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Barriers to Managing Risk in Large Scale Weapons System Development Programs

Thomas K. Glennan, Jr., Susan J. Bodilly, Frank Camm, Kenneth R. Meyer, Timothy J. Webb

Project AIR FORCE

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PREFACE

This study grew out of a concern that Department of Defense (DoD) and Air Force efforts to contain their risks in weapon systems development programs—for example, risks that costs would escalate, performance would be deficient, or that a program would be canceled because its development was too expensive—were resulting in policies shifting inappropriate risk to their contractors or creating other unanticipated side effects. At the suggestion of Maj. Gen. John Slinkard, SAF/AQC, this study was initiated to examine the way in which risk was identified and managed in a group of recent program development efforts. The purpose was to develop a better empirical basis for discussion and to provide senior Air Force, DoD, and congressional officials with an overview of the important policy issues.

This report summarizes and integrates the findings from the study, while the major part of the research is documented in other RAND publications:

- Susan J. Bodilly, *Case Study of Risk Management in the USAF B-1B Bomber Program*, N-3616-AF, 1993.
- Susan J. Bodilly, *Case Study of Risk Management in the USAF LANTIRN Program*, N-3617-AF, 1993.
- Frank Camm, *The Development of the F100-PW-220 and F110-GE-100 Engines: A Case Study in Risk Assessment and Risk Management*, N-3618-AF, 1993.
- Frank Camm, *The F-16 Multinational Staged Improvement Program: A Case Study of Risk Assessment and Risk Management*, N-3619-AF, 1993.
- Kenneth R. Mayer, *The Development of the Advanced Medium-Range Air-to-Air Missile: A Case Study of Risk and Reward in Weapon System Acquisition*, N-3620-AF, 1993.

Two related case studies by Timothy J. Webb on risk management during the development of the Global Positioning System Block I Satellite and risk management in preparing for development of the Joint Surveillance Target Attack Radar System (Joint STARS) are as yet unpublished.

The study was initiated before the Cold War seemed so completely concluded and deals with developments that largely took place during the 1980s. In the present policy environment, it seems unlikely that the same pressures that drove system acquisition in that decade will remain. However, the study investigates problems that accompany any effort by large organizations to manage complex and risky development efforts in the face of scarce resources. Moreover, several of the techniques that program offices used to manage weapons developments seem particularly well-suited to the weapons acquisition environment of the 1990s.

This study reflects an understanding of acquisition processes derived from 35 years of research on research and development and acquisition management by RAND, most of it under the auspices of Project AIR FORCE. The lessons derived from this research, which were summarized some years ago in a RAND report by Michael D. Rich, Edmund Dews, and C. L. Batten, *Improving the Military Acquisition Process: Lessons from RAND Research* (R-3373-AF/RC, February 1986), are generally confirmed by the research presented here. However, the emphasis in this report is somewhat different. The earlier research dealt with acquisition policies that, if implemented, RAND judged would lead to superior outcomes. The research here focuses on the implementation of existing policies. The authors seek to show how organizational incentives, political processes, and communication difficulties shape the implementation of these policies, often in ways that defeat their original intent.

This research was sponsored by the Deputy Assistant Secretary for Acquisition (Contracting) of the United States Air Force as part of the Resource Management and Systems Acquisition Program of Project AIR FORCE. This report is intended to be of interest to senior officials of the DoD and the Congress.

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SUMMARY

Managing the development of a major weapon system is, to a great extent, the management of risk. Top managers in the Air Force and its contractors will aim at managing development in such a way that the risks of shortfalls in performance or unacceptable development times and costs are monitored and controlled.

This report integrates the findings of seven case studies of major weapon system development efforts. It attempts to understand how the actions of major actors, including the System Program Office (SPO), supervising command, Air Force Headquarters, Department of Defense (DoD), the contractors, and Congress, interact to shape the character and levels of risk inherent in a development and to manage that risk throughout the development. The systems that are subjects of the case studies were chosen to represent a wide spectrum of development tasks and levels of risk and include the following:

1. B-1B Bomber
2. Advanced Medium-Range Air-to-Air Missile (AMRAAM)
3. Low-Altitude Navigation Targeting Infrared for Night System (LANTIRN)
4. F100-PW-220 and F110-GE-100, Alternate Fighter Engines (AFE)
5. Space Elements of the Global Positioning System ([illegible]
6. F-16/Multinational Staged Improvement Program (MSIP)
7. Joint Surveillance Target Attack Radar System (Joint STARS)

The studies, written largely from the perspective of the SPO, examine the management of risk during full-scale development but often reach back to the important planning and development activities in earlier stages of the acquisition process.

In our analysis, we grouped the seven programs into three categories. Three, the B-1B, AMRAAM, and LANTIRN, experienced substantial acquisition difficulties during full-scale development. Three programs, the AFE, GPS, and F-16 MSIP, proceeded fairly smoothly. The final program, Joint STARS, experienced modest difficulties and turned out to be the furthest from completion at the time of our research. This categorization was based only on the management difficulties, not on the ultimate outcome or value of the program.

The three programs categorized as experiencing significant acquisition difficulties share a number of important characteristics.

1. Each was viewed as central to key Air Force missions.
2. All possessed demanding cost, schedule, and performance objectives that resulted from two important pressures, (1) strong demands from operational commands, and (2) the need to sell the program to authorities outside the Air Force.
3. All included a high degree of concurrency between development and production.
4. Each was subjected to important constraints (funding caps, mandated schedules, etc.) that limited the capacity of the program office to manage the program.
5. In each, there was lack of expertise, personnel, and continuity in the SPO at some key points in the development process.
6. For a variety of reasons, top-level management oversight in the Air Force and DoD discounted lower-level assessments of the level of risk.
7. For each, there were important "holes" in the technology base, which were recognized but de-emphasized in the advocacy for the program.
8. In two of the three programs, the contractor bought into the program expecting to recoup early losses through the prospect of long-term sales that became increasingly problematic.

In contrast, the programs that proceeded fairly smoothly from an acquisition management viewpoint were characterized by:

1. Technologies that were well in hand or handled effectively in earlier phases of the development process.
2. Modest levels of concurrency.
3. Flexibility to make schedule, cost, and performance tradeoffs.
4. Strong and technically qualified program offices that possessed significant elements of staff continuity.
5. Relatively little external oversight.

Perhaps just as significant, there were a number of features of these programs that *do not differ* systematically across these programs, features that are important subjects of acquisition management policy for the development phase. In particular:

1. There were no systematic differences in the types of contracts used. All used fixed-price contracts during development; several used firm fixed-price contracts. But the terms of these contracts varied widely in areas, such as the share line, ceiling, and warranty.
2. Most had a consistent requirement through development, although Joint STARS had requirement instability due to difficulties in resolving Air Force and Army differences concerning the operational concept for using the system.
3. There was a spectrum of source selection procedures ranging from sole source to sustained competition, but the procedures did not seem consistently related to acquisition management outcomes.

4. The developments did not differ in the timing of when technological problems that faced developers in full-scale development (FSD) became known. *In all cases these problems were identified either very early in FSD or before.*

5. All (except the B-1B) dealt with significant externally imposed budget changes in the course of their developments.

Why did our systems differ in their apparent ability to manage risk effectively and to move through the acquisition process? On the basis of our field work, we conclude that the key ingredients of successful risk management are qualified technical staff, possessing sufficient flexibility (or slack) to respond to both expected or unanticipated difficulties in the program, coupled with oversight that is qualified and that forces consideration of program issues that are beyond the purview of the program managers. The programs that experienced difficulties did not consistently possess these ingredients. Those programs experiencing difficulty were relatively large and important to key Air Force interests. Advocacy required to advance them through the system led to early and often overly optimistic promises concerning their outcomes. They were so important to the Air Force that it was willing in some instances to agree to funding levels, schedule guarantees, and funding caps that were unrealistic. These squeezed out the program slack needed for effective risk management.

In contrast, the more managerially successful systems we examined did not require the same level of promises. They tended to be far less visible up the management line. The MSIP and the AFE both *evolved* out of strong and highly organized SPOs. The GPS was planned by a technically qualified program office that enjoyed a special, personal, and direct relationship with the office of the Director, Defense Research and Engineering (DDR&E); this seems to have been possible because the program was not absolutely front and center on the Air Force's agenda. The programs proceeded with comparatively broad specifications, so that their managers, when confronted with problems, could make tradeoffs they felt benefited the entire system.

It is important to emphasize we found nothing to suggest that the basic policies governing the management of large-scale developments are fundamentally flawed. Rather, the problems came in their implementation. Realistic cost, schedule, and performance goals, coupled with quality personnel, are the keys to good risk management. Where significant acquisition problems arose in the cases we studied, they were usually associated with schedules that were overly ambitious, budgets that provided no funds for contingencies and/or hedging, or a reluctance to adjust performance goals after the consequences of maintaining those goals became apparent. The reasons for this appear rooted in the decisionmaking processes of large bureaucracies, decisionmaking processes that provide strong incentives for optimistic promises and disincentives for full disclosure of problems. The most important message of this study is that the senior officials in the Air Force and the DoD who are charged with making decisions concerning strategies for developing new systems as well as setting guidance for schedule, cost, and performance targets should temper recommendations brought forth by their subordinates with an understanding of the intense advocacy environment that frequently shapes those recommendations. Moreover, they should also recognize that sometimes their own behavior shapes that of their subordinates.

