Competition and Innovation

in the U.S. Fixed-Wing Military Aircraft Industry

John Birkler · Anthony G. Bower
Jeffrey A. Drezner · Gordon Lee
Mark Lorell · Giles Smith · Fred Timson
William P. G. Trimble · Obaid Younossi

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PREFACE

Defense policymakers in the United States have grown increasingly concerned over the past decade that further consolidation in the industry that designs and manufactures U.S. military aircraft could degrade U.S. national security. They note that the number of prime contractors, which stood at 11 in 1960, has dropped to three, and they worry that, if this trend continues, the Department of Defense (DoD) may have no choice but to acquire aircraft that are designed and produced in a far less competitive and innovative environment than they were in the past.

The Senate articulated these concerns in December 2001, when it requested, as part of the DoD Appropriations Act of 2002, that the department prepare a comprehensive analysis of and report on the risks to innovation and cost of limited or no competition in contracting for military aircraft and related weapon systems for the Department of Defense.

This report responds to that request by examining the future of the U.S. military aircraft industrial base. It addresses specific questions posed by Congress that relate to the ability of the United States to preserve and retain adequate competition and innovation in the design and manufacture of its military aircraft. It also examines a broader set of issues related to changes under way in the U.S. aircraft industry, in the sources of innovation, and in the types of capabilities DoD likely will need in order to adequately respond to a range of new and evolving threats in the future.

Another RAND study, a companion to this report, provides a more extensive history and analysis of the U.S. fixed-wing combat aircraft industry from its earliest days to the present (2000):

> Mark Lorell, *The U.S. Combat Aircraft Industry, 1909–2000: Structure, Competition, Innovation,* Santa Monica, Calif.: RAND, MR-1696-OSD, 2003.

This research should be of interest to members of Congress, congressional staff, industry executives, and others in the civilian and uniformed defense policy community interested in the future viability of the U.S. military aircraft industrial base. It was sponsored by the Industrial Policy Office within the Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics. This research was conducted within the Acquisition and Technology Policy Center of RAND's National Defense Research Institute (NDRI), a federally funded research and development center (FFRDC) sponsored by the Office of the Secretary of Defense, the Joint Staff, the unified commands, and the defense agencies. NDRI is located within RAND's National Security Research Division.

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SUMMARY

In the first couple of decades following World War II, over a dozen firms competed vigorously to develop and produce U.S. military aircraft. During the ensuing years, some firms left the business and others merged, so that by 1990 only eight firms survived. In the following few years, the pace of consolidation quickened. Today, only three firms are capable of developing and producing major military aircraft systems. Policymakers have expressed concern that further consolidation could erode the competitive environment, which has been a fundamental driver of innovation in the military aircraft industry.

The issue crystallized in the fall of 2001 when the Department of Defense (DoD) chose Lockheed-Martin as winner of the Joint Strike Fighter competition and as the prime contractor to develop and manufacture the F-35. That decision came after an intense, 5-year competition between concept development and demonstration teams led by Lockheed-Martin (and including Northrop Grumman) and Boeing. The F-35 is the only new major military aircraft program currently planned. Its production is scheduled to continue through 2026. Over that period, some 3,000 of the jet fighters are slated to be integrated into forces fielded by the United States and the United Kingdom (UK), and as many as 3,000 more might be purchased by U.S. allies. The U.S. and UK sales alone, worth some $300 billion (in then-year dollars), make the F-35 one of the largest acquisition programs in history.

Even before DoD chose Lockheed-Martin as the F-35 prime contractor, senior DoD officials and members of Congress had begun to

voice concerns about the effect of that contract award on the ability of all three U.S. prime contractors to remain active designers and producers of military aircraft and on their long-term ability to operate in competitive and innovative ways. In December 2001, the U.S. Senate requested (in the DoD Appropriations Act of 2002) that DoD prepare a comprehensive analysis of and report on the risks to innovation and cost of limited or no competition in contracting for military aircraft and related weapon systems for the Department of Defense.

STUDY OVERVIEW AND APPROACH

In February 2002, the Under Secretary of Defense for Acquisition, Technology, and Logistics asked RAND to analyze the current and future adequacy of the military aircraft industrial base in light of (1) the trend toward consolidation and (2) the prime contractors' abilities to remain competitive and innovative. RAND built upon its earlier studies of the U.S. defense industrial base (Drezner et al., 1992; Birkler et al., 1993, 1994, 1997, 1998) to explore various ways that demand for military aircraft might unfold in the next couple of decades, how the industry might respond to those different levels of demand, and how competition and innovation might evolve, given those changes in demand and industry structure.

We translated Congress' concerns into four research tasks:

1. *Describe the military combat aircraft industry*—This task involved characterizing the current industry structure and capabilities qualitatively and quantitatively, as well as examining how the industry structure, capabilities, and business environment have changed over the past several decades.

2. *Evaluate what is needed to maintain a high level of innovation in the military combat aircraft industr*y—We adapted an analytic model of innovation (Porter, 1990) used in business and economic studies to understand the contribution of competitive pressures as a stimulus to technological innovation.

3. *Assess prospects for innovation and competition in the military aircraft industry*—In this task, we assessed the effect of alternative future aircraft-demand scenarios on prime contractors' abilities

to remain competitive in the military aircraft industry and their incentives to innovate.

4. *Identify policy options open to DoD*—In this task, we assessed policy options available to DoD to guide the evolution of the industry and ensure maintenance of critical abilities and characteristics.

The analysis RAND conducted attempted to stay close to congressional concerns as expressed in legislation. Thus, we have focused on maintaining the present competitive structure and capabilities of the current prime contractors. We limited our analysis to consideration of fixed-wing aircraft, drawing on information that is now unclassified.

In support of this analysis, we collected information from three prime aircraft contractors: Boeing, Lockheed-Martin, and Northrop Grumman. We also held discussions, including site visits, with each firm. Various DoD offices provided substantial supporting information and data.

RESULTS

Task 1—Describe the Military Aircraft Industry

The U.S. military aircraft industry has been evolving continuously for almost a century. The number of prime contractors peaked at 16 in 1945, after which firms either merged or exited, and no new firms entered. Changes in industry structure—in particular, the number of dominant firms—are closely associated with *revolutionary changes* in aircraft technology, changes that led to a fundamental transformation in the performance of combat aircraft—e.g., jet engines, low observability. In most cases, the key innovations enabling those changes in technology came from firms that were not dominant players at that time and who thus became dominant in the area of their innovation. Revolutionary innovation rarely came from the dominant firms in an era.

Task 2—Evaluate Methods for Encouraging a High Level of Innovation

According to economic and business literature, this pattern—in which revolutionary change and innovation come from firms that are not dominant—is similar to the experience of other industries. Although it is not possible to directly measure innovation, past analyses have identified factors affecting the pace and degree of innovation within an industry. Some of these factors are beyond the direct control of any government agency, but DoD can exert significant influence over three critical factors: It can directly affect investments in the technology base and the level of demand for aircraft, and it can indirectly affect the level of competition in the industry by the way it structures programs and distributes business among the firms.

Task 3—Assess Prospects for Competition and Innovation in the Military Aircraft Industry

Several changes related to competition and demand have affected the military aircraft industry in recent years. First, the nature of demand is changing. Funding has been increasingly focused on fewer programs, with emphasis on platforms that are joint, interoperable, and common across service and mission. For instance, in the past, the three versions of the F-35 would have been three distinct programs: Conventional Take-Off and Landing (CTOL), Short Take-Off and Vertical Landing (STOVL), and carrier-based. The consolidation of all three functions into one aircraft will likely make competitions for manned aircraft, both experimental air vehicles and major combat aircraft, less frequent.

Second, the complexity of the systems being developed has grown significantly through increasing reliance on information technology to provide enhanced functionality. Additionally, Unmanned Air Vehicles (UAVs) and Unmanned Combat Air Vehicles (UCAVs) have entered the market, posing a new set of design and development challenges to defense contractors.

Lastly, the role of prime and subcontractors has changed. To address the performance demands of the customer, the primes have increasingly focused on the complex system-integration function. Design tools, such as computer-aided 3-D programs, and institutional structures, such as integrated product teams, have allowed the supplier base to become responsible for design, development, and production of key components. Significant innovation now occurs at all levels of suppliers, as well as at the prime-contractor level.

The most serious risk facing major prime contractors today is that there might not be enough new military aircraft design and development work in the second half of this decade to enable all three of the present primes to sustain an adequate team of engineers and technical managers for conducting technology development, advanced design studies, and demonstrator/prototype development and test of future system concepts. Sustaining an adequate team of such specialists is necessary if the firm is to be a strong competitor for future programs. Those teams, and the skills they comprise, represent the true foundation of future aircraft designs. If no major aircraft-development programs are initiated in the next few years, it seems likely that those teams will dwindle to below-critical size in at least some of the primes.

We also note that the industry is entering an era in which decisions on starting or stopping even one program can have major effects on overall industry size and composition.

Task 4—Identify Policy Options

Our findings indicate that procurement funding will likely be adequate to sustain the basic institutional structure of the current prime military aircraft contractors through at least the end of the present decade. New research and development (R&D) activities with a high likelihood of occurrence (a new tanker, new intelligence, surveillance, and reconnaissance [ISR], and a new UCAV) may be sufficient to sustain the design and development capabilities of the current primes through the middle of this decade. However, commercial derivative and UAV/UCAV programs as currently planned will be insufficient to sustain the current industry structure and capabilities beyond this decade. A DoD decision to begin a new major combat-aircraft program before the end of this decade would provide a stronger basis for sustaining current structure and capability. Conversely, if the number and frequency of major aircraft programs continue to diminish, it will be increasingly difficult to sustain an industry of the present size and posture.

We also explored ways to sustain the design and development capabilities of the current primes in the absence of any major near-term system-development programs. Co-production of the F-35 had been suggested, but that option is very expensive and does little to directly support design and development skills. A more attractive option would be to fund a number of design and development projects for Advanced Technology Demonstrations (ATDs) or Advanced Concept Technology Demonstrations (ACTDs) that push technology in directions reflecting desired future military capabilities. This option, which we believe would help sustain competition and innovation in the military aircraft industry, is not a complete solution in itself: It does not address production and the underlying business base needed to support design and development infrastructure over the long term.

A CONCLUDING OBSERVATION

This research has focused on preserving competition and innovation in the current military aircraft industry. But this focus begs the question of whether it is in the country's interest to preserve the current industry structure and capabilities for military aircraft. U.S. defense policymakers should recognize that industry has already evolved toward a different posture and different capabilities in response to a changing demand and business environment. The policy questions that need to be addressed are, What role can the government play and what role should it play in this natural evolution of industry structure and capabilities?

ACKNOWLEDGMENTS

This work could not have been undertaken without the special relationship that exists between the Office of the Secretary of Defense (OSD) and RAND under the National Defense Research Institute (NDRI). For that relationship, we are grateful. Many individuals throughout the United States Department of Defense and the three major aerospace firms—Boeing, Lockheed-Martin, and Northrop Grumman—provided data and shared insights that were critical to our quantitative analysis and to our interpretations and conclusions described in this report. Their names and contributions would fill several pages.

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Lastly, the authors owe RAND colleague Joan Myers an incalculable debt for her thorough and patient administrative assistance at every stage in the project.

ACRONYMS

ABL	Airborne Laser
ACTD	Advanced Concept Technology Demonstration
AF	Air Force
AFRL	Air Force Research Laboratory
ASTOVL	Advanced Short Takeoff and Vertical Landing
ATD	Advanced Technology Demonstration
ATF	Advanced Tactical Fighter
AWACS	Airborne Warning and Control System
BA	Budget Activity
BAE	British Aerospace
BTP	Build-to-Print
C4ISR	command, control, communications, computers, intelligence, surveillance, and reconnaissance
CAD	computer-aided design
CAIV	Cost As an Independent Variable
CAM	computer-aided manufacturing

CFE	Contractor Furnished Equipment
CRADA	Cooperative Research and Development Activity
CTOL	Conventional Take-Off and Landing
DARPA	Defense Advanced Research Projects Agency
Dem/Val	demonstration and validation
DoD	Department of Defense
EMD	Engineering and Manufacturing Development
EO/IR	electro-optical/infrared
FFF	Form-Fit-Function
FFRDC	federally funded research and development center
FY	fiscal year
FYDP	future years defense program
GDP	gross domestic product
GFE	Government Furnished Equipment
ICP	integrated core processing
IPPD	Integrated Product and Process Development
IPT	Integrated Product Team
IR&D	Independent Research and Development
ISR	intelligence, surveillance, and reconnaissance
IT	information technology
JAST	Joint Advanced Strike Technology
JPATS	Joint Primary Aircraft Training System
JSF	Joint Strike Fighter

JSTARS	Joint Surveillance and Target Attack Radar System
MC2A	multi-mission command and control aircraft[1]
MCA	major combat aircraft
MDA	McDonnell-Douglas Aerospace
MDS	Model-Designation-Series
MMA	multi-mission maritime aircraft
MRF	Multi-Role Fighter
NASA	National Aeronautics and Space Administration
NATF	Naval Advanced Tactical Fighter
NDRI	National Defense Research Institute
NGC	Northrop Grumman Corporation
PE	Program Element
R&D	research and development
RDT&E	Research, Development, Test, and Evaluation
S&T	science and technology
SAR	Selected Acquisition Report
SD&D	system development and demonstration
STOVL	Short Take-Off and Vertical Landing
T/ISR	tanker and intelligence, surveillance, reconnaissance [aircraft]
TMS	Type-Model-Series

[1]Also known as the multi-sensor command and control aircraft. It is not the same as the MC2C, multi-sensor command and control constellation, which may not be an aircraft at all.

TOA	total obligational authority
UAV	Unmanned Air Vehicle
UCAV	Unmanned Combat Air Vehicle
UK	United Kingdom
USD(AT&L)	Under Secretary of Defense for Acquisition, Technology, and Logistics

Chapter One

INTRODUCTION

Over the past several decades, a substantial change has occurred in the composition of demand for military aircraft, as has a consequent change in the size and composition of the industry supplying those aircraft. At one point in the middle of the last century, when the technology of jet engines and jet-powered aircraft was evolving rapidly, the Air Force alone was simultaneously funding eight jet-fighter research and development (R&D) programs and seven jet-bomber R&D programs (Lorell, 2003). During that period, 12 to 15 different military aircraft models were usually in production at the same time, not counting trainers.

That plethora of development programs and active production lines provided work for over a dozen vigorously competitive prime contractors. In contrast, since 1990, just two major new manned military aircraft programs have started full engineering development—the Advanced Tactical Fighter (F-22) in 1991 and the Joint Strike Fighter (F-35) in 2001,[1] and today there are five lines (F/A-18, F-22, C-17, C-130, and E-2C) producing new manned military aircraft for DoD, two lines refurbishing older aircraft (E-8 and AV-8B), one line producing military trainers (T-6), two lines producing older combat

[1]During that same period, at least two unmanned air vehicle (UAV) programs entered engineering development: the Predator and Global Hawk. Those early UAV programs are typically an order of magnitude smaller than major manned military aircraft programs and thus less effective at supporting the kind of commercial organizations that now serve as prime contractors for military aircraft. The possible role of future UAVs as major lines of business for prime contractors is explored in Chapter Four.

aircraft (F-15 and F-16, mainly for foreign customers), and two Unmanned Air Vehicle (UAV) lines (Predator and Global Hawk).

It is not surprising that the industry has undergone a consolidation that roughly tracks the reduction in the number of different military aircraft programs in the United States. Figure 1.1 shows the period when each firm was active, starting in 1960 and extending to the present time. The right-hand end of each bar represents the date at which the firm left the military aircraft business (e.g., Fairchild in 1987) or was purchased by, or merged with, another firm (represented by vertical arrows). The two black bar segments indicate periods when the firms retained their corporate identity but were not active as military aircraft primes. This figure clearly shows that, although some consolidation occurred in the earlier years, most of it occurred in the first half of the 1990s. Today, just three firms (as noted by the three horizontal arrows) remain as prime contractors for military aircraft: Lockheed-Martin, Boeing, and Northrop Grumman.

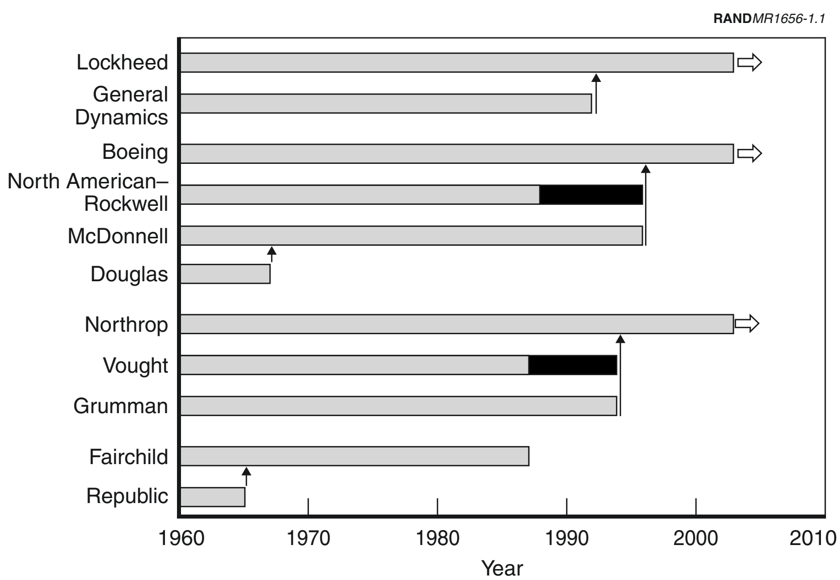

Figure 1.1—U.S. Military Aircraft Prime Contractors, 1960–Present

ORIGINS OF THIS STUDY

This combination of fewer and fewer military aircraft programs and fewer and fewer firms to perform work on such programs has led to concern about the capability of the industry to meet future needs. Critics note that vigorous competition between firms has been an important contributor to the technological innovation that provided the United States' military services the dominant combat-aircraft capabilities it now enjoys vis-à-vis other nations' air forces. Such criticism leads to three interrelated questions:

- Can DoD count on that same level of innovation in the future, with a much-consolidated industry and few projects for them to compete on?
- Is the overall national industry posture in danger of shrinking to a point past which it could not adequately respond to plausible future demands for new aircraft designs?
- Might the diminished number of competitors lead to reduced pressure to contain costs in the current and future programs?

These concerns were sharpened when the F-35 program was awarded to Lockheed-Martin, thus apparently concentrating much of the new business in one firm and diminishing future opportunities for the other firms.

Congress expressed its concerns in the FY2002 Defense Appropriations Bill. Section 8162 of that legislation stated that[2]

> It is the sense of the Congress that the military aircraft industrial base of the United States be preserved. In order to ensure this we must retain—
>
> (1) adequate competition in the design, engineering, production, sale and support of military aircraft;

[2]The Department of Defense and Emergency Supplemental Appropriations, 2002, PL 107-117, section 8162.

(2) continued innovation in the development and manufacture of military aircraft;

(3) actual and future capability of more than one aircraft company to design, engineer, produce and support military aircraft.

The legislation went on to direct that a study be conducted to determine the present and future adequacy of the military aircraft industrial base. The study reported here was performed in response to that directive.

STUDY SCOPE

The relationships between competition and innovation are complex. Competition is not a thing that is useful in itself; rather, it is a state that can lead to two different but related benefits: It constrains prices and prevents monopolistic price-gouging, and it stimulates innovation, which can itself lead to lower prices, together with improvements in performance and in the general value of the product.

The effects of competition on product price in military procurement have been studied extensively, but the results are not strongly conclusive.[3] In a 2001 RAND study that addressed the proposal to competitively produce the F-35 (Birkler et al., 2001), we concluded that likely cost/price reductions induced by competition would not be enough to pay for the extra costs incurred in dividing production between two producers. Given the available literature on this topic and the lack of strong evidence supporting competitive procurement of weapon systems as a means of price reduction, this aspect of competition will not be addressed further in the present study.

We are primarily interested here in the degree to which competition and innovation can be sustained in the military aircraft industry during the remainder of this decade. We are not especially concerned with the different products of innovation; those will depend on the goals to which innovative effort is applied. Our main concern

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[3] Please refer to the Competition Effects on Weapon Systems Costs portion of the Bibliography.

is with how innovation can be encouraged through the presence of competition, and how factors other than competition might also encourage innovation.

The study scope is further defined by five limitations that were imposed because of the short time available (six months) for the study:

1. This study focused mainly on preserving competition and innovation among the prime contractors now active in developing and producing fixed-wing military aircraft. Although we include the important relationships between prime contractors and component suppliers in our analysis, we neither examined the supplier base per se nor addressed the possible emergence of new, fully capable aircraft prime contractors.

2. We include consideration of wide-body transport aircraft adapted to military missions, but exclude rotary-wing and hybrid (V-22) types.

3. All information was drawn from unclassified sources. Therefore, no consideration is given to any aircraft programs that might be under way but whose existence is now classified.[4]

4. Our analysis includes the full range of design, development, and production activities, from applied research and concept studies, to development of major aircraft systems, through full-rate production and major-modification programs. We have not examined post-production and operational support in any detail.

5. The procedures covering acquisition of military aircraft include many rules regarding contracting and accounting practices. Those rules, and their effects on the industry, have been widely examined in earlier studies and are not reexamined here so that study resources could be applied to analysis of competition and innovation in the industry.[5]

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[4]An example is the Boeing "Bird of Prey" experimental aircraft, developed in the mid-1990s but publicly announced in late 2002.

[5]See the Acquisition Reform Issues portion of the Bibliography.

APPROACH

We translated the list of congressional concerns into four specific research tasks. It should be noted at the outset, however, that these concerns are not new. They have been addressed in varying ways and degrees in numerous studies over the past decade or so.[6]

Task 1—Describe the Present Military Aircraft Industry and Apparent Trends That Might Lead to a Changed Industry Structure in the Future

In this task, we pursued a series of linked questions:

1. What is the actual activity level of the military aircraft industry today?
2. What projects are active, and at what funding levels?
3. How are those projects and their associated funding distributed across the major firms (referred to as *primes* in this study)?
4. How are the primes organized and staffed to support the current activities?
5. How have these various descriptive parameters changed over time, for the individual firms and the industry as a whole, and what further changes appear likely in the next few years based on DoD budget projections?

The quantitative data and insights created during this task provided the foundation for assessing current industry capabilities and for projecting how those capabilities might change in the future.

Throughout our collection of the descriptive information, we maintained a distinction between (a) resources devoted to developing and producing approved weapon *systems* and (b) the wide range of resources and activities devoted to advancing the technological state of the art, developing new design concepts, and generally preparing to participate in vigorous competition for the next major military aircraft acquisition program. Any firm that wishes to remain, or be-

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[6]See the Industrial Base Issues portion of the Bibliography.

come, a prime contractor for a major military aircraft acquisition program must maintain or develop a significant in-house capability and general expertise in both kinds of activity. That assertion might become less true in the future as the institutional structures of firms change and as the way firms team on projects continues to evolve. But until such changes become a proven reality, we base our analysis on the concept of a "full-service" prime containing the complete range of capabilities needed to conceive, develop, and produce an aircraft system.

A critical issue we examined in Task 1 is the minimum level and content of business required to sustain a firm so that it is capable of functioning successfully as a prime contractor for a military aircraft program. As the number of concurrent aircraft programs declines, some firms will fall below threshold levels of business necessary to maintain a minimum level of expertise in the full range of development and procurement activities. Those firms will either exit the business, combine with another firm, or enter into teaming arrangements with other primes or major suppliers. The first two such actions would clearly lessen the level of long-term competition that exists between primes. The third action, teaming, may reduce the competitive posture of industry, but the long-term implications of extensive teaming remain uncertain. We needed to understand that threshold in order to estimate how the industry structure might change in the future.

Task 2—Develop a Methodology for Examining the Relationship Between Competition and Innovation

The linkage between competition and innovation is not well defined, and neither competition nor innovation can be directly measured in analytically satisfying ways. In Task 2, we sought to better understand factors affecting innovation so that defense policymakers can provide a posture that ensures a continued high level in the future. We especially sought to understand competitive pressures as a stimulus to technological innovation.

Task 3—Assess Future Prospects for Innovation and Competition in the Military Aircraft Industry

In this task, we examined how the level and composition of demand for military aircraft might change over the next decade or so, and how such changes would affect the structure, competitiveness, and overall levels of capability of the industry, especially at the prime level:

1. Are the currently programmed development and production projects likely to sustain the present three prime contractors and an adequate level of key suppliers?
2. If not, how many, and what kind of, new projects would be needed to sustain all three present firms as full-service primes, each capable of vigorously competing for the next major system acquisition program?

Task 4—Identify Policy Options Open to the Department of Defense

Task 4 examined policy options available to DoD to guide the evolution of the industry and ensure maintenance of critical abilities and characteristics. The task examined the costs and benefits of alternative ways in which DoD could address industry futures that the analyses in Tasks 1 through 3 revealed to be less robust than desired.

