Vol. 24, September 2020

MITCHELL INSTITUTE
Policy Paper

Key Points

The USAF should procure low-cost A/R UAVs in significant numbers to increase its combat capacity, lethality, and survivability in contested environments.

A/R UAVs are complementary, force-multiplying capabilities, not replacements for 5th generation stealth aircraft needed to maintain the USAF's combat advantage over peer adversaries.

Given their modest payloads, A/R UAVs could have the greatest combat value if used for electromagnetic warfare, persistent C2ISR, and other non-kinetic missions that take advantage of their force-multiplying potential.

The low cost and modularity of A/R UAVs will improve the USAF's ability to rapidly innovate, operationalize advanced technologies to meet changing requirements, and speed new capabilities to warfighters.

The USAF should experiment to explore the value of A/R UAVs for multiple missions and quickly field prototypes to allow warfighters to develop concepts that integrate their operations with other manned and unmanned aircraft.

The Air Force should determine logistical support and other requirements to launch and recover large numbers of A/R UAVs from distributed theater locations without airfields.

Understanding the Promise of Skyborg and Low-Cost Attritable Unmanned Aerial Vehicles

By Mark Gunzinger
Director, Future Concepts and Capability Assessments, The Mitchell Institute for Aerospace Studies
Lukas Autenried
Senior Analyst, The Mitchell Institute for Aerospace Studies

Abstract

Over the next decade, the U.S. Air Force (USAF) must find a way to maintain its current readiness, modernize an aircraft inventory that is its oldest ever, and grow to 386 operational squadrons. The reason for this is clear: threats are on the rise, and U.S. leaders need new defense options empowered by a next-generation combat air force with increased capacity. A defense budget downturn could deprive the Air Force of the resources it needs to pull off this balancing act and force harmful compromises that increase the risk of mission failures.

Historically, the USAF used two approaches to modernize and grow its capacity. First, it bought new, more advanced aircraft with life cycles spanning decades. Second, it procured larger quantities of single-use capabilities such as precision-guided munitions that are expended to achieve operational effects. There will soon be a third choice.

The Air Force is developing a family of unmanned aerial vehicles (UAV) that can fly a limited number of sorties and are cheap enough to use in threat environments where the risk of attrition is too high for manned aircraft. These "attritable/reusable" (A/R) UAVs will have artificial intelligence-enabled autonomy that allows them to team with other aircraft to conduct multiple missions. Procuring low-cost A/R UAVs in addition to required high-end capabilities such as F-35As and B-21s is an affordable way to grow the USAF's combat capacity and balance its other requirements. A/R UAVs that do not require airfields for launch and recovery would also help the Air Force remain an "inside force" capable of generating combat power from dispersed expeditionary locations within range of Chinese or Russian anti-access/area-denial (A2/AD) threats. This will help change adversary defense calculations and impose costs on opponents to the advantage of U.S. interests.

Introduction

America's global security interests are now being challenged to an extent that has not been seen since the Cold War. China and Russia's revisionist ambitions threaten peace and stability in multiple regions. North Korea and Iran—aided by weapon proliferators like China and Russia—seek the ability to deliver devastating missile attacks over long ranges. At the same time, the so-called Islamic State, al Qaeda, and other non-state actors continue to plan attacks against the United States, its allies, and its friends. These challenges drive national defense requirements that cannot be met by a U.S. military that has suffered from decades of force structure cuts and inadequate modernization funding.

There is no question that fielding the next generation of U.S. fighters, bombers, and other advanced capabilities is critical to countering China and Russia's A2/AD threats and other home-field advantages.

In the case of the Air Force, its capacity to perform many of its missions is spread exceedingly thin. This includes forces needed for intelligence, surveillance, and reconnaissance (ISR); electromagnetic warfare (EW); offensive and defensive counterair operations; and long-range strikes.[1] Furthermore, the USAF's shortfalls would be magnified by China and Russia's home-field advantages in a major conflict in critical areas such as the Taiwan Straits and Baltic Sea region. Physical proximity to these battlespaces gives their militaries advantages in time and space compared to USAF forces that must sustain operations thousands of miles from the U.S. homeland. China and Russia's A2/AD weapon complexes further alter regional balances of military power in their favor. These complexes include advanced integrated air defense systems (IADS) and large inventories of guided missiles that China and Russia can launch against the linchpin of the Air Force's ability to generate combat power: its theater airbases. Large-scale missile salvos against U.S. theater airbases, not air-to-air or surface-to-air engagements, will likely be the most significant cause of USAF force attrition in a major conflict with a peer adversary. The response to this must not include a preemptive retreat, such that the U.S. military moves away from an adversary's reach. This would downgrade the U.S. military's options to project power before a shot is fired, and it would threaten the stability of alliance structures that are critical to the defense of the United States. Instead, U.S. theater strategies must seek a broader range of force employment options.

There is no question that fielding the next generation of U.S. fighters, bombers, and other advanced capabilities is critical to countering China and Russia's A2/AD threats and other home-field advantages. The missions these aircraft execute are essential and cannot be replicated by alternate means. However, there is a limit to what the Air Force can achieve unless it can also radically grow the size of its force and improve its ability to operate from dispersed postures. The USAF's traditional approach to increasing its potential to project combat mass—its capacity to "concentrate the effects of combat power at the most advantageous place and time to achieve decisive results"—is to buy more forces during infrequent peacetime defense build-ups or rely on the U.S. industrial base to surge production during crises.[2] Neither approach is a safe bet now. Counting on surge production to fill the Air Force's known shortfalls in a crisis is not feasible given the many months or even years needed to significantly ramp-up the manufacture of modern combat aircraft and other sophisticated capabilities. COVID-19 budget realities likewise suggest there is little hope that the U.S. defense build-up that began a few short years ago will continue. Instead, flat or declining budgets will require the USAF to make

difficult choices between how it should allocate its resources to maintain its current readiness, sustain the size of its force, and modernize for the future. Simply put, the service cannot cut its current readiness or further reduce its forces without serious impacts on its ability to perform its mission today, and it will not receive the years of budget plus-ups it needs to increase procurement of all of the high-end capabilities it requires. A middle path is needed that maintains current capacity in the near term, preserves programs of record to grow capacity over time, and fields new, force-multiplying capabilities that will be necessary to operate in highly contested areas.

A middle path is needed that maintains current capacity in the near term, preserves programs of record to grow capacity over time, and fields new, force-multiplying capabilities that will be necessary to operate in highly contested areas.

To this end, another approach that could help the Air Force balance its requirements is to invest in lower-cost capabilities that will increase its ability generate combat power from inside A2/AD threat envelopes. This is a key objective of the Air Force's Skyborg and Low-Cost Attritable Aircraft Technology (LCAAT) programs. Skyborg, LCAAT, and their associated initiatives are developing a family of attritable and reusable unmanned aerial vehicles (UAV) with price points low enough to use in contested areas where the risk of attrition is higher than what is acceptable for manned aircraft. A future family of attritable/reusable (A/R) UAVs enabled by a common artificial intelligence (AI) backbone will be able to team with other manned and unmanned aircraft to augment their airborne operations. Buying a significant number of AI-enabled A/R UAVs would help fill growing capacity gaps in multiple mission areas and improve the survivability of the USAF's operations as a whole. Other related Mitchell Institute insights and recommendations that could help the Air Force create a more survivable, lethal, and higher capacity combat force include the following:

- A/R UAVs will be complementary, force-multiplying weapon systems, not replacements for the 5th generation aircraft needed to maintain the USAF's technical advantage over peer adversaries. Instead of replacing manned aircraft, the greatest combat value will result from determining how to best combine the operations of A/R UAVs that have some advanced survivability design features with 5th generation F-35As, B-21s, and other manned and unmanned aircraft to achieve effects in contested battlespaces.
- In addition to their low procurement and sustainment costs, the modularity and open software architecture of a family of A/R UAVs will improve the USAF's ability to rapidly innovate, incorporate maturing technologies to meet changing requirements, and speed new capabilities to warfighters. A/R UAV modularity also has operational implications—it may be possible to change an A/R UAV's modular mission systems between sorties, allowing commanders to quickly recompose their forces to meet evolving mission needs.
- Given the modest payload capacity of current A/R UAV prototypes capable of launching and recovering without runways, the greatest combat value might be achieved by using them for non-kinetic missions such as electromagnetic warfare, persistent C2ISR, as part of kill meshes, and other operations that multiply effects created by aircraft that can carry a much

larger number of expendable weapons.

- A critical step in transitioning a new weapon system to the field is creating concepts for its use that maximize its warfighting potential. The Air Force should conduct rapid experimentation and demonstrations to examine the military utility of a range of A/R UAV missions and supporting capabilities needed to employ large numbers of A/R UAVs. The service should also field initial A/R UAV prototypes as quickly as possible to allow operators to experiment and develop concepts that integrate their operations with other weapon systems. In addition to developing these concepts, establishing an understanding of communications and other requirements to conduct manned and unmanned aircraft networked operations should be prerequisites for procuring A/R UAVs at scale.
- A/R UAVs and other containerized transportable systems could have significantly reduced logistics footprints compared to similar quantities of manned aircraft in theater. The Air Force should conduct analyses to determine the complexity, cost, and other logistical requirements to operate large numbers of A/R UAVs from distributed postures in the Indo-Pacific region and Europe.[3]

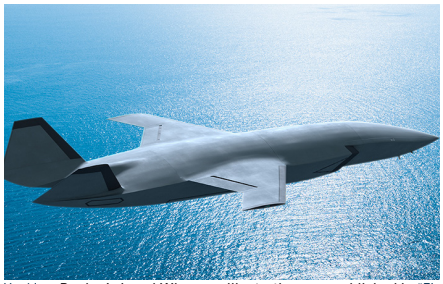
What Are Attritable/Reusable UAVs?

A/R UAVs are low-cost, unmanned aircraft that are designed to conduct a finite number of sorties in contested environments. These aircraft will integrate the full spectrum of autonomous capabilities as the Air Force develops and tests them.

Attritable. The Air Force uses the term "attritable" to describe a new class of UAVs that will be low cost, highly reliable, and have some durability. Unlike manned fighters and bombers that have structures, engines, and mission systems that must last for decades, attritable UAVs have less expensive components and life cycles that are measured in a few years or possibly only a number of months. While some A/R UAVs may have features that reduce their potential to be located and tracked by enemy air defenses, they are designed to be attritable and do not need very low observable designs, the onboard ability to fuse information from multiple sources, and other features that give 5th generation stealth aircraft their ability to survive in contested areas. This design approach could reduce the procurement and sustainment costs of A/R UAVs to a point that is cheap enough to permit their use in high-threat areas that would be too risky for manned aircraft.[4]

Reusable. The Air Force also uses the term "reusable" for this new category of UAVs since they are not single-use systems like cruise missiles that must be destroyed

Figure 1: A XQ-58A Valkyrie during a test flight, an artist's concept of the Royal Australian Air Force's Loyal Wingman, and an artist's concept of C-130s launching and recovering Gremlins.



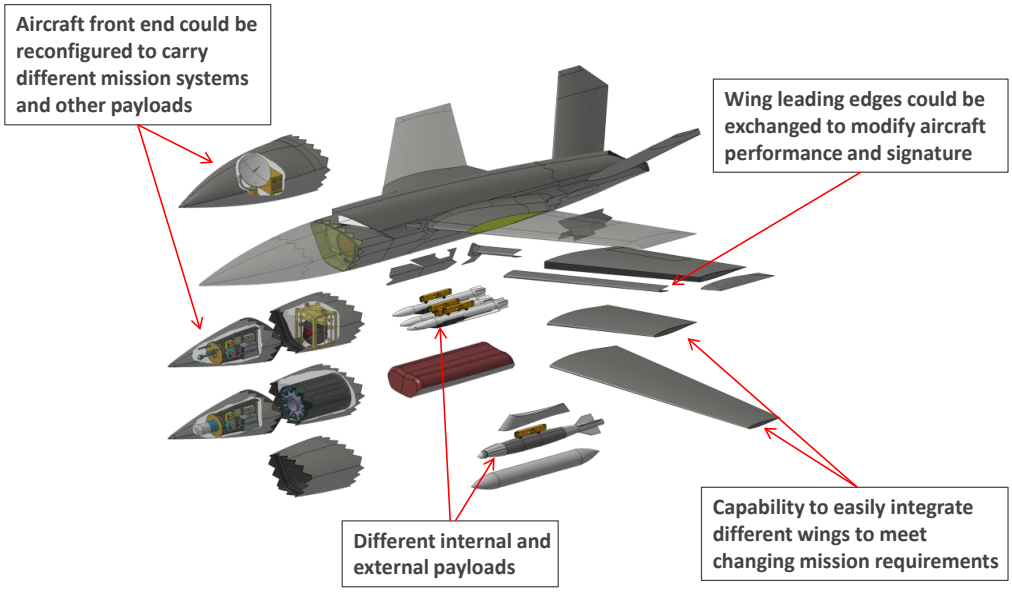
Sources: The XQ-58A Valkyrie is an Air Force photo by Senior Airman Joshua Hoskins. Boeing's Loyal Wingman illustration was published in "First Loyal Wingman handed to RAAF," *Australian Defence Magazine*, May 5, 2020. The Gremlins graphic was released by DARPA.

to create desired effects on targets. The XQ-58A Valkyrie, which first flew in March 2019, may be the Air Force's best-known prototype of an attritable/reusable unmanned combat air vehicle (UCAV). The Valkyrie can be launched from a relocatable containerized rocket-assisted takeoff (RATO) assembly and recovered after a mission by parachute. Other candidate A/R UAVs include a variant of the Airpower Teaming System being developed for the Royal Australian Air Force and the Defense Advanced Research Projects Agency's (DARPA) Gremlin UAV that can be launched and recovered inflight by cargo aircraft, such as C-130s, or from the ground.[5]

Low-cost. The Air Force is taking advantage of novel and agile manufacturing, small advanced turbine engines, modular components, and other cutting-edge technologies to greatly reduce the cost and time to manufacture A/R UAVs—possibly to weeks instead of the 18 months or more needed to produce an advanced manned fighter. According to AFRL, "by emphasizing future flexibility, openness, modularity and expandability, attritable aircraft technologies represent an innovative way for the U.S. to prepare for potential engagements with near peer adversaries at a fraction of the cost of traditional systems."[6] A/R UAVs could have unit flyaway costs of a few million dollars to low tens of millions depending on their size, range, payload, mission systems, and other attributes. At the low end of the cost spectrum, A/R UAVs like XQ-58 Valkyries with minimal mission systems may cost only $2–3 million each. Additional avionics, sensors, and other systems for fully missionized A/R UAVs could increase their unit cost to $10–15 million, and, at the higher end of the capability spectrum, some may cost $20 million or more.

The cost to operate A/R UAVs will likely be a fraction of the average flying hour cost of a typical manned fighter. A/R UAVs with short operational life cycles will not need as much maintenance as fighters and other manned aircraft that will remain in the inventory for 30 years or more, and there will be less need to fly A/R UAVs to train and maintain the proficiency of their pilots. Moreover, like an employee that

Figure 2: Example A/R UAV aircraft and mission system modularity.



