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DISRUPTIVE DEFENSE PAPERS

Process Over Platforms

A Paradigm Shift in Acquisition Through Advanced Manufacturing

By Aaron Martin and Ben FitzGerald

Center for a New American Security

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Cover Image
A X-47B UCAS sits in a Proof Test Fixture.

(Photo courtesy of Northrop Grumman Corporation)

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I. INTRODUCTION

By Aaron Martin and Ben FitzGerald

Every year the U.S. Department of Defense (DOD) spends billions of dollars to develop and acquire weapons systems that ensure America's armed forces remain the best-equipped in the world. The system for doing this is outdated, expensive, inflexible and slow. However, a number of emerging technologies mean that the DOD does not have to be bound by this paradigm. This paper envisions a future for unmanned aircraft systems (UAS) in which development cycles are short, production schedules are accelerated and both overall and unit costs are reduced to create an environment in which forces can surge rapidly to meet operational needs.

Current acquisition efforts involve diligent, well-intentioned actions to ensure that capable products arrive on schedule and at planned costs. Despite expectations, however, those objectives are rarely met in their entirety due to demanding (and often changing) requirements, desire to develop and field immature technologies, system complexity and demanding testing regimes.

Few observers would defend the current system as cost-efficient or timely. Of the 16 major studies on acquisition reform since 1986, most "arrived at most of the same findings and made similar recommendations."[1] These studies often highlighted the continual growth in both costs and time of new acquisition programs, and although the DOD and its industry partners have worked hard to address these challenges, they persist to this day.

The rapid pace of technological change compounds the challenges inherent in developing military capability. Internationally, the barriers to entry are being lowered for access to advanced military capability and technology that has military utility.[2] This applies equally to U.S. competitors, which are acquiring capability that a few years ago was available to only a handful of nations, and to violent non-state actors, which are acquiring a range of advanced capabilities including UAS, submersibles and information technologies.

The current and future technological environment, combined with an increasingly constrained fiscal environment, is therefore ushering in an era in which the way military capability is developed may be more important than which specific capabilities are developed.

Responding to this trend, Admiral Jonathan Greenert, Chief of Naval Operations, argues the value of "payloads over platforms."[3] He observes that while platforms (ships and aircraft) take a long time to develop and field, all while accruing high and rising costs, they cannot easily adapt to uncertain and changing security environments during their long service lives. Given the high costs of replacing platforms as new needs arise, he argues, the military acquisition system should begin to emphasize payloads, which can adapt technologies quickly and can be developed and fielded at a faster pace than platforms.

Admiral Greenert makes a valid case, but what if the process used for platform design, production and fielding could capitalize on the same dynamic refresh that applies to payloads?

Discussions about acquisition tend to fall primarily into three categories: the stratospheric – acquisition reform and the future of the defense industrial base; the tactical – how 3D printing might support deployed war fighters; and the technical – research in basic science and materials.

The concept presented here explores an end-to-end consideration of a particular capability segment, combat aircraft. This particular capability is well-suited to the concept based on technical complexity, associated high system and training costs and their associated processes. Additionally, the current strategic decision to invest in smaller numbers of technologically superior aircraft may not hold valid in future scenarios where advanced enemies could field sophisticated UAS swarms or large numbers of manned aircraft.[4]

Paradigmatic shifts can only occur when concepts and technology align in time to address relevant challenges.[5] To that end, this paper considers current challenges and emerging technologies, linked to operational capabilities that can enable a fast, flexible and efficient acquisition process as well as the operational advantages of a new approach.