To this broad conclusion, we would add two more limited suggestions. First, two of the programs we examined, the AFE and the F-16 MSIP, seem to us to provide useful guidelines for research and development management for a significant proportion of the Air Force's acquisition program. The long-term continuity of the program office, use of matrixed program and technical staff, sustained and flexible contracting, and evolution of technology-specific development doctrine appeared to contribute to successful development outcomes.

Second, several of the programs in our study could be said to have gotten "out of control" in that they were subjected to a continuing series of reviews, site visits, program revisions, congressional interventions, and personnel changes that, in our judgment, often seemed to have deleterious effects on the program outcome. We think that many of the actions taken by complex and political bureaucracies when a program is in deep trouble are counterproductive because they constrain program managers in making needed changes. The Air Force and DoD should consider some form of special management for programs that are experiencing great difficulty—something akin to putting a business into receivership.

ACKNOWLEDGMENTS

This report owes much to the willingness of numerous people in program offices and industry to take the time to talk with us, to guide us through program files, and to explain issues that we did not initially understand. In addition, the staffs of the Historical offices at both the headquarters of the Air Force Systems Command and the Aeronautical Systems Division were very helpful. Throughout Lt. Col. Clinton Asbury, AF/AQE, served as project monitor and helped us to make necessary contacts. Within RAND, Giles K. Smith and Arnold Levine provided helpful and complete reviews of this report and the case studies that underlie it.

A/C	Aircraft
AFE	Alternate fighter engines
AFSC	Air Force Systems Command
AIL	Airborne instrument laboratory
AMRAAM	Advanced Medium-Range Air-to-Air Missile
APREP	AMRAAM Producibility Enhancement Program
ARPA	Advanced Research Projects Agency
ATF	Advanced tactical fighter
ATR	Automatic target recognizer
DDR&E	Director, Defense Research & Engineering (Office of the)
dem/val	Demonstration/validation
DoD	Department of Defense
DSARC	Defense System Acquisition Review Council
FFP	Firm fixed-price
FPI	Fixed-price incentive
FSD	Full-scale development (now called Engineering and Manufacturing Development, EMD)
FTI	Fixed-target indicator
GD	General Dynamics
GE	General Electric
GPS	Global Positioning System
IOC	Initial operational capability (date of)
IR&D	Independent research and development
JPO	Joint Program/Project Office
Joint STARS	Joint Surveillance Target Attack Radar System
LANTIRN	Low-Altitude Navigation Targeting Infrared for Night System
LRIP	Low-rate initial production
MLRS	Multiple-launch rocket system
MOA	Memorandum of Agreement
MOU	Memorandum of Understanding
MSIP	Multinational Staged Improvement Program
MTI	Moving-target indicator
OMB	Office of Management and Budget
OSD	Office of the Secretary of Defense
PM	Program manager
P&W	Pratt and Whitney
R&D	Research and development
SPO	System Program Office
USAF	United States Air Force

INTRODUCTION

The development stages of a major weapon system acquisition are inherently concerned with the management of risk. To be sure, much effort must be devoted to understanding the nature of the operational needs that give rise to the development, inventing the system concepts that promise to meet those needs, organizing personnel to design, test, and fabricate hardware and software that implement the concept, creating the capability to produce the system, and designing the training and maintenance support needed to field the weapon system. But the top managers in the Air Force and its contractors will be concerned with managing the program in such a way that the risks of shortfalls in performance or unacceptable development times and costs are monitored and controlled.

This report integrates the findings of seven case studies of major weapon system development efforts (see Table 1). It seeks to understand how the actions of major actors, including the system program office (SPO), supervising command, Air Force Headquarters, Department of Defense (DoD), the contractors, and Congress interact to shape the character and levels of risk inherent in a development and manage that risk throughout the development. The systems that are subjects of the case studies were chosen to represent a wide spectrum of development tasks and levels of risk. The studies, written largely from the perspective of the program office, examine the management of risk during full-scale development but often reach back to the important planning and development activities in earlier stages of the acquisition process.

The story we tell is a complex but common one. The manner in which levels of risk are set and managed is determined to only a limited degree by such policies as those embedded in the DoD 5000 series of directives and regulations. To a much greater

Table 1

Programs Selected for Study

	Program
1.	B-1B Bomber
2.	Advanced Medium-Range Air-to-Air Missile (AMRAAM)
3.	Low-Altitude Navigation Targeting Infrared for Night System (LANTIRN)
4.	F100-PW-220 and F110-GE-100, Alternate Fighter Engines (AFE)
5.	Space Element of the Global Positioning System (GPS)
6.	F-16/Multinational Staged Improvement Program (MSIP)
7.	Joint Surveillance Target Attack Radar System (Joint STARS)

extent, the level and management of risk is a result of complex interactions among many actors and organizations, their operating procedures, and the nature of the technology itself. The problems that the Air Force and the DoD have with managing risks are often *system's* problems not policy problems. The normative view of risk management embodied in DoD Directive 5000.1 seems solid and well-founded. However, as we are finding in many other areas of our society, improved performance of important private and governmental functions requires an understanding of the full organizational and political systems as well as a willingness to deal simultaneously with the many determinants of the performance of that system. We cannot provide such a full understanding and array of proposed actions from the research effort to be described here. Rather, the goal of this study is more limited: to contribute to our understanding of the system itself and to the appreciation that broad prescriptive policies so often preferred by policymakers may have little effect in the face of the myriad incentives built into our complex government and business organizations.[1]

THE VIEW OF RISK USED IN THIS STUDY

For the purposes of this study, we have a very straightforward concept of risk. From the point of view of top-level management, risk is the probability that program outcomes occur that have seriously adverse consequences for the nation. In terms of the traditional metrics of acquisition management (costs, schedule, and performance), risk is the probability that costs will be so high that few of the systems can be acquired or that the schedule is delayed so that capabilities needed by military forces to meet perceived threats will not exist in a timely fashion, or that the performance of the system will not allow the forces to meet that threat.

While in real life, measures of cost, schedule, and performance are complex and multidimensional, intuitively we can represent this notion of risk for a single outcome dimension quite simply as we do in Figure 1. This is a picture of a subjective probability distribution of some important outcome held by leaders of a program. In this diagram, the outcome value *O* represents a level below which the performance is deemed seriously inadequate for the mission, and the shaded area is the probability that such inadequate performance will be obtained.

The level of risk can be changed in a number of ways. For example, additional resources might be added to allow the project to sustain two approaches to achieving the performance. The joint probability that both approaches fail to meet the performance level *O* should be less than that of a single approach; the distribution would be moved to the right (and changed in shape) so the shaded area decreases. Alternatively, the designers and operators might take actions in other parts of the system or revise their operational concept so that the outcome *O* is less critical and the mission can be achieved at a lesser level of performance. The vertical line at *O* moves to the left, and the risk is reduced.

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[1]The fieldwork for the case studies was done in late 1990 and early 1991. The cases themselves deal with Air Force and contractor operations as they existed roughly between 1975 and 1990. Since this time, a profound restructuring of the Air Force has been initiated. Surely, these new organizations would manage programs such as we describe differently (and perhaps better). We remain persuaded, however, that the general phenomenon we describe and the perspective we take remain relevant in this new era.

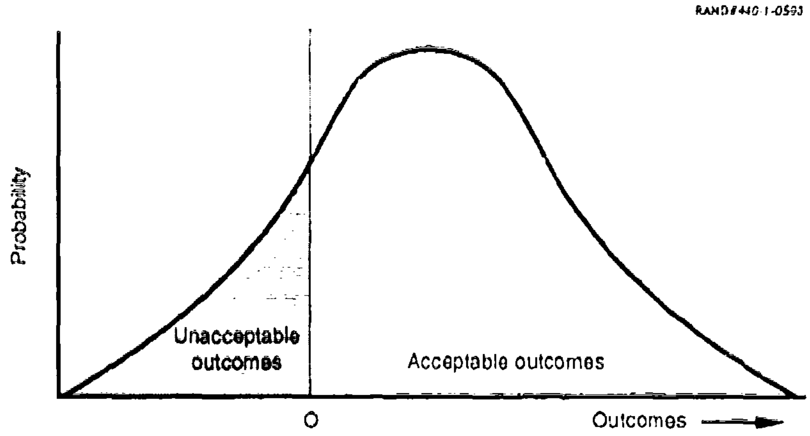

Figure 1—Representation of Risk

This simple representation requires qualification in two ways for our needs. First, the number of outcomes that are properly of concern is enormous and estimations of the type of distribution shown in Figure 1 are not normally possible. For very simple cases, formal analytic techniques exist to create such distributions. Such techniques may be used to provide inputs to program planning, but managers seldom rely exclusively on them. Rather, when dealing with programs as a whole, managers prefer to adopt robust strategies that drive the risks of catastrophic downside events to an acceptably low level. This involves a good deal of organizational attention to risk assessment but not generally a reliance on formal analytic techniques.