Source: Adapted from a figure provided to the Mitchell Institute by Kratos.

never requires sick leave, there will not be a need to take A/R UAVs out of service for months at a time for programmed depot maintenance. This would help maintain high mission ready rates for a future fleet of A/R UAVs.

Modular. Unlike traditional weapon systems such as fighters and bombers that are designed with highly integrated sensors, datalinks, and other mission systems to perform multi-role functions, the Air Force's intent is to field a family of A/R UAVs that can be tailored to meet different mission requirements using an adaptable open architecture and a "plug and play" design philosophy. This would see single mission focus as the priority, with A/R modularity allowing the flexibility to rapidly incorporate new technologies and mission systems as operational requirements evolve. For instance, modular A/R UAVs could be configured with sensors to perform as ISR platforms for a number of sorties and then be quickly reconfigured with different mission systems to conduct airborne electronic attacks or other missions as operational needs change. Modularity can also include the ability to change the wings and other A/R UAV aerodynamic structures to increase their range and endurance or reduce their signature in the electromagnetic spectrum (see Figure 2).

A/R UAVs will be a step forward in the evolution of autonomous unmanned weapon systems.

AI-enabled. A/R UAVs will be a step forward in the evolution of autonomous unmanned weapon systems. Over time, advances in AI technologies will make A/R UAVs far more capable of autonomously reacting to unforeseen threats and other events during missions than USAF remotely piloted aircraft (RPAs) now in the force. The Air Force uses the term "RPA" for unmanned aircraft such as MQ-9 Reapers that are controlled by human crews on the ground. This man-in-the-loop command and control (C2) approach is dependent on maintaining secure communications between RPAs and their ground control stations. Since datalinks for A/R UAVs operating deep in contested areas may be vulnerable to enemy jamming and other countermeasures, the Air Force intends to use more of a man-on-the-loop approach for their command and control that takes advantage of AI-enabled autonomy. Northrop Grumman is designing a Distributed Autonomy/Responsive Control (DA/RC) prototype system that will "manage a complex air battle at a speed far beyond human abilities" to support this approach.[7] A/R UAVs will be able to detect threats and other changes in the operating environment and then use their AI algorithms to decide on appropriate actions. Similar to self-driving cars, man-on-the-loop C2 will allow human operators to monitor and intervene as needed to change decisions made by A/R UAVs during missions. According to former Air Combat Command Commander General Mike Holmes:

> *The low-cost, attritable aircraft we've been looking at will be more autonomous than the*

AFRL on Skyborg

"The primary goal of the Skyborg program is to deploy a modular, fighter-like aircraft that can be used to quickly update and field iteratively more complex autonomy to support the warfighter."

"Skyborg is an autonomy-focused capability that will enable the Air Force to operate and sustain low-cost, teamed aircraft that can thwart adversaries with quick, decisive actions in contested environments." See endnotes 4 and 6.

> *RPAs we fly now. We'll give it goals, and we'll tell it about its operating environment, we'll prioritize targets and actions for it, and, through machine learning, we'll teach it to make more decisions on its own.*[8]

Said another way, this is the next step in UAV development. Teamed with manned and unmanned aircraft, AI-enabled autonomous A/R UAVs could have as significant an impact on future USAF combat air operations as stealth, precision guidance, and other technological innovations have realized over the last three decades.

Skyborg. Skyborg is one of three Air Force vanguard science and technology (S&T) programs that are prototyping and experimenting with new weapon systems and operating concepts to "deliver remarkable new capabilities that provide warfighters with superior advantages in the battlefield."[9] Vanguard status provides Skyborg with the requisite level of institutional and warfighter support needed to push AI-enabled, autonomous A/R UAVs through the so-called acquisition valley of death and into the hands of America's warfighters.

Skyborg is focused on developing a digital AI architecture and accompanying software for a family of A/R UAVs capable of manned-unmanned teaming operations: "The intent of Skyborg is to integrate an autonomy mission system core and suite of services ... with multiple low-cost air vehicle systems, each designed to perform one or more mission types."[10] Skyborg will also demonstrate technologies and concepts for the large-scale generation of A/R UAV sorties from forward operating locations without the need to use runways and other airbase infrastructure that are vulnerable to an adversary's missile attacks.[11]

AFRL selected Leidos as the Skyborg System Design Agent to integrate software and other technologies from multiple developers to create a core of AI-enabled software for A/R UAV variants that will learn and mature over time. This process will involve conducting experiments to determine AI technologies needed by different A/R UAVs, which could range from relatively simple algorithms to fly the aircraft and control them in airspaces to much more advanced AI to enable team decision making.[12] It will also entail incorporating AI techniques such as machine learning algorithms to improve the ability of A/R UAVs to perform their assigned tasks over time by training and learning alongside the pilots teamed with them, which can be supplemented by simulator training.[13]

AFRL's Autonomous Collaborative Platforms (ACP) program. AFRL's ACP program is an enterprise strategy to create autonomous technologies, airframes, propulsion, sensors and interfaces, and mission systems for A/R UAVs that can team with other aircraft, launch and recover without runways, have ranges of 3,000 nm or more, and be expended or recovered depending on mission needs. ACP will also provide a development pipeline for future A/R UAV capability spirals.

The Air Force's LCAAT initiative has been a foundational part of the ACP program, providing vehicle concepts, methods, and tools for designing low-cost attritable aircraft.[14] Under LCAAT, the Low Cost Attritable Strike Demonstration (LCASD) Joint Capability Technology Demonstration (JCTD) developed the XQ-58A Valkyrie, the first example of a flight tested attritable unmanned aircraft.[15] The XQ-58A is supporting Air Force networked UAV experiments and could become a fully capable aircraft that, in addition to the ISR,

strike, and communications support now performed by legacy RPAs, could conduct a broader range of non-kinetic missions such as electromagnetic warfare. Future A/R UAVs acting as decoys or jamming air defense communication links would also increase the survivability of high-value/low-density USAF assets such as F-22 fighters and E-3 Airborne Warning and Control System (AWACS) aircraft that are no longer in production and cannot be replaced. This is a situation where collaborative operations will make the total team of manned and unmanned capabilities better and more effective.

A/R UAVs will be reliable weapon systems despite their limited lifespans. "Reliable" and "limited lifespans" are not contradictory objectives—commercial industry makes products that fit this description all the time. BIC lighters, which are extremely reliable and just as effective as their more expensive permanent counterparts are one well-known example. BIC lighters are also attritable in the sense that they are designed to have short lifespans and are cheap enough to throw away when they are out of lighter fluid. In addition to keeping their unit costs low, designing UAVs for a limited number of missions instead of 30-year-plus service lives will greatly reduce their life cycle sustainment costs and eliminate the need to periodically replace their engines and other major components.

Another LCAAT research development effort feeding Skyborg and future ACP spirals is the Low Cost Attritable Aircraft Platform Sharing (LCAAPS) program. The near-term goal of LCAAPS is to deliver two A/R UAV variants derived from a common system architecture that share core system features and are tailored to perform specific missions, similar to Valkyrie's modular approach. In essence, LCAAPS envisions developing a core system for a variety of A/R UAVs analogous to how car manufacturers created a common chassis suitable for different car models. This is expected to result in reduced airworthiness requirements for the variants and an accelerated transition timeline allowing the AF to rapidly refresh A/R UAV technologies and be more responsive to changing requirements. Similar to the car chassis, common A/R UAV airframes could be outfitted with specialized equipment and software required for different missions. Continuing with the car analogy, the advent of advanced manufacturing will increase the resiliency of A/R UAV production and improve defense industry's ability to surge their production to meet urgent operational requirements.

Related Department of Defense (DOD) initiatives. There is also a broader effort across the DOD to develop technologies and concepts relevant to AI-enabled A/R UAVs. For example, the Air Force is working closely with DARPA's Air Combat Evolution (ACE) program, which is developing AI technologies needed for scalable, autonomous air combat operations. ACE is also focused on increasing warfighter trust in air combat autonomy, a critical step toward future manned-unmanned platform teaming operations.[16] As Acting Deputy Under Secretary of Defense for Research and Engineering, Dr. Mark Lewis recently pointed out that building this trust is essential to fully leverage the relative strengths of human pilots and AI-enabled machines in future warfare: "I don't see human pilots being phased out…I see their work, their effectiveness being enhanced by cooperation with artificial intelligence systems."[17] Notably, the ACE program recently completed AlphaDogfight trials that were designed to demonstrate advanced algorithms capable of performing simulated, within-visual-range air combat maneuvering.[18]

Another example is the Collaborative

Figure 3: The Air Force must grow to by 24 percent to 386 operational squadrons to execute the *National Defense Strategy* at a moderate level of risk.

Source: USAF..

Operations in Denied Environments (CODE) program, a DARPA program that recently transitioned to the Navy's Naval Air Systems Command (NAVAIR). CODE focused on enabling groups of UAVs to collaboratively operate together under a single mission commander instead of requiring mission operators for each UAV. In addition to developing new algorithms and software to improve such collaborative autonomy, CODE helped create operating concepts for CODE-enabled systems.[19] Operating concepts for teaming manned and unmanned aircraft are designed to take advantage of what humans do best, such as reasoning, creativity, and making critical decisions during missions, as well as what machines can do best, such as quickly processing and fusing large amounts of data and executing repetitive tasks. Although the Navy now owns the program, CODE algorithms and software were designed so they could be ported into existing or future A/R UAVs across DOD and customized for their different mission sets.[20]

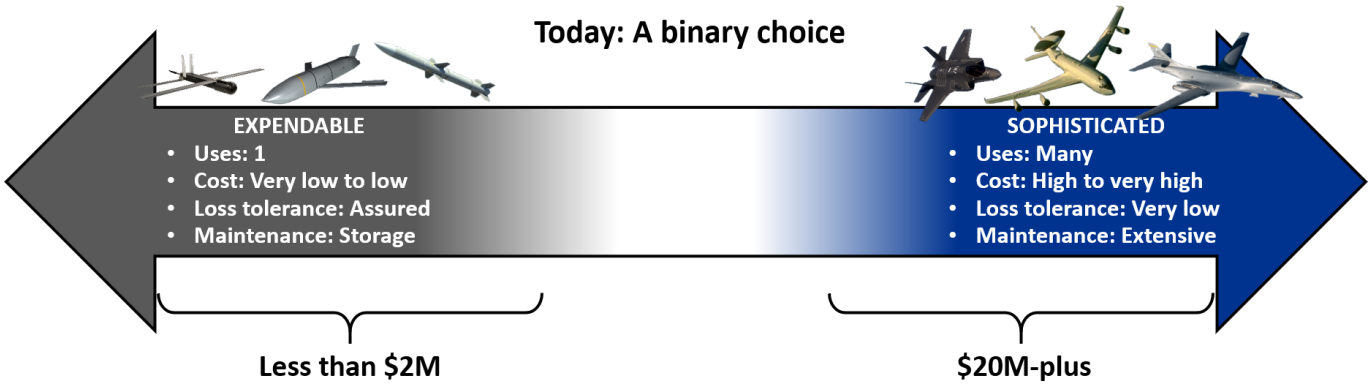
A/R UAVs Are an Affordable Means to Increase Combat Power

The Air Force must increase the size of its forces. After decades of DOD policies that prioritized organizing, training, and equipping U.S. forces for counterterror and counterinsurgency operations, the 2018 National Defense Strategy directed the services to prepare to "deter and, if necessary, to prevail over a major power adversary like China or Russia in a strategically significant, plausible scenario."[21] Threat realities, overlaid with American global interests, implicitly align with this vector. This force sizing requirement is in addition to simultaneously providing forces to deter a second lesser aggressor such as Iran or North Korea, defend the U.S. homeland, sustain nuclear deterrence, and disrupt imminent terrorist and weapons of mass destruction (WMD) threats.

According to a comprehensive Air Force study mandated by Congress, the service must grow by about 24 percent—from 312 to 386 operational squadrons—to execute these requirements at a moderate level of risk.[22] Building this force, called The Air Force We Need, will require DOD and the Congress to break from previous resource allocation decisions that consistently gave the USAF the smallest service share of the defense budget since the end of the Cold War. This reality is only exacerbated with the creation of the Space Force, which now sees two services funded by a budget topline meant for one.[23]

Two independent analyses required by Congress agreed the USAF is now too small, too old, and lacks the survivability and lethality needed to execute the *National*

Figure 4: Depiction of the Air Force's traditional binary acquisition choices.



Source: Mitchell Institute, informed by a graphic released by the Air Force and based on USAF "blue" budget data provided by the Air Force. See Gunzinger and Rehberg, *Moving Toward the Air Force We Need?*; and ABMS Team, "ABMS Industry Day," Department of the Air Force briefing, May 2020, slide 47.

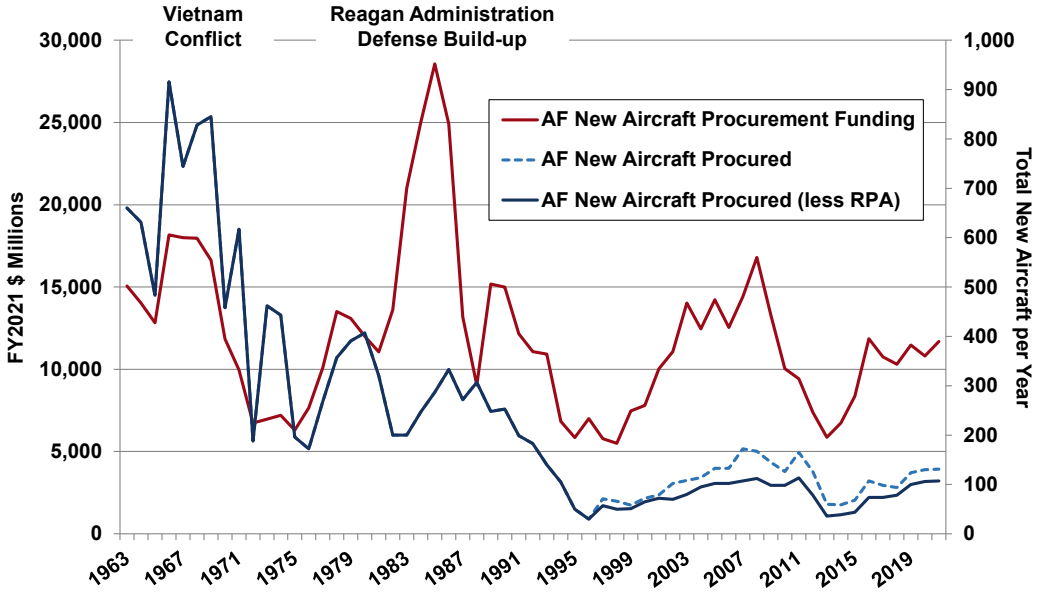
Defense Strategy.[24] In the aggregate, the USAF's diminished force structure cannot project enough combat mass needed for a major conflict with a peer adversary plus meet the service's other operational requirements. Said more directly, the USAF does not have enough aircraft to defend the U.S. homeland, sustain nuclear deterrence, put enough conventional weapons on targets to quickly defeat Chinese or Russian forces invading a U.S. ally, and simultaneously deter a second opportunistic aggressor. Nor does it have sufficient force capacity to deal with factors like combat attrition and losses.