ORGANIZATION OF THE REPORT

The tasks outlined above are addressed in separate chapters. Chapter Two (Task 1) is devoted to a description of the industry and the associated business base, and how both have changed over the past several decades. Chapter Three (Task 2) develops a conceptual model of the sources of innovation, with particular attention to the contributions of competition and demand. Chapter Four (Task 3) outlines some alternative futures in the level and composition of demand for military aircraft systems, and explores how well these alternatives would sustain the present set of prime firms. Chapter Five examines some hedging strategies that might be used to support those elements of the industry judged necessary and appropriate. Chapter Six (Task 4) draws on the previous four chapters to compare alternative policies and their likely effects on the military aircraft industry. We have also included a Bibliography arranged by the main topics the report addresses.

Chapter Two

AN EVOLVING MILITARY AIRCRAFT INDUSTRY

The United States now has nearly a century of experience building aircraft for military use. The present report deals with the recent past and the near future; however, a review of the longer span of experience appears in order here for providing a richer understanding of the forces and events that have led to the current status and issues.

We begin with a brief overview of the industry, from its beginnings to the end of the Cold War, focusing on changes in the number of prime contractors and the major events that caused those changes. The important observation from that overview is that the military aircraft industry has been changing continuously since its inception, and we have good reason to expect that pattern to continue.

In the second part of this review, we present additional information on patterns of demand for military aircraft over the past 20 to 30 years, and outline plausible connections between changes in demand and changes in industry size and structure. We then describe some ongoing changes that are affecting industry structure and capabilities, and discuss the implications of those changes in terms of the minimum capabilities that need to be preserved in order to meet future military needs.

HISTORICAL PERSPECTIVE ON INDUSTRY STRUCTURE AND CONSOLIDATION

The development of military aircraft has been marked by several periods of revolutionary innovation, by which we mean technological advances that have been integrated at key points in history in ways that have led to a fundamental transformation in the performance of combat aircraft. An examination of changes in industry structure and composition provides some insight into how industry structure, competition, and innovation interact. In this historical review, we focus on prime contractors and integrators involved in designing and developing combat aircraft (fighter, fighter/attack, and bomber aircraft).[1]

Figure 2.1 shows the number of contractors specializing in fixed-wing combat aircraft by their combat aircraft specialty.[2] The changes in the number of firms over time are steep and dramatic. No U.S. prime contractors specialized in combat aircraft in 1915. From 1920 to 1935, between five and seven contractors had this specialization; that number nearly tripled in the next ten years, peaking at around 16 in 1945. As a result of the economic mobilization of World War II, the number of prime contractors with areas of combat-aircraft specialization expanded to the largest number in history.

But with the end of the war, the industry experienced mass cancellations of huge planned production programs, and the number of prime military aircraft contractors had fallen to 11 by the mid-1950s. The industry remained at this size for about a decade, but began to decline again in the 1960s, falling to eight by the mid-1970s. It stayed at that level until the end of the Cold War.

In the 1990s, as it retrenched in the face of declining defense budgets, the industry consolidated even more dramatically than in the years immediately following World War II. By the beginning of the new millennium, only three military aircraft prime contractors remained: Lockheed-Martin, Northrop Grumman, and Boeing.

Figure 2.1 also indicates five major eras of revolutionary innovation in combat aircraft: the biplane era (1910–1930); the propeller (prop)

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[1]Combat aircraft makes up a subset of military aircraft, which also includes tankers, cargo, trainers, and special-purpose systems.

[2]For more details on the history of innovation in combat military aircraft, see Lorell (2003).

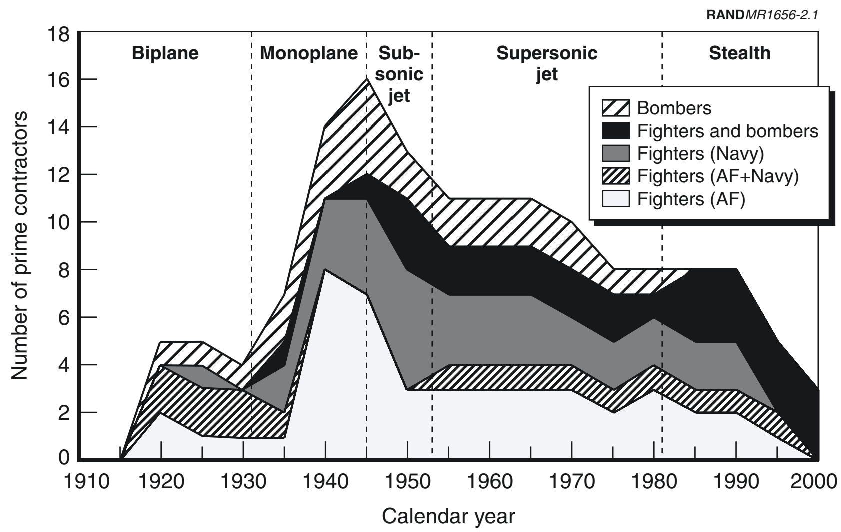

Figure 2.1—U.S. Combat-Aircraft Prime Contractors and Principal Technology Eras

monoplane era (1930–1945), the subsonic-jet era (1945–1955), the supersonic-jet era (1955–1975), and the stealth era (1975–2000).[3] The transition from one major era to the next was often, but not always, the period of greatest innovation. The findings from our broad assessment of the industry dynamics across these eras are as follows:

1. Starting with the biplane era, the next four eras of technology innovation began with extraordinary periods of revolutionary innovation in combat aircraft. Each of these periods was characterized by robust competition among eight or more prime contractors/integrators that specialized in combat aircraft.

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[3]Selection of these specific periods and dates is based on informed individual judgment. Alternative periods and dates are plausible. However, we believe that the periods we identify capture the most-significant and most-revolutionary eras of innovation in combat aircraft. In addition, our findings do not depend on precise adherence to the exact dates presented here. Those dates are meant to be a guide for the reader.

2. Each era resulted in the emergence of dominant industry leaders among prime contractors/integrators in key specialty areas in combat aircraft, and other levels of second-rank[4] or niche players.
3. The key breakthroughs that led to the next era in technological development most often arose from one or more of the following types of firms:
   - Second-rank or niche prime contractors
   - Leader firms expanding outside their existing area of special ization
   - New entrants to the industry.

Note that the dominant firm or firms in an era were rarely the source of revolutionary innovation leading to the next era. We return to this observation in the next chapter, where we discuss the factors that drive innovation.

In the biplane era, the domestic market was small following World War I. As well, government procurement and contracting policies were aimed at maintaining the industrial base through directing production contracts to selected firms. As a result, the fighter and bomber market structures supported few credible prime contractors/integrators, little competition, and minimal innovation.

The industry's perception of a dramatic increase in market potential was key to bringing about the change from the technologically stagnant 1920s to the revolutionary innovation of the 1930s (monoplane era). That perception resulted from three factors: the emergence of a potentially robust foreign military market, the stirrings of an increasingly viable civil-aircraft market in the United States, and the high technological overlap between commercial transports and combat aircraft, especially bombers. This market expansion led to numerous new entrants into the combat aircraft market—and to intense competition. That competition spurred even greater innovation.

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[4]*Second-rank* refers to those prime contractors during a specific technology era that enjoyed significantly smaller shares of the combat aircraft market than did the market leaders. However, it is not meant to suggest or imply that such firms were necessarily any less capable or skilled in design and development than the market leaders were.

The period from the mid-1940s through the early 1950s (the subsonic-jet era) can best be characterized as a time of particularly rapid and dramatic technological advancement and change, as developers exploited the enormous increases in performance made possible by the jet engine. Dominated by new ideas and experimentation, this era also was characterized by fierce competition. As the huge production orders of World War II came to an end, new entrants were taking advantage of rapidly advancing technology to rise to leadership positions. By 1955, 11 primes were still active. Republic, Lockheed, and Northrop concentrated on Air Force fighters, while North American and Convair specialized in Air Force fighters and bombers. McDonnell performed well with both Air Force and Navy fighters. Three other firms—Grumman, Vought, and Douglas—specialized in Navy fighters. Boeing and Martin focused on bombers, but they also engaged in fighter competitions.

Supersonic flight posed technological challenges in aerodynamics, materials, and propulsion that were daunting, and in many respects called for far more radical innovations than the transition from fast prop fighters to first-generation jets had dictated: dramatic new wing shapes and cross sections, novel fuselage-shaping requirements to solve the problem of transonic drag, variable-geometry air inlets, variable-geometry and variable-incidence wings, engine afterburners, manufacturing with titanium and other exotic materials, and a myriad of other design and technology issues. None of these technological advances would have been pursued with tenacity without strong service support and generous government funding, as well as a highly competitive industry structure with many qualified players.

The 1960s and 1970s witnessed shifts in the design emphasis and technology focus for new fighter aircraft as a result of changes in operational doctrine and other factors. The focus on increasing speed and altitude that had dominated the 1950s disappeared in the following decade, replaced by a focus on maneuverability, maintainability, and systems integration.

The feverish pace of fighter-platform R&D evident in the 1940s and 1950s slowed considerably in the 1960s and 1970s.[5] Only two new Air Force and two Navy tactical fighters entered full-scale development in the 1960s and early 1970s: the F-15, F-16, F-14, and F/A-18. One tactical fighter-bomber also completed development: the F-111.[6] No new entrants came into the arena, not only because the number of new programs was shrinking but also because the rate of overall technological change was slower during the period, providing fewer openings for new firms.

Nonetheless, a significant number of contractors remained in the market, guaranteeing the continuation of robust competition. In 1965, 11 prime contractors with combat aircraft specializations—the same number as in 1955—continued to compete. Ten years later, eight prime contractors were still in competition, although several of them had clearly become second-rank prime contractors, as indicated by their lack of major contracts. Almost every major prime contractor submitted credible proposals in nearly every military aircraft effort during this period. With the decline of service specialization among contractors, the number of credible entrants in competitions often actually increased over what was typical earlier.

The stunning innovation and technological breakthroughs witnessed during the stealth revolution in the 1970s took place in an environment of intense competition among as many as seven prime contractors. Two contractors not then dominant in the conventional fighter market—Lockheed and Northrop—pursued radical and innovative new technologies in an attempt to dethrone the reigning leaders of the fighter market in the pre-stealth era, McDonnell-Douglas and General Dynamics (which had merged in 1968).

A wrenching consolidation and downsizing of the U.S. aerospace industry began in the early 1990s, after the collapse of the Berlin Wall and with the end of the Cold War. In just over four years, four historical leaders in fighter R&D had been eliminated as independent entities. The transformation began in early 1993, when Lockheed

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[5]The slowing was in the performance attributes of top speed and altitude, which had been emphasized in the past. Enormous advances continued to be made in other attributes, such as aircraft agility, and avionics and sensors.

[6]Two major attack aircraft programs were also initiated: the A-7 and the A-10.

purchased General Dynamics' Fort Worth fighter division; in May 1994, Northrop purchased Grumman, and three months later the newly named Northrop Grumman completed its purchase of LTV Corp.[7] Boeing bought Rockwell's Aerospace and Defense Divisions in 1996, followed by a merger with its long-time rival, McDonnell-Douglas. In July 1997, Northrop Grumman agreed to be acquired by Lockheed-Martin. Concerns over the anti-competitive effects of that proposed merger prompted the U.S. government to eventually block the merger.[8]

RECENT PATTERNS OF DEMAND FOR MILITARY AIRCRAFT

It is useful to examine the patterns of demand that accompanied the major consolidations that occurred in the 1990s to determine whether we can make a simple correlation between changes in overall business levels and consolidation in the industry.

We first examine patterns for demand for new aircraft designs. Figure 2.2 shows the development phase of all fixed-wing, air-breathing aircraft that reached flight status in the past three decades. This assemblage was created to represent major military design and development projects, thus reflecting the level of activity provided for industry design teams. Only designs that have reached first flight are shown; the exceptions are the F-35, X-45C, and X-47B, which seem assured of reaching flight status.

The number of new programs and the rate at which they were introduced suggest that the level of design activity and opportunities for

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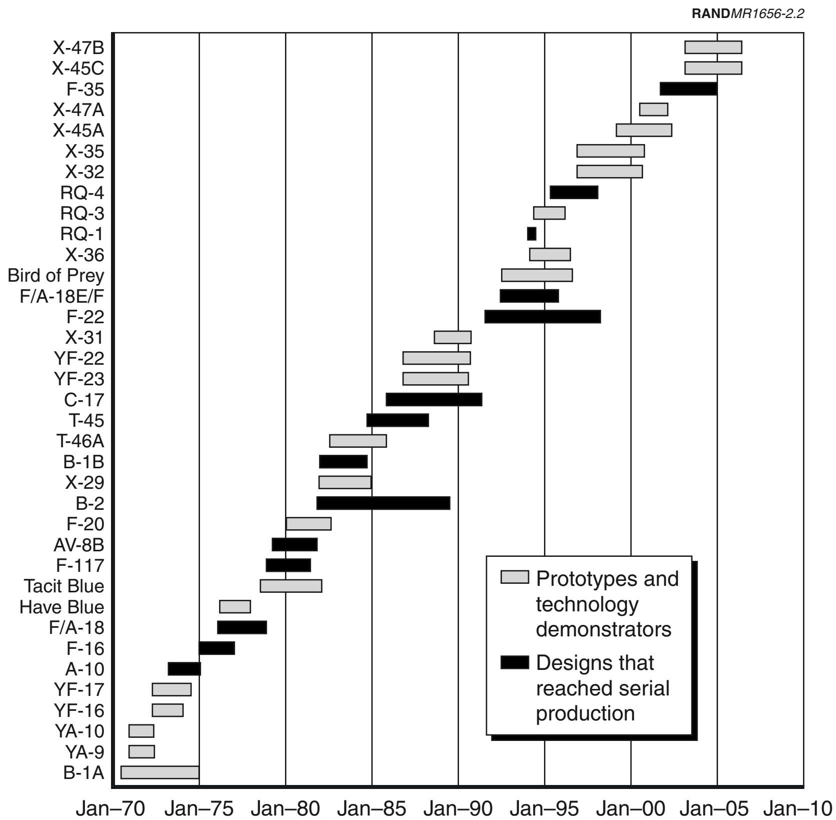
[7]Northrop had purchased a 49-percent interest in LTV Corp. in 1992.

[8]Northrop Grumman's future status as a military aircraft prime contractor remains uncertain. The company has already expanded well beyond its status as a defense electronics and information-technology specialty house, and it is once again a platform/system integrator. In mid-1999, it acquired Ryan Aeronautical, thus inheriting the Global Hawk program for the development of a large, high-altitude, long-endurance unmanned vehicle. In 2000–2001, the firm acquired Litton Industries, together with its Ingalls Shipyard and Newport News Shipbuilding. In July 2002, Northrop Grumman announced the planned purchase of TRW, a leading developer and producer of military satellites and other aerospace products. Completion of that purchase makes the Los Angeles–based company the second-largest U.S. defense contractor behind Lockheed-Martin.



NOTE: This display includes development of new designs, by which we mean either completely new configurations or configurations that were significantly different from a predecessor. It excludes all commercial designs and military derivatives of commercial designs, and all designs with an empty weight of less than 1,000 lb. Each bar on the chart extends from the date when design and construction of a flight vehicle were authorized to the date of first flight. Three designs shown for the 2000–2003 period have not flown as of publication date; however, the F-35, X-45C, and X-47B programs are well under way and flight status seems assured. Of course, additional programs involving design of a new vehicle might be introduced later in the decade.

The X-45C and X-47B programs were started after the analysis reported in Chapter Four through Six was completed and are not reflected in those chapters. These two programs are included here to reflect information available at the publication date.

Figure 2.2—New Aircraft Designs, 1970–2003

competition have been sustained and substantial. A slight slowing has occurred in the pace of new design activity, but it is barely discernible in the figure. Twelve new designs started in the 1970s, with five proceeding to production. That number dropped to 10 new design starts in the 1980s, with four going into production. Of the 10 new design starts in the 1990s, four also were put into production. The four new design starts observed in the first third of the present decade suggest a general continuation of the recent trend, although no additional design starts are now scheduled for the remainder of this decade. And although Lockheed has won the last two major combat program competitions—resulting in the F-22 and F-35 programs—it teamed with Boeing on one and with Northrop on the other. Sharing of work and responsibilities among team members and senior partners is discussed more fully later in this chapter.

The number of active fixed-wing military aircraft production lines has also remained robust. Figure 2.3 shows that there were actually 12 active production lines in 2000: nine producing new manned fixed-wing aircraft, one producing UAVs, and two performing major modifications. In spite of the several lines producing at low rates (e.g., F-15 and F-16), the data suggest a significant amount of ongoing production activity.

Since profit earned on production contracts forms the basis for the pool of available private investment in new technologies, the high level of production activity that has been sustained relative to the 1980 level does not directly explain the accompanying consolidation in the industry that occurred during the 1990s. Note, however, that between 1990 and 2000 the number of active production lines shrank by a third, and the number of new designs slated for near-future production also shrank substantially. The cumulative effect of these trends on the outlook for future business is explored in Chapter Four.

So far, we have been discussing activities at the industry level. It is useful also to decompose the data down to the individual-prime-contractor level. To determine the average funding received by a prime contractor in a given year, we divided the number of contractors in each year into the total Research, Development, Test, and Evaluation (RDT&E) funding for those years. As the trend in Figure 2.4 shows, the average R&D funding stream to a prime contractor has

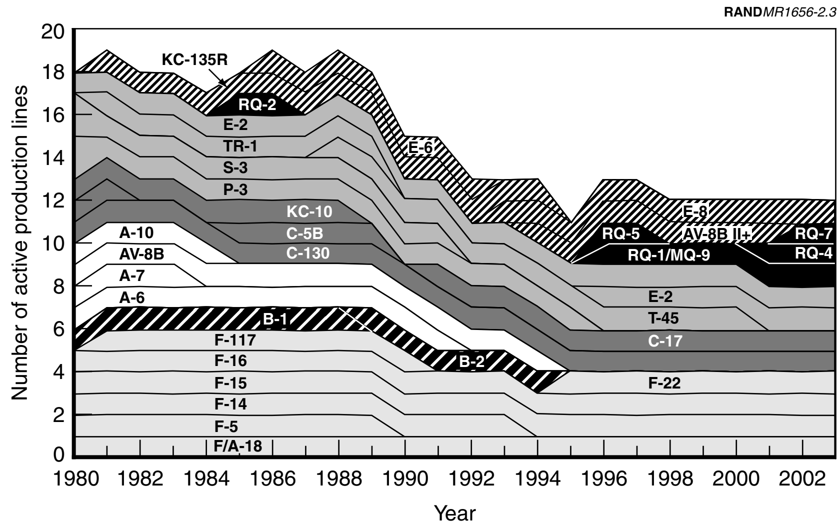
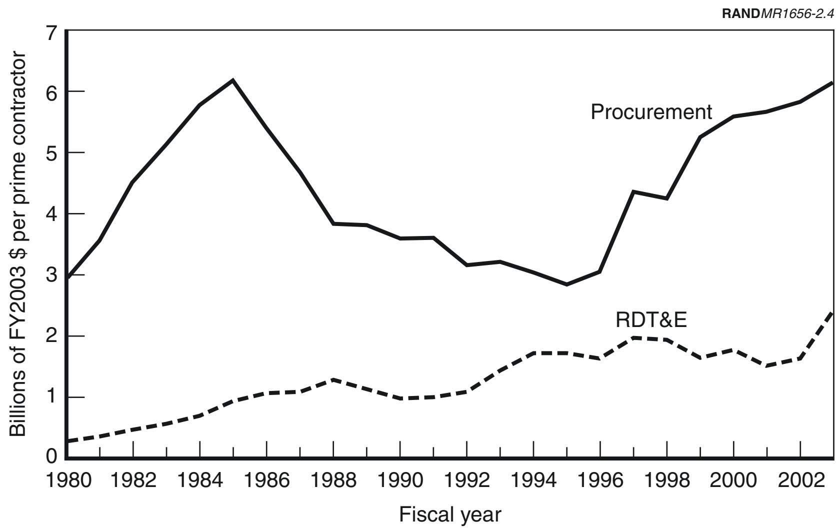


Figure 2.3—Active Production Lines for Fixed-Wing Military Aircraft

actually increased over time. The procurement trend appears to be more variable, but it, too, has increased significantly over the past several years. These findings might reflect that while there are fewer combat aircraft programs today, current ones are bigger than their predecessors and they are distributed among fewer primes.

We also calculated a simple metric corresponding to R&D opportunities and, therefore, the potential experience base for an organization. Figure 2.5 shows the ratio of the number of new aircraft designs (that actually flew during each decade) to the number of prime contractors active during that decade.[9] In the 1970s, the 12 new designs that started were spread among 9 primes, yielding an average of 1.33

[9]The ratio was calculated by counting the number of new design projects that started in a decade (see Figure 2.2) and dividing by the average number of primes active during that decade. That average was determined by summing the fraction of the decade in which each prime was active.



NOTE: This figure slightly overstates the "average revenue" stream available to a prime contractor. These data were generated by taking the total R&D and procurement funding for fixed-wing aircraft and dividing by the number of traditional aircraft primes. Some of this funding goes to other contractors and to cover government costs charged to the program.

Figure 2.4—Ratio of DoD Fixed-Wing Aircraft Budgets to the Number of Prime Contractors

new designs per prime. In the 1980s, only 9 new designs were started, but industry consolidation had shrunk the average number of primes to 8.2, yielding an average of about 1.2 designs per prime. The 1990s saw the number of new designs for *manned aircraft* drop to 5, but the average number of primes changed by a corresponding percentage, dropping to 4.2, which leaves the average number of new designs per prime at 1.2, the same as in the 1980s.

But the 1990s also saw the beginning of significant activity in unmanned aircraft. Four new designs were started, for an average of 0.9

design per prime (shown as the gray bar in Figure 2.5).[10] Thus, the total level of design starts was increased to slightly over 2 per prime, a higher value than the industry has experienced since the 1950s and 1960s. Looking at programs started during the first few years of the 2000 decade, we see that total design activity per contractor for conventional manned aircraft has dropped substantially, because the F-35 essentially substituted for what would have been three new designs. The introduction of two new UAVs brought the totals to nearly the level of the 1970s and 1980s.[11]

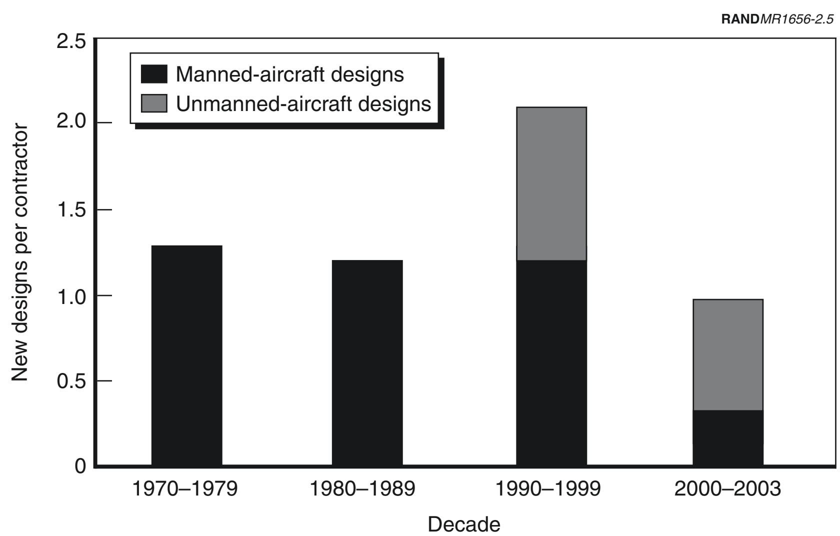


Figure 2.5—Average Number of New Aircraft Designs per Prime Contractor per Decade

[10]In recent decades, there have been new-design programs that were not conducted by traditional military aircraft "primes"—e.g., Raytheon's T-6 Joint Primary Aircraft Training System (JPATS) and General Atomic's RQ-1 Predator and MQ-9 Predator B.

[11]We expect several additional aircraft programs to achieve first flight this decade, including multi-mission maritime aircraft (MMA), multi-mission command and control aircraft (MC2A), and a tanker replacement. However, most of those programs are expected to be derivatives of commercial or existing military aircraft and would not represent new designs according to the definition used to create Figures 2.2 and 2.5.

We argue in Chapter Four that the resources needed to develop this initial generation of unmanned aircraft are considerably smaller than needed for manned aircraft such as the F-22 and F-35, but those unmanned systems make an important contribution to sustaining an experienced cadre of design engineers.

This analysis provides perhaps the strongest explanation of the consolidation that has occurred since 1970. As we discuss below, a firm needs to develop at least one new system every few years to sustain its staff experience and overall capabilities. Without the consolidation that occurred in the 1990s, the number of new design projects available to each firm would have fallen to an average of less than one design every two decades, far less than what we believe is needed for a firm to remain viable.

Although these trends in the ratio of new design starts per firm are useful for understanding some of the sources driving industry consolidation, they also require careful interpretation. When both numerator (new design starts per decade) and denominator (number of active prime contractors) are large, small changes in one or the other make only small changes in the ratio. Furthermore, small changes in the distribution of designs among the contractors can still leave each contractor with enough business to sustain its competency. But so far in the first part of the present decade, there are four design starts and three firms, and one of those designs has been largely completed. A change of only one in the count of either term would make a major change in the ratio and an even larger change in the business level of a particular firm.

