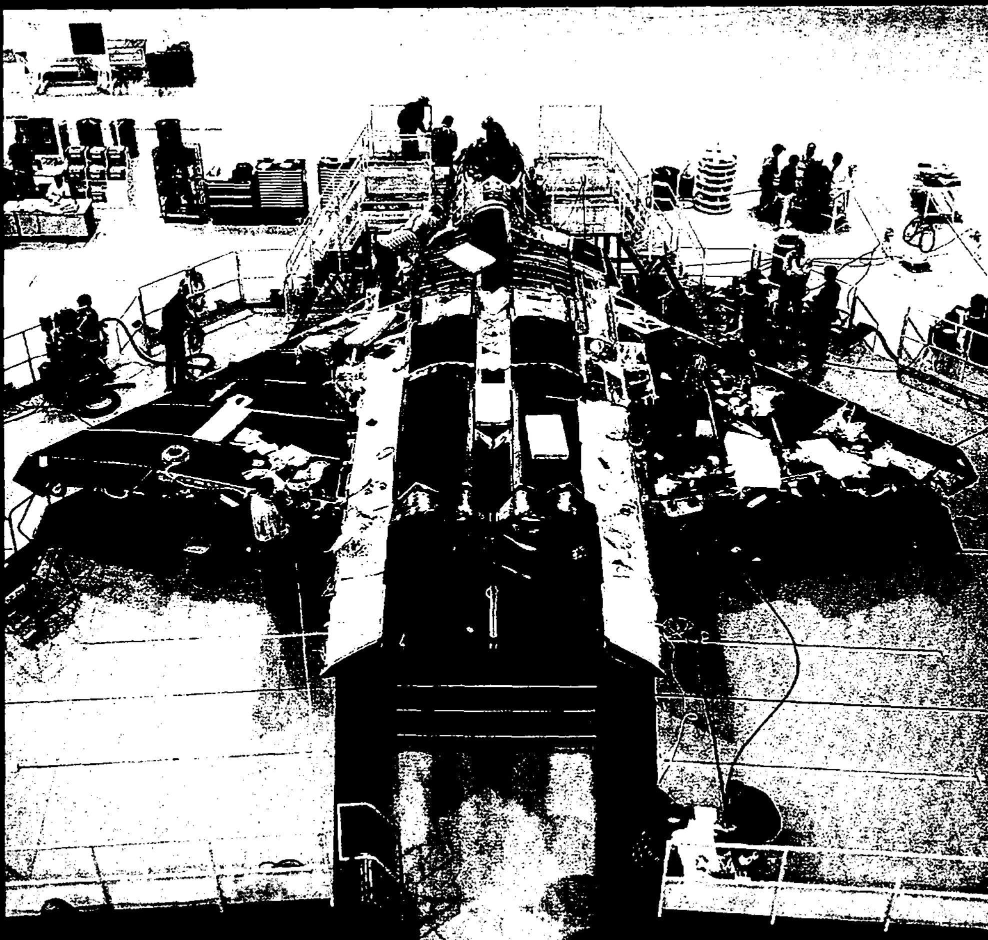
★ U.S. GOVERNMENT PRINTING OFFICE: 1999 – 454 - 121 / 00002



"The F–22 program application of principles—focused on a disciplined process, in an environment of integrity, teamwork, and logic—has worked well to meet the challenge of weapon system complexity."

Published by National Defense University in cooperation with Defense Acquisition University