The Air Force's capacity shortfalls cut across most of its highest priority mission areas, including its ability to attain the degree of air superiority needed to enable all joint operations, launch large-scale precision strikes into contested areas, and perform electromagnetic warfare against sensor and C2 networks that are the foundation of China and Russia's A2/AD complexes. Failing to increase the Air Force's capacity to project combat power into contested areas would reduce options available to U.S. commanders and increase the risk of failures at all levels of conflict. It would also create an opportunity for peer competitors to gain additional advantages—possibly decisive—in their ability to quickly achieve their campaign objectives. To put it bluntly, without a robust future Air Force, the nation cannot conduct viable joint operations.

The Air Force must also avoid a force recapitalization / modernization "death spiral." While there is significant support on Capitol Hill for the Air Force to grow to 386 operational squadrons, there is a persistent debate over what it should buy to increase its ability to project combat mass.[25] The USAF has traditionally procured two types of military capabilities: expendable single-use systems, such as cruise missiles and other munitions that must be destroyed to create effects on a target, and exquisite, multi-mission systems, such as fighters, bombers, and ISR aircraft that are designed to have service lives of 30 years or more.

Whereas the Air Force's high-end weapon systems have become more survivable, lethal, and operationally versatile over time, they have also become more expensive to buy and operate in the small numbers the Air Force's declining post-Cold War budgets have allowed it to procure. In December 2019, the Mitchell Institute published a policy paper on how insufficient funding to buy new aircraft was a key reason the Air Force was unable to modernize since the Cold War.[26] This trend continued with the FY 2021 President's Budget (PB), where the Air Force's request for new aircraft funding dropped to 16.2 percent of its total "blue" budget, which will

Figure 5: The number of new aircraft bought by the Air Force has remained relatively flat over the last 25 years.



Source: Mitchell Institute using USAF blue budget data. 20 percent of the Air Force budget goes to intelligence agencies over which the USAF has no control. The "blue" budget is that portion of the Air Force budget spent on Air Force programs.

barely buy about 100 total aircraft excluding RPAs, far less than it needs for a healthy modernization rate.[27] This is significantly less than the USAF's average from FY 1962–FY 1989, when it spent just over 30 percent of its budget on procurement each year.[28] Furthermore, the FY 2021 PB requested $11.7 billion to buy new Air Force aircraft, which is less than the $14 billion on average it received each year from FY 1962 to FY 1989, and well below what it spent to buy new aircraft during the Reagan administration (see Figure 5).[29] Although Congress increased the USAF's FY 2020 aircraft procurement budget, this incremental increase was not enough to reverse the damage created by decades of insufficient funding. With aircraft increasingly worn out and less relevant to meet modern operational demands, the Air Force must reset with new aircraft. Doing nothing is not an option if leaders want the capabilities the Air Force provides.

In addition to procuring too few new aircraft, the Air Force's operations and maintenance (O&M) spending remains significantly higher than its historical average as a percent of its overall total obligational authority. This reflects the high cost of operating and sustaining an aircraft inventory that is the oldest in the service's history.[30] Insufficient funding and Secretary of Defense decisions to prematurely halt procurement of next-generation USAF aircraft such as the F-22 and B-2 are major reasons the service was

Buying "new-old" is not a good alternative

There is a school of thought that the USAF should buy more new-old capabilities such as upgraded 4th generation fighters to increase its capacity to project combat power. In truth, these aircraft would cost the same or more than 5th generation F-35s and would be far less cost effective than F-35s, which are designed for future battlespaces instead of threat environments of the 1970–1980s. Using 4th generation fighters against the modernized forces of a peer adversary would increase risk the USAF would suffer attrition at rates it cannot sustain. Even if the U.S. defense industry could quickly replenish aircraft lost in combat, which it cannot, replacing their experienced pilots would take many years.

unable to modernize its combat forces over the last 30 years.

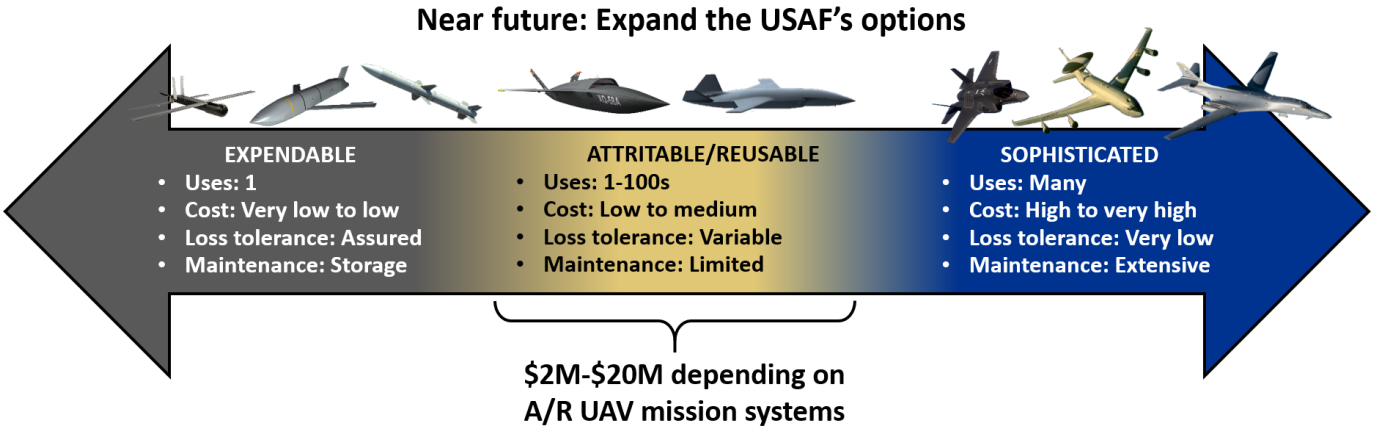
The USAF is now at risk of experiencing another cycle of the modernization death spiral it has been in since the end of the Cold War. Emerging threats and evolving mission demands have created requirements to replace legacy combat capabilities with more technologically advanced weapon systems. Insufficient budgets cause the USAF to buy only small numbers of these next-generation aircraft, which, in turn, increase their unit procurement and sustainment costs and further constrain the Air Force's ability to fund needed modernization programs.[31] If this cycle continues as it has in the past, the result would be a future force that is even smaller and older than it is today. Small fleets flown at high ops tempos to meet requirements can wear out prematurely and stress their associated personnel to extreme levels—neither are sustainable in the long term. From an operational perspective, failing to modernize would require the Air Force to rely on its aging F-15s, A-10s, F-16s, and B-1Bs even longer than currently planned, which could lead to mission failures and higher loss rates in a peer-on-peer conflict. Unlike failures against lesser regional adversaries in the past, the inability to quickly prevent China or Russia from achieving a fait accompli could have existential implications to the United States and its allies and friends.[32]

Increasing the Air Force's ability to generate and project combat mass would be further complicated by a downturn in defense spending due to COVID-19 spending and other budget pressures. The requirement to modernize, combined with flat or shrinking defense budgets, will increase the need to seek affordable, cost-effective systems such as A/R UAVs that will help fill the USAF's capacity shortfalls.

A/R UAVs: a new option to affordably increase the USAF's ability to achieve combat mass. The Air Force has recognized it is at risk of falling behind the combat mass competition with peer adversaries, and these odds do not improve given that opponents have home-field advantages such as shorter logistics lines of communication, the ability to generate combat sorties from airbases in their homelands, and IADS that extend over potential battlespaces. According to Gen Jeff Harrigian, Commander U.S. Air Forces in Europe, "We must not forget that mass is an important principle of war. We must put capabilities in numbers in the hands of our Airmen—numbers that allow them to dominate. Weapons development and deeper arsenals must be pursued aggressively."[33]

Air Force leaders also know a future

Figure 6: A/R UAVs are a new, affordable option to increase the USAF's capacity to generate and project combat power in A2/AD threat environments.



Source: Mitchell Institute, informed by a graphic released by the Air Force. See ABMS Team, "ABMS Industry Day," Department of the Air Force briefing, May 2020, slide 47.

Table 1: A/R UAVs will have lower unit and flying hour costs compared to a typical manned fighter.

	Range (takeoff to recovery)	Payload in Pounds	Launch and Recovery	Average Unit Cost	Cost per Flying Hour Compared to F-16
F-16C fighter	Air refuellable	16,000 external carriage	Long, improved runways	About $70 million	Estimated $21,000
LCAAT medium-large UAV (Valkyrie) with limited mission systems	3,000 nm	600–1,200+ internal could include: Sensors Non-kinetic mission systems Decoy Comm node	Rocket assisted takeoff (RATO), parachute recovery; may use runways of 5,000' or less	$2–3 million	Less than 10%
LCAAT medium-large UAV (Valkyrie) with additional mission systems and variants	3,000 nm	600–1,200+ internal could include: Sensors Non-kinetic mission systems Air-to-air missiles Air-to-ground weapons	RATO, parachute recovery; may use runways of 5,000' or less	$10–20 million depending on mission systems	Less than 10%

Source: The Mitchell Institute derived data for Table 1 from Air Force Magazine, *USAF Almanac 2019* (Arlington, VA: Air Force Association, June 2019), 100 and 122; and "Unmanned Systems Overview," briefing provided to the Mitchell Institute by Kratos. The briefing from Kratos provides surrogate performance specifications for several classes of A/R UAVs. Flying hour costs for the A/R UAVs do not include the cost of equipment needed to launch and recover them.

force design approach that only relies on procuring ever-more complex and higher-cost systems to meet emerging threats will fall short. This is why the service is interested in buying low-cost A/R UAVs.

Technologies are sufficiently mature to support the near-term fielding of AI-enabled A/R UAVs that could cost as little as $2–3 million each—or as much as $20 million depending on their mission systems. Due to their limited lifespans, A/R UAVs will not need the same depot maintenance and other investments that modern manned military aircraft require to remain in the force for decades. They will also not need to fly as frequently as manned aircraft for training and other purposes. These differences reduce the projected cost to fly A/R UAVs to less than 10 percent of the flying hour cost for a mature manned weapon system, such as the F-16.

Given their low cost, A/R UAVs should form a distinct part of the solution to the USAF's combat mass deficit. Although A/R UAVs cannot replace 5th generation stealth aircraft, it is unlikely the Air Force will be able to buy all the high-end capabilities it requires—and numbers count. If fielded in large enough quantities, U.S. commanders could simultaneously use A/R UAVs in multiple areas of the battlespace to degrade an enemy's combat tempo, overwhelm its air defenses, and prevent it from concentrating forces. Using them in this way may be somewhat similar to how the Army used its Sherman tanks during World War II. Although Sherman medium tanks did not match the technical sophistication of Germany's Tiger heavy tanks, they were less expensive, easier to produce in large numbers, and lighter/easier to deploy across the Atlantic and throughout the European Theater of Operations. Tiger tanks cost about six times the unit cost of Sherman tanks that rolled off their assembly lines at a rate of 2,000 per month at the height of the war.[34] Despite the Sherman tank's lighter armor and armament, the Army could mass them in large numbers on the battlefield in ways that "overwhelmed enemy armored

Figure 7: U.S. Army picture of an M4 Sherman tank production line in Detroit during World War II.

Source: U.S. Army picture. The United States produced up to 2,000 Sherman tanks a month at the height of the war.

forces."[35] In the modern context, the Air Force needs to increase both its capability *and* capacity—hence the suggested hybrid approach of procuring more 5th generation technologies and A/R UAVs.

AI-enabled A/R UAVs operating independently or teamed with other 5th generation aircraft will expand offensive and defensive options available to commanders. They will also be force multipliers. To cite one example, they could be part of the USAF's Next Generation Air Dominance (NGAD) system-of-systems that will ensure U.S. forces have the air superiority needed to accomplish their missions in contested environments. A 6th generation combat aircraft envisioned by the Air Force as part of NGAD would likely improve on the low observability, advanced sensors, and integrated automated information processing and fusion capabilities that currently give 5th generation stealth fighters their survivability and mission effectiveness. However, budget pressures combined with the cost to develop and procure these aircraft may constrain the Air Force's ability to buy 6th generation aircraft in the quantity it needs. A/R UAVs equipped with the right mission systems and weapons could extend the effective sensor range and kill radius of F-22s, F-35As, and NGADs, allowing smaller numbers to cover larger areas of the battlespace and kill more threats per sortie.

A/R UAVs could also be force multipliers in another sense. Using them in peacetime for surveillance, freedom of navigation, and other missions could reduce the operations tempo and extend the service lives of manned aircraft that are more expensive to operate and maintain. The readiness of a force can be shattered by years of "high operations tempo (OPSTEMPO) that compounds the effects of aging on our inventory."[36] This can lead to flight restrictions on aging airframes, more frequent maintenance and replacement of worn out aircraft parts, and requirements to replace aircraft well before their planned retirement dates. Near non-stop B-1 deployments to support contingency operations in the Middle East over the last decade broke the fleet to the point where B-1s were temporarily withdrawn from combat. The Air Force subsequently decided to retire 17 B-1s that had the most severe structural and other maintenance issues caused by an excessive OPSTEMPO.[37] A/R UAVs could help reduce OPSTEMPO for the USAF's stealth fighter forces, saving their flight hours and readiness for when they are most needed: during a crisis to deter or defeat America's enemies.

In summary, procuring A/R UAVs that are less expensive and easier to manufacture than manned combat aircraft could help the Air Force grow its capacity to project power in a COVID-19 budget environment. This said, there will still be a need to buy

Synergies through collaborative teaming

A/R UAVs are not a replacement for manned aircraft. Instead, the Air Force's intent is to leverage the relative strengths of human operators and machines to achieve positive synergies. Manned-unmanned collaborative operations could actually require pilots to take on an even greater role, since they will need to perform as mission commanders responsible for orchestrating multiple platforms. Collaborative teaming in contested airspace will also increase the need for the sensor fusion capabilities provided by 5th generation aircraft that can gather, process, exploit, and share information to generate a robust common operational picture with minimal active control from a pilot. Unencumbered by the burden of managing and interpreting the large volume of information coming into the cockpit, pilots of 5th generation combat aircraft can instead focus on higher-level cognitive functions such as choreographing teamed aircraft and other relevant assets to achieve mission objectives.

F-35As, B-21s, and other high-end weapon systems in the numbers now required by the Air Force. A/R UAVs will be most effective when combined with these next-generation capabilities to execute a campaign strategy that targets the vital means on which an enemy's military enterprise depends.[38] Fifth generation F-35As are already force multipliers in the sense that they can share their operational picture of the battlespace with other air, ground, and sea weapon systems and perform as battle managers in contested areas. Teaming A/R UAVs with F-35As would further multiply the effects that F-35As can create in the battlespace and do so more affordably "without the [same] logistical or manpower costs of traditional aircraft."[39]

A/R UAVs Can Help the USAF Generate Combat Power from Inside A2/AD Threat Environments

The Air Force has long relied on its ability to generate combat sorties in high volume from airbases located close to the borders of regional aggressors. This was true during the Vietnam conflict, Operation Desert Storm, Operation Iraqi Freedom, and other operations against lesser aggressors. Operating the USAF's combat aircraft and other forces close-in to an enemy was only possible in the past because of the lack of significant threats to its airbases. Today, this is no longer the case. China and Russia understand that attacking an enemy's airbases is one of the most efficient ways to suppress an opposing air force. Both have fielded thousands of guided missiles that can crater runways, destroy fuel storage and maintenance facilities, and wreak havoc on other U.S. airbase facilities that are critical to generating air combat power in a theater of conflict. Large-scale attacks on U.S. and allied airbases in Korea, Japan, the Philippines, and Western Europe that now lack sufficient air and missile defenses could severely degrade the Air Force's ability to generate the hundreds of sorties needed to rapidly halt a Chinese or Russian attack. The inability to provide combat airpower in the volume required by U.S. commanders could have a devastating effect on a theater campaign, making a conflict with a peer adversary far "longer and more costly."[40]

There has been debate inside the Air Force on how it should adapt its warfighting concepts and capabilities to counter the growing missile threat to its theater airbases. One school of thought is to create an "outside force" that would rely on generating the preponderance of the Air Force's combat sorties early in a conflict from airbases that are located outside the range of most of a peer adversary's missiles. This could shift much of the USAF's sortie generation operations early in a conflict with China to bases in Australia and along the Western Pacific's 2nd Island Chain, Hawaii, Alaska, and even the West Coast of the United States.[41] Another approach is to develop operating concepts and capabilities that would ensure the USAF remains an "inside force" that can continue to generate combat power inside A2/AD threat envelopes as well as from more distant airfields.

