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Industry Study

Final Report
Aircraft Industry

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AIRCRAFT INDUSTRY STUDY 2013

ABSTRACT: The aircraft industry is the healthiest industrial segment in the world with nearly 50 percent growth over the last ten years in the face of worldwide economic downturns. Innovation within the industry is essential to retain U.S. competitive advantage and ensure future economic growth. This year's Aircraft Industry study examined the impact of reduced government spending on innovation and U.S. competitive advantage in the aircraft industry—specifically fighters, unmanned aerial systems (UAS), and rotorcraft and provided several recommendations. First, the U.S. government and the defense industry must resist reducing R&D spending to mitigate sequestration impacts. The government must reform the DoD acquisition system to encourage risk-taking and enable competition to prevent further consolidation of defense firms. The DoD should revisit U.S. service functions to eliminate waste without discouraging innovation and seek cost-effective materiel solutions that are "good enough" instead of the best. Finally, the government should prioritize and publicize the highest priority technologies required for future military capabilities to encourage technology development by enterprising firms.

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PLACES VISITED:

Regional Visits

25 January	Aerospace Industries Association	Arlington, VA
7 February	Lockheed Martin	Crystal City, VA
28 February	Boeing	Ridley Park, PA
8 March	Northrop Grumman Electronic Systems	Baltimore, MD
21 March	Pratt & Whitney	East Hartford, CT
21 March	Pratt & Whitney	Middletown, CT
22 March	Sikorsky	Stratford, CT
7 May	Naval Air Systems Command	Patuxent River, MD

Domestic Travel 1

8 April	Boeing	Everett, WA
8 April	Boeing	Renton, WA
9 April	Northrop Grumman	Palmdale, CA
10 April	Lockheed Martin Skunk Works	Palmdale, CA
10 April	Scaled Composites	Mojave, CA
11 April	General Atomics	Poway, CA
11 April	Advanced Machining & Tooling	Poway, CA

Domestic Travel 2

30 April	Lockheed Martin	Forth Worth, TX
1 May	Elbit Systems of America	Fort Worth, TX
1 May	Bell Helicopter	Hurst, TX
2 May	Turbomeca USA	Grand Prairie, TX

NOTE: Sequestration precluded international travel for the 2013 Industry Study Program.

America's aviation industry, in both the commercial and military sectors, has long been a source of strategic advantage for the United States. In the first half of the 20th century, explosive growth across the industry enabled dynamic American responses to a variety of military and commercial challenges. By the end of World War II, the United States had secured its position as the world's leader in aircraft development and production. Throughout the Cold War, the Soviet Union aggressively challenged the United States. As part of the broader arms race, intense competition to build better fighters, bombers, and air defense systems contributed to the economic decline that ultimately led to the demise of the Soviet empire.

Innovation is the linchpin of American aviation primacy. Nearly every crucial technological breakthrough in aeronautics originated in the United States. In those rare cases in which others led the way, such as the development of jet engines, American firms adopted and adapted the new technologies rapidly and ultimately improved upon the original designs. As commercial and military challengers emerged to threaten U.S. primacy, the government and the defense industrial base worked together to find innovative solutions.

Today's global strategic environment is much different than at the end of the Cold War. The lack of a single, identifiable threat has perhaps suppressed the U.S. appetite for constant innovation in the military sector. However, global competitors are not sitting idly by. Numerous competitors are challenging America's advantage in the military sector. The Europeans offer strong competition to American products. Historic rivals like Russia and China are developing and bringing new products to market. The traditional American advantage in innovation is eroding.

Conventional wisdom suggests that the current and projected fiscal crisis puts preservation of America's strategic edge at risk. Flat or declining budgets, combined with sequestration's indiscriminate cuts, threaten government-funded ventures in science and technology (S&T) and research and development (R&D). Industry partners are experiencing financial pressures too, as fewer government orders lead to smaller profits. History suggests that firms will limit R&D spending during defense downturns to maximize their profitability. Reduced funding exacerbates the innovation challenge and elevates the risk that the U.S. may not have the weapon systems it needs to be successful in future conflicts.

This paper presents the findings of the Eisenhower School's 2012-2013 Aircraft Industry Study Group's effort to answer the following research question: What is the impact of reduced government spending on innovation, and therefore U.S. competitive advantage, in the aircraft industry—specifically fighters, unmanned aerial systems (UAS), and rotorcraft? The remainder of this paper addresses our methodology; innovation definition as applied to our research; sources of, and barriers to innovation; the current state and future of each of the three industry subsectors; and concludes with policy recommendations to industry and government leaders to preserve and enhance innovation during defense spending downturns.

INNOVATION AS A RESEARCH LENS

This study uses innovation as a lens to analyze the short and long-term market, competitive landscape, and industrial base implications associated with fighter aircraft, UAS, and rotorcraft. Our analysis focuses on specific platforms and processes that reflect varying levels and forms of innovation. Using an innovation framework helps to contextualize insights the seminar gleaned from an examination of the relevant literature and field study of the commercial and military aviation sectors. Many definitions of innovation populate business literature. Given the complex socio-technical aspects of the aviation industry, the seminar adopted the foundational view that innovation is "*new processes, products, services, designs, or organizations which result in productivity increases and widespread market adoption and expansion*" to gain industrial and military competitive advantage.[1]

The seminar considered four core types of innovation—scientific, sustaining, disruptive, and breakthrough—that mirror the predominant perspectives in academia. Pure scientific and true breakthrough innovations are so rare that they lie outside the boundaries of our research paradigm. Therefore, while the seminar searched for evidence of all types of innovations across the continuum, this study focuses primarily on sustaining and disruptive innovation and the strategic decisions made by firms, their customers, and supporting networks to advance the aircraft industry. Examining how the national innovation system contributes to this narrow subset of innovation, in various military aircraft subsectors, helps illuminate how business, academia, and government support U.S. strategy.[2]

Innovation is a dynamic concept as illustrated by the different paths it may follow along the continuum depicted in the graphic below. Part of the dynamic nature of innovation is temporal. A product or process may immediately disrupt the market or enter more slowly as a sustaining innovation and eventually evolve into a disruptive innovation. The time required to make this evolution from sustaining to disruptive is another significant point. For example, while Boeing believes the 787 will have disruptive effects on the market, it is too early to determine if it will be disruptive and if so, to what extent.

None of these developments are predictable with any degree of certainty however. For example, some innovation efforts are meant to be disruptive but fall short of this goal. The Concorde is a good example of this from a civilian industry perspective. Conversely, some innovation efforts are intended to be sustaining, but evolve into disruptive innovations. The F-35 may follow this second path from an industry, acquisition process, and strategic relationship perspective. These negative effects highlight the point that not all the effects of innovation are positive, an important concept to consider when making investment decisions.

Another aspect of innovation's dynamic nature is the understanding that the place a particular innovation resides on the continuum is a matter of perspective. There are myriad perspectives to consider, but two of the main perspectives for military aircraft are the effects on the military sphere and the effects on the market. Significantly, both of these two categories can be subdivided even further. A salient example of this is the F-22. From an industry perspective, the F-22 is not considered a disruptive innovation. However, from a warfighting perspective, many consider the F-22 a disruptive innovation. Adding another level of difficulty in assessing innovation is that individual perspectives based on experience and worldview matter greatly. Combined with the temporal aspect of innovation discussed earlier, the nuances of perspective illustrate the complexity of innovation.

The Continuum of Innovation

In examining both disruptive and sustaining innovation, sustaining innovation is the most effective at improving solutions to well-defined problems such as powered flight.[3] Consequently, firms apply sustaining innovation approaches to deliver positive changes in materials, technology, capital, processes, human resources, and supply chains to innovate along a relatively well-known path.[4] The decision to invest in sustaining innovations is predicated on the prevalence of the established design in the market and supportability of fielded products and services.

Alternatively, disruptive innovation involves fundamental changes to products, processes, and markets that lead to a paradigm shift. Applying Christensen's guidelines to military innovation, disruptive innovation creates an entirely new market for a weapon system, renders an existing weapons system obsolete, or creates disruptive effects for an adversary in a commercial or military sense. Military innovation scholars also suggest that disruptive innovations drive internal changes to organizations, culture, doctrine, and tactics. In that light, given current and projected fiscal constraints, one key aspect of disruptive innovation is viability. If a new system is too expensive, its disruptive effects may not be pervasive and therefore, may result in a limited disruptive impact. The reduced quantity of USAF F-22 Raptors in the inventory illustrates this point.