Suppose that no new design projects are started in the next few years, and that one of the UAVs now under development (X-45C or X-47B) is cancelled. That would leave two design projects to be distributed among three firms, a situation markedly different from that of shifting from 12 to 11 new-design starts distributed among nine firms. Thus, while we might interpret the present average level of design activity per contractor as reasonable by historical standards, we also note that the industry is entering an era in which decisions on starting or stopping even one program can have major effects on overall industry size and composition. Some examples of such effects are explored in Chapter Four.

DEFINING INDUSTRY CAPABILITIES

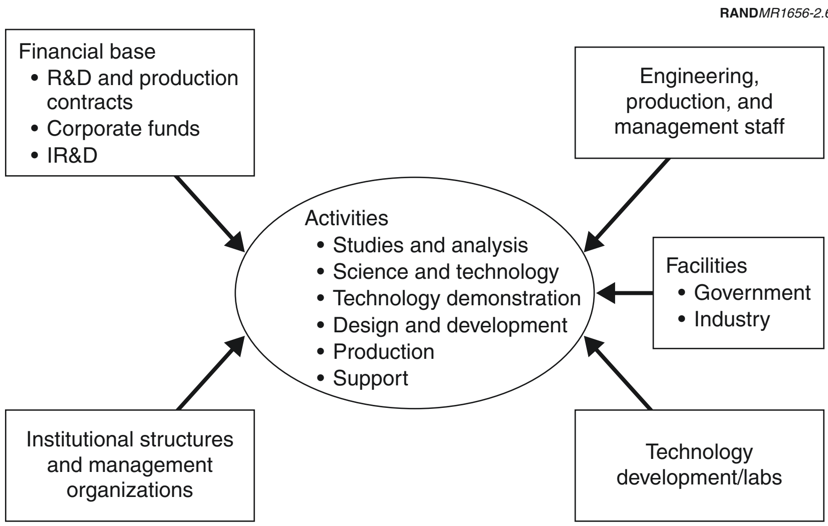
In the historical summary above, and in further analyses described in subsequent chapters, the concept of a “minimum viable firm” plays an important role. A substantial infrastructure and financial resources are required to design and test even a modest-sized technology demonstrator. A considerably greater infrastructure and overall level of resources are required to develop and place into production a new weapon system intended for widespread deployment.

When a firm is engaged in a large, long-running production program, and has contracts for one or more development programs, the breadth and depth of resources are adequate to support innovation and exploratory studies needed to enable vigorous competition for future systems. Inevitably, however, a firm will experience periods when it does not enjoy that breadth of business support. To be a viable competitor in future programs, throughout those lean times the firm must somehow sustain some minimum core staff and level of activity in technology development and design innovation. The size and cost of that minimum core, together with the firm’s expectation of future business opportunities, play an important role in a firm’s decision whether to remain in the business and in an “outsider” firm’s decision whether to attempt to enter the business.

We first describe our concept of a *minimum viable firm* in the recent past. We then outline some of the major changes now affecting the industry. Finally, we discuss how those changes might affect our interpretation of a *minimum viable firm.*

A Minimum Viable Firm in the 1990s

In 1991, RAND conducted an Air Force–sponsored study to attempt to understand what might be needed to ensure that the industry retained a strong capability to produce innovative designs of new aircraft weapon systems (Drezner et al., 1992). As part of that study, we enumerated the industry elements and capabilities that appeared to be necessary to ensure that a firm’s design, development, and production capabilities could meet DoD’s future demand for fixed-wing military aircraft. From the top-level representation of those capabilities and their interactions in Figure 2.6, we can see that the financial



SOURCE: Jeffrey A. Drezner et al., *Maintaining Future Military Aircraft Design Capability*, Santa Monica, Calif.: RAND, R-4199-AF, 1992.

Figure 2.6—Elements of a Fully Capable Military Aircraft Organization

base must be sufficient, with funding from contracts, corporate investment, or Independent Research and Development (IR&D), to enable design, development, and production activities. The engineering, production, and management workforce must have the requisite skills and experience. Facilities and equipment, often unique to certain classes of military aircraft, must be available to enable the workforce to carry out any activity. The technology-development community, including government labs, generates the flow of ideas and innovations that can be incorporated into new aircraft designs. Finally, these elements are organized within institutional structures and management organizations in the context of a wide range of specific activities, from basic research to production and support of operational systems. The elements that make up a design, development, and production capability are so varied and complex that government facilities, equipment, and in-house R&D programs play an important contributing role, largely embodied in the nation's laboratory and test-range structure.

The final report of that study on maintaining military aircraft design capability (Drezner et al., 1992) defines a *minimum viable organization* capable of conceiving and demonstrating advanced design concepts for a next-generation system as being about 1,000 engineering and technical management personnel and operating with an annual budget of about $100 million (in 1992 dollars). This organization—an "advanced-design team"—was one part of a larger firm that might have several such teams at different locations with different specializations.

Throughout most of the post–World War II period, such core advanced-design teams represented the critical engineering and technical heart of an aircraft firm. Staffed with talented and experienced engineers, the teams created the new design concepts that formed the basis for next-generation development and production programs, and their members would then form the core of the larger teams needed to design and develop an operational weapon system. It was critical to the future of the firm that these advanced-design teams be supported and nurtured during periods when no system development projects were under way.

Judging from data provided by a number of the prime contractors in 1990–1991, we concluded that this small core could survive for several years between major development programs, engaged in a mix of concept and technology development and demonstration activities. Financial support would come from DoD contracts, IR&D funds recovered through DoD production contracts, and internal corporate funds.

When new development-program starts were frequent, and the services supported an extensive menu of technology development and design study projects, it was not difficult to sustain core advanced-design teams. Today, however, as we note above, small changes in total business level and distribution among firms can have large effects on a particular firm. Furthermore, several other important parameters have changed over the past decade. Some of those parameters should affect the way a minimum viable organization capable of advanced design and concept demonstration leading to a next-generation system is characterized. Because these changes are an important element in understanding the present and future capabilities of the military aircraft industry, we reexamined them in this study and describe them in the following subsection.

Recent Changes Affecting Industry Structure and Capabilities

Many changes have occurred in industry structure and business practices over the past decade or so, and further changes are emerging today. An understanding of their effects on industry structure and capabilities is critical to understanding future competition and innovation in the military aircraft industry.

We have identified six such changes that appear to have the greatest effect on industry. They fall into two general categories:

1. Changes in the nature of demand for new systems and capabilities:
   a. Changes in overall program composition
   b. Changes in system complexity
2. Changes in the organization and business arrangements employed by major participants in the industry:
   a. Rise in teaming
   b. Changes in the roles of primes and suppliers
   c. Changes in design processes
   d. Changes in the overall corporate business base.

We discuss each change in turn in the following subsections.

Changes in Overall Program Composition. It appears that funding is becoming more concentrated in a few programs. In the 1980s, there were several large system development and production programs. The number declined during the 1990s, and, in spite of the increasing budget during the 2000s, the number of large programs continues to decrease.[12]

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[12] This decline is influenced significantly by the F-35, which is one program but replaces three previous aircraft that had separate programs.

This decline is illustrated in Figure 2.7. For this figure, we identified the major military aircraft programs that had $500 million or more funding (system procurement, plus modifications, plus post-production support) in any fiscal year. We counted the number of aircraft programs and totaled their funding. The figure shows the numbers of aircraft programs plotted as bars and the percentage of the total procurement funding they accounted for as a line. Both measures fell to a minimum in 1996. Although the number of large programs rises and falls a couple of times, the percentage of the total funding they account for has generally increased since then.

Note that the year 1996 was near the midpoint of the last major wave of consolidations, which we discussed earlier in this chapter. The drop in procurement funding might have been a spur to consolidation.

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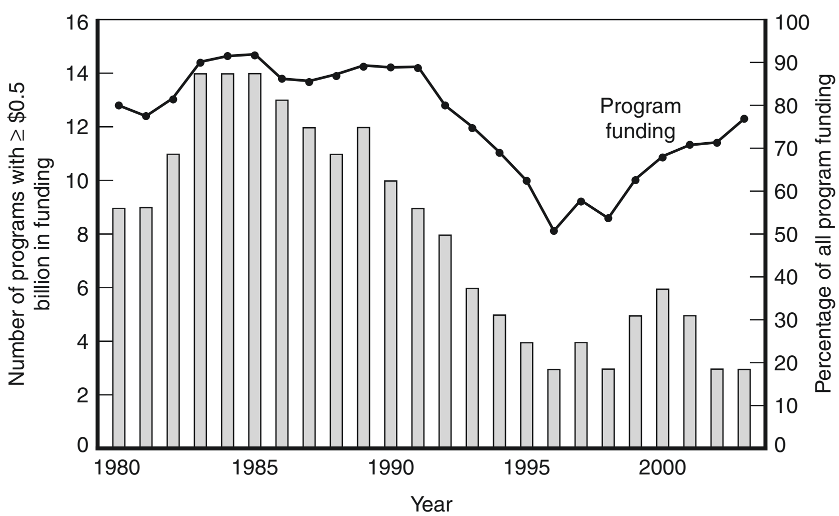

SOURCE: U.S. Department of Defense, *Fiscal Year 20BY1/20BY2 Program and Budget Review Submission, RDT&E Descriptive Summaries*, Volume 1, Exhibit P-1, Procurement Program.

Figure 2.7—Programs with Annual Procurement Funding of More Than $0.5 Billion

Because funding has become more concentrated in fewer programs, the affordability of such programs has become an increasing concern. DoD has been trying to elevate cost considerations to the same level as system performance, evidenced most visibly by the Cost As an Independent Variable (CAIV) policy, which mandates that cost concerns receive greater attention.[13] While affordability has clearly been a formal program goal in recent aircraft programs, the effects of this goal on industry's competitive posture and innovation have not yet been determined.

The recent trend toward fewer, larger systems might be countered by the services' growing interest in UAVs and UCAVs (Unmanned Combat Air Vehicles). Although air vehicles, the absence of an onboard pilot on these systems creates new design challenges at the same time that it enables new operational concepts. The performance of the Predator and Global Hawk in Afghanistan demonstrated the utility of such systems. Tactical UAVs have demonstrated their utility in training exercises. These systems, and the technology and operational concepts upon which they are based, are still relatively immature, and we expect this market to increase significantly in the near future. How that growth will affect the structure of the military aircraft industry is unclear at this time.

Changes in System Complexity. As systems become more complex, unit costs rise. With aircraft, this complexity often involves information-technology (IT)-based systems and the associated dependence of weapon systems on software. Aircraft are increasingly designed to operate with a wider range of other weapon and command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) systems, thus enabling network-centric warfare concepts (Alberts et al., 1999). Such changes in aircraft design and complexity have led the primes to focus attention on system-integration tasks, relying on the lower tiers to design and develop subsystems and components. Figure 2.8, which illustrates the increasing complexity of aircraft systems as a function of aircraft flyaway cost, indicates a steady increase in this metric over time.

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[13]Dr. Paul Kaminski, "Reducing Life-Cycle Costs for New and Fielded Systems, USD(AT&L) Memorandum for Distribution, Washington, D.C., December 4, 1995.

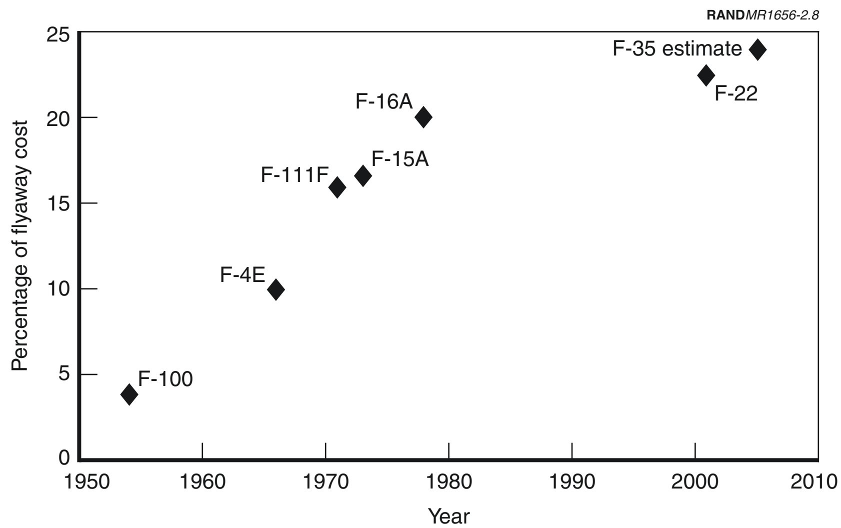

Figure 2.8—Increasing Complexity as Evidenced by Avionics Costs as a Percentage of Flyaway Costs

Rise in Teaming. Changes in the size and composition (i.e., mix of aircraft types) of demand for military aircraft have culminated in a fundamental change in business processes. New, large, and complex systems have required that teams be formed to bring together the skills and experience needed to successfully design, develop, and produce modern aircraft systems. As shown in Figure 2.9, all three recent fighters—F/A-18E/F, F/A-22, and F-35—represent major teaming efforts among aircraft prime contractors. No single firm can be expected to be the best across the full set of capabilities; rather, the primes engage in teaming, either among themselves or with the top levels of the supplier base, to bring together these capabilities.

These teams include members from across the primes' or team members' organizations to form an integrated team, which incorporates capabilities and skills from all the disciplines required in the development, production, and support of a weapon system. These teams are called Integrated Product Teams (IPTs), and the process is referred to as Integrated Product and Process Development (IPPD).

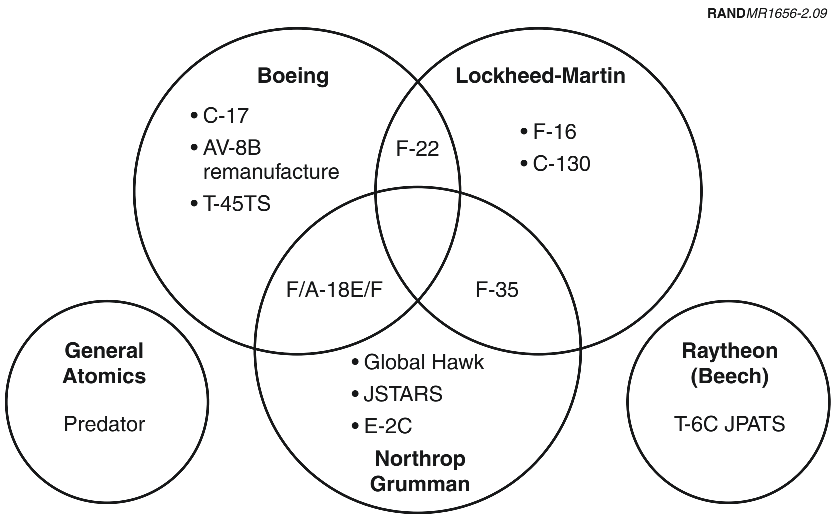

Figure 2.9—Recent Military Aircraft Teaming Arrangements

Changes in the Roles of Primes and Suppliers. The IPT/IPPD approach allows suppliers to get involved early in the development of a weapon system, as part of the IPT, and have the ability to influence the design. Suppliers are expected to stay involved throughout the life cycle of the product. In addition, the prime can often benefit from the technical capabilities and skills that these suppliers offer. For example, the Joint Strike Fighter (F-35) program is planning to keep suppliers involved throughout the production process. Suppliers will design and manufacture major F-35 airframe components, most of which will be integrated with subsystems and electronics prior to being shipped to the prime (see Cook et al., 2002).

The primes still lead design teams today, but they focus more on systems integration and less on subsystems design. They are relying more on supplier expertise to design new subsystem solutions or modify proven designs to meet their requirements. The primes' design teams often include participants from other major airframe firms and a number of critical equipment suppliers.

Table 2.1 lists prominent suppliers involved in the military aircraft business today and their respective component or components: for example, airframe sections, avionics components and systems, hydraulic subsystems, and engines. We see from the table that a larger number of firms supply avionics, airframe structures, and hydraulic subsystems than specialize in engines, radars, ejection seats, and landing gear. The specializing firms are particularly critical to the military aircraft industrial base and are sources of technological innovation.

The share of items bought from suppliers as a percentage of the unit cost for the latest configuration of a representative list of military aircraft is generally about 50 percent, as shown in Figure 2.10.[14] The trend has been for primes to outsource more of the production activities as the primes gain confidence in the maturity of the design and the manufacturing processes. For example, during the F-16 production run, the proportion of unit cost provided by suppliers increased by a factor of 4.[15]

Changes in Design Processes. One important factor that has enabled this change in the roles of primes and suppliers is a fundamental change in the design and development process itself. Computer-aided design and manufacturing (CAD/CAM) tools allow the sharing of detailed design information and the integration of inputs from multiple sources in a way that traditional design processes could not. Design files are shared electronically across different organizations within the prime and the suppliers. Design changes can be made and the interface issues addressed using a single database of (electronic) drawings and information. Thus, innovation embodied in new materials, components, and subsystems can be more easily integrated into a new system. Once the design is complete, this process should help integrate all the pieces of an aircraft system and considerably reduce the scrap and rework during production. This supplier involvement continues throughout the entire life cycle of a weapon system.

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[14]This estimate is based on contractors' response to the RAND questionnaire to industry.

[15]This was an industry response to the RAND questionnaire.

Table 2.1

Military Aircraft Supplier Base

Supplier	Airframe Structure	Radar[a]	Avionics	Ejection Seat	Hydraulics	Landing Gear	Engine
Boeing	■						
Lockheed-Martin	■	■	■			■	
Northrop Grumman	■	■	■				
Vought	■						
BAE Systems	■		■				
Raytheon	■	■	■				
Collins			■				
Smiths Industries			■				
Conrac			■				
Honeywell			■		■		
Flight Dynamics			■				
SCI Systems			■				
Moog			■				
TRW			■				
Lucas			■				
Goodrich			■	■		■	
Texas Instruments			■				
Rockwell			■				
Delco			■				
Martin Baker				■			
Fairey Hydraulics					■		
Vickers					■		
Parker					■		
Sterer					■		
Eaton					■		
Essex Industries					■		
Cleveland Pneumatics						■	
Messier-Dowty						■	
Rolls Royce							■
General Electric							■
Pratt & Whitney							■

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SOURCE: Adapted from *Aircraft Supplier Guide*, Aerospace America Special Report, July 2002.

[a]Radar is technically an element of avionics; however, its relative importance warranted separate identification.

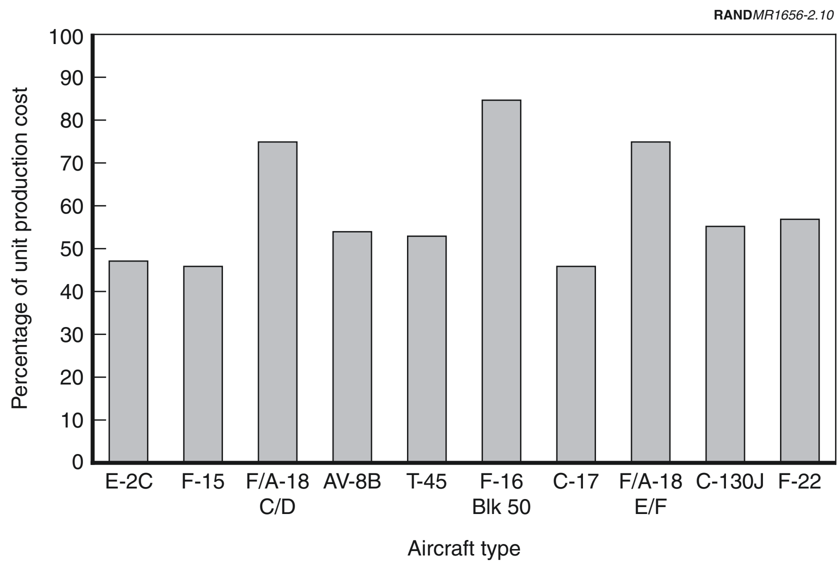

Figure 2.10—Supplier Share of Unit Cost for Current Military Aircraft

Changes in Overall Corporate Business Base. Foreign sales can be a significant portion of a firm's business base, as shown in Table 2.2. Total quantities produced for foreign purchase range from 11 percent of total production for the F-14 to 48 percent for the F-16. While not all this production occurred in the United States, the numbers are still substantial.

It is also important to recognize that the industry acquisitions and mergers over the past decade or so have changed the portion of the firms' total business devoted to military aircraft. In 2001, revenue from military aircraft programs constituted less than one-fourth of total revenue for each of the three aircraft primes.[16] Trends in the ratio of military aircraft to other business have not been consistent

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[16]The value was calculated from fixed-wing aircraft revenue data provided by the three firms.

Table 2.2

Foreign Sales of Selected Military Aircraft

Aircraft	Series	As of Year	U.S. Quantity	Foreign Quantity	Total Quantity	Percentage Foreign
F-16	A–D	2001	2,231	2,056	4,287	48
AV-8	B	1991	286	121	407	30
F-14	A,D	1990	626	80	706	11
F-15	A–E	2001	1,110	245	1,355	18
F/A-18	A–D	1996	1,036	431	1,467	29

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across all three firms, except that this ratio has declined steadily for Northrop Grumman, largely due to its acquisition of Litton and Newport News Shipbuilding businesses.

Implications of Change for a Minimum Viable Organization

Our current research suggests that the earlier concept of a core staff within each prime contractor might not be an appropriate characterization of a *minimum viable organization* in the current and future environment, for the following reasons:

- The emergence of UAVs and UCAVs as a new system type provides several new opportunities for holding competitions, incorporating innovations, and gaining experience in developing new military aircraft.
- Teaming is now the standard business practice. A single prime no longer needs to maintain within its own organization the complete set of skills required to execute a major development program.
- With the primes focusing more and more on system integration, suppliers become an increasingly important component of a design team.

- An increasing amount of the functionality of today's aircraft systems is embodied in information technology. Instead of firms having separate military aircraft divisions, they have a single military aircraft organization embedded within a larger defense systems division.

These changes have led us to conclude that the definition and characteristics of a minimum viable organization have changed. We now characterize a *minimum viable design team* as a team that may be composed of individuals drawn from several firms. It is difficult to define the size and composition of this new team precisely; however, we have identified several general characteristics this team must have:

- Facilities and equipment to develop new technologies
- Projects that lead to exploration of advanced design concepts
- Opportunities to periodically build and flight-test prototypes or demonstrators.

The size and composition of a minimum viable design team is largely a function of the scope of its anticipated activities. A wider and more diverse scope of activities implies a larger minimum team. However the team is organized, it must have a reasonably constant stream of projects on which to work. Furthermore, there is no reason to expect that the total funding required to support a design team will be much different whether the team is composed of participants from several firms or is housed entirely within one firm. We also expect the prime to be the lead agency for managing activities performed under contract; therefore, much of the external funding would flow to the prime and through it to other team members.

As in our earlier study (Drezner et al., 1992), we sought data from today's three prime contractors to enable an updated estimate of the size of a minimum viable team. We obtained histories of engineering staff size over time and roughly correlated them with identifiable project activity. Here, we tried to determine the actual staff size that firms are assigning to various activities, as distinct from staff size they might prefer under optimal conditions. These data were augmented by comments on the topic, provided by each of the primes.

Crisp results cannot be derived from such information. Organization formats (i.e., organization charts) and functional activity labels (i.e., titles for jobs such as engineer, computer specialist) differ among firms, and they change from time to time within each firm. However, the data were sufficient to suggest that firms today are maintaining core advanced-design staffs and activities somewhat larger than suggested in our earlier study. Data provided by the three prime contractors for the present study suggest that the size of a design team in the current environment ranges between 1,000 and 2,000 engineering and direct-support personnel at a total cost of $250 million to $500 million annually. As reported in our earlier work, this is the team size needed to sustain a capability for innovative design and demonstration of new military aircraft concepts. This minimum team would form the core of a larger organization that could support a major military aircraft development and production program.

It is not completely apparent why the current estimates of minimum team size and cost are somewhat larger than the estimates we made in our earlier study. Part of the growth might be driven by the fact that, with fewer firms, each firm must sustain capabilities across a wider variety of system types. Part can be attributed to the growing complexity of modern systems. One contractor official noted that

> [A] broad base skill set is required and it is getting broader. As we now consider a network centric environment for all of our system development initiatives, new virtual simulation tools and the ability to develop innovative and creative operational concepts which maximize the effectiveness/cost ratio [are] essential and this requires a new set of personnel skills to integrate these steps into the overall development process.

The results of our current analyses are persuasive and more valid for today's environment than were the results of our study ten years ago. Therefore, we use these larger estimates of minimum design team size in the analyses presented in the following chapters.

We believe that a firm such as one of today's primes, functioning as a participant in one or more of these teams, can sustain itself for two to four years between major development programs; this result is similar to the finding in our 1992 report.

A review of revenue streams and engineering-workforce profiles over time yields additional insight. We note that pre–Engineering and Manufacturing Development (EMD) activities have highly variable funding streams, with sharp increases and decreases, depending on the characteristics of the specific activity. Engineers are transferred into and out of the advanced-development organization within a firm in support of both pre-EMD and EMD activities. In the main, engineers involved in production and post-production activities represent skills and capabilities different from those of engineers in pre-EMD and EMD activities; few transfers occur between such staffs.

