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Key Points

The US Air Force faces a serious capacity-to-combat mission requirements gap—particularly with its bomber and fighter force. Thanks to advancements in autonomy, processing power, and information exchange capabilities, the Air Force will soon be able to fly traditionally manned combat aircraft in partnership with unmanned aircraft. This effort promises to boost affordable, effective combat capacity.

Approaching this opportunity in a graduated fashion with limited risk allows the operational community to explore new concepts of operation and tactics in an evolutionary fashion, honing attributes to drive later new mission-specific designs.

This effort is not about remotely piloted aircraft (RPA) operating in mass with traditional aircraft, but rather true autonomous "machine-to-machine" partnering, where manned-unmanned collectives can ope-rate at "machine speeds" to overwhelm an adversary's decision-making.

Manned-Unmanned Aircraft Teaming: Taking Combat Airpower to the Next Level

By Douglas Birkey
Executive Director, The Mitchell Institute for Aerospace Studies,

Lt Gen David Deptula, USAF (Ret.)
Dean, The Mitchell Institute for Aerospace Studies

and Maj Gen Lawrence Stutzriem, USAF (Ret.)
Director of Research, The Mitchell Institute for Aerospace Studies

Abstract

Modern airpower is on the cusp of a major technological and operational transformation. Thanks to advancements in autonomy, processing power, and collaborative information exchange, the US Air Force will soon be able to fly traditionally manned combat aircraft in partnership with unmanned partners. At a time when the service desperately needs to add combat capacity, while also developing new and enduring advantages in a world of competitive, burgeoning threats, this is an opportunity that must be explored and exploited. Though this technology is promising, this does not mean compromising the Air Force's commitment to advanced systems like the F-35 and B-21, but instead raises the imperative to think about a new composition of aircraft to achieve mission capabilities that maximize the attributes of human operators and autonomy in a highly interdependent fashion. To achieve this, the Air Force should explore the advantages that could be yielded through collaborative teaming of manned and unmanned combat aircraft. This combination may provide increased numbers of affordable aircraft to complement a limited number of exquisite, expensive, but highly potent fifth-generation aircraft.

Introduction: The Manned-Unmanned Transformation

Airpower is on the cusp of a major technological transformation. Thanks to advancements in autonomy, processing power, and collaborative information exchange, the US Air Force will soon be able to routinely fly traditionally manned combat aircraft in tandem with unmanned aircraft.

This transformation does not mean simply operating remotely piloted aircraft (RPA) *en masse* with traditionally piloted airframes—it signifies true autonomous machine-to-machine partnering, where manned-unmanned collectives can operate across a broad front at "machine speed" to overwhelm an adversary's decision-making process. At a time when the Air Force desperately needs to add capacity while also developing enduring advantages in a world of burgeoning threats, the service must explore this opportunity. While the US Air Force still possesses the most formidable air arm in the world, the spectrum of challenges it faces mandates change, not only in what the service buys, but also in how it operates.

The ability to hit any target on the globe in a matter of hours can yield strategic effects of the highest order—especially when considering alternate delivery methods generally involve days, weeks, or months.

The Air Force faces a serious capacity gap when it comes to fulfilling combat mission requirements with its current inventory—especially bombers and fighters. The combined effects of the post-Cold War draw-down, overriding focus on ground operations in the wake of the September 11, 2001 terror attacks, and constrained budgets following passage of the Budget Control Act of 2011 (BCA) have drastically reduced the number of aircraft the service has in its inventory to execute critical missions. The impact has become clear: combatant command (COCOM) requirements have gone unmet, pilot retention issues are rising, and combat aircraft in the inventory are wearing out at an accelerated rate. At the same time, the global security environment continues to present new challenges. If developments in multiple theaters, such as crises on the Korean Peninsula, Ukraine, and Syria, required decisive and concurrent US military engagement, the Air Force would be stretched thin to meet critical objectives.

This dynamic portends danger for the United States and its allies, because the effects achieved by bombers and fighters, namely precision strike and air superiority, are essential national security options that policy leaders must consider in the event of a conflict. The ability to hit any target on the globe in a matter of hours can yield strategic effects of the highest order—especially when considering alternate delivery methods generally involve days, weeks, or months. Naval ships steaming across the globe at 20 knots and mass Army ground force deployments generally do not represent expeditious options. Air Force aircraft also provide essential protection for the other US military service components participating in joint operations, by ensuring forces are not attacked from the sky by hostile aircraft, missiles, or gunfire. In an era where precision weaponry and sensor technology have proliferated to a broad number of potential adversary states, ships at sea, forces on the ground, and even satellites in space are at high risk in the face of robust, accurate enemy strikes. This situation leaves vast swaths of the US military force structure vulnerable in ways not seen since World War II.

Adding back combat airpower capacity to address these challenges requires that the Air Force take a new approach: one that seeks to deliver capabilities in a more effective and efficient fashion. First, this does not mean compromising the Air Force's commitment to advanced fifth-generation aircraft such as the F-35 and B-21. These are essential aircraft whose unique contributions will prove invaluable by providing leaders with effective, prudent military policy options in the future (in fact, they are already late to need). Given that procurement of both the F-22 Raptor and B-2 Spirit was prematurely curtailed before established requirements were met, the service has been juggling tremendous risk in two critical mission sets far too long. A resource of 185 fighters and 20 bombers is fundamentally limited in world where their capabilities are in high demand. Airmen and their aircraft, no matter how well trained or technologically advanced, cannot be in two places at once, and older aircraft retained in the inventory for want of replacement cannot meet mission needs indefinitely. Potential adversaries understand these shortfalls, and are filling the resulting void with policies and activities counter to US interests. As recent actions in Ukraine and Syria indicate, this includes overt combat operations.

Addressing this shortfall, while still maintaining key modernization goals, involves recognizing that the Air Force needs additive, complementary, and affordable capability on the ramp as soon as possible. To this end, the service should explore the potential gains that may result from collaborative teaming of manned and unmanned combat aircraft, where attritable numbers of inexpensive RPA complement a limited number of exquisite, but costly aircraft.

From a technology perspective, RPA and their associated enterprise have experienced tremendous capability growth over the past two decades—with much of this applicable to a manned-unmanned teaming construct. This involves the collaborative partnering of aircraft that are crewed in a traditional fashion and uninhabited aircraft that are operated through remote link or autonomy. In addition, research and development (R&D) organizations such as the Air Force Research Laboratory (AFRL) and the Defense Advanced Research Projects Agency (DARPA) are developing capabilities that allow unmanned aircraft to execute autonomous actions. This self-directing function would become critically important when manned-unmanned teams operate in contested environments that feature degraded or jammed communications and Global Positioning System (GPS) capabilities—the modes of control used in current RPA operations.

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From a budget-sensitive perspective, the Air Force can pursue development of manned-unmanned teams through a phased approach. Existing combat aircraft now maintained in storage, such as many fourth generation F-16s for example, can be reactivated into the operational inventory and be converted for employment as unmanned combat aircraft. In fact, DARPA has developed robotic cockpit control technology that would enable an F-16 to take off, fly, and land in fully autonomous mode.[1] Empowered by new mission system software, these assets could be operated in partnership with traditional manned combat aircraft to yield a highly potent, diverse, and numerically robust force package. If successful, this approach could be extended to other elements of the Air Force inventory, while also pioneering technology and concepts of operations for the next generation of unmanned aircraft— the long-awaited MQ-X.

One of the principal benefits of approaching the manned-unmanned teaming concept by modifying existing, surplus assets is that it allows the Air Force and its technology support community to concentrate their efforts on specific focus areas with platforms that can match the flight profile needs of complementary manned platforms. Given that these airframes are already bought and paid for, minimal capital investment is required to yield a significant operational return. The concept also would allow the Air Force to increase its sortie rate and project greater combat capacity without further exacerbating its current pilot shortfall. This also translates to lower cost per desired mission effect. Finally, approaching this opportunity in a gradual fashion with limited risk will allow the operational community to explore concepts of operation and tactics in an evolutionary fashion—honing attributes that will later drive mission-specific new designs.

The Problem Set: Aerospace Power in Today's Security Environment

Combat aircraft do not exist for their own ends, but to serve as tools that empower national security leaders with a range of effective policy options. In other words, everything comes down to basic demand: what resources does America need to defend its interests around the globe? A robust and varied toolkit is needed. As Senate Armed Services Committee Chairman Sen John McCain (R-AZ) declared in his 2017 defense whitepaper, *Restoring American Power: Recommendations for the FY 2018-FY 2022 Defense Budget:* "We now face, at once, a persistent war against terrorist enemies and a new era of great power competition. The wide margin for error that America once enjoyed is gone."[2]

McCain is not alone in making this assessment. Secretary of Defense James Mattis explained in recent testimony that America's security challenge today "is characterized by a decline in the long-standing rules-based international order, bringing with it a more volatile security environment than any I have experienced during my four decades of military service."[3] Security developments prompting these statements include Russia's increased aggression in places such as Ukraine and Syria; China's militarization of the South China Sea; North Korean and Iranian pursuit of nuclear arsenals; the continued strength of non-state actors such as the Islamic State, Al Shabab, and Al Qaeda; and new threats posed in domains such as cyberspace and outer space.