Second, this discussion has assumed that the risk is assessed by a rational actor who has a clear understanding of the national interest. In fact, many actors, including members of the program office, development and using commands, Air Force headquarters, DoD, Congress, and the contractor community, are involved in planning and other activities that set the risk surrounding a weapon system development and affect the capacity to manage that risk. These actors vary in the dimensions of downside risk that they emphasize and in their knowledge of the factors that determine that risk. The technical staff of a contractor may have a traditional concern for the failure of the system to achieve performance levels within available budget. For the contractor's top management, the risks may be failing to win a competition or the possibility of a cancellation of an existing program that will have effects on the corporation's sales and profits. Air Force leaders may emphasize the risk of poor or untimely performance or of termination of a program. The Congress may be concerned over program outcomes that injure their constituents or affect budgetary decisions they have previously made. The program office, the focal point of the government's risk assessment and management activities, shares many of the perceptions of these other actors, but its individual staff members (along with many of the contractor's staff) may also factor in concerns for adverse risks related to career advancement.

The concerns of these actors are legitimate and, our cases show, often affect the dimensions of risk that receive emphasis, the levels of that risk, and the capability of the contractors and program office to manage that risk. In a costly program central to Air Force core missions, for example, negotiations will take place between the Air

Force and the DoD and the Congress concerning cost, performance, and schedule levels. To maximize the probability of program approval, the Air Force has incentives to represent its program in the best possible light. It will want to promise high levels of performance and timeliness, coupled with reasonable costs, to persuade its superiors that the system should be approved or continued. The Congress or DoD, on the other hand, recognizing the incentives driving the Air Force, are concerned that the promises may be optimistic and that the risks of failure to meet the promises are high. The actual choices of key outcomes are the result of this complex bargaining process involving actors with a variety of perspectives and objectives. Our analysis suggests that under some circumstances, this bargaining process has the effect of increasing the levels of risk to the nation of ineffective acquisitions. It does this both by increasing the outcome thresholds that are used to judge whether the acquisition is seriously deficient and by reducing the time and resources available to program managers to deal with threats to outcome shortfalls.

This is easily illustrated by Figure 1. Suppose that the outcome dimension is some measure of payload/range/penetration capability for a new bomber. Given some estimate of the threat, advocates of the system have every reason to promise the best performance measure possible—to try to move the value *O* to the right. But at the same time, there will be pressures to show that the costs for achieving this capability are reasonable and that the capability can be obtained in a timely way. Both these pressures will tend to shift the distribution of outcomes in Figure 1 to the left, because fewer resources will be available to cope with technical difficulties, and quite possibly, greater levels of concurrency between development tasks and development and production will reduce the time that the developers have to deal with unexpected development outcomes.

These observations are scarcely new. The incentives we describe are well-known, and Air Force and DoD procedures intended to modify and cope with them have long been in place. Most prominent are the DoD 5000 series directives and regulations. These directives specify an acquisition process whose broad features have remained unchanged for many years. The principal phases of the process are shown in Figure 2.

A formal concept formulation phase focuses on the mission needs and the alternative operational and technological approaches to meeting those needs. The demonstration/validation (dem/val) phase is used to try out critical components of the system and often involves tests of prototypes of key system components. Only when the risks have been reduced by both these development and test activities and continuing mission analysis is the program supposed to be approved for entry into full-scale

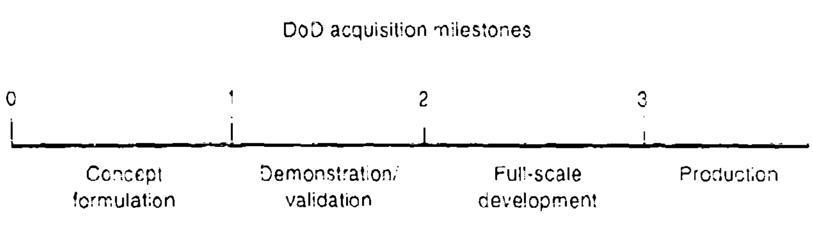

Figure 2—Phases of the Acquisition Process

development (FSD).[2] These two phases are expected to have costs that are modest compared with those of full-scale development and to reduce the risks of FSD substantially by sharpening the understanding of desirable outcome targets and identifying areas of technical risk that must be specifically addressed during this critical phase of activity.

The goal of our study, then, is to understand better how risk is identified and managed during these two critical development phases and to suggest ways in which that process might be improved.

ORGANIZATION OF REPORT

The empirical basis for our findings is in the case studies. Chapter Two outlines factors that we anticipated would affect the level of risk and the capability of the program office and contractors to manage that risk. It describes how we chose the systems for study and briefly describes those systems. (The studies themselves are published separately.) Chapter Three summarizes what we found concerning how factors affecting risk were treated in our cases and provides an overall analysis that serves as the basis for the findings and recommendations contained in Chapter Four.

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[2]Full-Scale Development is now called Engineering and Manufacturing Development (EMD), but the earlier terminology is retained in this report.

MANAGING RISK IN SEVEN SYSTEM DEVELOPMENTS

STUDY DESIGN AND SELECTION OF CASES

Our study design uses seven case studies of weapons acquisition to examine the manner in which risk was dealt with during their development. On the basis of previous research and our review of the literature, we expected that a number of factors would affect both the level of risk at various stages of the program and the capacity of the Air Force and the contractor to manage that risk. In particular, we identified the following:

1. The degree to which the technology underlying the development is well in hand at the initiation of full-scale development.
2. The stability of the requirement for the system through the development.
3. The qualifications and continuity of experience of key members of the SPO staff.
4. Features of the program management strategy, such as the level of concurrency.
5. The nature of the contractual relations between the contractor and the government.
6. The prominence and nature of intra-governmental or inter-service involvement in the program.
7. The use of competition throughout the program.
8. The nature of the contractors.
9. The nature of constraints external to the program created by Congress, the DoD, or Headquarters United States Air Force (USAF).

The case studies examined these factors and attempted to understand how they interacted to affect program outcomes.

In selecting cases for study, we wanted a spectrum of development situations. We sought to look at a variety of technologies and types of systems rather than restricting ourselves to aircraft, missiles, or space systems. We wanted to examine both large and small programs; politically controversial programs as well as ones about which considerable consensus existed. We thought it important to look at programs with low expected production volumes as well as those for which long production runs were anticipated. Finally, we wanted to look at relatively recent programs, both because they would have been conducted under acquisition policies that were similar to those existing as we initiated our study and because we felt data and people would be more readily available. Thus we tried to examine programs that were initiated in the mid-1970s or later. Table 2 lists the systems that we examined.

The history of each of these programs is complex and idiosyncratic, as is always the case with research and development activities. The conduct and outcomes depend in no small measure on personalities, luck, and the nature of the political environment in which the program is carried out. Our case studies try to capture some of this richness and must be read to understand the specifics of each case. However, the task of this report is to try to step back from these individual features and ask what the collection of cases as a whole tells us about acquisition management and more particularly the management of risk. To facilitate this, we provide only brief overview descriptions of the programs here.

B-1B BOMBER

The B-1B case concerns the procurement of an entire platform and its component systems. In 1981, President Reagan announced plans to buy a fleet of 100 strategic bombers to replace the aging B-52 force. This decision was the culmination of a decades-long debate over whether (and with what) to replace the aging bomber force. At the same time that the B-1B bomber program was announced, the Air Force also undertook the development of a stealth bomber, the B-2, to replace the B-1B.

The B-1B was designed with many improvements over the B-52. It was stealthier because its radar cross section was significantly less visible to enemy radar than the old B-52. The design incorporated improved offensive and defensive avionics to combat the increased Soviet capabilities.

Table 2

Systems Selected for Case Studies

	Type of System	Size of Program (Billions of 1989 $)	Ratio of R&D to Production Costs (%)
B-1B Bomber	Aircraft	30.7	14
Advanced Medium-Range Air-to-Air Missile (AMRAAM)	Missile	6.8	21
Low-Altitude Navigation Targeting Infrared for Night System (LANTIRN)	Avionics	3.3	25
F100-PW-220 and F110-GE-100, Alternate Fighter Engines (AFE)	Aircraft engines	>10.0	<7
Global Positioning System (Space Elements) (GPS)	Space system	2.7	149
F-16/Multinational Staged Improvement Program (MSIP)	Modification program	24.0	4
Joint Surveillance Target Attack Radar System (Joint STARS)	Command and control	7.1	81

NOTE: Figures are approximate and include estimates, because production is not finished for most systems.

The decision to procure the B-1B was made by the President, in consultation with the Department of Defense, and by the Congress after negotiations over the quantity, cost, and schedules for procurement. Rapid development was essential. At the time the program was undertaken, some defense planners felt the United States would be vulnerable to a Soviet counterforce attack without the B-1B bomber. These planners talked of a window of vulnerability that, without the B-1B, would leave the United States open to a devastating attack by superior Soviet strategic forces. Congress and the President were convinced of the need for a bomber to guard against this attack, but Congress was concerned about the cost of the procurement.

The high-level negotiation, outside of the control of the SPO, culminated in a program management plan with severe constraints. Both branches of government agreed to a firm and urgent date of initial operational capability (IOC) requiring extensive concurrency, a funding cap, a multi-year contract, and an additional role for the SPO to act as the system integrator to reduce the costs of the procurement. This decision was based on the assumption that technical risk was low because the contractors had previously developed the B-1A.

This assumption proved to be false. The B-1A had not been fully tested and developed when its program was canceled. Further tests showed significant problems that would have to be addressed in the B-1B program. Moreover, the B-1B design called for improvements based on untested technology in several areas, the most important of which was the defensive avionics. When technical difficulties in this and other systems began to appear, the program office was so constrained by the negotiated program goals that many remedial actions were precluded.