SUMMARY OF INDUSTRY EVOLUTION AND CAPABILITIES

The changes discussed above have important implications for competition and innovation in the military aircraft industry. Industry structure will increasingly be defined through teaming arrangements and participation of all stakeholders throughout a product's life cycle. There has been an increasing level of competition among suppliers that perform independent design and development functions, thus driving innovations at the systems level. Over time, even the characteristics of the prime contractors today may change radically. Future prime contractors will be more integrated across defense systems, and they may be smaller as a result of focusing on system-integration activities while relying on partners from the supplier base for design innovation in key components and subsystems.

Chapter Three

INNOVATION IN THE AIRCRAFT INDUSTRIAL BASE: PAST PERFORMANCE AND CURRENT PROSPECTS

The preceding chapter provided an overview of how the military aircraft industry evolved throughout the twentieth century. It paid particular attention to aspects of that evolution that might affect competition among the firms. But competition has no particular value in and of itself; instead, it is a mechanism for achieving other goals, such as enhancing innovation and controlling costs.

In this study, we are interested in how competition in the military aircraft industry affects the rate of technological innovation in that industry, and especially in whether a reduction in the number of competing firms might affect the overall rate of technological innovation. Unfortunately, there are no widely accepted and quantitative linkages between competition and innovation; therefore, we must devise a general strategy for addressing this problem. This chapter outlines our strategy.

The topic of competition has been central to the economics of industrial organization since the early twentieth century. Joseph Schumpeter (1934) is credited with the fundamental idea that competition helps to create innovation. Ever since, the debate has been on how much competition is the "right" amount.

The consensus that has emerged is that the links between market structure (including competition) and innovation are extremely complex (Scherer, 1992). Part of the reason for this complexity is that the forces that affect innovation are countervailing. On the one hand, when firms are competitive, each firm has an incentive to invest in innovation in order to produce better products, thus gaining market share and reaping higher profits. But competition also tends to limit market price for the products, thus limiting funds available to invest in innovation. On the other hand, if little competition exists, the firms can reap higher profits and thus have more money available to invest in innovation—but less incentive to do so.

It is apparent that competition and innovation are linked but that they are of very different character. An innovative industry is the desired state; competition is one of several factors that stimulate innovation. Thus, we need to address the broader issue of how to stimulate innovation, paying particular attention to the role played by competition.

We address this complex set of issues by asking two related questions:

1. What drives innovation? Can we derive a useful conceptual model of innovation that will clarify the role played by competition, along with those played by other factors?
2. Can we use that model to examine the present and projected levels of support for innovation in the military aircraft industry?

WHAT DRIVES INNOVATION?

Despite the difficulties in directly measuring innovation, significant progress has been made in the study of innovation in nondefense industries. Porter's seminal work in 1990 on the competitive advantage of nations is the largest effort in this area of which we are aware. Porter finds that competitiveness is not so much a national characteristic as a sector-specific characteristic. For example, the U.S. health care sector has dominance in pharmaceuticals, medical devices, generic pharmaceuticals, and biotechnology products. Although U.S. policies (e.g., investments in research and having patent laws that protect profits in proprietary products) have benefited the sector, most of the innovativeness is attributable to other factors, such as leading biological research at universities, a large supply of talented scientists, and a vigorous and sophisticated venture-capital market.

Porter has built a "competitiveness diamond," which refers to four causal factors of international sustained competitive advantage (a close proxy for continuous innovation). The four points of Porter's diamond are (a) national factors, (b) supporting industries, (c) demand conditions, and (d) the nature and amount of competition. The methodology for developing this model is beyond the scope of this report but is essentially inductive. Through data collection and careful review of the drivers of profitability and sustainable advantage, Porter has created a valid model of innovation.

Porter's work is arguably the most influential of its kind in explaining innovation and has been validated on dozens of industries. The Porter model was produced by studying a broad set of industries and national settings, including a large number of complex manufacturing industries, such as robotics and aircraft. To strengthen the application of the model to the military aircraft industry, the RAND research team has kept the original four drivers and added another two—R&D, and status and attractiveness—both of which reflect defense-specific issues that seem especially salient.[1]

Figure 3.1 depicts the six sets of drivers in our model of innovation. Each set of drivers comprises multiple specific metrics reflecting some aspect of the general category. Thus, no single measure of R&D or of demand or of competition fully captures all aspects and nuances of these driver categories.

One important facet of the drivers is that they tend to be easier (although not uniformly easier) to measure directly than is innovation. Further, although all drivers are important, it seems plausible to suggest that competition and demand conditions are among the *most* important drivers—a fortunate situation, given that DoD has the most influence over these drivers in the military aircraft industry.

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[1]Since R&D activities are a fundamental driver of innovation, and since DoD plays an important role in funding such activities (apart from its role in demand for military aircraft), we found it useful to call out this driver separately rather than treating it as a subset of demand. We identified status and attractiveness as important to DoD, since the defense industry has gone through periods in which it had trouble attracting and retaining the most-talented engineering and technical personnel, as well as attracting investment capital. The most recent period when these problems occurred was during the dot.com surge from about 1997 through 2000.

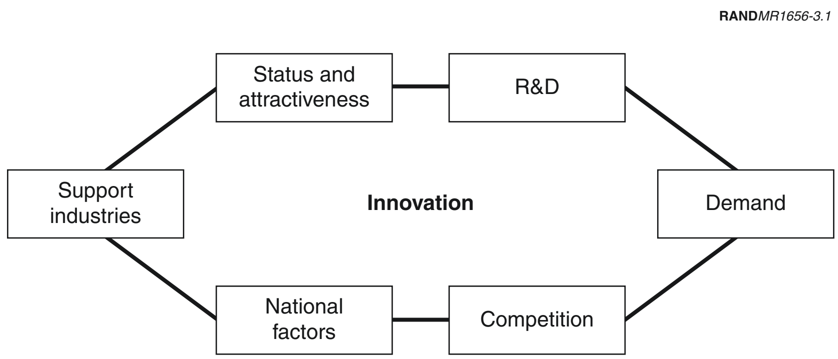

Figure 3.1—Innovation's Six Drivers

We believe that our extension of the Porter model is broadly useful in identifying and relating the various drivers of innovation in the military aircraft industry. As such, it provides us with a systematic method for examining the overall level of support for innovation by examining the level of activity and support in each of the individual drivers. To provide a reference point for the projections of future driver status presented in Chapter Four, we now assess the trends and present levels of support in each of the six drivers.

EVIDENCE ON THE TRENDS AND PRESENT LEVEL OF SUPPORT FOR INNOVATION IN THE MILITARY AIRCRAFT INDUSTRY

To assess the outlook for sustained innovation in the military aircraft industry, we collected data on status and trends that were relevant to each of the drivers. Time and resources did not permit an exhaustive search for all possible data for a driver, nor was there any formal check of validity of the measure. We did try to ensure that the measure was plausibly related to the driver (so-called face validity) and checked on several related objective measures. Consequently, the analysis below, rather than being definitive, might be considered as a strong starting point for in-depth analysis.[2]

We start by examining national factors, support industries, and status and attractiveness, drivers that are important but over which DoD has little direct control. We then examine R&D, demand, and competition, drivers over which DoD can exert some influence and control.

National Factors

National factors refer to the resources necessary to produce a product, such as human resources, physical resources, knowledge, capital, and infrastructure. In neoclassical economic trade theory, these factors are dominant in determining comparative advantage and competitiveness. In our model of innovation, national factors are merely one of six sets of drivers affecting innovation.

For some industries, physical resources are paramount. For example, a significant oil-extraction industry is located in Saudi Arabia because that is where the oil is; and a strong timber industry is located in Canada, which is heavily forested; and so on. In many other modern economies, the most important national factors are a pool of highly skilled labor and capital. For the military aircraft industry, physical resources are important, but not as important as skilled labor and capital. Accordingly, we collected data on the trends in two key inputs to national factors: national education and capital markets.

A well-educated labor pool is an important prerequisite for innovation. Figure 3.2 shows that the number of U.S. citizens with college degrees (all subjects) has continued to increase since 1940.

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[2]We have not included any *direct* measures of innovation. The innovation literature finds that measuring innovation directly is difficult. Several measurement methods exist, none satisfactory for military aircraft. One of the most credible quantitative measures of innovation that we could find is patent counts. These counts are widely used, but the measure has important flaws for use in military aircraft and was, with reluctance, discarded. For what it is worth, we found that aerospace R&D dollars invested in the 1990s per patent was decreasing (which might imply increasing efficiency and innovativeness). Sources: Company annual reports, U.S. Patent Office, and RAND analysis.

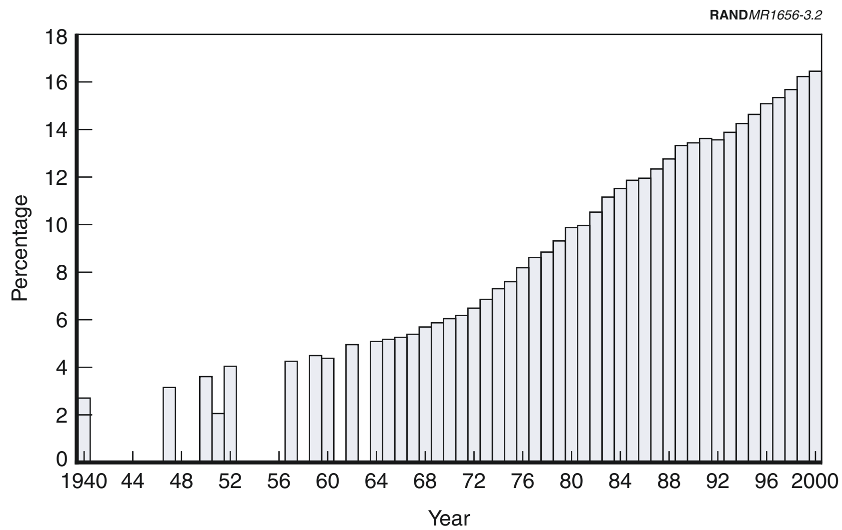

Figure 3.2—Percentage of U.S. Population with College Degrees, 1940–2000

Availability of capital to the military aircraft industry appears to be excellent. Stock prices, one measure of the price of equity capital, are up significantly since March 2000, and Lockheed-Martin has been outperforming the overall stock market by 100 percent or more (http://finance.yahoo.com/q?s=lmt&d=c, May 2002). Figure 3.3 shows the excellent relative performance of aerospace against other prominent stocks since December 31, 1999.

Stock prices are affected by many factors; however, the aerospace sector appears to perform not unlike other technology-based industrial sectors, and perhaps better than some of those sectors, on average. We found no evidence that innovation in the military aircraft industry was unduly constrained by lack of capital.

Status and Attractiveness

A trained and experienced workforce with the requisite mix of skills is critical to a firm's competitiveness and ability to innovate. Among other things, a firm must

- maintain a trained and experienced workforce with a skill mix appropriate to the program mix within the firm
- be sized in a way that balances efficiency in program execution and stability of the workforce
- maintain a balance between relatively junior staff gaining experience and relatively older staff with accumulated experience.

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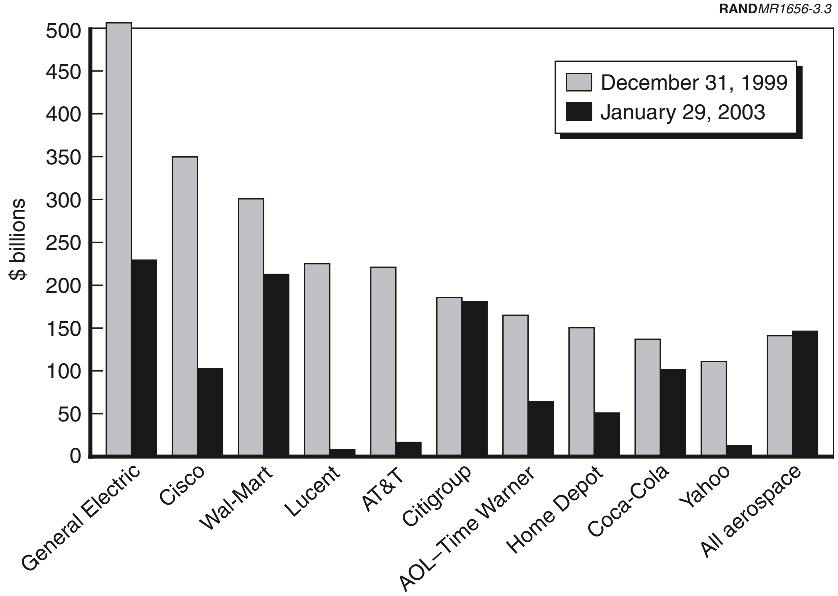

NOTE: Aerospace as defined by Defense Science Board Task Force, *Defense Science Board Task Force on Preserving a Healthy and Competitive U.S. Defense Industry to Ensure Our Future National Security*, Final Briefing, November 2000: Boeing, Honeywell, United Technologies, General Dynamics, Textron, Lockheed-Martin, Raytheon, TRW, Northrop Grumman, and Litton Industries.

Figure 3.3—Market Capitalization: Aerospace and Representative Firms in Other Industries, 1999–2003

These issues are manageable during robust times, when many firms are working on many projects. They are difficult to manage in an environment with fewer new program opportunities.

Today's three primes have very different workforce sizes, which are driven largely by the number, type, and maturity of their programs. All three show similar patterns of engineering and production workforce ramp-up as a new program matures.

As the mix of programs changes over time, with some programs ramping up and others winding down, the workforce shifts from program to program. In two of the three primes, the total workforce stayed remarkably stable despite such internal shifts. One underlying pattern in all three prime contractors was the apparent transition of engineering personnel into and out of the advanced-development components of the military aircraft organizations.

We obtained some anecdotal evidence that all three firms had difficulty hiring top-quality engineering graduates in certain skill areas in the late 1990s, particularly as the dot.com and IT sectors took off. After those sectors' bubble burst, these problems largely disappeared. At the time of this study, none of the primes indicated any problems with hiring personnel in any functional category.

A demographic analysis produced mixed results. All three primes had very similar age distributions for their manufacturing workforce; the workforce age was distributed normally around a mean in the 40-to-49-year-old category. Two of the primes had similar age distributions for engineering personnel, again normally distributed around a mean in the 40-to-49-year-old range. The third firm's engineering workforce had a significantly higher proportion of workers in the 50-to-59-year-old range. In general, we believe that workforce demographics are not a major issue for any of today's prime contractors.[3] We also found no evidence that workforce skills, training, and experience posed a major issue.

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[3]This is in contrast to assertions made by NASA with respect to a significant decline in aerospace graduates. See *NASA Aeronautics Blueprint for a Bold New Era in Aviation* (undated). www.aerospace.nasa.gov/aero_blueprint/index.html.

Support Industries

Porter identified *support industries*—vendors and suppliers—as important drivers of innovation and sustainable competitive advantage. Competitive advantages in some supplier industries confer potential advantages on a nation's firms in many other industries, because they produce inputs that are widely used and important to innovation (Porter, 1990, p. 100). Thus, innovation in military aircraft is, in part, affected by the competitive posture, innovativeness, and financial health of key support-industry sectors developing and producing key components and subsystems, such as those listed in Table 2.1.

It is difficult to measure the level of innovation in the military aircraft supplier base for the same reasons that it is difficult to measure innovation for the primes. However, as noted in Chapter Two, there appears to be a trend toward more value-added coming from suppliers. In the last decade, as the primes have placed more emphasis on systems integration and less on building components, the supplier base has become an increasingly important player during the development phase. This trend has been partially enabled by CAD/CAM technology and by a close working relationship between prime and subcontractor that intensified in the 1990s. Generally, the exchange of R&D and the joint problem-solving between primes and a growing number of innovative suppliers are leading to faster and more-efficient solutions to design problems.

R&D

The composition and level of research and development are important contributors to innovation. Porter does not include them because a number of industries are innovative even though they conduct very little formal R&D—for example, the profitable and innovative Italian shoe industry. However, formal R&D funds account for most of the innovation in military aerospace, and elaborate mechanisms are in place for funneling R&D dollars to promising technologies and projects. For this reason, R&D belongs in our model.

National R&D spending has been fairly constant for 40 years, at about 2.5 percent of the gross domestic product (GDP), as Figure 3.4 shows. It has been on the rise since the mid-1990s, even though that

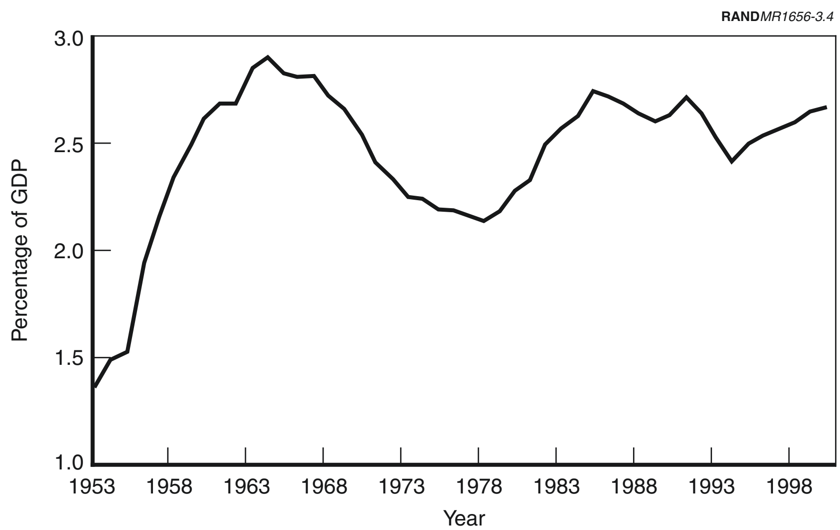
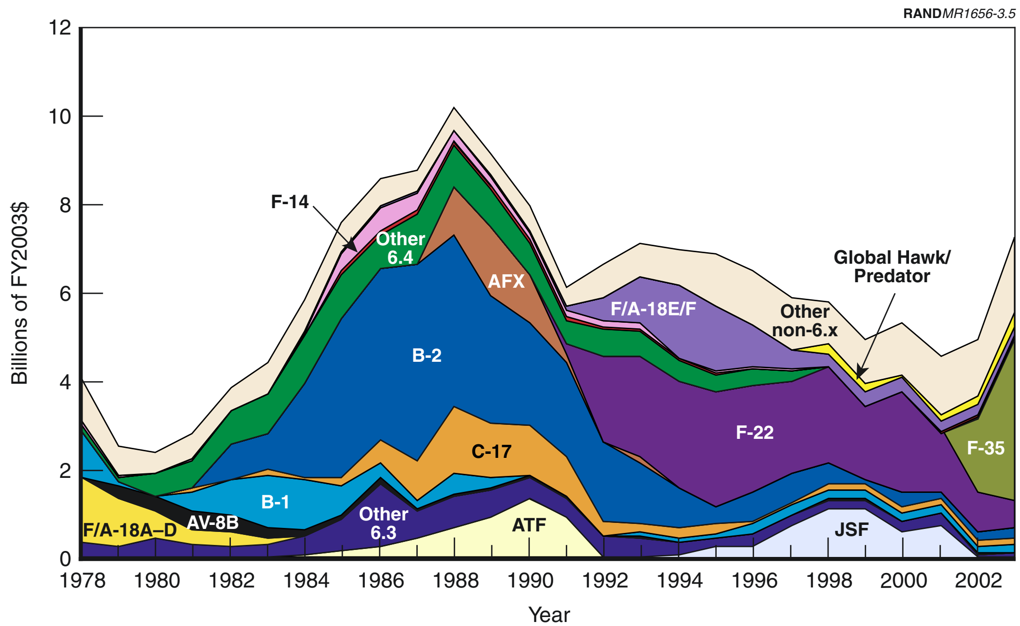


Figure 3.4—Total U.S. R&D Spending as a Percentage of GDP, 1953–2000

was a period of very strong GDP growth. Thus, at a broad level, the nation is investing in R&D.

Here, we are concerned with spending on R&D for fixed-wing military aircraft. It is not possible to extract such data from government or corporate records with great precision, because most financial records are not set up to make that particular distinction from among all R&D. However, it is possible to get information of useful precision by combining several data sets: Selected Acquisition Reports (SARs); and three volumes of the annual DoD Program and Budget Review Submission—R-1 (the exhibits for RDT&E), R-2 (the exhibits for RDT&E Budget Item Justification), and P-1 (the exhibits for Procurement Program). These documents show obligational authority (referred to here as *funding*) for the fiscal year of issue.

Fixed-wing military aircraft RDT&E funding, shown in Figure 3.5, reached a low point in 1980, followed by a sharp increase that led to the peak funding in 1987 (see Appendix). A gradual decrease through



SOURCE: Data were derived from the 1980 through 2003 R-1s (RDT&E Program exhibits), current and selected historical Selected Acquisition Reports (SARs), and the 2003 R-2s (RDT&E Budget Item Justification exhibits). Classified programs are excluded, except for those declassified before FY2002 (e.g., the B-2). All costs are expressed in constant FY2003 dollars. Escalation factors were taken from the FY2003 National Defense Budget Estimate (Green Book).

NOTE: See the Appendix for a clarification of the data sets and the Budget Activities from which the figure was constructed.

Figure 3.5—DoD RDT&E Obligational Authority for Fixed-Wing Aircraft, 1978–2003

2002 is now projected to be followed by another peak in the near future, as discussed in Chapter Four.

At any time, the overall pattern in system-development funding is driven by a few very large programs. The B-2 and F-22 stand out as considerably larger than other programs in the time period shown. Numerous RDT&E activities cover both major system develop ment and pre-EMD activities, such as Advanced Technology Demonstration (ATD) programs, demonstration and validation (Dem/Val) programs, and modernization and upgrade programs.

Government Investments in Science and Technology. Investment in science and technology (S&T) is critical to innovation, and it is useful to identify those activities separately from the overall RDT&E funding. Many concepts and technologies incorporated into future-generation aircraft systems are initially developed and matured in the RDT&E budget categories 6.2 (applied research) and 6.3 (advanced development and demonstration). It follows that any major reduction in the pace of technology-development projects would probably lead to a reduction in the pace of innovation in future aircraft designs.

To illustrate the critical importance of 6.2 and 6.3 budgets, Figure 3.6 outlines the development path for key technologies and concepts incorporated in the Joint Strike Fighter (JSF) Dem/Val designs (X-32 and X-35) and the F-35. Many of the programs listed in the "Prior Programs" box were completed more than a decade ago. Programs that specifically aimed to mature particular technologies over an extended period of time are a key aspect of the overall development process depicted in the figure.

Investments in S&T are included in Figure 3.5 but are largely masked by the much larger operational-system-development programs. Using a different display to more clearly separate small from large areas of investment, Figure 3.7 provides a more detailed look at the distribution of the RDT&E budget for fixed-wing aircraft across Budget Activities, the majority of funds for which went to System

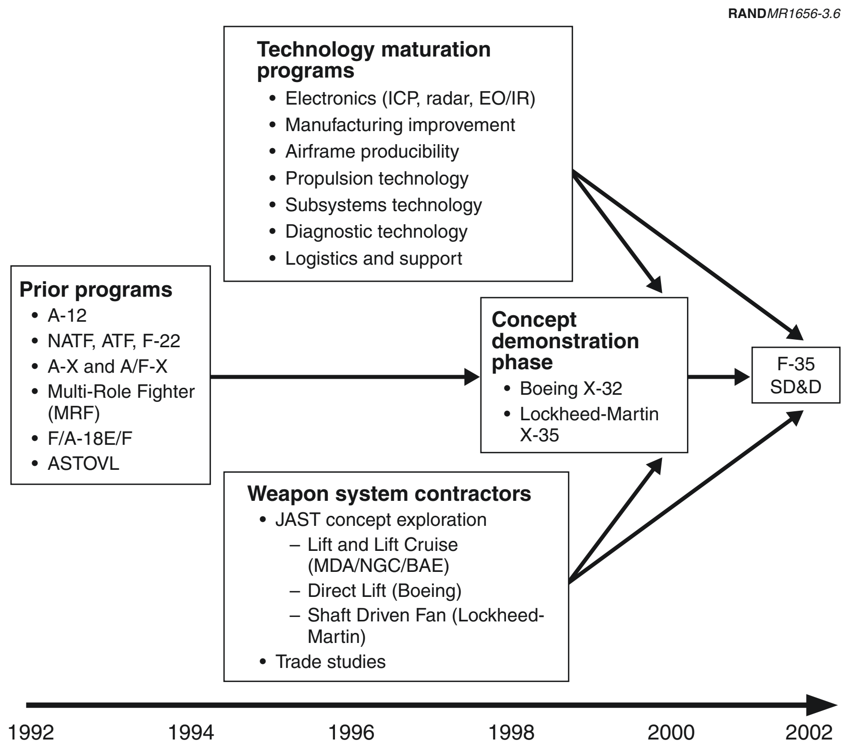


Figure 3.6—Technology-Development Path Leading to JSF

Development (see the Appendix for an explanation of the data sets and Budget Activities from which the figure was composed). Advanced Development and Demonstration funding can also be substantial. Funding levels are greatly affected by one or two very large programs, in this case the JSF and Airborne Laser (ABL).[4] Applied Research is a very small but steady budget category. The

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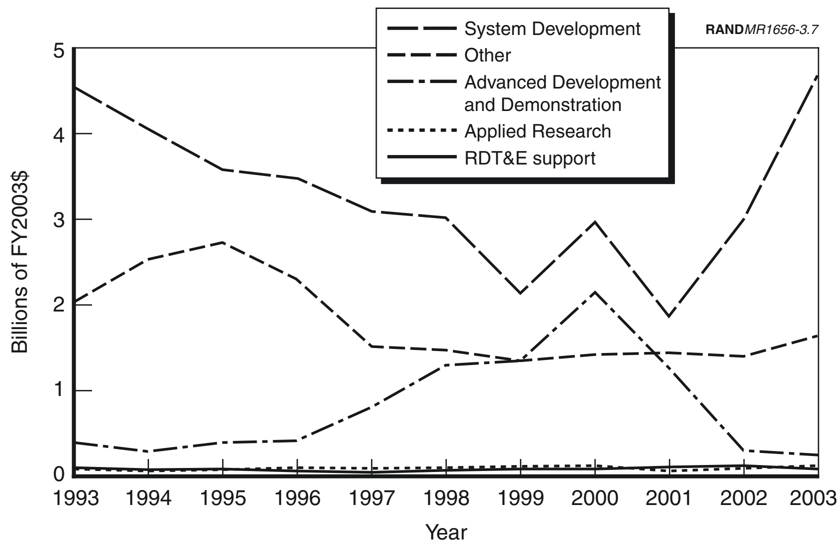
[4]The ABL program is not separately identified in Figure 3.5, because its funding is included in the National Missile Defense program and the SAR for the ABL program has been discontinued. However, it is identified in the RaDiUS database.



