BUILDING AN AGILE FORCE:

The Imperative for Speed and Adaptation in the U.S. Aerospace Industrial Base

MITCHELL INSTITUTE for Aerospace Studies

By Lt Gen David A. Deptula, USAF (Ret.)
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Executive Summary

It is no secret that the Air Force is at a crisis point. The Air Force's combat force structure is older and smaller than it has ever been since the service's inception, yet the ops tempo has not slowed down, nor is it likely to. More importantly, the high costs of sustaining overused and aged aircraft are crowding out the budget space for newer aircraft that could replace them. The Air Force could divest these legacy platforms to free up funding for future programs, but Congress has restricted the Air Force's ability to do so, and for good reason. The service's force structure is already too small for what the nation demands of it, and-next generation capabilities are still in the nascent phases of development.

This catch-22 is not just the result of strained budgets or post-Cold War strategic malaise, although these are certainly contributing factors. Distorted offset thinking—the persisting belief that, with enough advanced technology, a smaller force is better, more efficient, and cost effective—is a larger factor. The "smaller and more capable" mantra has created a sense of complacency in force planners who continue to believe that a smaller force, so long as it possesses technological overmatch, can affordably secure our nation and allies in any conflict.

In fact, this kind of offset thinking has created a self-reinforcing cost-capability dilemma for the defense establishment. Game-changing technology can enable a smaller force to prevail against a more numerous but less-capable adversary. However, a smaller force must also be more flexible—each aircraft must do more. To maximize a single weapon system's combat utility, each system must integrate more technologies, sensors, and functionality. Therefore, force planners look away from single-mission or specialized aircraft and favor multi-role aircraft that can be used across a range of mission sets. The more exquisite these multi-role platforms become, however, the more expensive they are, so fewer can be procured. This, in turn, drives the requirement to make each weapon system even more capable, which further drives up cost. It is a vicious cycle that has caused significant damage to the Air Force and the aerospace industry that supports it.

The myth of "smaller and more capable" has also adversely affected the defense industry by diminishing the number of new-start aircraft competitions. In the 1950s, six new Air Force fighters were fielded, and the service supported a robust experimental prototype portfolio. Since the 1980s, there has been only one new-start program per decade. In the last ten years, there have been none, and the Next Generation Air Dominance (NGAD) family is just on the horizon. This has caused a dramatic consolidation of the aerospace defense industry. At least nineteen major aircraft companies were considered prime competitors in the 1950s. Today, there are only three: Lockheed Martin, Boeing, and Northrop. This contraction has pernicious consequences for the Air Force and national security: decreased creativity and innovation in design choices; diminished engineering and manufacturing experience; extended and troubled developmental cycles; and perverse industrial incentives that reward vendor lock, sustainment contracts, and service life extensions over fleet refresh.

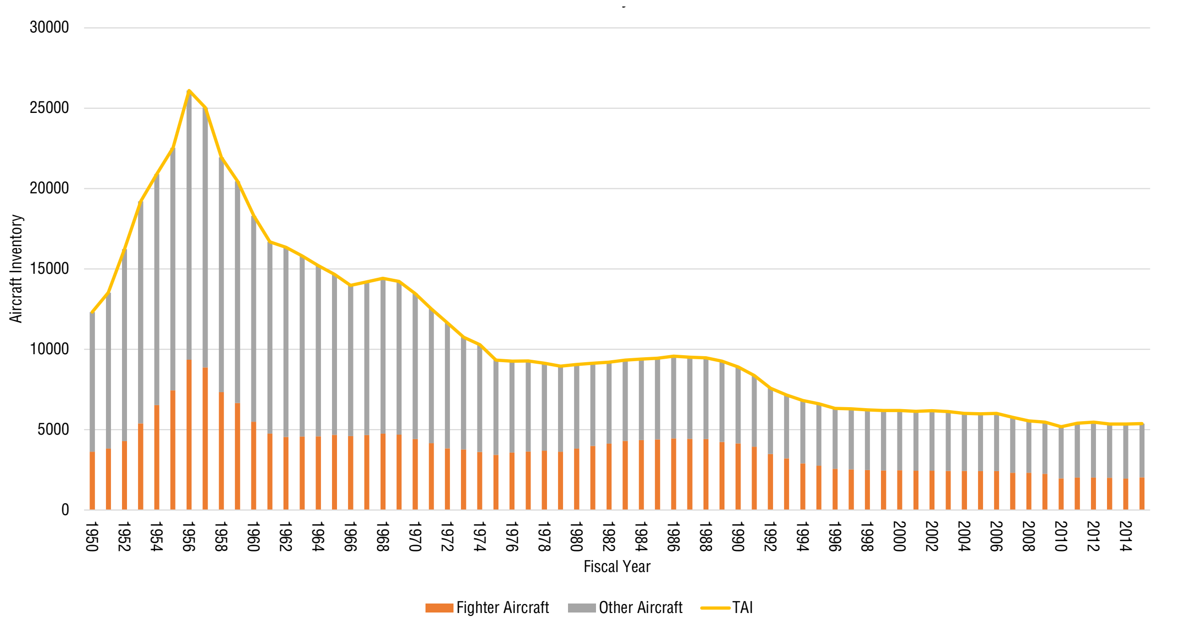

Figure 1: USAF Total Aircraft Inventory (TAI) 1950-2015. **Credit: Mitchell Institute**

In light of potential peer competition against a technologically advanced adversary, these trends indicate that today's defense industry is not optimized to field the force design required in future threat environments. This fact should be both obvious and deeply troubling to defense leaders. For too long, defense leadership has focused on using advanced capabilities as a means to cut force structure. This approach has neglected the other attributes available to achieve a strategic offset. While the quality of the force will still matter against a technologically advanced adversary, Air Force leaders must consider how to deliberately dial-up the other force attributes of quantity, diversity, adaptation, and speed in their force design. Unfortunately, the defense industry is not structured to develop and deliver this kind of force.

Today's defense industry is a monopsony system, where its only customer is the Department of Defense. Within the dynamics of this system, the Air Force has shaped the aerospace industry of today through its market conduct. The issues that trouble Air Force acquisition—high unit costs, aggressive award protests, cost overruns, extended developmental cycles, growing sustainment costs—are all the result of Air Force buying behavior. Without frequent competition and new-start production, the extended lifecycles of legacy platforms shift industry profit centers from innovation and production to modernization and sustainment, which, in turn, causes aerospace corporations to devalue the intellectual capital and industry experience needed to create new designs. The aerospace industry has had to consolidate and downsize their engineering teams and focus their expertise on system integration instead.

These defining features of today's defense aerospace industry risk leaving the nation ill-equipped to compete in future warfare. Traditional offset strategies, which derive advantage from game-changing technological leaps, require significant time and investment to develop. As technology has proliferated, weapon systems grown more complex, and the acquisition bureaucracy more layered, it becomes more difficult for defense aerospace companies to field capabilities in operationally relevant time frames. Yet, time is becoming a factor more today than ever before. The nation that can develop, field, and adapt faster than their competitors will achieve a capability advantage.

The imperative to grow agile force structure means that the Air Force can no longer tolerate extended developmental timeframes. The need for speed-to-field, quantity, and the continuing acceleration of technology and processing power means that capability advancements and insertion should be delivered through new aircraft. Retrofitting weapon systems through sustainment and modernization will not be enough. The aerospace industry must not just keep pace but outpace America's adversaries in fielding new and innovative capabilities. Adaptation is the advantage, and speed is the new offset. The Air Force must change its buying behavior—in essence, create more competition—if it is to revitalize both the defense aerospace industry and its own force design.

Restructuring for a New Strategic Offset

In today's global competition, the United States no longer has the luxury of supporting long developmental timelines for new aircraft. No longer can the service tolerate fifteen-year-long developmental cycles for new weapon systems. Waiting decades for a game-changing capability may render that system obsolete upon fielding. Success in today's global security environment demands advancing capability and rapid development and fielding. Speed and adaptation are the new offset.

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In this strategic approach, the U.S. aerospace industry must increase its speed-to-field and integrate new capabilities. This will enable the Air Force to rapidly connect, command, and create advantageous new force compositions. These advanced and untraditional systems can disrupt an adversary's ability to understand, predict, or target U.S. or allied operational architectures.

Implementing this new offset strategy will require the Air Force to alter its acquisition paradigms. The defense aerospace industry has already been forced to adapt and consolidate to optimize its procurement models and acquisition practices to match nearly thirty years of constrained Air Force investment simply to deliver new versions of aircraft from a bygone era. However, by using natural market incentives, the Air Force can responsibly expand the aerospace industry and refocus it to deliver capability at speed. Aerospace companies are rational actors and shape themselves according to the conditions presented to them. The Air Force can achieve quality, quantity, and adaptation at speed if it invests in existing talent, expands its aerospace base, enhances the integration skills of design teams, and commits to stronger new-start and production programs. Historical cases suggest this is a realistic and pragmatic path to follow. Recommendations to achieve this goal include:

- Expand the defense aerospace industrial base by valuing innovation and production over sustainment. A larger defense base means more competition, increased innovation, and greater design diversity. It provides the nation strategic depth of capability by cultivating seasoned talent and experience.

    - Incentivize rapid technological development.
    - Present opportunities to new industry entrants.
    - Provide ongoing, competitive, experimental prototype programs.
    - Avoid future joint aircraft programs.

- Enhance the integration skills of design teams by pursuing a strategy of rapid adaptation. The skill and creativity necessary for design teams to conceptualize and integrate complex systems underpin the strategy of rapid adaptation that will provide strategic and operational advantages in a peer contest. In other words, integration expertise is crucial to accelerating change.

    - Experiment with open systems, mission integration, containerization, and other technologies to create flexible and adaptive weapon systems.
    - Promote the development of mission integration tool sets.

- Return aerospace's major profit centers into production by pursuing more and diverse programs. With current major profit centers focused on sustainment and modernization, industry is inclined to perpetuate status quo force design and proprietary programs. Shifting profit centers back to production could shift industry toward rapid fielding and greater innovation.

    - Accelerate development and fielding cycles.
    - Accept smart risk by prioritizing rapidly fielded iterative improvements over perfect systems.
    - Develop adaptive and affordable manufacturing technologies.
    - Increase the frequency of new-starts, maintain multiple hot production lines.
    - Maintain a younger fleet age.

Introduction

To secure America's interests around the world, the U.S. military must be able to deter and defeat adversaries throughout the threat spectrum. This includes China and Russia at the top end, nuclear-ambitious Iran and North Korea at the mid-tier, and non-state actors in the Middle East and Africa at the low end of the threat spectrum. Given what is at stake at each level, addressing these threats is not optional. Each demands smart, credible options that rely on a balanced force design.

The U.S. Air Force provides some of the most crucial capabilities against all these geographically disperse and technically complex challenges. Because its core service missions include air superiority; long-range strike; global mobility; intelligence, surveillance, and reconnaissance (ISR); and many other niche capabilities, the Air Force provides greatly needed policy options to U.S. national security leadership that no other service departments alone can deliver. The demand signal of multiple, concurrent world-wide responsibilities, however, is straining the Air Force. Simply said, the Air Force is too old, too small, and too fragile for what the nation expects of it. David Ochmanek, a respected and experienced defense analyst, aptly sums up the impact of these dynamics when it comes to U.S. competitive advantage: "In our wargames, when we fight Russia and China, blue gets its ass handed to it."[1]

While advanced capabilities will certainly be important to prevailing in these future challenges, leaders must also seek additional points of advantage. The simple reality is that it is no longer a safe bet to assume that the United States will possess a unilateral technological advantage. Countries like China are aggressively pressing forward, and perhaps even outpacing the United States, in zones like machine learning.[2] This calls for securing new points of force design advantage: quantity, diversity, adaptation, and speed. These attributes, paired with a continual focus on quality and advanced capability, will prove crucial to achieving future success.

Neither the Air Force nor the aerospace industrial base are structured to rebalance the force to exploit the potential advantages of these attributes. Instead, they have developed a procurement and sustainment model that favors maintaining and upgrading legacy weapon systems; developing multi-role, multi-function platforms; and procuring budget economies by reducing type diversity. However, U.S. aerospace forces can no longer spend decades in a quest to secure the most exquisite capability, nor use capability as a reason to reduce capacity. We cannot do more with less.

In 1991, Operation Desert Storm showcased the Air Force's overwhelming operational advantages in stealth, information superiority, and precision. Many U.S. leaders have assumed those advantages would endure. In fact, this perceived superiority created a complacency that enabled an atrophy in procurement and development. In the wake of Desert Storm, the American defense establishment entered a decade known as the "procurement holiday," where numerous new programs were curtailed, deferred, or canceled altogether, and existing force structure was cut dramatically.[3] This was particularly pronounced for the Air Force, which absorbed the largest budget cuts of all the

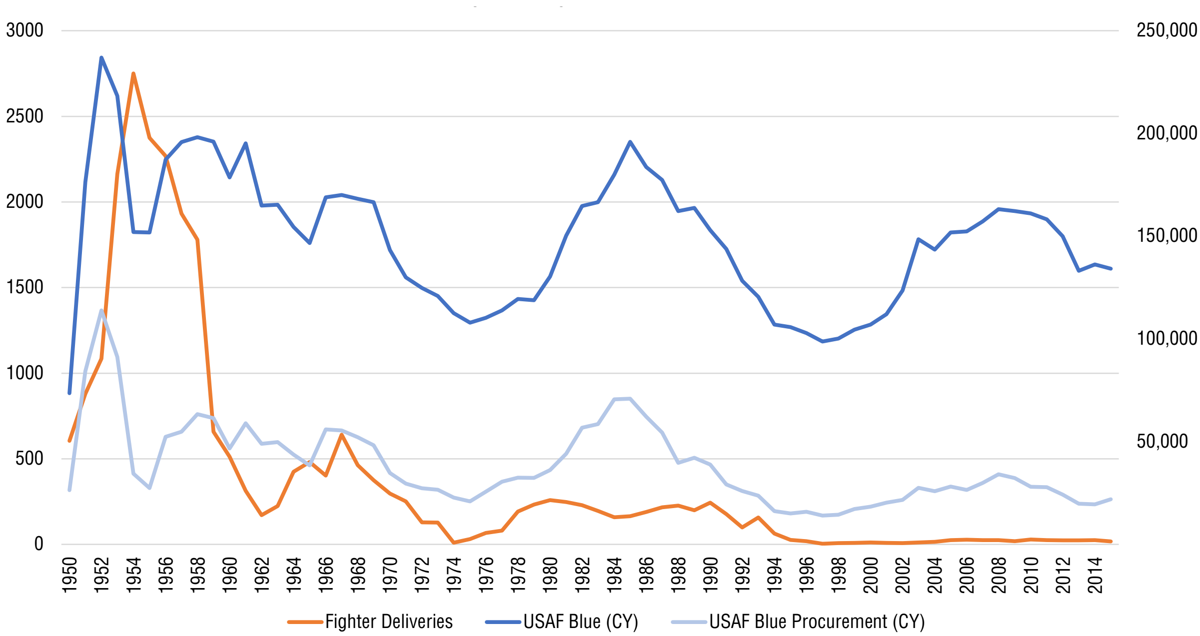

Figure 2: USAF Blue Budget and Fighter Aircraft Deliveries 1950–2015. **Credit: MItchell Institute**

branches in the decade following the Cold War. The U.S. Air Force now fields the smallest, oldest aircraft fleet in its history.

The Air Force never recovered. Comparing service budgets from 1989 to 2001 show that procurement funding was cut by over half, for a loss of 52 percent of its acquisition budget. In contrast, the Army and Navy procurement budgets were cut by roughly 30 percent.[4] Over the past 30 years, the Air Force inventory of fighter aircraft has dropped from roughly 4,400 to around 2,000.[5] The number of bomber aircraft similarly fell from 327 in 1990 to 157 in 2020—a record low since the founding of the service in 1947.[6] With the complexities and dangers across the globe only increasing, the warning should be clear: the deterioration of the Air Force places U.S. national security at risk.

The challenge is not only isolated to the service. The aerospace industry has also been impacted by these cuts. Defense companies adapted to market demands—or lack thereof—by consolidating, refocusing engineering talent, and shifting business models. With few new-start programs available to sustain companies, the 1990s saw a dramatic contraction and consolidation of the industry. In the mid-1980s, there were 51 firms that could be considered either prime contractors or major subcontractors.[7] Today, there are five, of which only three build aircraft. Former Assistant Secretary of the Air Force for Acquisition, Technology, and Logistics Will Roper expressed concern about the small number of prime contractors: "Right now we are down to just a couple of companies who can build tactical airplanes for us. We need to do everything in our power to start opening up that envelope again."[8]

Industry consolidation risks additional negative consequences when it comes to innovation and adaptation. A Stanford study found that consolidation of the defense industry decreased competition, while a CSIS assessment found consolidation within subsectors is correlated with greater contract termination.[9] Condensing activities within a few firms has a clear and adverse effect because "industry consolidation lowers the number of innovation projects."[10] In other words, fewer companies and less competition decrease creativity, the speed at which new designs or capabilities are developed, and the ability to successfully operationalize innovations. While DOD research and development programs might mitigate some of this impact, it is unclear just how much.

With few opportunities to earn revenue from new designs and new-start programs, companies have made a natural shift to sustainment as a crucial profit center. Today, production primarily serves to secure modernization and sustainment business, as these provide a stable, long-term revenue stream. This, in turn, motivates firms to guard their data rights and other intellectual property. In this model, the longer a weapon system is in service, the longer, more lucrative, and more secure the business. What may be good for business, however, is not what is best for national security strategy. As these aircraft age, sustainment and modernization costs inevitably squeeze money out of the budget that could otherwise be invested in new capabilities like the Air Force's new air superiority program, next generation air dominance (NGAD). Not only does this model not look forward to the challenges of tomorrow's battlespaces, it risks slowing innovation, adaptation, diversity of thought, and the transformation of the force. These are all profound dangers when facing a highly agile set of adversaries.

An optimal future force design will still need to have highly advanced technologies to compete with sophisticated peer adversaries, but the Air Force must also be able to field many different new systems rapidly and in quantity, and it must be able to quickly adapt, shift, and modify its forces and operational architectures.

The Air Force, and the defense aerospace industry that supports it, must seek to create a new force design. No longer can the nation make-do with the status quo force that is too small, too old, and too fragile. Yet this future force design cannot simply be more of the same. Highly capable, multi-role, multi-function platforms have had the effect of shrinking both numbers and diversity of the force. This type of force design, no matter how shiny and new, will be not have the mix of capabilities needed to offset any of the threats that the United States and its allies will face across the spectrum. Such a force would be too small and too homogenous to be effective at the high end of combat, yet too exquisite and expense at the low end. An optimal future force design will still need to have highly advanced technologies to compete with sophisticated peer adversaries, but the Air Force must also be able to field many different new systems rapidly and in quantity, and it must be able to quickly adapt, shift, and modify its forces and operational architectures. The future demands a new force design that rebalances the attributes of quality, quantity, diversity, adaptation, and speed.

We must recognize that, in future conflict, the combat advantage will not necessarily belong to the military that has the most exquisite technologies. Instead, success will go to the force that can adapt and field capabilities in cycles that outpace the adversary. This requires a force design that demands constant innovation and an industrial base geared toward experimentation and risk rather than maintenance and protectionism. This is the kind of defense industry and force design that will deny an adversary a stable, simple, and predictable target set. *Quality*, a colloquialism often used for advanced capabilities, will continue to be an enduring attribute of future force designs; it should not be the dominant one. Instead, *quantity* will provide the scale, redundancy, and resiliency necessary to fight in the vast regions of the Pacific against a peer adversary. A *diversity* of platforms will impose complexity on adversary strategies, as well as allow for tailored and appropriate force packages at the lower end of conflict. The ability to *adapt* these systems will deny adversary attempts to counter U.S. and allied operations. An ability to field new capabilities at *speed* will ensure the operational initiative by outpacing the adversary's ability to anticipate, target, or deny U.S. capabilities. Strategy should pursue these attributes as a priority, but current government-industry models do not support this, and it is unlikely that acquisition reform would either.

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Cultivating an aerospace industrial base that can build the Air Force we need will require a break from decades of acquisition and programmatic trends. This should not be confused with acquisition or regulatory reform. While such changes are needed, acquisition reform focuses on policy, process, regulation, and oversight. These reforms have repeatedly demonstrated change on the margins—they do not alter the fundamental dynamics. A recent Center for Strategic and International Studies Assessment found that acquisition reforms had little impact on accelerating the fielding of major defense acquisition programs.[11] Furthermore, acquisition reform risks creating additional bureaucratic burdens, which ultimately slow a program's speed.