A major shift toward an all-outside Air Force would be a self-defeating move in the long run for at least three reasons. First, it would play to China and Russia's strategies that seek to reduce the U.S. military's presence along their peripheries and convince regional powers the United States is unable to meet its extended security commitments.[42] During a Mitchell Institute event, Brig Gen Michael Winkler, Director of Strategic Plans, Requirements, and Programs at Headquarters Pacific Air Forces, said:

> *We think it's untenable from their [partners and allies] perspective to think that the United States Air Force is going*

to be there to support them in any kind of conflict, but we're going do it from 4,000, 5,000, or 6,000 miles away. It's just not a compelling argument. So, in order to assure our allies of our commitment to the theater, we want to be right next to them shoulder-to-shoulder in the face of a conflict.[43]

Second, as the distances aircraft must fly to accomplish their missions increase, the number of sorties they can generate per day decrease. This was aptly illustrated during the Vietnam War when USAF B-52s were based at Anderson AFB in Guam and U-Tapao airfield in Thailand. A roundtrip B-52 flight between Guam and Vietnam spanned nearly 6,000 miles and lasted 12 to 14 hours. Conversely, B-52s based in Thailand needed to fly one-third this distance, allowing them to fly more missions per day and thereby increasing their combat impact.[44] Operating fighters and other short-range aircraft from airfields located thousands of miles from an adversary would cut the USAF's sortie generation rates by 30–50 percent, increase air refueling requirements, and critically impact a theater commander's campaign strategy and timeline.

The United States must draw a line somewhere and commit to fighting in a smart, sustainable, and decisive fashion.

Third, China and Russia continue to develop longer range sea-, ground- and, air-launched missiles, and the Air Force can only move its forces so far back in a theater of operations. Russian air- and ground-launched missiles can strike airfields located anywhere on continental Europe and the United Kingdom. China's missile forces can employ intermediate-range ballistic missiles (IRBMs) to strike most airbases in the Pacific, and PLA Air Force H-6K bombers can carry up to six CJ-20 precision-guided air-launched land-attack cruise missiles (LACMs), giving them "the ability to engage U.S. forces as far away as Guam," a critical USAF hub for generating combat power.[45] Even if U.S. forces retreat, opponents will fill the void and further extend their ability to project power. The United States must draw a line somewhere and commit to fighting in a smart, sustainable, and decisive fashion.

The real answer, of course, is that the Air Force must do both—generate and project power from inside and outside an enemy's A2/AD threat envelope. Each has inherent advantages, and the concurrent benefits realized with harnessing both approaches are considerable. To do this, the Air Force must develop operating concepts and capabilities that enable it to fight alongside allies and partners that live inside A2/AD envelopes, including Japan, South Korea, the Philippines, Germany, Poland, and the Baltic states. Although there is no point solution for this, doing nothing and hoping for the best is not an option. A combination of concepts to conduct distributed operations within a theater such as Agile Combat Employment (ACE), high-capacity airbase missile defenses, and new combat capabilities that are less dependent on fixed runways—such as A/R UAVs—are needed to maintain the USAF's ability to generate combat power forward.[46]

A/R UAVs can increase the USAF's posture resiliency. A/R UAVs that can launch and recover from dispersed expeditionary locations without the need to use an airfield would increase the USAF's ability to generate combat power inside A2/AD threat umbrellas.[47] The ability to disperse and frequently move to different locations would complicate an enemy's ability to find, fix, track, and launch effective missile attacks against the USAF's combat forces. It would also be cost imposing. Instead of concentrating their attacks on a relative handful of main operating bases, China and Russia would have to fly

more ISR sorties and expend more weapons to find and attack USAF operating locations dispersed across a theater. This would greatly increase the cost of their attacks and create uncertainty over their effectiveness. More importantly, it could cause China or Russia to doubt if their campaigns will succeed.

AFRL and DARPA are developing A/R UAV prototypes that can be launched and recovered with or without runways. For example, XQ-58 Valkyries can be packaged in air-transportable containers with a RATO system and other equipment needed to launch them from small clearings. In the future, it may be possible to launch Valkyries using a smaller, lighter, and less expensive transportable version of the electro-magnetic aircraft launch system (EMALS) developed for the Navy's *Gerald R. Ford*-class carriers. The Valkyrie's RATO system now costs a little more than $20,000 per launch; a transportable EMALS powered by a mobile generator or a local power source could further decrease the cost of launching Valkyries and other A/R UAVs in volume. Valkyries can use a guided parachute system to recover after a mission, which could be augmented by airbags to help protect sensitive aircraft components from landing shocks.

Both China and Russia's A2/AD strategies call for attacking the U.S. military's logistics infrastructure to slow its force deployments and suppress its OPSTEMPO early in a conflict.

It may also be possible to use large "mothership" aircraft to launch and recover A/R UAVs in flight. DARPA's Gremlins program is developing a low-cost reusable UAV that can launch from large aircraft such as C-130s and bombers from "outside the range of adversary defenses" similar to cruise missiles.[48] These A/R UAVs could penetrate contested areas, accomplish their missions, egress, and then be recovered by C-130s equipped with a system that combines aerial refueling and airborne target towing technologies. C-130 motherships would return recovered Gremlins to expeditionary locations where they can be regenerated for another sortie "within 24 hours."[49] This is not a new idea; multiple drone types were launched by mothership aircraft during the Cold War, and airborne aircraft were also used to recover small parachute deploying capsules containing canisters of exposed film ejected by U.S. Corona reconnaissance satellites.

Future A/R UAV short takeoff and landing (STOL) variants could require significantly less than 5,000-foot runways for launch. These STOL-capable aircraft would further expand the USAF's options to generate combat power from a distributed posture, since there are many hundreds of civilian and military airfields that are 5,000 feet long or less located throughout the Western Pacific and Europe. STOL A/R UAVs equipped with a small RATO package may be able to use runways, roads, and other improvised areas for takeoffs. The ability to launch from short runways and roads could increase permissible A/R UAV takeoff gross weights, possibly allowing them to carry larger mission payloads and more fuel to extend their range or endurance.

A/R UAVs could improve the USAF's logistics resiliency while under attack. Following the Cold War, the Air Force sought to reduce its operations and support requirements in part by maximizing the efficiency of its overseas bases. The Air Force was able to do so in large part because its ability to rapidly achieve theater-wide air superiority meant its airbases were virtual sanctuaries from enemy attacks.[50] However, Secretary of the Air Force Barbara Barrett and then-Chief of Staff of the Air Force General Goldfein have testified that while the Air Force is now "extremely efficient in deploying large numbers of people, materiel, and weapon systems across the globe to fight

from a small number of forward operating bases," future adversaries "will not allow us to fight this way."[51]

Both China and Russia's A2/AD strategies call for attacking the U.S. military's logistics infrastructure to slow its force deployments and suppress its OPSTEMPO early in a conflict.[52] These attacks would include kinetic and non-kinetic (cyber and EW) strikes on logistics nodes, C2 networks, and other infrastructure on which Air Force sortie generation operations depend. Air-transportable containerized A/R UAVs and their launch systems would improve the USAF's ability to "rapidly move people and materiel to and within a theater" while under attack.[53] A/R UAVs and other transportable systems that have reduced logistics footprints compared to a comparable number of manned aircraft are exactly the kind of move-to-win capabilities that will help U.S. commanders defeat China and Russia's A2/AD strategies.[54] A recent study by the RAND Corporation determined that A/R UAVs like the XQ-58A could require "one-fifth the personnel and one-half the equipment" to operate and maintain compared to an F-16 fighter.[55] Moreover, deploying a force of XQ-58As and their operating support to forward operating locations could require only 20–35 percent the number of C-17 airlift missions needed to deploy F-16s forward, depending on the amount of XQ-58A materials that are prepositioned in a theater.[56] A/R UAVs with ranges of 3,000 nm or more between takeoff and recovery could also help reduce the USAF's aerial refueling requirements and free tanker fuel offload capacity for other high-priority combat operations.

The potential to expand a theater commander's options to conduct air operations in highly contested environments at acceptable levels of risk is one of the more significant advantages of A/R UAVs.

In summary, maintaining the Air Force's ability to generate combat power inside A2/AD threat envelopes will be critical to assuring America's allies and countering China and Russia's ambitions to push the U.S. military further away from areas they seek to control. Procuring A/R UAVs that are not dependent on vulnerable airfields combined with innovative concepts for distributed operations and the fielding of new technologies for airbase missile defenses would be major steps toward this objective.[57]

A/R UAVs Will Increase the Air Force's Operational Risk Tolerance, Survivability, and Resiliency

Increase operational risk tolerance in a peer conflict. The potential to expand a theater commander's options to conduct air operations in highly contested environments at acceptable levels of risk is one of the more significant advantages of A/R UAVs. In conflicts with a peer adversary, there may be areas of the battlespace where the uncertainty about threats or the risk of attrition are simply too high to use manned aircraft. Today, commanders have the choice of accepting the risk or taking actions such as launching strikes from standoff ranges to reduce threats to an acceptable level for manned systems. Both approaches could advantage an enemy. In the former case, the Air Force may not be able to quickly replace pilots and high-value combat aircraft that are lost in combat. In the latter case, suppressing air defenses to reduce risk to manned penetrating aircraft could take a significant amount of time, which an enemy could use to achieve its campaign objectives.

A/R UAVs will give U.S. commanders new options to take the fight to the enemy. On night one of a conflict with China or Russia, U.S. commanders could use hundreds of less capable (and less expensive) A/R UAV variants to stimulate enemy air defenses to reveal their locations, jam air

defense C2 nodes, locate mobile SAM systems, and perform other missions that improve the survivability of all U.S. forces. Theater commanders may be willing to accept much higher rates of attrition for A/R UAVs compared to manned fighters and bombers. According to Dr. Roper, Skyborg UAVs will "allow the Air Force to take measured risk with attritable platforms to keep our high-value aircraft in the fight."[58] As threats are reduced, commanders could shift toward using a larger number of higher-end A/R UAVs and manned aircraft for operations in contested areas.

Similar to its other new capabilities, the Air Force should strive to maximize the combat value of A/R UAVs in the battlespace. Given the 600 to 1,200-pound estimated payload capacities of some developmental A/R UAVs (equivalent to two to four GBU-39 Small Diameter Bombs), it may be more cost effective to use them to multiply the kinetic effects that can be created by other combat aircraft that have greater payload capacity. Equipping A/R UAVs to act as extended-range sensors teamed with fighters and bombers, perform as C2 nodes, and conduct EW operations that increase the survivability of other penetrators could be more cost effective than using their limited payloads to attack a small number of targets.

A/R UAVs could conduct EW to increase force survivability. Warfare during the Industrial Age focused on defeating an adversary by attacking and destroying its military forces and capabilities. However, information is the lifeblood of modern warfare, and the U.S. military's effectiveness increasingly depends on its ability to collect and exploit information faster and more accurately than its adversaries.[59] Getting and staying inside an adversary's decision cycle—to act faster and more accurately than an enemy—requires resilient communications, the ability to sense, receive, fuse, and exploit information from sensors in all domains at machine speeds, and highly accurate positioning, navigation, and timing data.

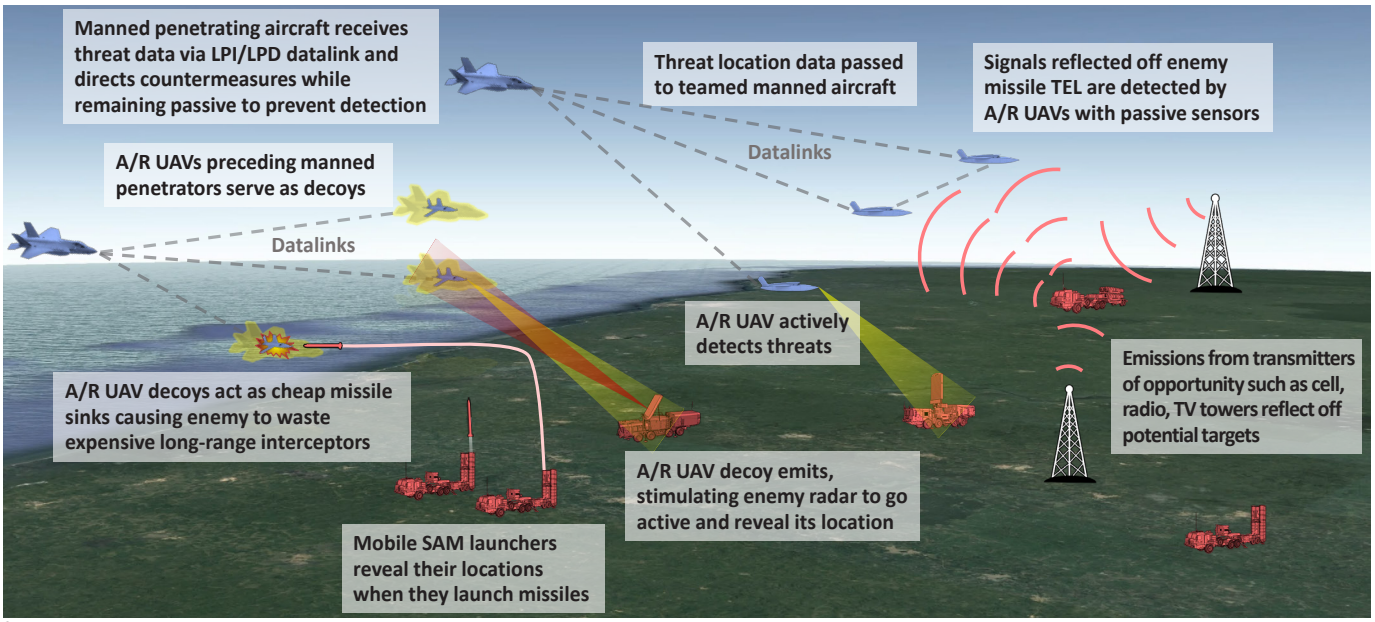
Electromagnetic warfare

DOD replaced the term electronic warfare with "electromagnetic warfare," (EW) which it defines as the use of electromagnetic energy and forms of directed energy such as lasers and high power microwaves to "control the EMS or to attack the enemy." Electromagnetic warfare is sub-divided into electromagnetic attacks, electromagnetic support, and electromagnetic protection. See endnote 60.

