Thinking About the U.S. Military's Next-Generation UAS Force:

Final Report

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Executive Summary

For over twenty years, the U.S. military has enjoyed a near monopoly over the ability to integrate wide-area sensors, real-time battle networks, and precision-guided munitions (PGMs) into a reconnaissance-strike complex (RSC). As early theorists of precision-strike warfare foresaw, the combination of these three military technologies to form an RSC has helped enable new operational concepts for warfare that have rendered the previous operational paradigm—massed industrial warfare—increasingly obsolescent. Since 2001, the U.S. Department of Defense (DoD) has extended its lead in this nascent precision-strike regime through the development and acquisition of unmanned aircraft systems (UAS)[1] that can act as both sensors to detect potential targets for precision strikes as well as platforms for precision-guided munitions. The rapid expansion of DoD's UAS capabilities has been focused on procuring relatively affordable aircraft (often based on existing demonstration programs) with ISR sensors to support counterinsurgency and counterterrorism operations in permissive environments.

Having observed the success of U.S. unmanned aviation operations over the last twelve years, other states and some non-state actors are beginning to develop their own UAS forces. Today, the United States has a dominant edge in the design, development, and fielding of unmanned aviation technology, with its nearest "competitor" being Israel, a close U.S. ally. There is a great deal of evidence, however, that states other than Israel are beginning to invest heavily in UAS, and U.S. dominance in unmanned capabilities may soon begin to erode. Given the high costs associated with developing and maintaining advanced manned aircraft, military competitors such as China and Iran are pursuing multiple UAS designs that could support surveillance, precision strike, and other missions that could impose costs on their enemies.

The rapid growth in global UAS research, development, and procurement over the last decade, in combination with the ongoing proliferation of precision strike and other advanced military systems, are indicators that a UAS-enabled mature precision-strike regime (MPSR) could be emerging. Equipped with a new generation of UAS and attendant technologies such as precision positioning, navigation, and timing (PNT) and satellite-based command and control (C2), America's enemies could develop new operational concepts to strike targets that are located hundreds and perhaps thousands of miles from their borders with precision. The exact nature of this emerging MPSR is difficult to ascertain given the large number of variables involved. This assessment therefore focuses instead on the emerging UAS competition to address the following questions:

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[1] DoD defines "unmanned aircraft" as "an aircraft or balloon that does not carry a human operator and is capable of flight under remote control or autonomous programming." DoD defines an unmanned aircraft system (UAS) as "that system whose components include the necessary equipment, network and personnel to control an unmanned aircraft." See Joint Publication 1-02, "Department of Defense Dictionary of Military and Associated Terms," November 8, 2010, as amended through May 15, 2011, p. 388. For the purposes of clarity, UAS will be used in this report to represent an unmanned aircraft and its system components.

- What are the key capability characteristics of the UAS forces that DoD and other militaries have developed or are planning to build? How do their militaries think about UAS and their future roles?

- How might UAS enable competitors to conduct extended-range ISR, strike, airborne electronic attack, and other missions in support of their power-projection operations?

- Could the emergence of a UAS competition threaten to erode the U.S. military's dominance of the air domain? What are the alternative paths the U.S. military could take to develop a next-generation force that would sustain its UAS advantage and enable new operational concepts to fully exploit the air domain and impose costs on future enemies?

- What are the major drivers of UAS development—technological, cultural, institutional, and doctrinal—and how will they encourage or inhibit the emergence of UAS as an important part of an MPSR?

- To what extent could robotic air systems displace manned aircraft, much as naval aviation eventually displaced battleships? Or will they comprise part of a "high-low" mix of manned and unmanned air systems in the U.S. military's future air forces?

Answers to these questions sketch out an emerging competition in which U.S. forces are now using unmanned capabilities to enable or enhance existing methods of operation, while other militaries may be more willing to create new UAS concepts of operations for a wider range of missions. In particular, China appears to be willing and able to invest its considerable resources in programs that could lead to a sophisticated UAS fleet that could support regional power-projection operations. Given China's propensity for conventional military brinksmanship over disputed territories along its perimeter (e.g., the Senkaku Islands) UAS promise to provide a low-risk/high-reward means support its regional ambitions. The People's Liberation Army (PLA) for example, views UAS as important capabilities to support future long-range air and missile strikes. Moreover, China might be able to take the lead in developing autonomous unmanned aircraft because it faces fewer internal constraints about the use of armed UAS and automated targeting compared to the U.S. military.