NOTE: See the Appendix for a clarification of the data sets and the Budget Activities from which the figure was constructed.

Figure 3.7—Fixed-Wing Military Aircraft Funding by Budget Category, 1993–2003

Other category includes a wide variety of aircraft-related activities, from technology development to upgrades for systems currently in the fleet. Funding for many of the recent UAV-related and intelligence, surveillance, and reconnaissance (ISR) payload-development activities is included in the Other category. It is not possible to use the DoD R-1 and R-2 databases to identify basic research targeted to aircraft-related projects.

DoD is not the only government agency that funds RDT&E related to aircraft. NASA's Aerospace Technology Enterprise includes almost $800 million in aircraft-related funding.[5] NASA's activities include basic research in propulsion and flight technologies; a significant part of the Space Launch Initiative is identifying and exploring tech-

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[5]All NASA information is derived from the FY2003 President's Budget. The detailed discussion of specific programs available at the R-2 level allows aircraft-related activities to be identified, and other activities to be eliminated, with some confidence.

nologies and concepts for a second-generation reusable launch vehicle.

Several Defense Advanced Research Projects Agency (DARPA) programs fall into the S&T category of research, including the UCAV (X-45) program, for which Boeing is the prime contractor; a Navy UCAV, for which Northrop Grumman is a key competitor; and the Quiet Supersonic Platform. The FY2003 funding for these programs is relatively low; however, published budget projections indicate substantial growth in the next several years.

In summary, the limited data we have been able to assemble suggest a substantial government-funding stream supporting S&T activities related to aircraft design.

Corporate Investments in Research and Development. Industry also invests in R&D to conceive, develop, demonstrate, or incorporate innovations into aircraft systems. These company investments come in many forms, including

- direct corporate investment
- IR&D, some of which can be recovered through overhead on DoD contracts
- collaborative arrangements with government labs through a Cooperative Research and Development Activity (CRADA) or cost-sharing arrangements
- cost-sharing or supplemental funding of major government contracts.

Substantial corporate investments were made in both the Advanced Tactical Fighter (ATF; YF-22/YF-23) and JSF (X-32/X-35) programs. Discussions with the prime contractors indicated that the vast majority of corporate investment in aircraft comes from reinvesting the profit made on aircraft-production contracts.

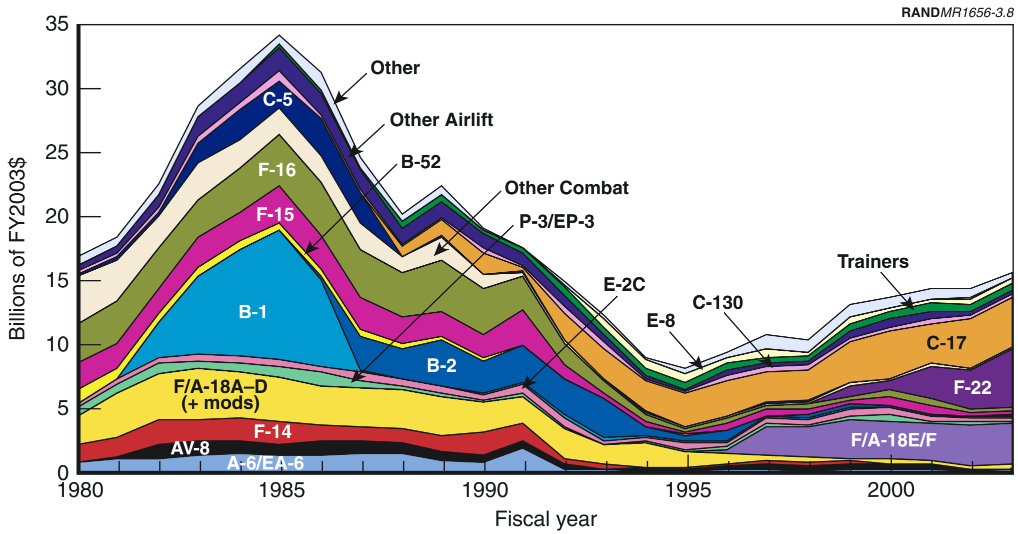
Data from the prime contractors, as well as those from industry associations, suggest that industry investment levels (IR&D, profit, etc.) have remained fairly stable, whereas government funding has decreased (Aerospace Industries Association of America, 2002, p. 101). This situation increases the relative importance of industry investment in generating innovations and incorporating them into systems.

Demand Conditions

Demand conditions not only refer to the dollar level of demand, but also include how that demand is distributed across different kinds of products and across different segments of the industry, and the sophistication and insistence on quality from the buyer. The composition of demand shapes how firms perceive, interpret, and respond to buyer needs. The majority of sales of these firms is made to DoD; therefore, it is difficult to overemphasize the importance of DoD support for developing an innovative industrial base.

It is important to distinguish between two aspects of overall demand for a sector's products: demand for the *development* of new products and demand for the *production* of existing products. In the above discussion, we noted DoD funding support for new designs and capabilities. However, it is production that earns revenue for the firm and its investors. That revenue, in turn, has important implications for the amount of resources available for investment leading to innovation. With that aspect in mind, we looked for measures of both level and composition of demand for production of military aircraft.

Figure 3.8 shows obligational authority for fixed-wing aircraft procurement, from 1980 to 2003 (see the Appendix). Funding peaked at $34.2 billion in FY1985 and had dropped to $8.1 billion by FY1995. Since then, it has grown back to $15.6 billion (FY2003) and is projected to peak at $22 billion in FY2007. An interesting observation to be drawn from this chart is that funding is becoming more concentrated in a few programs. The seven or eight large programs of the 1980s declined to three during the 1990s. And, in spite of the increasing budget during the 2000s, that trend seems likely to continue if only because the F-35 replaces three previous aircraft that had been separate programs. However, procurement levels of around $15 billion per year represent robust support for an industry currently made up of only three primes.



SOURCE: Data for this figure were taken from the 1980 through 2003 P-1s (Procurement Program exhibits), current and selected historical SARs, and the 2003 P-40s for Air Force and Navy fixed-wing aircraft programs. SARs were also used to fill in missing historical P-1 data (e.g., B-2 program). All costs are expressed in constant FY2003 dollars.

NOTE: See the Appendix for a clarification of the data sets and the Budget Activities from which the figure was constructed.

Figure 3.8—DoD Procurement Obligational Authority for Fixed-Wing Aircraft

Competition

Competition is arguably the most important driver of innovation. It is a focus in Porter's work and has been shown to be important in study after study (see, especially, the discussions of competition in Birkler et al., 2001, Chapters Three and Seven). *Competition* is not only the number of firms but also the nature and intensity of the rivalry among firms.

Identifying the optimal number of firms for innovation has been studied at theoretical and empirical levels. Generally, the amount of innovation in an industry follows an inverted-*U* shape (Scherer, 1992; Baumol, 2002; Aghion et al., 2002), as in Figure 3.9. At the left, monopolies engage in little innovation: They have no rivals they need to beat. A firm with a dominant market position maximizes secure profits by choosing a leisurely, inexpensive R&D pace, and by paying more attention to defending a monopoly position. At the far right side of the graph, little innovation occurs with perfect (i.e., full and complete) competition because firms have little profit to reinvest in innovation and, perhaps, because of large technology spillovers.[6] Oligopolistic rivalry appears to be preferred for innovation, although the optimal number of firms will depend on the industry. Some authors believe that the effects of firm size and concentration on innovation, if they exist at all, do not appear to be important (Cohen and Levin 1989, p. 1078, quoted in Scherer, 1992). Several early tests supported the inverted-*U* conjecture, but that result has tended to disappear when other explanatory variables were included. However, more-recent work also finds theoretical and empirical evidence for an inverted-*U* shape (Aghion et al., 2002).

The evidence for a relationship between number of firms and innovation is weak, and it calls into question any policy designed to affect the number of firms when the main objective is to stimulate innovation (except in the special case when the number approaches one).

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[6] *Technology spillovers* refer to the unintentional, unpaid transfer of intellectual property from one firm to another. Spillovers may occur from the flow of employees between firms or by more overt means, such as reverse engineering.

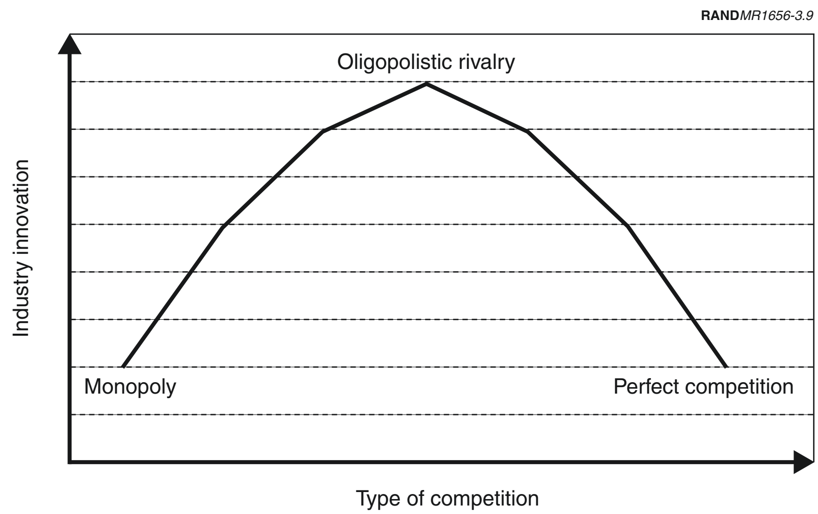

Figure 3.9—Relationship Between Type of Competition and Innovation

When assessing the role of competition in support of innovation, it is important to note that effective competition can, and does, sometimes come from firms not necessarily at the forefront of the industry. Thus, an examination of whether there is enough competition must include possible challenges from firms other than today's primes.

James Utterback (1994) has studied the characteristics and the sources of revolutionary innovation and has arrived at a compelling theory that was designed to be general and applicable to all industries. We believe that it is applicable to military aircraft. In a study of 41 industries, Utterback looked for variables—*characteristics of innovation*—that would explain whether a revolutionary innovation would come from "inside" or "outside" the established industry. For example, Lockheed-Martin, Boeing, and Northrop Grumman would be considered "inside" the military fixed-wing aircraft industry today; all others would be considered "outside." The following variables were found to be highly explanatory of where an innovation originates:

- Is the product assembled?
- Does the product expand demand?
- Does the product destroy competency of existing competitors (i.e., does it threaten the current product designs)?

Figure 3.10 summarizes Utterback's findings. Here, the distribution of revolutionary innovations is arrayed according to where the innovation occurred (inside or outside the industry) and how many of the characteristics of innovation were present. We can see that presence of an increasing number of the characteristics leads to a strong increase in the probability that the revolutionary innovation will come from outside the industry.

Applying this finding to the military aircraft industry, we note that an aircraft is an extreme example of an assembled product. By and large, in defense, a revolutionary innovation shifts demand away from older products but does not expand total demand to a significant degree (unlike, say, the massive increase in computer-processing speed that led to a boom in home computing). Finally, an innovation in aircraft might, or might not, destroy the competency of existing competitors. Therefore, a revolutionary innovation in military aircraft will likely have a "score" of either 1 or 2 of the characteristics of innovation.

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Characteristics of the Innovation

- Assembled product
- Product expands demand
- Product destroys competency of existing competitors

Source of Innovation
(N = 41 industries)

Number of characteristics displayed at left	Prime	Non-prime
0	7	0
1	6	6
2	1	16
3	0	5

Figure 3.10—Source of Revolutionary Innovation

An innovation in military aircraft that did not destroy competency of an existing competitor (an example might be a manufacturing process that radically reduces the costs of composites) would have a "score" of 1, indicating roughly a 50:50 chance of coming from outside the industry. However, a competency-destroying innovation would have a score of 2, indicating a high probability that it would come from outside the industry. This suggests at least an even probability, and, in some cases, a much higher probability, that a revolutionary innovation will come from outside the then-existing core firms such as today's primes.

Lorell and Levaux (1998) and Lorell (2003) show that the history of military aircraft broadly agrees with this work. They found that revolutionary innovations, such as the early applications of jet propulsion or the achievement of practical and effective stealth designs, were made by firms that, although in the military aircraft business, had little current business. That circumstance led those firms to take bigger risks in design and allowed them to beat out the current incumbents if their design risks paid off. Those product-enhancing innovations could have come from inside or outside.

Note that Utterback allows for only two classifications. Lorell and Levaux essentially have a third classification: insiders with little or no current business. It is interesting to note how this third category, which straddles the insider and outsider categories, is responsible for many of the revolutionary product-enhancing innovations in aircraft. While not conclusive, since the analyses use different categories, the two seem highly consistent. The insider/outsider split found by Utterback seems consistent with Lorell and Levaux's "insider who is currently an outsider" categorization. In addition, we might predict that truly competency-threatening innovations would more than likely come from pure outsiders, rather than from this combined category.

SUMMARY OBSERVATIONS

Having explored the links between competition and innovation, we are now better prepared to address the heart of the competition question: Will there be enough competition to stimulate innovation in the military aircraft industry? Surely, the reduction in the number of primes from 11 in 1960 to three today leads to concern for the future. However, legitimate reasons can be given for this consolidation: a decrease in the number of new military aircraft programs over the past decade and the ability of firms other than the present three primes to produce products that might, in the future, perform some of the missions now performed by traditional aircraft systems. For example, there is likely to be vigorous competition for the next-generation UCAVs and UAVs, and it is reasonable to expect that some new firms will compete for those new system concepts.

The final resolution of this issue will depend on the future levels of demand for military aircraft, whether the composition of that demand is such that new entrants have a chance to compete with the present primes, and on how the primes themselves respond to the evolving marketplace.

The model discussed above provides a strategy for estimating the stimulus that can be expected for innovation in the military aircraft industry. Three of the drivers we examined—national factors, status and attractiveness, and support industries—depend in part on what occurs in the broad national economy over the coming years. At this time, there appears to be little cause for concern. Those drivers are expected to continue to strongly support innovation in the military aircraft industry.

The remaining drivers—R&D support, demand for products, and competition among the players—will depend importantly on the policies and practices of DoD.

In the following chapter, we explore the extent to which near-future patterns in demand might affect the level of competition that can be sustained in the industry.

Chapter Four

WHAT MIGHT THE INDUSTRY LOOK LIKE IN THE FUTURE?

In Chapter Two, we summarized some past and current trends in the size, composition, and revenue of the military aircraft industry. Although the industry has consolidated from over a dozen firms in the 1940s to three today, those three firms appear to be vigorously competitive. Unfortunately, the history of the past and circumstances of the present do not provide strong insights into how the industry structure is likely to evolve over the future—or even over the next few years. That future evolution is important: If further consolidation does occur, the remaining firms—or firm—might not exhibit the same level of competitiveness as do the present firms.

In Chapter Three, we described the main characteristics of an industry that we believe are necessary to support vigorous innovation by members of that industry. The existence of vigorous competition is an essential characteristic. Therefore, to explore the likelihood of retaining a vigorously innovative military aircraft industry, we must explore the likelihood of retaining a vigorously competitive industry.

We postulate that the level of competition among military aircraft firms that is likely to exist in the next few years depends critically on the kind and amount of business that those firms experience, and that kind and amount, in turn, will depend on the demand for military aircraft development and procurement stemming from the Department of Defense. In this chapter, we explore the demand issue by asking two questions:

1. What size and composition of military aircraft development and procurement programs can be expected in the foreseeable future?

2. Are those future programs likely to sustain the present industry structure? If not, what are the critical deficiencies? In particular, is there a reasonable basis for expecting further consolidation of the industry, which will lead to at least the possibility of reduced competition in the future?

We addressed these questions by first examining the present program for acquiring military aircraft, as reflected in the FY2003 Future Years Defense Program (FYDP).

We estimated the amount of RDT&E funding and production funding that would flow to each of the three primes from currently programmed projects, and assessed whether that funding would be sufficient to sustain them in approximately their present configurations. This assessment was made relative to their capability to be prime contractors for manned military aircraft. The results of that analysis provided a base case against which we could compare the consequences of alternative future weapon-system development and production scenarios.

Next, we postulated some additional future development and production scenarios for programs that could plausibly be expected to start sometime within the next decade or so. Because such futures are highly uncertain, we examined a range of possibilities, starting with programs expected to start soon and extending to more-speculative options that might start later. In each case, we made assumptions about how those future programs might be distributed across the present three primes and assessed how those streams of business might affect the industry posture and capabilities. Finally, we examined results from each of those analyses to identify which elements of industry capability might be at greatest risk.

One of the driving issues behind this study is the concern of Congress set forth in Chapter One that there be a "future capability of more than one aircraft company to design, engineer, produce, and support military aircraft." We structured our analyses to consider all three of the current major military aircraft prime contractors. Hence, we had to assign new programs across the three contractors. As an analytic convenience, we considered whether the new programs were particularly suited to a specific contractor (e.g., commercial derivatives to Boeing) and the sequence in which contractors would begin having funding shortfalls. This exercise does not indicate that we recommend a specific contractor for any program.

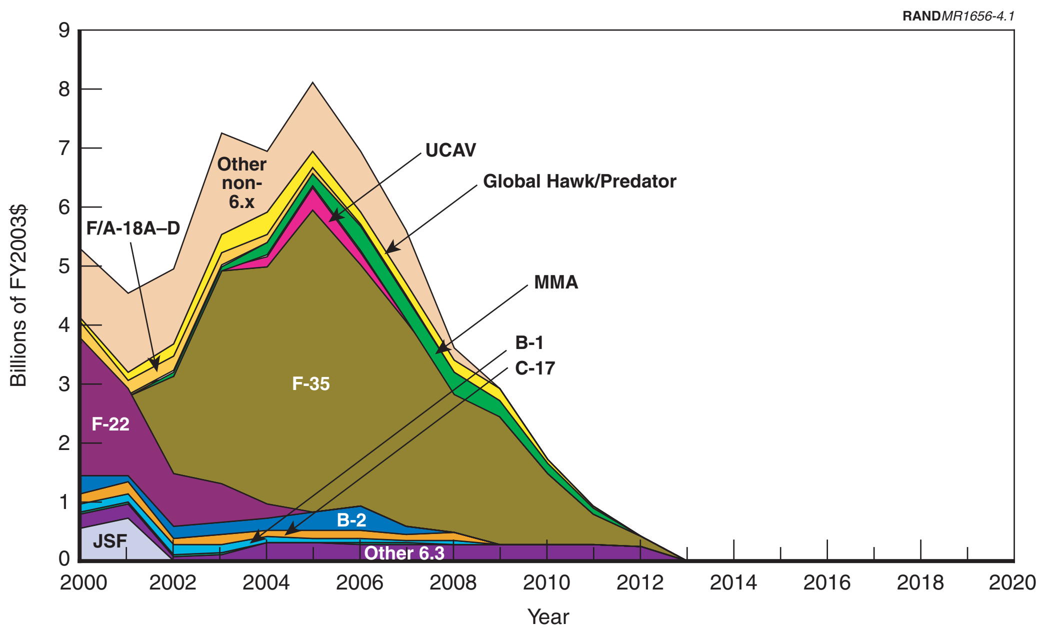
The remainder of this chapter is presented in two sections, corresponding to the base case and some alternative scenarios of future development and production programs.

BASE CASE

Figures 4.1 and 4.2 display the RDT&E-funding and procurement-funding profiles comprising all fixed-wing aircraft programs in the FY2003 FYDP, plus projections for major defense acquisition programs presented in the December 2001 SARs. This limited picture of the future is not accurate, because new programs will almost certainly be started during that time period. However, we selected these programs as the starting point for our analyses because they did not require assumptions regarding new programs. Such assumptions were reserved for the future scenarios.

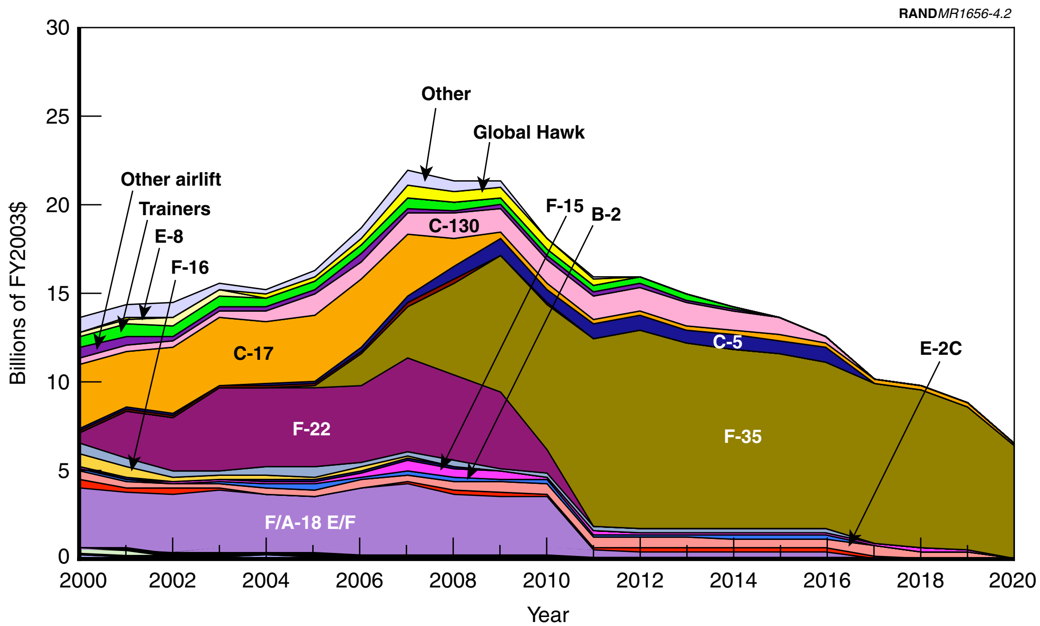
The funding shown in these figures raises two concerns: one for the overall levels of funding and one for the distribution among the prime contractors. Are the levels and distributions adequate to support multiple, full-service prime contractors? As noted in Chapter Three, the current funding levels are robust. Procurement funding remains so through the end of this decade, and the level is not a problem. RDT&E funding drops shortly after the end of the current decade, becoming a critical problem. For both RDT&E and procurement, funding in the later years is dominated by the F-35 program.

As we show below, the *distribution* of funding among the contractors is a problem for both RDT&E and procurement. Because we judged the overall level of *procurement funding* to be adequate for the period we studied, we measured the distribution between contractors in percentage terms. *RDT&E funding* is a problem in terms of both level and distribution; hence, we treated it in dollar terms.



SOURCE: Based on the FY2003 FYDP.

Figure 4.1—Base-Case RDT&E Obligational Authority



SOURCE: Based on the FY2003 FYDP.

Figure 4.2—Base-Case Procurement Obligational Authority

The funding data shown in Figures 4.1 and 4.2 are total obligational authority (TOA),[1] which includes funding that goes to prime contractors, funding for contractors that provide Government Furnished Equipment (GFE) to the primes, and funding for government organizations' costs directly related to the program. For RDT&E, we estimated the portion of TOA that goes to the prime contractors as between 70 and 90 percent, based on contract estimates at completion and funding over the corresponding contract years as reported in SARs for several recent programs.

Because we present the distribution of procurement funds between contractors in percentage terms, we did not estimate the amount of procurement TOA that goes to the primes.[2] For programs that involve more than one prime, we used estimates for the distribution between the contractors as reported in the open literature or as related by the contractors. To avoid revealing proprietary information, the values we used are approximate.