The program had elements of both success and failure. It met its nominal funding cap and schedule but failed to meet the original performance requirements. In particular, it failed to meet the performance levels required during the predicted window of vulnerability.

ADVANCED MEDIUM-RANGE AIR-TO-AIR MISSILE (AMRAAM)

The AMRAAM program was initiated in response to Air Force studies of air-to-air combat that indicated a need for a significant improvement over the capabilities of the current medium-range missiles in the Air Force inventory. The major innovation in AMRAAM was a fully active guidance system that would give AMRAAM a true "launch and leave" capability. This would free pilots from the need to illuminate the target aircraft with their own radar (as they had to do with the AIM-7 Sparrow, which incorporated a semi-active guidance system), and permit multiple engagements in a single pass. AMRAAM would also be superior to the AIM-7 against low-altitude targets and electronic countermeasures. The Air Force projected that AMRAAM would achieve twice the combat capability of the AIM-7 at one-half the cost.

The program encountered serious technical, cost, and schedule difficulties, largely related to the failure of anticipated technologies to mature as planned. In addition, external demands placed on the program hamper the ability of managers to respond to development problems. The Air Force Systems Command (AFSC) shortened the development schedule, which, in turn, dictated an extremely high level of concurrency, and required that a second source be qualified early in the development phase. The Office of the Secretary of Defense (OSD) mandated that rigid test goals and thresholds be established, and congressional requirements stipulated that the program would have to meet all of the original performance specifications. In response to cost increases, the Air Force initiated an extensive redesign effort in 1985, the AMRAAM Producibility Enhancement Program (APREP), designed to reduce program costs.

Though AMRAAM's cost, despite APREP, is still much higher than the initial estimates (by a factor of three to five), and IOC was achieved five years later than originally anticipated, the missile has met performance expectations.

LOW-ALTITUDE NAVIGATION TARGETING INFRARED FOR NIGHT SYSTEM (LANTIRN)

The LANTIRN is an avionics system providing single-seated fighters with the capability to navigate and target at night and during poor weather. At its initiation, it was expected that LANTIRN would dramatically increase the capabilities of the tactical air forces. As such, it was viewed as an urgent requirement by the Air Force.

The early requirements imposed technically demanding specifications for system performance. Engineers involved in the program described the technical advances needed to meet these standards as high risk and high cost. However, because of the urgency of the requirement and the assertion that technical problems had been dealt with in an earlier "special-access" program, LANTIRN proceeded without a dem/val stage to test its technical concepts prior to the commitment to procurement. Our research suggests that advocates for the program inadequately acknowledged these risks when discussing the program with Congress. They described the program as a low-risk, low-cost program, setting up unrealistic expectations in congressional sponsors.

The failure to recognize fully the risk involved translated into an ambitious management plan that called for extensive concurrency. The program suffered numerous setbacks, and the performance requirements were periodically relaxed until they coincided with technical realities. The program suffered from high R&D and unit cost overruns and was very late relative to the initial schedule. While it lacked the full performance sought in the original requirements, it is regarded as an important expansion to force capability.

F100-PW-220 AND F110-GE-100 ALTERNATE FIGHTER ENGINES (AFE)

The AFE development involved two parallel development efforts that ultimately provided the basis for the "Great Engine War," a series of annual production competitions between the F110 and F100-PW-220 engines. To remedy serious operability and supportability problems with the F100-PW-100/200 engines that it used in its F-15 and F-16 aircraft, the Air Force pushed their manufacturer, Pratt and Whitney (P&W), to develop several significant modifications. To improve its leverage with P&W, the Air Force also supported a small-scale effort by General Electric (GE) to derive a fighter engine from the engine it had developed for the B-1 bomber. As the GE effort came to fruition, yielding the F110, support for a production competition between this new engine and a P&W engine grew in the Air Force. P&W eventually combined a set of the modifications it was developing into a configuration that became the F100-PW-220, allowing the competition to occur.

As suggested by the description above, this development was very dynamic. The Propulsion SPO, which was in place before these developments started and was staffed by an experienced and technically sophisticated team, managed the developments skillfully, responding effectively to growing support for formal competition and coordinating the parallel developments so that effective competition would ultimately be possible. The SPO took deliberate actions to limit risk by using as much proven technology as possible in the new engines, imposing demanding performance warranties to ensure realization of its development goals, using its technical capabilities to monitor both developments closely on a day-to-day basis.

In the end, the Air Force achieved its principal development goals with approximately the cost and schedule expected. The new GE engine forced P&W to address major problems in its F100 engine. Both new engines embodied new reliability engineering that dramatically improved the durability of the engines the Air Force used in its F-15 and F-16 aircraft. Both engines effectively eliminated the stall stagnation operating problem that had presented safety problems in these aircraft. The existence of two engines supported an ongoing production competition that improved the Air Force's leverage with both contractors. The developments went so well that the Air Force formalized the implicit competitive approach it used in them to develop the engines that replaced the F100-PW-220 and F110.

GLOBAL POSITIONING SYSTEM (GPS)

The GPS is a space-based, radio positioning and navigation system that is designed to provide extremely accurate three-dimensional position and velocity information, together with system time, to suitably equipped users. It is composed of a constellation of satellites that broadcast signals that are interpreted by autonomous receivers; the satellites are supported in their operation by a ground-based control segment. The GPS consists of three major segments: space, control, and user.

The GPS has its roots in two distinct parts of the military operational community: the Navy, which traditionally assumed responsibility for the development and implementation of aids to marine navigation, and the Air Force, which became interested in precise navigation because of the lack of capability to bomb targets with sufficient precision during the Vietnam War. These respective interests spawned separate programs in the late 1960s directed toward developing satellite-based radio-navigation capabilities. These programs were eventually merged into the GPS program, to address both needs with greater efficiency.

The management strategy for full-scale development of the Block I spacecraft was probably less important to the success of the development than was the management strategy for dem/val. For the dem/val, the SPO chose to proceed with deployment of a series of experimental satellites, learning progressively through experience. This trial and error approach was possible in part because of the low visibility of the program, a circumstance that generally allowed technical imperatives to take precedence over more political or bureaucratic imperatives.

FSD was structured to pursue only modest advances in satellite design beyond that of the dem/val phase. This was less true for user equipment, for which FSD involved advancing from large experimental sets on pallets to much more modular equipment integrated in operational configurations into a variety of combat platforms. The basic management strategy with regard to the spacecraft can be described this way:

beat down the technical risk to low levels by experimentation and set only modest goals for technological advance during FSD (this was true even before the budget shortfall necessitated a less ambitious set of performance specifications for FSD).

Demonstrating enabling technology for the GPS satellite in the dem/val phase seems to have contributed substantially to the relatively smooth progress of FSD. There were few technological surprises. The surprise with the greatest consequences for the development program as a whole (though not for the spacecraft design) was the Challenger accident, which revealed the weakness of relying exclusively on the shuttle for transporting GPS satellites to orbit.

This case suggests that the distinction between dem/val and full-scale development is somewhat ambiguous and circumstantial; the GPS satellite full-scale engineering development took place in large part during dem/val. In this case, the transition from proof-of-principle experiments to operational capability proved to be rather gradual and incremental.

The GPS program resulted in deployment of a system that is generally regarded as having met cost, schedule, and performance expectations. Though there were instances of cost overrun, schedule slippage, and modification of performance specifications, these did not fundamentally alter the timeliness or utility of the system.

F-16/MULTINATIONAL STAGED IMPROVEMENT PROGRAM (MSIP)

As it began to field its first F-16 A/Bs, the Air Force anticipated the need to upgrade the aircraft systematically over its lifetime as the threat changed and new technical capabilities became available. The Air Force worked with General Dynamics (GD), the F-16 developer, to devise a formal mechanism for developing new versions of the aircraft. The MSIP was the result. It ultimately provided a mechanism for improving new F-16s in a series of stages, customizing models for each country that bought the aircraft, upgrading existing U.S. and foreign aircraft to take advantage of new technical capabilities, and developing derivatives of the F-16 for specialized missions.

The F-16 SPO used time-tested methods for developing the F-16 A/B to coordinate the testing and integration of a large number of subsystems in parallel with one another and with the formulation of complete new configurations for the F-16 itself. Underlying multi-year production contracts limited risk by stabilizing demand schedules for the U.S. aircraft. The major residual risk lay in subsystems that would not perform as expected or would not be ready when promised. The MSIP dealt with this problem by (a) seeking subsystems based on well developed technologies, (b) coordinating test and integration activities with subsystem developers early, (c) preparing contingencies to substitute available systems for those not yet available on new production aircraft and to retrofit new subsystems as they became available, and (d) using an experienced and well-trained staff to manage inevitable surprises as they arose. Such activities were possible only because the F-16 SPO had great flexibility and maintained close, mutually satisfying working relationships with GD, in particular, and most of the other organizations involved in developing and testing subsystems.

Most observers view the MSIP as a great success. Difficulties in the development of subsystems delayed the operational availability of new capabilities in the F-16 fleet, but the mechanism devised to maintain the preplanned production schedule and bring new capabilities on-line as they did become available worked well. Methods based on the MSIP also allowed rapid and confident development of a wide variety of F-16 variants to match the many missions that this multi-role fighter now serves in the United States and elsewhere.