Additionally, a sustaining innovation may have disruptive characteristics and effects, and characterizing innovation as one or the other is a matter of perspective. For example, UASs have disrupted certain aspects of the USAF culture, organization, doctrine, and tactics because they are unmanned, but they are not disruptive from the adversary's perspective simply because they are unmanned. Instead, the differentiating feature from the adversary's point of view is the persistence afforded by UASs. By contrast, the introduction of the jet engine fundamentally altered the entire aircraft industry and aircraft support system, as well as society at large. Finally, while Boeing considers the 787 a disruptive innovation, it does not meet the criteria set out by scholars at this time because it has neither created a new market nor has it made other aircraft obsolete. The seminar's research separates marketing and business development claims from the academic taxonomy selected for this analysis.

The innovation continuum can be applied to both products and processes. Product innovation entails improvements to platforms, weapons systems, hardware, and software. Alternatively, process innovation refers to improvements in building, maintaining, and sustaining systems. These two types of innovation are closely related. Product innovation, such as improving accessibility to internal aircraft systems, facilitates maintenance and thus enables process innovation. Similarly, process innovation such as advanced composites manufacturing enables product innovation by providing lighter aircraft with increased fuel efficiency and range.

SOURCES OF INNOVATION

The seminar's research and field visits revealed numerous sources of innovation within the aircraft industry and specifically in the military aircraft market. Innovation occurs through an ad hoc collaboration between the public sector, private industry, and academia.[5] Examining innovation from a national perspective proves useful despite trends toward increased globalization at macro and micro levels. Additionally, especially in the aircraft industry, innovation produces spillover effects that positively influence national security and economic prosperity. External and internal drivers interact with this national system to spur innovation, and the various elements of the system participate due to the need to solve a problem combined with business competition.

These drivers house various sources of innovation; this section highlights the sources most relevant to the military aircraft subsectors. Competition serves as the key common thread across all innovation sources and drivers.

Two competitive sources comprise the external drivers of innovation. The nature of current and projected threats serves as the first and most important source within the military aircraft industry. Since the innovative products developed by this partnership provide the means of fighting and winning the nation's wars, advances in a competitor's capability spurs creativity to generate and sustain a competitive advantage. Under the national innovation paradigm, government and industry collaborate to identify potential materiel solutions to emerging threats. Complex, niche technical challenges may find solutions in the academic world and then transfer to industry. Increases in adversary capabilities inform technology development priorities within the Department of Defense (DoD). With adequate R&D funding, the services can address these problems and help the industrial base develop the necessary capabilities to protect the nation.[6]

Business competition also serves as an external driver of innovation. U.S. aircraft manufacturers face global competition in both the commercial and military markets. In the military fighter market, Lockheed Martin and Boeing's 4th generation offerings compete with European, French, and Swedish products in Western markets. Russian firms remain active in the international marketplace, and emerging competitors like China are beginning to introduce exportable aircraft as well. These influences resulting from globalization and international industry competition drive innovation as U.S. firms attempt to increase market share by developing new relevant technologies and increasing sales. The multinational nature of firms also creates opportunities for innovation by sourcing ideas and technology globally.

Internal innovation drivers lead to opportunities through the components of the national system. The U.S. government serves as a key pillar of the national system by promoting innovation and technology development through direct and indirect sources.[7] Direct sources include aerospace R&D funding to the DoD and the National Aeronautics and Space Administration (NASA).[8] Within the DoD, interservice rivalry serves as a source of innovation as well. Competition for limited funding and the desire for service relevancy stimulate innovative materiel and non-materiel solutions to tactical and operational problems.

The DoD concentrates its research, development, test and evaluation investments in operational systems development, system design and demonstration, advanced component development and prototypes, and basic research, applied research, and advanced technology development in decreasing order of importance.[9] Therefore, as technology matures, the DoD funding commitment increases. Basic research provides the underlying technologies needed for innovation, but involves greater risk and limited returns, and therefore requires government investment. System development and demonstration efforts introduce new aircraft platforms and offer more opportunities for disruptive innovation. Operational systems development activities provide sustaining innovations to improve existing aircraft. The focus on operational systems development within DoD funding aligns with the military's preference for incremental innovation.

The government also encourages innovation indirectly through tax incentives and other favorable policies.[10] For example, current policies encourage innovation by granting tax credits to industry for R&D investment and promote partnerships with government agencies and universities.[11] The objective of indirect incentives is to increase collaboration, develop marketable products, and drive industrial and economic growth.[12]

Industry plays a crucial role in fostering innovation through their internal or independent research and development (IR&D) efforts that generate new ideas, technologies, products, and processes. Field study visits demonstrated that innovation often stems from a firm's passion to solve their customer's problem and earn new business or industry's desire to shape the market by creating something new. Successful firms and programs leverage prior experience within the market, especially when dealing with a U.S. government customer, to provide innovative solutions.[13] Additionally, firms' desire to ensure their competitive advantage requires a continuing commitment to anticipating future requirements, and developing the required technological solutions internally.[14]

IR&D trends illustrate changes occurring within the aircraft industry. Defense prime contractors currently spend less on IR&D than commercial firms or lower-tier defense suppliers, which analysts attribute to the changing role of primes from technology developers to systems integrators.[15] This drives the requirement for innovation to the supplier level where key aircraft component technologies reside. In addition, firms now establish design and research centers overseas in order to gain alternative perspectives.[16] With limited IR&D funding, commercial and military original equipment manufacturers (OEMs) focus more on upgrading existing platforms and less on new platforms.[17]

Industry also works closely with universities to sponsor R&D efforts that could lead to innovation. For example, Pratt &Whitney collaborates with Penn State University, funding research that benefits the company and the university.[18] These collaborations also benefit industry and provide a training ground to grow future aerospace engineers. This arrangement creates an industry-friendly alternative to government contract support, which could result in disputes over intellectual property rights.[19]

Other collaborative arrangements at the national level are less formal. Several firms, including major defense OEMs, now utilize open innovation forums that expand outside of their organizations or partnering agreements, to foster ideas and collaboration at the national level.[20] Shrinking defense budgets have forced firms to become more creative; soliciting informal, external help to solve problems facing the industry.[21]

BARRIERS TO INNOVATION

The same analytical framework used to assess sources of innovation is also applicable to innovation barriers. For the purposes of this study, barriers to innovation impede the national system of innovation's ability to provide optimum solutions to problems that require materiel solutions.

The first barrier within the external driver of innovation is the lack of a single, coherent threat that focuses national attention. During the Cold War, the Soviet Union provided credible threat that allowed the national system of innovation to focus on solving direct, palpable tactical, operational and strategic problems. Since the end of the Cold War, interservice rivalry and the desire for service relevancy has influenced the characterization of various threats. In the twelve years since 9/11, the national system has focused primarily on threats to the mission and personnel in Iraq and Afghanistan. This focus was necessary, but sapped efforts to anticipate and deal with other emerging threats and competitors. The result was diffuse innovation across a broad spectrum, and many high-cost, high-risk, high-technology programs were deferred or delayed.

Globalization also creates barriers to innovation as an external, business-oriented driver. Historically, industries were wholly contained within the borders of a nation and military capacity was generated indigenously. Now, many firms are multinational organizations with a global presence. Companies have exported manufacturing, engineering, and R&D facilities in order to reduce costs and remain competitive. This “off-shoring” of capabilities comes with a cost to innovation. Government regulations such as the International Traffic in Arms Regulations (ITAR) and industrial attempts to guard against unauthorized transfer or theft of intellectual property create firewalls that inhibit innovation and increase development costs. Building and maintaining global supply chains create additional complexity.

Internal drivers that impede innovation fall across the public and the private sector, with the majority of barriers created by the government. The first significant barrier is the threat of R&D funding reductions as budgetary pressures increase. Although the defense budget remains a large part of the government’s outlays, social welfare programs and interest on the national debt are beginning to crowd out defense spending. A 2010 McKinsey & Company analysis found a strong correlation between the level of R&D spending and future quality of military equipment. Their analysis predicted that the United States would remain in the lead regarding military capability for the near future; however, the balance of military power would eventually shift to emerging countries such as China and India.[22] Fiscal constraints will negatively affect innovation if R&D funding is cut too deeply. Industry is likely to reduce IR&D commensurately. Simultaneous cuts in public and private sector R&D will put the U.S. ability to field new, quality weapons systems in adequate quantities at risk.

A second internal barrier is the increased time required to develop new weapons systems. Time between new starts is symptomatic of a dysfunctional and plodding defense acquisition system that struggles to field new systems in a timely manner. Since every new platform presents an innovation opportunity, increased development time leads to fewer new platforms and fewer opportunities for innovation. The time required to field new military aircraft is significantly longer than either the commercial aircraft or automobile industries (8 and 3 years respectively). The F-22 and V-22 each took 19-23 years to deliver and the F-35 development timeline may be even longer. Career-long development times also leads to experience gaps in the design and manufacturing workforces further stifling opportunities for innovation. Lastly, long development times require existing platforms to remain in service longer forcing firms to focus resources on incremental, sustaining innovations rather than searching for the next disruptive technology.