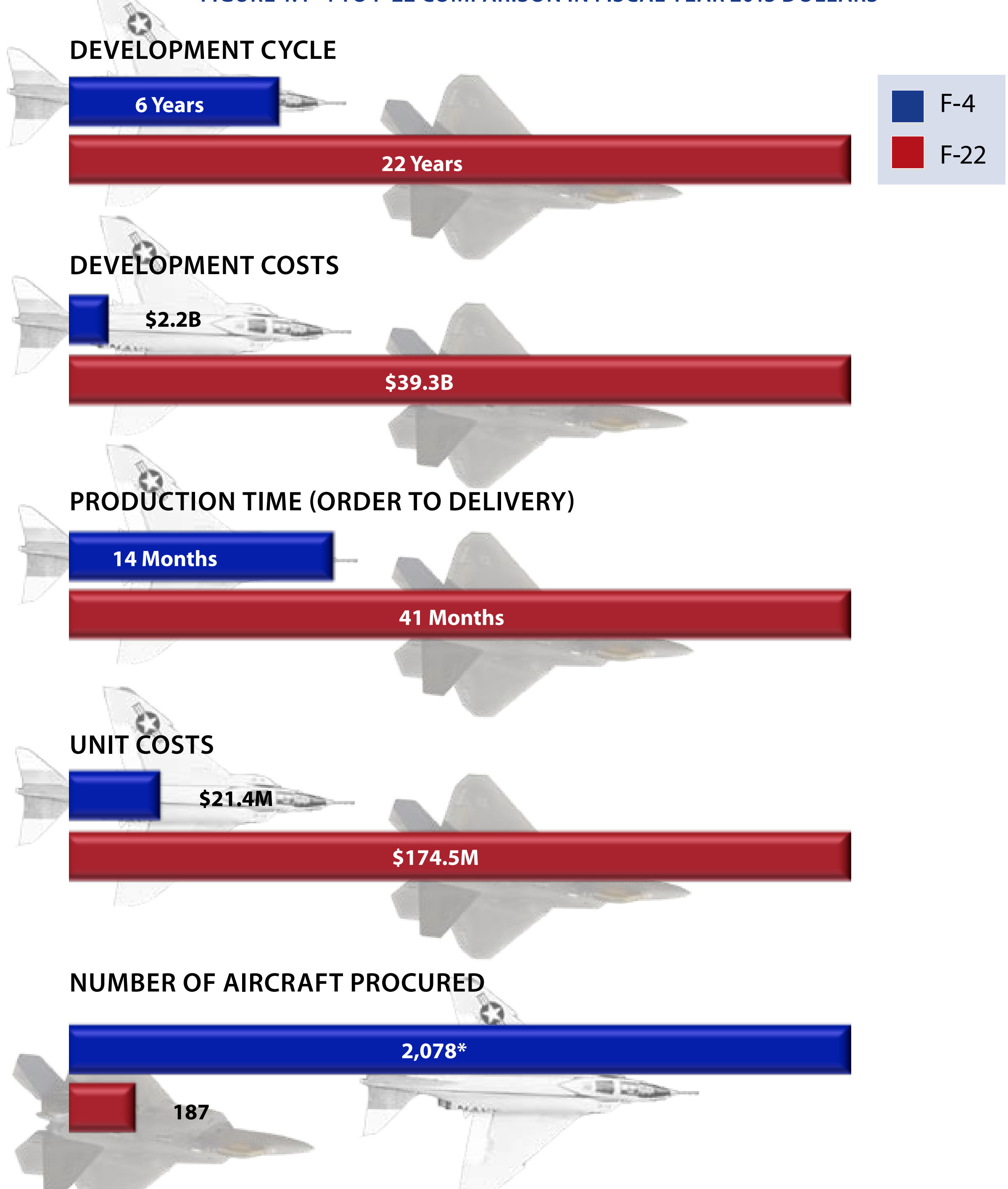
Increasing Costs of Maintaining Military Superiority

A comparison of the DOD's most recently completed air superiority fighter acquisition program, for the F-22 Raptor, to that of the F-4 Phantom II, a fighter developed and acquired in the 1950s and 1960s, summarizes the growing costs and timelines associated with combat aircraft acquisition.

Development times and costs for these two aircraft systems varied significantly.[6] It took three times longer to develop the F-22 than the F-4. Formal development of the F-4 began when the Navy awarded McDonnell Aircraft a development contract in 1955, and a limited production contract followed in 1958. The Navy equipped its first F-4 squadron, VF-74, in 1961, just six years into formal development of the program.[7] The Air Force recognized the need for a new air superiority fighter in 1983 and awarded demonstration and validation contracts in 1986 for the Advanced Tactical Fighter (later F-22) program to Lockheed and Northrop. The Air Force subsequently awarded a low-rate production contract to Lockheed Martin in 2001, and the F-22 reached initial operating capacity (IOC) in 2005, 22 years after development began.[8]

The increasing time required to develop and field aircraft systems has important operational and strategic implications. It raises the likelihood that new technologies will emerge and potentially lead to changes in requirements. A DOD presentation noted that computers at IOC for the F-22 were 512 times faster and held 65,000 times more information than they did early in development.[9] Further, geopolitical changes during development can

FIGURE 1: F-4 TO F-22 COMPARISON IN FISCAL YEAR 2013 DOLLARS



Sources: F-4 production reported in the figure includes only those procured by the U.S. Air Force. Total F-4 production including the U.S. Navy, Marine Corps and allies was 5,195. Estimates in charts derived using René J Francillon, McDonnell Douglas Aircraft since 1920: Volume II (Annapolis, MD: Naval Institute Press,1979), George C. Sponsler, et al. The F-4 and the F-14 (Gaithersburg, MD:Columbia Research Corporation, 1973), Torsten Anft, "VF-74 Be-Devilers," July 1, 2013, http://www.anft.net/f-14/f14-squadron-vf074.htm, Knaack, Encyclopedia of US Air Force Aircraft and Missile Systems: Volume 1, U.S. Department of Defense, Selected Acquisition Report: F-22, RCS:DD-A&T(Q&A)823-265 (December 31, 2010), http://www.dod.mil/pubs/foi/logistics_material_readiness/acq_bud_fin/SARs/DEC%202010%20SAR/F-22%20-%20SAR%20-%2025%20DEC%202010.pdf, Federal Procurement Data System, U.S. Air Force, "Air Force Accepts Final F-22 Raptor," May 7,2012, .http://www.jber.af.mil/news/story.asp?id=123301143, and FY2011 U.S. Air Force Budget Submission.