The complexity of the present threat environment becomes clear when juxtaposed with the challenges that confronted the United States in the 1990s after the Cold War, with Russia posing little overt strategic challenge, and China still a rising regional power. The Reagan build-up of the 1980s had paved the way for the tremendous overmatch achieved against Iraqi forces in Operation Desert Storm from both a technological and capacity perspective. Campaigns in places such as Somalia, Bosnia, and Kosovo during the 1990s led to unique military demands, but the real issues that defined these engagements were often political and diplomatic in nature—US military might was never in question.

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Even after September 2001, America's wars in Afghanistan, Iraq, and campaigns against Al Qaeda networks elsewhere never pushed US forces to the brink. Air superiority was attained in a matter of hours and days in all of these conflicts. Adversaries never credibly challenged freedom of navigation at sea or the ability to harness cyber or space-based capabilities. Hardships experienced on the ground, while severe at times and demanding tremendous bravery, never escalated to a point where existential US interests were at stake. While the last seventeen years may have been a grinding slog of counterinsurgency campaigns, threats encountered during this period occurred in largely permissive environments that did not seriously stress America's military power from a capacity or capability perspective.

Today, the US faces a complex and interconnected globe, filled with competing interests and capable technologies in the hands of potential adversaries. Though the United States has enjoyed unparalleled overmatch since the end of the Cold War, this does not mean others were not building their own security infrastructure to better attain their respective objectives. As an added benefit to potential adversaries seeking to grow their military power, continual US military engagements over the past two decades provided the world with clear insights into how to counter US power projection practices. As the Air Force's Deputy Chief of Staff for Intelligence, Surveillance, and Reconnaissance Lt Gen VeraLinn "Dash" Jamieson explained during a recent Mitchell Institute event: "Our adversaries are watching us — they're learning from us."[4] American military effectiveness over the past 25-plus years in Iraq and Afghanistan have also inspired actors to invest in similar solution sets that, once the exclusive preserve of the US Department of Defense (DOD), are now increasingly available on the international marketplace. Today, capabilities that were once the sole realm of the US and the Soviet Union are now available to a broad range of nation states and international actors.

As an example, in the Cold War, the United States and the Soviet Union invested significant sums in aircraft, satellites, and their associated operating infrastructure to gain visual situational awareness through imagery. The famed Corona spy satellites and the SR-71 Blackbird reconnaissance aircraft represented the height of technology when they were fielded. No other nation's aerospace assets could come close to gathering the overhead imagery these assets could gather. Today, any individual with a smartphone and a data connection can access high-quality pictures of nearly every corner of the planet thanks to applications such as Google Earth and other computer programs. Such intelligence allows countries and non-state actors to radically improve how and when they use their military forces. This capability will become increasingly pernicious as commercial space companies populate low earth orbit with small satellites that continuously capture available data over the entire planet.

Even the most advanced military technologies—including stealth aircraft, precision munitions, highly capable RPA, autonomous systems, and space-based intelligence satellites—are no longer the domain of a few nations. For example, the US has enjoyed an effective monopoly on operational stealth technology since the 1980s. Strategy, operational considerations, and tactics were shaped around the premise that the US would maintain the asymmetric stealth advantage for years. Yet technological proliferation has brought stealth capabilities to a growing number of nations, whose interests compete with those of America's. China's J-20 and J-35, as well as Russia's Su-57, represent a new generation of low-observable combat aircraft that will enter operational status and be available for export over the next few years. Thus, military planners now need to radically rethink what it means to project American power and provide credible defenses when others also possess such capable aircraft. Formerly enduring asymmetric advantages are now only temporary, short-term advantages against highly competitive adversaries who are no longer satisfied with "second best" capabilities.

This range of threats and strategic challenges demand both military capability and military capacity to respond effectively. It has become obvious to nefarious actors when United States military forces are spread thin—185 F-22s and 20 B-2s can only be in so many places at a given time.

The same logic applies to precision strike. Potential adversaries now possess these munitions in an operational context. Russian operations in Syria demonstrated this to an ample extent. According to Russian President Vladimir Putin:

> *It is one thing for the experts to be aware that Russia supposedly has these weapons, and another thing for them to see for the first time that they do really exist, that our defense industry is making them, that they are of high quality and that we have well-trained people who can put them to effective use.*[5]

Looking to the Asia-Pacific region, the DOD's annual report to Congress on Chinese military power—*Military and Security Developments Involving the People's Republic of China*—lays out similar precision strike achievements: "The DF-26, which debuted publicly last year, is capable of conducting intermediate precision strikes against ground targets that could include US bases on Guam," the 2017 edition of the report states.[6] This long-range precision strike capability, in the hands of China (and those it sells these weapons to) portends a massive impact on how the US and its allies train, organize, and equip their respective forces.

When it comes to advanced RPA, one need only look to recent foreign military sales. China has sold sophisticated RPA types to countries such as Jordan, Saudi Arabia, Egypt, and the United Arab Emirates.[7] These systems, which mirror many MQ-1 Predator and MQ-9 Reaper size and capability characteristics, afford nations a powerful sensor-shooter capability. The US has used this to great effect in Iraq, Afghanistan, and beyond. Now, it needs to think about guarding against a similar capability in the hands of adversaries. This presents a question regarding both threat capability and capacity.

Nor is the challenge facing the United States just one of technology. At any given moment, US forces must manage non-state actors such as the Islamic State, Al Qaeda, the Taliban, Al Shabab, and other groups. Beyond this, countries such as Russia and China are choosing to engage in overt hostile acts, in Eastern Europe and the South China Sea, for example. This demands a robust, credible, and consistent US presence to deter further aggression, reassure allies, and project actual combat power should circumstance warrant. Middle powers such as Iran and North Korea have pursued courses of action that also present a severe threat to US security interests, especially with regard to the development and use of nuclear weapons. Whether considering multiple credible nuclear threats or the danger posed by a non-state actor, Americans at home today face greater risk of a credible attack than they have in decades.

This range of threats and strategic challenges demand both military capability and military capacity to respond effectively. It has become obvious to nefarious actors when United States military forces are spread thin—185 F-22s and 20 B-2s can only be in so many places at a given time. Russia's actions in Syria and Ukraine present a good example regarding the capacity challenges US commanders would face if operations in both regions escalated concurrently. Both involve sophisticated threats, requiring the most advanced US systems. Lacking the means to engage in concurrent contingencies, the US would either have to withdraw forces from one zone, ceding its interests in Syria, or not engage in Ukraine. Either course would damage US interests and severely harm its overarching credibility. The Russian government would act as the driver in that sort of scenario, with the United States in a reactive position—a bad strategic posture for America. By building a broader reserve of capabilities, the US is better able to mitigate such risks, and adversaries are less likely to press the limits of aggressive behavior if they know they will face painful repercussions.

The Air Force's Essential Contribution

In the present range of conflicts and potential crises, there is one universal constant: airpower is a core necessity throughout the spectrum of military operations. Whether in the context of operations against non-state actors in regions such as Africa or the Middle East; forces required to deter, and if necessary defeat, North Korean and Iranian military aggression; or a set of capabilities necessary to counter and deter major powers such as Russia and China, airpower is an essential tool for a range of potential military operations—from peacetime to a hypothetical nuclear exchange. No other element of the military is called upon in such a consistent, essential fashion across the range of potential conflicts.

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In comparing the present US Air Force inventory with real-world demand, it is very obvious that the service is stretched thin. As Secretary of the Air Force Heather Wilson and Air Force Chief of Staff Gen David Goldfein explained in their 2017 posture statement:

> *Any objective evaluation of today's US Air Force reaches stark conclusions. First, the Air Force is too small for the missions demanded of it and it is unlikely that the need for air and space power will diminish significantly in the coming decade. Second, potential adversaries are modernizing and innovating faster than we are, putting at risk America's technological advantage in air and space.*[8]

This inventory shortfall is particularly acute with bombers and fighters. At the end of the Cold War, the United States possessed more than twice as many bomber and fighter aircraft than it does at present—aircraft that were also far newer at the time (See Figure 1, page 7). The current security environment demands a bigger toolkit better empowered to meet real-world demands, especially when considering the unique value long-range strike and air superiority capabilities present to the US.

