SUMMARY

A RAND research effort sponsored by the Office of the Secretary of Defense examined the future of the U.S. fixed-wing military aircraft industrial base. Its focus was the retention of competition and innovation in the military aircraft industrial base. The first major research task in that study involved a careful examination of the evolution of the industry structure over time, which emphasized an analysis of the role of competition and its links to innovation throughout the history of the industry. This report provides our findings and "lessons learned" from that part of the larger RAND research project.

The purpose of this survey was to identify issues relevant to the current policy debate on whether adequate levels of competition and innovation in fixed-wing combat aircraft development can be maintained over future decades. The debate has arisen from two recent developments: (1) the dramatic reduction in the number of credible combat aircraft prime contractors and lower-tier suppliers as a result of extensive mergers and acquisitions—consolidation—throughout the past decade and (2) the continued reduction in the number of anticipated new development and production programs for manned combat aircraft over the same period.[1] It is often explicitly or im-

[1]In the 1990s, the number of credible U.S. prime contractors for the development of fixed-wing combat aircraft declined from seven to two. (Some observers would not include Northrop Grumman as a third because, in 2000, in spite of its prominent role on the Lockheed-Martin Joint Strike Fighter [JSF] program, it did not enjoy the status of prime contractor on any major manned fixed-wing military or commercial aircraft program.) At the beginning of the new millennium, only one new manned combat aircraft program—the JSF—seemed likely to be funded in the foreseeable future.

plicitly assumed that high innovation in combat aircraft design is associated with large numbers of prime contractors (developers), because large numbers of prime contractors indicate a high degree of competition.

The fundamental goal of this report is to review the history of the U.S. aircraft industrial base to determine what insights, if any, can be gained regarding this assumption. This report does not pretend to provide definitive or comprehensive answers. We fully recognize the inherent limitations of a relatively brief top-level survey that draws heavily on published material and other existing research that was often conducted for other purposes.[2] Therefore, our objective is modest: We aim at identifying issues and questions based on past historical experience that may be indicative of what type of conditions may need to hold in the future for maintaining the level of competition and its potential linkage to innovation, in the hopes that our findings may inform strategies developed for bettering future DoD competition and innovation. Perhaps more realistically, it may point the way to future high-leverage research on the interaction of competition and innovation in the military aerospace industry.

Our analysis aims at identifying periods of revolutionary innovation in combat aircraft development and examining the aviation/aerospace industry structure and the role of competition during these periods. By *revolutionary innovation,* we mean technological advances that were integrated at key points in history in ways that led to a fundamental transformation and large advances in the performance capabilities of combat aircraft. Our goal is to ascertain the numbers and types of prime contractors, the nature of the competition among them, and the links among industry structure, competition, and innovation. The focus is on prime contractors and

---

Development and production of the JSF F-35 fighter was expected to be led by only one prime contractor—Lockheed-Martin—raising concerns that, in future decades, the Department of Defense (DoD) would have only one experienced prime contractor to turn to for new fixed-wing combat aircraft development.

[2]This overview draws heavily on prior published and unpublished research sponsored by the USAF and conducted under the auspices of the Resource Management Program of RAND's Project AIR FORCE.

integrators involved in the design and development of combat aircraft (fighter, fighter/attack, and bomber aircraft).[3]

We used several databases to examine all contractors, by aircraft specialization, which competed in the period 1909 through 2000.[4] Our survey of the data suggests that it is possible and reasonable to identify at least five distinct technology eras over the history of fixed-wing heavier-than-air combat aircraft, as shown in Table S.1: the

Table S.1

Five Principal U.S. Technology Eras and Their Innovation Periods for Fighters and Bombers (Airframe/Engine), 1909–2000

		Innovation Periods	
Years	Era	Technology Revolution	Technology Refinement
1909–1931	Biplane	1909–1916	1916–1931
1931–1945	Prop monoplane	1931–1940	1940–1945
1945–1953	Subsonic jet	1942–1947	1947–1953
1953–1981	Supersonic jet		
	Early supersonic jet	1953–1962	1962–1972
	Agile supersonic jet	1972–1974	1974–1981
1981–present	Stealth	1981–1990	1990–present

[3]Many of the most important improvements in combat aircraft performance have resulted from technological innovation in power plant development. We fully recognize the key role played in aeronautics by research and development (R&D) in engine technology. However, the history of competition and innovation in the aircraft engine industry is a proper subject for a separate study and is not attempted in this report. A brief overview of this subject is available in O. Younossi, M. Arena, R. Moore, M. Lorell, J. Mason, and J. Graser, *Military Jet Engine Acquisition: Technology Basics and Cost-Estimating Methodology,* Santa Monica, Calif.: RAND, MR-1596-AF, 2002.