Iran also appears willing to develop and procure UAS that could help it to overcome its shortfalls in manned military aircraft. Like China, Iran sees unmanned systems as key capabilities that could support long-range missile attacks. Iran is also exploring the potential to use UAS as airborne versions of the Iranian Revolutionary Guard Corps Navy's swarming small boat units to conduct massed, cost-imposing strikes. The relatively low cost of some unmanned systems, coupled with their lack of a human pilot, may make them well suited for executing cost-imposing attacks designed to overwhelm air defenses or even serve as "launch and leave" expendable weapons that can loiter over a battlespace awaiting targets of opportunity.

As for Israel, long a global leader in UAS technologies, its manpower deficiencies and proximity to regional enemies may encourage it to explore more innovative uses of UAS compared to the U.S. military. Rather than subsume unmanned aircraft primarily to providing ISR information as is presently the case with the United States, Israel may be willing to develop unmanned *combat* air systems (UCAS) that are capable of automated/autonomous long-range strike missions. Given the long ranges associated with some potential strike operations, UCAS capable of flying "suicide" missions might be one of the best options for delivering PGMs, including conventional penetrating munitions.

The emerging military regime may therefore see the use of UAS for a much broader range of missions that DoD—with its focus on using UAS in permissive environments to provide supporting ISR—may not have fully explored. For the most part, it appears that DoD is still focused on procuring UAS that can perform functions similar to what they have performed over the last twelve years in support of irregular warfare and counter-terror operations. The potential emergence of an MPSR and the UAS development paths of competitors such as China and Iran suggest that the U.S. military should be exploring a different mix of capabilities and new concepts of operation (CONOPS) that could permit its next-generation UAS force to perform a wider range of supporting and combat missions.

Embarking on this new development path will require DoD to integrate new technologies in its UAS designs. For instance, current long-range UAS are almost entirely dependent on space-based systems for PNT and C2. Given the vulnerability of space-based PNT and C2 systems to jamming or kinetic attacks, DoD will need to develop alternatives such as advanced on-board inertial navigation systems to provide PNT and greater automation and autonomy to reduce the demand for man-in-the-loop command and control. New, more efficient power plants could further extend the mission endurance of UAS, while the incorporation of directed-energy weapons such as high-power lasers and high power microwaves could give them a magazine depth limited only by ability to generate and store electrical power while inflight. These technological barriers, while not insignificant, are increasingly more a matter of engineering and integration than invention.

Eventually, it is possible that advances in artificial intelligence (AI) could support the development and fielding of UAS that could fundamentally alter or subvert the missile-dominated precision-strike regime. Fully autonomous aircraft with advanced AI and powerful directed-energy weapons could maneuver and respond to enemy threats and target opportunities so quickly that even large salvos of anti-aircraft missiles may not be sufficient to saturate their defenses. In the future, a new generation of increasingly autonomous, multi-mission UAS could replace manned aviation for some missions and enable U.S. military competitors to develop precision-strike complexes. As autonomous as they may become over the next decade, however, it is unlikely that UAS will “render obsolete or subordinate existing means for conducting war.”[2] Instead, it is likely that unmanned aircraft will augment and enable the existing precision-strike regime to mature, rather than subvert it and lead to wars that are “fought by airplanes with no men in them at all.”[3]

Cost and institutional resistance to expending resources on new programs in an era of austerity are likely to be significant obstacles to developing at new generation of DoD UAS. The Defense Department has already cut its UAS research, development, and procurement funding by nearly 50 percent over the last three years. As UAS become more capable, and potentially more costly than existing systems, they could threaten to crowd out investments in established manned aircraft programs that have the support of large constituencies. Even while DoD’s budgets were growing in the last decade, the Office of the Secretary of Defense had to direct the U.S. military to procure more MQ-1 Predators and MQ-9 Reapers for operations in Iraq and Afghanistan. As DoD’s budgets continue to decrease a result of the budget sequester, it is possible that institutional resistance may surpass technological hurdles as the most significant barrier to developing a UAS force that could impose costs on future enemies, empower new concepts of operation that span the spectrum of conflict, and sustain America’s unmanned aircraft advantage well into the future.