If the Air Force is to succeed in accelerating change, it must evolve its behavior in ways that shift industry profit centers from sustaining the past to inventing, investing in, and producing capabilities for the future. Business responds to revenue. The Air Force can use normal market incentives to create a more diverse, innovative, and responsive aerospace base. By increasing new-start market opportunities for the defense industrial base, the Air Force can motivate innovation and adaptation at speed by moving primary revenue lines away from sustainment and back into development and production.

The need to rebalance the attributes of the force design is not a call to "blow up" current production lines and design efforts for types like the F-35, B-21, KC-46, T-7, and other recapitalization programs. The reality is that the service needs those platforms in large numbers as soon as possible to meet the global demands on the force. Terminating programs to pursue the next greatest power-point capability—"skipping a generation"—will leave the Air Force incapable of executing key missions. The nation cannot afford to repeat the past mistakes made with programs like B-2 and F-22. Billions were invested in research and development, but, due to short-term and short-sighted decision making, too few were procured to replace older legacy fleets or even provide a viable operational capacity.

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The current force needs resetting now. If the Air Force is to shift industry profit centers away from sustaining legacy platforms and into development and production of a new force design, the systems currently in production are the place to start. This study also offers a pathway for the Air Force to deliver a rebalanced force design, starting by altering its current acquisition trends and using natural market forces.

This future force design is not likely to be a simple a high-low mix of exquisite capability and cheap, low-end platforms. Instead, it must balance the attributes of quality, quantity, diversity, adaptability, and speed. These attributes will allow force presentations to be flexibly composed and tailored to the demands of the strategy and scenario. Furthermore, it is important not to conflate quality with multi-function or multi-role. Advanced capability can be metered within "simpler" platforms that enable affordable quantity and diversity. Together, these attributes allow forces to rapidly adapt their composition as the scenario demands.

Given current paradigms, such a force seems unobtainable. Quality and quantity seem mutually exclusive. Diversity is antithetical to force design trends which emphasize efficiencies, and adaptability and speed seem unrealistic in today's acquisition world. Whether considering these attributes from the Air Force or industry side, it does not appear that either has the ability to deliver this new force design.

Fortunately, Air Force history—including case studies of aircraft programs from the "Century Series" to today—provide insight on how the Air Force can make research, development, and production a more profitable and reliable revenue stream. Using those lessons, the service can fundamentally reshape the aerospace industry for quality, quantity, diversity, adaptation, and speed without sacrificing the innovation that provides a combat edge. Given the urgent need for the Air Force to recapitalize and transform its force design, time is no longer a luxury—it is the challenge. The Air Force must change its procurement paradigms if the aerospace industry is to accelerate change and win.

Offset Strategies: The Quest for Asymmetric Advantage

In symmetrical competitions, two opposing sides compete on similar merits. Both sides might share similar force designs and pursue similar technologies, strategies, or strengths. As a consequence, symmetric contests often result in attrition-based warfare, where superior numbers dictate the victor. They can conversely initiate a race, in which incremental improvements made faster that the competitor's improvements provide the advantage.

An offset strategy, on the other hand, seeks to shift the competition away from symmetry. In an offset, one competitor leverages or cultivates an area of strength against the other's weakness. The goal of this shift may be to compensate for a symmetrical weakness, but if the adversary is unable to compete in that new area it may also lead to a long-term advantage. A look at past U.S. offset strategies can show how such advantages have been achieved by U.S. forces throughout the 20th century.

Since the end of World War II, the U.S. military has largely relied upon two major defense offset strategies. These strategies were designed to deliver effective, efficient military options when traditional courses of actions that depended wholly on superior numbers were unsustainable. Both were aimed at deterring and, if necessary, prevailing in a conflict with the Soviet Union during the Cold War. The Soviet Union had mass and incredible industrial might, so the United States sought to leverage its advanced technologies to enable a smaller standing military to successfully offset a larger Soviet force. U.S. offset strategies drove a force design that largely valued quality, or capability, over other force design attributes. This strategy also bred the notion that quality/capability could replace quantity.

Offset Strategies

An offset is a long-term strategy that seeks to shift the nature of the competition to an area that can provide our side an asymmetric advantage. Past U.S. offsets have focused on leveraging advanced technologies and new operational concepts to enable new, more effective forms of employment as a means of compensating for smaller relative quantities.

The Evolution of U.S. Offset Strategies

The first offset strategy

The first offset strategy originated in the wake of World War II. One of America's principal advantages in the Second World War was its production might. Indeed, the Allies' victory is often credited to America's as the "arsenal of democracy." Industry both in and outside of the defense sector were able to shift to producing mass quantities of war materiel at a speed and scale its adversaries could not match. The United States produced 12,692 B-17s and 18,190 B-24s during the four-year course of WWII.[12] In this experience of total and existential war, the United States maximized every attribute of force design that it could: quality, quantity, diversity, adaptation, and speed. Post-war demobilization and declining defense budgets sunset much of this enterprise as the nation returned its manufacturing base to commercial products. With the subsequent rise of the Cold War, U.S. defense leaders had to develop a different, more sustainable means to compete against the burgeoning military might of the Soviet Union.

Deterring this threat would require a strategy that rested on something other than national mobilization and a large standing military. In the 1950s, the CIA assessed that the Soviet Union could field about 175 divisions along the European central front, with another 125 divisions in reserve that could be deployed within a month. The United States, by comparison, had 29 Army and Marine Corps divisions, with only another seven in reserve.[13] Unable to match the conventional forces of a much larger Soviet military, U.S. defense leaders instead chose to leverage the strengths of the American science and technology enterprise. Specifically, President Dwight Eisenhower shifted the competition into the nuclear realm, where America's lead and pace in nuclear weapons development provided a unique edge. This formed the basis of his administration's "New Look" strategy and is widely recognized as America's first defense offset.

New Look required the military and its defense industry partners to develop and field a broad range of advanced nuclear weapons and associated delivery systems. Tactical nuclear munitions would be used for battlefield engagements, while U.S. defense strategy sought to deter strategic escalation by holding the Soviet heartland at risk through massive nuclear retaliation.[14] Supersonic delivery speeds were key to this nuclear strategy, and acquisition programs of the era emphasized that capability. Development of nuclear delivery platforms included the Century Series of aircraft like the F-105; the B-47, B-52, and B-58 for strategic attack; and a host of brand-new technologies in the form of Intercontinental Ballistic Missiles (ICBMs).[15] The Army and Navy also developed with their own respective capabilities in this realm. The principle of time also applied to America's air defense with supersonic aircraft like the F-102, F-104, and F-106, supported by an early-warning command and control network.

This deterrence approach worked. The conflicts the United States did fight were smaller in scale and nature and did not involve direct, overt war with the Soviet Union. Although these engagements were "hot," they were largely viewed as sub-tier priorities relative to the potential for a direct military confrontation with the lead communist power, and they did not alter the Air Force's broader force design decisions. Most acquisition programs prioritized capabilities optimized for the Soviet Union in a potentially nuclear context.[16] Leaders assumed they could apply this hardware throughout the spectrum of conflict when demand arose. As such, these peripheral wars were generally fought with existing weapons systems that were modified as operational exigencies demanded.

The Century Series fighters, although often maligned for their performance in Vietnam, proved relatively versatile and adaptable to a conflict for which they were not designed. This was largely because of their loosely coupled and federated mission systems. Although developed as integrated weapon systems, their internal avionics architectures were flexible enough that they could be modified to perform roles that their designers had not envisioned. What could not change was their aerodynamic performance. The physical design and aerodynamic attributes of the aircraft were fixed, but new variants were often fielded with improved aerodynamic designs and adaptations to replace older models. Together, the iterative model of fielding and the federated adaptability of these aircraft enabled the Air Force to meet unexpected operational demands by innovating new missions and modifying the aircraft accordingly.

The F-100 is illustrative of this pattern. Developed in the wake of the Korean War, where the United States gained firsthand experience against highly capable Soviet MiG designs, the F-100 was a direct attempt to develop a fighter aircraft to engage Soviet airpower above Europe and in continental defense missions over the United States.[17] When the Vietnam War erupted in 1965, the U.S. Air Force deployed F-100s to the conflict and flew them in a wide array of mission sets far different than what their original mission specifications envisioned. The F-100 proved inherently adaptable even if it was not optimized for the roles it assumed. Originally meant to dominate in the air-to-air realm, F-100s were ultimately used as close air support assets, as "Wild Weasel" platforms, and as "Fast FAC" forward air controllers.[18]

A similar fate befell the F-105. As one airpower historian observed, "The Thunderchief was designed to fight a nuclear war in which the delivery of one nuclear weapon at low altitude and high speed was all that was required."[19] Yet the F-105's primary operational use was as a conventional bombing aircraft in Vietnam. It served as a "Wild Weasel"—a modification to defeat enemy surface-to-air missiles—and it was modified to conduct specialized all-weather and night bombing. The F-105 was not well-suited aerodynamically for any of these roles, but it had the fundamentals to adapt to these missions.

The Air Force New Look force design, training, tactics, and policies were optimized for and focused on the broader conflict with the Soviet Union—to include nuclear weapons delivery. But these aircraft, and the men who flew them, served in far different circumstances. Although it was not a deliberate attribute of the force design, the service benefitted from diversity and adaptability of its fleets. This diversity enabled

Figure 3: Republic F-105 Thunderchief. The Thud is often maligned as being so specialized for tactical nuclear delivery that it could not flex to the missions it was assigned in Vietnam. Nearly half of the 833 F-105s built (397) were lost, and the F-4 took over the mission of interdiction from the F-105. Yet the reality of Vietnam proved that the F-105 was very adaptable, flying missions ranging from interdiction to Wild Weasel. Between 1965 and 1968, the Thud carried out more strikes than any other aircraft, and over the course of the conflict scored 24 gun victories and 3 missile victories. The extreme attrition rate of the F-105 had more to do with the nature of its missions, which required low level ingresses and weapon deliveries. More Air Force aircraft were lost to surface fires than any other reason combined. Because Robert McNamara shut down the F-105 production line in 1965, the Air Force could not replace F-105 aircraft or pilots at the needed rates. Consequently, the McDonnell F-4 Phantom II took over interdiction missions from the Thud, in addition to the Phantom's other roles. The Air Force lost 528 F-4s over the course of the conflict, but with a hot production line, the service could continue to backfill lost aircraft and crew.

the aircraft to be used in different roles than those for which they had been designed. Still, the Vietnam War revealed some significant vulnerabilities in how the Air Force had planned to offset Soviet capabilities. Vietnam was not war with the Soviet Union, but the United States found itself fighting an adversary armed with Soviet equipment and fighting the air war in a Soviet manner. The conflict served as a proving ground for the Air Force and provided crucial insight into the strengths and capability gaps to which the service had to respond.

Efforts to speed the fielding of new capabilities to mitigate the vulnerabilities of the New Look force laid the groundwork for what became as the second offset. If the New Look force was strained by fighting Soviet equipment operated by the North Vietnamese, how could it prevail in an all-out war with the Soviet Union? Defense professionals were aware that they needed to adapt in the face of these challenges. As a result of its difficult experience in Vietnam, the U.S. Air Force shifted its force design against the broader Soviet context.

One of the starkest lessons to emerge from the Vietnam air war was the difficulty of getting bombs on the target while flying against lethal air defenses. Poor accuracy of unguided bombs meant that large strike packages of support and attack aircraft were required to increase the odds of a hit. Crews often had to revisit targets to achieve the desired destruction. Repeat missions were highly problematic. For one, they made the overall force less effective because it prevented attacks on other key targets. Secondly, repeat missions against the same targets made these missions predictable and therefore vulnerable against air defenses.[20] For example, the infamous Than Hoa bridge survived more than 700 sorties and 12,500 tons of bombs dropped against it—attacks during which 29 aircraft and their aircrews were shot down.[21] In this case, quantity did not result in mission success.

This problem led to the development of precision-guided munitions. Systems like laser-guided bombs provided increased target accuracy, improving the overall effectiveness of attacks and the force as a whole. The Air Force began developing laser-designators for aircraft and seekers and guidance kits for bombs in 1965. By 1968 some F-4s had been adapted for operational experimentation.[22] Early "Pave Knife" targeting pods paired with "smart" laser-guided bombs answered theater commanders' demands for greater bombing precision.[23] The mission effect was staggering. The Than Hoa Bridge was successfully dropped in 1972 by twelve F-4s, each employing two precision guided bombs. The advanced technology of laser-guided bombs more than made up for quantity because of its ability to hit desired aim points reliably and precisely.[24]

In a similar vein, high losses of aircraft to Soviet air defense equipment demanded enhanced survivability. Missions over North Vietnam largely relied on electronic jamming to degrade the performance of enemy air defense systems. Every strike aircraft required four jamming aircraft on average. Even with such support, aircraft were still shot down at alarming rates.[25] During Operation Linebacker II in December of 1972, the United States lost fifteen B-52s in twelve days.[26] These were the very same type of aircraft that were tasked with striking deep into the heart the Soviet Union. Given their vulnerability in Vietnam, the B-52's ability to deliver nuclear weapons into Soviet territory in sufficient numbers was in serious doubt. The takeaway from Linebacker II was clear: the survivability of U.S. combat aircraft needed to increase. Jamming was not enough.

The answer to this came in the form of stealth. The Defense Advanced Research Projects Agency (DARPA) first began to champion stealth as a technology that would not just counter radar detection and tracking, but side-step it altogether.[27] After an initial investigation with Northrop and McDonnell Douglas in 1974, DARPA and the Air Force awarded both Northrop and Lockheed individual contracts for the Experimental Survivable Testbed (XST) program in 1975.[28] Each team pursued different approaches to reducing radar signatures, proving a useful means to rapidly develop an innovative technology while providing a hedge for failure.

Lockheed won the low radar-cross section measurement and began development of Have Blue, the plane that would evolve into the F-117. This first low-observable stealth aircraft became operational in 1983. Although Northrop did not win that phase, they continued development work, creating the next generation of stealth in the smoothed form of the B-2. Multiple, concurrent yet diverse industrial efforts yielded a robust, multifaceted set of technologies. Stealth became a long-term advantage for U.S. forces in the B-2, F-22, F-35, and eventually the B-21—an offset that continues to endure.

Combined, precision strike and stealth were responses to the exigencies of actual combat and the emergent opportunity presented by technology. The shortfalls of the Air Force's force design in the 1960s and 1970s, paired with the Soviet Union's nuclear parity and continued advantage in pure numerical mass, illuminated the need for a new offset. To compensate for smaller numbers, the Air Force pursued a force design that emphasized quality in the form of technology and training. In addition to stealth and precision-guided munitions, advanced processing; intelligence, surveillance, and reconnaissance (ISR); and positioning, navigation, and timing (PNT) were developed as part of a force design to counter Soviet defenses and forces.[29] This transformation, however, took decades to realize. In 1981, then-Secretary of Defense Harold Brown described what was only beginning to coalesce as the second offset strategy: "Technology can be a force multiplier, a resource that can be used to help offset numerical advantages of an adversary."[30]

Together, these second offset technologies provided a synergistic advantage against the Soviet military, in which quality offset quantity. The effect of these innovations was not merely additive. A major study

Quantity is Still Required

Quantity has an impact on pragmatic matters of force management, not just offset strategies. While it is true that some degree of force cuts were justified in the wake of the Cold War, too few leaders asked how small was too small. Compounding this mistake was the failure to procure quantities to allow for realistic attrition and loss inventories. Instead, budgetarily convenient assumptions used an immaculate notion of warfare and perfect operational practices. Pragmatic math speaks otherwise. With such a small fleet, the United States lost 5 percent of its long-range stealth bomber force when a single B-2 crashed in 2008. With no active bomber production line, the Air Force had to eat the loss. When it nearly lost another B-2 due to a severe engine fire, the Air Force had to endure an incredibly expensive rebuild because the nation simply could not afford to lose a single aircraft's operational potential. Policy leaders need to have a certain inventory of tools to facilitate options, and that inventory needs to have sufficient resiliency to reset when mistakes happen. Today, with half the fighter force structure than at the end of the Cold War, there is no such margin.

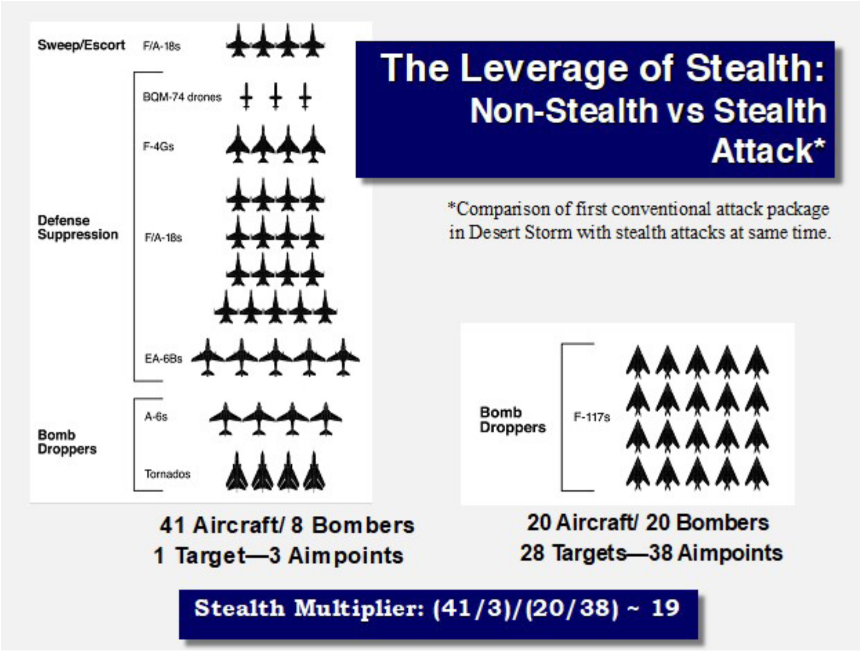


Figure 4: The Impact of Stealth and Precision on Force Sizing. Operation Desert Storm clearly demonstrated the value of second offset's stealth and precision. Advanced technologies realized the promise of the second offset strategy. Combat operations were more efficient and effective. In the decade that followed, this had the perverse effect of perpetuating the belief that that U.S. military could become ever more capable while also becoming smaller and, therefore, more affordable.

Credit: D.A. Deptula

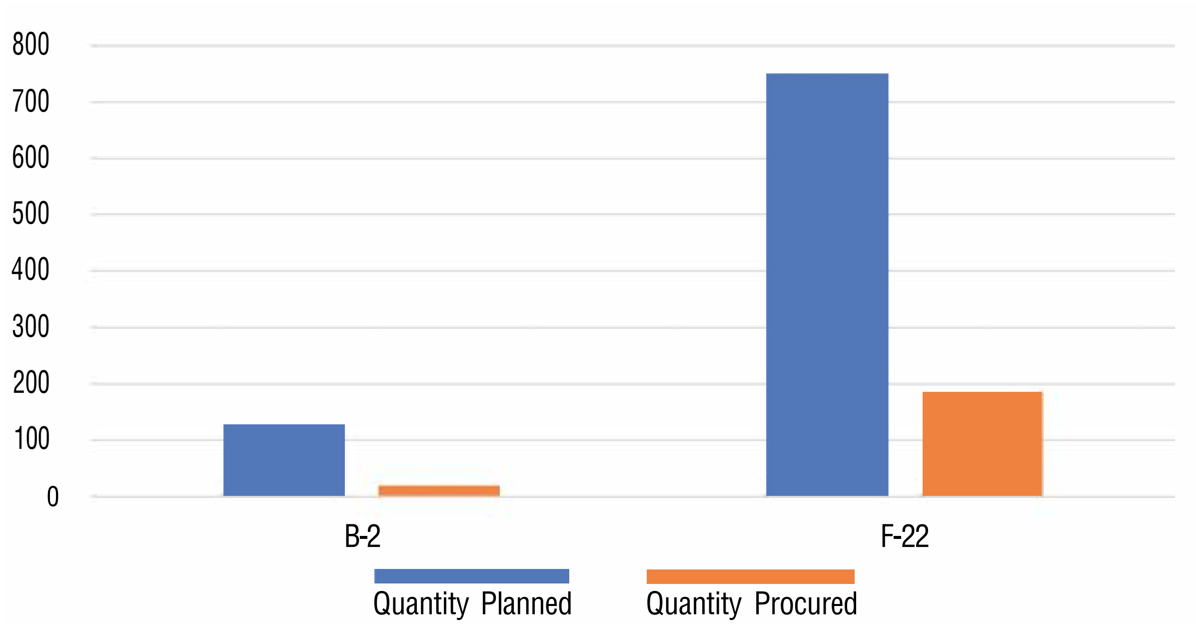
in 1986 by the Commission on Integrated Long-Term Strategy recognized the revolutionary nature of this technological collaboration: "Particularly important in this connection is the prospective use of 'low observable' (stealth) technology in combination with extremely accurate weapons and improved means of locating targets."[31] Stealth aircraft could deny adversary air defense forces not only the ability to target U.S. forces, but even the knowledge of impending attack. Advanced electronics and processors, precision weapons, and navigation and timing resulted in a battlespace awareness with an unprecedented degree of insight and enabled the force to precisely deliver bombs on target, on time, and return home intact to fly a future mission.