JOINT SURVEILLANCE TARGET ATTACK RADAR SYSTEM (JOINT STARS)

The Joint STARS is an aircraft-mounted, radar-based system that can detect mobile armored forces. Joint STARS facilitates the accurate attack of enemy forces by providing position information on enemy targets to direct attack aircraft, artillery, and standoff missiles. Additionally, Joint STARS can be used to gather wide area surveillance information on the disposition of enemy ground forces. The Joint STARS program was initiated by OSD to consolidate separate Air Force and Army programs directed toward accomplishing these targeting and surveillance objectives.

For a number of years before Joint STARS, both government and industry had conducted demonstrations of enabling technologies for long-range location and tracking of armored vehicles. The Army laboratory at Fort Monmouth, New Jersey, and the Air Force Rome Air Development Center in New York (through the work of Lincoln Laboratory) had each demonstrated not only the laboratory feasibility of various enabling technologies, but had conducted field demonstrations to prove that these technologies could be usefully integrated into aircraft. The enabling technologies were moving target indicator (MTI) radar to detect slow moving ground targets, fixed target indicator (FTI) to identify and classify fixed targets, signal processing to allow a single antenna to serve both functions, data links to pass information, weapon interface units, and the like.

Each service addressed the operational objective of defeating enemy concentrations of heavy forces, but they had different focuses for their efforts; the Army was most interested in striking first-echelon enemy armor (relatively near the forward line of battle) with artillery and the multiple launch rocket system (MLRS), while the Air Force was most interested in striking second-echelon enemy armor with air-to-surface weapons. Although technical concepts for locating and destroying enemy armor differed in the candidate systems, both incorporated airborne radars.

The management strategy for Joint STARS was not so much the product of centralized planning as it was the result of a series of negotiations among the Air Force, the Army, and OSD. The basic program/priced options approach reduced the risk that full-scale development and production would call for greater performance than the budget could support. The choice of a single, large platform reduced a set of technological risks that might not have been easily managed: those of engineering a multimode radar to fit into airframes with little margin for error.

The formation of the joint program, though difficult, accomplished several important functions: It began the process of reconciling Air Force and Army views on long-range surveillance needs for AirLand Battle; it provided a forum for the services, OSD, and the Congress to argue about what Joint STARS should be, particularly during the platform decision and requirements scrub. The formation of the joint program, and the preparation for FSD, served as a focal point for debate over the desirability of the system. The program office performed its management functions reasonably well as this debate proceeded. Though some of those interviewed complained about uneven qualifications and relatively rapid turnover of personnel, the program office nevertheless managed risks with a fair degree of success

The capacity of the program office and contractors to manage risk during full-scale development was largely determined by the ways in which they managed risks *before* full-scale development. Though the development took several years longer than was originally hoped, and cost 30 percent more than originally planned, it nonetheless generated a system that has proven useful in an operational environment. This was possible in large part because of skillfully executed technological and proof-of-principle demonstrations preceding FSD, which reduced the technical risks of conducting the Joint STARS program.

The Joint STARS program is not yet complete—production is only now under way. The developmental system was deployed during the Persian Gulf War, and valuable operating experience gained has been reflected back into the development program. The Joint STARS program has experienced substantial delays, cost growth, and performance changes, due in part to a concept for operation of the system that has evolved continuously.

FINDINGS ACROSS THE CASE STUDIES

At the beginning of this chapter, we listed nine factors important in understanding the management of risk in weapon-system development programs. The case studies, taken jointly, confirm the importance of these factors. In this section, we summarize this experience. At the end of the chapter, Table 3 provides thumbnail comments about each factor for each case. Those interested in more detailed treatment of particular programs should examine the individual case studies.

State of the Underlying Technology

To minimize risks during development, acquisition policy has devoted considerable attention to assuring that the technology required for a new system is well in hand before large commitments are made to that system. Emphasis on the dem/val phase of a program, strong pressures to make use of prototypes, and advocacy of vigorous exploratory and advanced development programs are all intended to assure that systems enter full-scale development either with their technologies well in hand or with problem areas clearly identified and plans for dealing with them in place.

Despite these policies, the technology underlying several of the programs in our sample was clearly not fully developed and ultimately caused substantial difficulties for these programs.

The Quality and Stability of the Requirement for the System

The DoD 5000 series directives and Office of Management and Budget (OMB) directive A-109 place considerable emphasis on beginning the acquisition process with a well-developed and specified statement of needs. If the requirement is unstable, there is an increased probability that the system will come to be viewed as lacking appropriate performance attributes, or that cost increases and schedule slippage will occur as the program scrambles to adjust to new perceptions of operational needs.

In the past, some systems were started before needs were well-understood and had to be modified as the understanding of threat and doctrine evolved. In other cases, the requirement was the product of adversarial bargaining among constituencies with a stake in the approval of the system, and it changed as the bargaining proceeded.

With the exception of Joint STARS, the requirements for the systems that we examined were well-specified and stable. As always, with hindsight, one might have specified a requirement differently; our finding is that, with the single exception, instability of the requirement did not cause great development problems.

The Quality and Continuity of Experience of the SPO Personnel

As we have noted, the management of risk requires considerable expertise to identify where risks are and to devise program strategies that contain and ameliorate that risk. This in turn requires personnel with training and experience—particularly experience with the technologies germane to the system and the specific development activities leading to the full-scale development. Absent such staff and experience, the risks to the Air Force are increased because of the reduced ability of the SPO to anticipate and respond to adverse events affecting program outcomes.

We found no procedures that dealt well with risk in the absence of qualified people in the program office. In our sample, there was considerable variability in the manner in which SPOs were staffed and the quality of the SPO leadership. These had marked effects on the program outcomes.

Features of Management Strategy

There are a variety of features of management strategy that have important impacts on risk. Most prominent in our sample and in policy debate is the level of concurrency among technological development, full-scale development, and production. The higher the level of concurrency in these activities, all other things equal, the greater the risk of schedule slip, performance shortfalls, or cost increases—or all three.

Although concurrency is the most prominent example of a management strategy, there are others. Several of the programs carried out parallel developments to lower risks; one carried a second source to maintain cost discipline and minimize the possibilities of cost escalation.

Management strategies were clearly articulated by the senior staff of the program offices. The problems inherent in high levels of concurrency are so widely recognized that they are always an extensively debated issue in program planning; the programs examined are no exception. The problem, at least as shown in our case studies, is obtaining and using good information on the program-specific risks associated with concurrency. It appears that the variety of actors with interests in programs such as the B-1B, LANTIRN, and AMRAAM held widely differing perceptions on the nature and levels of these risks.

Contractual Terms and Conditions

When this study started, there had been significant complaints by aerospace contractors about the use of fixed-price contracts for research and development. These contractors and their allies claimed that such contracts, particularly when awarded in sharply contested competitions, placed too much risk on the contractor. Several contractors established policies of refusing to accept such contracts. The most prominent adverse effect cited was the possible erosion of the industrial base as firms chose to leave the market, but it is also clear that contract terms that cause one or the other party to bear major financial responsibility for cost, performance, or schedule deficiencies will shape program decisions and the relative power of the parties to the agreement.

Virtually all the major contracts in our sample were fixed-price contracts. However, there was a rich variety in their terms and conditions, the warranties required, the indemnities provided, the process by which engineering changes were agreed to, and the ceilings and share rates that were imposed. Our sense was that the high-level policy debates over contract terms are largely irrelevant to what actually happens because of the complexity of the contractual agreements. Although our studies were too limited to investigate contracts thoroughly, it seems clear that an appreciation of the nature and level of risks strongly informed the actual bargains struck.

Requirements for Intra-Governmental or Intra-Service Agreement

Three of the seven programs had joint sponsorship by the Air Force and the Navy, although the Navy played but a small role in the Alternate Fighter Engine development. Most involved significant cooperation with other development efforts, either because they relied on components developed for other systems or because they were to be integrated with some other system. One program, the MSIP, was predominately concerned with coordinating the efforts of different program offices and contractors.

On its face, "jointness" in the conduct of a development effort seems likely to increase risk because of the differences in perspectives on requirements as well as priority to the services or SPOs. Our cases include examples of both highly successful joint efforts (GPS) and less successful ones (Joint STARS). The MSIP program had worked out a quite routinized and apparently successful procedure for dealing with the coordination problems.

The Use of Competition Throughout the Development Program

The contractors for FSD in the sample were selected in a variety of ways. In most cases, some form of competition was involved. But the situations were complex. For example, there are only two major aircraft engine manufacturers in the United States. In the AFE program, development of the engines proceeded in parallel through the early phases of what amounted to full-scale development. Production contracts that included development work were awarded to both, but the negotiated terms were the result of playing one contractor off against the other. A competition was held for the dem/val phase of the GPS and the winner was carried through the initial production contract. A new competition then resulted in changing contractors, something that appears possible in spacecraft but less so in aircraft or missile systems. In the AMRAAM program, a second source was carried through the development and production phases. In one case, the B-1B, there was no competition, in part as a result of the contractors' participation in the prior B-1A program and in part because it was felt there was insufficient time or money to afford the competition.

The presence of competition has obvious effects upon program risks, most of them positive. A spirited competition for a development contract will often reveal information about technical and production risks in the program because of the distinctive approaches that the competitors take. Continuing competition during development provides both a hedge against the performance failure of a particular contractor (and its technical approach) and a tangible motivation to the competitors to perform well. However, competition coupled with lack of realism on the part of the program office and higher-ups can lead to overly optimistic promises regarding performance, schedule, and costs, which may subsequently constrain program management decisions in undesirable ways. *To the extent that those promises become the criteria by which the overall performance of the program is judged*, competition may actually increase the risks inherent in the program.