All of these functions rely on use of the electromagnetic spectrum (EMS), an operational domain where conflicts with a peer adversary can be won or lost. China and Russia have aggressively developed new EW operating concepts and capabilities to attack vulnerabilities in the U.S. military's ISR, battle management, and command and control networks.[60] Similar to the other services, the Air Force failed to keep pace with China and Russia's EW investments over the last 30 years—and as a consequence, it may be at risk of losing its supremacy in the EMS.

Appropriately equipped A/R UAVs capable of teaming with other aircraft could increase the Air Force's EW capacity and enhance the survivability of all U.S. forces operating inside A2/AD envelopes. For instance, using A/R UAVs as remote sensors in contested areas would reduce the need for manned penetrating aircraft to emit radar energy that could be detected by an enemy's defenses. Teams of A/R UAVs with active or passive sensors could detect and compare the information they gather to geolocate air defense search and track radars and other threats that are emitting energy. These UAVs could relay threat information

Figure 8: A/R UAVs could passively detect threats, act as decoys to absorb SAMs, and stimulate threats causing them to emit or otherwise reveal their locations.



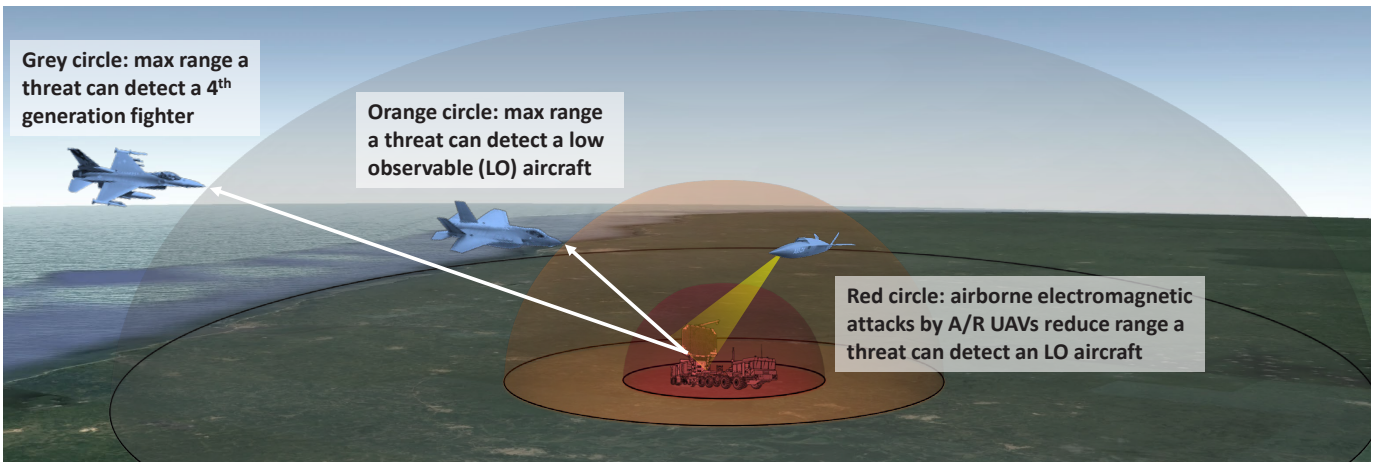
Source: Mitchell Institute.

to manned aircraft, enabling them to maneuver to avoid threats or direct attacks to suppress them. A/R UAVs operating in teams could also exploit reflected ambient energy to locate potential threats. Emissions from enemy communications systems and non-military television and radio transmitters that reflect off threats such as a SAM site could be passively detected by teamed A/R UAVs, which could share their data to determine the threat's location (see Figure 8).

Other A/R UAVs could radiate or otherwise stimulate enemy defenses to emit, causing them to reveal their locations and open them to attacks by friendly standoff or penetrating strike aircraft. Another tactic might be to use A/R UAV decoys that create a signature in the EMS similar to high-end fighters or bombers to force an enemy to react. Using a large number of A/R UAVs in this fashion could cause an enemy to exhaust its most capable (and expensive) surface-to-air and air-to-air weapons, creating windows in time and space for U.S. manned aircraft to successfully penetrate and accomplish their missions.

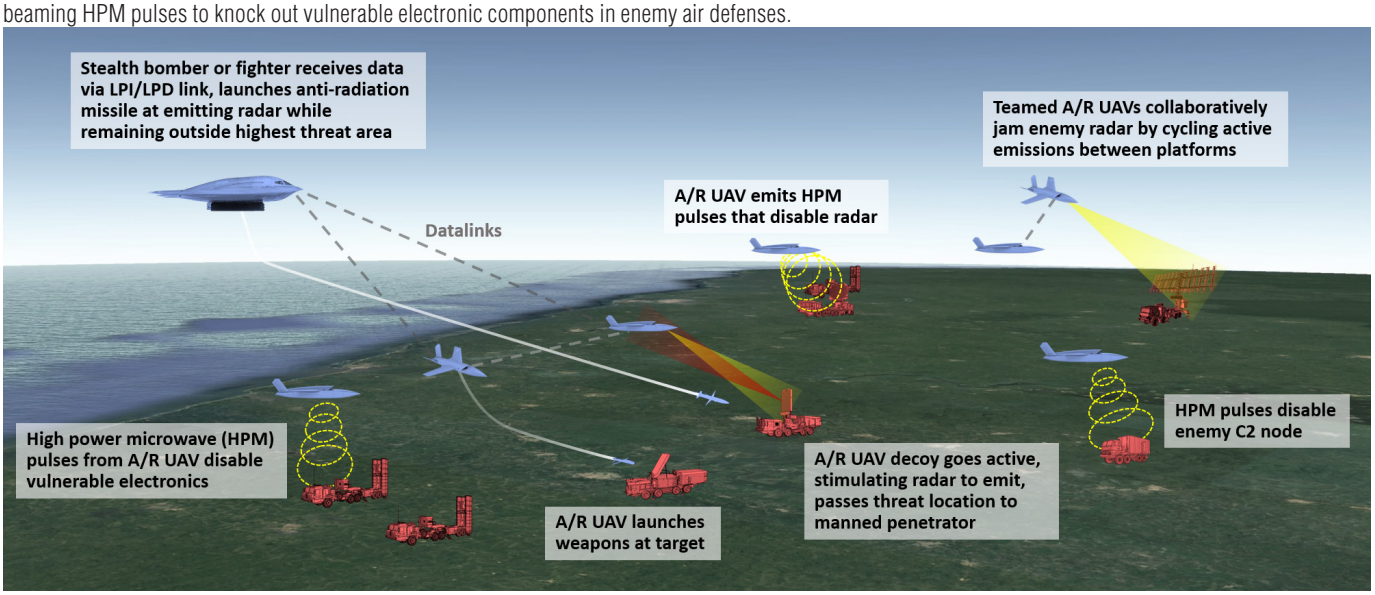
Other A/R UAVs equipped with jammers could conduct electromagnetic attacks on enemy acquisition radars, C2

Figure 9: A/R UAVs can conduct electromagnetic attacks that reduce an enemy's ability to detect low observable penetrating aircraft.



Source: Mitchell Institute.

Figure 10: A/R UAVs could conduct active EW operations such as jamming enemy sensors and C2 nodes, attacking threats with anti-radiation weapons, and beaming HPM pulses to knock out vulnerable electronic components in enemy air defenses.



Source: Mitchell Institute.

links, and other air defense components to increase the survivability of U.S. stealth aircraft and weapons penetrating contested areas. There is a synergistic relationship between stealth and electromagnetic attacks. Generally speaking, locating any airborne aircraft is a matter of detecting the signature it creates from background "noise" in the EMS. A 5th generation stealth aircraft's low observability is due in large part to its shape and materials such as external coatings that absorb or deflect radar energy away from an enemy's radar receivers. These technologies reduce the stealth aircraft's signature in the EMS, along with the probability that it will be detected. Electromagnetic attacks can also increase noise in the EMS, which would further reduce an enemy's ability to discern a stealth aircraft's already slight signature.

Other A/R UAVs equipped with high power microwave (HPM) payloads could disrupt and destroy multiple electronics-based threat systems per sortie. The Air Force successfully tested a prototype HPM cruise missile several years ago and is now partnered with the Navy to develop an HPM payload that could be "integrated on an advanced airborne platform."[61] Integrating an HPM weapon into an A/R UAV would give the Air Force a reusable means to degrade and render inoperable multiple enemy electronics-based threats per sortie at a fraction of the cost of attacking each with an expendable weapon. A/R UAVs may also be able to launch future small anti-radiation missiles that can home in on emitting air defense systems. Depending on their payload capacity, these A/R UAVs could have sensors to find, fix, and track targets or rely on aircraft they are teamed with for target cueing information.

Conduct offensive/defensive counterair operations. In addition to EMS superiority, achieving sufficient control of the air—air

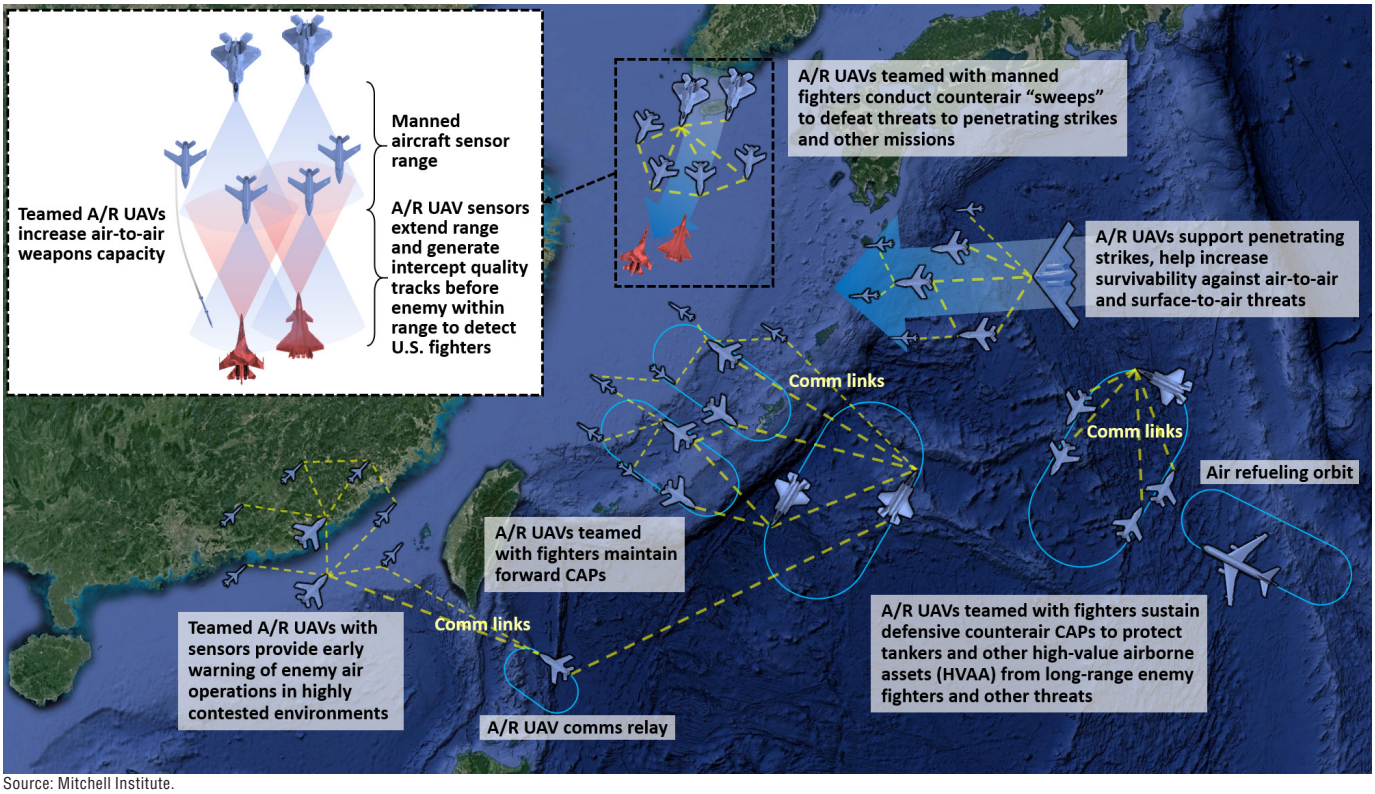
Counterair operations

Counterair forces conduct "offensive and defensive operations to attain and maintain the joint force commander's (JFC's) desired degrees of control of the air and of protection by neutralizing or destroying enemy aircraft and missiles." Within the counterair framework, offensive counterair includes attack operations, suppression of enemy air defenses (SEAD), fighter escorts, and fighter sweeps. Defensive counterair consists of active and passive air and missile defense actions taken to protect friendly forces and vital interests from enemy airborne attacks. See endnote 62.

superiority—is a critical prerequisite for the success of all U.S. joint operations. DOD defines air superiority as the degree of control of the air domain that allows friendly forces to conduct operations at given times and places without prohibitive interference from enemy air and missile threats.[62] Air superiority provides freedom to access contested areas, freedom to gain awareness of the battlespace through the air, and freedom to attack through the air domain, all while denying an adversary use of the air to do the same. To achieve and maintain the desired degree of control of the air, U.S. forces conduct both offensive counterair (OCA) and defensive counterair (DCA) operations.

The ability to not just control but dominate the air has been a U.S. asymmetric advantage for so long that air superiority is often taken for granted. However, adversaries have observed the effectiveness of U.S. air superiority operations and worked hard to counter them. Peer competitors continue to acquire, field, and proliferate around the globe advanced capabilities to contest control of the air. At the same time, the USAF has failed to recapitalize and modernize its fleet of air superiority platforms—now its oldest and smallest ever. This threatens the service's ability to achieve air superiority.[63] The Air Force recognizes that addressing growing shortfalls in its air superiority capacity will not be achieved solely by building a high-end, next-generation fighter. Instead, the Air Force's NGAD program is maturing novel technologies and exploring candidate operating concepts to deliver a family of systems that "will integrate legacy and future platforms with a mix of manned, unmanned, and optionally-manned aircraft" to enable air superiority for U.S. forces in the most challenging operational environments.[64] As part of this family of systems, A/R UAVs could operate independently or team with manned counterair aircraft to increase the survivability of all U.S. forces and expand options available to commanders to conduct operations against peer adversaries.

Figure 11: Teamed with manned air superiority aircraft, A/R UAVs can be force multipliers that extend the sensor range and increase the air-to-air weapon capacity.



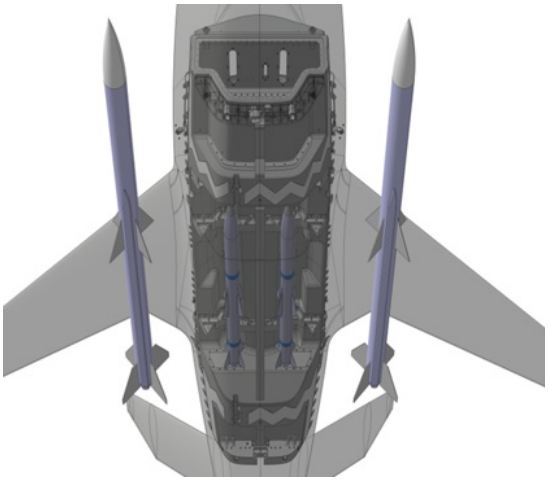
Source: Mitchell Institute.