The promise that technology could offset an adversary's larger force took over two decades to bring together but was ultimately validated in the overwhelming success of Operation Desert Storm. Although the Iraqi army was 500,000-man strong and battle-hardened from its long war with Iran, the United States and coalition partners operated with near impunity in the highly decisive conflict. Small numbers of stealthy F-117s navigating with GPS dropped individual laser-guided bombs against targets with such precision and devastating effect that the "lopsided U.S. victory was widely considered to be evidence of an ongoing revolution in war."[32] Desert Storm air campaign lead planner Lt Gen (ret.) David Deptula noted, "In some cases, a single aircraft and one PGM during the Gulf War achieved the same results as a 1,000-plane raid with over 9,000 bombs in World War II—and without the associated collateral damage."[33]

Better and smaller? The deleterious legacy of the second offset

After the overwhelming success of Desert Storm and the fall of the Soviet Union, the military and technological dominance of the United States inverted the purpose of the offset approach. With the Soviet Union no longer a threat, great power conflict was likewise no longer driving force design. The U.S. military seemed too big for the threats it would encounter. In the past, America's reliance on technology as an offset was to compensate for a smaller force. Now, it conversely justified a smaller force. Offset thinking in this era produced an insidious notion that capacity was not a key factor in force design. Instead, the notion of offset strategy was used to justify radical capacity cuts. Technology allowed the military to be smaller and still get results in an era dominated by lesser regional threats—not peer adversaries.

America grew highly reliant upon and complacent with this "offset" thinking. Capacity reductions were taken to an extreme, falling below what it would even take to sustainably project power against regional adversaries. In 1993, the Air Force dropped its fighter wings from 36 to 27. The Office of the Secretary of Defense's Bottom-Up Review, completed that same year, further reduced the Air Force's strength to 20 fighter wing equivalents.[34] Leaders in the Department of Defense and Congress prematurely terminated the full procurement of key platforms like the B-2 and F-22, using capability as a justification to reduce quantity. B-2 production, originally planned for 132 aircraft, was stopped at 21. The highly advanced stealth F-22 saw its program of record numbers fall from 750 to 339 aircraft over the decade.[35] Production would ultimately end at 187 aircraft. Ironically, these reductions in total quantities did not even come with a commensurate cost savings, since the cost per platform tended to increase with the reduction in numbers. The difficulties of managing such small fleets also increased cost. Older, legacy platforms that were supposed to be replaced, like the B-52, B-1, and F-15, have had to remain in the inventory to support high operational tempos due to unanticipated conflicts. Their outsized sustainment costs are now a growing burden on the Air Force's budget and a major revenue center for industry.



Credit: Mitchell Institute

Figure 5: B-2 and F-22 Original Quantities v. Actual Buy. Curtailed procurement of key aircraft modernization programs meant that the Air Force lost out on fielding more advanced capability, but it also meant that it had to keep older aircraft in the inventory. The B-2 actual procurement was 15% (20 of 132) of planned, and the F-22 25% (187 of 750). This imposed costly sustainment bills and upgrade programs that diminished available budget space for new aircraft development. The smaller fleets of the B-2 and F-22 also meant that sustaining and operating these newer aircraft were more expensive than planned, and the associated high ops tempo has placed tremendous stress on both aircraft and aircrew, prematurely aging the fleets.

The premature termination of new production aircraft not only withdrew the opportunity to reap the benefit of these technological investments and reset the Air Force's force design, but it also sent a signal to the aerospace industry that production programs are unreliable business lines. Had programs like the B-2 and F-22 been procured in their original quantities, the Air Force would not be in as dire a crisis as it is today. This crisis now spans both the Air Force and the aerospace industry.

The Air Force is struggling with its aged, legacy aircraft that demand expensive sustainment and service life extensions. It missed the chance to recapitalize aging platforms, but it also bypassed key opportunities to realize the advantage of crucial technology investments. For example, stealth, in an operational context, has existed for nearly four decades, yet, today, only 19 percent of the fighter inventory and 13 percent of the bomber inventory are low observable.[36] The originally planned smaller numbers of F-22 and B-2 were predicated on stealth aircraft being more survivable, but now their relatively small quantity—even with F-35 aircraft entering the fleet—may not be sufficient to achieve the desired effect of the offset strategy approach.

These production cancellations—with new-start programs few and far between—created pressures that the aerospace industry had to adapt. Relying on foreign military sales to prop up aircraft production of legacy types, industry adapted its structures to align better with its profit centers: sustainment, modernization, and integration. Aerospace companies cannot afford to hold excess engineering talent on speculation. They have optimized their organizations for the business they have and can project. The consequence of canceled and terminated programs is diminished core competencies like aerospace design teams and production capacity.

Too many planners now assume level of asymmetric dominance thanks to the existence of key technologies, but they fail to realize that the anemic quantities of aircraft procured lack the capacity to deliver true overmatch.

Under current conditions, the United States has at least a three-year time horizon for strategic surprise. Even under the best circumstances in the current era, assuming a hot production line exists, it generally takes at least three years to fabricate an aircraft and put it on an operational ramp. Said another way, the nation does not have the ability to rapidly surge aircraft production in the event of a crisis. Without the needed quantity in the force, such timelines present a serious risk to airmen, service members, our nation, and our allies. This is truly a case where, as Secretary of Defense Donald Rumsfeld said, "You go to war with the army you have, not the army you might want or wish to have at a later time."[37] If any Black Swans or even open signs of impending hostilities occur within a three-year time horizon, it is already too late for the nation to adequately prepare.

While acquisition policy and bureaucratic constraints could be overcome in a crisis, there are still very real physical limitations to the speed and scale of manufacturing. It takes time to acquire raw materials, produce long-lead items, fabricate major systems and subassemblies, and conduct final assembly. All this assumes an existing design with hot production and an active supplier line. If a production surge was required, add even more years to this; current production lines are sized for low-rate production. It takes time to create additional manufacturing capacity because of factory limitations, tooling creation, and workforce. It would take even longer for a new aircraft type that needed to go through the design, prototype, testing, and initial production, not to mention the time needed to work through the pragmatic details of operationalizing the type. Given the complexity of multi-role, multi-function platforms, the development, production, and fielding of these weapon systems would be exceedingly difficult to compress. Air Force acquisition trends have depleted the aerospace industry's ability to meet such a challenge. Defense companies are ill-suited to rapidly design and produce a diverse and adaptable force.

All this means that the United States has few options in the event planning assumptions are wrong and an unforeseen threat emerges. History has proven that U.S. crisis forecasting is poor. Simply consider Pearl Harbor, North Korea's invasion of South Korea, the U.S. entry in Vietnam, Saddam Hussein's invasion of Kuwait, the fall of the Soviet Union, the attacks of 9/11, the resurgence of an aggressive Russia, and the rapid military modernization of China. Forecasts missed each one of these significant changes to the defense environment.

Decisions to cut capacity and defer recapitalization have had serious consequences not just on the Air Force, but the aerospace industry.

Actions taken by the U.S. defense establishment over the past three decades have restricted the nation's flexibility and resiliency to competently respond to unforeseen threats and events. That is why the country "keeps getting its ass handed to it" as Ochmanek so succinctly stated. As the Air Force, DOD, Office of Management and Budget (OMB), and Congress cut and canceled planned recapitalization programs, the service has had to extend the service lives of older aircraft. Reductions have ultimately yielded a force design that is unable to realistically match the strategies it is now charged with executing.

This deficit strains current Air Force operations, which must sustain commitments around the globe, because limited budgets are focused on sustaining existing capabilities, not accelerating innovation and production. Too many planners now assume level of asymmetric dominance thanks to the existence of key technologies, but they fail to realize that the anemic quantities of aircraft procured lack the capacity to deliver true overmatch. They are not a "silver bullet" force, they are a hollow force. The Air Force is too small for its legacy aircraft to be effective, and they do not have enough "next-generation" aircraft to fully enable new operational concepts. Decisions to cut capacity and defer recapitalization have had serious consequences not just on the Air Force, but the aerospace industry.

Finding New Attributes to Offset Adversaries

Past U.S. offsets have focused on, specifically, leveraging advanced technologies. But an offset strategy could focus on other attributes, such as *quality*, *quantity*, *diversity*, *adaptation*, and *speed*. Force design choices based on an offset strategy can dial any one of these attributes up or down to yield a holistic advantage. To achieve the desired strategic effects of an attributes-based offset, it is first important to understand and define these attributes and their properties:

Quality generally refers to advanced technologies and is often synonymous with "capability." Leaps in technology shaped U.S. military dominance for over forty years—technologies like stealth, precision strike, highly accurate navigation and timing, and global reach. While advanced capability will continue to underwrite U.S. strategy and forces, adversaries are quickly developing and fielding similar technologies and weapon systems, turning the competition into a symmetrical one. Given the long lead times needed for the United States to field its newest, most capable technologies, this is a competition that it risks losing.

Quantity is reemerging as an essential element of force design, and it is driven by three challenges: 1) effectively covering range and geography with tempo and mass; 2) presenting the adversary with sufficient system complexity to complicate their targeting and operational strategy; and 3) withstanding attrition in contested environments to remain operationally resilient and effective. A symmetric competition of attrition is no longer the only objective of this attribute. Instead, defense leaders must understand how to best leverage quantity in its force design to offset adversary strategies.

Diversity describes how many different types of capabilities are in each mission area. For example, the Air Force has three types of bombers: B-52, B-1, and B-2. Diversity fosters resiliency through optionality and redundancy—if one platform is unavailable, another can fulfill the tasking. Diversity also complicates the adversary's planning and targeting, as it must account for more than one type of weapon system. When combined in different force packages, diverse systems create a complex presentation to the adversary. Yet, the desire to gain efficiencies has reduced diversity in U.S. force structure for decades. Continuing this trend would only simplify an adversary's targeting problem.

Adaptation includes the ability to field new capabilities, readily modify existing weapon systems, and pursue new, flexible operational architectures and force compositions—to include how those platforms collaborate in the battlespace. Finding offsets based on this attribute would disrupt the adversary's understanding of U.S. capabilities and operations—by constantly evolving them—in ways that provide U.S. forces the initiative and advantage.

Speed is the pace at which the United States can develop new capabilities, produce and field them in operationally significant quantities, and then adapt them to battlespace exigencies. It might also be considered the rate of change. This attribute is crucial to disrupting adversary awareness, understanding, decision, and action. This pace must exceed an adversary's ability to adapt. It is also key to maintaining operational relevancy.

Time as the new Offset

Without the pressing threat of the Soviet Union, military budgets shrunk in the post-Cold War era. This fueled the perception that more advanced capabilities were more effective and enabled a smaller force size. But developing advanced capabilities takes time and decreases the force's overall adaptability. It also takes money. As defense leaders of the past three decades sought to find economies in force management, this diminished force diversity. Budget pressures also drove smaller fleet sizes. This phenomenon only increased the imperative for advanced capabilities and accelerated the move to consolidate these capabilities in multi-role platforms. The flexibility of these aircraft to cross mission sets justified even smaller fleets and further accelerated the loss of diversity. Perpetuating this reliance on small fleets of multi-mission aircraft ultimately diminished the force's ability to compete in adaptation and time.

In a world where peer adversaries have technological parity or even a genuine lead, the real strategic offset now is time. No longer can the nation afford to wait decades for a single, game-changing, multi-role weapons system.

Today, the Air Force's force design reflects decades of choices that have prioritized *quality* over any other attribute. To achieve a competitive advantage now, the Air Force must pivot to harness the advantages of adaptation and speed. No longer is the development of exquisite and enduring technologies the exclusive purview of the United States. The proliferation of advanced engineering and manufacturing bases around the globe has reduced the long-term outsized value that such efforts once afforded. In a world where peer adversaries have technological parity or even a genuine lead, the real strategic offset now is time. Speed of adaptation must now drive all the other attributes of force design. No longer can the nation afford to wait decades for a single, game-changing, multi-role weapons system. Rapid, incremental fielding of advancing quality through diversity and scale is how the United States will be able to meet the range of its national security commitments.

Previous offset strategies relied upon massive leaps past adversary capabilities. The advantages inherent with such technological developments relied on the assumption that resulting gains could be held for an extended period. While such progress can take years or even decades to develop, each successive advancement would buy the window necessary to field the next major step. Whether pursuing smaller warheads of various nuclear yields, massive air defense systems and associated interceptor aircraft, precision-guided munitions, or stealth, these kinds of technologies took time to field, but they provided an enduring advantage.

The advantages afforded by offsets last only so long as the capability is exclusive. Once an adversary fields their own symmetric capabilities, the overwhelming advantage that technology provided is mitigated. The technology then becomes a baseline from which to advance a new competition. Stealth is one example of how such competition evolves. Once an exclusive U.S. capability, America's adversaries have been pursuing stealth as well as developing air defenses that may be able to track and target low observable aircraft. This does not mean the United States should give up on stealth attributes in its future force—that imprudent choice that would simply make U.S. forces easier to target and give away a key advantage. Instead, stealth must be a baseline from which to compete. Other technologies, like electronic warfare and space surveillance, will likely follow a similar path. To relinquish those technologies would simply cede the offset advantage to the adversary.

To this point, New Look was credible as a deterrent only so long as U.S. nuclear forces could maintain unambiguous superiority. This was one reason that the Soviet launch of Sputnik in 1957 was so destabilizing to U.S. national security. Sputnik signaled that the Soviet Union had an advantage in the development of intercontinental ballistic missiles (ICBMs), a nuclear delivery mechanism for which the United States had no defense or counter.[38] Sputnik spurred not just the race to the moon, but a missile race. By 1962, the United States had more land- and sea-based launchers, but it still had to compete with the Soviets in the missile and warhead technology. Although each pursued a slightly different missile strategy—the Soviets preferred large missiles with high-tonnage, while the Americans preferred the more numerous and precise MIRVS—this had become a symmetric competition.[39] All the while, nuclear weaponry still remained a key part of each country's defensive calculus.

Speed will provide the asymmetry required to prevail in any peer contest. Technology is not the exclusive advantage of the United States.

In 2014–2015, DOD leaders proposed a suite of technologies as a third offset, but these are unlikely to remain exclusive advantages to the United States. Areas of research included "autonomous learning systems, human-machine collaborative decision-making, assisted human operations, advanced manned-unmanned systems operations, and network-enabled autonomous weapons and high-speed projectiles."[40] The pursuit of these technologies will, like past offsets, maximize the combat potential of a constrained U.S. force. Innovation will always remain an important aspect of maintaining a competitive edge, and it should be pursued. However, many defense professionals assess China to have a lead in some of these technologies already. Machine learning and artificial intelligence are key areas where China's structure and massive data provide a clear lead.[41] Furthermore, China is aggressively pursuing hypersonic missiles such as the DF-17 boost-glide and the Xingkong-2 hypersonic waverider vehicles.[42] While debate may surround the maturity and capabilities of these efforts, what is clear is that these third offset technologies will not be the sole advantage of the United States. Time, paired with continued technological innovation, may be a better offset strategy.

In this new offset strategy, time—operationalizing new capabilities at speed—is the asymmetric advantage. Technologies still matter, and advancing capability still matters, but these innovations do not need to be massive game-changers in the traditional sense; they do not need to confer decades of advantage. Instead, rapid adaptation should be the focus. The United States must be able to field a force that can present unexpected force mixes with unanticipated operational architectures at speed.

A force design that could support such an offset strategy requires a diverse portfolio of capabilities. Quality, in this context, does not mean multi-function or multi-role aircraft, but the constant advancement of technologies that may be fielded in mission-specific or simple-function types. Uncertainty is imposed on the adversary through the different and unpredictable force compositions made possible by the combination of quality, diversity, and quantity. When viewed as whole, this is what enables the force design to be adaptable. At a technological level, this force design constantly innovates, fields, adapts and changes at a pace that fundamentally disrupts the adversary's strategy and operations. To support this, industry must be capable of rapid-cycle fielding such that adversaries are denied the opportunity to study U.S. operations and architectures to target their strengths and vulnerabilities.

There are three crucial elements to a temporal advantage. First, the United States must be able to field new capabilities faster than it has in the past. In recent decades, extended development timelines have made U.S. force structure predictable, allowing adversaries to easily anticipate and lead-turn U.S. technologies. Second, the United States must be able to field a technology or adaptation faster than the adversary's ability to negate it. This can roughly be considered "faster than red," and provides U.S. forces an advantage because it enables them to operate inside adversary adaptation cycles. Finally, the United States must field capability fast enough for it to be operationally relevant. This shifts the risk calculation from demanding 100 percent perfection before a system is fielded to understanding that quickly getting to the warfighter, even with some limited capabilities, is of greater importance and advantage.

Speed will provide the asymmetry required to prevail in any peer contest. Technology is not the exclusive advantage of the United States. A new offset strategy must shift the competition out of symmetry, and time offers that potential. In this context, the pursuit of new capabilities is about how quickly it can get to field. Adaptation at speed is the new advantage. Yet the defense enterprise is not positioned to compete in this new kind of offset.

How Defense Offsets Have Shaped the U.S. Aerospace Industrial Base

The aerospace industrial base has been shaped by, and is the product of, the acquisition choices and policy actions of the Department of Defense, the Air Force, and other government entities like OMB and Congress. In recent decades, Air Force procurement decisions have largely been driven by the Cold War-era assumption that quality can continue to offset smaller quantities. However, as discussed, this will likely only lead to solutions that are easy for adversaries to predict and plan against. Furthermore, these choices have caused the defense industrial base to optimize its structure and business models for predictable programs, not frequent new-start programs of extremely complicated designs. Of course, the defense industry is a highly rational actor merely responding to the conditions and circumstances presented to it by the government customer. Aerospace companies have been particularly affected because of the intensive capital and talent demands associated with aircraft design and production. The companies that survived the "optimization" of the industry—through exits, mergers, and acquisitions—evolved their business models to maximize profitability in the face of these trends.

A primer on the trends that shaped the U.S. aerospace industrial base

The 1950s was a vibrant decade for the aerospace industry. Harnessing the diverse design and production infrastructure created by World War II, Air Force leaders had the luxury of soliciting ideas and inputs from a broad set of highly competent actors. The unique nature of the Soviet nuclear bomber threat and the need for air superiority and interdiction over Korea meant that airpower was recognized as a critical military advantage. Defense strategies aligned with this perspective. Consequently, the Air Force enjoyed roughly 50 percent of the defense budget.[43] The service aggressively pursued new engine technologies, supersonic airframes, and advanced electronic systems. The Air Force had a robust experimental aircraft program, over ten major aircraft manufacturers, and fielded six aircraft—a rate never since matched. The diversity of aircraft designs and multiple production lines provided the Air Force significant optionality in adapting to emerging mission needs, compensated for unexpected delays or discoveries, and generally provided a strategic hedge.