reshape operational requirements and decrease the overall utility of a weapon system. For example, the F-22 was designed to operate in the fairly constrained region of the central front in Europe, but the shift in focus to the Asia-Pacific region now places a greater premium on range. Longer development times also provide opponents more opportunities to react to system development by countering the system or through espionage. For all these reasons, DOD leaders recently indicated that they are very concerned about lengthening development cycles, and they announced that reducing development cycles is one of their priorities in the Better Buying Power initiatives.[10]

Development of the F-22 cost the DOD about $39 billion, nearly 20 times more than estimated F-4 development costs of about $2.2 billion.[11] For some context, the Congressional Research Service estimated that the Manhattan Project to develop the atomic bomb cost the equivalent of about $24 billion from 1942 to 1946.[12] When development costs for a single weapon system require such a large national investment, the number of new aircraft programs that the Air Force and Navy can pursue is severely limited. In the past 20 years, the services have pursued relatively few new development programs. This has not always been the case; from 1945 to 1960, the U.S. military initiated 88 development programs, about six per year.[13]

After the transition to production, the time to build new systems also continues to grow, nearly tripling from the F-4 to the F-22. The delivery time for the Air Force's first F-4 was about 14 months.[14] In comparison, the contract for the final F-22s was signed in November 2008 with delivery in May 2012, three and a half years after order.[15] While delivery times could be improved in extreme circumstances, the long times required to build highly complex modern combat aircraft mean that the DOD could not field large numbers of highly capable aircraft quickly in a crisis.

Procurement cost growth continues to accelerate, as well. The procurement cost of F-22s in the FY2009 budget was about $174.5 million per aircraft, while the procurement cost of each F-4E was about $21.4 million.[16] With such significant cost growth, the Air Force spent less to develop and build a fleet of more than 2,000 F-4s than it did for a final fleet of 187 F-22s.

While there is really no comparison in terms of aircraft quality between the F-22 and F-4, numbers do matter. The small F-22 fleet size increases the inherent value of each system. In some operational contexts, the loss of even one aircraft in combat could turn into a public relations or strategic victory for an adversary even if the enemy cannot match U.S. forces tactically. Getting out of this seemingly inexorable cost and schedule death spiral is vital to the United States' ability to maintain deterrence and field an effective war-fighting capability.

II. MANUFACTURING FUTURE SYSTEMS

This paper explores an entirely new approach to the development and acquisition of future combat aircraft. The concept envisions much shorter development cycles, accelerated production schedules, reduced costs and more flexible force structures that can be expanded rapidly to meet operational requirements. This approach focuses on integrating several emerging technologies, beginning with advanced manufacturing methods and robotic assembly to produce combat UAS.[17]

Historically, advances in manufacturing techniques have provided new ways to improve military capability. In the 1800s, the application of replaceable parts, as envisioned by Eli Whitney and Samuel Colt, greatly improved the production of firearms; during World War II, the application of Henry Ford's assembly line allowed the U.S. military to mass produce weapon systems; and the integration of automated manufacturing processes beginning in the 1950s allowed the military to develop significantly more complex systems that ensured technological superiority throughout the Cold War.

Additive Manufacturing

The concept begins with the application of additive manufacturing (AM) to facilitate flexible production and optimization of system components. Exciting new technologies often make great news headlines, and AM is not an exception. In the past few years, periodicals from *The Economist* to *Foreign Affairs* included articles about the coming additive manufacturing revolution.[18] President Barack Obama has called for significant federal investment in AM and other advanced manufacturing technologies with the establishment of 15 innovative manufacturing hubs, and signs point to AM generating a major impact on the U.S. and global manufacturing base.[19]

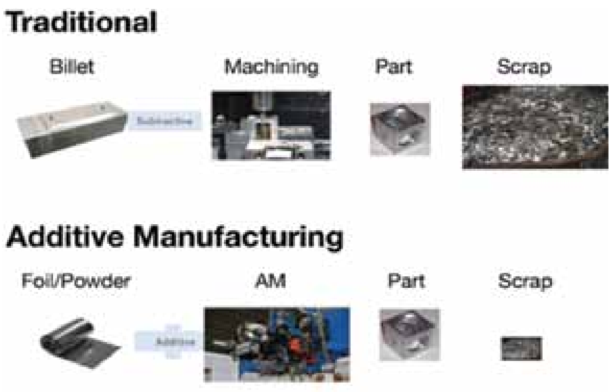
The rubric of additive manufacturing encompasses a number of different manufacturing technologies that share a few common attributes. The processes each fabricate components by adding materials layer by layer from digital data, such as computer-aided design (CAD) models. This differs significantly from traditional methods of making parts and structures, which typically focus on removing material through machining, as shown in Figure 2. AM technologies emerged in the 1980s; at that time the processes focused on plastic parts and were used primarily for prototyping.