Figures 4.3 and 4.4 show the distributions between the current three major prime contractors for RDT&E funding and procurement funding, respectively. Given the dominance of the F-35 program as shown in Figures 4.1 and 4.2, it is not surprising that Lockheed-Martin dominates the distribution pictures and that Northrop Grumman holds up in procurement. However, the RDT&E distribution highlights a potentially more serious condition. Recall that the funding level for a minimum viable firm, noted in Chapter Two, ranges between \$250 million and \$500 million annually. Figure 4.3 shows Boeing's funding falling below this band between approximately 2006 and 2008, with Northrop Grumman close behind (2008–2010). There may be a year or so slack in this because we are plotting TOA and not expenditures. However, the spend-out for RDT&E is not spread over as many years as for procurement. In the absence of near-term action, it is not clear that the incentive will be adequate for Boeing and Northrop Grumman to maintain their fixed-wing

[1]*Total obligational authority* pertains to the funds corresponding to the total budget authority across DoD or some specified part of it in a given year.

[2]This approach implicitly assumes that the percentage of procurement TOA that goes to the program prime contractor is approximately the same across all programs.

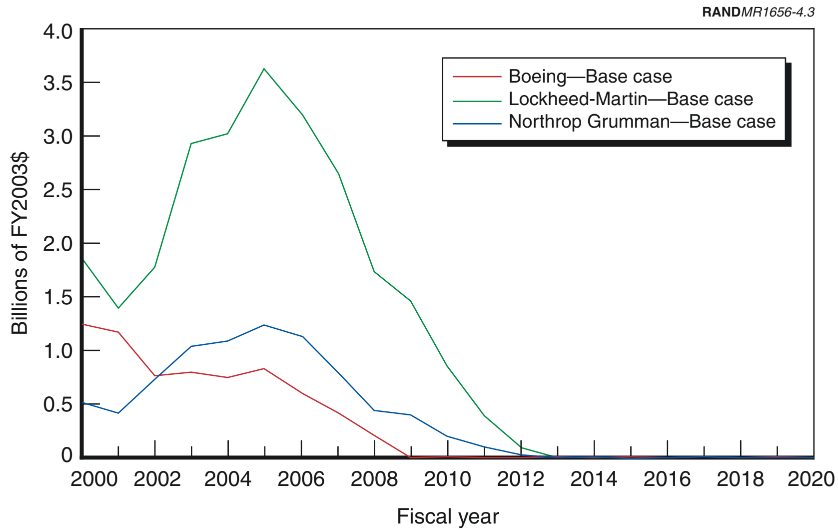


Figure 4.3—Distribution of RDT&E Obligational Authority Among Primes—Base Case

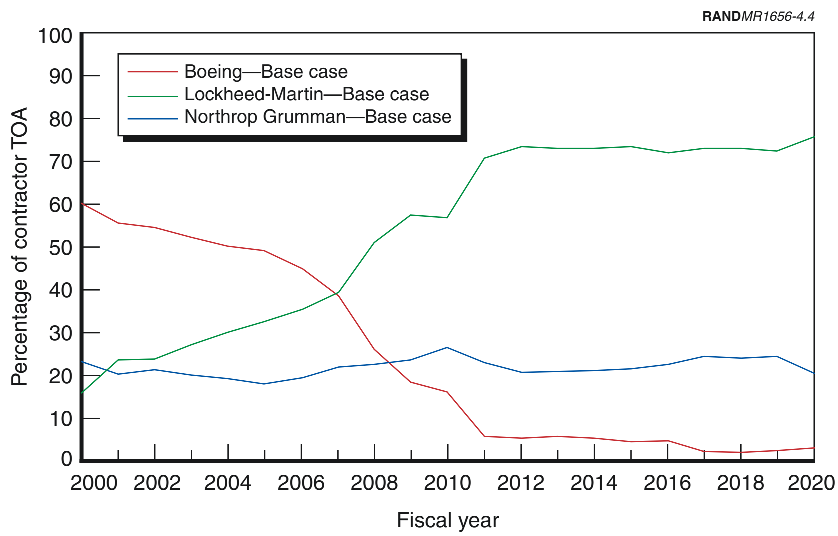


Figure 4.4—Distribution of Procurement Obligational Authority Among Primes—Base Case

military aircraft design and development capabilities into the next decade. Moreover, it appears that Lockheed-Martin will face a similar situation two years after Northrop Grumman. Note, however, that the RDT&E funding picture is based on the funding profile in the December 2001 F-35 SAR. Given how early it is in the F-35 EMD program and past experience with schedule slips, it is likely that the total RDT&E funding profile will shift to the right, which would delay the problem faced by Northrop Grumman and Lockheed-Martin, but not that by Boeing.

SOME ALTERNATIVE FUTURE PROGRAMS

The contents of the current budget and SARs represent only today's outlook for the future. Experience shows that the RAND research team's ability to make such predictions is imperfect and that the content of those future years will turn out to be different from today's projections. In particular, it is almost certain that some new programs will be started within that time period, and that the funding streams now forecast for current programs will change. Therefore, we need to explore some alternative future scenarios and how they might affect the military aircraft industry.

We postulated three scenarios of future aircraft development and procurement programs, starting with programs that we believe are highly likely to start in the next few years, and then extending to more-speculative scenarios for later in the decade. Each scenario represents different dollar levels of activity and different kinds of design and development work, allowing us to get some idea of how those two parameters might interact to support the industry in different periods. The general scenarios examined were

1. Near-term procurement of wide-body transport derivatives to replace aging aircraft in several roles (tankers and MC2A, a collection of various functions related to command, control, and surveillance), plus one UCAV weapon system.
2. Scenario 1, plus a family of UAVs that might be configured to support a variety of missions.
3. Scenario 1, plus a new major combat aircraft (MCA) program.

For each program we

- specified start dates, program durations, and production quantities
- estimated RDT&E and procurement funding
- overlaid resource profiles on top of the base case
- assessed likely effects on industry.

Scenario 1: Near Term

Our discussions with contractor personnel, DoD officials, and colleagues at RAND identified three programs that could begin major acquisition activities in the next few years: a replacement for the KC-135 tankers; a replacement for the 707/C-135–based ISR aircraft (AWACS, JSTARS, Rivet Joint, etc.); and the Unmanned Combat Air Vehicle (X-45 and X-47) programs. Table 4.1 summarizes cost, schedule, and quantity assumptions for these programs. Figures 4.5 and 4.6 show the funding profiles for these programs overlaid on the base case.

The most likely platforms for the tanker and ISR aircraft are commercial aircraft. The Boeing 767 is the most commonly referenced

Table 4.1

Acquisition Program Characteristics—New Near-Term Programs

System	Tanker	ISR	UCAV
EMD Cost ($B)	0.5	6.0	3.0
EMD Start (FY)	2006	2007	2007
EMD End (FY)	2011	2012	2011
Procurement Unit Cost ($M)	150	400	50
Procurement Quantity	270	100	100
Procurement Start (FY)	2007	2010	2009
Procurement End (FY)	2020	2017	2016

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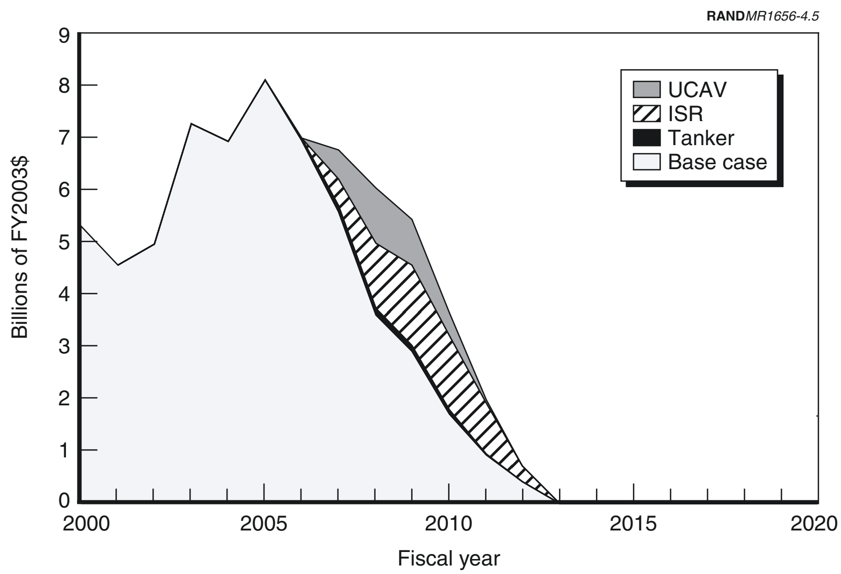

Figure 4.5—RDT&E Obligational Authority—Base Case Plus Postulated Near-Term Programs

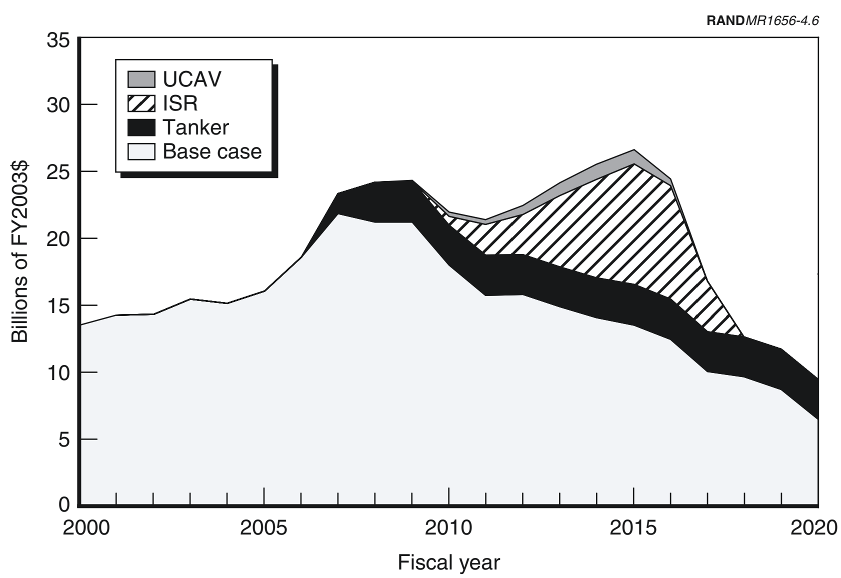

Figure 4.6—Procurement Obligational Authority—Base Case Plus Postulated Near-Term Programs

option. Boeing also is performing the UCAV Advanced Concept Technology Demonstration (ACTD) program. Consequently, we allocated all three of these programs to Boeing, which yields the distribution among contractors shown in Figures 4.7 and 4.8. Boeing receives a major boost in both RDT&E and procurement support, but RDT&E funding for all contractors begins to fall through the minimum viable threshold in the later half of the 2000–2010 decade.[3]

The near-term programs contribute mainly to procurement. The modest additions to RDT&E do not extend funding beyond FY2012. For the tanker and ISR aircraft, the EMD efforts involve modifications to commercial platforms, and the UCAV is unmanned. Consequently these programs do not provide strong support for skills required to design, develop, and test high-performance, multimission fixed-wing combat aircraft.

Supporting multiple design and development teams for fixed-wing tactical aircraft beyond FY2012 will require new program activity, but no major programs are on the planning horizon for this time period. We postulate two possible general approaches to compensate for this lack. The first is to design, develop, test, and field a series of new UAVs, which would be awarded in turn to each of the three primes. The second is a single major combat aircraft, which would be codeveloped and produced by the three primes. We note that neither of these approaches is particularly strong in terms of establishing a sense of competition between the primes. Also, a single major program means that only one (or perhaps two, through teaming arrangements) of the three contractors would garner significant experience in weapon-system integration. Nonetheless, these programs illustrate the extent of coverage that can be provided for particular levels of funding.

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[3]Note that the schedules for the tanker and ISR aircraft we used in this analysis are three years later than current unofficial plans. Had we used the earlier schedules, the RDT&E shortfall would have been worse and the peaks in both RDT&E and procurement funding would have been higher.

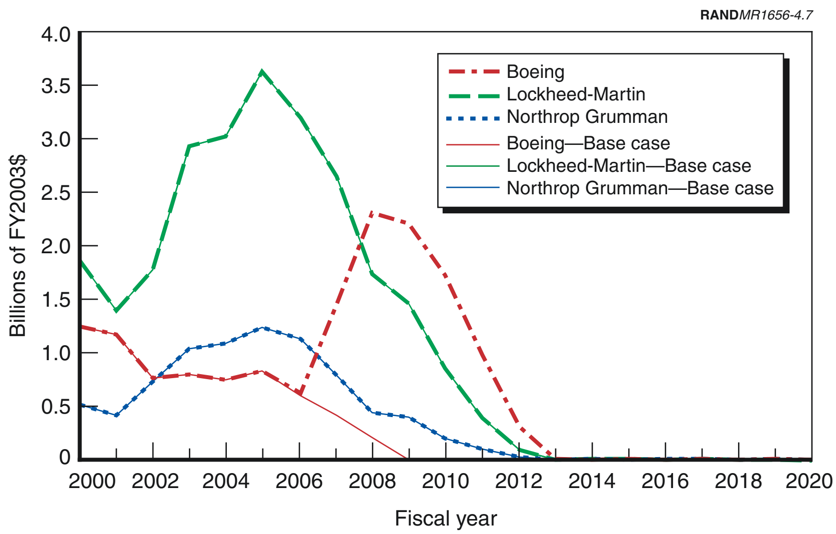

Figure 4.7—Distribution of RDT&E Obligational Authority Among Primes—Base Case Plus Postulated Near-Term Programs

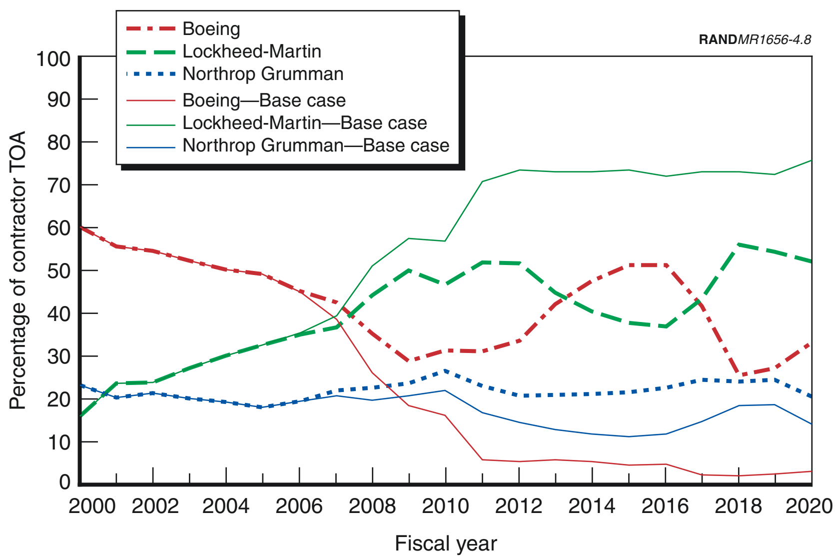

Figure 4.8—Distribution of Procurement Obligational Authority Among Primes—Base Case Plus Postulated Near-Term Programs

Scenario 2: Additional UAV Programs

This scenario represents a significant shift to widespread use of UAVs. For this scenario, we consider beginning a new UAV program every four years. We do not specify which military service would operate these systems, or even whether these systems would be combat-capable. The EMD and procurement costs are order-of-magnitude estimates, and the schedules are representative. To reflect a major move to UAVs, we assumed a production quantity of 1,000 units. Table 4.2 summarizes the cost and schedule assumptions.

Figures 4.9 and 4.10 show the resulting RDT&E and procurement funding profiles, respectively. The distributions among contractors are illustrated in Figures 4.11 and 4.12. These figures suggest that a rolling series of programs of approximately the magnitude and schedule in the table will provide a level of RDT&E funding that is adequate to support three minimum viable design/development teams. They also suggest that this particular schedule results in a pattern of two contractors having funding at any given time while the third experiences a hiatus. This scenario points out an additional problem that DoD faces when the number of contractors and pro-

Table 4.2

Acquisition Program Characteristics—Near Term Plus UAV Series

System	Tanker	ISR	UCAV	UAV-A	UAV-B ···	UAV-X
EMD Cost ($B)	0.5	6.0	3.0	6.0	6.0	···
EMD Start (FY)	2006	2007	2007	2011	2015	···
EMD End (FY)	2011	2012	2011	2019	2023	···
Procurement Unit Cost ($M)	150	400	50	35	35	···
Procurement Quantity	270	100	100	1,000	1,000	···
Procurement Start (FY)	2007	2010	2009	2014	2018	···
Procurement End (FY)	2020	2017	2016	2023	2027	···

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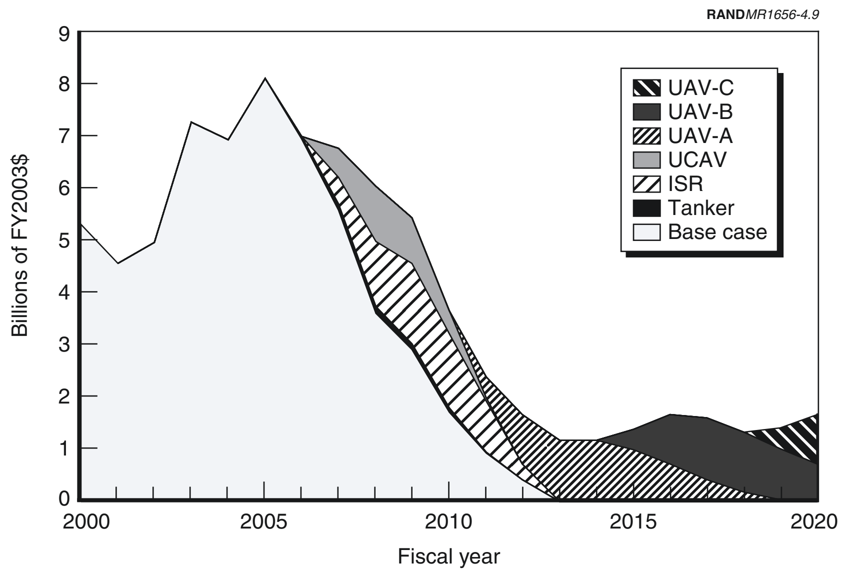

Figure 4.9—RDT&E Obligational Authority—Base Case Plus Postulated Near-Term Programs and UAV Series

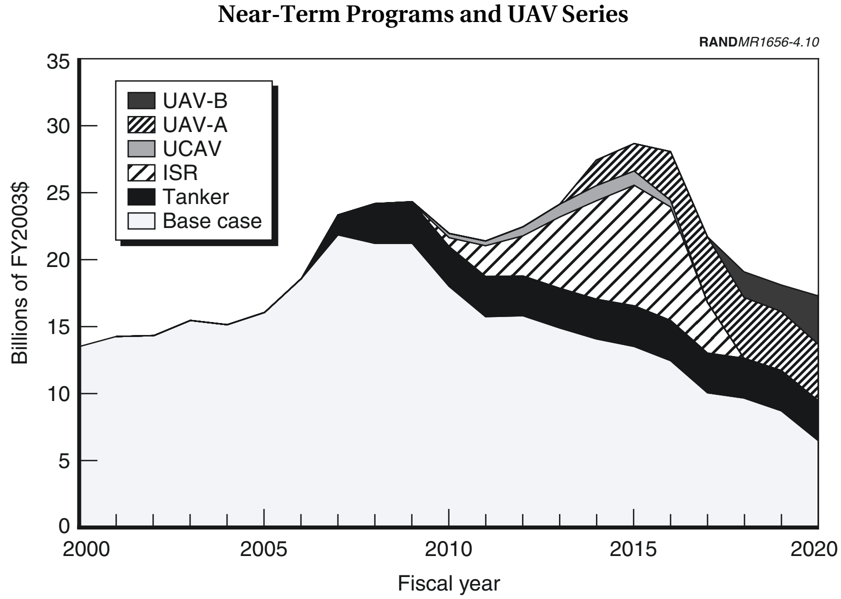

Figure 4.10—Procurement Obligational Authority—Base Case Plus Postulated Near-Term Programs and UAV Series

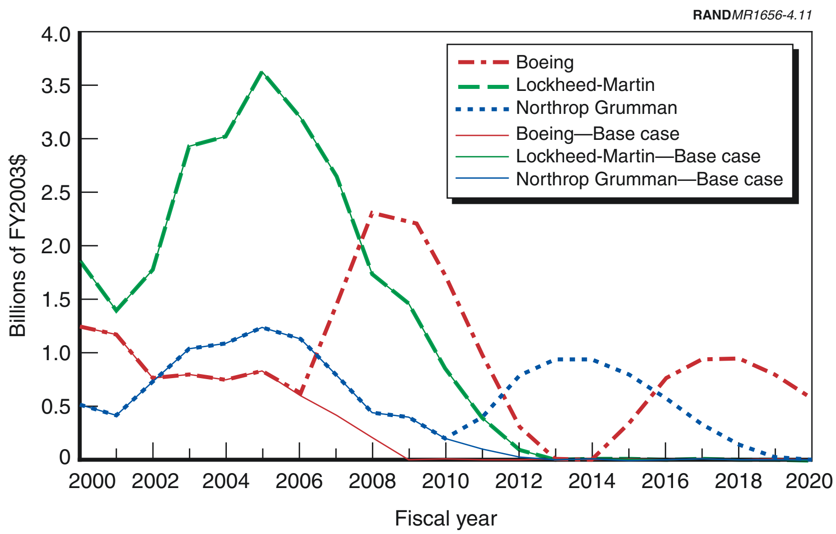

Figure 4.11—Distribution of RDT&E Obligational Authority Among Primes—Base Case Plus Postulated Near-Term Programs and UAV Series

grams is small: Delicate balancing is required to ensure that all three contractors have some funding all the time.

The procurement-funding picture is perhaps too robust. The projected peak funding is $28.8 billion in FY2015, nearly $7 billion higher than the FY2007 base-case projection (Figure 4.2) and only $5.4 billion below the FY1985 peak (see Figure 3.8).[4]

Eliminating the pattern of two contractors having RDT&E funding while the third does not would require some schedule adjustments. This scenario appears to provide sufficient funding and activity for each firm to maintain a minimum viable capability in fixed-wing design and development. The procurement distribution shown in Figure 4.12 is better than the one without the UAVs. A final drawback of this scenario is that it provides no new concept formulation, design, development, or test work related to manned aircraft.

[4]This robustness could be alleviated by stretching the ISR aircraft procurement schedule.

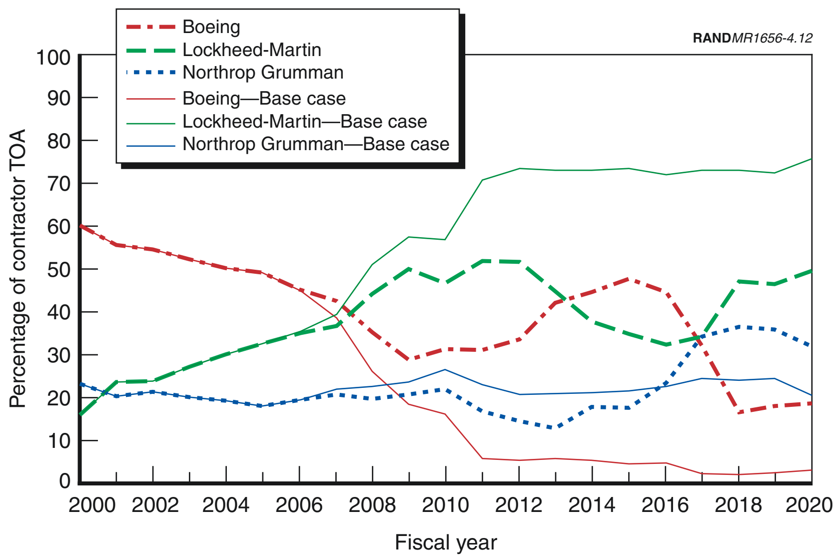

Figure 4.12—Distribution of Procurement Obligational Authority Among Primes—Base Case Plus Postulated Near-Term Programs and UAV Series

Scenario 3: A Major Combat Aircraft

In Scenario 2, we showed levels of development and production business that might result from DoD decisions to start several new programs in the near future. However, such a mix of new-program starts might be considered unlikely, given the programs that are currently under way or planned in the near term. Besides, the RDT&E funding picture indicates that all three programs would need to be started within a short time span to support all three contractors.

In this scenario, we posit one new MCA instead of the series of UAVs. Present DoD planning documents provide little guidance about what such a new system might be. However, given the existence of the F-35 program, we assume that it would have the general characteristics of a relatively large, long-range strike system. We further assume that such a system could not be a derivative of existing or near-term wide-body transport aircraft designs. A long-range strike aircraft would almost certainly differ in many ways from a derivative commercial or military transport aircraft and would require a completely new design and development program.

The program characteristics are summarized in Table 4.3.

Figures 4.13 through 4.16 present the RDT&E and procurement funding profiles and distributions among the contractors. To provide support to all three contractors, we assumed that the MCA is shared by all three, with Northrop Grumman as the integrator.