To cite an example, A/R UAVs could improve the situational awareness of formations of manned and unmanned counterair aircraft over large areas. Modular A/R UAVs distributed widely across the battlespace could carry a variety of active and passive sensor payloads. Sensor data collected by these A/R UAVs could be shared via robust line-of-sight datalinks across the formation and transmitted back to manned aircraft that could fuse the information with data collected by its own sensors and other assets. Once threats are detected, the battle management system onboard a manned penetrator such as an F-35A or future NGAD could coordinate the A/R UAVs to optimize their cooperative sensing and then engage threats or provide high-quality targeting data to remote shooters that can remain out of range of threats.[65] Extending the sensor and weapons reach of counterair aircraft in this manner would help ensure the USAF maintains its first-look, first-shot, first-kill air superiority advantage.

The Air Force could also use teamed A/R UAVs to conduct defensive counterair combat air patrols (CAP) that screen high-value airborne assets such as aerial refueling tankers from long-range fighters and other threats. This use case could be somewhat less challenging in lower risk threat environments; communications systems would be more secure, and supporting assets such as the widebody AWACS aircraft that have traditionally detected, identified, and tracked airborne threats may be available to support CAPs.[66] The value of using A/R UAVs to extend sensor and weapon coverage in contested airspace would be much greater, as they will need to operate well beyond the effective sensor range of non-stealth AWACS aircraft that must remain out of range of an enemy's surface-to-air and air-to-air threats.[67]

Future A/R UAVs capable of near-supersonic speeds and long endurance missions could also team with manned aircraft to conduct sweeps that locate and defeat airborne threats in contested airspace. A/R UAVs teamed with manned air superiority aircraft could increase both the formation's overall situational awareness and air-to-air weapon capacity. Distributing A/R UAVs equipped with air-to-air missiles throughout the battlespace would supplement the payload capacity of U.S. manned fighters, increase their number of potential attack vectors, and complicate an adversary's ability to conduct countervailing operations. The ability to bring more friendly air-to-air missiles into a fight, when teamed with 5th generation sensors, will address a significant capacity gap the Air Force has long sought to fill. The ability of A/R UAVs to launch weapons is not technically challenging—the USAF's RPAs have done so for years. However, unlike RPAs, A/R UAVs with artificial intelligence could enable man-on-the-loop C2 operations. For instance, A/R UAVs could detect and determine the best approach to counter threats as their teamed manned battle managers maintain an appropriate degree of control over the lethal use of weapons.

Figure 12: A/R UAVs such as Valkyries could carry SACM-sized air-to-air missiles internally or larger missiles externally.



Source: Artist's depiction courtesy of Kratos.

A/R UAVs could also escort penetrating strikes to increase the survivability of U.S. fighters and bombers against air defense threats. A/R UAVs could probe enemy air and ground defenses and shape their air defensive operations in ways that are advantageous to U.S. forces. By using A/R UAVs as off-board weapons stations for air-to-air missiles, strike aircraft could carry larger numbers of air-to-ground munitions, increasing the number of targets they can strike per sortie. Increasing weapons delivered per sortie can have a critical impact on the time needed to achieve a theater commander's objectives.[68]

Developing smaller and shorter-range air-to-air weapons would be a key enabling capability for A/R UAV counterair operations. Although A/R UAVs such as the XQ-58A can carry larger missiles such as the AIM-120 AMRAAM on its wing stations, external weapons carriage increases both the radar signature of an aircraft and aerodynamic drag, which reduces the aircraft's range and mission endurance. Although less of a concern for DCA missions, these stealth, range, and endurance attributes are critical for long-range operations that penetrate contested airspace. This underscores the need to develop smaller weapons that A/R UAVs and other fighter-sized aircraft can carry internally. To that end, the Air Force is pursuing new counterair weapons such as the Small Advanced Capabilities Missile (SACM) and Miniature Self-Defense Missile (MSDM).[69]

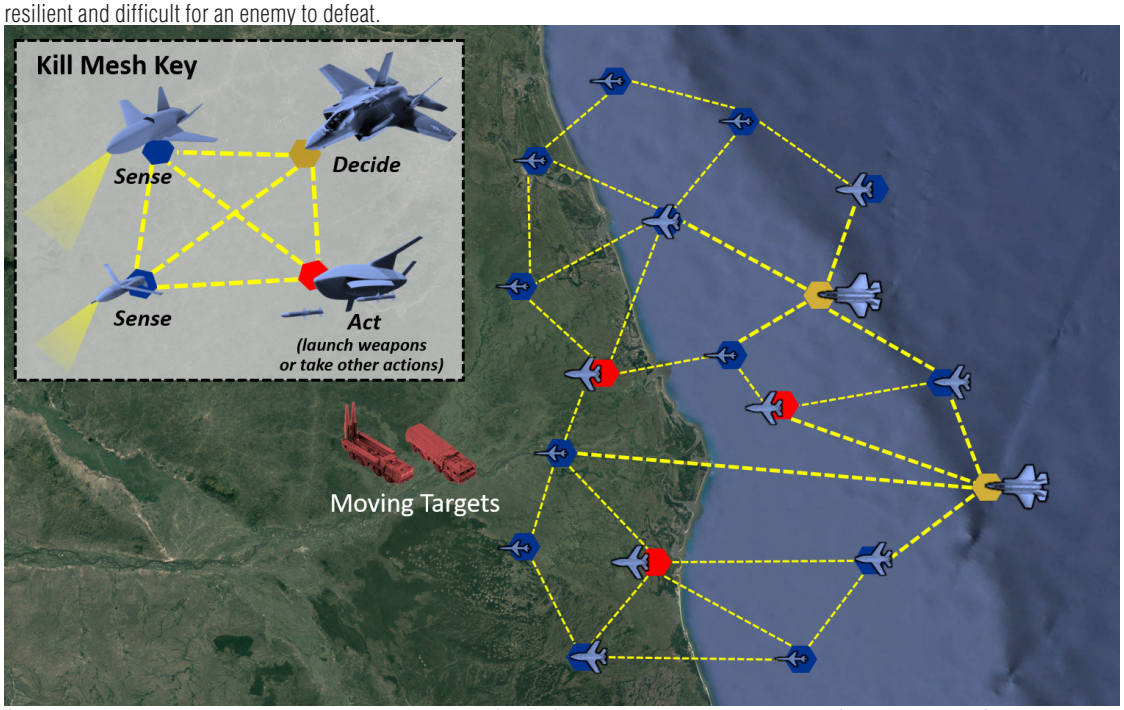
A future CAF that is too small would reduce options available to U.S. commanders during a major conflict with a peer adversary.

A/R UAVs could improve the resiliency of the future force. The increased cost of the USAF's multi-mission combat aircraft and years of insufficient acquisition funding both contributed to the creation of a Combat Air Force (CAF) that is now smaller and more homogeneous than at any time in the service's history. Generally speaking, the Air Force's traditional warfighting concepts use combinations of multi-mission aircraft that each have their own internal systems to sense the operational environment, communicate with other capabilities, defend against threats, deliver weapons, and perform other tasks. Over time, buying these multi-mission aircraft in the reduced numbers the Air Force could afford with inadequate acquisition budgets increased their overall unit and sustainment costs. This also increased barriers to funding programs for new USAF combat aircraft. During the Cold War, the Air Force fielded a series of new aircraft each decade to maintain its technical advantage over the Soviet Union. Over the last 30 years, it has been able to afford roughly one new combat platform per decade—the stealth B-2 in the 1990s, the F-22 in the 2000s, now the F-35A, and in a few years the B-21 "Raider" stealth bomber will join the force.

There is no question that aircraft like the F-22, F-35A, B-2, and B-21 are required in volume and will prove essential for many years. They uniquely perform key missions and will not be replaced anytime soon. However, a future CAF that is too small would reduce options available to U.S. commanders during a major conflict with a peer adversary. Moreover, an increasingly homogeneous future CAF could make the USAF's combat operations increasingly predictable to an enemy. Both these factors would reduce the USAF's ability to pose multiple simultaneous operational challenges to an enemy.

A/R UAVs could help create a future force that is more heterogeneous, less predictable, and more capable of distributed operations. Disaggregating active and passive sensing across multiple A/R UAVs would increase the resiliency of the USAF's ISR operations in contested areas. Instead

Figure 13: A/R UAVs teamed with 5th generation aircraft acting as airborne battle managers could create kill meshes that are more resilient and difficult for an enemy to defeat.



Source: Mitchell Institute, informed by DARPA Mosaic Warfare concepts. See Tim Grayson, "Mosaic Warfare," briefing, DARPA Strategic Technology Office, July 27, 2018.

of targeting a handful of high-value manned ISR aircraft such as the USAF's E-3 Airborne Warning and Control System (AWACS) and E-8 Joint Surveillance and Target Attack Radar System (JSTARS), an enemy would have to attack hundreds of individual A/R UAVs to degrade a U.S. commander's battlespace awareness.

A/R UAVs with the right mission systems could also help disaggregate monolithic kill chains to create "kill meshes" that consist of multiple—possibly hundreds—of sensors, shooters, and C2 nodes. As described by a recent RAND report, hundreds of A/R UAVs operating in coordination with each other could detect and maintain situational awareness of enemy forces operating over large areas. Each A/R UAV could observe and then communicate their data to other UAVs throughout the mesh, which would then be provided to penetrating or standoff shooters and other weapon systems as needed. The use of the term "mesh" is appropriate because, unlike a linear kill chain that can be broken if a single link is lost, "a mesh can retain structural integrity even when multiple elements fail."[70] Kill meshes created by A/R UAVs would increase the resiliency of the USAF's offensive operations, enable a smaller number of 5th generation manned penetrators to search for mobile and highly relocatable targets over larger areas in contested environments, and create multiple problems that are difficult for an enemy to solve.

A/R UAVs could help create a future force that is more heterogeneous, less predictable, and more capable of distributed operations.

Beyond increasing combat mass, a more heterogeneous force that includes a family of AI-enabled autonomous UAVs would add complexity and increase the unpredictability of U.S. air operations, which would complicate an enemy's ability to quickly assess and understand a U.S. commander's intentions. A/R UAVs could also enable commanders to conduct highly distributed simultaneous offensive operations that overwhelm an adversary's capacity to react and defend. An enemy's defensive challenge would be further complicated if it were not able to discern appropriately configured A/R UAVs from

manned fighters and bombers. This could cause an enemy to use its high-end defenses to engage multiple A/R UAVs, diluting the threat to U.S. manned penetrators. These and other effects would help U.S. commanders to gain decisive operational advantages.

Other Potential A/R UAV Advantages

A/R UAVs could help the USAF transition to ABMS. Initially intended as a replacement for legacy battle management command and control (BMC2) aircraft, the scope and intent of the Air Force's Advanced Battle Management System (ABMS) has evolved significantly.[71]

ABMS now serves as the Air Force's technical engine for creating Joint All-Domain Command and Control (JADC2) capabilities, which will be critical to conducting future Joint All-Domain Operations.[72] The goal of ABMS is to connect, as necessary, any decision-maker, sensor, and weapon across U.S. and allied forces. One of the Air Force's ABMS objectives is to build a combat cloud that will enable U.S. commanders make faster decisions and better integrate forces and their actions across all domains. Rather than focus on specific platforms, ABMS development is focused on six product categories and 28 specific product lines, all of which are underwritten by digital engineering, open architecture, and data standards that allow disparate ABMS elements to snap together to conduct integrated operations.[73]

Penetrating A/R UAVs with sensor and communications payloads could team with standoff BMC2 aircraft to offset this loss of coverage and provide multiple pathways to securely relay information.

Although the ABMS program doesn't "start talking platforms until the end," there are several areas where A/R UAVs could help the Air Force realize its ABMS vision.[74] The most obvious A/R UAV application is related to the ABMS program's attritableONE initiative that focuses specifically on leveraging multi-role attritable capabilities. Although ABMS broadly seeks to expand the number of available options to accomplish each step of a kill chain—and ultimately create more adaptable kill meshes as described in the previous section—an immediate need is to supplement battlespace awareness capabilities that are traditionally provided by the USAF's widebody BMC2 aircraft.[75] The increasing range and lethality of adversary IADS will force non-stealth widebody aircraft such as E-3 AWACS and E-8 JSTARS to standoff at distances from contested areas that exceed the effective range of some of their sensors.[76] This could create critical gaps in a commander's awareness of the battlespace and ability to direct actions against highly dynamic enemy forces. Penetrating A/R UAVs with sensor and communications payloads could team with standoff BMC2 aircraft to offset this loss of coverage and provide multiple pathways to securely relay information in and out of contested areas via LPI/LPD datalinks.[77]

Another application for A/R UAVs that the Air Force is actively exploring falls within the gatewayONE product line that is part of the ABMS Connectivity initiative.[78] A key objective for ABMS is to make it backward compatible to ensure existing capabilities can communicate with each other as well as other elements in the overall network. The challenge is that many of these legacy systems were developed decades apart and have incompatible communications systems.[79] Rather than attempting to standardize their waveforms, which would be very costly and difficult to do, an alternative approach is to create communication gateways that serve as master translators between incompatible communications systems.[80] Although the

Air Force already utilizes gateways such as the Battlefield Airborne Communication Node (BACN) that are carried by E-11A and EQ-4 aircraft, A/R UAVs—particularly low observable variants—could extend this capability deep into contested environments. This would allow penetrating capabilities such as F-22 and F-35 fighters to share information with each other and with other platforms inside and outside contested areas without compromising their stealth signatures. A/R UAV communication gateways could therefore help maximize the capabilities of these aircraft, create a more complete operational picture, and enable the exchange of target-quality information at machine-to-machine speeds across distributed strike platforms. This would give commanders new options to sense, decide, and then act at speeds that cannot be matched by an adversary.

Potential to improve acquisition resiliency. One of Skyborg's objectives is to create an open architecture and modular A/R UAV designs that allow the USAF to take advantage of technologies from other DOD programs that are developing autonomous systems for networked operations and meet changing requirements. The ability to cross-flow technologies from other programs will reduce the risk that a family of A/R UAVs will suffer from the "technology obsolescence, vender-unique technology and single sources of supply and/or maintenance" that are typical of closed system designs.[81] In combination with an open software architecture, A/R UAVs capable of accepting new modular hardware and software payloads will improve the Air Force's ability to continuously innovate to compete with peer adversaries and rapidly respond to changing operational conditions in a crisis.

Creating a larger and more diverse vendor base would improve the potential to surge A/R UAV production in a crisis as well as encourage innovation.