[4]These databases are drawn from earlier published and unpublished RAND research sponsored mainly by the USAF and conducted under the auspices of RAND Project AIR FORCE. Some of these data are available in Mark A. Lorell and Hugh P. Levaux, *The Cutting Edge: A Half Century of U.S. Fighter R&D*, Santa Monica, Calif.: RAND, MR-939-AF, 1998.

biplane era (1909–1931), the propeller (prop) monoplane era (1931–1945), the subsonic-jet era (1945–1953), the supersonic-jet era (1953–1981), and the stealth era (1981–present). The supersonic-jet era includes two major sub-eras: the early supersonic-jet sub-era (1953–1972) and the agile supersonic-jet sub-era (1972–1981). Each of these eras began with a period of revolutionary innovation, high rates of technology advancement, and significant improvements in performance.

Each technology era and sub-era is divided into an initial period of revolutionary technological change and innovation ("technology revolution"), followed by a period of less-revolutionary technological change, characterized by refinement and consolidation of the technology advances first applied during the revolutionary period ("technology refinement").

Our broad assessment of the industry dynamics during each of the historical technology eras produced a variety of observations and hypotheses, most of which require further testing and analysis and further research to determine their validity and applicability to the current and future conditions that may characterize the U.S. combat aircraft industrial base. Providing a guide for further research,[5] they include the following:

- Each of the five historical technology eras began with distinct periods characterized by bursts of dramatically increased innovation in combat aircraft. The resulting new combat aircraft based on new designs and technology exhibited large advances in performance capabilities over the previous generation of combat aircraft.
- The initial periods of high technological innovation that began each technology era were all characterized by an increased competition to innovate among at least seven experienced, credible prime contractors/integrators specializing in combat aircraft.
- Following the initial period of increased innovation that started each new technology era, prime contractors tended to focus on

[5]RAND has conducted a larger parallel study of projected future conditions and structure of the defense aerospace industry to test these and other hypotheses. See Birkler et al., 2003.

refinement of the new technologies and configuration that had recently emerged. Except for the period of biplane technology consolidation in the 1920s, these periods were also characterized by vigorous competition among at least seven credible prime contractors. Contractors continued to innovate, except at a pace that was slower and less revolutionary. Eventually, however, the designs and technologies characteristic of the specific technology era reached a point of dramatically diminishing marginal returns in engine/platform performance.

- After an initial industry shake-out following the period of high technology innovation in each new technology era, new dominant industry leaders among prime contractors/integrators emerged in key specialty areas in combat aircraft. Other companies declined to positions that could be characterized as second-rank or niche players with respect to reputation, winning program competitions, and/or sector sales.
- From the historical evidence, the precise relationship between competition and increased innovation at the beginning of each new technology era is unclear. The competition to innovate during these periods was usually triggered by factors related to increased market demand, various technology developments, and military threat perceptions and system requirements.

  More specifically, the types of factors that historically seem to be linked to high-innovation bursts and the increased competition to innovate that began each new technology era include (1) industry perceptions of a potential or actual increase in market demand, (2) maturity and applicability of new component technologies, particularly when a new design and technology approach promised to offer high returns in desirable performance improvements, and/or (3) significant changes in government buyer performance and capability requirements.
- The prime contractors that tended to be the technology leaders and greatest innovators during the periods with initial bursts of intense competition to innovate that began each new technology era, were most often not among the industry leaders of the prior technology-refinement era. Rather, they were one of the following types of firms:

  - — Second-rank or niche prime contractors
  - — Leader firms expanding outside their existing area of specialization
  - — New entrants to the industry.
- The historical evidence suggests, but does not prove, that an industrial structure that includes numerous prime contractors during periods of slower technological advance, some of which are dominant in sales and some of which are second rank, is conducive to encouraging the onset of periods of higher innovation when demand changes and market conditions are right. To displace the dominant market leaders, second-rank firms are willing to take greater technological and financial risks, thus setting off an intense competition to innovate among many qualified contractors seeking market expansion.
- Our more detailed review of the 1920s and the early 1930s seems to support, but does not prove, the contention that larger numbers of experienced, credible prime contractors are more likely than lower numbers of competitors to promote the greater competition to innovate that leads to new technology eras. Unlike any other historical period, the post–World War I biplane era was dominated by only two credible and experienced developers of fighters and one or two leading developers of bombers. U.S. innovation in military aircraft slowed dramatically, to the point of stagnation, during this period. This period was characterized by both the smallest number of dominant prime contractors in fixed-wing military aircraft and arguably the lowest level of sustained technological innovation of any comparable period in U.S. aviation history. However, the relative lack of innovation during this period was also strongly influenced by the fairly low demand and lack of market opportunities. Furthermore, the existence of relatively low entry barriers meant that, when demand increased, competition and innovation went up.
- The historical evidence suggests, but does not prove, that higher levels of demand promote new entrants and much greater competition among contractors to innovate. The existence of only one or two dominant credible contractors, combined with high barriers to entry, may reduce the incentives for competition to innovate, even during periods of rising demand.

These findings raise potentially serious questions about the level of competition and innovation in a future environment that may be dominated by only one or two prime contractors with the credible capability to develop a new-generation fixed-wing combat aircraft. These questions require further study and analysis.