AM processes offer the defense industry several important advantages over traditional manufacturing.

- **Part consolidation.** Using AM technologies, many parts that traditionally required assembly of subcomponents can be built as a single component.
- **Topology optimization.** AM offers a new opportunity to reconsider the features of a given component. Software allows engineers to reduce the amount of materials used to build a component while also offering opportunities to select and vary material properties throughout a part.
- **Tooling reduction.** AM processes permit rapid and flexible fabrication of parts from a common production machine that could allow for significant reduction of tooling to build and assemble parts.

Recently the numbers of materials and material properties of AM products have dramatically expanded, and many of the processes are now capable of making production parts. Many U.S. aerospace contractors already employ AM to fabricate prototypes; manufacturing tools and many aircraft already have a number of polymer components, such as the aircraft duct in Figure 3. An aircraft duct highlights the ability to consolidate parts through AM, as ducts built using traditional processes require multiple parts that are fastened together.

FIGURE 2: MANUFACTURING PROCESSES



Graphic courtesy of Fabrisonic LLC, http://www.fabrisonic.com/

AM processes are improving to the extent that metal parts can be produced. The X-47B unmanned carrier-based aircraft includes a titanium warm air mixer built using AM processes. Based on the types of parts produced, manufacturing teams have realized up to 50 percent cost reductions and significant reductions in fabrication times when using AM.

While significant efficiencies for part or tooling fabrication have already been achieved, a broader application of AM could dramatically change the production of defense weapon systems. Such a change would leverage the advantages of AM in the system design phase while broadening the application of AM to produce monolithic structures as well as aircraft subassembly and components. Currently, aircraft structures are produced using multiple materials and processes, which are very time-consuming to fabricate using highly skilled workers. The construction of monolithic aircraft structures using AM would allow new designs with integrated skins, structure and subsystems, leading to reduced costs and lead time for aircraft construction.

Further, since CAD drives AM, the development process would benefit from the ability to prototype and change part design rapidly. Transitions from development to production would not require significant investment in tooling for a new production line and thus would go more smoothly. The broader application of AM would introduce other changes in military aircraft production, as well:

- Software-driven production, reducing touch labor
- Reduction or elimination of whole subassemblies, tooling and engineering drawings
- Design features to allow rapid assembly of whole systems
- Improved sustainment, printing replacement parts at forward locations, reducing bulk shipping for logistics

Automated Assembly

The broader application of integrated robotic assembly can enable fast and flexible production of military aircraft systems. While neither new nor unique to aircraft manufacturing, the integration of robotic assembly with automated production processes would be a significant innovation that could provide a more efficient software-driven assembly process.

A survey of the literature on robotics in manufacturing highlights industries that use robotic assembly along with the application across the world. The automotive and electronics industries apply robotics to a greater degree than most other industries. Manufacturing application of robotics also varies widely by country. Manufacturers in Korea and Japan are the largest users of robots; there, manufacturing industries apply nearly 350 multipurpose industrial robots per 10,000 manufacturing employees. U.S. manufacturers are seventh in the world and are well above the average.[20]

In recent years, the automotive industry has achieved significant breakthroughs in rapid, flexible assembly through robotic processes. Japanese automotive firms have nearly one robot installed

An airduct duct (top) vs. an X-47B warm air mixer (bottom).

(Photos courtesy of Northrop Grumman Corporation)

for every five workers, "allowing some companies in Japan to operate 'lights out' factories, where robots perform manufacturing around the clock."[21] Furthermore, the industry's investment in robotics has provided a means of building multiple classes of vehicles on the same manufacturing line. As early as 2008, Honda was able to transition between Civic and CR-V models in about five minutes at its plant in East Liberty, Ohio.[22]

The military aircraft industry applies robotics to build modern military systems, but not to the same extent as automotive manufacturers. The large investments required for automation mixed with the low production quantities demanded for advanced military aircraft restrain greater investment in automated assembly.

Investment in the integration of AM with robotic assembly would create a future for aircraft production that is both fast and flexible. The goal would be to go from order to delivery of aircraft within days and weeks instead of several years. Robotics would also provide a cost-efficient way to develop a latent capacity to expand production rates if needed. Additionally, integration of these technologies could provide an opportunity to produce multiple types and potentially multiple classes of aircraft using the same manufacturing line.