Ever since World War II, American leaders have relied upon long-range strike aircraft to hold any target around the globe at risk. At times of peace, this capability is instrumental in deterring potential adversaries, reassuring allies, and shaping security dynamics. When conflict occurs, long-range strike aircraft can hit the most vital targets in a decisive, overwhelming fashion. The US regularly deploys bombers to Europe and the Asia-Pacific as shows of highly visible, credible strength. One recent deployment of B-2s, B-1s, and B-52s to Anderson AFB, Guam sent a clear signal to aggressors in the region.[9] A similar deployment of all three bombers in the US inventory occurred to Europe in the summer of 2017 as a signal to Russia.[10] The DOD has nothing else in its arsenal that can yield comparable effects. These bombers also perform their tasks efficiently, with one aircraft able to strike over 80 independent targets on a single mission. Commanders are quick to appreciate this value. During the occasional US Navy aircraft carrier gaps that have occurred during Operation Inherent Resolve, the missing capacity of the carrier air wing was backfilled by flying an extra one or two B-1 sorties per day.[11]

Despite the importance of the long-range strike force, the United States currently faces a capacity gap in excess of 100 aircraft. At the end of the Cold War in 1990, the US Air Force fielded a force of 366 bombers that were assigned to 17 bomb wings. That total is now down by over half, to a total force of 158 bombers in five bomb wings: 62 B-1B Lancers, 20 B-2A Spirits, and 76 B-52H Stratofortress (See Figure 1).[12] As the inventory was cut, mission demand increased with combat sorties flown in places such as Afghanistan, Iraq, Libya, and Syria, plus a growing deterrent requirement in Europe and the Pacific. There is no slack in this mission set—all aircraft are heavily used on a routine basis. A major combat operation would stretch available bombers to the breaking point, leaving high-priority mission requests unmet. Given current COCOM demands and nuclear deterrence requirements, the Air Force at present requires at least 12 operational bomb squadrons, with additional units for training. Today, it only has nine operational squadrons available. Stated another way, a balanced force able to meet wartime requirements, while also affording a sustainable rotation base, would consist of 264 long-range strike aircraft: the number of bomber squadrons it would take to fully equip the Air Expeditionary Force (AEF) force presentation model.[13] The eventual arrival of the B-21 presents the Air Force with an opportunity to remedy this shortfall. However, those aircraft will not arrive for many years and action must be taken to consider bolstering capacity sooner. Also, given the trend of global threats, the Air Force may find that it needs far more bombers than current projections suggest. Combatant commanders need more survivability, range, payload, and rapid global response, not less.

FIGHTERS			
1990		**2018**	
F-4D/E	906	F-15C/D	235
F-15C/D	867	F-15E	218
F-16A/B/C/D	1433	F-16C/D	941
		F-22A	187
		F-35A	119
Total	3206	Total	1700

BOMBERS			
1990		**2018**	
B-1A	96	B-1A	62
B-2A	1	B-2A	20
B-52G/H	254	B-52H	75
F-111A/D/E/F & FB	327		
F-117A	59		
Total	737	Total	157

Figure 1: Chart of fighter and bomber inventory, 1990 and 2018.

The picture is similarly bleak when it comes to the fighter force. Air superiority is a fundamental precondition for any successful military operation. Troops on the ground, ships at sea, support aircraft such as tankers and airlifters, and regional bases are at extreme risk if an enemy is free to strike from the sky. Years' worth of divestiture paired with anemic recapitalization efforts have left the fighter aircraft inventory on the brink of combat insolvency. The US Air Force possesses a total of 954 aircraft capable of air-to-air combat: F-15s, F-16s, F-22s, and F-35s. A-10s, while often categorized as fighters, are only capable of air-to-ground missions, and therefore do not figure in to the full-spectrum air superiority count.[14] These aircraft are deployed at over a dozen locations around the world and provide the backbone of numerous contingency plans to meet US security objectives. Given global demands, operational considerations, and force rotation factors, the Air Force can now muster fewer than 100 fighter aircraft in a particular location at any given time. Because aircraft are employed in a rotational fashion—with one set of aircraft on station, another returning home, and a third set preparing to launch—about 30 fighters would be active at any given time. Of this force, only a handful would be stealthy and possess fifth-generation capabilities, especially when it comes to the ability to gather, process, and share information. Bluntly, that number simply does not suffice to project viable, credible capability. As with bombers, the demand for the fighter mission set is likely to rise. With more nations obtaining advanced aerial capabilities, the need to secure access to and from the sky will stand as an increasingly important mission set. The assumed US and allied aerial superiority of the last two decades will likely soon be seen as an historic anomaly.

This current predicament was never supposed to come to pass. When the Cold War ended, the US had an air superiority force structure of 3,212 fighters. However, the 1990s saw this number cut in half to 1,814 F-15s and F-16s. Wars in Iraq and Afghanistan saw the inventory shrink further to free up funding for wartime accounts. Explaining the difficult tradeoffs in this era, Goldfein highlighted one area in which these hard choices led to very direct tradeoffs: "To build the [RPA ISR] processing, exploitation, and dissemination that we enjoy today, we retired ten squadrons of legacy fighters in 2010."[15] RPA yielded tremendous results during this period, but gaining this capacity involved significant offsets within the Air Force. Specifically, these cuts were taken in Fiscal Year 2010 as part of the Combat Air Forces Reduction Plan (CAF REDUX)—seeing the retirement of

112 F-15C/Ds and 134 F-16C/Ds. This action was supposed to be temporary, but has now become normal in the post-BCA era. Modernization efforts such as acquisition of the F-22 were prematurely cancelled because leaders of the time failed to appreciate the importance of the air superiority mission. The sole remaining recapitalization effort, the F-35, was continually delayed and acquisition rates reduced to meet budget targets. Global realities suggest a need to reset this force structure.

Nor were all of the setbacks tied to airframes. Vital upgrades to equipment such as radars and avionics have been dramatically curtailed. Thus, not only did the US fail to secure the new-build aircraft plan, but leaders also undercut the stated fallback positions of modernizing the existing inventory. Compounding risks have piled up for so long that many decision-makers have lost track of the scale and scope of the cuts.

It is worth noting that attrition and loss is something most of the US military services stopped planning for in any large-scale fashion due to budget pressures. These elements were cut in the name of seeking "efficiencies." The price of preventing such losses is fundamentally tied to buying back a credible, capable air superiority fleet.

The net effect is that the United States would be extremely hard pressed to secure air superiority in accordance with the current National Security Strategy. With regions spanning the globe embroiled in troubling security dynamics, the Air Force would likely be underequipped to attain air superiority objectives if any of these scenarios, from the Korean Peninsula to Eastern Europe, escalated in a concurrent fashion. During Operation Desert Storm — America's last quick and decisive military victory—the Air Force possessed 134 fighter squadrons. Today it has 55, a 60 percent reduction in forces. Thirty-eight fighter squadrons participated in Desert Storm—70 percent of today's total—yet Desert Storm was the only major regional conflict at the time, and one involving a threat far less complex than many facing the US today.

This is not just an Air Force problem; it places US national security imperatives on a precarious footing. Are senior leaders willing to put forces in harm's way knowing they could be ravaged by enemy aerial strikes? The casualties resulting from such a threat could prove extreme. It is worth noting that attrition and loss is something most of the US military services stopped planning for in any large-scale fashion due to budget pressures. These elements were cut in the name of seeking "efficiencies." The price of preventing such losses is fundamentally tied to buying back a credible, capable air superiority fleet. The shortfall in both long-range strike and air superiority demands action. Such risk is not tenable over the long term, with key mission areas stretched to the brink in a time when the world is a very dangerous place.

In many ways, the solution to this problem already exists in the form of the B-21 and F-35. These next-generation long-range strike and air superiority aircraft are well placed to fill the shortfalls facing the US. The US military needs large numbers of these aircraft in the operational inventory as soon as possible. However, current budgets simply do not see enough of these aircraft entering service as fast as real-world demands necessitate. The Air Force lacks the money to accelerate their modernization efforts given the fiscal constraints and broad number of priorities that must be balanced over the next several years. These priorities include procuring at least 10 satellite programs, the KC-46 aerial tanker, the Ground Based Strategic Deterrent (GBSD) ballistic missile replacement, UH-1 helicopter replacement, the Combat Rescue Helicopter (CRH), the T-X training aircraft and system, and a new generation of aircraft under the umbrella of the Penetrating Counter Air (PCA) program.

Given this situation, the Air Force must find a way to add capacity in a way that does not harm core modernization programs such as the B-21 and F-35, while still bringing appreciable combat capabilities into the fold to meet current requirements. National security demands wholly depend upon the acquisition of new equipment as soon as possible, but added capacity must also be generated in the near term given that B-21 and F-35 acquisition is programmed to run into the 2040s. Meeting this challenging set of circumstances requires the Air Force to pursue a new approach—one that seeks to join existing legacy inventory assets with new technology to yield a new force projection paradigm.