A major combat aircraft program should provide adequate funding to sustain three contractors to almost 2020. However, it is not clear that all three contractors would maintain complex system-integration skills. Procurement funding under this option is very robust and equitably distributed, but another major program would be needed close to 2020 to continue to sustain the design and development elements of the industry.

SUMMARY OBSERVATIONS

It appears highly likely that the combination of the F/A-18E/F, F-22, and F-35 programs, together with one or more tanker and

Table 4.3

Acquisition Program Characteristics—Near Term Plus Major Combat Aircraft

System	Tanker	ISR	UCAV	MCA
EMD Cost ($B)	0.5	6.0	3.0	30.0
EMD Start (FY)	2006	2007	2007	2010
EMD End (FY)	2011	2012	2011	2019
Procurement Unit Cost ($M)	150	400	50	500
Procurement Quantity	270	100	100	100
Procurement Start (FY)	2007	2010	2009	2015
Procurement End (FY)	2020	2017	2016	2022

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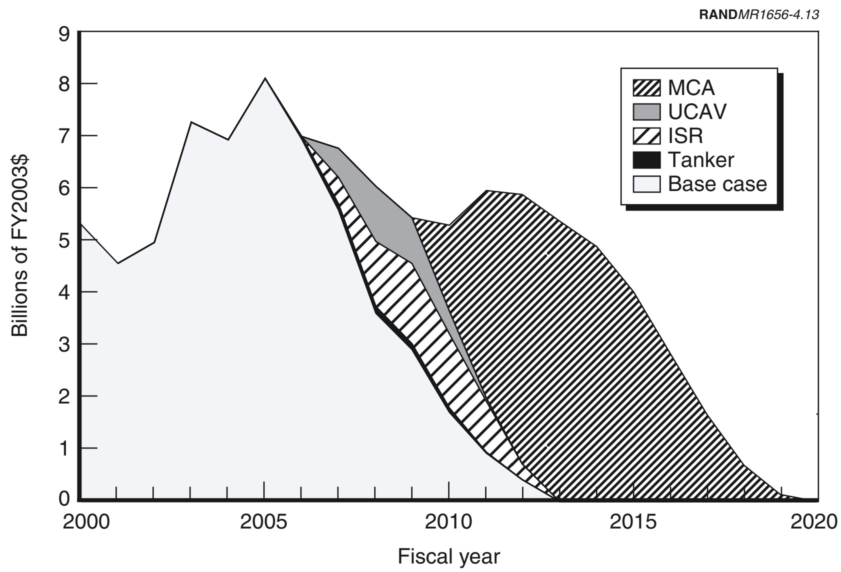

Figure 4.13—RDT&E Obligational Authority—Base Case Plus Postulated Near-Term Programs and MCA

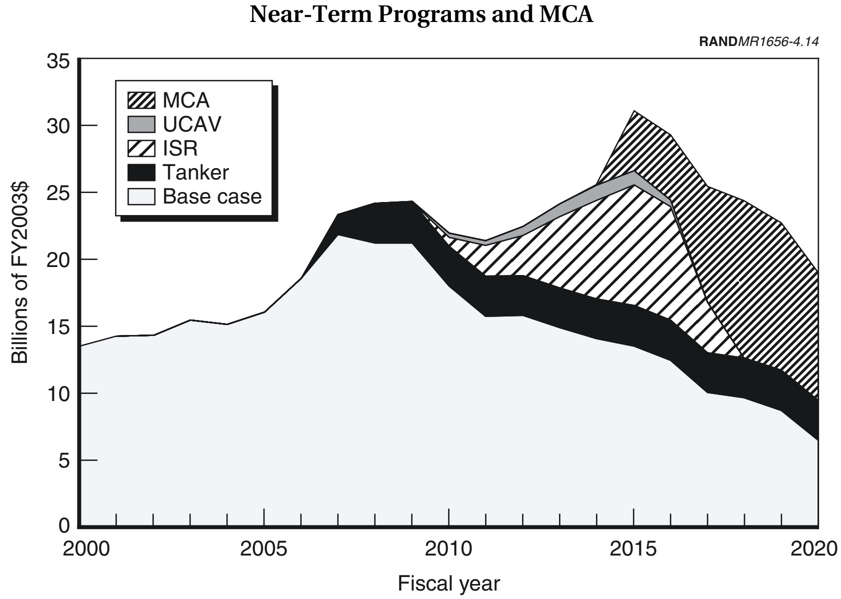

Figure 4.14—Procurement Obligational Authority—Base Case Plus Postulated Near-Term Programs and MCA

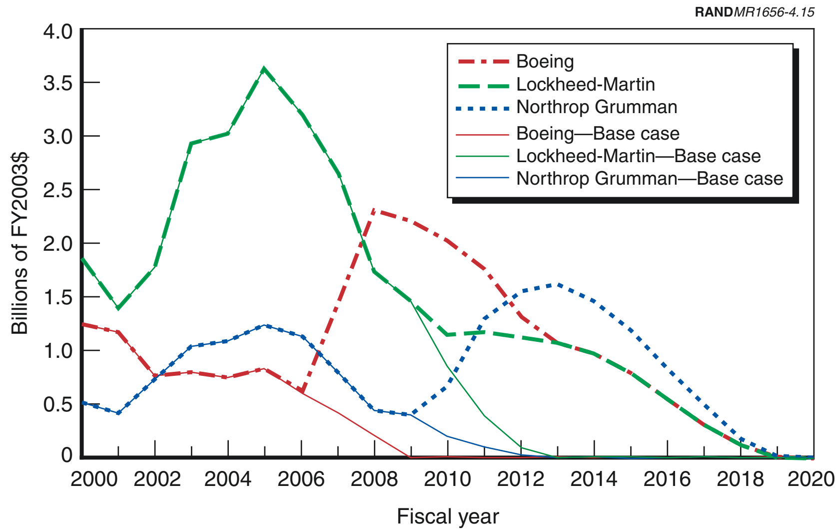

Figure 4.15—Distribution of RDT&E Obligational Authority Among Primes—Base Case Plus Postulated Near-Term Programs and MCA

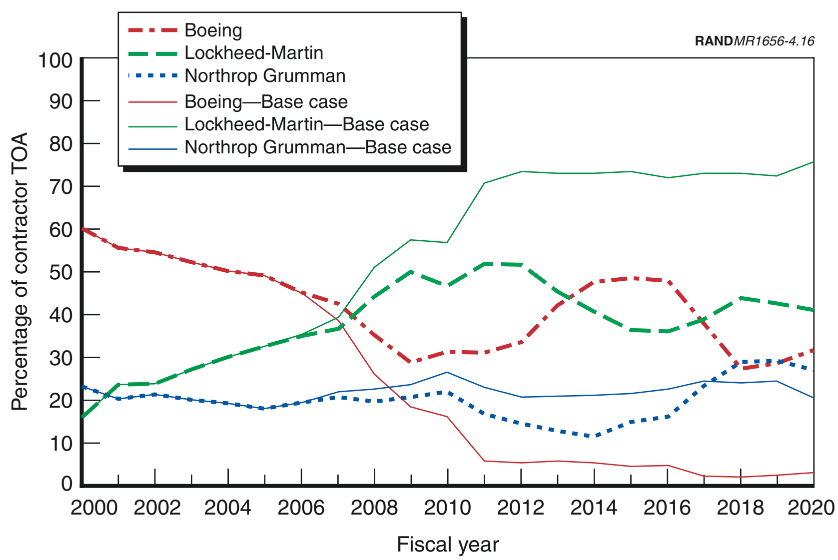

Figure 4.16—Distribution of Procurement Obligational Authority Among Primes—Base Case Plus Postulated Near-Term Programs and MCA

MC2A replacements derived from existing transport aircraft designs, will provide a substantial amount of business to all three prime contractors well into the next decade. However, with the exception of the F-35, little new aircraft design and development work is involved in those programs, and even the F-35 should be substantially through its design and development phase by the end of this decade. All the primes are developing UAV demonstrators for a variety of missions. However, with the exception of Global Hawk, none of those projects has reached system-acquisition status. The history of ACTD programs suggests that transition from demonstrator to system-acquisition status is far from assured; even when it occurs, it can take years before full weapon-system development begins. Furthermore, while those UAV programs typically involve some elements requiring innovation, they tend to be small relative to a major fighter in vehicle size, program cash flow, and size of design/development staffs.

Another problem DoD faces is that maintaining a small number of prime contractors in an environment of a small number of programs requires that programs be assigned or allocated to specific firms to provide continuing support. This practice cannot enhance the sense of competition between contractors, and it may significantly lessen it.

We conclude from this examination that the most serious risk facing the major primes today is that not enough new military aircraft design and development work might be available beyond the second half of this decade to enable all three firms to sustain an adequate core of engineers and technical managers who are able to conduct technology development, advanced design studies, and demonstrator/prototype development and test of future system concepts. Sustaining an adequate core of such specialists is necessary if the firm is to be a strong competitor for future programs.

In fact, those teams, and the skills they comprise, represent the true foundation of future aircraft designs. If no major aircraft development programs are initiated in the next few years, it seems likely that those teams will dwindle to below critical size in at least some of the primes. In the next chapter, we explore some strategies DoD might take to mitigate this risk.

Chapter Five

SOME RISK-REDUCTION MEASURES

In the preceding chapters, we presented information suggesting that production business is likely to be sufficient to sustain the general corporate structure of all three firms, but we can foresee situations in which the amount of new design and development business might fall short of that needed to enable all three firms to sustain a vigorous competition on future weapon-system programs. Thus, we believe it appropriate to examine options for sustaining key elements of the industry through a fallow period without new system starts, should that occur.

Of the several approaches that have been suggested for addressing this situation, we examine two in this chapter: dividing the F-35 production program between two contractors; and funding demonstrator or prototype programs to bridge a gap until another major program is initiated.

SPLIT F-35 PRODUCTION

Before the F-35 program source selection, it was suggested that the program be divided between two contractors. The primary purpose was to have two complete production lines, thus sustaining complete aircraft-manufacturing capabilities for two contractors and providing a revenue base to the second contractor. The latter could support IR&D activities as well as provide profits, some of which could be invested in maintaining a design and development capability.

This approach was explored in considerable detail in a recent RAND study (Birkler et al., 2001), which proposed two alternatives for distributing production to another firm: Build-to-Print (BTP), whereby the competing firm would build to the original design (i.e., have access and build to the complete drawing package); and Form-Fit-Function (FFF), whereby the competing firm would create its own design for those portions of the aircraft it produced, but ensuring that those portions would "fit" with components built by the original designer. Both of these options result in higher costs because of additional nonrecurring expenses and loss of production learning over the shorter production runs at each firm. The incremental costs for applying these options to the complete aircraft[1] (excluding the engine) are summarized in Figure 5.1.

Without accounting for any cost reductions that might accrue from competitive pressures, we estimated that dual-source production of the F-35 would increase total program production costs by $25 billion to $40 billion, depending on the option selected. While competitive pressure might be expected to reduce those costs somewhat, an analysis of earlier dual-source production results indicated that there would be a very small chance that all of those additional costs would be recovered (Birkler and Large, 1990).

DoD subsequently decided to award the F-35 contract to a single source. Now that a winner has been selected and full system design and development activities are under way, the FFF option is no longer feasible. However, splitting production on a BTP basis could still be accomplished. If splitting were done and no savings were realized to offset the production-cost penalty, then each contractor would average about $400 million in profit per year over the 20-year production run, assuming a 10-percent profit factor. Hence, the second contractor would have $400 million per year to allocate to dividends, support of design and development personnel, etc. Given all the demands for retained earnings and their priorities, the amount going to design-team support would likely not be enough to maintain a minimum viable team.

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[1]The previous study (Birkler et al., 2001) analyzed splitting production for various sections and systems of the aircraft. Applying the FFF approach to the total aircraft corresponds to two separate SD&D activities for the complete aircraft. Both cases involve two separate production lines.

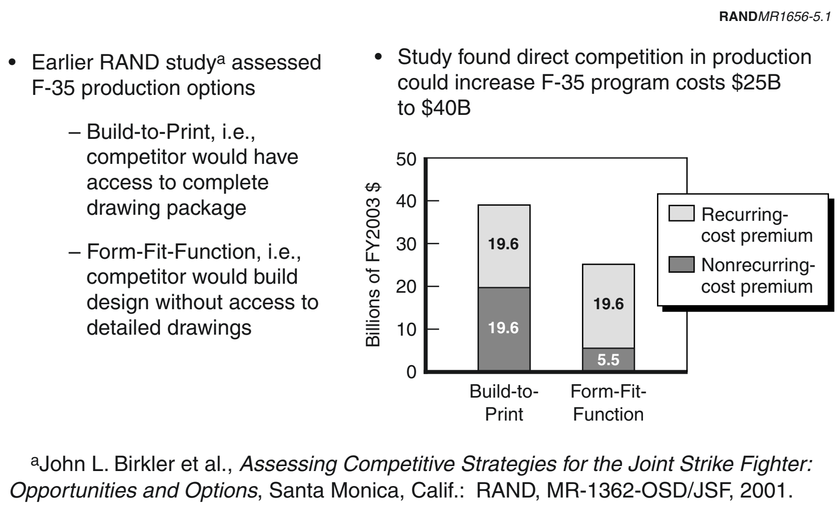

Figure 5.1—Additional Costs of Splitting F-35 Production

Thus, we concluded that, although dual-sourcing production of the F-35 would indeed distribute large amounts of revenue to a second prime contractor, it would almost certainly increase the overall cost of the program and not be likely to offer significant support for internal R&D efforts. We recommend that this choice *not* be adopted because there are better ways to use such additional funds, as described below.

FUND ADVANCED DESIGN PROJECTS

Support of advanced-design-concept studies and demonstrator programs is the other approach that DoD might adopt to ensure that all three primes retain a vigorous capability to compete in future programs.

If one firm has a hiatus of five years in design and development work, then one 5-year project will keep a team employed over the hiatus. If the project funding falls between $250 million and $500 million per year, then the team size would roughly correspond to the minimum viable concept described in Chapter Two. The total funding requirement for the 5-year period would range between $1.25 billion and $2.5 billion, an amount of funding that could support some significant projects. The total spending (contract plus cost sharing) for each ATF Dem/Val team falls at the high end of this range (in FY2003 dollars). The Global Hawk ACTD equates to about half of the low end of the range. Hence, a fully funded ATF-like Dem/Val would provide robust support for a design and development team, while two Global Hawk–sized ACTDs would provide the minimum level of support.

Depending on the length of the hiatus and the number of firms without significant RDT&E activity, some combination of these types of programs could be very effective. However, this conclusion assumes that all the contractors have adequate production programs to support their general business structure and overheads. Comparing the estimated funding to support a minimum viable design and development team and the approximate costs of significant ACTD and Dem/Val programs with the estimated production cost penalty for dual-sourcing the F-35 production, we can see that significantly more benefit can be derived from supporting multiple design and development projects. The number and scale of such projects needed to maintain three vigorous design teams will, of course, depend on whether other system development and production programs are started in the near future.

Chapter Six

A COMPARISON OF POLICY OPTIONS

In this study, we have argued that the future composition and capabilities of the military aircraft industry depend largely on the amount of business they receive from DoD and on how that business is distributed among development of technology, development of new designs, and production of completed designs. From this general perspective, we examined three broad policy options:

- ***No New Investments Beyond FY03 FYDP.*** This is the "base case," in which it is assumed that no new system-development programs will be introduced during the next few years, beyond those programs already included in the FYDP. The corresponding policy is to assume that the industry will take care of itself.
- ***New Investments in Warfighting Programs.*** This is the "new-business case" described in Chapter Four, in which we explored the consequences of some new investments in warfighting system programs that might be started in this decade.
- ***New Investments in Industry Capabilities.*** This is a "hedge" strategy, discussed in Chapter Five, for which the policy is to make investments in industry capabilities during a period when at least some firms might otherwise suffer significant reductions in competitiveness and overall capability.

In this chapter, we provide a summary comparison of these alternative policies. The main elements of each policy, and an outline of the key costs and benefits, are shown in Table 6.1.

Table 6.1

Costs and Benefits of Alternative Strategies

Policy	Costs and Other Penalties	Benefits
Option 1: No New Investments Beyond FY03 FYDP		
No initiative beyond those included in FY03 FYDP	• Diminishes competition for next weapon system • Diminishes support for innovation • Might cause full development and production of next major system to take longer, cost more than if a stronger industry base were available	• Least near-term cost
Option 2: New Investments in Warfighting Programs		
2a: Assume near-term acquisition of derivative support aircraft: tankers and ISR, plus one UCAV program	• $10 billion EMD • $85 billion production • Does not preserve the full range of skills and knowledge necessary to design, develop, and test high-performance aircraft	• Strengthens ability of third firm to maintain design and production skills and facilities and to support general corporate infrastructure • Enables third firm to be full competitor on next system program • Contributes to force capability
2b: Option 2a, plus start a series of new UAV programs, one every four years	• As in Option 2a, plus: $6 billion for each UAV EMD $35 billion for each UAV procurement program • Does not preserve the full range of skills and knowledge necessary to design, develop, and test high-performance aircraft	• Preserves strong design and production teams to meet future national needs • Supports innovation in a wide range of technologies • Enables competition in design of next major system • Adds new force capability • Gives users opportunity to test evolving capabilities and employment strategies

▷

Table 6.1—continued

Policy	Costs and Other Penalties	Benefits
Option 2: New Investments in Warfighting Programs—continued		
2c: Option 2a, plus start a major combat-aircraft program, with EMD to start no later than 2010	• As in Option 2a, plus: $30 billion for EMD $50 billion for procurement	• Preserves strong design and production teams to meet future national needs • Supports innovation in a wide range of technologies • Enables competition in design of next major system • Adds new force capability
Option 3: New Investments in Industry Capabilities		
3a: Competitively co-produce the F-35, with competitor building to print	• About $25 billion over life of F-35 program • Does little to strengthen design and development capability of competitive producer • Adds no additional force capability	• Supports corporate infrastructure and specific production skills and facilities of co-producer • Enables co-producer to electively invest in innovation and design skills
3b: Competitively co-produce the F-35, with competitor designing some elements (FFF)	• About $40 billion over life of F-35 program • Adds no additional force capability	• Strengthens ability of third firm to maintain design and production skills and facilities, and supports general corporate infrastructure • Enables third firm to be stronger competitor on next system program
3c: Fund multiple technology developments, advanced design studies, and demonstrator aircraft programs	• $250 million to $500 million per year per firm • Might cause full development and production of next major system to take longer, cost more, than if design staffs have recent experience in full EMD and production programs	• Preserves critical elements of industry design and development capability • Supports innovation • Creates opportunity to develop and demonstrate transformational system concepts • Enables competition in design for next weapon system

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EVALUATION OF POLICY OPTIONS

In Figure 6.1, we compare the policy options and scenario alternatives explored in this study, color-coded to simplify interpretation. Each column represents one of the seven options discussed in Chapters Four and Five. Each row depicts a particular option, assessed against each of the three goals identified by Congress as desirable characteristics of the military aircraft industry, listed at the far left.

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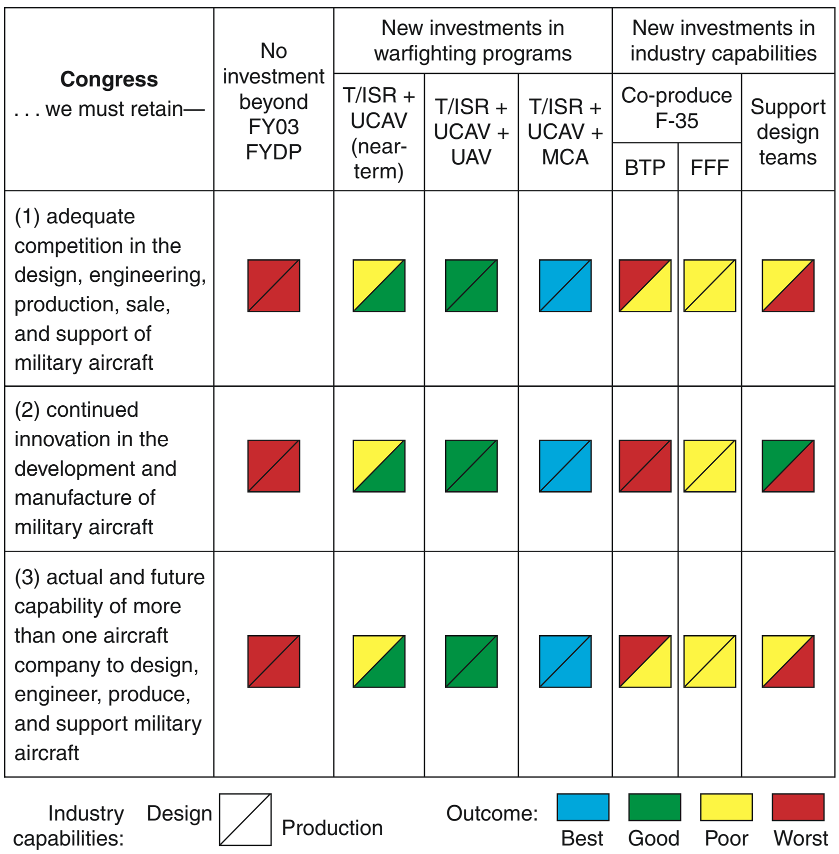

Figure 6.1—Consequences of Alternative Investment Decisions

Each combination of an option and an assessment criterion is further divided into two parts: how it would support RDT&E capabilities (upper left half of each cell) and how it would support production capabilities (lower right half of each cell). Each such element is ranked on a four-step scale: worst, poor, good, and best.

Note that the options are ranked relative to each other, and there is no assurance that any option would guarantee that the present industry structure and capabilities would be preserved through the foreseeable future, nor that any option would guarantee an industry capable of fully meeting all future needs.

The results have four broad implications:

1. ***If no major system development programs are introduced by about the middle of the current decade, DoD can expect some further consolidation in the industry, or at least some reductions in RDT&E capabilities in at least one of the present primes.*** The currently approved programs and funding are not sufficient to enable all three firms to sustain a strong RDT&E component in their business base.

2. ***A vigorous, competitive industry roughly similar to that of today would probably be sustained if DoD chooses to invest, well before 2010, in new system development and production programs.*** Implementing near-term programs (full acquisition of at least one UCAV program, together with procurement of a derivative wide-body aircraft to replace a variety of aging systems) would strengthen both RDT&E and production activities. Adding more UAV systems would help, but probably only marginally because such programs are expected to be relatively small. If a major new combat aircraft program were to be started in this decade, it should provide strong support to both RDT&E and production capabilities across the industry, provided that the work is distributed appropriately among the three primes.

3. ***Lacking any new development and production programs in this decade, DoD could take other measures to invest in sustaining industry capabilities.*** Co-producing the F-35 would have little effect on RDT&E capability, and would come at a very high cost. Ensuring a stream of technology demonstrator and system concept demonstrator programs would strengthen design capabili-

ties, and it would support force-transformation goals by enabling competition among alternative mission concepts. However, it would provide little benefit to production capabilities. This option is considerably more effective at maintaining robust competition and innovation in the military aircraft industry when it is combined with the options that include one or more new programs.

4. ***Preserving three full-service prime contractors capable of developing and producing manned combat aircraft in an environment of three, or less, manned combat aircraft programs would require careful allocation of programs.*** This option might not provide a robust environment for competition and innovation.

FINAL THOUGHTS

This analysis has characterized the choices that DoD has *if the policy goal is to sustain the current military aircraft industry structure and capabilities.* Whether any of those choices can be justified when compared with other ways to enhance overall national defense is beyond the scope of this analysis.

Furthermore, over the course of this research, we identified several important issues that affect the policy choices available to DoD:

- The nature of the industry could be quite different in the future. The roles and responsibilities of the prime contractors and lower tiers have already changed. Could primes be different from what they are today and still satisfy DoD needs by teaming and drawing on specialty firms in innovative ways?
- UAVs, UCAVs, and commercial derivatives appear to be a substantial part of any future business base. Will these programs require skills and corporate institutions different from those of the business base today? How much do these programs contribute to continued innovation in military aircraft and associated design, development, and production capabilities?
- Are there opportunities to substantially restructure the relationship between DoD and industry in ways that would strengthen prospects for a strong and innovative industry in the future?

These questions need to be addressed in order to obtain a more complete picture of the problems facing the military aircraft industry and the solutions available to address those problems. We did not have sufficient time and resources to address them here. However, our research on the linkages between competition and innovation suggested one broad policy option that we believe deserves careful consideration: a strategy we call mission-based competition.

By *mission-based competition* we mean explicitly conveying to firms that purchase decisions are traded off among all product concepts that can fulfill the same mission, and that ideas and offerings are sought across that broad range of concepts. Instead of seeking competitive proposals from industry to satisfy a specific system concept, this strategy would open, to formal industry competition, solutions to a much broader range of mission needs, such as is performed in the Analysis of Alternatives process. Industry now participates in such analyses, but generally through informal communications rather than formal "mission-based competition."

Mission-based competition is very closely related to the concept of *economic substitutes.* Existing research suggests a powerful benefit of creating mission-based competition: It is likely to spur innovation among new *and* old military aircraft technologies, as it has done repeatedly in other industries. We review some of the evidence below.