Secretary Robert McNamara's work throughout the 1960s sought to rationalize and centralize defense programming to achieve cost and business efficiencies. These transformations were largely based upon economic practices he observed in the commercial sector during his leadership tenure at Ford. But the commercial practices he introduced set the stage for the long-term decline of the defense aerospace business. McNamara imposed the joint procurement of the F-4 and the A-7 on the Air Force.[44] By forcing the convergence of aircraft fleet types across the services through joint procurement, McNamara effectively denied market opportunities to multiple aircraft manufacturers. McNamara also sought to achieve cost efficiencies through joint development of the TFX (Tactical Fighter Experimental), which became the F-111. The program had significant cost overruns, and the joint development imposed many design compromises on the aircraft. When the Navy abandoned their version of the F-111, the Air Force was left to make the best of what remained in the design through a conventional strike aircraft and dedicated

Photo: USAF

Figure 6: General Dynamics F-111 Aardvark. Robert McNamara forced the joint Tactical Fighter Experimental (TFX) program on both the Navy and the Air Force to rationalize the Department of Defense and generate cost efficiencies. Yet the operational realities of the two services could not be reconciled, even after significant design compromises. The Navy ultimately left the program and built the swing-wing fighter it really wanted, the F-14, but not before the TFX left its mark – the joint program diminished competition opportunities and caused several aircraft companies to wholly exit the industry. The Air Force was left with a sub-optimized design and never realized the promised cost savings.

nuclear attack variant. Commonality and advanced capability were incompatible. The TFX program failed in its intent when the Navy left, but the notion that a jointly developed fighter could both meet the mission performance requirements of multiple services while delivering cost efficiencies would later have a profound impact on shaping the Joint Strike Fighter (JSF) program and shrinking the industrial base.[45]

The 1970s was a reversal of this trend. The iconic Air Force fighters of that decade—the F-15, A-10, and F-16—were all approved and developed after McNamara left office in 1968. Air Force senior leaders recognized the value of quality, diversity, and speed as they sought to reset their force design from the Vietnam era. The increasing specialization and capability of weapon systems—driven by the emphasis on offset technologies—ran counter to McNamara's desire for commonality.[46]

Three main factors widened the market for industry: the services' bid to regain control of their programs, the failures of joint development, and the specialization of mission sets based on the need to out-pace Soviet advantages. Recognizing it needed a successor to the F-4 and to avoid having the Navy's F-14 imposed on the service, the Air Force emphasized performance capable of countering the MiG-25 Foxbat, which neither the F-4 nor the F-14 could match.[47] The first of these specialized aircraft was the F-15. Lessons from Vietnam highlighted the need for a specialized air-to-air combat fighter, and the Air Force refused to compromise the air superiority mission to fulfill secondary requirements.[48] The A-10 close air support aircraft was a rejection of the Navy-developed A-7, and the F-16 was an Air Force-specific exploration of the lightweight fighter concept.

The desire to avoid another TFX or joint procurement was not simply bureaucratic posturing. The mission-specific design of these aircraft provided clear focus for engineering teams and enabled smart trade-off decisions. Although being revolutionary and incredibly complex for its time, as a mission-specific design, the F-15 was simpler than an equivalent multi-role design, and it was subsequently able to field in just over seven years after contract award.[49] The A-10 and F-16 had even faster fielding times. It is worth noting that these mission-specialized aircraft have carried the Air Force for an unprecedented length of time—over four decades. They fundamentally raised the bar of quality and adaptability. While many of these aircraft later gained multi-role capabilities, those were added in later models, after focused mission systems had matured.

The 1980s are well known as the defense build-up, but the Reagan years were largely a decade of force structure turn-over as older types were retired and new production examples were fielded. The Air Force aircraft inventory remained relatively flatlined from a quantity perspective, but the robust build rates of highly capable aircraft were incredibly important to the select companies that had secured production contracts.[50] Conversely, despite aggressive buy rates of existing designs, this decade did not offer companies opportunities for new-start Air Force contracts. Vought, largely a Navy-specific firm that had built the F4U, F-8, and A-7, turned to sub-system production as a means of survival. Companies like Republic and Fairchild, producers of the P-47, F-84, F-105, and A-10, do not even exist anymore in any form because there was no follow-on business.

Photo: USAF

Figure 7: McDonnell Douglas F-15 Eagle. The F-15 was as much an institutional response to McNamara's multi-mission TFX as it was a response to the hard-learned air combat lessons from the skies over Vietnam. The specialized mission focus on air superiority, articulated in the program motto "Not a pound for air-to-ground," provided engineers and managers clear criteria for design trade-offs. Although the F-15 was the most sophisticated aircraft of its time, with new sensors, technologies, and system integration, it was fielded only 7 years after contract award.

Ironically, the numbers produced during the Reagan build-up and their inherent performance qualities ultimately laid the groundwork for an industry bust cycle. The fall of Soviet Union in 1991 set the strategic context that justified large defense budget cuts. Without any clear threat, the Air Force could coast on its existing inventory while still clinging to the notion of offset superiority. Service life extensions and capability modernization programs would bridge any perceived shortfalls. This meant a drought of production, as the Air Force competed its buys, and no new-start competitions.

At the infamous "Last Supper" in 1993, Secretary of Defense William Perry told a group of CEOs that there would not be enough defense business to sustain the sector.[51] This explicit direction would create the most dramatic exit, contraction, and vertical integration the aerospace industry had ever seen. With defense budgets dropping in the wake of the Cold War, DOD leadership believed that they had excess industrial capacity. Perry told the industry that "We expect defense companies to go out of business. We will stand by and watch it happen."[52] The impact of this turning point cannot be overstated. In fact, this cycle has not stopped. Perry would come to regret the period of consolidation that followed the last supper. In 2015, he characterized the outcomes as "unnecessary, [and] undesirable," noting that the overhead efficiencies and cost reductions the department was seeking never materialized. "What we got was the consolidation of the defense industry—few large companies, less effective competition… We would have been better off with more, smaller firms that with a few large ones."[53]

Understanding the aerospace industrial base of the 21st century

Since the 1990s, Air Force acquisition trends have prioritized economies of force—maximizing the mission roles of any single weapon system—to the continuing detriment of the industrial base. In pursuing an offset approach that relies upon highly advanced technologies over quantity, speed, or adaptability, the DOD has chosen to shrink the available market for new production. Advancing technology has only exacerbated this trend. The ever-increasing need for processing power has pressured the service to expand multi-mission capability to gain even more force efficiencies. The result has been extremely capable, multirole platforms that negate the need for alternate mission-focused or single-role systems. The net effect has been a decrease in the diversity and quantity of Air Force inventory. While some may positively perceive operational and sustainment cost savings resulting from consolidating and downsizing the force, it has also had the effect of shrinking the aerospace industry in ways that diminish the development of future capability. The trend toward homogenization of the Air Force inventory has created a market dynamic which decreases defense companies' opportunities to compete and win new business.

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To understand why this is so, it is first important to understand that the U.S. aerospace industrial base is a monopsony. In commercial markets, multiple suppliers compete for the business of a wide array of customers. Companies must adapt to changing environments, products, and consumer preferences, but the sheer volume of customers allows for multiple companies to exist in the same market and for companies to even shift their target markets. In a monopsony, this is not possible. Companies are hostage to the buyer's behavior; there is no alternative market. As a monopsony system, defense companies are reliant on one major customer: the U.S. Department of Defense. Business is even further complicated by the many equities in defense management and budgeting, including the DOD, the political administration, OMB, and Congress.[54]

In other words, because defense is a monopsony market, the aerospace industry has been significantly impacted by the acquisition choices of the past 30 years. Companies must adapt to DOD buying trends in terms of their products, structures, and business models. Despite industry efforts to shift business to the international market, there is no real alternate customer.[55] This is especially true for the most capable weapons systems critical to these kinds of offset strategies. The Obey Amendment, for example, precludes the F-22 from being licensed or sold to any foreign country, even the most trusted U.S. allies.[56] Even lesser forms of technology, like unmanned aerial vehicles, are difficult to sell abroad thanks to provisions of the Missile Control and Technology Regime (MCTR). In the defense monopsony, sellers are largely fenced from the full range and diversity of potential buyers.[57]

If the Air Force, and the DOD writ large, continue to cling to what are misplaced notions of "smaller and better," it risks continuing this trend. The last thirty years of deferred and aborted recapitalization are now a lost opportunity. The Air Force is facing a recapitalization cliff because it did not procure key capabilities like the B-2 and F-22 in planned quantities. The F-35 now risks this same fate. Because the service failed to field these important technological advancements, it then had to extend the life of the legacy platforms those new systems were meant to replace. Subsequent fleet management dynamics are also driving the Air Force toward a smaller, more homogeneous force design. Cut buys and deferred replacements have left the service with old fleets and high sustainment bills for aircraft that are not survivable in a peer competition. The higher the sustainment, the less discretionary budget to recapitalize, which decreases total quantities. It is a vicious cycle. Now, the high cost of sustaining and modernizing those older aircraft comes at the expense of exploring new operational concepts, developing, and fielding newer types of capabilities, and creating a more diverse mission portfolio. Furthermore, smaller inventories increase the need for new platforms to be multi-mission and extremely advanced. But the increased sophistication means a higher cost-per-unit, which in turn pressures program rate and total procurement. The net effect of this dysfunctional dynamic is the decreased diversity of aircraft types, total production quantities, and frequency of new-start competitions.

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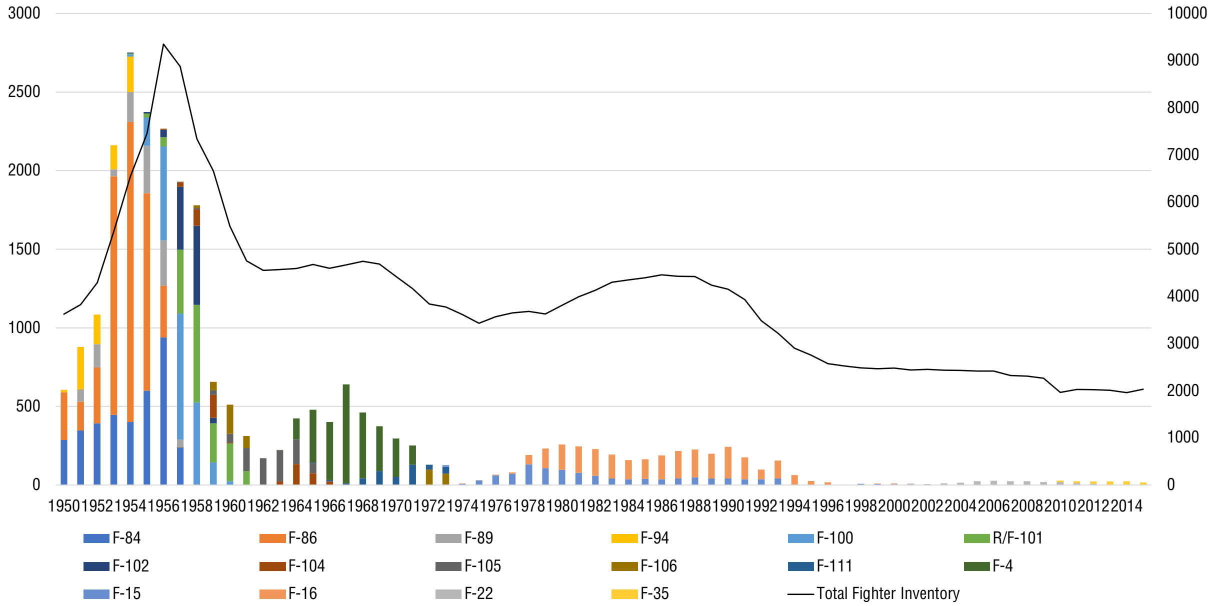
Industry has optimized for Air Force programmatic paradigms and acquisition behavior, which has, in turn, contracted the industry. Some companies have exited aircraft design, development, and production to specialize in subsystems. Others have merged or been acquired by larger companies. Yet others have left the industry entirely. Cuts in planned buys only further amplify the challenges for industry—winning a competition and securing a contract is not a guarantee on a major return in mass production and sustainment.



Credit: MItchell Institute

Figure 8: Fighter Production and Inventory, 1950–2015. The 1950s was a period of rapid technological refresh in the Air Force's fighter fleet, as production nearly matched total inventory. Furthermore, it represented a diversity of fighter types, enabling rapid innovation among a large competitive aerospace base. At its peak in 1954, fighter production reached 2,700 of six different types. Production numbers and diversity dropped off radically in the 1960s, but a stable total fighter inventory also indicates the service began to retain aircraft across a longer service life. What is largely remembered as the Reagan build-up in the 1980s is actually a fleet turn-over, where aircraft designed in the 1970s, the F-15 and F-16, replaced earlier types. As can be seen from the historically low fighter production from the mid-1990s onward, production rates have not come close to replacement rates; aircraft designed in the early 1970s remain the backbone of the fighter fleet.

The complexity of exquisite systems and the need to partner in major platforms for design, engineering, systems, and political support has caused the three remaining prime defense contractors to refocus their major engineering expertise into system integration. They have also found sustainment and modernization work more lucrative, given the extended duration of aircraft service life and time between competitions. This ultimately pulls resources from development and production in the broader budget construct. Over four decades into the second offset, these adaptations have become inherent in the current defense aerospace sector.

Consolidation of the aerospace industry and lead system integrators

The last thirty years has seen the most dramatic consolidation of the defense industry since WWII. One defense analyst found that by the end of the 1990s, 107 defense companies had become five.[58] Mergers and acquisitions have not slowed down. In April of 2020, Raytheon and United Technologies completed a merger, bringing together two large defense portfolios of sensors, subsystems, engines, and weapons.[59] Again, these industry mergers, acquisitions, and exits are all rational responses to defense acquisition trends and procurement paradigms.

With fewer new business opportunities, companies have had to expand the range of their business portfolios to ensure growth. No longer can a company succeed on a single value proposition like aircraft design and production. The mergers and acquisitions that created the massive defense primes of today did preserve some areas of expertise and skills that might otherwise have been wholly lost. However, the extreme consolidation of the industry has also created such a narrow field of competition that it risks losing out on the innovation and creativity that a more diverse defense industry could offer. Perhaps even more worrisome is that the extreme consolidation of the aerospace defense denies the Air Force, and the nation, strategic hedging options as the service builds into a future force.

In 1950, there were at least nineteen credible military aircraft companies. Today, only three major producers exist: Northrop Grumman, Boeing, and Lockheed Martin. As prime contractors, these companies tend to specialize in type. Northrop Grumman builds bombers; Boeing builds airlift and aerial refueling platforms; and Lockheed Martin builds fighter aircraft. Yet as "competimates," these companies often partner with each other. Both the F-22 and the F-35 are representative of today's defense aerospace industry. These programs involve multiple major defense companies: the major partners on the F-22 are Lockheed and Boeing; the F-35 is built largely by Lockheed Martin, Northrop Grumman, and BAE.

This trend to partner on major programs has shifted the engineering talent of large prime contractors toward system integration. Partnering on a single program spreads limited production business across the industry, maintaining a larger pool of companies than what might be possible to otherwise support. Additionally, companies have different strengths, and partnering allows a program to leverage their expertise and specialties. System integration is actually an advantage of the industrial base as the Air Force looks to future warfare. Still, a hidden risk of this evolution is that the traditional aircraft design and program experience needed to field new aircraft may be lost.

Integration has always been a basic skill necessary for aircraft design. What is different in today's design ecosystem is the extent to which aircraft design is outsourced beyond the prime contractor. Different companies design and even fabricate sub-assemblies like the wings, main fuselage, cockpit, and so forth, while the prime contractor manages, oversees, integrates, and conducts final assembly. The F-35 program has more than 1,900 domestic suppliers and integrates major parts and sub-assemblies from over eleven global suppliers.[60] The Boeing T-7 had major design and production participation from its partner, Saab, drawing core elements from the Swedish contractor design of the Grippen aircraft.[61] This globally distributed model of design, integration, manufacturing, and assembly now largely defines aircraft development and production.

This strategy may spread revenue and political support across the industry, but it does not create a deep bench of holistic experience or innovation in aircraft design and development. It endangers the industry's ability to cultivate engineering talent. With few new-start opportunities, engineers may only have narrow experience on a single program, depriving them of the repetitions, variety, and experience that truly enables unique insight and innovation. These dynamics are only further exacerbated over the long developmental time of current programs. A multi-decade effort could see one person focused on a single design for their entire professional career. Conversely, famed Lockheed design leader Kelly Johnson worked on 40 individual aircraft during his tenure.[62] Aircraft engineers like Lloyd Stearman, who was a pioneering figure in the 1920s and 1930s, concluded his career in the 1960s working on vertical take-off and landing jets, as well as space reentry vehicles.[63] This allowed for tremendous intellectual discovery and, most importantly, the ability to apply lessons learned across a diverse portfolio of systems. Today, things look very different in the professional ranks, with career progression opportunities focused on management, not design, opportunities. The insights and wisdom gained through iterative new design work is limited. As with anything, excellence is generally honed through practiced repetition and lost without it.

Aircraft design solves the very real and physical problems of range, payload, maneuverability, speed, altitude, endurance, stealth, and newer attributes such as software, weight, power, and cooling. Each of these attributes comes at a cost to another. The art of aircraft design is managing these trade-offs to optimize the system for its mission requirements. For example, a highly maneuverable aircraft is unlikely to have an extended combat radius or a significant payload. Similarly, an aircraft optimized for endurance is unlikely to be fast or highly maneuverable. Hence, the F-16 cannot match the unrefueled range or carry the same weapon load-out of a B-1; an RQ-4 has incredible endurance but cannot pull 9 Gs, nor can it provide the turn rate of an F-16. Meeting tomorrow's challenges will demand balancing these variables in new and insightful ways. It will also demand innovation to accomplish what was previously deemed impossible. Traditional attributes of aircraft design will persist, but essential design aspects are expanding to include stealth shaping, engine types, materials, and other critical physical attributes for modern sensor, avionics, processing, and weapons capability such as support for software, weight, power, and cooling. While some may argue that there is nothing new in aircraft design, these newer attributes will likely drive different design tradeoffs, especially within the context of the Pacific theater.

The physical integration of components and sub-assemblies is not the only area where aerospace contractors are focusing their integration skills—nor is it the most important. Software and processing power are emerging as linchpins of a combat aircraft design. Future critical combat capabilities include advanced sensing, data links, autonomy, artificial intelligence, machine learning, machine-teaming, and other software-based functions. Integrating software such that all the disparate elements of a system—including information from off-board platforms—operates in a seamless fashion is perhaps the most important skill an aerospace prime can bring to the government in the modern era. Proof of this new focus is evident in the F-35, which is by far the most advanced operational aircraft in the world. It has over 8 million lines of source code and another 16 million lines are in the sustainment, mission planning, and maintenance support equipment.[64] It is not just an airplane, it is a flying computer system of immense capability.

Integrating the many sensors, mission computers, and weapons is tantamount to a company's "secret sauce." It is the valuable intellectual property that gives it a unique competitive edge. Most of a weapon system's equipment comes from many vendors, and it is the prime contractor's skill in seamlessly knitting such disparate data and systems together that makes its platform so effective. These are not easy problems. As system-of-systems architectures become more tightly coupled and complex, the drive for highly experienced engineers increases. The better a company is at software integration, the better their end products perform.

It is this software integration skill and the associated data rights that drive the corporate profit centers and shareholder value. This is one reason why companies guard their data rights so viciously in contract negotiations with the government. Owning the data rights for the platform and the software architecture provides the original equipment manufacturer (OEM) a distinct advantage in securing the long-term sustainment contract. The government has increasingly stated concerns about what it considers "vendor lock," where ownership of data rights effectively secures sustainment and modernization contracts to the OEM for the lifetime of the system. When development and production contracts are limited, and annual production contracts and quantities are unreliable or even volatile, owning the data rights for follow-on sustainment and modernization programs is the key to profitability for companies.

System integration skills will only grow in importance when it comes to cultivating a competitive industrial base for the future, but they cannot eclipse the traditional capabilities of aircraft and weapon system design and production. Physical platforms will be needed in greater numbers and diversity in the battlespace, and the Air Force will need industry to design and build them. So long as new-start programs remain few and far between, the profit potential of integration and sustainment will act as a lid on innovating and building the future force.

Sustainment is the primary profit center

With new-start aircraft programs occurring so infrequently and actual production quantities unreliable, aerospace companies have had to shift their primary profit centers from production into sustainment and modernization. This sustainment business model provides predictable long-term revenue for companies, as well as value for their shareholders, but it may negatively affect the Air Force's ability to successfully compete in a peer competition in the long term. So long as sustainment is a crucial industry profit center, Air Force paradigms and industry business models will center upon preserving a legacy force design—not inventing and building a future force.