Generating New Mission Effects: The Manned-Unmanned Teaming Concept

The vision for near-term manned-unmanned teaming is simple: equip existing surplus legacy aircraft with autonomous mission control hardware and software that allow these airplanes to collaboratively achieve mission effects with complementary manned assets. This may seem like an unorthodox approach to attain badly needed capacity, but research and development (R&D) organizations such as DARPA have demonstrated this capability exists today. In particular, gains over the last several years in the field of autonomy increasingly mean that concepts once deemed the realm of science fiction are within operational reach. Given the strains facing the Air Force, with mission demand far exceeding available aircraft capacity, it is now time to give serious thought to investing in this new approach.

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As with any new mission capability, manned-unmanned teaming would not focus on the most taxing scenarios. However, providing additive unmanned capacity at the low and middle ranges of the spectrum would free up more capable manned assets to focus on more challenging missions. Nor would all functions have to be wholly autonomous. A first-generation unmanned autonomous aircraft might execute significant portions of its mission in an independent fashion, but require human authorization for application of kinetic force. It is also important to highlight that not all threats are created equal. In many scenarios, an early generation of manned-unmanned force structure would prove sufficient given the threat environment and associated operational demands. This new approach, regardless of the details, would have a positive net effect as it would make a broader level of capacity available to ensure that the Air Force could execute an increased number of concurrent taskings. As autonomous technology advances, these systems would be pushed forward to address higher levels of mission complexity.

In considering the manned-unmanned model of future operations, some individuals often express concerns about the technical readiness levels of such a solution. Would this envisioned capability be too far beyond the reach of mature technology? Will creating a functioning capability take too much time and money? In answering these concerns, it is important to recognize that near-term manned-unmanned teaming potential would build upon gains made from years' worth of technical investment and operational lessons learned in contemporary RPA operations. Systems such as the MQ-1 Predator, MQ-9 Reaper, and RQ-4 Global Hawk have turned key facets of this technology into everyday operational tools.

Looking at these RPA systems, a few important technological innovations stand out. First and foremost, these assets pioneered the notion of global, distributed operations. Aircraft halfway around the world from the continental United States can be operated in real time from interface stations thousands of miles distant. This has had a tremendous impact upon the concept of command and control, and ties directly to manned-unmanned teaming. Looking into the future, technologies under development today at DARPA and AFRL will form adaptive kill webs in which autonomous aircraft flying in collaboration with manned aircraft could receive inputs from a range of actors. In one instance, a pilot of a manned aircraft provides an input. If that individual is overloaded with tasks, or has lost linkage, is shot down, or is otherwise unavailable, control could then transfer to an air battle manager on an aircraft such as an E-3 Airborne Warning and Control System (AWACS), E-8 Joint Surveillance and Target Attack Radar System (JSTARS), or even a ground control station. If all forms of communication are lost and the unmanned asset cannot execute its assigned mission in a wholly autonomous fashion, it would revert to a failsafe set of instructions.

Regardless, highly distributed control pioneered by MQ-1 Predators and MQ-9 Reapers strongly suggests that manned-unmanned partnerships could be augmented with multiple layers of real-time human support. One particular method should not be considered the de facto means of control. If a data link exists, any authorized user should be able to partner with the autonomous vehicle in question to achieve a desired effect.

The notion of distributed control touches upon two different operating approaches—the "human in the loop" and the "human on the loop." The former, which the MQ-1 and MQ-9 use, involves an unmanned aircraft proactively flown with the mission crew carefully monitoring and commanding systems to control desired outcomes. The RPA effectively functions like a remotely controlled airplane at extreme distances. The latter approach, which directs RQ-4 Global Hawk mission systems, uses automated technology to execute mission functions with minimal human interaction. The aircraft functions more like a satellite, with operators making occasional inputs, as opposed to a traditional aircraft requiring hands-on guidance. This impressive capability was demonstrated early in the Global Hawk's development and operational deployment, when an RQ-4 flew autonomously from California to Australia, landing directly as promised on the centerline of a runway thousands of miles away without proactive human direction. This "man-on-the-loop" approach will increasingly serve as the control standard as autonomy increases in sophistication and reliability.

Clearly the Global Hawk's non-kinetic intelligence, surveillance, and reconnaissance (ISR) mission is a less-complex undertaking than adjusting and responding to the dynamic variables encountered in a kinetic strike or air-to-air combat mission, but when evaluating autonomy's role with manned-unmanned teaming, it is important to highlight that sorties comprise numerous phases and associated control demands. Current levels of autonomy may suffice to enable tasks such as basic flight, formation position holding, threat detection, and target identification. Present-day technology may even be reliable enough to allow an unmanned aircraft to employ munitions and other effects generators (such as directed energy, or electronic attack tools) in extended kill chain scenarios where unmanned sensing, electronic warfare, and strike platforms operate inside a threat ring under the control of a manned aircraft supervising the operation at a relatively safe range from threats. Here, it is important to recognize that distributed control will allow human participation when autonomy requires the aid of human decision making.

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Looking beyond the current operational examples of RPA, it is useful to recognize the accomplishments experts have made in extending autonomy's potential through research and development. A number of programs have developed technology to perform autonomous aerial refueling with both a boom and a hose and drogue. These experiments not only demonstrated that aerial refueling is possible with unmanned aircraft, but also show that autonomy can be used for complex functions such as formation flying and position holding.[16] These behaviors are essential when looking at operationally suitable manned-unmanned swarming missions designed to overwhelm integrated air defense system (IADS) threats with large numbers of affordable, attritable unmanned strike aircraft.

The US Army has also explored the art of the possible in manned-unmanned teaming by pairing its AH-64 Apache attack helicopters with MQ-1 Gray Eagle RPA, aircraft roughly equivalent to the Air Force's MQ-1 Predator-class of aircraft. Helicopter crew members can control the RPA's sensors and receive video feed. While these linked platforms do not yet have weapons launch authority, the Army is pursuing that goal, as well as eventual aircraft control.[17] This reinforces the potential of distributed control and multi-vehicle partnering of assets to achieve desired effects.

The DARPA-led Joint Unmanned Air Combat Systems (J-UCAS) project of the early 2000s saw unmanned aircraft execute a highly complex set of missions, including suppression of enemy air defenses (SEAD), electronic attack (EA), strike, and ISR. J-UCAS eventually demonstrated its ability to execute mission tasks as circumstances developed in real time.[18] As Boeing J-UCAS X-45 Vice President and Program Manager David Koopersmith explained after a 2005 test, the X-45A "proved it could autonomously react to a dynamic threat environment while engaging a priority target."[19] Technology pioneered during the J-UCAS experiments has continued to advance over the ensuing years. Even more broadly, highly capable autonomy software has proved effective for years. Advancing it to an operational level of capability may depend more on priorities and policies than technological factors.

While the Air Force ultimately canceled its portion of the J-UCAS test program, the Navy continued to advance its portion of the program through the Northrop Grumman-built X-47B. That aircraft pioneered a host of autonomous functions, including taking off from and landing on an aircraft carrier. The rapid assessment and associated flight control input the automated technology had to execute in this highly dynamic environment was impressive. The Navy will ultimately field this capability in an operational context through its Carrier Based Aerial Refueling System (CBARS)—an unmanned carrier-based tanker aircraft. The CBARS may also eventually expand to produce an aircraft with ISR and strike functions.

Nor is progress restricted to the Navy. In 2015 and 2017, AFRL and Lockheed Martin partnered on a series of tests named "Have Raider" in which an F-16 was equipped to function as an autonomous aircraft, albeit with a pilot in the aircraft to serve as a safety backup. The autonomous aircraft executed a series of mission tasks in cooperation with a conventionally operated F-16. The 2015 test demonstrated the autonomously controlled F-16's ability to fly in collaboration with its manned counterpart and execute a strike mission against a pre-planned target. The Have Raider team achieved further success two years later by successfully fielded technology that empowered the autonomously controlled F-16 to dynamically adjust its mission tasking priorities. In the test scenario, the aircraft detected a pop-up threat, determined a course of action that differed from the planned objective, struck the target, and rejoined in formation with the conventional F-16. The ability for an autonomously controlled aircraft to detect a change in circumstances, make a value judgment to pursue a new course of action, and successfully attain a desired outcome marked a major technological achievement. It is one thing for autonomous systems to follow a pre-planned script, but quite another to respond dynamically to an evolving situation. Nor do these assets simply act like RPA with extreme command and control reach. Demonstrated dynamic, automated re-tasking is a major achievement that suggests a new threshold of combat airpower is within reach.