These same traits could also increase the U.S. defense industry's ability to surge production of A/R UAVs in a crisis. Assuming Congress approves the funding requested by the FY 2021 President's Budget, the Air Force could begin fielding Skyborg prototypes as soon as FY 2023. Production of operational aircraft could ramp to six or more per month within a year or two, depending on funding availability and other factors—such as the number of vendors selected by the Air Force to produce A/R UAVs. In a surge scenario, it may be possible to increase A/R UAV production to 600–1,000 aircraft per year, an order of magnitude more than an optimistic surge production rate for a more complex manned 5th generation fighter.[82]

This said, surging the production of A/R UAV common airframes may be an easier task than quickly ramping up the manufacture of their engines, sensors, and other mission systems that are produced by multiple vendors. Faced with declining defense expenditures and fewer modernization programs after the Cold War, the U.S. defense industry eliminated much of its excess production capacity through downscaling, mergers, and other means. According to a 2018 Interagency task report on the U.S. defense industrial base, this has created risks for DOD that "range from greater reliance on single sources, sole sources, and foreign providers to workforce gaps, product insecurity, and loss of innovation."[83] Today, most defense vendors are optimized to be as efficient as possible in peacetime and lack the standing capacity to quickly surge production in war. The good news is the modularity and open systems architecture of Skyborg's family of aircraft could lower the barrier for multiple vendors to compete for contracts

to manufacture its critical components. An open system with a well-designed interface and software development kit will make it easier for smaller firms, especially ones that may not typically do business with DOD, to participate in A/R UAV programs. Creating a larger and more diverse vendor base would improve the potential to surge A/R UAV production in a crisis as well as encourage innovation.

Conclusion

America's Air Force is now too old and lacks the capacity to generate enough combat mass to simultaneously defeat great power aggression and meet other national defense strategy requirements. Recent plus-ups to its budget have not provided it with the resources needed to reverse the damage done by decades of insufficient modernization funding. The flat or declining budgets to come will threaten the Air Force's ability to maintain its readiness, modernize as it must, and grow to a required future force of 386 operational squadrons.

Low-cost attritable and reusable UAVs are a new class of force multipliers that could help the Air Force balance its requirements and modestly grow its force capacity.

Low-cost attritable and reusable UAVs are a new class of force multipliers that could help the Air Force balance its requirements and modestly grow its force capacity. A/R UAVs take advantage of two of the most promising technologies—artificial intelligence and unmanned systems—that will change how the Air Force operates in peace and in war. These technologies are sufficiently mature to support the near-term fielding of a family of A/R UAVs that will increase the USAF's operational risk tolerance, survivability, and lethality in contested battlespaces. Teamed with other manned and unmanned aircraft, A/R UAVs will give U.S. commanders new options to persistently surveil large areas, prosecute electromagnetic warfare, conduct counterair missions, and perform other operations. Moreover, A/R UAVs capable of launching and recovering without airbases will help the Air Force remain an inside force capable of generating combat power alongside U.S. allies and friends that are threatened by Chinese or Russian A2/AD complexes. All of these capabilities will increase a commander's ability to rapidly halt great power aggression and impose costs that could cause a peer adversary to question the effectiveness of its campaign plan.

In conclusion, the following insights and recommendations should inform development of the Air Force's future force design plans and investments:

- Procuring low-cost A/R UAVs in significant numbers would help the Air Force increase its combat capacity, lethality, and survivability in contested operational environments.
- Similar to other unmanned aircraft, A/R UAVs will be complementary, force-multiplying capabilities, not replacements for the 5th generation fighters, bombers, and other advanced aircraft needed to maintain the USAF's technical advantage over peer adversaries. Instead of replacing manned aircraft, the greatest combat value will result from determining how to best combine the operations of A/R UAVs and manned aircraft to achieve effects in future battlespaces.
- In addition to their low procurement and sustainment costs, the modularity and open software architecture of a family of A/R UAVs will improve the USAF's ability to rapidly innovate, incorporate maturing technologies to meet changing requirements, and speed new capabilities

to warfighters. A/R UAV modularity also has operational implications—it may be possible to change an A/R UAV's modular mission systems between sorties, allowing commanders to quickly recompose their forces to meet evolving mission needs.

- Given the modest payload capacity of current A/R UAV prototypes capable of launching and recovering without runways, the greatest combat value might be achieved by using them for non-kinetic missions such as electromagnetic warfare, persistent C2ISR, as part of kill meshes, and for other operations that multiply effects created by aircraft that can carry a much larger number of expendable weapons.
- A critical step in transitioning a new weapon system to the field is creating concepts for its use that maximize its warfighting potential. The Air Force should conduct rapid experimentation and demonstrations to examine the military utility of a range of A/R UAV missions and supporting capabilities needed to employ large numbers of A/R UAVs. The service should also field initial A/R UAV prototypes as quickly as possible to allow operators to experiment and develop concepts that integrate their operations with other new and legacy weapon systems. Developing these concepts and an understanding of communications and other requirements to conduct manned and unmanned aircraft networked operations should be prerequisites for procuring A/R UAVs at scale.
- A/R UAVs and other containerized and transportable systems could have significantly reduced theater logistics footprints compared to similar quantities of manned aircraft. The Air Force should conduct analyses to determine the complexity, cost, and other logistical requirements to operate large numbers of A/R UAVs from distributed postures in the Indo-Pacific region and Europe.

Maintaining the Air Force's current readiness, modernizing its forces for the future, and building The Air Force We Need will require the service to seek new, cost-effective alternatives for its investments. Procuring a family of low-cost A/R UAVs would help the Air Force achieve this balancing act and improve its ability to generate and project combat mass from within A2/AD environments. This does not mean that A/R UAVs should be seen as a cheap means to build the future force at the expense of the F-35A, B-21, and other advanced capabilities. Instead, A/R UAVs are part of the next step in the evolution of AI-enabled unmanned systems that could team with these next-generation systems to achieve decisive effects in the battlespace. Unlike force design approaches that would simply buy more legacy systems with capabilities that are well known to America's competitors, A/R UAVs will create new options for U.S. commanders to defeat great power aggression. ✪

Endnotes

1 DOD now uses the term "electromagnetic warfare" instead of electronic warfare. See Joint Chiefs of Staff (JCS), *Joint Electromagnetic Spectrum Operations*, Joint Publication 3-85 (Washington, DC: JCS, May 22, 2020), I-5.

2 According to Air Force doctrine, "The purpose of mass is to concentrate the effects of combat power at the most advantageous place and time to achieve decisive results. Concentration of military power is a fundamental consideration in all military operations. At the operational level of war, this principle suggests that superior, concentrated combat power is used to achieve decisive results. Airpower is singularly able to launch an attack from widely dispersed locations and mass combat power at the objective, whether that objective is a single physical location or a widely dispersed enemy system or systems. From an Airman's perspective, mass is not based solely on the quantity of forces and materiel committed. Airpower achieves mass through effectiveness of attack, not just overwhelming numbers." See "Mass," in *Air Force Doctrine Volume 1, Air Force Basic Doctrine* (Maxwell AFB, Montgomery, AL: Curtis E. LeMay Center for Doctrine Development and Education, February 27, 2015).

3 The Air Force should consider historical case studies to inform its development of A/R UAV operating concepts, such as its employment of Firebee/Lightning Bug unmanned aircraft during the Vietnam conflict, its deployment of BGM-109G Gryphon ground-launched cruise missiles in the 1980s, and concepts to operate Harrier STOL/VTOL fighter aircraft from distributed locations.

4 The USAF's Air Force Research Laboratory released a Capability Request for Information to industry on the Skyborg program that described "attritable" as "an aircraft that is at a low cost price point where there is increased tolerance to lose the asset to achieve a military objective. Systems that are attritable may be designed to a higher single-flight probability of failure and have lower expectations for total service-life. An attritable vehicle is designed to be reusable." Air Force Research Laboratory, "Capability Request for Information (CRFI) for Skyborg Autonomous Unmanned Combat Air Vehicle," October 29, 2019, 8.

5 The Air Force selected Kratos Unmanned Aerial Systems, Boeing, General Atomics Aeronautical Systems, and Northrop Grumman to form a "vendor pool that will continue to compete for up to $400 million in subsequent delivery orders in support of the Skyborg Vanguard Program." Boeing, which is supporting the Royal Australian Air Force's Loyal Wingman Advanced Development Program, is developing a variant of its Airpower Teaming System for Skyborg. Daryl Mayer, "AFLCMC Awards Skyborg Contract," Air Force Life Cycle Management Center Public Affairs, July 23, 2020; and Sara Sirota, "Air Force Selects Four Companies to Compete for Up to $400 Million in Skyborg Contracts," *Inside Defense*, July 23, 2020.

6 "Skyborg," Air Force Research Laboratory.

7 Steve Trimble, "Northrop Grumman Unveils SG-2 Vision for Replacing MQ-9," *Aviation Week*, September 11, 2020.

8 John A. Tirpak, "Q&A: Munitions and Platforms Evolution," *Air Force Magazine*, June 1, 2020.

9 The other Vanguard programs are Golden Horde, which is developing precision-guided munitions capable of collaborative strikes, and Navigation Technology Satellite 3, which will be a satellite launched into geosynchronous orbit to provide global positioning, navigation, and timing information. "Air Force Vanguards," Air Force Research Laboratory; and USAF, *2030 Science and Technology Strategy* (Washington, DC: USAF, April 2019), 11.

10 Summary of Skyborg Statement of Work quoted in Jackson Barnett, "Air Force Launches Search for AI-Enabled 'Skyborg' Drone," *Fedscoop*, May 20, 2020. The full SOW is not public.

11 Skyborg's AI-enabled A/R UAV software will help the Air Force to "posture, generate, and sustain multi-mission sorties at sufficient tempo to thwart adversary attempts at quick, decisive action in contested and highly contested environments." DOD, *Department of Defense Fiscal Year (FY) 2021 Budget Estimates*, Justification Book Volume 1, *Research, Development, Test & Evaluation, Air Force Vol–I* (Washington, DC: DOD, February 2020), 260.

12 Bryan Ripple, "Skyborg Program Seeks Industry Input for Artificial Intelligence Initiative," *U.S. Air Force News*, March 26, 2019.

13 Rachel Cohen, "Rapid Autonomy Development Team Sets 18-month Plan for Autonomous Fighter Jet," *Inside Defense*, May 30, 2018.

14 In FY 2021, the USAF will take the logical step of consolidating activities and funding from numerous programs it previously initiated to develop A/R UAV technologies, including the LCAAT and its Low Cost Attritable Aircraft Platform Sharing (LCAAPS) program.

15 Pat Host, "AFA 2019: US Air Force Seeks to Tailor Airworthiness Process for Low Cost Attritable Aircraft," *Janes*, September 20, 2019; and Richard Scott, "Unmanned Upstart: Kratos Casts Off Its Cloak," *Jane's International Defence Review*, August 24, 2016.

16 Danial Javorsek, "Air Combat Evolution (ACE)," Defense Advanced Research Projects Agency (DARPA).

17 Joe Gould, "AI's Dogfight Triumph a Step Toward Human-Machine Teaming," *Defense News*, September 10, 2020.

18 DARPA Public Affairs, "AlphaDogfight Trials Foreshadow Future of Human-Machine Symbiosis," DARPA, August 26, 2020.

19 "The unmanned vehicles would continuously evaluate their own states and environments and present recommendations for coordinated UAS actions to a mission supervisor, who would approve or disapprove such team actions and direct any mission changes. Using collaborative autonomy, CODE-enabled unmanned aircraft would find targets and engage them as appropriate under established rules of engagement, leverage nearby CODE-equipped systems with minimal supervision, and adapt to dynamic situations such as attrition of friendly forces or the emergence of unanticipated threats." Scott Wierzbanowski, "CODE Demonstrates Autonomy and Collaboration with Minimal Human Commands," DARPA, November 19, 2018.

20 "In the Sky and on the Ground, Collaboration Vital to DARPA's CODE for Success," DARPA, March 22, 2019.

21 Elbridge A. Colby, testimony before the Senate Armed Services Committee, hearing on "Implementation of the National Defense Strategy," January 29, 2019, 7. According to then-Secretary of Defense Mattis, "Great power competition, not terrorism, is now the primary focus of U.S. national security." Speech by Secretary of Defense James Mattis at Johns Hopkins University School of Advanced International Studies, January 19, 2018. Also see Office of the Secretary of Defense (OSD), *Summary of the 2018 National Defense Strategy of the United States of America: Sharpening the American Competitive Edge* (Washington, DC: DOD, January 2018).

22 See "The Air Force We Need: 386 Operational Squadrons," USAF, September 17, 2018.

23 Compared to the Army and Navy, the Air Force absorbed the largest cuts to its annual budgets in the 12 years between the end of the Cold War and the end of FY 2001. Obama administration defense reductions and the 2011 Budget Control Act created another hole in the service's budget that it filled by further cutting its forces and modernization programs. See Mark Gunzinger and Carl Rehberg, *Moving Toward the Air Force We Need? Assessing Air Force Budget Trends* (Arlington, VA: Mitchell Institute for Aerospace Studies, December 2019).

24 For a short summary of the USAF's The Air Force We Need analysis, see Headquarters USAF, *Fiscal Year 2018 National Defense Authorization Act (NDAA) Section 1064 Study: Aircraft Inventories for the Air Force* (Washington, DC: USAF, March 2019). Two independent U.S. think tanks also completed studies as directed by the 2018 NDAA. See MITRE Corporation, "MITRE U.S. Air Force Aircraft Inventory Study Executive Summary," 2019; and Mark Gunzinger, Carl Rehberg, Jacob Cohn, Timothy A. Walton, and Lukas Autenried, *An Air Force for an Era of Great Power Competition* (Washington DC: Center for Strategic and Budgetary Assessments, 2019).

25 According to the Senate version of the FY 2021 NDAA, "As soon as practicable after the date of the enactment of this Act and subject to the availability of appropriations, the Secretary of the Air Force shall seek to achieve a minimum of not fewer than 386 available operational squadrons, or equivalent organizational units, within the Air Force." S.4049 National Defense Authorization Act for Fiscal Year 2021, July 23, 2020, 60.

26 Gunzinger and Rehberg, *Moving Toward the Air Force We Need?*

27 There is a difference between the service's topline budget, which includes all funding appropriated to it for a given fiscal year, and its blue budget, which excludes pass-through funding the USAF receives for programs that it does not control (mostly national intelligence-related). See Gunzinger and Rehberg, *Moving Toward the Air Force We Need?*

28 This is based on USAF blue budget data in Gunzinger and Rehberg, *Moving Toward the Air Force We Need?* updated with information in Headquarters USAF, *Department of the Air Force Budget Overview 2021* (Washington, DC: USAF, February 10, 2020).

29 All dollar amounts are in Constant Year 2021 dollars. The Reagan defense build-up began in FY82 and ran through FY87.

30 According to a Congressional Budget Office report on the increased costs to sustain the USAF's aging aircraft, "As aircraft age, they generally become more expensive to operate. …The faster costs grow as a system ages, the more funding will be needed to maintain existing aircraft and the sooner it becomes cost-effective to replace aging systems with new aircraft." Congressional Budget Office (CBO), *Operating Costs of Aging Air Force Aircraft* (Washington, DC: CBO, September 2018), 1. Also see Gunzinger and Rehberg, *Moving Toward the Air Force We Need?*

31 For more on the need to assess the cost of achieving effects in the battlespace, see David A. Deptula and Douglas A. Birkey, *Resolving America's Defense Strategy-Resource Mismatch: The Case for Cost-Per-Effect Analysis* (Arlington, VA: Mitchell Institute for Aerospace Studies, July 2020).