As already described, development and production have proven an unreliable source of profit during the last thirty years of defense acquisition cycles. Infrequent requirements for new design types, program cancellations, rate reductions, cut-backs on total quantities, antagonistic contract negotiations, and low profit margins have induced tremendous instability into programs—with hazardous consequences for companies and their investors. Since the curtailment of the B-2 from 132 aircraft to a mere 21, the Air Force has met few of its original aircraft production goals on major design types. The Air Force's Next-Generation Bomber, announced in 2003 and then canceled in 2009, is one example. The cancellation of the 2018 JSTARS recapitalization program after nearly two decades of various modernization excursions is another.[65] Both the F-22 and F-35 experienced production rate reductions, leaving Lockheed Martin with excess capacity, larger overhead costs, and decreased revenue. The F-22 was prematurely terminated with 187 aircraft—well short of the final defined requirement of 381 and its original requirement of 750. Companies may make significant investments in preparing a design to compete for a new program, only to find their internal efforts are for naught as the services, Department of Defense, or Congress cancel a program before its official requirement is met.

Even profit rates are uncertain. Despite having total transparency into actual costs of contractors, OSD in 2011 began the implementation of "Should Cost Management."[66] This saw acquisition program managers identify a target cost for program elements and price contracts accordingly, even when "should cost" figures were well below company actuals.[67] Nowhere in this metric is any consideration of effectiveness, which is fundamentally the purpose of building the new aircraft. In 2016, low-rate initial production Lot 9 contract negotiations for the F-35 were so contentious that the Air Force unilaterally imposed a contract upon Lockheed Martin, well after production for that lot had already started.[68] Defense company profit margins are already far below most commercial rates, averaging between 5 and 9 percent.[69] Nominal profit margins for Silicon Valley companies run 60 to 80 percent. Aerospace companies that are unable to meet "should cost" targets—which often means pressuring down-stream suppliers for even lower pricing—eat the difference in profit.

Still, certain production contracts can hold major value to a company as a means to secure the lucrative, stable, and long-term sustainment business associated with the aircraft. Major defense companies' externally facing financial documents obscure the exact breakdown of profit margins (percentage) and total profit (absolute dollars) the company derives from either production or sustainment and modernization of aircraft. However, one might surmise the relative value of production and sustainment using the 2019 F-35 Selected Acquisition Report (SAR) as an example. According to the Congressional Research Service, the total F-35 acquisition costs for development and production (excluding military construction) for 2,456 aircraft in then-year dollars total $392.6 billion dollars. Operations and sustainment (O&S) costs over the next fifty years is assessed as costing over $1 trillion dollars.[70] Because this estimate includes fuel and labor costs, the real net value of the F-35's sustainment is far more difficult to ascertain—yet the relative difference between the estimate for production and O&S is illustrative. Another important reference point is the time frame for sustainment: fifty years. This unprecedented and extended duration, of course, increases the total O&S estimate, but it also shows the value of the sustainment business to the company and its stockholders: long-term, reliable, and lucrative revenue. Since 2015, the year the U.S. Marine Corps declared IOC with its F-35 variant, Lockheed Martin stock has gone up from roughly $225 to over $380 a share. Lockheed Martin's excellent performance across its portfolio contributes to its strong share value, but the F-35 is such a large program that it must be considered a driving force for the company.

These dynamics pressure companies to be much more discerning as to when they seek to bid on a program. Northrop Grumman chose to exit the Air Force's advanced jet trainer competition despite having developed a flying prototype. Northrop statements said that the company "decided not to submit a proposal for the T-X Trainer program, as it would not be in the best interest of the companies and their shareholders."[71] Similarly, the company chose to not bid on the Navy's MQ-25 program, even though Northrop Grumman was an incumbent, having performed very successfully with the X-47B. Then-Chairman and CEO Wes Bush explained their decision, describing their calculus as not considering their ability to win programs, but the ability to make a profit: "We looked at that deal, we said I don't think so."[72] These industry decisions are sensible given the broader market context. However, they should seriously concern decisionmakers in DOD and the services as the pool of available creative ideas and innovation is artificially reduced.

Boeing's unsolicited offer to the Air Force of the F-15EX is an example of how the focus on sustainment can constrain a company's internal design options. The F-22 production had been prematurely terminated with no viable air dominance replacement, so the Air Force had to retain older legacy F-15C aircraft to meet capacity and mission requirements. According to Lieutenant General David Nahom, the deputy chief of staff for plans and programs, serious structural problems and obsolete equipment limit the operational relevance of these older F-15s while imposing large sustainment bills: "Not only are they costing us too much money, but they're offering us too much risk."[73] Instead of a fresh air dominance design, Boeing elected to extend the F-15 franchise by offering the Air Force the F-15EXs. This will also extend established long-term sustainment revenue at relatively little new cost to Boeing.

Instead of offering the Air Force a new stealth aircraft that would provide real value against the pacing threat of peer competitors, Boeing worked within the DOD to extend the production line of a McDonnell aircraft design that began in the late 1960s. Ensuring Boeing remained a viable fighter production company with an active line is critical to the nation's defense interests, and the Air Force needs diversity in aircraft types and greater overall quantity. Boeing proposes to update the F-15EX with new features like open mission systems and containerized software approaches like Kubernetes, and the company argues that the aircraft will be a promising proof-of-concept for more modular mission systems.

Still, the return on Air Force investments and system architecture advancements in aircraft like the F-15EX are limited, given that the aerodynamic design lacks the stealth necessary to successfully operate in future conflicts against advanced adversaries. The F-15EX is a decades-old airframe design that lacks the minimum survivability standards for today's threat environment. While the Air Force should increase the quantity and diversity of its force, this is akin to fielding propeller-driven fighters in an era of supersonic jet engines.

Technological regression does not make operational sense. It did not work in Vietnam, as the high loss rate of the earlier-era propeller-driven aircraft proved. To improve survivability, and therefore mission effectiveness, the Air Force replaced observer and forward air control aircraft like the O-1, O-2, and OV-10 prop planes with the F-100 jet, or, similarly, the propeller-driven combat search and rescue A-1E with the subsonic A-7. Today, stealth is the new baseline for survivability, whether the aircraft is a manned fighter, bomber, or autonomous system.

Boeing made a gamble by not proposing a forward-leaning new design that would holistically advance the full spectrum of required capabilities. The F-15EX does not increase the diversity of the force design; it simply replaces earlier F-15s. It is unlikely to add to quantity either, given the high cost and the small numbers programmed. Boeing's F/A-18 presents similar limitations. It is an aircraft that may have newer systems, but these are still encapsulated in a physical design that is no longer survivable in anything but a permissive threat environment. By winning this gamble, what message is DOD sending Boeing and other defense contractors writ large? True growth and innovation in the aerospace industrial base is crucial to the health the Air Force, but this is not accomplished by going back in time.

Boeing's commitment to these legacy production lines not only speaks to the value of their sustainment revenue but may provide insight into the relative health of Boeing's engineering teams. Both the F-15 and F/A-18 are McDonnell Douglas designs, developed before its acquisition by Boeing. They do not draw upon current Boeing military design expertise, which may be thin given the dearth of new-start competition designs over the past thirty years.[74] Industry experts felt it was only Boeing's partnership with

Saab on the T-7 that compensated for this potential deficit, and cited the partnership as the main reason Boeing could potentially overcome the challenges of designing and building a clean-sheet trainer prototype in three years.[75] Without supplemental help, firms who let their core design staff remain dormant for too long are likely to lose the ability to rapidly innovate in a forward-leaning fashion. The F-15EX and T-7 are both evidence of how extended lifecycles of legacy platforms, sustainment growth, and lack of new-start programs can ravage key intellectual capital and industry experience.

Conclusion

Optimized for and shaped by Air Force acquisition paradigms, industry's adaptations of consolidation, system integration, and sustainment have met near-term Air Force requirements. Consolidation preserved legacy company expertise; instead of wholly losing valuable engineering and design capital, acquisitions and mergers retained these valuable assets within viable companies. Integration has shared fewer new-production contract values across a diminishing field, spreading risk as well as revenue across remaining companies. This also provides companies valuable experience in managing technical, programmatic, and software system complexity. Finally, industry's shift to sustainment has supported the Air Force's move to extend the life of legacy platforms while upgrading capabilities. Multiple service life extension programs, as well as modernization plans, have kept—and will keep—fleets flying and operationally viable for decades well past their original divestiture dates.

The imperative to grow agile force structure means that the Air Force can no longer tolerate extended developmental timeframes. Adaptation is the advantage, and speed is the new offset.

These attributes have allowed the Air Force to continue to provide for the nation's security through nearly thirty years of continuous combat operations, budget pressures, and down-sizing. However, what worked for the past three decades is no longer a viable answer to tomorrow's challenges. The broader security environment demands that it is time to stop treading water and instead press forward.

Today's defining features of the defense aerospace industry have significant implications for the Air Force's future force design and risk leaving aerospace companies and the Air Force ill-equipped to compete in future warfare. Traditional offset strategies, which derive advantage from game-changing technological leaps, require significant time and investment to develop. As technology and weapon systems have grown more complex and the acquisition bureaucracy more layered, it is ever more difficult for defense aerospace to field capabilities in operationally relevant time frames. Yet time matters more than ever. The nation that can develop, field, and adapt faster will wield the capability advantage.

The imperative to grow agile force structure means that the Air Force can no longer tolerate extended developmental timeframes. The need for speed-to-field, quantity, and the continuing acceleration of technology and processing power means that capability advancements and insertion should be delivered through new models and new types. Retrofitting weapon systems through sustainment and modernization will not be enough. The aerospace industry must not just keep pace, but outpace, the ability of America's adversaries to field new and surprising capabilities. Adaptation is the advantage, and speed is the new offset.

Beyond Acquisition Reform: The Imperative to Reshape Defense Business Models to Reshape the Industry

The United States can no longer rely on offsets whose development are assumed to provide decades of advantage. New capabilities must be fielded at a pace that surpasses and surprises peer competitors, disrupting their understanding of the battlespace and hindering their ability to target our systems and operational architectures. This is what it means to "accelerate change," a focus of the new Chief of Staff, Gen "CQ" Brown. The challenge is that the defense enterprise is not positioned or structured to deliver technological adaptation at speed. In the past, efforts to improve how the Department of Defense better acquires systems have focused on acquisition reform. As important as such improvements are to remove unnecessary barriers that will help speed rapid capability development and fielding, it will not be enough. The Air Force, and the DOD writ large, must use natural market incentives to transform the structures and business models of the aerospace industry so that they can accelerate change.

Defense acquisition has long and continuously been the target of reform efforts in search of lowering cost, increasing speed to field, and mitigating risk.[76] Such reform efforts at times can also be high-profile. For example, the 2018 National Defense Strategy listed acquisition reform as one of its three main lines of effort, along with greater lethality and strengthening alliances and partnerships.[77] Yet, despite some notable successes, these reform efforts have not appreciably improved acquisition speed overall.[78] Instead, DOD and the services have resorted to operating outside the traditional system to encourage rapid innovation and achieve speed to field. such as through the Strategic Capabilities Office (SCO) or the Rapid Capabilities Office (RCO). It is also evidenced by the expanding use of Other Transaction Authorities (OTA) that enjoy certain statutory waivers, enhanced authorities, and other advantages.[79] However, the lessons learned from operating these "go fast" constructs have thus far not translated into the broader acquisition community.

Part of this is cultural—something the directors of both the Department of the Air Force RCO and Space RCO recently emphasized as the "secret sauce" that enables their offices to increase acquisition speed. In these cases, speed is mostly achieved by pushing decision-making as far down as possible and encouraging staff to be proactive and solutions-based.[80] Unfortunately, the broader acquisition community is, instead, incentivized to be risk-averse, wherein both reform efforts and culture reinforce the idea that "lowering cost and avoiding protest are more important than the speed of delivery."[81]

The more fundamental issue is that acquisition reform alone cannot enable the transformation the aerospace industrial base needs. Acquisition reform focuses on process, not the paradigm. It is the current defense procurement paradigm that has shaped the defense industry—most notably the dynamics set in motion from defense procurement holiday that followed the end of the Cold War. Repeated deferment of recapitalization has forced the Air Force to rely on an ever-shrinking inventory of increasingly exquisite platforms. Repeated program cancellations—well short of reaching stated inventory requirements—

have also served to create dysfunction between industry and government where speed and agility are the objectives. The acquisition process is a bureaucratic approach that prioritizes cost efficiency and risk avoidance. Defining requirements early simplifies source selection, insures against protests, and holds contractors accountable. But it also seeks to prescribe capability solutions based on a set of assumptions about the distant future. Together, these dynamics stifle innovation and significantly slow the acquisition cycle. They reflect an industrial age model in an era that is now defined by the speed of information.

The behavior and acquisition trends of the Air Force, the DOD, and Congress have shaped the aerospace industry of today. Aerospace companies are not well positioned to compete in an offset defined by adaptation at speed because they have responded to Air Force procurement behaviors and optimized their structures and business models to fit that unique marketplace. First, the consolidation of the defense industry has contributed to a lack of design diversity, which undermines the imperative for greater resilience and adaptability. Second, the focus on tight integration of multi-role capabilities means that aircraft do not have excess space to incorporate new capabilities. Furthermore, they are incredibly difficult and expensive to retrofit with new systems or adapt with innovative architectures. As Dr. Will Roper pointed out, "early computerization and integrated system-of-systems aircraft designs [were] unavoidable, even necessary to win the Cold War, but it is a crippling millstone in the current competition."[82] Third, sustainment-dominated business cases actively disincentivize innovation as companies seek to recoup the losses incurred during design and early production by ensuring their aircraft remain in the inventory for as long as possible. To reinvigorate the aerospace industry into one that can support a faster, more adaptive, and more diverse and advanced force design, the Air Force must shift its acquisition paradigm and industrial base.

The experience of the Soviet Union may provide a cautionary tale of what might happen should the United States fail to accelerate change. The Soviet General Staff recognized early that the speed of their industrial model could not compete with the rapid American military-technical revolution. Because the Soviet theory of victory relied upon industrial might, the American shift into information left the Soviet military-industrial complex unable to compete. Soviet equipment was not exquisite or sophisticated. To the contrary, their strength relied upon rugged, brute force, and they were unable to transition their industrial complex. As one military historian noted, "Having this production capacity available, however, assumed that one knew what weapons the military would need; the Soviet system, after all, depended on planning. In the late 1970s, Soviet theorists realized that rapid changes in technology made it impossible to plan for production capacity, since it took time to tool up production lines. The Soviets could not shift their production fast enough to keep up with American technology."[83]

Such transformation into a new paradigm is not an impossible task. There are historical precedents and examples that can guide the Air Force and DOD in their efforts to shift this paradigm and cultivate the industrial base that can provide adaptation at speed.

Restructuring for a New Offset: How the Air Force Can Cultivate an Aerospace Industrial Base for the Future

The Soviet experience—that they could not restructure their industrial base to compete with the technological sophistication of the United States—should be a bellwether for the Air Force. The aerospace industry must be reoriented to provide relevant capabilities in timeframes that outpace any adversary and deny them the ability to target and disrupt our operational architectures. This cycle is not about developing technological overmatch that takes decades to field. Instead, industry must be agile enough to rapidly push innovation and production at a pace that disrupts our adversaries' ability to understand and therefore counter our operational architectures.

Competing in time is not solely the arena of software and sensors. Aircraft will still be needed. If anything, future warfare will require a diverse fleet of more aircraft, unmanned aerial vehicles, and other weapon systems than the Air Force has today. Future warfare concepts will need to maximize the effectiveness of U.S. and coalition forces through optimizing information in the battlespace, and large numbers of different kinds of platforms will be essential to those complexities. One experienced defense analyst observed:

> [The emphasis of sharing information is] an important step forward and shows much promise, but it does not replace the need for a certain level of mass. In many ways, it harkens back to the Royal Air Force's experience in the Battle of Britain, where radar and command and control air defense networks proved vital but would not have won the day without enough defending fighter aircraft.[84]

Reinvigorating the aerospace industrial base is essential to achieving the capacity and capability the Air Force will need to successfully compete in a peer contest.

The DOD has expressed concern over the ability of the defense industrial base to rise to the challenge laid out in the 2018 National Defense Strategy. The DOD found that the "unintended consequences of U.S. Government acquisition behavior," was one of a handful of major challenges that "erode the capabilities of the manufacturing and defense industrial base and threaten the Department of Defense's ability to be ready for the 'fight tonight' and to retool for great power competition."[85] One defense official justified the decision to procure the F-15EX as centering around the question, "How are we going to maintain a robust industrial base?" They concluded that, "For the future of the Department of Defense, it's going to be good to have multiple providers in the tactical aircraft portfolio."[86]

The Air Force's interest in commercial companies demonstrates its recognition that the current dynamics with traditional defense companies are dysfunctional. One of the efforts the Air Force has pursued to change acquisition behavior is standing up AFWERX, an innovation partner-hub and incubator. The Air Force intends to act as a venture capitalist, investing in new commercial technologies; connecting airmen with commercial companies to solve military problems; and transitioning commercial products for military use.[87] The Air Force is right that it is time to move beyond business-as-usual, and commercial companies excel at innovation, speed to market, adapting to changing market needs, and spiraling rapid software cycles. The fresh perspective that commercial companies could bring to defense problems could stimulate surprising cycles of innovation.

As the Air Force explores bringing these companies into the defense fold, it should also be aware of the friction that defense acquisition practices are likely to create with commercial companies. As appealing as it may be, turning to commercial companies and products may not always provide the best solution to achieve speed and innovation with traditional weapons system requirements. There are many important differences between civilian and government markets, including regulations, and requirements. Studies have shown that commercial companies are highly unlikely to develop the types of major weapon systems needed to wield an advantage in combat, and commercial-off-the-shelf systems are not likely the best answer either.[88] Commercial companies may also view the government's demand for data rights as problematic. The Air Force should be clear-eyed about both the potential as well as the limitations of commercial companies as it seeks to expand its industrial base.

These novel approaches provide the service access to companies and ideas outside the traditional defense sector, but there are reasons to temper the enthusiasm for commercial products. For major combat capabilities, the Air Force should be cognizant of the difficulties involved in transitioning commercial technologies for a military applications and major weapon systems. Studies have found that a source of major cost and schedule growth in these types of initiatives comes from the service's "underestimation of the challenges of modifying and integrating commercially derived technologies and approaches into complex weapon system programs."[89]

There comes a point where we need to recognize that our large-scale combat aircraft producers are an asymmetric crown jewel for our nation. These companies have a base of rich experience, possess incredible expertise, and understand military operational problems intimately. These are the only companies capable of delivering advanced military aircraft designs, system integration, and innovation at capacity. Their present structures and business models require adjustment, but their depth of experience and ability to produce high-confidence articles is not going to be replicated elsewhere at a cost and a schedule that aligns with our broader interests or demands. This is a question of evolving the drivers that shape their performance, not "blowing them up."

The Air Force should use natural market incentives—programs, contracts, and revenue—to reshape, refocus, and expand the traditional aerospace defense base. There are many under-valued benefits that defense-oriented companies offer, such as having the compliance and reporting mechanisms in place necessary to do any business with DOD. More important, however, is that these are companies that have proven track records, long experience with the service and its missions, and a core of engineers and skilled manufacturers that, with the right objectives and incentives, can deliver the rapid adaptation and force design the nation needs.

Expanding the Defense Aerospace Base

The Air Force should take action to reverse the contraction of its prime aerospace companies in order to provide the nation strategic diversity and depth of capability and capacity. While the major defense companies control vast portfolios and possess significant talent, a robust aerospace base requires a larger pool of diverse competitors that can act as a strategic hedge. Achieving this goal comes down to a simple proposition: if the Air Force wants a larger business base, it must provide more opportunities for business.

The value of a healthy industrial base goes well beyond attaining favorable unit prices for various technologies. A robust competitive field will drive the innovation that is critical to solving current and future challenges by allowing multiple stakeholders to engage in problem solving. As a RAND report explained, "Intense competition at the design stage among large numbers of credible contractors [may contribute] materially to the high degree of innovation in design and technology."[90] Conversely, "The dramatic downsizing and consolidation of the aerospace industry … may have serious unanticipated long-term technology consequences."[91]

Given the dramatic consolidation of the defense industry over the past thirty years, this means that the DOD must seek to expand the number of viable prime contractors. The competitive field must grow, and this means extending beyond the established major prime contractors. That said, this is not a call to undermine established aerospace firms—quite the opposite. That talent is essential, but so, too, are fresh perspectives. Regardless of whether a firm is an existing prime or a new entrant, market potential and stability will prove crucial for industry to deliver the desired capabilities in a rapid, forward-leaning fashion. To grow the field, companies must believe that the government will buy the full, planned quantities of a program, and that there will be other competitions available to win as well. In other words, there has to be enough business to sustain the entire field if it is to grow.