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Building on the trends of operationally-relevant autonomy, DARPA, in association with AFRL successfully completed an 11-day flight test of BAE Systems' Distributed Battle Management (DBM) software in September 2017. DBM assumes a "systems-of-systems" future landscape for warfare, in which networks of manned and unmanned platforms, weapons, sensors, and electronic warfare systems interact over robust satellite and tactical communications links.

The company has a history with recent autonomy advances. BAE Systems was the original developer of the autonomy software used in the J-UCAS program, and has continued to mature the technology in the intervening years. In this particular effort, which is slated to continue through 2019, the team worked to field and test software that achieved two primary objectives: 1) create a system that establishes a common operating picture and make it available to a group of manned and unmanned users; and 2) create a distributed, adaptive mission planning capability that allows individual aircraft to collaboratively execute mission functions, even when communication links are degraded. Stated another way, the aircraft take off with a common mission plan. As they fly their mission and experience communication challenges, they can still attain their objectives because they are not tied to an inflexible linear script that demands sequential task execution or direct control. Instead, they know the ultimate mission objective and can execute tasks in an adaptive, non-linear fashion. This allows them to compensate and adjust given dynamic mission variables. Given that communication links may be degraded, a central element of the technology involves constant network assessment to maximize windows of connectivity to facilitate data transfer. Nor does the system try to send everything; instead, it prioritizes the data. This means that communication is not an all-or-nothing proposition: necessary collaboration can occur by transmitting what is essential at a given time and place based on evolving, dynamic mission parameters. In the particular test example, the software succeeded in building a common, shared operating picture and associated tasking orders that enabled manned-unmanned teams to complete complex air-to-air missions in a simulated threat environment. This included operations with degraded communication links. The next round of tests, slated for July 2018, will address air-to-ground missions.[20]

In assessing these latest experiments, it is important to understand that they involve two layers of autonomy: inner and outer loops of control.

In assessing these latest experiments, it is important to understand that they involve two layers of autonomy: inner and outer loops of control. The former focuses on basic flying. The system senses the external conditions, compares this data to a set of desired standards, and then "commands" actuators to meet understood goals. This is all about data analysis—seeking to maintain aircraft performance aims through constant assessment.[21] Operational examples such as the RQ-4 Global Hawk, as well as complicated tests such as air refueling and the carrier landing trials, clearly demonstrate advanced autonomous capability with sophisticated inner loops of control. In fact, the technology to autonomously transit the globe, fly in exceedingly precise formation for refueling, or land on a pitching aircraft carrier deck extends the reach of control far beyond what only the most highly trained humans can execute. The latter element of control, the outer loop, involves the decision-making process harnessed to net desired mission effects far more complex than basic controlled flight. This connects to nuanced mission execution. Programs such as J-UCAS and Have Raider have demonstrated significant ability in this area, with further gains netted since those tests.[22]

To better understand the inner and outer loops of control, it is important to understand the key role autonomy plays in decision making. Autonomy technologies constantly gather and process information to ensure system determinations are tied to desired ends. This is far more advanced than simply following a script, because the system must prudently self-navigate through a broad range of evolving options.[23] This might require the constant processing of newly gathered data through the weighted rule sets used in expert systems, or through context-based learning algorithms used in modern artificial intelligence systems. The paradigm must also recognize that in some situations partnering between human operators and autonomous systems will net enhanced mission effectiveness above and beyond what either the manned or unmanned member could have secured in a unilateral fashion. This is especially true when unanticipated circumstances arise where dynamic human decision-making capacity will help enhance an autonomous system's decision making. The end approach must always seek to maximize mission effect, not to achieve autonomy for autonomy's sake. Regardless of the approach, there will always be risks associated with the role autonomy plays in manned-unmanned team decision making. It is therefore prudent to consider crawl, walk, and run implementation approaches that center upon scaling the number and types of decisions that must be made on a given mission.[24]

Initially, operations with predictable circumstances will be best suited for manned-unmanned teaming systems because mission logic can be built around a greater number of understood variables. Increasing the number and complexity of choices adds risk, because the system may encounter events that developers did not foresee. In those circumstances, the system would have to either self-derive a favored path, seek human decision-making assistance, or revert to a failsafe mode. Whatever course of action the autonomic system pursues, the most important variable is predictability. As AFRL autonomy expert Kris Kearns explains:

> *It is crucial to evolve this technology so it behaves as a predictable teammate—trust is everything. Just as Airmen are trained to make certain value judgments, so too must autonomy. What responses do you want within a prescribed set of options and conditions? A successful system will operate within a defined concept of operations so that it works with you, not you with it.*[25]

From a human operator perspective, predictability and trust go hand-in-hand. This is why doctrine, concepts of operations, tactics, and training are so crucial. A flight lead needs to have confidence that their wingman will execute as expected in complex situations where information is flowing at a very rapid pace, and decisions must be made nonstop—where to position the aircraft, how to maximize positive mutual support, how to avoid threats, and how to achieve desired mission effects. Ensuring autonomous systems perform in a dependable fashion that earn their human counterpart's trust will demand intensive testing and evaluation. As former F-15C fighter pilot and autonomy expert Col Ray O'Mara, USAF (Ret.), PhD, explains:

> *When I think about manned-unmanned teaming, I need to believe that the autonomous aircraft will behave in a safe, predictable fashion. My overriding concerns center upon basic flight behavior—maintaining position in a formation, not colliding with me or other assets, letting me know when an unmanned partner has a problem, and dependably reverting to failsafe settings in times of trouble.* [26]

These priorities have a unifying goal: to ensure the unmanned aircraft does not harm the manned aircraft. When pursuing a new technology, it is crucial to ensure that the potential solution does not instead worsen the situation. For a pilot flying in close formation with autonomously controlled aircraft, this concern is existential, since an unmanned wingman could easily turn into a lethal hazard if it cannot execute basic, predictable flight functions. It is hard enough to survive against the enemy in combat; aircrews do not need to worry about fratricide due to a lack of competent autonomous airmanship. When seeking to execute mission objectives, it is crucial for humans to trust that an unmanned aircraft armed with lethal stores will not shoot them down, cede control to the adversary, or mistakenly engage other friendly forces.

Aircrews must also have confidence that once committed to a target, either in the air or on the ground, the autonomous system will follow a predictable set of tactics so that teamwork can occur. Coordination is only possible if both partners know what the other actor is doing. Interestingly enough, this sort of trusted collaboration between man and machine has existed for decades in the form of guided munitions. Air-to-air missiles and precision air-to-ground weapons are unmanned assets following a set of commands to achieve a specific objective. Pilots today implicitly trust that a missile or bomb coming off their aircraft will perform within a given set of parameters—not pose a threat—and achieve a desired effect. Effective manned-unmanned teaming in the combat arena will demand building this same level of trust.

Given the possibilities afforded by distributed command and control, initial levels of autonomy may require human permission to engage in certain scenarios. While technology for threat detection and identification is exceedingly advanced in present-day systems, in certain situations Airmen may still need to validate that an unmanned team member is not mistakenly engaging a friendly partner. While this may seem like a significant burden to place upon a pilot in the midst of a combat operation—having to check in with his or her unmanned partner—it is important to remember that many actors in a conflict may be granted authority to provide necessary guidance. It is also important to recognize that future technology may mean that pilots no longer fly their aircraft in the traditional fashion. As AFRL's Kearns explains, in the future, pilots "may be acting more like mission commanders for a distributed force, with their actual aircraft doing much of its flying in an automated fashion." If an autonomous unmanned aircraft can engage in a tactically competent fashion, so too might a future F-35 or B-21. Kearns further explains that stepping back and forth between flying the jet and focusing on broader mission command "may be a new skill that will prove very important in making the most of a manned-unmanned team."[27] The point is clear: trust must be preserved, as it stands as a crucial imperative for any successful manned-unmanned teaming effort.

The DARPA Unmanned Combat Rotorcraft (UCAR) program sought to address the pilot-trust issue by applying BAE Systems' J-UCAS autonomy software to the US Army aviation mission back in 2004. This program spearheaded the manned-unmanned teaming approach, in which the weapons officer in an AH-64 Apache simply became the commander of a "wolfpack" of unmanned armed rotorcraft. The Apache weapons officer made simple decisions about what to attack and confirmed identification before missile launch. Though this program was cancelled before first flight, pilot-in-the-loop simulation testing included Apache pilots from the field who demonstrated substantial mission effectiveness gains through manned-unmanned teaming over an all-manned team. Furthermore, through these virtual demonstrations, pilots began to trust the autonomous systems and began to coach pilots newly rotated into the DARPA program on how best to leverage the unmanned armed rotorcraft teams.[28]

In considering more advanced forms of aircraft autonomy, developers must tackle challenges presented by the unknown. It is impossible to anticipate every conceivable challenge, set of dynamics, engagement parameters, or other factor that an unmanned system may encounter in air-to-air or air-to-ground combat. The number of lines of code involved with trying to take a "boil the ocean" approach would be crippling, and even then, developers would likely fail to anticipate some scenarios.[29] Here commercial autonomy experts have a major advantage over their military counterparts. While creating a self-driving car may be a very complex undertaking, at least designers can begin with some known factors: traffic rules, performance parameters of other cars, the generally predictable pattern of roads, operating in two dimensions, and other variables.[30] But few of these standards exist in the world of aerial combat—especially when surprise and innovation are major attributes sought by any credible competitor. This means a successful military application involving autonomy must rely on mathematical analysis of multiple permutations to derive the best path forward when it comes to tasks such as optimizing sensor coverage, avoiding threats, pairing a weapon to a target, etc. It also involves letting humans on the outer loop of control inject critical thinking into the mission as it evolves.