III. LINKING ACQUISITION AND OPERATIONS – WHAT TO BUILD

Innovative use of emerging manufacturing technologies, whose integration would enable fast and flexible production, has wide application and benefit across many DOD capabilities. Perhaps the highest impact utilization of these technologies for military aircraft systems would be in the production of unmanned systems, which would present military planners new opportunities in terms of systems, force structure and surge capacity.

Most importantly, faster production of military aircraft would allow the U.S. military to field new systems as replacements for current aircraft more quickly or to expand force structure rapidly. Most major conflicts in the past led to growth in U.S. military forces along with rapid changes in the size and shape of the force. The most recent example of this occurred in the past decade in Iraq and Afghanistan, which led to about 18 percent growth in active-duty ground forces and rapid fielding of a new class of armor-protected Mine Resistant Ambush Protected wheeled vehicles to replace tactical vehicles that were more vulnerable to improvised explosive devices.[23] The types of aircraft used during these operations also changed significantly as U.S. forces applied long endurance unmanned systems capable of armed reconnaissance and surveillance missions in large numbers. Future conflicts are likely to lead again to rapid demand for additional capacity and new systems.

Increasing the number of systems is useful for the U.S. military only insofar as forces can operate the added systems. The capability to manufacture UAS in a matter of weeks would outpace the ability of the Air Force and Navy to train new pilots. The increasing use of semiautonomous unmanned systems flown by "digital pilots" as part of the force would allow for faster growth during wartime. First of all, operator training on UAS is very different to manned aircraft. Human operators need far fewer training hours to learn to operate UAS, and common mission management systems would create easy transition between different classes of aircraft. Furthermore, it is possible to increase the number of UAS that a human operator can fly. Future UAS may be designed to allow a single operator to fly an entire swarm formation. In this case, the operator would make key operational decisions such as determining the flight location or weapons usage while relying on software to fly the aircraft.

Increased reliance on UAS could also provide other opportunities to reduce overall costs of the aircraft systems fielded. For example, the use of swarm formations may allow military planners to consider distributing mission capability across many single-mission platforms rather than ensuring that all platforms are multi-mission. This could reduce the overall numbers of payloads required to outfit a fleet.

The DOD may also consider changing the testing regime for unmanned systems relative to manned aircraft, focusing on operational tests and reducing individual aircraft safety requirements, since there is no onboard crew to protect. The use and reuse of some aircraft design features and software may also allow for accelerating test schedules, creating a more rapid transition into operational flight tests and aircraft deployment.

Finally, the use of UAS as a portion of the fleet may provide more operational flexibility for commanders as they weigh the risks of combat losses for some operations. The small numbers and high costs of manned combat aircraft increase the overall operational costs of any combat losses. However, the DOD may be willing to accept more attrition in a fleet of UAS that is quickly replaceable and does not risk the lives of pilots.

The integration of AM and robotic assembly to produce UAS portends a future in which

Notional representation of a future assembly line.

(Photos courtesy of Northrop Grumman Corporation)

development of new aircraft would feed seamlessly into production and production time would be diminished on a flexible, scalable manufacturing line. Manufacturing processes begin with the production of components and structures; AM would be applied for much of this work. There would remain parts and assemblies, such as engines and sensors, for which AM processes are either less efficient or incapable of production; these would need to be procured using more traditional methods. As parts are produced or delivered, the assembly process would be highly automated. Software that choreographs both production and assembly would facilitate the overall manufacturing process in this environment. The graphics above highlight how this factory could potentially work with the integration of both AM and robotic assembly capabilities.

The flexibility of the production process would enable a future in which the output is multiple classes and variants of UAS, ranging from very small, low-capability aircraft to larger ones with significantly more combat potential.

IV. ACQUISITION COMPARISON

The emerging capability to produce UAS in a low-cost, agile manner offers an opportunity to reshape not just the U.S. military's approach to acquisition but also how the military generates and employs operational forces. A comparison of the current approach with that afforded by a shift to an AM-centered process highlights the risks that could be mitigated and the opportunities achieved using a new approach.

In the past 30 years, based on the strategic logic and dictates of the prevailing acquisition process, the DOD has begun relatively few new major aircraft development programs. Force planners must anticipate flying systems for many years after they reach operational capability to manage returns on investment for production platforms and the timelines associated with new platform development. Given that, the process typically results in many new capability requirements that necessitate significant advances in aircraft system and subsystems technologies during development. The "high bars" set in the requirements play a key role in increasing the time needed to develop and test a system.

Under the current process, the development phase of a program begins after requirements have been settled and, for recent aircraft, lasted for about 20 years from start to finish. For the F-22, the time from the government's recognition of the requirement for a new aircraft to IOC was about 22 years (1983 to 2005); the F-35 will be similar (1996 to 2015-2017 currently expected).[24] During this long development cycle, most programs experience challenges associated with schedule delays and cost growth. Meeting the initial requirements is typically very challenging. Aircraft development also takes place in the context of changing technological and operating environments, both of which can lead to changes from initial requirements. After a painfully slow development cycle, programs transition into production to provide operational capability to the DOD. During this entire process, programs receive scrutiny from Congress, which can inject additional uncertainty into the funding stream needed to execute the program.