Another consequence of excessive development times is an undesirable relationship between weapon programs and the political environment. The global strategic environment is changing faster than new platforms can be fielded thereby making them of questionable utility. In other words, the threat a platform was designed to counter may no longer exist by the time it is fielded. Worse, the development timelines often exceed the political life span of most elected officials. This makes it easy to defer capabilities even longer, which only aggravates the utility problem previously discussed. The military services can contribute to political difficulties as well, as some administration officials or members of Congress are more apt to view some programs (or some services) more favorably than others. Powerful individuals can ensure the survival of programs or their demise. Interservice rivalry can thus be considered both a source of, and a barrier to, innovation.

As weapon systems have become more complex, the acquisition system has become more onerous. Reporting requirements that only large, established firms can manage create barriers to market entry for small companies. It was apparent through many industry visits that tension is high between industry and the government. Cost overruns and schedule delays result in increased government oversight and efforts at reform, an increase in required reporting and changes in preferred contract vehicles. Industry is concerned that the trend toward “Lowest Cost Technically Acceptable” discourages them from offering additional capability that could enhance aircraft performance. Increased reliance on firm fixed price contracts is pushing industry to use proven capability instead of pursuing an innovative solution in order to reduce financial risk. Additionally, the government's renewed pursuit of data rights represents significant risk for companies' intellectual property, further stifling their desire to take risk.

Trends within the private sector suggest a disappointing future for innovation within the military aircraft sectors. In an effort to streamline training and support costs, the military began consolidating their platform portfolios. This trend forced the defense industry to eliminate excess manufacturing capacity. In the case of fighter aircraft, only Lockheed Martin has the experience to build 5th generation fighter aircraft. The consolidation of manufacturers and suppliers left the defense industry with large companies who seek incremental innovation for proven designs in order to maximize capital investments in legacy programs and to reduce the risk of non-selection in new start acquisition programs.

Ironically, diversification presents another barrier to innovation for defense firms. Many large firms, including traditional defense-only firms, diversified their business portfolios as a hedge against reduced defense spending. As a result, defense business segments must compete with sister non-defense business units for declining IR&D funds. Given the poor defense budget forecast for the remainder of the decade, it is likely that firms will provide IR&D money to those non-defense business segments most likely to provide the largest return on investment.

PRODUCT INNOVATION IN MILITARY AIRCRAFT

The aircraft production industry is the healthiest industrial segment in the world with nearly 50 percent growth over the last ten years in the face of worldwide economic downturns.[23] While both U.S. civil and military aircraft markets have contributed to this growth, commercial aircraft have dominated the U.S. aircraft production industry, securing seventy-five percent of the market's value.[24] Although the future remains bright for commercial aircraft sales, the military aircraft sector's future remains uncertain, especially in the mid to long-term. Fiscal constraints, decreased demand, increasing unit costs, lengthy production timelines, and increased airframe lifespans may contribute to further industry consolidation and a subsequent loss of competition and innovation. Additionally, there are emerging foreign military aircraft and alternative acquisition models that may compete with the U.S. and threaten current U.S. market dominance.

Although market structures and competition vary by product, the U.S. desires a healthy military aircraft industry marked by a number of prime and subprime contractors. A healthy industry fosters competition and innovation and enables governmental influence and a level of control over the acquisition process. This benefits the U.S. military, the defense industrial base, and the U.S. economy. Significantly, a healthy industry also allows the U.S. to use the military aircraft sector as a strategic tool to build international relationships, dependencies, and influence.

The conditions are ripe for innovation in the military aircraft sector though. First, there is an urgent need for the U.S. to recapitalize its aging military aircraft fleet. As an example, the majority of U.S. Air Force fighter aircraft in service today were acquired in the 1980s when the average aircraft age was approximately ten years.[25] Many factors, including the 1990s procurement holiday and the wars in Iraq and Afghanistan have contributed to the current 21.3 year average fighter age. By 2009, 80 percent of U.S. fighters had used more than 50 percent of their service life.[26] Additionally, the U.S. re-balance to the Asia-Pacific region presents both challenges and opportunities. The emergence of modern Chinese aircraft and alternative acquisition models may serve as both a military and an export business threat. The Chinese threat can also be viewed as an opportunity as nations in the region are incentivized to enhance their military capabilities. Finally, there are emerging technological advances in some fields that may enable innovation in other areas. For example, advanced propulsion systems may provide the necessary power and cooling required for radically new weapons.

This section of the paper discusses three U.S. military aircraft subsectors based on the seminar's focus during the semester: fighter aircraft, unmanned aerial systems, and rotorcraft. Each subsector discussion analyses the current market status, and trends and drivers. This section offers specific subsector recommendations while the overall paper provides comprehensive industry-wide recommendations.

Fighter Aircraft

Fighter Aircraft Market Status

The U.S. currently dominates the fighter market with high barriers to entry for potential competitors. The strategic military advantage provided by this market is complimented by the political and financial benefits of foreign military sales of F-15, F-16, F-18, and F-35 aircraft. However, both Russia and China have made significant investment in their fighter aircraft industry and with the help of increased rates of technology diffusion and advanced manufacturing processes, are reducing the U.S. lead. Investments by foreign competitors, combined with the planned production line closings for the F-16 in 2017 and the F-15 and F-18 in 2020 could significantly change the market.[27] This is especially relevant when placed in the context of aging fighter fleets in need of recapitalization.

The U.S. lead in this market is also at risk from skyrocketing unit costs, increased budgetary pressure, a reduction of U.S. purchasing power, and long production timelines. All of these factors increase program costs and decrease production numbers and forces the military to sustain aircraft longer than originally planned. As previously discussed, these factors have resulted in industry consolidation, reduced numbers of fighter aircraft (and the number of different types of fighter aircraft) as well as decreased competition and innovation. This is a pivotal time in the U.S. fighter industry.[28] The next five years may be the most significant in the history of the fighter market.

Fighter Aircraft Trends and Drivers

Significant technological, economic, and political trends are emerging. Fighter aircraft unit costs continue to increase substantially. Augustine's ninth law best illustrates this trend that fighter costs are increasing at an exponential rate over time, especially when compared with the growth of the U.S. defense budget.[29] By the year 2054, if the current trend continues, the entire defense budget would only be able to purchase one new fighter aircraft.[30] While Mr. Augustine deliberately generated this inflated scenario, unit costs of new fighter aircraft have exceeded U.S. GDP growth, as exemplified by the price of the F-22 and F-35.[31] It appears the U.S. is executing a cost imposition strategy on itself. As a senior USAF official recently remarked, "we cannot sustain this cost curve any more, it is simply too expensive."[32]

These increased unit costs are reducing production numbers as well. For example, during World War II, the U.S. produced over 15,000 P-51 Mustangs.[33] The USAF currently plans on buying 1,763 F-35s, the largest fighter aircraft contract since the F-16, of which the USAF purchased 2,230.[34] This decrease in the number of aircraft is a problem for many reasons. As

Joseph Stalin once stated, "Quantity has a quality all its own."[35] It is important to note that despite improvements in aircraft capability and quality, the U.S. is rapidly approaching the point where there are insufficient numbers to achieve U.S. interests.

Two innovations would help mitigate the effects of a smaller inventory of advanced aircraft. The first is innovation in networks, network subsystems, and information technology. Evidence suggests that these technologies may be shifting the importance from aircraft platforms to sensors and networks, increasing the importance of open architecture.[36] This is a significant mindset shift that carries substantial implications for the industry and enables platforms with narrow roles to contribute to a wide-range of military solutions through innovation at the systems level.[37]

The second innovation is the evolution of unmanned aircraft technology (discussed in more detail later) and the potential for integration with, or substitute for, manned fighter aircraft. While many challenges and uncertainties remain, Northrop Grumman's X-47B and General Atomics' (GA) Avenger are making substantial progress in this area.[38] Additionally, Raytheon and GA have teamed to equip the MQ-9 Reaper with miniature air launched decoys which "enable remote, unmanned suppression of enemy air defenses."[39] If successful, this capability would help enable unmanned systems to accomplish another mission currently executed by manned fighter aircraft.

Perhaps the most significant trend is fighter prime and subprime contractor consolidation. There has been insufficient demand for new fighter design, development, and production work to satisfy a large number of defense contractors and subcontractors. As recently as 1960, there were eleven prime fighter contractors. Currently, there are only two, Lockheed and Boeing, which has led to a decrease in industry rivalry. Significantly, many lower tier suppliers face consolidation, extinction, or may decide not to accept DoD contracts as they diversify their portfolios as previously discussed.[40] This will negatively affect the ability to improve subsystems on aircraft that exist for an extended time.[41] Further consolidation is possible if DoD does not take action soon as Boeing may opt out of the manned fighter aircraft production business.[42]

Fighter Aircraft Recommendations

The U.S. should take actions and develop policies to create opportunities for competition and innovation at the prime and subprime levels, while deliberately supporting and balancing both disruptive and sustaining innovation. This balance includes striving for disruptive innovation to produce a 6th generation fighter, focusing on systems over platforms, and investing in sustaining innovations for current 4th and 5th generation fighters. This balance is required to maintain the U.S. competitive advantage, preserve competition in a healthy industrial base, and provide a portfolio of export options to U.S. allies.