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Unforeseen circumstances are inevitable and can take many forms in combat, and call for dynamic decision making. What happens when situations exceed the parameters covered by the preprogramed commands? What if sensors pick up an unidentified aircraft that is behaving like an offensive fighter? What if a ground target is maneuvering in such a fashion that known weapon engagement parameters cannot be met? How do planners take into account that adversaries may be flying aircraft also used by friendly forces? Such situations obviously create an imperative for anticipatory knowledge discovery that will help build a robust library of information and corresponding actions to guard against surprise.

Fortunately, developers should generally have access to accurate information about US and allied technologies and behaviors. This is a crucial factor to consider given that the directive to "do no harm" to friendly forces is the overriding precondition to operational employment of any combat system. If an autonomous system simply cannot understand its environment and humans in the area cannot take charge with necessary insight and decision-making ability, then the autonomous assets must fall back upon an established set of procedures: take no action, disengage, or avoid an unknown object. The circumstances that proved confusing would have to be robustly analyzed as soon as possible to ensure the autonomous aircraft can take appropriate actions in future encounters with similar conditions. However, to maximize positive mission results, the ultimate goal for autonomy should focus on empowering a machine to confront a new situation and choose an action based upon a broad range of inputs. Learning-based recognition, which enables a system to reach beyond its basic rule set and gather necessary situational awareness to form a new conclusion, is a tremendously ambitious goal, but achieving it is not impossible.[31] Until that sort of autonomy is possible, following established rules of engagement will likely remain the safest course of action.

In exploring the core functions of autonomy in the aerial realm, all efforts must focus on how machines can better help humans achieve their objectives. As AFRL's Kearns points out, autonomy is "not about removing people from the battlespace, it is about making them more capable."[32] O'Mara agrees, explaining that researchers, service leaders, policymakers, and others "must understand what people do well and where machines excel. Pairing the respective strengths and weaknesses in a collaborative fashion will make for a very potent partnership." From a technical perspective, it is important to highlight that a key facet of "understanding what humans do well" comes down to a robust understanding of combat tactics. O'Mara is very careful to highlight that, "This new technology cannot be invented in a vacuum by well-intended technical experts that have no pragmatic understanding regarding the combat missions in which their systems will engage."[33] In many ways, building autonomous unmanned mission partners is like training young Airmen. It is crucial to ensure they execute their mission functions in ways that correspond with established methods and are able to plug and play into the broader enterprise in a positive fashion. Flying in poor formation and entering the merge in a way that does not add up in the real operational world will not work. This places a premium on a robust developmental partnership between the technical autonomy experts developing the autonomous aircraft systems and the operators who will use them.

For humans to improve their proficiency and learn, they must constantly train on an individual basis, whereas machines can be upgraded across the board, making it possible to improve the performance of the entire unmanned fleet all at once.

On the other side of the equation, it is also important to recognize that bringing unmanned autonomous assets into the operational fold will demand that Airmen question established doctrine, strategy, rules of engagement, and tactics. Human performance factors are a major driver behind current aerial combat practices. Humans can only pull a certain number of Gs, fly for a certain number of hours, or process a certain amount of information at a given time. Machines will bring different attributes and limiting factors to the air combat equation. The only way to maximize new opportunities and minimize vulnerabilities will be to challenge assumptions and seek new ways of better attaining effects. Granted, the Air Force should not discard a century's worth of aerial combat lessons. But, changes must earn their way into the equation. This will demand significant testing and exercising.

To highlight the way in which manned-unmanned teams will collaborate to maximize their respective strengths and weaknesses, consider the following factors. First, people are highly effective in dealing with ambiguity—gathering multiple inputs and coming up with favorable courses of action. Human operators will hold the edge in this area for quite some time in the manned-unmanned collaborative equation. On the other hand, machine learning presents enormous potential for capability growth and operational efficiency. For humans to improve their proficiency and learn, they must constantly train on an individual basis, whereas machines can be upgraded across the board, making it possible to improve the performance of the entire unmanned fleet all at once. If one autonomous aircraft determines a better way to intercept an enemy aircraft, these parameters can be uploaded to all the other autonomous aircraft. Learning will be truly universal.

The unmanned aircraft force also does not risk its mission proficiency if it does not fly very often. Given the possibilities afforded by live, virtual, constructive training (LVC), the vast majority of peacetime unmanned flying may be simulated. The autonomous aircraft can be replicated on displays for humans executing their respective training functions. This not only saves expenditures on items such as fuel, consumable parts, and manpower, but also opens the aperture for entirely new deployment patterns. If the US were seeking to deter an adversary, it could deploy a wing of unmanned aircraft. The signal presented to nations in the region would be very clear and the manned aircraft could cycle in and out of the zone as circumstances warranted. A minimal crew of pilots and maintainers would simply operate the RPA at a level sufficient to ensure they did not become inoperable from lack of use, and perform basic maintenance. This would allow the US to project power at a fraction of the current cost and with far less burden on the manpower deployment system, logistics chains, and forward operating base infrastructure. The human Airmen would meanwhile train at home and could rapidly deploy if circumstances warranted their presence. The positive potential of such an arrangement is undeniable. It also would place tremendous cost upon any adversary, because the US could radically complicate the problem sets they would face in the event of a conflict.

As a near-term factor, pressing forward with manned-unmanned teaming would help remedy another problem afflicting the Air Force: the pilot shortfall. The service is struggling to recruit and train sufficient numbers of pilots, especially for its fighter aircraft. Throughout the 2000s, service leaders faced a severe challenge to staff burgeoning RPA pilot requirements in an era when resources and training capacity were relatively stable. While retiring aircraft without backfill freed some manpower, the numbers fell far short of the thousands required to fly RPA sorties—a mission set that saw demand grow over 1,300 percent in 11 years. Facing a dearth of incoming supply, Air Force leaders chose to take risks in other mission areas and shifted pilots from fighter aviation into RPA operations.[34] The net effect was a hollow pilot force, with current estimates suggesting the Air Force faces a 2,000-person shortfall. With commercial airlines now hiring at an aggressive rate, this problem will continue to grow. The impact on the flight line is now clear: individuals stretched thin to meet mission demands. As Air Force Secretary Heather Wilson said in a recent interview, the service is "burning out our people because we're too small for what the nation is asking."[35]

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Of special concern, as new pilots are directed into the system to compensate for the shortfall, the ratio of experienced to novice pilots falls badly out of balance. It takes years to train a new pilot into a competent, dependable combat capable Airman. The necessary skills are gained in squadrons, years after flight training, as younger Airmen are taught by experienced, seasoned pilots who pass down knowledge in a real-world, applied fashion. When there are too few experienced pilots, and a large supply of young airmen, the system experiences challenges. The former commander of the 50th Flying Training Squadron at Columbus AFB, MS observed the dynamics of experience ratios in flying squadrons in a conversation with the authors. "A poor ratio of experience to inexperience in a fighter squadron can negatively impact mission readiness, overall squadron capability, even flight safety. Too little experience can create demands that affect the retention of experienced pilots," he notes.[36]

Further, it is crucial to recognize the important functions pilots fulfill when they are out of the cockpit throughout their careers. Pilots spend a significant percentage of their careers in non-flying staff jobs, for a simple reason: if the Air Force expects to develop insightful strategies and operational plans, competently oversee procurement efforts, and develop new technologies, it needs experienced Airmen with operational backgrounds to inform the process. For far too long, the Air Force has not had sufficient numbers of pilots to staff these billets. This has a major impact on how the Air Force operates at a corporate level. Well-meaning, intelligent non-experts simply cannot bring the same level of insight and perspective possessed by veteran pilots to key problem sets. This void has impeded prudent decision making throughout the Air Force at a variety of levels.