Because of the significant investment needed to field modern military aircraft, the DOD often plans to continue operating them for 20 to 50 years after they reach IOC. Current plans call for F-22 retirement as late as 2049, nearly 45 years after reaching IOC and 66 years after the initial request for proposals. If such plans had been in place at the end of World War II, the United States would have retired the F-86 Sabre around 2011.[25] System capability cannot remain static for such a long period, so the DOD continues to invest in research and development and modifications for aircraft programs to improve postproduction capability.

By contrast, the convergence of AM, robotics and unmanned systems provides an opportunity to disrupt this paradigm. The new paradigm would be characterized by shorter, more frequent acquisition cycles based on an iterative development process that could quickly develop many different aircraft systems, thus allowing planners to focus on nearer-term, and therefore better understood, threats.

Each development cycle would conclude in a few years, and the product of each cycle would be a different type of aircraft to be built from a common assembly line that integrates AM with robotic assembly. Planned quantities of any one aircraft type would likely be low, but the common assembly line would be designed to increase production of any developed aircraft rapidly, as needed. The unmanned systems could be flown by "digital pilots" guided by human battle managers. Since the operational value of the system would be short, requirements could be more modest and oriented toward the short term. The short operational life span – and reduced training hours required by unmanned systems – would also cut aircraft fatigue life requirements to lower unit cost.

While the development of aircraft subsystems has typically paced and been a part of modern aircraft programs, the proposed approach would seek to decouple subsystem and weapon development from the platform. Instead, each version would be designed to accommodate existing subsystems, and the production of a new system, sensor or weapon would be incorporated into future models.

This new approach, where production is fast, flexible and capable of being rapidly scaled up, could also create a new construct for sizing aircraft fleets. Currently, the DOD sizes fleets to meet the potential demand of its most challenging scenarios and must procure more aircraft than needed to deal with anticipated attrition and training needs. Accordingly, as new aircraft programs begin the desired fleet size is typically very large. There are few opportunities to grow force size rapidly because it takes so long to build aircraft and train pilots, leaving U.S. military forces with a limited ability to surge.

In a new paradigm, rapid production and the ability to reproduce previous aircraft designs would allow for the elimination of an attrition reserve, which constitutes up to 20 percent of a fleet. Since the aircraft would be unmanned, the training fleet could be much smaller because most training could be completed using simulators. Further, instead of acquiring a fleet to meet all potential demands, the DOD could procure a fleet that is large enough to meet operational testing and forward presence requirements. As potential operations become more likely, the DOD could then increase production of the types of aircraft it anticipates needing during the operation (providing just-in-time operational capability).

The concept could allow the DOD to build a new mix of aircraft in the future, one in which rapidly produced unmanned systems complement a higher-end force composed of F-22 and F-35 aircraft. This would allow U.S. forces to develop a significant and cost-effective surge capacity, giving those forces more options during a protracted conflict and placing an adaptation and capacity burden on potential adversaries.

The overall concept as presented has huge implications for costs associated with acquisition, operations and force structure. The annual costs for aircraft acquisition would be significantly reduced relative to the current model, under which the DOD must buy more aircraft than needed for operations since fleets must account for attrition and training and the fleet is sized for the most challenging anticipated scenarios. Once the manufacturing line is established and the aircraft proven, the government currently seeks to fill out its force requirements as quickly as possible, which requires significant funding. Under the proposed concept, the DOD could use operational funding to bring fleets up to the desired size when risks of confrontation increase and could keep acquisition costs relatively low when the risks of confrontation are down.

The focus on use of UAS also carries significant cost implications. According to a 2011 analysis by the Center for Strategic and Budgetary Assessments, "the total lifecycle cost of the unmanned system is less than half the cost of the manned system."[26] These savings accrue from the reduced training flying hours, smaller procurement requirements and fewer personnel needed to sustain the aircraft throughout its lifetime. The greater use of autonomy in UAS offers the opportunity to scale up the number of aircraft and gain significant personnel efficiencies.