This requires DOD, the Air Force, and Congress to follow through on contracts in play—completing full buys of systems where standing requirements remain valid. This is occurring too infrequently today, hindering the transformation of the force through recapitalization. Completing planned procurement quantities maximizes the return on sunk R&D investment, provides stability to industry, and allows for a rational evolution toward a new force design.

To net this objective, history can serve as a guide for the Air Force in seeking to counter the continuing industrial consolidation. The following are recommendations derived from historical case studies that the Air Force can act upon today to shift its acquisition paradigms, rejuvenate and expand the industrial base, and increase the range and rate of innovative capabilities.

Do not break the industrial base you have

There is no elasticity in the modern defense aerospace base. In the 1950s, it mattered little if an aircraft manufacturer exited the defense business—there were still many viable and credible companies to choose from. With as thin as the industry is today, it is crucial that the Air Force and the Department of Defense do not arbitrarily harm the current base of defense aerospace companies. There are no strategic industrial alternatives to the primes.

This industry contains some of the world's greatest engineering talent, ingenuity, and manufacturing skill—as proven over decades of developing some of the most advanced and nearly miraculous defense capabilities. History has shown that once aerospace companies exit the defense business or pivot to become a sub-tier supplier, they do not return to become prime manufacturers. As giant as the major defense companies are, the actual industrial base of prime military aircraft manufacturers is quite austere.

In any action the Air Force takes, it must also be sure to not wreck the expertise, capacity, and sub-tier suppliers of the industry. This does not mean coddling the companies. The Air Force must have industry partners that are capable and eager to develop a new force design. Those that are unable or unwilling to shift their business models and organizational constructs away from sustainment to support this new paradigm should not win new contracts. The defense aerospace sector must again transform to survive.

Although contractors will most likely resist any shift from the established acquisition paradigm, the major companies have also deliberately cultivated broad portfolios to provide some insulation for themselves and Wall Street. They can and must withstand the disruption that will come with change. They should have the resources and talent to embrace and benefit from this new model. The current industrial base has evolved to its present condition given market dynamics; there is no reason to think these companies cannot further transform if given new imperatives and incentives.

Change will require the Air Force to create sufficient market forces, viable business cases, and the necessary stability to build trust in the new system and allow firms—both old and new—to invest with confidence in the new vector.

Leverage the opportunity of rapid technological development to experience new industry entrants

Historical periods of rapid technological innovation, coupled with strategic urgency, have enabled new entrants to grow their technical chops and establish themselves as credible defense companies. These windows also allow opportunities for new actors to gain market entry because technological barriers are often lower when all actors, even incumbents, are in a phase of discovery. The Air Force should take advantage of the current pace of development to create the opportunity for smaller, less established companies to mature and grow through robust research and development programs. New entrants that joined the industrial field through the avenue of remotely piloted aircraft stand as proof of opportunity manifesting as new industrial capacity. Increasing autonomy will likely provide a similar window.

This pattern has repeated throughout history. In the 1930s, aircraft were transitioning from wood-and-fabric biplanes to all-metal, monocoque designs with retractable gear. European war clouds were on the horizon, which spurred a need to invest in new types and opened up the opportunity for new entrants: "Almost overnight, small, marginal, and even entirely new companies—or established companies that

Figure 9: McDonnell F-101 Voodoo. McDonnell had not been a fighter production company in World War II. Although it developed a bat-wing prototype, McDonnell was primarily a parts supplier. The development of jet engines created the opportunity for McDonnell to establish themselves as a credible military aircraft manufacturer. Jet engines were not powerful or responsive enough to meet the operational needs of the carrier-based U.S. Navy, so the Navy kept their prime aircraft companies developing piston-driven fighters and awarded experimental jet fighter contracts to its lower tier companies. McDonnell won one of these contracts, ultimately developing the Navy FH-1 Phantom. McDonnell leveraged their Navy jet experience to win Air Force experimental jet prototype contracts in the XF-88. This design became the foundation for the F-101 Voodoo, Strategic Air Command escort fighter that ultimately saw use as an interceptor, fighter-bomber, and reconnaissance aircraft. The iterative application of experience from the FH-1, the XF-88, the F-101, and then the F-4 show the family resemblance in how McDonnell continued to refine and improve their designs.

had not competed seriously before in fighter R&D—became major contenders."[92] This period of dynamic technology transition enabled companies like Seversky (later Republic), Lockheed, North American, and Bell to establish themselves as highly credible fighter aircraft companies. Past giants such as Fokker failed to make the technological transition and were outpaced by the new entrants.

Coming out of World War II, jet engines and aerodynamics were on the cusp of dramatic advances. Within the context of growing tensions with the Soviet Union, the exploration of these new realms once again reduced the relative value of the established track records of more dominant companies: "Jet-fighter technologies were so new and evolving so rapidly that nearly all credible aircraft contractors has a reasonable shot at new fighter R&D work and thus entered the fray."[93] McDonnell, which would later build the iconic F-4 Phantom II and the F-15 Eagle, was a virtual unknown at the end of World War II. It was simply a sub-component producer for the prime firms. Sensing a window of opportunity, the company successfully secured early jet aircraft contracts and was able to establish itself in the defense industry thanks to R&D programs that eventually led to the Navy FH-1 Phantom and the Air Force F-101 Voodoo.[94] The same could be said for General Electric, which used its position as a turbo-supercharger manufacturer in World War II to transition into a leading jet engine company thanks to the window afforded by new technology.

The strategic threat prompted the availability of the necessary resources required to invest in and develop new technologies. Success required the services to embrace robust research and development, adopt a willingness to accept risk, and drive a rapid pace of technological advancement. The Air Force finds itself in similar place today. Such change will not occur magically—it will take careful, deliberate action.

Part of this process involves encouraging new entrants to scale. The rise of General Atomics and the innovation they brought to the field of remotely piloted aircraft not only revolutionized how ISR and strike missions are executed, but also paved the way for the next steps in increasingly autonomous flight activities. The continued entrance of new actors, like Kratos, suggests room for growth remains viable from a business perspective.

Unmanned and autonomous aircraft systems, artificial intelligence and machine learning, and advanced processing power are areas where the service can deliberately cultivate a broader set of credible aerospace companies. To this point, Kratos is a relative newcomer to the defense aerospace sector. It is developing the stealthy XQ-58 Valkyrie, an autonomous aerial combat system in the Air Force's Low Cost Attritable Aircraft Technology portfolio.[95] Dynetics, a Leidos company, is participating in DARPA's Gremlins program with their X-61A air vehicles. This program is exploring aerial launch and recovery of these autonomous systems.[96] Both firms follow in the path successfully forged by remotely piloted aircraft pioneer General Atomics. Positive growth is not isolated to unmanned aircraft; supersonic business jet development, with applications suitable for certain military missions, is also growing with new entrants like Aerion and Boom.

It all comes down to the Air Force seeking opportunities to invest in ways that cultivate the talent, expertise, and experience of new entrants. This type of focus pays off, opening the field for fresh perspectives. Hungry for the opportunity, these new entrants are generally unhampered by legacy business interests and are willing to take design risk and foster new ideas in their pursuit to make their mark and win business.[97] Targeting these smaller or non-traditional defense companies can yield significant returns when it comes to cultivating and increasing the innovation available to the Air Force.

Provide ongoing, competitive, experimental prototype programs

Design repetition is crucial to building the kind of experience and expertise needed to mature newer entrants. It also keeps the engineering and manufacturing teams of established companies sharp. Maintaining ongoing experimental prototype competitions can function to expand the base of viable companies. It can also offer established design teams the opportunity to explore and push their ideas. Similar to the Lightweight Fighter (LWF) program that became the F-16 and the proposed Combat Aircraft Prototype (CAP) program of the 1980s, the Air Force should establish an effort solely dedicated to competitive prototyping.

Experimental prototyping, because it was not connected to the development of a program of record, minimized government liability and opened the aperture for companies to innovate, "allowing them to take some technical risk rather than avoiding technical risk altogether, which stifles progress [and] achieve a greater advance in the state of the art than a more conventional program would be likely to produce."[98] At the same time, the experimental prototype was not a pure X-plane, whose purpose was pushing basic aerodynamic research. Highly experimental or immature technologies or designs were not the objective of this kind of prototyping. Instead, experimental prototypes straddled an operationally focused and pragmatic middle-ground between an X-plane and the developmental phase of a production program. Experimental prototypes explored and matured potential technical paths to burn down risk, provide hard and demonstrated data for programmatic planning, and accelerate the speed to field of weapon systems.[99]

Figure 10: General Dynamics F-16 Fighting Falcon. The Lightweight Fighter (LWF) experimental program was a return to competitive prototyping from paper studies, analysis, and proposals. Actual flight demonstrations of aircraft and hardware was intended to de-risk any potential follow-on program by providing real, representative data. The LWF focused on performance goals, not detailed specifications, to allow the companies as much design freedom as possible to explore different approaches to the LWF concept. Northrop (YF-17) took a much different approach to the design challenges than did General Dynamics (YF-16), but both yielded important achievements and areas for additional development for future programs. Because the LWF did not have a follow-on production contract associated, companies could be more innovative in their technical approaches with less risk to both the contractor and the government. It was the interest of NATO countries to replace their aging F-104 fleets that resulted in the Air Combat Fighter (ACF) competition, which changed the LWF experimental prototype program into a direct competition and led to F-16 production.

Whereas the LWF program that eventually resulted in the Air Force F-16 and Navy F/A-18 is, perhaps, the best-known experimental prototype program, it is important to emphasize that the intent of the program was not for those designs to ultimately become established programs of record. The LWF program's objective was to evaluate the operational utility of a lightweight fighter and identify potential features of such an aircraft.[100]

Because it was not tied to the evaluation or engineering development of production contract, the competitive nature of the LWF program pushed the teams and permitted the Air Force to evaluate different technical approaches. For example, the LWF allowed the contractors to explore a wide range of technical options that were unique to the contractor teams' individual design philosophies: "The General Dynamics/Northrop combination covered 1 vs. 2 engines, 1 vs. 2 vertical tails, and fly-by-wire vs. conventional flight control."[101] Air Force officials said of the program that "competition is vital. There is simply no other contractual or management incentive that is as effective as competition."[102]

The objective of the Combat Aircraft Prototype (CAP) program was to foster innovation, explore new design concepts, and provide industry crucial design repetitions. But there was a more urgent reason for it—the Air Force and DOD were concerned about the health of industry design teams. Air Force documents pointed to the "unprecedented gap in U.S. fighter developments," and observed that "industry design teams have not been afforded the essential experience involved in translating design concepts into actual flight hardware." They continued, "The CAP program provides a means to address these problems and ensure that fighter design, capability, technical options and manufacturing processes are available for future fighter programs."[103]

To exercise this essential industrial capacity, the Air Force planned to start new prototype projects every two years, each having a duration of two to three years. Although the CAP was not tied to any specific follow-on contract, these prototypes could identify new technologies for requirements, validate operational concepts, and even be considered as potential candidates for the development of new aircraft.

A program loosely modeled on the LWF and CAP programs would go far in resourcing and structuring the aerospace defense industry for the kind of design optionality peer competition will require. This prototyping program could also focus on new manufacturing techniques for a design that would facilitate the ability to pivot production lines, scale up new models from prototype to production, switch between models, or have different models running concurrently. This approach would buy down risk when the service was ready to invest in operational capabilities, since concepts already developed would be available for use, teams would be more practiced, lessons learned could be applied, and the manufacturing agility would be developed. There is a reason why an Olympic athlete trains vigorously. Aerospace firms should not be expected to "go for the gold" with cutting-edge projects unless they regularly exercise their skills, too. Given the challenges many current programs have faced in recent years, it is also clear that there is a cost to not providing such work. It would be far preferable to expend those funds in a positive fashion versus resetting preventable design mistakes.

No future joint aircraft programs

F-35 aside, the Air Force should resist future participation in any joint aircraft procurement or development programs. History and analysis have shown that anticipated benefits of joint aircraft procurement or development programs do not yield the savings or commonality such programs promise. Instead, joint aircraft programs decrease design diversity and have the effect of consolidating industry. If companies fail to win, they are likely to shift their technological focus or exit the industry entirely.

Joint programs have historically failed to demonstrate the anticipated operational or cost efficiencies, primarily because they are unable to deliver the necessary levels of commonality. This design divergence has held true across the F-4, F-111, A-7, and even the F-35. According to Lieutenant General Chris Bogdan, program executive officer of the JSF program office from 2012 to 2017, the three F-35 models are only 20 to 25 percent common, and that commonality is primarily in the cockpit.[104] This variance, however, is not the fault of the contractor. Instead, in all of these aircraft, the companies were attempting to accommodate multiple service-specific aerodynamic and mission requirements. This should not be surprising; the Tactical

Fighter Experimental (TFX) program demonstrated the difficulties of developing a common aircraft design. The Navy's ultimate rejection of their TFX model, the F-111B, indicates that service requirements are often irreconcilable.[105] A survey of joint aircraft programs by RAND found that "common joint fighter designs [increase] programmatic and technical complexity and risk, thus prolonging RDT&E and driving up joint acquisition costs."[106]

Because joint programs diminish competition through the consolidation of service new-starts, they also act to consolidate industry. The RAND study found that "joint aircraft programs are associated with a shrinking combat aircraft base."[107] A few notable examples prove illustrative. In 1961, Secretary of Defense Robert McNamara sought to bring corporate rationality to defense. When a fly-off between Republic's F-105 and McDonnell's F-4 proved equal, McNamara imposed the acquisition of the F-4 on the Air Force instead of continuing F-105 production.[108] As a consequence, Republic was acquired by Fairchild Hiller in 1965.[109] Neither exist today as that firm failed to secure business past the A-10, and its factory sits empty in Hagerstown, MD. Aircraft firms shuttered never return. Similarly, Douglas Aircraft was acquired by McDonnell when it failed to win business on the TFX.[110] The resulting company, McDonnell Douglas, was later bought by Boeing when it failed to advance in the JSF competition.

Conclusions

If the Air Force is to grow and expand its base of prime contractors capable of delivering an innovative and diverse portfolio of weapons system designs, it should leverage the current opportunity of rapid technological innovation and provide the repetition of experience and exploration through a robust prototyping program. The service is already moving in this direction with programs like Skyborg and Valkyrie. DARPA has long stood as a technology incubator for companies of all sizes. But science projects are not enough. A company must be able to transition promising and relevant technologies into a program of record—something that can be difficult, if not impossible given the disconnect between the requirements development process and the work accomplished in R&D-oriented organizations. A standing prototype competition like the CAP can help bridge this gap by further developing these technologies into more mature, operationally focused capabilities. Successful and promising prototypes may then be considered for production. New manufacturing technology is needed to facilitate the quality, quantity, diversity, adaptation, and speed of a new force design, and to do so at scale, if necessary. It is important, however, to avoid any future joint weapon system program for the adverse impacts on the competitive base of the industry.

Enhancing Integration Skills Will Grow Innovation

The aerospace industry has already shaped itself for system integration, and this is a trend that should be further developed. Since the Century Series aircraft of the Cold War-era, which were developed and managed as the first modern complex weapon systems, the integration of onboard electronic systems has been a critical skill to both programmatic and operational success. The need for system integration in the modern environment—whether on a singular weapon system or across a much larger kill web of multi-domain platforms—will increase in the future. The skill and creativity necessary to conceptualize and integrate complexity is critical to the rapid adaptation that will provide strategic and operational advantages in a peer contest. In other words, integration skills can accelerate change. It is a task that must be done in modern warfare. How ingenious, competent, and proficient engineers are determines the speed at which the integration can be accomplished.

This is the kind of unpredictable complexity that will confound adversaries who have studied U.S. operational architectures for decades. No longer will adversaries have confident knowledge of the capabilities of a specific platform.

Traditionally, integration tasks occur in conjunction with development and modernization programs. Companies must win a production contract before they begin the actual work of selecting sensors and avionics and then figuring out how to make them all work together. Modernization is an extension of this task, where teams engineer how to fit new capabilities into upgraded older systems. As weapon systems have become even more tightly coupled, these integration tasks become more complex and laborious due to the many interactions and dependencies in these systems. These systems are very difficult to change, and doing so takes time. Outside of these lines, there are few opportunities for teams to gain repetitions across the range of potential integration challenges.

System integration must move beyond weapon systems to extend to the overall operational architecture. Furthermore, the need to increase the adaptability of both platforms and the overall force design means that tightly coupled—and therefore fixed—architectures must be evolved to become more flexible. This is about more than accelerating modernization programs for major weapon systems, although that certainly is needed. Connecting sensors together in new ways—integrating sensors across disparate platforms such that they can collaborate machine-to-machine—can yield surprising innovation.

This is the kind of unpredictable complexity that will confound adversaries who have studied U.S. operational architectures for decades. No longer will adversaries have confident knowledge of the capabilities of a specific platform. No longer will future missions center around a set form of force presentation, but instead a rapidly composable set of options that can be custom tailored for a given set of operational demands. Anticipating those formulations will prove exceedingly challenging for an opponent. Rapid integration to achieve adaptation at speed of both individual weapon systems and larger operational architectures will require enhancing software and system integration skills. Service history points to examples that today's Air Force can use to further encourage the development of these key skills.

Leverage open systems, mission integration, containerization, and other technologies to create flexible and adaptive weapon systems

The Air Force is pursuing open architectures and containerized software as a means to achieve a more modular system architecture that allows for rapid adaptation. In January of 2020, an Air Force software team at Hill Air Force Base ran a Kubernetes-developed mission software on an F-16, beginning the proof of concept for containerized mission applications that can be adapted in days or even hours.[111] In October, that same team loaded software on specially instrumented flight-test T-38s to experiment with the intersection of software and hardware adaptation.[112] If these approaches prove out, the Air Force will be able to rapidly integrate new hardware or software on a weapon system any time, and not have to wait on long, traditional modernization cycles.

History proves the value of this kind of open and modular adaptation. The F-100 and F-105 proved highly versatile compared to their mission design intent. Unlike some of their contemporary aircraft, such as the F-102 and 106, the F-100 and F-105 had loosely federated systems that were not tightly integrated. Because of this, both aircraft were able to be rapidly modified with newer mission systems that allowed them to flex to missions that they were not designed to accomplish: for example, the F-100F "Misty Fast FACs" forward air controllers, or the F-105 "Wild Weasel" hunter-killer teams conducting suppression of enemy air defenses.[113] The adaptability of these aircraft to new roles was largely achieved because new mission systems could be added to the aircraft in a simple fashion with minimal integration or disruption.

Perhaps the best example of a flexible platform has been the F-16. Fielded as low-cost general-purpose fighter, the F-16 had excellent maneuverability but fairly basic sensors and avionics. The federated architecture of the aircraft, however, has enabled subsequent models and blocks to undergo such significant upgrades that the F-16C model is now a highly networked aircraft with powerful processors, advanced sensors and avionics, and precision weapons.[114] The federated and open nature of the F-16 has enabled iterative cycles of modernization to have a transformative effect of the jet's capability. Future weapon systems must be able to accelerate this kind of transformation so that it can occur not over decades, but in more operationally relevant timeframes.

As weapon system capability depends ever more on software, the service will depend ever more on open mission systems, containerization, and skilled system integrators to speed adaptation to field. This includes developing the toolsets and techniques to rapidly upgrade or modify older legacy systems, as well as ensuring that new platforms are built with adaptable architectures from the get-go. This may even mean the ability to change software code at the unit-level, because operational timelines may not have the luxury of waiting for the SPO to respond. Because of this, the service should consider the value of organic system and software integration, not only in Software Engineering Groups but also in operationalizing that capability in combat units. Continuing to experiment with how quickly system integration and how far forward mission adaptation can occur will be important to achieving critical advantage at speed.

Promote the development of mission integration tool sets

Future warfare will require new and surprising combinations of weapon systems, platforms, sensors, and other combat capabilities to create a synergy of effects that will frustrate an adversary's ability to successfully target and disrupt U.S. systems and operational architectures. Many of these force composition activities will need to occur at a pace that is much faster than traditional modernization activities, which can take years to develop, test, and field. To achieve this kind of adaptation at speed—where old platforms are connected in new ways and new capabilities are seamlessly fitted to add complicating dimensions—mission integration toolsets are required.