Given that resources are stretched thin for the foreseeable future, this problem becomes even more acute. Every dollar must count, but qualified experts must inform the decision-making process if this is to happen. If the Air Force is making decisions regarding modernization of forward-leaning systems such as the F-22 and F-35, it needs experts at the table who can draw from personal experience, not hypotheses. The Air Force could remedy the pilot shortage problem with a significant increase in resources, but this option is likely not going to be available anytime soon. Here especially, manned-unmanned teaming could prove especially useful: it could deliver effects without imposing a direct burden on limited pilot resources.

Potential Missions for Manned-Unmanned Teams

In looking at near-term possibilities for manned-unmanned teaming, initial mission potential exists in areas such as ISR, air defense, air-to-ground strike missions using extended kill chains, and stand-off air-to-air engagements. The main driver of all these functions would be access to the large quantities of information required to develop autonomy algorithms. In an ISR mission scenario, autonomous technologies would likely have pre-mission access to large amounts of terrain and target data. Three-dimensional terrain data would likely come from the National Geospatial-Intelligence Agency's (NGA's) foundational terrain data sets. The Air Force would use large volumes of target data to train autonomous systems to recognize priority objects using relevant mission sensors. Autonomous assets in a base defense scenario would draw upon a high degree of situational awareness—the physical surroundings would obviously be known. US and allied forces in the region would also be well understood, as would most offensive assets an enemy might use to strike the area in question. For example, the Chinese could only use certain types of aircraft and missiles to strike a target such as Andersen AFB, Guam. Flight paths could be generally anticipated in an approximate fashion and egress routes would also be recognized. Unmanned aircraft and their manned counterparts would also receive real-time-tracking, providing a clear picture of the inbound threat. Most important from a communication perspective, data links would be less likely to be seriously challenged over friendly territory.

Examining the air-to-ground strike mission, both J-UCAS and Have Raider have demonstrated the ability of autonomous technologies to recognize certain sets of targets and engage them. Specific functions include detecting and identifying the item of interest, prioritizing it within other potential task options, then employing ordnance on a target.[37] In order to limit complexity, near-term unmanned missions might focus on fixed targets. This would free up more capable manned aircraft to strike more dynamic targets. Autonomous aircraft could also gather valuable sensor data and fuse it into the manned-unmanned formation's overarching situational awareness, or execute functions such as laser designating a target to guide a precision munition. The Air Force would also benefit by sending unmanned aircraft against extremely dangerous targets, such as surface-to-air-missile (SAM) batteries and anti-aircraft-artillery (AAA). Ideally, unmanned aircraft would be far more affordable than manned aircraft that provide exquisite capabilities, so that losing a number of autonomous aircraft might be far cheaper than losing a manned aircraft, and would avoid the risk of sacrificing the life of an Airman. Lastly, unmanned aircraft would be exceedingly helpful in adding complexity to an attack plan. Large numbers of aircraft engaged in a broad range of activities inject a high degree of complexity into the battlespace, forcing an enemy to try to ward off many concurrent threats. This variable is especially important variable to consider given the small fleet of current Air Force aircraft. Sending in only a handful of aircraft, no matter how sophisticated, allows an enemy to employ their defenses in a more linear fashion.

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While the air-to-air mission is often dismissed as overly ambitious to address in the first round of manned-unmanned teaming, the Air Force should consider different types of mission sets. Air-to-air combat is an art that takes the most competent pilots years to learn and requires constant training. However, not every mission involves a close-in dogfight. A combination of manned-unmanned aircraft flying in a dispersed formation would put numerous sensors into the air. Fusing this data provides a tremendous level of situational awareness, the combined fleet of manned and unmanned aircraft would be carrying a large number of missiles, and circumstances will undoubtedly arise where enemy aircraft fly within an unmanned aircraft's weapons engagement zone—especially if a human is able to provide assistance regarding how and when to engage. Unmanned aircraft could very well fly at the front end of a formation, with the manned aircraft in the rear. This would allow the Airmen to act as quarterbacks, using sensor fusion to develop tremendous situational awareness and numbers of aircraft to provide multiple engagement options. If a missile can fly to a merge with current technology, then why not an unmanned autonomous aircraft?

Regardless of how the Air Force might employ unmanned-manned teaming, the simple existence of these capabilities would require adversaries to radically rethink power projection concepts, defensive measures, and force sizing assumptions. For years, the US military has been reducing the size of its aerial arsenal. The addition of large numbers of affordable, unmanned aircraft has the potential to swing the pendulum the other direction. Factors such as readiness would also change, with autonomous aircraft maintaining their proficiency no matter how often they fly. Supporting an ally might involve deploying a squadron of unmanned aircraft and letting them sit visibly on a ramp as a deterrent—something far less expensive than conventional deployments. Additional unmanned aircraft could also be generated without taxing the Air Force's deployment system too much.

Nor would the DOD have to invest significant sums in the first generation of unmanned-manned aircraft teams. A few squadrons of first generation autonomous aircraft would likely prove more than sufficient to test concepts, mature technology, develop new tactics and concepts of operation, along with sending a strong signal to potential adversaries. Additionally, these first-generation autonomous combat aircraft would presumably be designed and built to adapt to a changing technology base, so that as technology grows more mature, the cost to upgrade a system would increase at a sub-linear rate. This is especially important given the current fiscal realities facing the military services and DOD. The positive potential of manned-unmanned teaming and autonomy's role in combat aviation is undeniable. Taking a staged approach to the problem would allow innovation within the bounds of present fiscal realities. It may be years before funding exists for a highly advanced MQ-X that would represent a 100 percent solution to the problem, but that does not mean that the Air Force cannot tackle elements of the challenge today with available resources and technologies.

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Airpower Rejuvenated: Turning Old Aircraft Into New Assets

This leads to the second aspect of the unmanned-manned partnering concept: the airframe. The Air Force currently has numerous aircraft in long -term storage at the 309th Aerospace Maintenance and Regeneration Group (AMARG) at Davis-Monthan Air Force Base in Tucson, Arizona. These airplanes are bought and paid for, possess sensor apertures, have hard points to carry munitions stores, are combat capable, and are available. While they may not be the type of aircraft the service would want to send into harm's way with an Airman inside, they could prove exceedingly useful when employed in an unmanned fashion, particularly when teamed to create extended kill chains that enhance lethality and increase the survivability of exquisite manned aircraft. Also, these aircraft would likely accrue few additional hours when compared to their manned counterparts because so much of the training would occur in live, virtual, and constructive environments. This is an unconventional concept, but given that the Air Force faces a major capacity crunch and a set of resource challenges, and has aircraft that could be aligned to yield a capable tool, advanced unmanned technology and combat-capable aircraft available could prove most useful.

A hybrid manned-unmanned approach based around legacy airframes must be viewed through the lens of a building block approach designed to manage multiple levels of risk. Because the airframe, support infrastructure, mission systems, and other elements are all mature capabilities, technologists can focus their efforts on specific enhancements while operators can evolve tactics and procedures. Using mature aircraft avoids the need to invent too much new technology all at once, allowing the re-use of existing capability to buy down risk and rapidly field early blocks of manned-unmanned teams. This will subsequently set the stage for more advanced, mission-specific designs that the Air Force may procure at a later date.

The F-117 Nighthawk stealth fighter typified this approach. The low-observable signature of the aircraft was the real technological focus point; nearly everything else on the aircraft was borrowed or adapted from an existing system. The flight control computers came from the F-16, the landing gear was sourced from the F-15E, and the engines were derived from the F/A-18. This allowed the Lockheed team and their Air Force counterparts to direct their energy in a focused fashion and yield a tremendously impressive accomplishment that redefined power projection. The F-117 achieved initial operating capability a mere five years after production began.[38] Compare this to the F-22 and F-35, which both took more than 20 years to achieve initial operating capability due to massive concurrent program innovations on multiple fronts.

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In a similar fashion, the Air Force could harness surplus aircraft and in so doing, avoid having to invest significant resources in designing, building, and fielding a new piece of hardware. An aircraft such as an F-16 already has a digital interface because it is a "fly-by-wire" aircraft—a computer flies it via human inputs. Plugging autonomy technology into a digital flight computer will provide an automatic link to the flight control, weapons systems, and other aircraft system elements. The airplane does not care whether a human is commanding its computer, or an autonomous system is at the helm. This is in many ways how the Air Force's QF-16 target drone program functions, with control systems commanding the aircraft digital systems.

The QF-16 program also highlights the significant cost advantages that may result from repurposing surplus combat aircraft. In 2017, Boeing, the prime contractor for the QF-16 charged with reactivating the legacy fighters from their desert storage and making necessary modifications, was awarded a $24.6 million contract to convert 18 F-16s into QF-16 target drones.[39] That works out to be roughly $1.38 million per jet. Granted, a QF-16 involves simpler capabilities than those required for a combat-optimized "MQ-16," because it represents peacetime man-in-the-loop levels of control versus combat-capable autonomous control. However, these jets should not be thought of as low-end. They have been modified with elements that would be required for autonomous operation, such as auto takeoff and landing functionality, and a good portion of their mission systems have been reactivated.[40] Most importantly, the fundamental cost of the QF-16 program stands in stark contrast to new manned combat aircraft production, with unit prices hovering around $100 million depending on specific mission systems, even for new build fourth-generation aircraft.[41] That profound difference leaves significant room for the development and inclusion of autonomous technology with fourth generation aircraft.