Further, a change in the current DoD mindset that it must develop all aircraft for the worst-case scenario is required. As an Air Force general officer said, "this is an approach that the U.S. cannot afford and does not need."[43] In addition to a limited number of high technology aircraft suited for the most dangerous scenarios, it is prudent to develop more affordable, lower-level technology aircraft with growth potential, similar to the F-16.[44] This deliberate decision to invest in sustaining innovation would help solve the short-term problem of reduced budgets as well as help prevent the long-term reoccurrence of the current situation.

The U.S. should also continue to invest in disruptive innovations such as the 6th generation fighter as directed by DoD's Next Generation Air Dominance Study. This will provide defense contractors meaningful work in the critical research and development phase.[45] Research and development is a very perishable skill that a fighter firm must exercise regularly. Analysts argue that the "minimum viable firm" to maintain a credible fighter research and development program is a team of one thousand personnel in a company's research and development department to, "conduct technology development, advanced design studies, and demonstrator/prototype development and test of future system concepts every few years."[46]

In addition to the Next Generation Air Dominance Study, procurement of additional 4th generation plus aircraft such as the F-18 E/F would help keep Boeing in the fighter production business. It would also create competition and innovation between lower tier suppliers of subsystems such as sensors and electronic warfare equipment.[47] A senior industry executive recently noted that second and third tier supplier consolidation is imminent, which will lead to further erosion of the U.S. fighter industrial base.[48] Preventing this may require a revision to the Better Buying Power 2.0 policy guidance currently in place to enable the U.S. to protect vital subsystem suppliers and to require open architecture.[49] It also may require the U.S. to pay a sovereignty price to save worthy suppliers. Which suppliers the U.S. should protect and how it would protect them deserves further study.

Unmanned Aerial Systems (UAS)

UAS Market Status

Unmanned aerial systems are a significant and growing portion of the U.S. aircraft industry. The U.S. military market alone is projected to generate $86.5 billion from 2013-2018.[50] As these aircraft have grown beyond intelligence, surveillance, and reconnaissance (ISR) systems on simple platforms to full-fledged strike aircraft, they have provided a significant source of research funding and innovation to the military aircraft market. As previously described, U.S. manned fighter designs have become once in a generation efforts and are contributing to industry consolidation and stagnation. Conversely, UAS programs are providing a significant spark to the industry. In fact, the Congressional Research Service's 2012 study of UASs provided examples of 22 different unmanned military aircraft in use or development by seven different manufactures.[51]

Three active programs illustrate the level of investment and potential for innovation in this market; the Navy's Unmanned Carrier Launched Airborne Surveillance and Strike System (UCLASS) program, the Air Force's Long-Range Strike-Bomber (LRS-B) and the Marine Corps KMAX unmanned helicopter.[52] Of these, the UCLASS will likely have the most significant near-term impact. The Navy is expected to issue four contracts for preliminary design reviews for the UCLASS air vehicle in the summer of 2013 with the hope of having a fully fielded system in the next three to six years.[53]

UAS Trends and Drivers

One driver of UAS expansion, and often the overriding one, is that the use of these systems does not risk human life.[54] However, tradeoffs are required when weighing the benefits of direct human influence versus investing in autonomous operation innovation. Another important benefit driving innovation in UASs is the removal of human physiology as a limiting factor. By removing humans from aircraft, tremendous advantages in persistence have been realized. For example, MQ-9 Reapers fly continuously for up to 32 hours and Lockheed's Integrated Sensor Is Structure Command & Control, Intelligence, Surveillance and Reconnaissance autonomous airship is being designed to fly continuously for up to 10 years.[55] The force of gravity is another performance limitation that can be overcome by removing humans from the cockpit. The highest performing U.S. fighters today are limited to around 9 times the force of gravity. As UAS designs and material technologies improve, there is the potential to produce aircraft that exceed sustainable human limits.

Cost is another often-cited benefit to UASs but costs are trending the same way as manned fighter aircraft as the size and complexity of UASs increase. According to the Congressional Research Office, the Navy's Broad Area Maritime Surveillance aircraft is expected to cost $55 million per aircraft and the Air Force's MQ-9 Reaper is $26.8 for the aircraft and its ground station.[56] Lower costs seem to be realized only if capability requirements remain narrow and lower performance is acceptable for mission accomplishment. As multi-role or advanced non-ISR capabilities are pursued and as unmanned aircraft performance approaches that of manned fighters, costs will inevitably rise, perhaps threatening further innovation.[57]

While the USAF favors remotely piloted aircraft, the Navy and Marine Corps are exploring autonomous system innovations. Autonomous systems are most relevant when constant control may not be possible or required, but there are significant challenges to this capability. Although future unmanned aircraft would employ low observable technology to minimize the chances of detection, they will not add the ability to react to threats like 5th generation manned fighters currently provide and are vulnerable to jamming and cyber-attack if anything less than fully autonomous. Even if unmanned systems could be programmed to gather information and make decisions commensurate with human pilots, organizational limitations against full autonomy could therefore still limit the possibility of a disruptive innovation such as a fully unmanned military aircraft fleet.

UAS Recommendations

The UCLASS program mentioned above is shaping up as a major competition between four prominent defense contractors for this fighter-like design. This level of competition has not seen since the height of Cold War and may determine the path of future military UAS platform development. As the market is adding increased competition with more firms for more customers in more mission areas, the best thing the U.S. government can do is to let it happen and not to regulate out competition. By facilitating additional test facilities through the removal of FAA UAS prohibitions the federal government is already removing barriers to innovation in the UAS market. Such efforts to increase market participation should be pursued vice any governmental attempts to narrow or control this healthy and growing industry.

In addition to complimenting manned systems through ground controlled UASs, there is room to further explore air controlled UASs. The Defense Advanced Research Projects Agency (DARPA) speculates that autonomous UASs that fly on the wing of manned aircraft are in the realm of the possible.[58] Responding to the actions of a manned flight lead, these UASs may provide lower cost specialized vehicles that allow pilots to choose their wingmen based upon a specific mission profile. Though still vulnerable to jamming and other electronic countermeasures, there is a significant degree of utility worth exploring if the technology proved practical and cost savings could be realized. This concept is important since it multiplies the capabilities of manned aircraft capabilities but does not rely completely on the ability to communicate with unmanned aircraft over intercontinental distances.

Other areas ripe for sustaining innovations provided by UASs are suppression of enemy air defenses (SEAD) and command, control, and communications. UASs equipped with standoff jamming equipment and systems like the F-16's High-Speed Anti-Radiation Missile Targeting System hold much promise in the SEAD realm.[59] Additionally, the Global Hawk EQ-4 and Lockheed's ISIS airship may add significant capabilities to communications, command and control. With the combination of the EQ-4's ability to extend communications over the horizon and ISIS's advanced radar, a command, control, and communication network significantly aided by UAS airborne radars and communications links are certainly possible.

Finally, it is important for DoD to stop looking for the next UAS platform and instead weigh the costs versus benefits of manned and unmanned systems to fulfill specific military requirements and find the best solution. Labeling the Air Force's LRS-B as optionally manned is a step in the right direction since analysis of feasibility, cost, vulnerabilities, and mission requirements will decide if this weapon system is most effective as a manned or unmanned platform.

Rotorcraft

Rotorcraft Market Status

Dominated by Bell Helicopter (Textron), Sikorsky (United Technologies), and Boeing, the U.S. military rotorcraft market has enjoyed strong growth over the past decade propelled by heavy utilization and faster refresh rates due to demands from operations in both Iraq and Afghanistan.[60] Whereas Boeing and Sikorsky enjoy the majority of the U.S. military market with a wide range of mission platforms, Bell Helicopter maintains a strong presence in the U.S. Marine Corps by continuing to produce AH-1Zs, UH-1Ys, and V-22s.[61]

While the last ten years has been a boon for the rotorcraft market, the forecast and direction of the future market is uncertain due to both the high cost of rotorcraft platforms and the conclusion of combat operations U.S. in Iraq and Afghanistan. Additionally, possible substitutes such as UAS create uncertainty in the market. One positive note is that rotorcraft transcend traditional combat roles and have unmatched utility in homeland defense, disaster relief, and peacekeeping roles.