There would be additional costs associated with capital infrastructure for new production capabilities. However, these costs would be offset based on the flexibility and multiuse nature of their capabilities. New facilities would only need to be built for major changes to capability or production volume, unlike the current process, which requires a new

TABLE 1: COMPARISON OF ATTRIBUTES: CURRENT PROCESS VS. FUTURE CONCEPT

ATTRIBUTES	CURRENT PROCESS	FUTURE CONCEPT
Platform Relevance	40-70 years	5-10 years
Capability Requirements	2+ times current	Limited
Mission Set	Multimission	Single mission
Survivability	Cutting edge	Medium/high: Adapt with version
Technology Development	Unobtainium	Modest
Software Development	Highly complex pacing item	Reuse, single mission emphasis
Production Tooling	Specialized	Reduced & regenerative
Production Labor	High	Lower: Shift toward design
Production Output	Single system	Multiple aircraft classes
Cost of Production Capacity	High, no excess	Moderate, excess capacity
Technology Insertion/Upgrades	Redesign	Add to new versions
Unit Cost	High	Variable: Low-moderate
Baseline Quantity	High	Low
Quantity Fielded	Less than baseline	Per emerging needs
Scalable	Very limited	Yes
Life Cycle Operations	High: 8,000-16,000 hours	Low: 2,000 hours
Day to Day Peacetime Costs	High: Test, train, operate	Low: Test, operate

facility for each new platform. Other savings would be derived from the lower workforce costs required for aircraft production. Additionally, the infrastructure could serve multiple purposes, ensuring high levels of utilization and offering the ability to generate other revenue if not focused on aircraft production.

While the technologies required to enable this new paradigm have not yet reached full production maturity, they already exist in limited applications, as described earlier, and are maturing rapidly. The technology to make the current process operationally feasible in the future can most easily be described as "unobtainium."

V. CONCLUSION

The concept outlined in this paper represents one slice of one capability segment in one operational domain, highlighting the enormity of both the challenges and opportunities associated with developing new approaches and paradigms. This concept may not apply, or may have to be instantiated differently, for other capability segments in the air or other war-fighting domains. However, the current paradigm is clearly unsustainable across all operational domains and critically so, given the strategic and economic trends facing the United States. Modest improvements to the existing paradigm will only slow the rate at which the nation loses its long-standing and significant capability advantage. Despite this, an approach such as the one proposed would likely face significant resistance, as new technologies and concepts undermine existing financial and institutional drivers in both government and industry.

The structural challenges associated with the current acquisition process can be seen as the natural byproduct of changes to the strategic, technological and economic circumstances of the United States, combined with the inherent issues of change in large, risk-averse organizations. Reform, while clearly needed, is unlikely to be achieved by further reviews, and top-down reform, in particular, appears unlikely given the myriad challenges facing the DOD in the years ahead. Change is painful, especially for large organizations building highly complex systems worth billions of dollars that are matters of life and death. But the current system is already beset with significant challenges that will become increasingly untenable and, without a change in approach, will lead to a diminished future force.

The rise of new technologies and methodologies affords the opportunity for paradigm-shifting innovation in ways that increase U.S. capability while managing costs and risk more effectively. Bold solutions do not require formal or top-down reforms. DOD can support such efforts through experimentation, capability demonstrations, requirements definition, contract structure and evaluation. Concomitantly, the defense industry has powerful incentives to innovate for competitive differentiation in a time of shrinking budgets. Focusing innovation on how to acquire capability (process) in addition to payloads and platforms will be critical to maintain capability superiority in a technologically sophisticated geostrategic environment.

Future U.S. technological superiority is far from guaranteed, and other actors will soon have similar access to the technologies explored in this paper. The United States has a rich tradition of innovation and leadership in defense and technology development and possesses the ability to develop the concepts and technology required to address these challenges at the right time. But if the DOD and U.S. defense industry do not innovate boldly, others will.

ENDNOTES

1. J. Ronald Fox, *Defense Acquisition Reform, 1960-2009: An Elusive Goal* (Washington: U.S. Army Center of Military History, 2011).

2. Paul K. Davis and Peter A. Wilson, "Looming Discontinuities in U.S. Military Strategy and Defense Planning" (RAND Corporation, 2011).

3. Jonathan W. Greenert, "Payloads over Platforms: Charting a New Course," *Proceedings Magazine* (July 2012).

4. See Andrew Davies, "Geek of the Week: Frederick Lanchester and why quantity has a quality all of its own," The Strategist blog on ASPIstrategist.org, September 20, 2013, http://www.aspistrategist.org.au/geek-of-the-week-frederick-lanchester-and-why-quantity-is-a-quality/.

5. See Shawn Brimley, Ben FitzGerald and Kelley Sayler, "Game Changers: Disruptive Technology and U.S. Defense Strategy" (Center for a New American Security, September 2013).

6. All costs reported in this paper are in constant FY2013 dollars.

7. Here we compare the initial development of the F-4 for the Navy to the development of the Air Force F-22. See Torsten Anft, "VF-74 Be-Devilers," July 1, 2013, http://www.anft.net/f-14/f14-squadron-vf074.htm. This would be similar to initial operating capability for modern aircraft systems.