The F-16 also does not represent the only source for manned-unmanned aircraft technology. Nearly any modern aircraft in the Air Force surplus inventory could serve as the starting platform for manned-unmanned teaming. F-117 stealth fighters would certainly be potent unmanned partners, and manned-unmanned teams would benefit greatly from the range and payload afforded by a B-1 or even, in time, the B-2. In fact, experimenting with many different types would further complicate an enemy's defensive calculus—adversaries would not be able to focus their efforts against a specific range of capabilities. Uncertainty is a very difficult element against which to defend and drives costs very high.

Open mission systems would be a crucial element of future manned-unmanned aircraft teaming. Such systems would allow different sensor packages, weapons, and associated technologies to be swapped in a low cost, rapid "plug-and-play" fashion. They would turn the unmanned aircraft into an agnostic "truck" able to haul and interface with a wide range of technologies and promote experimentation. [42] This approach should also extend to open software systems to facilitate faster, easier software updates. In addition, thanks to integration technology developed in DARPA's System of Systems Integration Technology and Experimentation program, even legacy systems with proprietary message formats and interfaces can be integrated quickly and affordably.[43]

Another benefit to the re-use of existing platforms is that deploying these aircraft would not be very difficult. Bases are already equipped to handle them, they are air-refuelable, and spare parts are available, as is industry support. The Air Force already has personnel who know how to operate and maintain these aircraft. If unmanned overflight issues present challenges in deploying the aircraft around the world, then pilots could easily fly these jets to their destinations. With variants such as the F-16 still operating with a large number of allied nations, the possibility also exists for sharing the technology with certain partners.

The Air Force must also consider another important factor when assessing the potential of reactivating retired aircraft. The complexity of modern combat airplanes paired with anemic procurement budgets has yielded an industrial base with little surge production capacity. If the United States becomes engaged in a war that involves significant aircraft losses, the production system would be hard pressed to compensate for downed airframes, especially if aircraft lines such as the B-1 or F-22 are no longer active. Reactivating retired aircraft would create a significant war reserve arsenal that could prove vital if the Air Force found itself needing mass quantities past what industry could supply in new build aircraft. In many ways, the same holds true for pilot production—a situation with similar capacity flow-through issues. As previously discussed, this is a hugely important variable, because producing trained Airmen is even more complex and time intensive than producing the airplanes they fly. Manned-unmanned teaming can deliver iron on the ramp without the dollars and time associated in building a combat capable pilot.

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Conclusion: The Path Forward for Manned-Unmanned Success

While critics may argue against the manned-unmanned teaming concept, highlighting the technological risk involved and the unknown operating factors, all must acknowledge the capacity and capability shortfall facing the United States in an era where the world is growing increasingly dangerous. Remote piloted aircraft combat operations combined with a host of research projects in the field of aerial autonomy have yielded impressive capabilities. In many ways, some individuals often take for granted modern RPA operations, failing to realize that such undertakings were nearly impossible to imagine two decades ago. With the right amount of focused investment and attention, the next 20 years are bound to yield even more impressive results in this field.

Realizing a combat-capable manned-unmanned aircraft teaming effort will require further technological investment. While test results in the research and development domain look promising, they do not the meet the reliability requirements of the operational domain. Specific challenges include data links robust enough to ensure vital team communication can occur in areas where data links will be under attack. Managing information flows also requires the ability to process and quickly make sense of data that may arrive in a disrupted fashion due to interference. Capabilities such as timing, respective position keeping, and collaborative targeting through sensor teaming involve high levels of data exchange, and all team elements must understand mission intent when information flows in an irregular, disrupted fashion. External sensors and on-board processing must replicate the ability of humans to reorient themselves rapidly by looking outside the cockpit. Developers must also refine algorithms that can balance the demand for speed, reliability, and precision—rebooting is not an option when the system is over the target.

As discussed earlier, new types of autonomous aircraft will have to increasingly make sense of uncertainty. This will demand higher levels of artificial intelligence to sort various pieces of information, much of it new, in a way that can yield a credible course of action. Part of this information management also requires understanding of how to form a "self-healing" network—knowing how to re-order tasks to ensure top priorities are serviced if an asset is shot down or loses link.[44] Significant work has been executed in this area and results appear promising. However, the Air Force must prioritize continued investment to ensure autonomous aircraft attain the necessary levels of operational reliability. All these challenges boil down to achieving the common objectives of trust and predictability. The autonomous system must be able to execute dependable actions that focus on mission results in accordance with understood norms that allow for effective collaboration.

It is important to note challenges not listed, especially regarding developing the airframe and related systems. This suggested iterative approach would allow efforts to focus on highly specific but "solvable" problems, without bankrupting the rest of the Air Force enterprise in the process. To achieve this aim, it may be advisable for the Air Force to stand up a system program office to integrate technologies and demonstrate capability. Analysis could also focus on manned-unmanned aircraft operational mission constructs.

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In evaluating future challenges, technology will probably not represent the top impediment. Instead, it will likely be humans and various bureaucracies. As multiple people interviewed for this paper noted, any new concept, especially one as game changing as manned-unmanned teams, is likely to challenge long-held assertions and assumptions. This will invariably lead to pushback. Courses of action that lie well outside the way we operate today are going to be shunned as too risky when in truth they offer reduced risk as well as greater levels of capability or capacity, one expert noted. But, this is an expected bureaucratic mode of response. When evaluated from a perspective of winning in war, the potential benefits of blending manned and unmanned airplanes is extremely attractive, if not required.[45]

The Air Force will also confront difficulties in reading budget priorities in the future. From that standpoint, the answer is twofold. Programs such as the B-21 and F-35 are non-negotiable, with the Air Force needing more of these systems to get onto flightlines as fast as possible. However, given budget and production realities, supplementary force structure is an important consideration, especially when autonomous technology could yield significant capabilities for future power projection. It is unlikely any other solution would afford so much combat capacity for such a low price tag.

This paper focuses on turning legacy aircraft such as the F-16 into unmanned partners for modern weapons platforms such as the B-21 and F-35—but the Air Force cannot realize this potential until the initial investigation and application of legacy unmanned partners begins in earnest. In the world of complex military technology development, the iterative approach is always far more successful than a radical "Hail Mary" pass. The Air Force is also unlikely to have budget space in the foreseeable future to launch a new program that creates a manned-unmanned teaming capability from scratch. Air Force procurement budgets will be stretched thin for years as the air service buys 10 satellite programs, the KC-46, the GBSD missile, the UH-1 replacement, a new combat rescue helicopter, the T-X training system, and the Penetrating Counter Air (PCA) aircraft. These are all "must buy" systems, necessitated after decades of procurement delays, with each of the capabilities these programs are replacing currently relying on small, rapidly aging inventories. Either the Air Force procures new systems, or it must radically curtail missions as existing platforms become unusable for want of replacement.

Viewed in this light and given the stakes, failing to invest in an initial generation of manned-unmanned aircraft is truly a risk the United States cannot afford to take. Manned-unmanned teams promise too high a potential to ignore, and if the US does not take the lead in this field, others will.✪

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About the Authors

Douglas Birkey is the executive director of the Mitchell Institute for Aerospace Studies.

Lt Gen David Deptula, USAF (Ret.) is the dean of the Mitchell Institute for Aerospace Studies. A decorated military leaders with decades of experience in both combat and leadership roles in major joint combat operations, he has planned, flown, and commanded air operations ranging from humanitarian relief efforts to major theater war. Deptula serves as the principal air attack planner for Operation Desert Storm in 1991; was a joint task force commander in Iraq from 1998 to 1999; led the initial air campaign of Operation Enduring Freedom in late 2001, and also led several other significant operations. Deptula retired after 34 years on active duty in 2010, serving in his last assignment as the Air Force's first deputy chief of staff for intelligence, surveillance, and reconnaissance. He is a prolific author and speaker on aerospace power, and a thought leader on defense, strategy, and ISR.

Maj Gen Lawrence Stutzriem, USAF (Ret.) is the Mitchell Institute's director of research, and an expert in combat aircraft operations, aerospace power, and national security affairs. Stutzriem served more than three decades in the US Air Force as a fighter pilot, flying the F-4, F-16, and A-10. His assignments included directing air activity for Operation Southern Watch, and was a member of the planning and operations team that led the initial air operations over Afghanistan as part of Operation Enduring Freedom in 2001.