By 2020, most major rotorcraft programs of record will be complete, thus leaving a void in the industry. Recognizing the need to spur the development of the next generation vertical lift platforms, Deputy Secretary of Defense Ashton Carter recently signed a Strategic Plan for Vertical Lift Aircraft that is intended to address current vertical lift aircraft performance gaps.[62] DoD has also established the Vertical Lift Consortium (VLC) to improve the long-term state of the military's vertical lift aircraft and the vertical lift industry similar to the Next Generation Air Dominance Study initiated for the USAF and USN.[63]

Rotorcraft Trends and Drivers

Due to many factors including technological limitations and threats, sustaining innovation is the consistent trend in the rotorcraft industry. Although recent DoD budgets have contributed roughly $10 billion annually towards military rotorcraft development, the funding of upgrades and replacements hasn't changed the basic mechanical functioning and technology of helicopters since the late 20th century.[64] Much like other aviation industries, the rotorcraft industry has strong and long lasting buyer-seller relationships that erect high barriers to entry to prevent disruptive innovations that often bring game changing capabilities to the market.

There is a three-pronged approach to innovation emerging in the rotorcraft industry. In the short-term, the services and industry are pursuing sustaining innovations such as the AH-1W, SH-60 Romeo and Sierra, and CH-47F Chinook. In the mid-term, these stakeholders are pursing projects such as FVL. In the long-term, they are pursuing projects such as DARPA's VTOL X-Plane. There are several problems with this approach.

One problem is the projected production gap between the short and mid-term approaches as mentioned above. Additionally, industry and the DoD seem willing to spend a great deal of time, effort, and resources for advertised disruptive innovations that are more accurately characterized as sustaining innovations. It would be more beneficial for stakeholders in the rotorcraft business to make a conscious decision to pursue sustaining innovation based on the previously discussed barriers to disruptive innovation. Sustaining innovation may be "good enough" for the rotorcraft industry.

Struggling to focus on the future and resist designing rotorcraft for the last war, DoD and industry are having difficulty in both articulating and forecasting requirements for FVL. It appears they are torn between solving one of two distinct problems. The first involves solving the payload problem in hot and high altitude environments that manifested itself in somewhat in Iraq, but especially in Afghanistan. The second involves increasing the speed and range of rotary wing platforms to address future operational concepts like the Air-Sea Battle where the need to project power over great distances in the global commons and particularly in the western Pacific puts a premium on speed and range.[65] It is clear from the seminar's industry visits that firms are weighting their efforts based on how they envision the future market.

As an early attempt to determine what technologies are feasible and possible for FVL, the Joint Multi-Role (JMR) Technology Demonstrator (TD) has generated a great deal of industry interest. As a possible precursor to a trend in winning the competition for FVL, Boeing and Sikorsky recently announced that they are teaming up on the JMR-TD and have submitted Sikorsky's X2 coaxial rotor configuration for their proposal.[66] Although some see this teaming as a way of preventing smaller industry players from competing in FVL, the current 50/50 venture between Boeing and Bell to build the V-22 has experienced pervasive challenges that will most likely preclude an industry partnership proposal for FVL. These shifting relationships and the anticipated decrease in future demand contribute to industry uncertainty and may eventually lead to future industry consolidation.

Rotorcraft Recommendations

Due to the dangerous combination of few new rotorcraft development programs and a dearth of funding, a wide range of sustaining FVL technologies should be pursued through various S&T efforts and the utilization of the VLC. In order to implement a strategy that both facilitates current modernization efforts and encourages that development of technologies for future platforms, DoD should treat FVL not as replacement platforms but as a collective effort to bring doctrine, technology, and the government-industry partnership together to improve the overall state of rotorcraft capabilities.

Early debate on the JMR-TD has centered on the strategy to build flight demonstrators versus spreading out the work and maturing different technologies. While some suggest that it might be wiser to invest in the design and development of subsystems because prototype airframes have historically tended to be single-purpose technology demonstrators, others argue that in order to preserve U.S. engineering capability, prototypes built by industry could radically advance technology.[67] Because FVL should be considered a technology development effort and not a platform at this point, both strategies have merit as demonstrators in which both large OEMs and small business can assist in informing the achievable technology readiness of FVL while subsystem development funding could be provided to academic institutions specializing in rotorcraft research**.**

Because of its overarching and disruptive potential across the services, the DoD should review FVL's potential impact on current roles and missions and strive for clear delineation of FVL's roles within each service and its application in future warfare. This effort could also sharpen requirements for all FVL classes and drive future joint doctrine that would help focus the effort in pursuing new FVL capabilities.

PROCESS INNOVATION

The research seminar also explored the impact of reduced government spending on process innovation. Reduced spending appears to have had no impact on process innovation efforts across three relevant subsectors of the military aircraft industry, as well as the commercial sector. This is because businesses are encouraged to maximize marginal profits regardless of the fiscal environment. A common theme from industry leaders was "those who do not innovate, lose." Over the course of high volume production runs, marginal profits are enhanced through the smart application of process innovations. Several distinct trends were observed during field visits to OEMs and lower-tier suppliers across the commercial, fighter, UAS, and rotorcraft sectors.

The first trend is that all firms optimize their processes to squeeze efficiencies from production lines. Most firms employ industrial engineers and production managers who are well versed in "lean" manufacturing techniques and use management tools such as Earned Value Management. Leaders at several firms made overt references to efficiency lessons learned from automobile production lines, while highlighting the challenges associated with the higher amounts of touch labor required to manufacture aircraft. As a result, many firms are reducing the frequency of quality "turnbacks" on production parts by automating the more technically challenging aspects of the manufacturing process. Robotic drills that process complex parts to exacting specification are commonplace across the industry. Emphasis on production efficiency and quality was observed at all tiers of the supply chain.

A second process innovation trend is the migration toward the "lead system integrator" business model. The publicly traded firms the seminar visited have all adopted this model to one extent or another. Complex processes, especially fighter aircraft production, tended to reflect higher levels of outsourcing of airframe components and subsystems. For programs such as the F-35, however, it was difficult to discern exactly when the outsourcing was done for competitive efficiency reasons, political reasons (such as ensuring production from as many states as possible), or partner nation/Foreign Military Sales offset production agreements. Regardless of the firms' motivation, this model maximized the ratio of highly skilled and trained labor to the overall labor force, which should maximize the design potential of these firms over time.

Privately held firms appear more likely, for now at least, to remain "vertically integrated," producing many of their own subsystems including machined parts and even integrated circuit boards. Several private firms suggested that this was a more efficient approach than the "lead system integrator" model, but observations from larger firms raise doubts about this conclusion.

It seems more likely that vertical integration allows private firms to maximize marginal profits because they do not have to share profit margin with lower-tier suppliers.

The third trend is that firms are willing to make large capital investments despite significant fiscal pressures and uncertainty across the defense market. According to one major manufacturer, the impetus for capital investments in process innovation comes from the desire to drive down production costs and stay ahead of the competition.[68] Robots and other automation innovations replace costly human labor, producing large quantities of certain components at exceedingly high quality rates. This trend was most noticeable in composite materials manufacturing, as fiber placement machines now allow for mass production of large composite pieces with complex shapes.

The last process innovation trend, coupled with the capital investment trend, was the use of creative financing options to share the financial burden of product development and production tooling. Every production line observed had a unique ownership combination of land, facilities, and tooling. For example, one firm leased a building from the government, on government land, but owns the production tooling within the facility. In another, the firm owned the building and the land, but not the tooling. This is an example of a business innovation that becomes a process innovation because it allows firms to defray costs on a negotiable timeline according to its unique capitalization and cash flow requirements.

The majority of this paper has focused on the positive aspects of innovation, but not all innovations have entirely positive outcomes. The Boeing 787 and F-35 reflect process innovations that suffered from unintended consequences of pushing the development envelope. In the case of the 787, Boeing outsourced most of its production activity and attempted to manage an extremely complex program as a systems integrator. Several unanticipated problems arose during 787 development and early production, ranging from supplier quality and schedule issues to integration difficulties. These issues caused a program delay of several years beyond the anticipated fielding date and may have cost the firm some amount of market share. The F-35 has faced a host of similar issues. Nagging cost and schedule issues have been exacerbated by outsourcing and complexity, and the future of the program remains uncertain.

Boeing appears to have learned its lesson about overreach on the 787. Boeing will almost certainly maintain tighter control over its next development project to avoid outsourcing company risk along with design and production. Yet some of this decision is probably driven by the market's response to Boeing delivery delays and resulting loss of market share. Given the generational gaps between new defense starts, it is too early to tell how Lockheed Martin and its partners will respond to the challenges posed by F-35 development and early production efforts.