8. U.S. Department of Defense, *Selected Acquisition Report: F-22*, RCS: DD-A&T(Q&A)823-265 (December 31, 2010), http://www.dod.mil/pubs/foi/logistics_material_readiness/acq_bud_fin/SARs/DEC%202010%20SAR/F-22%20-%20SAR%20-%2025%20DEC%202010.pdf.

9. Al Shaffer, keynote address (NDIA Science and Engineering Conference, National Harbor, MD, April 24, 2013). //

10. Frank Kendall, *Memorandum – Better Buying Power 2.0: Continuing the Pursuit for Greater Efficiency and Productivity in Defense Spending* (November 13, 2012).

11. F-4 development costs estimated using René J Francillon, *McDonnell Douglas Aircraft since 1920: Volume II*, (Annapolis, MD: Naval Institute Press, 1979) and George C. Sponsler, et al., *The F-4 and the F-14* (Gaithersburg, MD: Columbia Research Corporation, 1973); F-22 development cost estimated using U.S. Department of Defense, *Selected Acquisition Report: F-22*.

12. Deborah D. Stine, "The Manhattan Project, the Apollo Program, and Federal Energy Technology R&D Programs: A Comparative Analysis," RL-34645 (Congressional Research Service, June 30, 2009).

13. Data collected using Mark Lorell and Hugh P. Levaux, *The Cutting Edge: A Half Century of U.S. Fighter Aircraft R&D* (Santa Monica, CA: RAND Corporation, 1998).

14. Marcelle Size Knaack, *Encyclopedia of US Air Force Aircraft and Missile Systems: Volume 1* (Washington: Office of Air Force History, 1978).

15. Estimate based on contracts data available at the Federal Procurement Data System and U.S. Air Force, "Air Force Accepts Final F-22 Raptor," May 7, 2012. http://www.jber.af.mil/news/story.asp?id=123301143.

16. Data collected from the FY2011 U.S. Air Force Budget Submission; F-4E costs calculated using Knaack, *Encyclopedia of US Air Force Aircraft and Missile Systems: Volume 1*.

17. While this approach could be applied more generally across different types of systems, we focus on aircraft systems in this paper because aircraft development challenges are more problematic than in some other classes of systems and the manufacturing technologies are well-suited for aircraft systems.

18. "The printed world," *The Economist* (February 10, 2011), http://www.economist.com/node/18114221; "3D printing scales up," *The Economist* (September 7, 2013), http://www.economist.com/news/technology-quarterly/21584447-digital-manufacturing-there-lot-hype-around-3d-printing-it-fast; and Neil Gershenfeld, "How to Make Almost Anything: The Digital Fabrication Revolution," *Foreign Affairs* (November/December 2012), http://www.foreignaffairs.com/articles/138154/neil-gershenfeld/how-to-make-almost-anything.

19. In 2012, the president proposed that the federal government provide $1 billion for the foundation of a National Network for Manufacturing Innovation. See http://manufacturing.gov/nnmi.html.

20. International Federation of Robotics, "Presentation: IFR Press Conference 30 August 2012," http://www.worldrobotics.org/uploads/tx_zeifr/Charts_IFR__30_August_2012.pdf.

21. Nir Barkan, et al., "Final Report: Robotics and Autonomous Systems Industry" (Industrial College of the Armed Forces, spring 2011), http://www.ndu.edu/icaf/programs/academic/industry/reports/2011/pdf/icaf-is-report-robotics-autonomous-systems-2011.pdf.

22. Kate Linebaugh, "Honda's Flexible Plants Provide Edge," *The Wall Street Journal,* September 23, 2008, http://online.wsj.com/article/SB122211673953564349.html.

23. Data collected from U.S. Department of Defense, Office of the Undersecretary of Defense (Comptroller), *National Defense Budget Estimates for FY2013*; the U.S. Army active force grew by 17.6 percent (from about 481,000 to 566,000 soldiers) from 2001 to 2010, while the U.S. Marine Corps grew by 19.1 percent (from 173,000 to 206,000 Marines) from 2001 to 2012.

24. U.S. Department of Defense, *Selected Acquisition Report: F-22*; and U.S. Department of Defense, *Selected Acquisition Report: F-35 Joint Strike Fighter Aircraft,* RCS: DD-A&T(Q&A)823-198 (December 31, 2012), http://www.dod.mil/pubs/foi/logistics_material_readiness/acq_bud_fin/SARs/2012-sars/13-F-0884_SARs_as_of_Dec_2012/DoD/F-35_December_2012_SAR.pdf.

25. The development of the F-86 Sabre began in 1945, with first flight in 1947. Aviation History Online Museum, “North American F-86 Sabre,” http://www.aviation-history.com/north-american/f86.html.

26. Todd Harrison and Evan Montgomery, “Changing the Business of Defense” (Center for Strategic and Budgetary Assessments, October 2011), http://www.csbaonline.org/publications/2011/10/changing-the-business-of-defense/.

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