Two sources of evidence clarify why mission-based competition improves innovation. The first is theoretical and the second, and perhaps the most compelling, is empirical. From a theoretical standpoint, a firm's innovation springs from its need to stay ahead of or to leapfrog the competition. Of great importance is that the firm's relative innovation performance will determine its share of future revenue. The firm knows that its ACTD or Dem/Val proposal is competing with *all* competitors' products that could serve the same purpose—a key notion. Such competition creates a larger set of competitors, which, theoretically, creates more innovation.

On the empirical side, case studies of revolutionary innovation from other industries yield clear results and illustrate the power of economic substitutes and mission-based competition.[1] Industries

[1]These examples are drawn from Utterback (1994) and Christensen (1997).

studied (in Christensen [1997]) have included mechanical excavating (hydraulic systems substituting for mechanical), disk drives (successively smaller drives substituting for larger), steel (mini-mills substituting for large mills), and ice delivery (ice making substituting for ice harvesting), among others. We draw on one historical example from the lighting industry to illustrate the general cross-industry concept.[2]

In the 1870s, gas-lamp companies dominated the market for home lighting. In the 1880s, Thomas Edison and his company introduced electric lighting into the New York market. The incumbent gas firms reacted, not by entering the electricity business but by focusing on improving gas-lighting technology. The ensuing battle saw the invention of the gas mantle, a major efficiency improvement that is still used in gas lanterns today. In this case, gas companies pushed hardest to improve their technology the most when they lost customers to electricity, not just to other gas companies—a typical pattern: Incumbents innovate in their old technologies in response to new entrants with the new technology. Eventually, and only in hindsight, the new technology prevails, driving out the old technology as it constantly improves, and at a faster rate than the old technology. For example, from 1881 to 1910, electric lighting improved its efficiency by a factor of 6.

Consider the lighting customers of the 1880s. They had a choice of two modern technologies instead of one: the tried and true, and now-improving, gas technology, and the new electric technology, a technology that was perhaps higher-risk and, at the outset, not a huge improvement over gas (yet). Customers who continued with gas benefited from the invention of the electric light, through the increased innovation in gas technology and, presumably, the pressure to lower gas prices. The new electric rivals pushed gas-lamp incumbents the hardest. The gas companies knew they were not just in the gas business; they were in the lighting business.

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[2] As discussed in the introduction, we did not uncover case studies in defense industries, much less military fixed-wing aircraft. The general concepts almost certainly hold for the industry in question; however, future research to validate these concepts in defense industries could be very worthwhile.

Likewise, military aircraft primes know that they are not solely in the military manned fixed-wing aircraft business; they are in the "precision engagement and dominant maneuver" business. The funding of ACTD and Dem/Val programs designed to achieve specific military missions reinforces the message that the new programs are intended to replace old systems and/or compete with alternative designs to achieve a mission in new ways. Furthermore, pursuing mission-based competition may make the industrial base more innovative by making it take greater advantage of early product life cycles. Young technologies tend to have the most risk. Young companies are small and have less-efficient production, but they do not stay young and small if they are successful. Other industrial settings have innovated older technologies rapidly when faced with a new technology, even when the old technology eventually lost. Old, well-understood, and innovative technologies leave behind many satisfied and secure customers in their phase-out period. Finally, the broadly placed bets—ACTDs and Dem/Vals—that result from mission-based competition might be cheaper than other options.

Appendix

DESCRIPTION OF DATA SETS AND BUDGET ACTIVITIES RELATED TO FIGURES 3.5, 3.7, AND 3.8

This Appendix clarifies the data sets and the Budget Activities from which Figures 3.5, 3.7, and 3.8 were constructed.

FIGURE 3.5

Data for Figure 3.5 were derived from the 1980 through 2003 R-1s (RDT&E Program exhibits), current and selected historical Selected Acquisition Reports (SARs), and the 2003 R-2s (RDT&E Budget Item Justification exhibits). Classified programs are excluded, except for those declassified before FY2002 (e.g., the B-2). All costs are expressed in constant FY2003 dollars. Escalation factors were taken from the FY2003 National Defense Budget Estimate (Green Book).

We identified records in the combined R-1 data set that were associated with fixed-wing aircraft. We included Air Force, Navy, and Defense Agency programs. The data in the figure represent 209 records, of which 153 have unique Program Elements (PEs). (Some PEs are associated with more than one Budget Activity [BA] during their existence. A mass change of associations occurred as part of the weapon system acquisition process changes made between FY1991 and FY1992.) The bulk of the funding is associated with major aircraft programs, most of which are labeled in the figure.

PE numbers consist of seven numerals followed by up to three characters, which are usually letters. The final characters identify the service branch or defense agency that has the primary responsibility for the program. The first two numbers run from 01 to 11 and identify the DoD program. The next two characters identify the Budget Activity and run from 01 to 07. Hence, the first four digits of PE numbers for Program Six run from 0601 through 0607. To simplify notation, we use 6.1 through 6.7. The chart builds up from 6.2 through 6.5. (No 6.1 programs can be identified as uniquely fixed-wing-aircraft–related.) Only one 6.2 program is uniquely defined for fixed-wing aircraft; its funding total is so small that it cannot be discerned in the chart.

The top band in the chart includes PEs that were not assigned a DoD Program Six (RDT&E) PE number. The band includes 80 (of 209) PEs and is primarily BA Seven (Operational System Development). The largest programs include ongoing development activities for the F-15, F-16, F-22, B-2, C-130, C-5, and C-17. The F-14 upgrade, F/A-18E/F, and Global Hawk/Predator programs are also in this category but are identified separately here because they are relatively large.

The lower bands in the chart comprise PEs that were initially designated as part of Program Six. The ATF and JSF demonstration and validation (Dem/Val) programs are shown separately from the rest of the 6.3 programs (53 additional PEs). Nine major 6.4 programs are broken out on the chart, leaving 55 more in "Other 6.4." The 6.5 group has only four PEs, of which the multi-mission maritime aircraft (MMA) program is the only one large enough to show on the graph.

FIGURE 3.7

The data for Figure 3.7 are derived from the DoD R-1 and R-2 databases, supplemented with information from RAND's RaDiUS database. This database is slightly different from the one used in Figure 3.5; these RaDiUS-based data contain additional detail and have more-consistent definitions.

DoD RDT&E Budget Activity definitions (such as "Demonstration and Validation" and "Systems Development") change over time and appear to contain items that, in our opinion, belong in other categories. To overcome this problem, we constructed our own categories, based on Program Element descriptions, that are similar to, but not exactly the same as, the DoD Budget Activities. To make the data consistent over time, we assigned PEs to our new categories, thereby correcting for any problems that might be introduced through changes in DoD Budget Activity definitions. The largest change in definition was in 1991, resulting in significant ambiguity about what type of activity is included in each Budget Activity.

FIGURE 3.8

Data for Figure 3.8 were taken from the 1980 through 2003 P-1s (Procurement Program exhibits), current and selected historical SARs, and the 2003 P-40s (Budget Item Justification Sheet exhibits) for Air Force and Navy fixed-wing aircraft programs. SARs were also used to fill in missing historical P-1 data (e.g., the B-2 program). All costs are expressed in constant FY2003 dollars.

The layers in the figure are built up in the order of Budget Activities (BA) for aircraft procurement. BA 1 is Combat Aircraft, BA 2 is Airlift Aircraft, BA 3 includes Trainers, and BA 4 is Other Aircraft. The largest-dollar-value aircraft programs are indicated in the figure. The Other Combat, Other Airlift, Trainers, and Other categories contain many programs whose dollar values are too small to show. (Some of the Other Combat programs are the A-10, KC-10, F-4, and F-111. Other Airlift programs include the C-141, all the commercial/civil derivatives, and more. Trainers include JPATS, T-45, T-38, and several others. The Other category includes Global Hawk, E-3, E-4, U-2 and others.)

Funding covers system procurement, modifications, and post-production support for all Air Force Model-Designation-Series (MDS) and Navy Type-Model-Series (TMS) aircraft. Funding for spares and repair parts, and modifications and post-production support not associated with a specific MDS or TMS aircraft are excluded.

Aircraft procurement is divided into seven BAs. System procurement includes BAs 1 through 4, as noted above; BA 5 covers modifications; BA 6 covers spares and repair parts; and BA 7 covers post-production support. The F-16 data in the figure cover aircraft procurement (1980–2005), modifications (1980–2016), and post-production support (1996–2016). The Air Force began separate tracking of post-production support in FY1995 for the F-15 and F-16 programs. The only programs for which post-production support data are provided are the A-10, B-1, B-2, C-5, C-130, E-4, and the F-15 and F-16. The Navy does not identify any TMS-specific post-production support costs.

Aircraft programs that are not in the current budget plans are not included. Classified programs are excluded, except those that were declassified by FY2002 or earlier (e.g., the B-2).

BIBLIOGRAPHY

COMPETITION EFFECTS ON WEAPON SYSTEMS COSTS

Archibald, Kathleen A., Alvin J. Harman, M. A. Hesse, John R. Hiller, and Giles K. Smith, *Factors Affecting the Use of Competition in Weapon System Acquisition*, Santa Monica, Calif.: RAND, R-2706-DR&E, February 1981.

Beltramo, Michael N., *Dual Production Sources in the Procurement of Weapon Systems: A Policy Analysis*, Santa Monica, Calif.: RAND, P-6911-RGI, November 1983.

Birkler, John L., E. Dews, and J. P. Large, *Issues Associated with Second-Source Procurement Decisions*, Santa Monica, Calif.: RAND, R-3996-RC, December 1990.

Birkler, John L., John C. Graser, Mark V. Arena, Cynthia R. Cook, Gordon T. Lee, Mark A. Lorell, Giles K. Smith, F. S. Timson, Obaid Younossi, and Jon G. Grossman, *Assessing Competitive Strategies for the Joint Strike Fighter: Opportunities and Options,* Santa Monica, Calif.: MR-1362-OSD/JSF, 2001.

Birkler, John L., and Joseph P. Large, *Dual-Source Procurement in the Tomahawk Program*, Santa Monica, Calif.: RAND, R-3867-DR&E, June 1990.

Daly, G. G., et al., *The Effect of Price Competition on Weapon System Acquisition Costs*, Alexandria, Va.: Institute for Defense Analyses (IDA), P-1435, September 1979.

Drinnon, J. W., and J. R. Hiller, *Predicting the Costs and Benefits of Competitive Production Sources*, El Segundo, Calif.: TASC, Report 1511, December 1979.

Flynn, Brian, and Dennis Herrin, *Analysis of Competitive Procurement of Selected Navy Weapon Systems,* 2nd ed., Washington, D.C.: Naval Center for Cost Analysis (NCCA), 1989.

Greer, Willis R., Jr., and Shu S. Liao, *Cost Analysis for Dual Source Weapon Procurement,* Monterey, Calif.: Naval Postgraduate School, NDS54-83-011, October 1993.

Lovett, E. T., and M. G. Norton, *Determining and Forecasting Savings from Competing Previously Sole Source/Noncompetitive Contracts*, Ft. Lee, Va.: Army Procurement Research Office (APRO), APRO 709-3, October 1978.

Margolis, M. A., R. G. Bonesteele, and J. L. Wilson, "A Method for Analyzing Competitive, Dual Source Production Programs," presented at the 19th Annual DoD Cost Analysis Symposium, September 1985.

Washington, William N., *A Review of the Literature: Competition Versus Sole-Source Procurement*, *Acquisition Review Quarterly,* Spring 1997, pp. 173–188.

Zusman, M., et al., *A Quantitative Examination of Cost Quantity Relationships, Competition During Reprocurement, and Military Versus Commercial Prices for Three Types of Vehicles*, Alexandria, Va.: Institute for Defense Analyses, S-429, March 1974.

TECHNOLOGY INNOVATION ISSUES

Aghion, P., N. Bloom, R. Blundell, R. Griffity, and P. Howitt, *Competition and Innovation: An Inverted U Relationship,* London, England: The Institute for Fiscal Studies, WP02/04, February 2002.

Alberts, David S., John J. Garstka, and Frederick P. Stein, *Network Centric Warfare: Developing and Leveraging Information Superiority,* 2nd ed. (rev.), Washington, D.C.: CCRP Publication Series, August 1999.

Audretsch, David B., and A. Roy Thurik, eds., *Innovation, Industry, Evolution, and Employment,* Cambridge, UK: Cambridge University Press, 1999.

Baumol, William J., *The Free-Market Innovation Machine*, Princeton, N.J.: Princeton University Press, 2002.

Birkler, John, Giles Smith, Glenn A. Kent, and Robert V. Johnson, *An Acquisition Strategy, Process, and Organization for Innovative Systems,* Santa Monica, Calif.: RAND, MR-1098-OSD, 2000.

Bower, Anthony G., and James N. Dertouzos, eds., *Essays in the Economics of Procurement,* Santa Monica, Calif.: RAND, MR-462-OSD, 1994.

Christensen, Clayton M., *The Innovator's Dilemma*. Boston, Mass.: Harvard Business School Press, 1997.

Cohen, Wesley M., and Richard C. Levin, "Empirical Studies of Innovation and Market Structure," in Richard Schmalensee and Robert Willig, eds., *Handbook of Industrial Organization,* Vol. 2, Amsterdam: North-Holland, 1989, pp. 1059–1107.

Daniel, Don, "Air Force S&T Investment Strategy and Funding," *U.S. Air Force, Science, Technology & Engineering,* February 2002.

Drezner, Jeffrey A., Geoffrey Sommer, and Robert S. Leonard, *Innovative Management in the DARPA High Altitude Endurance Unmanned Aerial Vehicle Program: Phase II Experience,* Santa Monica, Calif.: RAND, MR-1054-DARPA, 1999.

Harbison, John R., General Thomas S. Moorman, Jr., Michael W. Jones, and Jikun Kim, *U.S. Defense Industry Under Siege—An Agenda for Change,* Washington, D.C.: Booz, Allen and Hamilton, Inc., 2000.

Hundley, Richard, *Past Revolutions, Future Transformations: What Can the History of Revolutions in Military Affairs Tell Us About Transforming the U.S. Military?* Santa Monica, Calif.: RAND, MR-1029-DARPA, 1999.

Joint Chiefs of Staff, *Joint Vision 2020.* Washington, D.C.: U.S. Government Printing Office, June 2000.

Kennedy, Harold, "Air Force Research Branch in Pursuit of Innovation," *National Defense*, June 2002, pp. 36–37.

Lorell, Mark A., *The U.S. Combat Aircraft Industry, 1909–2000: Structure, Competition, Innovation,* Santa Monica, Calif.: RAND, MR-1696-OSD, 2003.

Lorell, Mark A., and Hugh P. Levaux, *The Cutting Edge: A Half Century of U.S. Fighter Aircraft R&D,* Santa Monica, Calif.: RAND, MR-939-AF, 1998.

Lundvall, Bengt-Ake, ed., *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning,* New York: Wellington House, 1992.

Nelson, Richard R., ed., *National Innovation Systems,* New York: Oxford University Press, 1993.

Norling, Parry M., and Robert J. Statz, "How Discontinuous Innovation Really Happens," *Research Technology Management*, May–June 1998, pp. 41–44.

Office of Management and Budget, *General Science, Space, and Technology,* Washington, D.C.: OMB, Budget Highlights, The Executive Office of the President, June 2002.

Porter, Michael E., *The Competitive Advantage of Nations,* New York: The Free Press, 1990.

Rice, Mark P., Gina Colarelli O'Connor, Lois S. Peters, and Joseph G. Morone, "Managing Discontinuous Innovation," *Research Technology Management,* May–June 1998, pp. 52–58.

Scherer, F. M., "Schumpeter and Plausible Capitalism," *Journal of Economic Literature,* Vol. XXX, September 1992, pp. 1416–1433.

Schumpeter, J. A., *The Theory of Economic Development: An Inquiry into Profits, Capital, Credit, Interest, and the Business Cycle,* London: Oxford University Press, 1934.

Utterback, James M., *Mastering the Dynamics of Innovation.* Boston, Mass.: Harvard Business School, 1994.

INDUSTRIAL BASE ISSUES

Aerospace Industries Association of America, *Aerospace Facts and Figures 2001/2002,* 2002.

American Institute for Aeronautics and Astronautics (AIAA), *A Blueprint for Action,* Washington, D.C.: Final Report published in conjunction with the AIAA Defense Reform Conference, 14–15 February 2001.

Birkler, J. L., *The Aircraft Carrier Industrial Base,* Santa Monica, Calif.: RAND, CT-142, 1997.

Birkler, J. L., Joseph P. Large, Giles K. Smith, and F. S. Timson, *Reconstituting a Production Capability: Past Experience, Restart Criteria, and Suggested Policies,* Santa Monica, Calif.: RAND, MR-273-ACQ, 1993.

Birkler, J. L., Michael G. Mattock, J. Schank, Giles K. Smith, F. S. Timson, James R. Chiesa, Bruce Woodyard, Malcolm MacKinnon, and Denis Rushworth, *The U.S. Aircraft Carrier Industrial Base: Force Structure, Cost, Schedule, and Technology Issues for CVN77,* Santa Monica, Calif.: RAND, MR-948-NAVY/OSD, 1998.

Birkler, J. L., J. Schank, Giles K. Smith, F. S. Timson, James R. Chiesa, Marc D. Goldberg, Michael G. Mattock, and Malcolm MacKinnon, *The U.S. Submarine Production Base: An Analysis of Cost, Schedule, and Risk for Selected Force Structures,* Santa Monica, Calif.: RAND, MR-456-OSD, 1994.

Center for Strategic and International Studies, *Defense Restructuring and the Future of the U.S. Defense Industrial Base*, Washington, D.C., March 1998.

Commission on the Future of the U.S. Aerospace Industry, *First Interim Report*, December 18, 2001; *Second Interim Report*, March 20, 2002; *Third Interim Report*, June 26, 2002; *Final Report,* November 17, 2002.

Committee on the Future of the U.S. Aerospace Infrastructure and Aerospace Engineering Disciplines to Meet the Needs of the Air Force and the Department of Defense, *Review of the Future of the U.S. Aerospace Infrastructure and Aerospace Engineering*

Disciplines to Meet the Needs of the Air Force and the Department of Defense, Washington, D.C.: National Academy Press, 2001.

Cook, Cynthia R., Mark V. Arena, John C. Graser, John A. Ausink, Lloyd S. Dixon, Timothy E. Liston, Sheila E. Murray, Susan A. Resetar, Chad Shirley, Jerry M. Sollinger, and Obaid Younossi, *Final Assembly and Checkout Alternatives for the Joint Strike Fighter,* Santa Monica, Calif.: RAND, MR-1559-OSD, 2002.

Defense Science Board Task Force, *Preserving a Healthy and Competitive U.S. Defense Industry to Ensure Our Future National Security*, Final Briefing, November 2000.

Drezner, Jeffrey A., Giles K. Smith, Lucille E. Horgan, J. Curt Rogers, and Rachel Schmidt, *Maintaining Future Military Aircraft Design Capability,* Santa Monica, Calif.: RAND, R-4199-AF, 1992.

National Aeronautics and Space Administration (NASA), *NASA Aeronautics Blueprint for a Bold New Era in Aviation,* n.d., available at www.aerospace.nasa.gov/aero_blueprint/index.html.

National Research Council, *Defense Manufacturing in 2010 and Beyond: Meeting the Changing Needs of National Defense*, Washington, D.C., 1999.

Office of the Under Secretary of Defense (Comptroller), *National Defense Budget Estimates for FY 2003,* Washington, D.C., March 2002.

ACQUISITION REFORM ISSUES

Birkler, J. L., Edmund Dews, and Joseph P. Large, *Issues Associated with Second-Source Procurement Decisions,* Santa Monica, Calif.: RAND, R-3996-RC, 1990.

Birkler, J. L., and Joseph P. Large, *Dual-Source Procurement in the Tomahawk Program,* Santa Monica, Calif.: RAND, R-3867-DR&E, 1990.

Deputy Under Secretary of Defense for Acquisitions and Technology, *Incentive Strategies for Defense Acquisitions*, Memorandum, Washington, D.C., 5 January 2001.

Deputy Under Secretary of Defense for Acquisitions, Technology, and Logistics, *Contractor Cost Sharing*, Memorandum, Washington, D.C., 16 May 2001.

——, *Future Competition for Defense Products*, Memorandum, Washington, D.C., 7 July 2000.

Drezner, Jeffrey A., and Robert S. Leonard, *Innovative Development: Global Hawk and DarkStar—Flight Test in the HAE UAV ACTD Program,* Santa Monica, Calif.: RAND, MR-1475-AF, 2002a.

——, *Innovative Development: Global Hawk and DarkStar—Their Advanced Concept Technology Demonstrator Program Experience, Executive Summary,* Santa Monica, Calif.: RAND, MR-1473-AF, 2002b.

——, *Innovative Development: Global Hawk and DarkStar—Transitions Within and Out of the HAE UAV ACTD Program,* Santa Monica, Calif.: RAND, MR-1476-AF, 2002c.

Drezner, Jeffrey, and Giles K. Smith, *An Analysis of Weapon System Acquisition Schedules,* Santa Monica, Calif.: RAND, R-3937-ACQ, 1990.

Gansler, Jacques S., *A Vision of the Government as a World-Class Buyer: Major Procurement Issues for the Coming Decade*, Arlington, Va.: The PriceWaterhouseCoopers Endowment for The Business of Government, January 2002.

Hynes, Michael V., Harry J. Thie, John E. Peters, Elwyn D. Harris, Robert M. Emmerichs, Brian Nichiporuk, Malcolm MacKinnon, Denis Rushworth, Maurice Eisenstein, Jennifer Sloan, Charles Lindenblatt, and Charles Cannon, *Transitioning NAVSEA to the Future: Strategy, Business, Organization,* Santa Monica, Calif.: RAND, MR-1303-NAVY, 2002.

Johnson, Robert V., and J. L. Birkler, *Three Programs and Ten Criteria: Evaluating and Improving Acquisition Program Management and Oversight Processes Within the Department of Defense,* Santa Monica, Calif.: RAND, MR-758-OSD, 1996.

Leonard, Robert S., and Jeffrey A. Drezner, *Innovative Development: Global Hawk and DarkStar—HAE UAV ACTD Program Description* *and Comparative Analysis,* Santa Monica, Calif.: RAND, MR-1474-AF, 2002.

Leonard, Robert S., Jeffrey A. Drezner, and Geoffrey Sommer, *The Arsenal Ship: Acquisition Process Experience—Contrasting and Common Impressions from the Contractor Teams and Joint Program Office,* Santa Monica, Calif.: RAND, MR-1030-DARPA, 1999.

Lorell, Mark, and John C. Graser, *An Overview of Acquisition Reform Cost Savings Estimates,* Santa Monica, Calif.: RAND, MR-1329-AF, 2001.

Lorell, Mark, Julia Lowell, Michael Kennedy, and Hugh Levaux, *Cheaper, Faster, Better? Commercial Approaches to Weapons Acquisition*, Santa Monica, Calif.: RAND, MR-1147-AF, 2000.

Office of the Deputy Under Secretary of Defense (Acquisition Reform), and Pilot Program Consulting Group, *Celebrating Success: Forging the Future*, Washington, D.C.: Department of Defense, 1997.

Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, *Report of the Defense Science Board Acquisition Workforce Sub Panel of the Defense Acquisition Reform Task Force on Defense Reform*, Washington, D.C., July 1999.

——, *Report of the Price-Based Acquisition Study Group*, Washington, D.C., 15 November 1999.

——, *The Road Ahead—Accelerating the Transformation of DoD Acquisition & Logistics Processes and Practices*, Washington, D.C., June 2000.

Perry, William, Secretary of Defense, *A Mandate for Change*, Washington, D.C., February 1994.

——, *Specifications & Standards—A New Way of Doing Business*, Washington, D.C., 29 June 1994.

Smith, Giles K., Jeffrey A. Drezner, and Irving Lachow, *Assessing the Use of "Other Transactions" Authority for Prototype Projects,* Santa Monica, Calif.: RAND, DB-375-OSD, 2002.

Smith, Giles K., Jeffrey A. Drezner, William C. Martel, J. J. Milanese, W. E. Mooz, and E. C. River, *A Preliminary Perspective on Regulatory Activities and Effects in Weapons Acquisition,* Santa Monica, Calif.: RAND, R-3578-ACQ, 1988.

Smith, Giles K., Hyman L. Shulman, and Robert S. Leonard, *Application of F-117 Acquisition Strategy to Other Programs in the New Acquisition Environment*, Santa Monica, Calif.: RAND, MR-749-AF, 1996.

Sommer, Geoffrey, Giles K. Smith, J. L. Birkler, and James Chiesa, *The Global Hawk Unmanned Aerial Vehicle Acquisition Process: A Summary of Phase I Experience,* Santa Monica, Calif.: RAND, MR-809-DARPA, 1997.

Stanley, William L., and J. L. Birkler, *Improving Operational Suitability Through Better Requirements and Testing,* Santa Monica, Calif.: RAND, R-3333-AF, 1986.

Thirtle, Michael R., Robert V. Johnson, and John L. Birkler, *The Predator ACTD: A Case Study for Transition Planning to the Formal Acquisition Process,* Santa Monica, Calif.: MR-899-OSD, 1997.