OBSERVATIONS, RECOMMENDATIONS, AND CONCLUSION

The seminar's study and analysis of three relevant subsectors of the aircraft industry allowed a broad enough data sample to answer the team's research question regarding innovation in an era of reduced government spending. The team noted several trends across the subsectors which, when considered with the subsector-unique recommendations described above, lead to several broad-based recommendations.

Observations

The research team learned a tremendous amount through independent and directed research, guest lecturers, and visits to a variety of government and industry sites. The following observations are the most salient across the three relevant subsectors.

1. The commercial aircraft sector is healthy and performing well. Significant aircraft order backlogs exist with increases in future orders forecast through 2035. The military aircraft sector is less healthy, with continued increases in unit costs, slowdowns in production rates, and rising tensions between the DoD and the industrial base.
2. Product innovations, especially disruptive innovations, require a combination of events in order to take root. Elements include:
    a. A tactical, operational, or strategic problem that must be solved.
    b. A relevant, ready technology that addresses the problem.
    c. An accommodating strategic context. This includes a "policy window" in which the bureaucracy is intellectually and emotionally prepared to accept an innovation. Organizations must also have the cultural capacity to adopt and adapt innovations for their use.

    This framework appears valid regardless of the innovation. Incremental, sustaining innovations have the same requirements, though they may be satisfied more easily than significantly disruptive innovations.
3. Businesses are predisposed to maximize profits through process innovations. Margins are improved whenever production is accomplished more efficiently; therefore, firms are incentivized to find efficiencies regardless of the fiscal environment.
4. There is a tremendous amount of industry uncertainty about the future strategic direction of the U.S. and the magnitude of defense spending reductions. This uncertainty translates into risk deferral by firms, with most IR&D funding directed toward projects with the highest probability of transition to production. These firms are doing their best to protect IR&D funds, but budget pressures will eventually erode the amount of IR&D money available.
5. Competition is changing across all subsectors of the military aircraft sector. The U.S. maintains a strategic and competitive advantage in fighter aircraft, but the qualitative and quantitative edges are eroding. The U.S. advantage in UAS is wider than in the fighter sector, but U.S. firms will likely face more competitors because of lower barriers to entry. European entrants are a serious threat to U.S. helicopter offerings, but the U.S. maintains an advantage in advanced rotorcraft vehicles like tiltrotors.

Policy Recommendations

The Aircraft Industry research seminar offers the following policy recommendations to enhance the potential to preserve U.S. strategic and competitive advantage. These recommendations are intended to encourage, assure, enhance, or develop the sources of innovation described in this paper. Conversely, they are also intended to mitigate, negate, and diminish barriers to innovation. Maintaining the traditional U.S. innovative edge enables more than just our military dominance; it also comprises a key element of our nation's economic growth.[69]

Government, industry, and academia must work together to maximize innovation in an era of reduced government spending.

1. Avoid reprogramming R&D funding to mitigate sequestration impacts. The government must sustain funding to research that advances technological superiority and keeps the U.S. ahead of the rest of the world. Such funding makes up only a small part of the budget, but is an essential investment in the future. It also provides life support to government agencies such as DARPA and NASA, the research arms of defense firms like Lockheed's Skunk Works, and research universities that partner with government and industry.
2. Formalize and update the currently ad hoc approach to industrial policy in an effort to provide stability and foster competition. Industrial consolidation has resulted in a de facto defense oligopoly, especially in the aircraft industry, and several factors combine to distort normal market behavior and limit competition. A limited industrial policy would aim to identify and orient elements of government, industry, and academia toward solving certain problems rather than supporting or subsidizing specific solutions.
3. Encourage risk taking and prototyping, even when they do not result in mature programs taken to production. Consider expanding partnerships with small, agile firms to leverage their innovative prototyping skills and elevated risk tolerance.
4. Manage capability development and procurement from a portfolio perspective at both the DoD and service levels. Most new development programs are typically designed to counter "worst-case" scenarios, yet the majority of the force is never stressed to that level. Investment in future capabilities should be balanced across disruptive and sustaining innovations, especially since predicting all the desired and undesired effects of a new product is nearly impossible.
5. Eliminate bureaucratic inefficiencies across DoD and the services, particularly in overhead areas in which no value is added by process duplication or redundancy. Identify specific warfighting mission areas where overlap will be maintained intentionally in an attempt to spur innovation through interservice rivalry.
6. Facilitate international competition by helping firms achieve greater access to emerging markets. Additionally, reform ITAR and other export control mechanisms to facilitate overseas sales while protecting intellectual property and crucial U.S. technologies.
7. Consider a national-level innovation effort (similar to the Defense Intelligence Agency's Project Socrates in the 1980s) to prioritize technology gaps across threatened military sectors. This currently occurs in an ad hoc manner, but funding constraints should force the government to prioritize the pursuit of some technologies over others. This is only possible with a stable, portfolio-based acquisition strategy and an industrial policy of some form.
8. Develop a coordinated nationwide STEM program.[70] All of the major military aircraft firms are losing experienced personnel to retirement and view U.S. STEM weakness as a threat to hiring, empowering, and retaining innovation enablers.

Despite the best efforts of the national system of innovation, there is no guarantee that R&D investment will yield sustaining or disruptive innovation. The best the system can do is foster the conditions deemed most favorable for innovation to occur. Apparently, today's fiscal environment is more conducive to sustaining innovations than disruptive innovations. However, the qualities that make disruptive or breakthrough innovations "disruptive" or "breakthrough" is that their introduction was at least somewhat unexpected by either users, competitors, or adversaries. The policy recommendations offered here are intended to maximize the potential for meaningful sustaining and disruptive innovations. These innovations have been, and will remain, a key source of American competitive and comparative strategic advantage.

Appendix: Issue Paper

Joint Acquisition Programs: Sources of, or Barriers to, Innovation?

As the research seminar deliberated over observations and recommendations for this paper, one topic proved elusive to consensus. When viewed through an innovation lens, should future acquisition programs be joint or even coalition efforts like the F-35? Or should the joint model be shelved in favor of service-specific programs? Since the seminar was divided on this issue (not evenly), and joint programs like FVL figure so prominently in today's acquisition environment, this issue paper is warranted to outline the most pertinent elements of each side of the argument. Regardless of which point of view prevails across DoD, policy makers must be aware of how acquisition decisions impact the collaborative network of government, industry, and academia that produce innovative solutions for the nation.

Some argue that joint programs create the most conducive environment for innovations, especially the disruptive type. In an era of reduced government spending, joint programs allow the services and DoD to pool limited resources and minimize the distractions posed by competing programs. Focusing the efforts of the collaborative network and minimizing funding perturbations should create a favorable environment for product innovation. Additionally, joint programs should help overcome organizational barriers like parochialism and turf protection to produce truly integrated joint capabilities. Designing joint solutions from the outset reduces the need for costly bridging capabilities required to enable joint interoperability. In short, more effective coordination across DoD would reduce redundancy across the services and mission areas, and lead to more innovative materiel solutions. Joint programs should also lead to cost savings, provided requirements and funding are stabilized to the maximum extent possible.

The opposing viewpoint argues that joint programs are barriers to innovation, primarily because they attempt to satisfy the divergent needs of various customers. The compromises required to satisfy each partner constituency result in a product that only partially satisfies some, and completely satisfies none. In the case of the F-35, for example, the A-model suffers performance loss to accommodate B-Model Short Take-Off, Vertical Landing (STOVL) requirements. The B-model's STOVL performance is hampered likewise by design attributes required to meet A-model specifications. Additionally, joint programs do not capitalize on interservice rivalry that can fuel innovation through a competition of ideas and a quest for service primacy. Finally, from a warfighting perspective, joint programs allow potential adversaries to focus on a more limited number of U.S. systems, thus simplifying their development of materiel and non-materiel counter moves.

Over the course of the semester, the seminar struggled to find an historical or current example of a successful platform-level joint program. The F-111 failed as a joint program but became a successful platform once absorbed exclusively by the Air Force. The Navy's F-4 program became joint after the Air Force decided to purchase the aircraft, but it was not designed that way. It is too early to declare the F-35 a success or a failure, though the seminar's consensus opinion was there are far more lessons that fall into the "avoid next time" rather than the "repeat next time" category. FVL is intended to be a joint endeavor, but "how joint?" is unanswerable at this point in time.

The seminar did find, however, many examples of successful joint programs below the platform level. These examples fall into two broad categories. First, joint R&D programs, such as those managed by DARPA, often demonstrate remarkable collaboration between the services. Second, lower complexity or commoditized acquisition programs (such as the Joint Direct Attack Munition, or JDAM), can be successful. The seminar concluded that there is at least anecdotal correlation between program intent and complexity, and success.