Mission integration tools will enable these system engineering tasks to be accomplished at the operational time and point of need. Like software tools,and programs that coders use to create, debug, or support other applications, mission integration tools facilitate the ability to connect and leverage the powerful synergy of disparate capabilities. The use of DARPA's Adapting Cross-domain Kill-webs (ACK) program and the System-of-systems Technology Integration Tool Chain for Heterogeneous Electronic Systems (STITCHES) in recent Advanced Battle Management Systems on-ramps is one example of how these tools can work. Instead of taking years' worth of source-code software design and testing, these two tools enabled machine-to-machine integration and real-time kill-chain construction and battle management without the need to upgrade hardware or break into existing system software.[115] Whether in support of building an air tasking order, upgrading a weapon system capability, connecting multi-domain platforms to share sensing and targeting data, or teaming manned and autonomous aircraft, these tools will facilitate rapid integration of functions and tasks in the battlespace.

Mission integration tools should become a new line of revenue for the aerospace industry. The success in any future contest relies on these technologies because they accelerate change of operational architectures to maintain combat advantage. The challenge for industry and the Air Force is that mission integration tools diminish the value of sustainment and modernization revenue lines, where integration tasks have traditionally been located. But the speed of conflict cannot wait for contractual processes and modernization cycles to play out. The need to adapt at speed means that many of these integration activities will need to be accomplished by airmen at all levels of operations. As original equipment manufacturers, industry is best positioned to create these mission integration tools, and the Air Force should take a more active role in facilitating this transition. This may also create an additional opportunity for industry to support airmen by supplying contractors to help implement and train in mission integration.

The skills of system and software integrators are woefully undervalued by the Air Force. There is no resource sponsor or appropriations program element for these crucial integration capabilities. Similarly undervalued is the potential that integration has to recompose the nature of weapon systems, information architectures, and operational architectures—all of which drive combat speed and effectiveness. The large primes have held onto the lead system integrator role, and their skills and experience are invaluable. But system integration is also a fast-paced area of technological advancement that could enable new entrants, such as smaller defense companies or even commercial software companies, to enter and expand the potential aerospace defense base.

The Air Force must also understand that integration tasks are not limited to weapon systems, although the service must increase the adaptability of those platforms in operationally relevant timeframes. Perhaps even more important, however, is the ability to integrate across weapon systems. These system architectures are how the United States goes to war, and developing the ability to rapidly enable novel combinations of platforms and surprising uses and collaborations among weapon systems will be key to U.S. operational advantage. Advancing systems engineering and integration will be crucial to future warfare.

The Air Force should create opportunities to exercise, experiment, and refine integration skills at all levels and across all of industry. There are no historic Air Force examples for this, but the competitive experimental prototyping for aircraft designs offers a good model, which DARPA "gauntlets" closely to approximate. For certain more technologically mature programs, DARPA puts the technology through an operationally oriented test to evaluate its combat utility. Recent gauntlets have focused on developing tools to enable the integration of weapon systems in larger, operational architectures. The Air Force is also beginning to experiment with operational integration in small, focused efforts like the Advanced Battle Management System "on-ramps." Although the objective behind these ABMS on-ramps is not quite aligned with the intent behind any competitive experimental integration "prototype," they still provide engineers unique integration opportunities. These repetitions, experiments, and exercises are necessary to further cultivate the experience and expertise of these crucial teams. The Air Force should aggressively expand the opportunities for system engineers to advance the state of the art of integration, at scales that range from weapon system to operational architecture.

The active recognition of the importance of integration does not minimize traditional notions of design or weapon system production. Indeed, system integration does not matter without the fighters and bombers and other aircraft and platforms in the battlespace. The importance of integration does not sunset the requirement for industry to invent, develop, and field new hardware. New aircraft designs are needed; new and advanced sensors are needed; hypersonics, autonomy, machine learning, and artificial intelligence remain important critical capabilities. Indeed, the F-22 and F-35 point the way: rather than a tedious engineering task, integration will enable these things to come together in a surprising and synergistic manner.

Returning Industry Profit Centers to Production

Perhaps the most critical thing that the Air Force can do to reshape and rejuvenate the aerospace industry is to return their major profit centers to production. Sustainment as a major busines line favors the status quo force design. Even with robust modernization programs, legacy aircraft have very real limitations. Whether considering the physical constraints of size, weight, power, or cooling; "orphan" software languages; or maxed out processors, they cannot continue to spiral upgrades and newer capabilities indefinitely. There also comes a point where, age aside, the airframe design is no longer relevant to the mission, nor the operational and threat context. Accelerating change, an imperative of Air Force Chief of Staff General Brown, does not mean more of the same. To accelerate and compete in time, the Air Force must transform its force design. This means developing, manufacturing, and fielding new systems at speed. To do this, the Air Force must use natural market incentives so that industry's business interests are aligned with and support the Air Force's—and our nation's—national security interests.

The irony is that given the Air Force's dire recapitalization crisis, market forces should already be shifting industry incentives away from sustainment and toward profit. The Air Force very nearly needs to replace everything, and now. Yet the instability and unreliability of current production programs, coupled with the infrequency of new-starts, continues to firmly locate business opportunities and profit in sustainment and modernization.

Several factors contribute to these problems, all of which are waterfall consequences of the misconceived "offset" thinking that highly capable weapon systems can justify a smaller force. Capable, in this context, typically denotes a tightly coupled, multi-function/multi-role weapon system. But pursuing multiple technological advances simultaneously increases the complexity and cost for development, engineering, manufacturing infrastructure, and tooling—not to mention increased unit cost for each aircraft. It is unlikely that economic strategies to control cost, like large annual buys, will be successful. High program or annual procurement costs can place a weapon system at increased risk for congressional cuts during any budget cycle.

The complexity of these weapon systems also drives time into the development. This is a major reason why weapon systems today take over a decade to field. The longer a weapon system is in development, the more opportunity there is that the operational problem for which the weapon system was developed will change. If a program maintains its approved engineering baseline, it risks diminishing its relevance. This is a major driver behind requirements creep in weapon system development. The complexity of multi-role aircraft makes these developmental pivots and requirements additions difficult because of how tightly their systems are now integrated. The service may pivot to alternate solutions and jeopardize total planned production quantities.

Operational relevance is not the only reason to accelerate development. In this endeavor, the adage holds true: time is money. Acquisition studies show that "the length of a tactical aircraft development program has been systematically related to a standardized measure of the aircraft's eventual procurement cost."[116]

In other words, the best proximate measure of an aircraft's cost is how long it is in development. This is a direct relationship; the longer it takes, the more it costs.[117] As adversaries accelerate their own capabilities, long developmental cycles in pursuit of exquisite systems can become perceived as both unaffordable and irrelevant. This perpetuates a cycle of premature program cancellations as the service seeks to shift resourcing into the next power-point generation of advanced technologies, skipping a technological generation in the pursuit of "program next."

Curtailed buys result in the dramatic underutilization and effective amortization of billions in R&D, production-related costs, and associated infrastructure expenses. In other words, premature program termination means that the Air Force is unable to realize the benefits of its financial and technological investments. When not replaced in sufficient quantity, legacy platforms persist in the inventory and drive higher sustainment and modernization bills as their lives are extended to provide gap coverage. The growth of these costs squeezes available budget space, making remaining funding for recapitalization even smaller. It is a deleterious cycle that favors the past and prevents both the Air Force and industry from fully moving into development and production.

Companies in the aerospace industry are rational actors who generally make responsible choices for their stakeholders. Ultimately, their decisions are graded by Wall Street, and the DOD would be foolish to disregard these realities. The success of industry and the success of the service are tightly coupled. To that end, history points toward successful models—as well as cautionary tales—to show how the service can productively evolve the transformation of the aerospace industry and the service force design for rapid adaptation.

Accelerate the development and fielding of weapon systems

The Air Force has recognized that it must dramatically accelerate the development and fielding of major weapon systems. Capabilities must be fielded within a window relevant to operational demand, which means outpacing the adversary's ability to predict, counter, and adapt to the new system. Furthermore, the longer a program is in development, the more it costs—both in the development phase, and for unit cost. It is a simple matter of economics. If the Air Force is going to control the escalating cost of weapon systems, it must field them faster. To do address these challenges, the service should leverage the previously proposed competitive experimental prototyping, both in airframe design and system integration; focus on a small set of improved attributes; and maximize the use of mature and common subsystems.

The F-117 was not a product of an LWF-style competitive prototype fly-off, but it did result from a competitive design process to win an experimental prototype contract.[118] Lockheed's Have Blue prototype was not a production-oriented developmental phase for the F-117, but it did demonstrate the stealth shaping and coatings, burning down risk in the same way that the YF-16 LWF program did for the F-16. An important and often overlooked element of these types of competitive prototyping programs is that it effectively jump-starts the Joint Capabilities Integration and Development System (JCIDS) process. Because requirements definition and competition occur early in the process, the Air Force does not need to re-start at an analysis of alternatives or open a new competition—nor should it. Competitive prototyping, although not committing the Air Force to production, can rapidly accelerate the fielding of weapon systems. It can also accelerate technology insertion through follow-on model production, similar to the many models of the Century Series fighters or blocks of F-16s. These were new-build aircraft with significant design improvements—not modernized sensors or software retrofitted to old aircraft.

It should be noted that although Have Blue was the experimental prototype, the F-117 was not simply a production version of Have Blue. It was a larger aircraft with some different major design features than Have Blue, such as the tail-cant. Still, like the LWF program, the experimental prototyping provided the Air Force the opportunity to explore and advance a technology without committing to a production program. When stealth proved successful and the Air Force did make the decision to transition, Have Blue's prototype experience rapidly accelerated the developmental phase of the production aircraft. The YF-117's first flight was in June of 1981, and the stealth bomber became operational in October of 1983. The F-117 went from contract approval to operational in less than five years, faster than both the F-15 and the F-16.[119]

Another factor that accelerated the F-117's fielding was the program's deliberately narrow focus for capability improvement. Aside from stealth and signatures, the program's performance requirements were not ambitious. Instead, they were fairly basic and did not push the state of the art. For example, mission parameters were set at a 400 nm mission radius and 5000-pound payload. The sharp focus on stealth shaping and signatures limited the volume of technologically ambitious objectives, providing engineers clarity and flexibility when they faced the inevitable design tradeoffs in full-scale development.[120]

Figure 11: Convair F-102 Delta Dagger and F-106 Delta Dart. Convair was awarded the 1954 Interceptor program in 1950 to develop a supersonic interceptor that would defend the United States from incoming Soviet bombers loaded with nuclear bombs. This interceptor was incredibly sophisticated. The operational concept had data links that allowed a ground station to fly the all-weather fighter to the point of intercept, where the pilot could then obtain a radar lock and fire missiles. The unknowns of designing supersonic aircraft (transonic drag and area ruling) coupled with the ambitious vision for the weapon system caused numerous delays. The Air Force made the decision in 1951 to continue developing the F-102A as an "Interim Interceptor," while continuing developmental work on the F-102B as the "Ultimate Interceptor." The F-102B eventually was so different that it was redesignated the F-106. The fastest and most sophisticated of all the Century Series fighters, by the time it was fielded in 1959, other systems has already been fielded to fill the capability gap, and the mission for which it had been designed was obsolete; the Soviets had pivoted their nuclear force from bombers to intercontinental missiles. The F-106 had the shortest and smallest production run of all the Century Series fighters.

The narrow focus accelerated development because it allowed the F-117 to re-use as many existing subsystems as possible. The program budget and schedule from Ben Rich, the head Lockheed's "Skunk Works" during that era, clearly stated that the aircraft would maximize off-the-shelf components and subsystems, to include avionics.[121] The F-117 built upon other advanced technologies that were matured in other programs of record. For example, it employed the digital flight control system developed on the YF-16 and fielded in the F-16. Other off-the-shelf parts included the inertial navigation system from the B-52; the GE F404 engines from the F-18; the ejection seat from the F-15, F-16, and A-10; and brakes from the Gulfstream III corporate jet.[122] A full two-thirds of the F-117's avionics also came from other advanced fighters, needing only minor modification.[123] According to Rich, "Using proven components from other aircraft allowed us [the F-117 design team] to reduce risk."[124]

This did not mean that the F-117 was "low-tech." The re-use of parts and subsystems provide design stability, which allowed Lockheed engineers to focus on the technical challenges that required development to achieve program objectives. Similarly, today's objective should be to integrate advanced technologies and mature technologies that have already been demonstrated. It is in this way that investments are leveraged and move the overall force design forward. As a result of experimental prototyping, design priorities, and maximizing the use of mature subsystems, the F-117 was built upon previous technology advancements to incrementally delivered game-changing combat capability at speed.

Speed matters. In this new offset paradigm, extended developmental timelines will result in a shorter operationally relevant life. Capabilities that require these long developmental lead times will simply be outpaced by other technologies or adversary threat capabilities. Leveraging competitive experimental prototyping for airframe design and system integration can accelerate the fielding of new platforms, as well as enable novel combinations of missionization. Focusing on limited capability advancement objectives can likewise speed these systems to field. This iterative approach must, however, be recognized as such, ensuring that innovations are transferrable to the next new design, as applicable. This prevents the dead-ending of technology development—the rapid spiraling of production types has a compounded effect on the total force design.

The need for speed

The F-106 is a cautionary tale regarding the consequences of extended developmental cycles. Called the "1954 Interceptor" for the year it was intended to field, the F-106 was an exquisitely complex aircraft with ambitious requirements. Anticipating the threat of supersonic Soviet nuclear bombers, in 1949 the Air Force let requirements for a supersonic interceptor. The interceptor would be automatically flown through data link by a state-of-the-art ground computer system until the pilot took control in the final stages of the intercept to fire missiles at incoming Soviet nuclear bombers.[125] Convair won the contract with their unique delta-shaped wing design, but critical systems like the fire control computer were not maturing on schedule, and the airframe design and system integration were suffering difficulties.[126] In 1951 the Air Force broke the program into two aircraft: the F-102 "interim interceptor," an aircraft of reduced capability, and the F-106 "ultimate interceptor."

But by the time the F-106 was fielded in 1959—the same year that Air Defense Command had originally intended to be the last year of front-line use—the interceptor was irrelevant to its original mission.[127] Alternatives to the F-106A, such as Nike surface-to-air missiles, BOMARC surface-to-air missiles, and other manned fighter-interceptors like the cheaper F-101, had filled the capability gap.[128] Even more critically, intercontinental ballistic missiles (ICBMs) had changed the strategic context of air defense because interceptors could not defend against inbound missiles from space. Air Defense Command chose to dramatically reduce its requirement for the highly capable weapon system.[129] The span from contract award to initial fielding for the F-106 was only nine years, but the world had already turned the page.

Better faster is better than perfect

It is also important to consider adjusting testing standards and other processes that, while important, often stand in the way of fielding "better" at speed in a quest to deliver "perfect" over an extended period. Clearly, baseline performance and quality standards need to be met, but time is a factor that must increasingly be weighed.

The F-100A, the first production model of the Super Sabre, had stability issues and some other design flaws that made it challenging to control at low airspeeds. Yet USAFE rushed the early F-100s into operational units because they provided a combat advantage over older types. Much like fielding a minimum viable product and then installing updates, later F-100 models corrected these deficiencies and replaced earlier jets. The F-100 proved to be the most numerous of all the Century Series, with over 3,300 aircraft produced by the end of the decade. Aircraft should be designed to readily adopt improvements, enhancements, and pragmatic fixes to previously unknown deficiencies in a low cost, rapid fashion.

The Department of Defense, Air Force, Congress, and other relevant stakeholders need to understand and appreciate this reality. It has a huge impact maximizing the amortization of R&D innovation across a longer stretch of time in an operational context. To this point, note that the E-8 JSTARS and RQ-4 Global Hawk were both fielded before their testing was complete. They were certified as operational capabilities years after their first combat employments. They were not perfect in their first iterations, but they delivered unique value far and above what else was available. There comes a point when holding out for a 100 percent solution drives higher risk than settling for good enough and working iterative improvements. It is only through the speed of operationalization—even though imperfect—that we will outpace our adversaries' capabilities. Over time, these iterations will have a compounding and complicating effect that provides a step-advantage for U.S. and allied forces.

Increase the frequency of new-starts and maintain multiple hot production lines

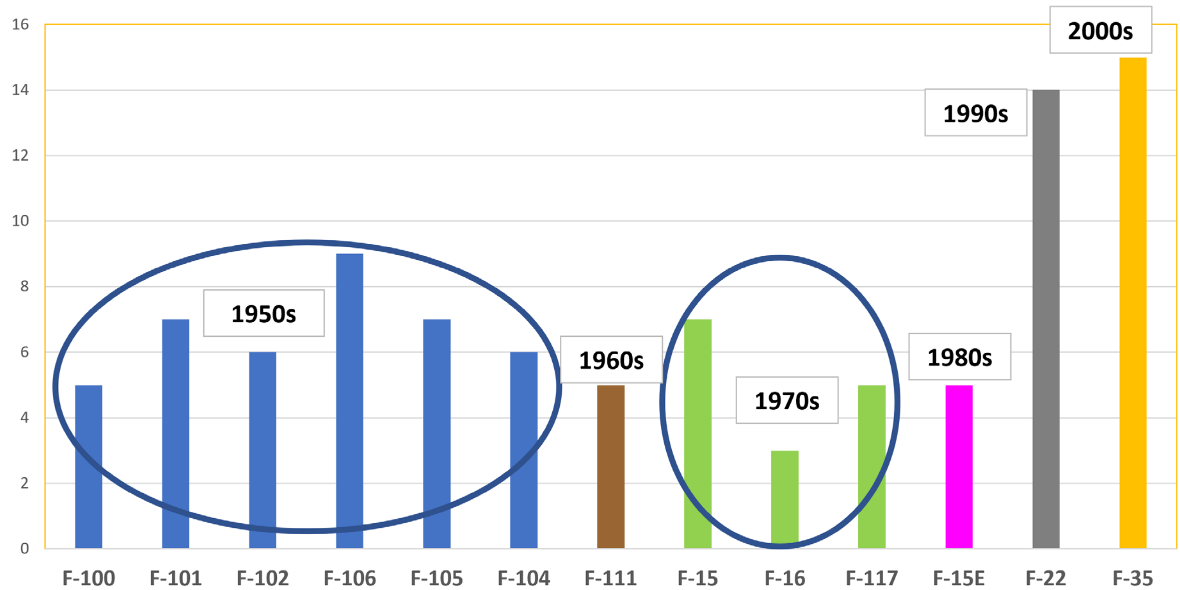
The Air Force should strive to start new production of major weapon system types every five to seven years. This limits technological ambition by allowing technical evolution versus abrupt revolution, refreshes the aged fleet, and increases the opportunity to divest technological obsolescence and conduct technology insertion. Additionally, the Air Force should strive to maintain at least two simultaneous hot production lines of fighters and UAVs, while ensuring one bomber and one airlift line remains active.

Photo: USAF

Figure 12: North American F-100 Super Sabre. Realizing that they had pushed the F-86 Sabre aerodynamic design to its limits, North American developed the F-100 on risk and submitted it as an unsolicited proposal, which the Air Force accepted. The F-100 pushed early supersonic aerodynamics and could be a tricky aircraft to fly. It was well known for the deadly "sabre-dance," where it could become uncontrollable at high angles of attack and low airspeeds. Despite high accident rates, it was in demand by theater commanders because it represented such a significant improvement over other fielded aircraft that its operational advantages outweighed its flaws. The F-100 was designed as an air superiority dog-fighter, yet it proved highly adaptable in Vietnam by flying interdiction, Wild Weasel, Fast FAC, and close air support missions in addition to the air superiority MiG CAP role.

In the 1950s, the Air Force had multiple, concurrent fighter programs in development and production, and over a dozen active aircraft manufactures. This depth and redundancy enabled the Air Force to mitigate risk in one program by leveraging another. RAND found that "Having a variety of fighter platform types … provides a hedge against flaws and maintenance and safety issues that could potentially cause fleet-wide stand-downs. Having a variety of fighter platform types also increase the options available to meet unanticipated enemy capabilities."[130] The F-102, for example, was a program that was highly troubled, and in 1953 Air Defense Command (ADC) deliberately sought backup options as the F-102 development extended and split into two efforts. The B variant of the F-101 Voodoo, then in production, was developed to include the all-weather interceptor capabilities, armament, and datalinks to meet ADC's requirements.[131] Similarly, the F-100 and F-104 also entered service as interceptors for Air Defense Command. These were important options for the Air Force, as this kind of redundancy provided an operational resiliency. For aircraft companies, this represented an opportunity to extend their production lines while also serving to incentivize program performance.