The case studies make it clear that the *nature* of the competition influences a program outcome. No senior program official with whom we talked wanted to conduct a program without having a credible threat of competition; similarly, no contractor is anxious to be totally dependent on a single supplier. The AFE case provides a striking example of what might be called managed competition that only in its final stages involved a formal competition among sources. At the same time, the situations examined were so rich and varied that it is difficult to see how policymakers can prescribe a standard means for creating competition.

The Nature of the Contractors

Outcomes are clearly influenced by the experience, the competitive position, the financial strength, and the level of business activity of the contractor. In several cases, problems were faced (and risks increased) because other programs were making demands on a limited design and development staff. In others, firms devoted additional resources beyond those on contract (presumably reducing risks) because they were seeking entry into a new market.

In a couple of cases, contractors "bought into a program," proposing prices that were lower than the costs they expected to incur to enter a new market or solidify market share. They undoubtedly expected to make this back either during subsequent production contracts or because of an enhanced future market position. However, if subsequent events suggest that production will not be there or the market is less important, the prospect of losses (coupled in some cases with tenuous financial positions) may constrain responses to untoward technical and operational events.

In general, in the cases we examined, it appeared that the Air Force had a good understanding of the nature of the contractors when they entered development.

The Nature of Constraints External to the Program Created by Congress, the DoD, or Headquarters USAF

DoD directives and regulations generally emphasize risks associated with features internal to a program. The development process is intended to deal with technological and managerial uncertainties. A few policies, such as those governing price escalators and indemnification clauses, deal with well-defined problems external to the program. But, in fact, a great deal of risk management in the programs we examined dealt with risks external to the program. In particular, program managers regularly had to manage responses to changing budget levels, the imposition of spending caps, special testing and reporting requirements, and newly imposed schedules. They had to be prepared to deal with events that were highly unpredictable and full of apparent arbitrariness.

Implicitly, most managers felt they were dealing with the risk of cancellation or substantial cutbacks in their programs. For example, whatever their formal justification, many of their actions—the early commitment to production or a preference for multi-year contracts—can be seen as a means of lessening the risk of cancellation or cutback. Although we have no clear means of measuring it, our interviews and reviews of program files suggest that much of the most senior managers' time was spent in managing risks to the program inherent in these external events. This was particularly true for high-visibility programs related to core missions of the Air Force.

SUMMARY OF FACTORS AFFECTING RISK IN SEVEN PROGRAMS

Our case studies describe each program in terms of each of these factors and, as we repeatedly note, they should be read for a fuller story. However, we summarize our findings in Table 3. This summary is used in the analysis of risk management contained in the next chapter.

Table 3

Factors Affecting Risk in Case Studies

Attribute	B-1B Bomber	AMRAAM	LANTIRN	Alternate Fighter Engines (AFE)	Global Positioning System (GPS)	F-16C/D MSIP	Joint STARS
Technolog, in hand?	Thought technology was in hand. Actually had serious avionics problems, as should have been expected.	No. Problems with solid-state transmitter, software.	No. Significant advances required, particularly in ATR.	Technology was well in hand. Developments sought operability, supportability, and cost improvements.	Yes. Satellites and payloads worked well. User equipment was overtaken by commercial developments.	Risks were those of subsystems. Program recognized and adapted to them well.	Technology generally proved in PAVE-MOVER. Software problems underestimated.
Requirement well-specified?	Requirement stable. Consensus among DoD, President, and Congress until program experienced difficulties.	Stable. But formalized into technical specs too quickly.	Overambitious. Required capabilities reduced when requirement could not be met.	Yes. But important consensus was on need for competition.	Yes.	Stable threat and strong consensus on requirement. Concern over logistics.	Agreement on broad requirement but considerable difficulty in dealing with differences in AF and Army needs. New defense environment adds additional uncertainty.
Experience and continuity in SPO?	Continuity from dem/val to FSD. Lacked expertise and staff to manage system integration.	Problem. Eglin not experienced and AF had not developed air-to-air missile in many years. Early problem with Program Manager turnover.	Little continuity from dem/val phase. Staff turnover occurred as program experienced problems.	Strong staff continuity in Propulsion SPO. SPO had significant numbers of technically qualified civilians.	Good expertise in SPO. First program director had 7-year tenure. Extensive experience in dem/val phase.	F-16 SPO was experienced. Good continuity in civilian staff.	MITRE provided the important continuity.
Features of management strategy	Extensive concurrency. Air Force role as integration manager. Strict management to IOC date. Funding cap.	Substantial concurrency dem/val and FSD and LRIP. Early introduction of second source for production.	Extensive concurrency.	Derivative development based on designs of earlier engines. Maintenance of competition. Test-analyze-fix approach.	FSD modest advance over dem/val stage. Dem/val used experimental satellites and trial and error to refine system concept.	Multinational governance. Good coordination with other system offices. Heavy use of simulations. Rely on test-analyze-fix strategy.	Air Force teamed with ARPA for proof-of-principle.
Contractual features	FPI contracts. High target ceilings and share lines shifted risk to government. Short warranty periods and dollar caps. Delayed performance specification.	FPI contracts with LRIP options. Required to qualify second source.	FPI, ceiling 130%, 80/20 sharing, warranty on mean time to failure. ATR under separate contract.	FSD contracts were FFP. Risks mitigated by focus on tasks rather than final product. Strong SPO oversight.	FPI contracts for dem/val, FSD, and production. Incentives for performance of satellites on orbit beyond normal life.	Development contracts FPI, 80/20 share, 12% fee, 125% ceiling. Integrated system performance clause.	Used FPI contracts with priced options.

Table 3—continued

Attribute	B-1B Bomber	AMRAAM	LANTIRN	Alternate Fighter Engines (AFE)	Global Positioning System (GPS)	F-16C/D MSIP	Joint STARS
Intra-Governmental agreements	None identified. Plans relied upon F-16 avionics developments and coordination was poor.	Problems obtaining attention of A/C SPOs.	Congressionally mandated competition with Navy system ignored.	Coordination important for tests and design of common engine bay and inlets.	*JPO organized to* include key service players. DSARC review forced early reconciliation of interests.	Used MOU or MOA with subsystem SPOs Used interface control working groups.	Important to resolving differences between Army, AF, and OSD.
Contractor selection	Sole source because *of time constraints* and prior B-1A experience.	Multiple source for *concept development and* competition for dem/val and FSD.	Initial competition *for competitive* prototypes, changed to single contractor.	Heavy use of competition during program but no formal competition for FSD.	Competition for dem/val phase but not for FSD.	Sole source to GD as prime on F-16. Various arrangements on subsystems.	Substantial competition between two contractor teams for FSD. Dem/val *conducted previously* by both teams under ARPA lead.
Nature of contractors	Qualified. Rockwell needed contract. All lacked production experience.	Hughes technically well-qualified. Viewed as high-cost contractor.	Anxious to gain market dominance, willing to underbid to obtain.	Competition between only two qualified U.S. contractors. P&W not responsive *to DoD needs.* GE anxious to gain market.	Rockwell less qualified than some others but invested more heavily in demonstrating key *technologies.*	GD brought experience with F-16A/B. Good working relationship with AF.	Good experience. Problems with software engineering.
Major external constraints	Congressionally specified funding cap and IOC date.	Shortened schedule mandated. Congressionally required certification. Early second source. Many investigations.	Sold to Congress as low risk. Continuous budget fluctuations. Competition from other systems and Navy.	No significant external oversight.	Significant for the positive role of DDR&E and DSARC process. Lack of appreciation of operational value a problem.	Low visibility. No significant OSD reviews of MSIP itself.	No significant congressionally imposed constraints. Heavy OSD involvement to force resolution of disagreements between AF and Army.

Chapter Three

DETERMINANTS OF LEVEL AND MANAGEMENT OF RISKS

We found it useful to group the seven programs we examined into three categories. Three programs, the B-1B, AMRAAM, and LANTIRN, seemed to us to experience substantial acquisition difficulties during full-scale development. (Because the B-1B was a fully concurrent program, the difficulties extended through the production as well.) Three, the Alternate Fighter Engine (AFE), Global Positioning System (GPS), and Multinational Staged Improvement Program for the F-16 (MSIP), proceeded fairly smoothly. The final program, Joint STARS, experienced modest difficulties. In addition, of the programs examined, it turned out to be the furthest from completion at the time of our research.

It is important to emphasize that we are not making judgments about the ultimate performance of these developments. The Air Force and the nation may well have obtained crucial capabilities at reasonable prices and in a timely fashion, even in those programs experiencing acquisition difficulties—and may not have done so in programs that proceeded smoothly. Acquisition difficulties are, to a large extent, measured by the degree to which planned performance, schedule, and cost objectives are met. It may be that these planned outcomes are unnecessarily ambitious. If the program had been planned with lower levels of performance or a less tight schedule, it would have been deemed a model of acquisition management. This, however, is a judgment considerably beyond the reach of this research report.