This finding warrants some degree of skepticism, and further study. It may be true that complex, joint programs are more apt to fail than small, exploratory programs or efforts to produce relatively simple products. In order to support this conclusion, joint programs must also be compared to single-service programs. What, then, are examples of successful complex, platform-level, service-specific programs? The answer to this question caused as much pause within the seminar as the original joint question. The F-22 program arguably collapsed in part under the weight of the complexity associated with pushing the boundaries of innovation. Some argue that the F/A-18E/F is one such example, but the extent of new innovation (and therefore complexity) in that platform versus earlier F/A-18 variants is certainly open to debate. While correlation may exist, it is impossible to rule out the possibility that all complex programs incur massive risk under today's acquisition system, regardless of who manages them, and how.

The arguments on both sides of this issue are compelling. Much like the discussion of which innovations are disruptive versus sustaining, though, individual differences in this debate often result from differences of perspective. The "right" answer probably lies somewhere between "always" and "never" conducting joint acquisition programs. As lessons learned from the F-35 and other joint programs are captured and (hopefully) applied to future systems, the seminar urges decision makers to view joint acquisition decisions through an innovation lens as well. The quality of the products developed for the warfighter, especially in the military aircraft sector, is closely correlated to the quality of the process used to acquire them. Applying the right degree of "jointness" in the process should lead to the right kind of capability for the warfighter.

Notes

[1] Patrice Flichy, *Understanding Technological Innovation: A Socio-Technical Approach* (Cheltenham, UK and Northampton, MA: Edward Elgar Publishing Ltd., 2007), 5.

[2] Chris Freeman, "National Systems of Innovation," *Cambridge Journal of Economics 19*, no. 1 (1995): 5-24.

[3] Clayton M. Christensen, *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail* (Boston: Harvard Business School Press, 1997), xiv. As described by Clayton Christensen, sustaining innovation can be broken down further into incremental, radical, and discontinuous forms. The F-16 is one of the best examples of sustained incremental innovation in the aviation industry given its relatively long lifecycle and continuous improvements to structures, flight systems, and communications. Similarly, UASs are an example of sustained discontinuous innovation because they "alter existing patterns of use and create new patterns of use." (Rajesh Chandy and Jaideep Prabhu. "Innovation Typologies," London, 2009. http://faculty.london.edu/rchandy/innovation%20typologies.pdf) Composite material usage on the Boeing 787 is a radical innovation because it "employ[s] substantially new technology and offer[s] substantially higher customer or user benefits." The integration of composites in the 787 is radical relative to existing metal airframes by delivering marked improvement in fuel efficiency. The end result, however, is still an aircraft that remains comparable to other aircraft in its class.

[4] Ashley Braganza, Yukika Awazu, and Kevin C Desouza, "Sustaining Innovation is Challenge for Incumbents," *Research Technology Management* 52, No. 4 (July-August 2009): 46.

[5] Judith Reppy, ed., *The Place of the Defense Industry in National Systems of Innovation* (Ithaca, NY: Cornell University, April 2000), 1.

[6] Ibid., 3-7.

[7] Wendy Schacht, Industrial Competitiveness and Technological Advancement: Debate Over Government Policy (Washington DC: Congressional Research Service, 2011), 1. Available from http://www.fas.org/sgp/crs/misc/RL33528.pdf.

[8] William A Chadwick et al, *Aerospace Industry Report 2011: Facts, Figures & Outlook for the Aviation and Aerospace Manufacturing Industr*y (Arlington, VA and Daytona Beach, FL: Aerospace Industries Association of America, Inc. and Center for Aviation & Aerospace Leadership, Embry-Riddle Aeronautical University), 140.

[9] Fairmont Consulting Group, Industry R&D Spending: "How Much is Enough? You're Asking the Wrong Question," February 2013, slide 11. Request via www.FairmontCG.com.

[10] Schacht, 1.
[11] Ibid, page 5.

[12] Ibid, page 2, 6, 7 &8.

[13] Mark A. Lorell and Hugh P. Levaux, *The Cutting Edge: A Half Century of Fighter Aircraft R&D* (Washington DC: RAND Corporation, 1998), 156.

[14] Ibid, page 161.

[15] Fairmont Consulting Group, slide 3 and 22.

[16] Chadwick et al, 139-142.

[17] Fairmont Consulting Group, slide 9.

[18] Penn State University, Office of the Vice President for Research at Penn State, "Pratt and Whitney Establishes Center of Excellence," July 1, 2008. Available from http://www.research.psu.edu/industry/11-29-12-archive-information-for-industry/theiron/summer-2008/pratt-whitney, accessed 13 May 2013.

[19] Ibid.

[20] Northrup Grumman Corporation, "Northrup Grumman Innovation Network." Available from http://www.northropgrumman.com/AboutUs/InnovationNetwork/Pages/default.aspx, accessed 13 May 2013.

[21] Ibid.

[22]Steven Browns and Scott Gebicke, "From R&D Investment Power to Fighting Power, 25 Years Later," *McKinsey on Government*, No. 5 (Spring 2010): 72.

[23] Richard Aboulafia, *World Aircraft Overview* (Fairfax, VA: The TEAL Group Corporation, Jan 2013), 2.

[24] Ibid. Commercial aircraft manufactures are predicted to deliver new deliveries worth $160-200 million per year and a total industry value, including after-market support, of $500-600 million (figure 2). The TEAL group predicts production of 51,604 turbine aircraft between 2012 and 2022 valued at $1.797 trillion with the military market accounting for $435 billion.

[25] Christopher Niemi, "The F-22 Acquisition Program, Consequences for the U.S. Air Force's Fighter Fleet," *Air and Space Power Journal* (November/December, 2012), 53.

[26] Ibid. and Mackenzie Eaglen, "The State of the U.S. Military." Jan 27, 2010, http://www.heritage.org/research/reports/2010/01/the-state-of-the-us-military, U.S. Navy and Marine Corps tactical aircraft average approximately five years newer than those in the Air Force thanks to continued purchase of the F-18E/F/G Super Hornet. These services are in a better position to deal with slips in the delivery schedule or the reduction of planned purchase numbers of the F-35 and will eventually have a better portfolio of capabilities to deal with an array of missions and threats. There is a need to recapitalize the U.S. fighter fleet and the complexity, delivery schedule, and price of fifth generation fighters is a challenge.

[27] Commandant's Lecture Series, Not for Attribution, Eisenhower School, National Defense University, Washington DC, May 7, 2013 and Andrea Shala-Esa, "Boeing Aims to Keep Building F/A-18 Jets Through 2020," May 10, 2013. www.aviatiationweek.com/Article/aspx?id=/article-xml/awx_05_10_2013_p0-577802.xml (accessed May 14, 2013) and Al Arabiya with Agencies, "Washington to Sell F-15 Fighter Jets to Saudi Arabia; Deal to Boost U.S. Economy," *Al Arabiya News* (December 29, 2011), www.alarabiya.net/articles/2011/12/29/185254.html (accessed May 12, 2013).

[28] Graham Warwick, "Decadal Decisions," *Aviation Week and Space Technology* (December 31, 2012/January 7, 2013), 71. Congressional Budget Office, *Alternatives for Modernizing U.S. Fighter Forces* (Washington DC: Congressional Budget Office, 2009), ix. 2020 is significant because the Boeing F-18 E/F Super Hornet and F-15 production lines will end and DoD is planning on completing major developments to the F-35 and finishing F-35B Initial Operating Capability by then. Additionally the true capabilities of the Russian and Chinese advertised 5th generation fighters will be clearer, giving more insight into their viability as battlefield threats and as export threats. 2015 is the beginning of the so-called "fighter gap" when inventories are predicted to fall below required numbers. 2030, the end of this paper's time horizon, is significant because all United States Air Force (USAF) Active Duty legacy aircraft are expected to be retired and the USAF will begin to field the 6th generation fighter replacement to the F-22. Another option instead of a new 6th generation fighter would be incremental innovations to 5th generation platforms or a new 5th generation fighter. This would be especially relevant if China and Russia's 5th generation fighters are delayed or prove to be unsuccessful. Additionally, 2019 is the predicted operational date of the Chinese J-20 5th generation fighter.

[29] Norman R. Augustine, *Augustine's Laws: And Major System Development Programs* (New York: American Institute of Aeronautics and Astronautics, Inc., 1982), 47.

[30] Ibid., 48.

[31] One important point is that even if innovative aircraft programs intend to break this trend, sometimes they do not. The F-35 is a good example, intending to cost $78 million per aircraft, now estimated to be $161 million per aircraft. Many predict this price to increase as well. Part of the cost increase is directly attributable to increased system complexity. According to the USAF Chief Scientist, 90 percent of F-35 development content is software-related, as opposed to only 5 percent for the F-4. The U.S. has been very ambitious with technology that drives aircraft to the far-upper right side of the cost-performance curve. The result has been significantly reduced purchases of the B-2, F-22, and most likely the F-35. This paper recommends the USAF target best value, the bend in the cost-performance curve, in certain programs. After discussions with the Next Generation Air Dominance Study lead, it appears the 6th generation fighter may follow the same path.