While strategic hedging was never an explicit objective of the Century Series, it was an outcome of which the Air Force took advantage. The Air Force today could aim for this objective as a deliberate choice today. With so many aircraft in stages of development or production, the Air Force could also cancel programs that are too immature or troubled or are no longer relevant without jeopardizing the viability of the company. It could also recognize superior performance with increased production orders or develop a



Credit: MItchell Institute

Figure 13: Fighter Development, Contract Award to IOC. Since the 1950s, average fighter development timelines have ranged between three years to almost seven years. Any longer, like the F-106, the aircraft risked obsolescence. The F-22 and F-35 are both disturbing exceptions to history and worrisome for the future fighter development schedules. Of note is that since the 1970s, only one production contract has been awarded per decade. In the 2010s, no new start fighter production contract was awarded, and none appear to yet be on the horizon.

model variant to fill an entirely different mission. For industry, this environment encouraged innovation because there were ample production opportunities through new-starts to apply new ideas or significantly advance a design through model series: "Contractors learned from experimenting through flight testing and developing specific designs, then sought to refine or expand on the design concepts with which they had built up experience."[132]

The multiple and concurrent production of the Century Series aircraft provided the Air Force strategic options, but the resulting force diversity was more complex to sustain. A more diverse force composed of different kinds of aircraft will introduce a level of sustainment complexity and cost across the entire enterprise. From maintenance training and pilot training to spares, ground equipment and support facilities like depots, a more diverse fleet will cost more. Streamlining maintenance and obtaining cost efficiencies were important rationalization motivations for McNamara's efforts to bring more commonality through joint programs to the DOD.[133] These goals continue to persist today, especially given the high cost of legacy sustainment. Yet the savings achieved through homogenization is not likely worth the trade-off in strategic and operational benefits. Modern information technology can make up for some of this if the "tail" is not stove piped to each platform. Instead of common aircraft, common subsystems across different aircraft types can yield similar measures of efficiencies. This is already done with engines and may serve as a useful model for other types of subsystems. It may also be possible to build one adaptive support infrastructure that can service the full diversity of this force design.

For a healthy and robust industrial base, frequent production opportunities matter. New production starts every five to seven years and maintaining multiple production lines may seem ambitious, but doing so provides the Air Force important strategic options and increases the quality, experience, and creativity of the industrial base. This pace also conditions industry for rapid development and fielding of new weapon systems—an important attribute when time is the offset. For a service that is facing the oldest fleet it has ever had, this may be the only way to reverse the curve.

Maintain a young fleet age

After thirty years of deferred recapitalization, the Air Force must aggressively reset its force to ensure the relevance of its weapon systems and free itself from growing legacy sustainment costs. This means deliberately designing aircraft for shorter lifespans and having the discipline to turn the fleet over to maintain a younger inventory. The Air Force will need to be willing to accept risk associated with design trades around aging and wear—it does not need to design a fighter for a 70-year life span—while not compromising on safety and reliability for the intended lifespan. This imperative is crucial to affordability, but fleet turn-over also creates the opportunity for tech insertion and injects uncertainty into our adversaries.

A 2018 Congressional Budget Office (CBO) study indicated that the optimal time frame for most types is to maintain an aircraft age of fifteen years or less. After twenty years of chronological age, aircraft readiness drops, and costs go up.[134] The assessment found that aging aircraft are increasingly costly to sustain. Even for relative low growth rates, these costs compound over time and can be significant. For example, a low 3 percent growth rate can nearly double sustainment costs when the fleet reaches 30 years, while 7 percent growth would quadruple costs.[135] Across an aged inventory, this adds up. This is the very problem that the Air Force has been struggling with, unable to keep its aircraft fleets at an 80 percent readiness rate or higher.[136]

These observations suggest that an age management model may prove useful to begin increasing readiness and capability, while reducing the service's deep sustainment bills. Both age and hours should be considered in managing fleets. Aircraft types should be replaced at a rate that keeps that individual fleet less than fifteen years and short of their hourly service life. This does not imply that successful designs should be arbitrarily retired. To the contrary, so long as an aircraft design remains operationally valuable and relevant, it should remain in the inventory—just not through service life extensions and extreme depot level sustainment activities. Successful types should remain in production with newer models replacing older versions as needed. The C-130 stands as a prime example of this option in action, and it likely should have been applied to the C-17.

The F-22, however, is one example where that opportunity is lost. According to congressional testimony in 2017 by Air Force senior leadership, the F-22 is planned to remain in the fleet "until the 2060 timeframe, meaning sustained effort is required."[137] With an airframe that will be relevant and dominant for decades to come, this small fleet of incredibly capable fighter aircraft will be over sixty years old when it is finally retired. Most of the F-22 fleet is at a point in its chronological life where its sustainment costs are still on the right side of the curve. According to the CBO analysis, the F-22 had experienced over a 50 percent drop in annual real growth in sustainment costs when the F-22 fleet was at an average age of five years.[138] But with its production line shut down, there will comes a point of diminishing returns. Current Air Force leaders have already begun to cede that they may, in fact, look to retire them as soon as the 2030s.[139]

Actively managing aircraft age provides operational and enterprise advantages. For one, model series can enable crucial technology insertion. As modular and adaptable as an aircraft may be designed, it is still a cyber-physical platform. There are elements that may be too integral or costly to replace, like upgrading the systems on the early Block 10/20 F-22s. Similarly, older fleets are plagued by diminishing manufacturing resources (DMS) and extinct software languages. As crucial as software is to today's combat capability, modernization is often limited by these older airframes whose core processors, software languages, and programs are often obsolete. The Air Force Studies Board found that for these older weapon systems, "the USAF is maintaining, sustaining, and developing software that represents different generations, architectures, and coding languages, some of which are 'orphans': languages with few if any commercial uses, coding communities, or economic viability."[140] A 2001 study on aging aircraft found that avionics are the second largest component of O&M costs, of which DMS is a rapidly growing percentage.[141] This certainly has only gotten worse. Funds spent to replace outdated parts come at a cost opportunity. Replacing aircraft with newer models and types allows for a critical technological refresh and the opportunity for the insertion of the latest processors and languages, both of which are foundational elements of advanced combat capability.

Importantly, maintaining a younger fleet age for all types reinforces the effort to shift industry away from the stable, long-term strategy of sustainment. Devaluing the profitability of aged fleet sustainment begins to loosen and even break industry's grip on the lifecycle of their products. Opportunity and fleet turnover can allow companies to make more revenue and profit from production and innovation. This can begin to free the Air Force of vendor lock and more fully open up the potential of open architecture and rapid system integration.

Develop agile manufacturing technologies

Increasing the number of new-starts, maintaining multiple production lines, and managing fleet age through replacement all rely upon production. If the Air Force is to shift industry profit centers into development and production in ways that are realistic and executable, then manufacturing techniques must be developed to align with and support the broader force design strategy. This will require industry to be able to affordably manufacture a diverse fleet rapidly, without losing the precision, reliability, and quality of production on which warfighters have come to rely.

Traditional manufacturing relies upon sophisticated tooling that is hyper-specialized for a single function for a very specific aircraft on the production line. Tooling is an essential element of modern production lines. More than just jigs, these tools are often robotic or even "smart." They ensure quality control, speed the construction process, and reduce touch-labor and man-hours. But these tools are not interchangeable among different aircraft designs, nor are they adaptable. According to the National Center for Defense Manufacturers and Machining, "Traditional automation solutions for aerospace manufacturing tend to be purpose-built machines, often dedicated to a specific aircraft or component. These machines demand large initial capital outlays and significant operating expenses."[142] That is, they cannot be modified to be used on different aircraft designs or components. They cannot be re-used or re-purposed.

Just as it takes time to design an aircraft, it takes time to design and "tool-up" a production line. Production prototype aircraft are typically hand-built, meaning that they are constructed with rudimentary jigs and tools. Companies know that even minor design changes are likely to result from the test program, so they intentionally build prototypes without significant investment in production-oriented tooling. But this can incur extended timelines if companies have to wait to fully test and finalize the system design, then design, build, and install the tooling. Although the technology for tooling has advanced, not much has changed from the 1950s.

Efforts to compress this schedule in order to accelerate the fielding of weapon systems has been experimented with since the 1950s. The "Cook-Craigie" plan, named after the generals who conceived of it, authorized the development of production tooling before prototype aircraft even conducted first flight. Initial production would be held at low rate until the majority of the flight test program was complete.[143] The Air Force anticipated that changes would be minor, modifications to tooling could be incorporated on the line and retrofitted. This was not the case. Despite wind tunnel testing, it was the flight test that revealed the F-102 would not reach its speed and altitude performance requirements. Convair had to scrap nearly two-thirds of the 32,000 tools it had already designed and procured for production. A weight reduction effort again resulted in discarding approximately half of the 28,600 tools that then comprised the F-102 production line—Convair then had to replacing those with another 20,000.[144] Not only did flight test discovery and design changes impact the development of the F-102, but redesigning and re-manufacturing the production tooling also delayed its entry into operational service. The inflexibility of production tooling is no trifling problem when seeking to accelerate the fielding of new designs.

This challenge to develop agile or adaptable production tooling takes on even greater urgency when considering the need to rapidly insert technology, accommodate new design models, conduct simultaneous production, or even pivot whole production lines. While production opportunities in this new paradigm will be more frequent, they are unlikely to be in the large total quantities that could amortize the cost of these specialized tools, regardless of whether funded by the government or industry. More adaptive and agile tooling is needed.

The Air Force should focus research and developmental efforts on agile and adaptive production technologies. In 2018, Air Force Research Laboratory (AFRL) did just that. AFRL partnered with Boeing on a dynamic, advanced robotic tool that can be programmed for different uses. The Advanced Automation for Agile Aerospace Applications (A5) Robotic System they developed used advanced sensing to sand 60 percent of a C-17, a task that typically requires manual labor.[145] Although this technology has yet to transition, the Air Force also appears to be pursuing advance manufacturing through the next generation air dominance (NGAD) program. These technologies include digital engineering, and likely also encompass 3-D printing, autonomous tooling, and skilled hand-labor, among others. Although the service has been cagey about the means, Dr. Will Roper, then-Assistant Secretary of the Air Force for Acquisition, Technology and Logistics, touted that the real revolution of this missionized, full-scale NGAD prototype is its production using cutting-edge advanced manufacturing techniques.[146] These processes must be proliferated among all U.S. aerospace manufacturers. This is not just about ensuring that a wide competitive field across the industry, but that America can stay competitive against China.

As the Air Force must increase its support of these manufacturing advances, it must also seek to provide experience to manufacturing teams. Like airframe and systems engineering design teams, manufacturing is both a science and an art. It takes ingenious production engineers, advanced tooling, and highly skilled technicians to build a weapon system with the precision and reliability that give U.S. warfighters a combat edge. And, just as with the design teams, repetitions, challenge, and experience are essential to cultivating the expertise of these teams. Repetitions create agility in the teams to tackle new and old problems in innovate ways. Again, there are opportunities to utilize the competitive experimental prototype program to give these production teams the experience and expertise the nation needs of them.

Given how elemental these advancements will be to rapidly developing and fielding new systems, the Air Force should not rely on industry to bear the burden of fully developing these production approaches simply to achieve a more competitive cost. In other words, industry cannot be expected to bear the cost and keep these key advantages nonproprietary. The Air Force should fund research and development efforts and leverage prototyping opportunities to cultivate this often-overlooked element as seeks to transform the force.

Deliberately and strategically managing revenue centers for industry can have a dramatic impact on industry. Defense aerospace companies are savvy and rational businesses that will respond to changes in Air Force acquisition paradigms. Historical cases provide insight regarding how the Air Force can rejuvenate and expand the industrial base, enhance system and software integration skills, and restore the health and size of its force structure by shifting industry profit centers to production. Restructuring the industry and accelerating the transformation of the service will require sustained and disciplined acquisition behavior and resource advocacy from the Air Force—a difficult task when leadership turns over every three years.

There are reasons, however, to be optimistic. The Air Force is already making many promising moves toward this improved vector. The Gremlin and Skyborg experiments offer a path to on-ramp new industry entrants and provide smaller defense companies the opportunity to develop niche expertise and credibility in unmanned aerial systems. Experiments in the Advanced Battle Management System spotlight the need for and challenge the ingenuity of system integration engineers. The Air Force's emphasis on open architectures is both increasing the value of integration skills, while decreasing the value of proprietary systems. By continuing these efforts and further shifting its acquisition paradigms, the Air Force can transform its force from one dominated by legacy, fourth-generation platforms to one that rapidly adapts by fielding new weapon systems and integrating advanced sensors and capabilities in surprising and unpredictable force compositions. This is how the Air Force wins.

Conclusion and Recommendations

The United States cannot assume that it holds sole exclusivity over exquisite defense technology, nor does the nation have decades to develop a new offset force. The demands of the global security environment, paired with the current state of military capabilities, demand rapid, decisive, and prudent action. This is especially true in the aerospace realm. Traditional offset approaches have normally relied upon highly advanced technologies to compensate for force size limitations. These capabilities required decades to invent, refine, produce, and field. While the resulting aircraft and associated systems were incredibly advanced, budget reductions lowered acquisition buys well below stated requirements, yielding significant capacity and capability gaps. This makes the need for rapid action ever more urgent.

In today's global competition, the United States does not have the luxury to follow a time-intensive model. Success in today's global security contest demands advancing capability while emphasizing rapid development and fielding to gain a comparative advantage in force presentation speed and agility.

In this strategic approach, American industry's ability to speed-to-field and integrate new capabilities will enable the Air Force to rapidly connect, command, and create surprising new force compositions. These advanced and unorthodox systems can disrupt an adversary's ability to understand, predict, or target U.S. or allied operational architectures.

Implementing this new offset strategy will require the Air Force to alter its acquisition paradigms in ways that will constructively revector and reshape the aerospace defense industry. The aerospace industry has been forced to adapt and consolidate in order to optimize its procurement models and acquisition practices to match nearly thirty years of constrained Air Force investment and deliver offset force structure models from an earlier era. Mainly, they have refocused their engineering talent and shifted their business models to center on sustainment rather than innovation. This model risks falling short of addressing future security demands and is ill-suited for the pace of competition that is unfolding in this new era.

By using natural market incentives, the Air Force can responsibly expand the aerospace industry and refocus it to deliver capability at speed. Aerospace companies are rational actors and shape themselves according to the conditions presented to them. The Air Force can achieve quality, quantity, and adaptation at speed if it invests in existing talent, expands its aerospace base, enhances the integration skills of design teams, and commits to stronger new-start and production programs. Historical cases suggest this is a realistic and pragmatic path to follow. These recommendations include:

- Expand the defense aerospace industrial base. A larger defense base means more competition, increased innovation, and greater design diversity. It provides the nation strategic depth of capability by cultivating seasoned talent and experience.

  - **Do not arbitrarily break the industrial base you have.** There is no strategic hedge in the industrial base, so do no harm. U.S. defense aerospace companies contain some of the world's greatest engineering talent, ingenuity, and manufacturing skill. For any action the Air Force takes, it must be sure to preserve the expertise and capacity of the current industry.

    - **Leverage the opportunity of rapid technological development to experience new industry entrants.** Periods of rapid technological change lower the barriers to entry, creating the opportunity for smaller, less established companies to mature and grow through robust research and develop programs.
    - **Provide ongoing, competitive, experimental prototype programs.** Ongoing experimental prototype competitions can provide the challenges and repetitions needed to generate innovation, experience, and maturity for newer entrants. They can also keep engineering and manufacturing teams from established companies sharp.
    - **Avoid future joint aircraft programs.** Joint aircraft programs decrease design diversity and narrow the aerospace industrial base through consolidation. Furthermore, analysis has shown that joint aircraft programs do not yield the intended cost savings benefits.

- **Enhance the integration skills of design teams.** The skill and creativity necessary for design teams to conceptualize and integrate complex systems underpin the strategy of rapid adaptation that will provide strategic and operational advantages in a peer contest. In other words, integration expertise is crucial to accelerating change.

    - **Leverage and experiment with open systems, mission integration, containerization, and other technologies to create flexible and adaptive weapon systems.** Leveraging open mission systems, mission integration tools, and software containerization technologies enables software and system engineers to explore how quickly system integration and how far forward mission adaptation can occur.
    - **Promote the development of mission integration tool sets.** Mission integration tool sets are needed to enable airmen to rapidly integrate systems and adapt operational architectures at the battlespace edge.

- **Return aerospace's major profit centers into production.** With current major profit centers focused on sustainment, industry is biased toward perpetuating the status quo force design. Shifting the dominant profit center back into production will concurrently shift a focus to rapid fielding of capability and innovation while loosening the grip of vendor lock.

    - **Accelerate development and fielding cycles.** Speed-to-field can be achieved by reviving competitive experimental prototyping, which also decreases risk; focusing programs on a small set of improved attributes, which enables teams to make better design decisions and trade-offs; and maximizing the use of mature and common subsystems.
    - **Accept smart risk by prioritizing rapidly fielded iterative improvements over perfect systems.** This would instill a record of trust with industry through disciplined and firm commitment to programmed production internally, at the OSD level, and on the Hill.
    - **Develop adaptive and affordable manufacturing technologies.** The Air Force should

deliberately cultivate the development of both the workforce and the manufacturing technologies that enable production lines to rapidly reconfigure, reuse and repurpose tooling, and support concurrent production.

- **Increase the frequency of new-starts, maintain multiple hot production lines.** New programs should start every five to seven years to bound technological ambition, refresh the inventory, and increase opportunities for technology insertion. In addition, the Air Force should strive to maintain at least two simultaneous hot production lines of fighters and UAVs, as well as ensure one bomber and one airlift line remains active to provide for strategic hedging and the health of the industry.
- **Maintain a younger fleet age.** Unsustainable sustainment costs for aging aircraft mean the Air Force must shift their funding toward aggressively recapitalizing and replacing at a rate that keeps individual fleets at less than fifteen years—and short of their hourly service life.

Closing Thoughts

The United States does not have an exclusive hold on developing advanced technologies. There are indications that other nation states—most worryingly, China—may be ahead of the United States in key areas like machine learning, artificial intelligence, and computation and processing. The global proliferation and acceleration of technological development means that pursuing old offset strategies of game-changing capabilities that take decades to develop and field may cause U.S. forces to be late to the game. Adaptation will be the new advantage, and time the new offset. We must field change at a pace that adversaries cannot match.

The global proliferation and acceleration of technological development means that pursuing old offset strategies of game-changing capabilities that take decades to develop and field may cause U.S. forces to be late to the game. Adaptation will be the new advantage, and time the new offset.

To achieve this, the Air Force must transform its force design to rebalance the characteristics of quality, quantity, diversity, and speed. To compensate for smaller force size relative to U.S. adversaries, past offset strategies have maximized quality through advanced, multi-function weapon systems that could take decades to field. Although that approach has been successful in the past, it will not remain so in today's national security environment. The aerospace industrial base is not currently structured or incentivized to develop or deliver this new offset.

U.S. defense aerospace companies contain some of the world's greatest engineering talent, ingenuity, and manufacturing skill. To field advanced capabilities at the speeds warfighters need, the defense industry must expand, and business models must shift away from sustaining the past. This can only be done through changing Air Force acquisition paradigms. As the Air Force seeks to transform and reshape this national resource to compete in a peer contest, and across the spectrum of conflict, it must take care to do so in a responsible way. This transformation must be a constructive—not destructive—evolution. The current aerospace defense industry cannot be arbitrarily broken. Their talents are proven, and the Air Force can build upon these strengths while expanding the marketplace, enhancing integration skills, and shifting industry focus toward models that thrive on rapid development and production.

The national security realm will become more, not less, complex in future years, and the nation's commitments remain non-negotiable. The Department of Defense and the services must not just keep pace with global peer threats, they must out-pace them. A rapid evolution of the defense aerospace base is needed to achieve force transformation at speed, and the most effective and responsible means to do this is by changing Air Force acquisition behavior. Shifting industry profit centers away from sustainment and back into R&D and production is the best way to achieve rapid adaptation. This future is not only possible, but imperative.

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