The three programs categorized as experiencing significant acquisition difficulties share a number of important characteristics:

1. Each was viewed as central to key Air Force missions.
2. All possessed demanding cost, schedule, and performance objectives that resulted from two important pressures: (1) strong demands from operational commands; and (2) the need to sell the program to authorities outside the Air Force.
3. All included a high degree of concurrency between development and production.
4. Each was subjected to important constraints (funding caps, mandated schedules, etc.) that limited the capacity of the program office to manage the program.
5. In each, there was lack of expertise, personnel, and continuity in the SPO at some key points in the development process.
6. For a variety of reasons, top-level management oversight in the Air Force and DoD discounted lower-level assessments of the level of risk.

7. For each, there were important "holes" in the technology base that were recognized but de-emphasized in the advocacy for the program.
8. In two of the three programs, the contractor bought into the program.

In contrast, the programs that proceeded fairly smoothly from an acquisition management viewpoint were characterized by:

1. Technologies that were well in hand or handled effectively in earlier phases of the development process.
2. Modest levels of concurrency.
3. Flexibility to make schedule, cost, and performance tradeoffs.
4. Strong and technically qualified program offices that possessed significant elements of staff continuity.
5. Relatively little external oversight.

Just as significant, there were a number of features of these programs that *do not differ* systematically across these programs, features that are important subjects of acquisition management policy for the development phase. In particular:

1. There were no systematic differences in the types of contracts used. All used fixed-price contracts during development; several used firm fixed-price contracts. But the terms of these contracts varied widely in areas, such as the share line, ceiling, and warranty.
2. Most had a consistent requirement through development, although Joint STARS had requirement instability due to difficulties in resolving Air Force and Army differences concerning the operational concept for using the system.
3. There were a spectrum of source selection procedures ranging from sole source to sustained competition, but they did not seem consistently related to acquisition management outcomes.
4. The developments did not differ in the timing of when technological problems that faced developers in FSD were known. In all cases, these problems were identified either very early in FSD or before.
5. All (except the B-1B) dealt with significant externally imposed budget changes in the course of their developments.

What are the implications of these observations for the management of risk? Based on our case studies, we conclude that the key ingredients of successful risk management are qualified technical staff, possessing sufficient flexibility (or slack) to respond to both expected or unanticipated difficulties in the program, coupled with oversight that is qualified and that forces consideration of program issues that are beyond the purview of the program managers. This is hardly a novel finding. Current policy directives and pronouncements are certainly consistent with the ideas, although one might argue that the exercise of judgment and the flexibility to make decisions may be inhibited in the environment created by a wide array of regulations, directives, and mandates imposed by Air Force Headquarters, DoD, or the Congress.

If this relatively straightforward requirement for good risk management is widely understood, why do programs experience acquisition problems? Our cases suggest that the reasons are systemic—related to the entire array of cultural norms and incentives that govern the activities of the Air Force and the DoD. The key problem is the strongly felt need to promise the very edge of plausible outcomes—in other words, to overpromise. This need is inherent in the decisionmaking environment within which new systems need to be sold. Proponents of a particular system or system concept face this at the initiation of a program when technical and operational ideas are competing to become the basis for design concepts, during contract competitions when designs are competing with one another, at headquarters levels when one command's system is competing with another's for funding, and at OSD and Congress where the systems (and other resource-consuming activities) are competing with those of the other services or other departments of the government.[1]

The pressure to overpromise is high when the program is competing to enter development, but it is also significant during the course of the program. If the program runs into technical or management difficulties or if the perceived threat changes somewhat, there is every incentive to portray the possibilities of "getting well" in terms as glowing as politically feasible.

The result of this bargaining process can easily be overly ambitious and rigid cost, schedule, and performance goals. In terms of Figure 1, these systemic pressures are forcing the outcome line *O* to the right, with the result that the risk of significantly negative program outcomes are increased. These outcomes are often promised to individuals with oversight responsibility in Headquarters USAF, OSD, or the Congress who possess limited technical backgrounds and thus may have limited capability to assess their reasonableness. The promises may become the basis for unrealistic expectations on the part of these individuals, which, if frustrated, may lead them to impose external constraints, such as funding caps and schedule requirements that constrain the responses of program managers to the problems that inevitably arise during the course of their programs.

These problems are exacerbated by another inherent reality of bureaucratic organizations. It is very difficult to communicate information about uncertainty and risk in complex organizational environments. The complex (and often intuitive) nature of that information is not easily packaged in the formal reports and briefings that are the communications media of large organizations.

Moreover, as we have already noted, acquisition management occurs in the midst of a large, often adversarial system. Important actors in that system are not anxious to dwell on risks. Telling an audience that there is a 15-percent probability of a particular performance deficiency does not help one's case, particularly when to be accurate it must be accompanied by five minutes of qualifications. There are a number of instances, in the cases we examined, where higher authorities appear to have ignored or disagreed with assessments of risks or even to have created reporting forums in which it was unlikely that a full discussion of risk was likely. Because of the limited nature of the cases, we cannot fairly assess the understanding and motivations of these authorities. Much of our information is taken from program office records and

[1]We frame this incentive in terms of promises for program outcomes. However, the same incentives can lead to the tendency to persuade decisionmakers (again all up and down the line) that the threat is high and requires the weapon system with the type of outcomes that are being promised.

interviews and thus disproportionately represents the perspectives of this level of the organization. Nonetheless, such behavior is widely discussed by individuals throughout the DoD and, indeed, in any large organization.

Why then did our systems differ in their apparent ability to effectively manage risk and to move through the acquisition process? We argue that those programs experiencing difficulty were relatively large and important to key Air Force interests. The advocacy required to advance them through the system led to early and often overly optimistic promises concerning their outcomes. They were so important to the Air Force that it was willing in some instances to agree to funding levels, schedule guarantees, and funding caps that seem to be unrealistic and unwarranted. To the extent that acquisition problems are measured simply by slippage from these goals, this might be a sufficient explanation. But they are not. The programs that did comparatively well also slipped in performance, schedule, and cost, but not to the degree that these systems did.

More significant from the risk management perspective is that these tight and well-publicized specifications squeeze the slack out of the process that we argue managers need to manage risks. In the LANTIRN program, parallel technological developments initially proposed to hedge against risks in the system as a whole and then in an important component (the ATR) were scrubbed because there were too few resources. In the B-1B, the agreed-to schedule did not allow the defensive avionics to proceed through the necessary development before production decisions were made. More subtly, the decision to have the Air Force manage the systems integration for the B-1B (coupled with understaffing in the SPO) meant that there were limited staff resources to deal with and craft solutions to problems that arose during the development phase. And the high levels of concurrency in each of the three systems reduced the options available for fixes because of the constraints imposed by existing production decisions.

In contrast, the more managerially successful systems we examined did not require the same level of promises. They tended to be far less visible up the management line. The MSIP and the AFE both *evolved* out of strong and highly organized SPOs. The GPS was planned by a technically qualified program office that enjoyed a special, personal, and direct relationship with DDR&E; this seems to have been possible because the program was not absolutely front and center on the Air Force's agenda. The programs proceeded with comparatively broad specifications so that their managers, when confronted with problems, could make tradeoffs they felt benefited the entire system.

Although it may be partially a function of the authors' interests, the most important parts of the stories concerning the AFE and the GPS lie not in the full-scale development but in the technology and operational demonstration programs that preceded them. These phases did not seem to loom as large in the less managerially successful programs, probably because the need was seen as so urgent that the Air Force pushed ahead before these phases had fully run their course. (In the case of LANTIRN, the advanced technologies part of the program was shrouded in covers of special access programs, which limited the ability of anyone to know their implications, and, in any case, few if any of the program office personnel had experience in these programs.)

The systemic nature of these problems limits the ability of the Air Force (or OSD) to craft policies that adequately deal with the problems we describe. For example, the finding that programs that did well in managing risk had relatively little top-level management oversight does not lead to a prescription to leave program offices alone. Indeed, despite the generally limited oversight of the GPS, such oversight was absolutely crucial in shaping the definition of the program in its initial stages. Moreover, it is clear no organization with large programs crucial to its core mission will permit such programs to proceed without oversight. What is needed is oversight that is tailored to the needs of specific situations—that varies with the urgency of the program, the nature of its ultimate users, the size of the effort, and so forth. This need for tailored solutions extends to many other areas—choice concerning development strategy, the staffing of program offices, the types of contractual arrangements used, and the nature of competition.

Rigid and binding policies will not achieve these tailored solutions. Unfortunately, most of the people in staffs above program offices are limited to making, monitoring, or enforcing such policies. Tailored solutions require program-specific fact-finding, familiarity with the management and technological problems, a capacity to make discretionary decisions, and considerable wisdom. It also requires an ability to make and correct mistakes. These solutions are difficult to formulate and implement in any public agency subject to legislative and media oversight, but they are even more difficult in the military services. In these services, the normal personnel rotation associated with service career progression and the comings and goings of political appointees militate against both the acquisition of expertise and the exercise of deeply informed and understanding oversight. Finally, the incentives driving program advocates are so strong, so deeply ingrained in the organization, and so intimately associated with other important organizational imperatives, that it is difficult to see how they can be contained by transient overseers or policy rules.

We believe there are some management lessons uncovered by our research that deserve further consideration. We turn to these in the last chapter. However, we do not believe that they provide robust answers to the problems we set out to address. What is important is that those who oversee development activities or make policies that govern such activities appreciate the nature of the environment in which they operate. The cases may provide some of this appreciation—and we think they are best read if one is not looking for villains but rather seeks to understand how the organizational, political, and legal systems in which these activities take place shape the outcomes that are found.