32 A campaign strategy to achieve a *fait accompli* is designed to rapidly achieve a commander's objectives before an opponent can effectively mobilize and deploy its forces. See Michael S. Gerson, "Conventional Deterrence in the Second Nuclear Age," *Parameters*, Autumn 2009.

33 Gen Jeff Harrigian, "Air Superiority is Fundamental for U.S. Air Force, but Our Enemies Are Gaining Ground," *Fox News*, July 25, 2020.

34 Seth Marshall, "The Tiger and the Sherman: A Critical Look," *The Military Historian*, November 13, 2017.

35 Blaine Taylor, "M4 Sherman: 'Blunder' or 'Wonder' Weapon?" *Warfare History Network*, Sovereign Media, November 15, 2016.

36 General Duncan J. McNabb, Air Force Vice Chief of Staff, "Department of the Air Force Presentation to the Senate Armed Services Committee on Readiness and Management Support," March 13, 2008, 6.

37 Brian W. Everstine, "Goldfein on Meeting Bomber Mission Requirements as B-1 Readiness Drops," *Air Force Magazine*, September 26, 2019.

38 According to Dr. Will Roper, Assistant Secretary of the Air Force for Acquisition, Technology and Logistics, AI-enabled autonomous A/R UAVs "will not replace human pilots, but instead allow them to perform higher-level cognitive tasks and battle management alongside our unmanned platforms." Harry Lye, "Dr. Will Roper on AI and autonomy in the US Air Force," *Air Force Technology*, December 3, 2019.

39 Lye, "Dr. Will Roper on AI."

40 Alan J. Vick, Sean M. Zeigler, Julia Brackup, and John Speed Meyers, *Air Base Defense: Rethinking Air Force and Army Roles and Functions* (Santa Monica, CA: RAND Corporation, 2020), 1.

41 The First Island Chain in the Western Pacific follows the Japanese island of Kyushu down the Ryukyus to the north of Taiwan, runs west toward Luzon, then south along Palawan to Singapore. The Second Island Chain includes the Northern Marianas and the Volcano Islands, runs south to Guam, then down to Palau and New Guinea.

42 Russia is "developing a new generation of advanced regional ballistic and cruise missiles that support its anti-access/area denial (A2/AD) strategy intended to defeat U.S. and allied will and capability in regional crises or conflicts," and "a key component of China's military modernization is its conventional ballistic missile arsenal designed to prevent U.S. military access to support regional allies and partners." OSD, *Missile Defense Review 2019* (Washington, DC: DOD, 2019), vi.

43 General Winkler also said, "We definitely need to have those capabilities to assure our allies of our commitment regardless of whether we're in the Pacific or Europe." Brig Gen Robert P. Winkler, "Long-Range Strike," Mitchell Institute for Aerospace Studies, June 19, 2020, 55:08.

44 John T. Correll, "Arc Light," *Air Force Magazine*, January 1, 2009.

45 Missile Defense Project, "DF-26 (Dong Feng-26)," *Missile Threat*, Center for Strategic and International Studies, June 23, 2020; and OSD, *Military and Security Developments Involving the People's Republic of China 2019*, Annual Report to Congress (Washington, DC: DOD, May 2019), 58.

46 ACE is a U.S. Pacific Air Force concept that combines adaptive basing, the operational maneuver of air forces, assured command and control, mission-type orders, and other elements to ensure it can generate and sustain combat sorties in A2/AD environments. One example would team F-22 air superiority fighters with C-17 cargo aircraft carrying logistics and other materials needed to generate F-22 sorties at distributed operating locations, and then recover and regenerate them for additional sorties. Broadly speaking, frequently air forces across a network of operating locations can degrade an enemy's ability to determine where they are located and then launch air and missile attacks against them.

47 A/R UAVs would also help the Air Force transition from the "large,

centralized, unhardened" basing posture of today to "smaller, dispersed, resilient, adaptive basing" as called for by the National Defense Strategy. OSD, *Summary of the 2018 National Defense Strategy of The United States of America*, 6.

48 Scott Wierzbanowski, "Gremlins," DARPA.

49 Wierzbanowski, "Gremlins." For more information on the XC-61A Gremlins program and how they will be recovered in flight by a mothership, see Pat Host, "DARPA, Dynetics Move Gremlins Focus to Aerial Recovery," *Janes*, January 22, 2020.

50 Alan J. Vick, *Air Base Attacks and Defensive Counters: Historical Lessons and Future Challenges* (Santa Monica, CA: RAND Corporation, 2015), 11-17.

51 Improving its ability to conduct logistics while under attack is an Air Force priority. See Air Force Secretary Barbara Barrett and Air Force Chief of Staff General David L. Goldfein, "United States Air Force Posture Statement Fiscal Year 2021," March 3, 2020, 6.

52 "PLA military writings detail the effectiveness of information operations and cyberwarfare in modern conflicts, and advocate targeting an adversary's C2 and logistics networks to affect the adversary's ability to operate during the early stages of conflict." Defense Intelligence Agency (DIA), *China Military Power: Modernizing a Force to Fight and Win* (Washington, DC: DIA, 2019), 46.

53 Barrett and Goldfein, "United States Air Force Posture Statement Fiscal Year 2021," 6. Skyborg A/R UAVs will "enable expeditionary operations that can generate massed combat power with minimal logistical footprints." Air Force Life Cycle Management Center, "Skyborg Prototyping, Experimentation, & Autonomy Development (SPEAD) Broad Area Announcement FA8650-17-S-6001," May 15, 2020, 2.

54 Barrett and Goldfein, "United States Air Force Posture Statement Fiscal Year 2021," 6.

55 James A. Leftwich, *Low-Cost Attritable Aircraft Technology: Logistics Concept of Support for Deployment and Employment* (Santa Monica, CA: RAND Corporation, forthcoming), viii-ix.

56 Leftwich, *Low-Cost Attritable Aircraft Technology*.

57 For more information on higher-capacity airbase air and missile defenses that DOD could field in the near-term, see Carl Rehberg and Mark Gunzinger, *Air and Missile Defense at a Crossroads: New Concepts Technologies to Defend America's Overseas Bases* (Washington, DC: Center for Strategic and Budgetary Assessments, 2018). For a summary of other concepts and capabilities that could improve the USAF's ability to conduct distributed operations, see Miranda Priebe, Alan J. Vick, Jacob L. Heim, and Meagan L. Smith, Distributed Operations in a Contested Environment: Implications for USAF Force Presentation (Santa Monica, CA: RAND Corporation, 2019).

58 Lye, "Dr Will Roper on AI."

59 According to DOD, modern militaries "cannot conduct high-tempo, effective operations without reliable information and communication networks." DOD, *Sustaining U.S. Global Leadership: Priorities for 21st Century Defense* (Washington, DC: DOD, January 2012), 5.

60 For DOD's definition of electromagnetic warfare and its functional categories, see JCS, *Joint Electromagnetic Spectrum Operations*, I-5. Both Chinese and Russian EW units routinely conduct jamming operations against communication networks, radar systems, and GPS satellite systems during exercises to improve their ability to operate in contested EM environments. For more on EW capabilities that could help the U.S. military regain its dominance in the EMS, see Bryan Clark and Mark Gunzinger, *Winning the Airwaves: Regaining America's Dominance in the Electromagnetic Spectrum* (Washington, DC: Center for Strategic and Budgetary Assessments, 2017).

61 HPM weapons generate very short-duration high-power pulses of electromagnetic energy using waveforms that are designed to damage sensitive electronic components in C2 systems, sensors, and other electronics-based systems. These pulses induce energy into target circuits that disrupt their operations or cause them physical damage. HPM weapons can create these effects in less than a second. Office of Naval Research (ONR), *Naval Air Warfare and Weapons* (Arlington, VA: ONR, 2017), 26. For a more detailed explanation of the generic effects of HPMs, see Philip E. Nielsen, *Effects of Directed Energy Weapons* (Albuquerque, NM: Directed Energy Professional Society, 2009).

62 JCS, *Countering Air and Missile Threats*, Joint Publication 3-01 (Washington, DC: JCS, May 2, 2018), ix.

63 USAF Enterprise Capability Collaboration Team, *Air Superiority 2030 Flight Plan* (Washington, DC: USAF, May 2016).

64 Barrett and Goldfein, "United States Air Force Posture Statement Fiscal Year 2021," 5.

65 Valerie Insinna, "Under Skyborg Program, F-35 and F-15EX Jets Could Control Drone Sidekicks," *Defense News*, May 22, 2019.

66 Douglas Birkey, David Deptula, and Lawrence Stutzriem, *Manned-Unmanned Aircraft Teaming: Taking Combat Airpower to the Next Level* (Arlington, VA: Mitchell Institute for Aerospace Studies, July 2018), 17.

67 John Stillion, *Trends in Air-to-Air Combat: Implications for Future Air Superiority* (Washington, DC: Center for Strategic and Budgetary Assessments, 2015), 40.

68 For an illustration of the potential operational impact of increasing weapons per sortie, see Mark Gunzinger, *Long-Range Strike: Resetting the Balance of Stand-In and Stand-Off Forces* (Arlington, VA: Mitchell Institute for Aerospace Studies, June 2020).

69 See Leigh Giangreco, "USAF Developing Next Generation Air Dominance Missile," *Flight Global*, May 30, 2017; and Sara Sirota, "Raytheon Beats Lockheed to Develop Miniature Self-Defense Missile for AFRL," *Inside Defense*, July 23, 2020.

70 Thomas Hamilton and David Ochmanek, *Operating Low-Cost, Reusable Unmanned Aerial Vehicles in Contested Environments* (Santa Monica, CA: RAND Corporation, 2020), viii.

71 U.S. Government Accountability Office (GAO), *Action Is Needed to Provide Clarity and Mitigate Risks of the Air Force's Planned Advanced Battle Management System* (Washington, DC: GAO, April 2020), 2-6.

72 Theresa Hitchens and Sydney J. Freedberg Jr., "Milley Assigns Service Roles in All-Domain Ops Concept," *Breaking Defense*, July 22, 2020. For more information on JADC2 and Joint All Domain Operations, see Curtis E. LeMay Center for Doctrine Development and Education, "Annex 3-1 Department of the Air Force Role in Joint All-Domain Operations," June 1, 2020.

73 Sara Sirota, "Air Force Developing 28 Capabilities to Enable Multidomain Operations via ABMS," *Inside Defense*, January 22, 2020.

74 Valerie Insinna, "Here's the No. 1 Rule for US Air Force's New Advanced Battle Management System," *Defense News*, July 9, 2019.

75 The term "kill chain" refers to the steps in the "find, fix, track, target engage, assess" (F2T2EA) chain of actions that are accomplished by a system or system-of-systems to successfully destroy or achieve other effects against a target or set of targets.

76 Herbert C. Kemp, *Rethinking the Information Paradigm: The*

Future of Intelligence, Surveillance, and Reconnaissance in Contested Environments (Arlington, VA: Mitchell Institute for Aerospace Studies, February 2018), 4.

77 The Air Force envisions a family of systems across multiple domains contributing to a future, more resilient ISR and BMC2 architecture. Critically, this architecture is intended to continually evolve as new technologies and capabilities become available. In addition to unmanned systems such as A/R UAVs, space-based technologies and cyber are likely to take on expanded roles, particularly in contested environments.

78 Dr. William B. Roper, Jr., Assistant Secretary of the Air Force (Acquisition, Technology & Logistics); Gen. James M. Holmes, Commander, Air Force Air Combat Command; and Lt Gen David S. Nahom, Air Force Deputy Chief of Staff (Plans and Programs), "Department of the Air Force Acquisition and Modernization Programs in the Fiscal Year 2021 National Defense Authorization President's Budget Request," presentation to the House Armed Services Committee, Subcommittee on Tactical Air and Land Forces, March 10, 2020, 21.

79 Brian W. Everstine, "The F-22 and the F-35 Are Struggling to Talk to Each Other … And to the Rest of USAF," *Air Force Magazine*, January 29, 2018.

80 For more information on gateways, see Corinne Wallshein, *Tactical Datalink Gateways Introduction* (Washington, DC: Air Force Studies and Analyses Agency, December 1999).

81 A 2019 AFRL Skyborg program Capability Request for Information described an open system as "a system in which the components and protocols conform to standards independent of a particular supplier, are modular, and are easily integrated with third parties. Open systems mitigate risks associated with technology obsolescence, vender-unique technology, and single sources of supply and/or maintenance." AFRL, "Capability Request for Information for Skyborg Autonomous Unmanned Combat Air Vehicle," March 15, 2019, 8.

82 This is based on Mitchell Institute discussions with potential A/R UAV vendors.

83 By one estimate, the number of DOD's prime vendors decreased by 17,000—about 20 percent—from FY01 to FY15 alone. Office of the Under Secretary of Defense for Acquisition and Sustainment, and Office of the Deputy Assistant Secretary of Defense for Industrial Policy, *Assessing and Strengthening the Manufacturing and Defense Industrial Base and Supply Chain Resiliency of the United States: Report to President Donald J. Trump by the Interagency Task Force in Fulfillment of Executive Order 13806* (Washington, DC: DOD, September 2018), 23 and 26.

About The Mitchell Institute

The Mitchell Institute educates about aerospace power's contribution to America's global interests, informs policy and budget deliberations, and cultivates the next generation of thought leaders to exploit the advantages of operating in air, space, and cyberspace.

About the Series

The Mitchell Institute Policy Papers present new thinking and policy proposals to respond to the emerging security and aerospace power challenges of the 21st century. These papers are written for lawmakers and their staffs, policy professionals, business and industry, academics, journalists, and the informed public. The series aims to provide in-depth policy insights and perspectives based on the experiences of the authors, along with studious supporting research.

For media inquiries, email our publications team at publications.mitchellaerospacepower@afa.org

Copies of Policy Papers can be downloaded under the publications tab on the Mitchell Institute website at https://www.mitchellaerospacepower.org

About the Authors

Mark Gunzinger is the Director of Future Concepts and Capability Assessments at the Mitchell Institute for Aerospace Studies. Gunzinger served as the Deputy Assistant Secretary of Defense for Forces, Transformation and Resources. A retired Air Force colonel and command pilot with over 3,200 hours in the B-52, he joined the Office of the Secretary of Defense in 2004, was appointed to the Senior Executive Service, and served as DOD's principle director of staff for the 2006 Quadrennial Defense Review. Gunzinger then joined the National Security Council staff as Director for Defense Transformation, Force Planning, and Resources. Gunzinger holds an M.S. in National Security Strategy from the National War College, a Master of Airpower Art and Science degree from the School of Advanced Air and Space Studies, an M.P.A. from Central Michigan University, and a B.S. in Chemistry from the United States Air Force Academy.

Lukas Autenried is a Senior Analyst at the Mitchell Institute for Aerospace Studies. Prior to joining the Mitchell Institute, Mr. Autenried was an Analyst at the Center for Strategic and Budgetary Assessments, where his work focused on the development of operational concepts, force planning, operations research, and defense budgeting and resourcing. His previous experience also includes work at the World Bank, the State Department's Bureau of Political-Military Affairs, and the Woodrow Wilson Center. Mr. Autenried holds an M.A. in Strategic Studies and International Economics from the Johns Hopkins University School of Advanced International Studies and a B.A. in Government and History from Georgetown University.