[32] Commandant's Lecture Series, Not for Attribution, Eisenhower School, National Defense University, Washington DC, March 18, 2013.

[33] Ibid.

[34] *F-16.net*, "USAF F-16 Purchases," http://www.f-16.net/f-16_users_article23.html (accessed March 2, 2013).

[35] Augustine, 53.

[36] Paul Bracken et al., "The Changing Landscape of Defense Innovation," *Defense Horizons* (July 2005): 1.

[37] Aboulafia, "Fighter/Attack Aircraft," 4; Sorin Lungu, interview by authors, Washington DC, March 28, 2013.

[38] Not for attribution panel, Eisenhower School, National Defense University, Washington DC, February 6, 2013. Not for attribution industry visit, Eisenhower School, National Defense University, Washington DC, April 11, 2013.

[39] *AFA Daily Report*, "Reaper Gets Decoy," e-mail to author, February 14, 2013.

[40] Aircraft industry panel, Not for attribution, Poway, California, April 11, 2013.

[41] Commandant's Lecture Series, Not for Attribution, Eisenhower School, National Defense University, Washington DC, March 27, 2013.

[42] John Birkler et al., *Competition and Innovation in the U.S. Fixed Wing Military Aircraft Industry* (Washington DC: Rand Corporation, 2003): 12.

[43] Commandant's Lecture Series, Not for Attribution, Eisenhower School, National Defense University, Washington DC, March 18, 2013.

[44] Ibid., As recently noted by a former aircraft program manager, the F-16 started with moderate performance but evolved into a tremendous asset. Not only has the F-16 performed admirably in combat, but the U.S. procured it in large numbers. Additionally, it has proven to be the most significant export fighter in U.S. history. The U.S. has sold the F-16 to twenty-five nations, which has helped develop long-term relationships and establish global U.S. influence.

[45] Commandant's Lecture Series, Not for Attribution, Eisenhower School, National Defense University, Washington DC, February 18, 2013.

[46] Air Force Manufacturing Technology Division, *U.S. Air Force Next Generation TACAIR (F-X) Industrial Base Quick Look* (Wright Patterson Air Force Base, Air Force Research Laboratory, June 1, 2011), 17 and Birkler et al, *Competition and Innovation*, xix, 23, 26. Additionally, the U.S. can use these programs as part of a cost

imposition strategy on competitors such as Russia and China. Cost imposition strategies in the global fighter market are an area for future study.

[47]Terry Milewski, "Boeing touts fighter jet rival to F-35-at half the price,"*CBCNews Online*, February 28, 2013 http://www.cbc.ca/news/politics/story/2013/02/27/pol-fighter-jets-boeing-superhornet-f-35-milewski.html (accessed March 12, 2013). The current Super Hornet unit cost is $55 million with average USN operating costs $15,000 per flying hour, compared with F-35 operating costs of almost $33,000 per flying hour.

[48] Commandant's Lecture Series, Not for Attribution, Eisenhower School, National Defense University, Washington DC, March 18, 2013.

[49] Not for attribution industry visit, Eisenhower School, National Defense University, Washington DC, April 11, 2013.

[50] "U.S. Military Unmanned Aerial Vehicles (UAV) Market Forecast 2013-2018," *Market Research Media Homepage*, http://www.marketresearchmedia.com/?p=509 (accessed March 28, 2012).

[51] Jeremiah Gertler, *U.S. Unmanned Aerial Systems*, (Washington DC: Congressional Research Service, January 3, 2012) 31-49.

[52] According to the U.S. Navy's Naval Air Systems Command, the UCLASS program is designed to fill the "need for an aircraft carrier based aircraft system providing persistent Intelligence, Surveillance, and Reconnaissance (ISR) and strike capabilities that will enhance the versatility provided by an aircraft carrier." This program was the natural follow on to the Navy-funded Northrop-Grumman X-47B designed "to demonstrate the first carrier-based launches and recoveries by an autonomous, low-observable-relevant unmanned aircraft."

[53] Northrop-Grumman will be competing a design based on the X-47B, while Boeing will likely compete its Phantom Ray derived from the canceled Air Force X-45. Additionally, General Atomics, the maker of the Predator and Reaper, is taking its existing design to the next step with the jet-powered Predator-C, know as the Avenger. Finally, Lockheed will compete a version of its stealthy RQ-170 ISR drone.

[54] High-risk missions, such as the use of the Air Force's Lightning Bug drone to measure the terminal guidance frequency of the SA-2 surface-to-air missile (SAM) in Vietnam, make a convincing case for the benefits of unmanned systems. (Thomas Paul Ehrhard, *Unmanned Aerial Vehicles in the United States Armed Services: A Comparative Study of Weapons System Innovation*, Doctoral dissertation submitted to Johns Hopkins University (Washington DC, 2000) 413.)

[55] Gertler, *U.S. Unmanned Aerial Systems*, 35 and "Integrated Sensor Is Structure (ISIS)," *Lockheed-Martin Homepage*, http://www.lockheedmartin.com/us/products/isis.html (accessed April 14, 2013).

[56] Gertler, 35, 39.

[57] "X-47B Unmanned Combat Air System Carrier (UCAS), United States of America," *Naval-Technology.com*, http://www.naval-technology.com/projects/x-47b-unmanned-combat-air-system-carrier-ucas (accessed April 16, 2013). The $813 million price tag for two X-47Bs is the harbinger of the cost growth to come and as the price tag for these systems increase they get less disposable, even if not risking human life.

[58] Mitch Burnside Clapp et al., "DARPA Robotics-Unmanned Systems Overview," briefing slides, Eisenhower School Robotics Industry, February 11, 2013.

[59] "High Speed Anti-Radiation Missile Targeting System," *U.S. Air Force Factsheet*, http://www.af.mil/information/factsheets/factsheet.asp?id=10330 (accessed April 16, 2013).

[60] Andrew Drwiega, "U.S. Army Aviation FY12 Budget Expectations," *Military Technology* 35, no. 10 (2011): 30.

[61] "Military Rotorcraft: Strongest Aero Market." *Aerospace America,* September 2011, 18.

[62] Mike Hirschberg, "The Crisis in US Army Aviation" *VERTIFLITE,* January/February 2012, 7.

[63] Margaret C. Roth, "Building a Better Rotorcraft," *Army AL&T* (2012): 152. Composed of manufacturers, members of academia, suppliers, and others involved in the vertical lift industry, the VLC is designed to facilitate a more competitive and open system that allows smaller industry players to participate in developing technological solutions for FVL.

[64] Julien Demotes-Mainard, "RAH-66 Comanche-the Self-Inflicted Termination: Exploring the Dynamics of Change in Weapons Procurement," *Defense AR Journal* 19, no. 2 (2012), 186.

[65] Dave Majumdar, "Industry Officials Divided over US Army Future Vertical Lift Requirements." *Flight International*, no. 753 (2013): 23.

[66] Graham Warwick, "Vertical Values," *Aviation Week & Space Technology* 175, no. 11 (2013): 42

[67] Valerie Insinna, "Future Vertical Lift Takes Step Forward," *National Defense* 97, no. 713 (2013): 24-26.

[68] Source not for attribution, 2013.

[69] Since the end of the Second World War, our competitive advantage has relied on developing disruptive technologies ahead of the rest of the world. These technologies have either had a solely military function, such as stealth, or have found great civilian use as well, such as GPS, the Internet, and microwave ovens, which also significantly contribute to our economic growth. Indeed, the United States has long held the goal of staying fifteen years ahead of the rest of the world in terms of state-of-the-art technology and research in aeronautics. But the rest of the world is catching up quickly. Sounding the alarm in 2002, the final report of the Commission on the Future of the United States Aerospace Industry cautioned: "the critical underpinnings of this nation's aerospace industry are showing signs of faltering."

[70] According to several companies we visited, the essential ingredient in their ability to perform cutting-edge innovation is a talented, skilled workforce. Without sufficient government business and resources dedicated to the aerospace sector, it is hard to retain and attract good people. "When you lose the people, you lose the ability," remarked a senior vice president at one firm. Already, the government, industry, and academia share both formal and informal mutual assistance in supporting advanced innovation. Many companies partner with research institutions and universities on a proprietary basis not just to develop technologies, but also people with the right skills to assist them in the future. But the constant pressure to reduce technical innovation costs through reductions in personnel, cheaper sources of labor from outsourcing or more efficient means of production, and fewer students graduating with the STEM (Science, Technology, Engineering, and Mathematics) skills needed by the industry have all negatively impacted the industry's workforce.