Chapter Four

CONCLUSIONS

The case studies that provide the empirical basis of our report do not suggest that there are significant problems with Air Force or DoD acquisition policy. It is Air Force and DoD policy that programs should not enter full-scale development before they possess a well-developed and understood technology base; the case studies amply illustrate the importance of this policy. Policy dictates that a well-developed and agreed-upon statement of mission need coupled with flexibility in definition of ways to meet that need is a precondition to entering development; the case studies illustrate the desirability of this policy. Policy emphasizes that programs are to be managed and overseen by expert staff; the case studies make it clear that this is very important to the successful management of risk. Air Force and DoD policies emphasize short, direct lines of communication between program managers and authoritative acquisition executives; again, the cases suggest the importance of such direct links to the quality of communication concerning risk.

These and many other acquisition policies seem, in concept, appropriate. The problems come in their application. In the programs we examined, acquisition problems most often arose from the character of the organizational system in which the policies are implemented. This system—the services, the DoD as a whole, and the Congress—operates in a highly political, advocacy-oriented environment. Resources seem perpetually to be limited relative to the needs that one or another component of the system views as key to its mission. In a wide variety of forums, advocates for the development of new systems, or for the continued acquisition of existing systems, vie for those resources. In the course of these proceedings, decisions are made and bargains struck that sometimes undermine the intent of the policies.

In the face of potential abridgments of policies, oversight organizations often try to strengthen these policies by making them more prescriptive. At various times, the military services have been told that they shall use prototypes or shall avoid concurrency. Following industry complaints, it became policy not to use firm fixed-price contracts for development. In the face of stringent competition for funds and authority, these policies may also seek to limit cost growth or schedule slippage by imposing funding caps or making further funding dependent on meeting a specified schedule. Similarly, further funding or authorization to enter into production may be made dependent on demonstrating a specified performance in a test situation. These attempts to control development efforts are understandable and may, taking full national interests into account, even be desirable. But it should be understood that they may very well limit the capability of the program office to manage the risks inherent in the program.

The keys to managing risk effectively appear to be having qualified people, possessing adequate "slack" in the program to cope with adverse events, and being overseen by people capable both of understanding development issues and reflecting concerns of the larger policy environment on decisions concerning those adverse events. By slack we mean the ability to make cost, performance, and schedule tradeoffs in dealing with those adverse events. Plans and policies that significantly reduce the slack available in the program (e.g., by simultaneously tightening cost, schedule, and performance imperatives), possibly coupled with the failure to staff program offices with adequate numbers of qualified staff, appear to be the principal program features that differentiate the programs with significant acquisition difficulties from those that proceeded relatively smoothly.

Policy is important. Bad policies are likely to lead to bad outcomes. But, based on these seven case studies, the Air Force and the DoD seem to us to have the broad policies about right. Problems arise when the intent of those policies is violated. This violation comes when other imperatives—perhaps preventing the cancellation of a program—seem more important. Those imperatives may indeed be more important, but it should be clearly understood that the effect of such violations is likely to be both heightened risk and lowered capacity to manage that risk. The most important message of this study is that the senior officials in the Air Force and the DoD who are charged with making decisions concerning strategies for developing new systems, as well as setting guidance for schedule, cost, and performance targets, should temper recommendations brought forth by their subordinates with an understanding of the intense advocacy environment that frequently shapes those recommendations. Indeed, they should also recognize that sometimes their own behavior shapes that of their subordinates.

To this broad conclusion, we would add two more limited suggestions. First, two of the programs we examined, the AFE and the MSIP for the F-16, seem to us to provide useful guidelines for R&D management at the program office level for a significant proportion of the Air Force's acquisition program. Second, several of the programs in our study could be said to have gotten "out of control," in the sense that they were subjected to a continuing series of reviews, site visits, program revisions, congressional interventions, and personnel changes that, in our judgment, often seemed to have deleterious effects on the program outcome. We think that many of the actions that complex and political bureaucracies take when a program is in deep trouble are counterproductive, and that the Air Force and DoD should consider some form of special management for programs that are experiencing great difficulty—something akin to putting a business into receivership.

PROMOTING LONG-TERM RELATIONSHIPS BETWEEN THE SPO AND CONTRACTOR

Two of the programs we studied involved long relationships between an SPO and one or more contractors. In the case of the AFE, the development began largely at the initiative of the Propulsion SPO, which had continuing relationships with the two major U.S. manufacturers of large aircraft engines. Those relationships were developed in the course of managing a number of diverse engine developments as well as providing much of the government oversight of the firms' independent research and development (IR&D) activities. This experience provided Air Force personnel with ample opportunity to understand the opportunities presented by the technical capabilities of the two contractors and their relative market positions. The development of the AFE seems to represent an effective example of the benefits of what we term *managed competition.*

The F-16 MSIP program presents a different but related picture. Here, the continuity of an SPO that has been in existence for more than 20 years, coupled with an association with a single prime contractor, permitted the development of a well-considered process for the incorporation of important and varied modifications in the F-16 system.

The program offices share some important qualities. Their longevity—amounting almost to permanence—permitted the offices to develop substantial technical capability. Much of this capability lies in a cadre of career civil servants, but effective and well-qualified uniformed officers appear to have been regularly assigned to and to have effectively led these offices. The size of the programs managed by these SPOs, coupled with their diverse responsibilities, permitted the development of a form of matrix organization that permits the retention of staff with substantial specialized expertise who work on several programs. This appears to promote transfer of learning from one project to another.[1] Doctrine has been developed based on experience; the Propulsion SPO in particular had developed a development doctrine that guided the activities of its own staff and that of the contractors. In the case of the AFE, the engines used derivative designs building on earlier engine designs, an important component of both the SPO and contractor development doctrines. The new versions of the F-16 can similarly be seen as derivative designs.

These important internal qualities of the SPO are reinforced by the stable, long-term relationships it possesses with its contractors. Program managers can accumulate a substantial understanding of the contractors they deal with. This permits far more informed and effective responses to the inevitable surprises that occur in the course of a development. These relationships are supported by the use of "relational contracts" that emphasize whole rather than component tasks and can be put in place and modified quickly as the situation dictates. The managed competition between General Electric and Pratt and Whitney provides a good example of how such competition can be used in conjunction with relational contracts to achieve results that seem clearly to have been beneficial to the Air Force and the nation. However, the importance of experienced and qualified SPO staff cannot be too strongly emphasized. We do not believe these policies will work in a turbulent and unstable organizational environment.

The Air Force has made several decisions that lessen the opportunity to use this style of management for engines over the past years. For security reasons, the B-2 engines were removed from the purview of the Propulsion SPO, and the engine for the advanced tactical fighter (ATF, now the F-22) was made the responsibility of the ATF SPO, apparently for reasons of economy and management control. We have not examined these decisions and cannot judge their appropriateness. But, given the evolving defense acquisition environment, we think the benefits of the type of acquisition practices used by the Propulsion SPO (and the F-16 SPO) deserve serious consideration for use in other areas.

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[1]This matrix actually extends to elements of the larger technical staff in the Aeronautical Systems Division (now the Aeronautical Systems Center) as well.

Obviously, with the perceived reduction of military threats attendant to the new world order, defense budgets have fallen and will continue to fall. Moreover, the nature of the threat itself has become less certain and more contingencies need to be hedged against. The lowered defense spending is likely to lead to fewer competitors and to a concern that the nation will have too few firms to maintain the type of competition that experience suggests is necessary to spur innovation and promote a degree of efficiency. In this situation, sustained relationships, emphasizing derivative designs, and the use of managed competition and relational contracts become more attractive. Acquisition policies that use competitions that are life-and-death affairs for contractors (or divisions of contractors) are not likely to be either efficient or effective in the new acquisition environment. Important system elements, such as ordnance, munitions, and various elements of avionics, seem potential candidates for such management.

SPECIAL MANAGEMENT FOR OUT OF CONTROL PROGRAMS

Existing procedures and bureaucratic incentives do not deal well with programs that have gotten into serious difficulty, as was the case with LANTIRN and AMRAAM. They lead to the imposition of tighter regulation and control when flexibility is what is needed. They suppress the discussion of uncertainty when openness is needed. They often focus on political concerns when the emphasis should be on technical and management issues.

The Air Force and DoD may want to consider using a special management unit and reporting structure for a program when it is judged to have gone out of control. Somewhat like a receivership for a business, the unit would take a hard and independent look at the problem, waive existing rules and requirements where appropriate, and make changes in both the design and management strategy. Special reporting channels and procedures would be required, but great authority would be delegated to the individual charged with managing the program. He or she would be provided with clear and explicit guidance concerning the essential program parameters within which he or she must work and authority to make needed tradeoffs within those parameters.

Implementing a policy such as this would be difficult. Criteria for identifying such programs are needed. The regular command structure can normally be expected to resist such designation because it will be widely seen as an admission of failure in performance. The procedures must be worked out with the Congress as they have been the source of many of the rigidities that inhibit program recovery. Their legitimate needs and concerns must be addressed by the actions, and they should concur in them.

The most effective way to deal with out of control programs, of course, is to prevent them from occurring. The organizational barriers to effective prevention have been the principal subject of this study. Understanding and respect for these systemic barriers to effective development of systems on the part of all participants is the best hope for improved effectiveness in R&D management of large weapon systems.