2 Michael G. Vickers and Robert Martinage, *The Revolution in War* (Washington, DC: Center for Strategic and Budgetary Assessments, 2004), p. 2.

3 Lawrence Spinetta, “The Rise of Unmanned Aircraft,” *Historynet.com*, November 10, 2010, available at http://www.historynet.com/the-rise-of-unmanned-aircraft.htm.

Introduction

This report is part of a broader effort on behalf of the Office of Net Assessment, Office of the Secretary of Defense (OSD/NA) to assess the characteristics of an MPSR and the military-technological competitions that could comprise it. The assessment builds on previous ONA-sponsored work by the Center for Strategic and Budgetary Assessments (CSBA) and incorporates insights developed during two workshops led by CSBA to explore the technological art-of-the-possible in unmanned aircraft systems (UAS) and the possible emergence of a robotic aviation competition with a particular focus on China, Russia, Iran, and Israel. Specifically, this report addresses a number of key questions regarding UAS:

- What are the key capability characteristics of the UAS forces the United States and other nations are building or planning to build? How do militaries think about UAS, and how do they envision their future roles?

- How might UAS enable competitors to conduct extended-range ISR, strike, airborne electronic attack, and other missions in support of their power-projection operations?

- Could the emergence of a UAS competition threaten to erode the U.S. military's dominance of the air domain? What are the alternative paths the U.S. military could take to develop a next-generation force that would sustain its UAS advantage and enable new operational concepts to fully exploit the air domain and impose costs on future enemies?

- What are the major drivers of UAS development—technological, cultural, institutional, and doctrinal—and how will they encourage or inhibit the emergence of UAS as an important part of an MPSR?

- To what extent could robotic air systems displace manned aircraft, much as naval aviation eventually displaced battleships? Or will they comprise part of a "high-low" mix of manned and unmanned air systems in the U.S. military's future air forces?

Organization

To answer these questions, Chapter 1 provides background information on the nascent precision-strike regime and emergence of an MPSR. Chapter 2 is a short history of the U.S. military's unmanned aircraft development, while Chapter 3 characterizes the growth and capabilities of its current UAS force. Chapter 4 addresses unmanned aircraft global trends and the emerging UAS capabilities of the People's Republic of China (PRC), Israel, Iran, and Russia. Chapter 5 builds on preceding chapters to identify insights that could help inform DoD's development of its future unmanned aircraft force. Chapter 6 addresses technological, resource, and institutional barriers that may affect the fielding of a new generation of unmanned aircraft. The conclusion proposes follow-on analyses to further explore the emergence of a robotic revolution within an MPSR.

Chapter 1. Background

Assessing the potential for a robotic air revolution within an MPSR requires a familiarity with the nascent precision-guided weapons regime, issues concerning the potential emergence of an MPSR, and the recent history of unmanned aviation. Since the U.S. military's widespread adoption of precision-guided munitions (PGMs) predated its more recent large-scale employment of unmanned aviation, this report briefly examines the rise of precision-guided warfare in Chapter 1 before turning to DoD's development of unmanned aircraft in Chapter 2.[4] Readers familiar with the basic theory of an MPSR may wish to skip this chapter and proceed to the next.

Overview of Precision Strike Theories and Operations

Soviet military thinkers such as Marshal Nikolai Ogarkov, Chief of the Soviet General Staff, began theorizing about the emergence of a military-technical revolution (MTR) beginning in the mid-1970s. This work postulated that the rapid advance of key technologies—and particularly information technology—would enable fundamental changes in the conduct of warfare. The combination of wide-area sensors, precision-guided submunitions carried aboard missiles, and automated command and control (C2) networks would be the embodiment of this MTR. The Soviets called this combination a "reconnaissance-strike complex" (RSC or "RUK" in the original Cyrillic). The accuracy, range, and wide-area coverage of RSCs would have a destructive power akin to tactical nuclear weapons without their attendant political-strategic baggage.[5] Soviet strategists believed that RSCs would enable a military to destroy a vast number of targets swiftly and accurately from long ranges, thus fundamentally altering the military balance of forces, which theretofore had been defined largely by the ability to mass formations of main battle tanks, mechanized infantry, heavy artillery, and nuclear weapons. In theory, the MTR would also render numerically superior forces subordinate to forces that were better able to acquire, analyze, and act quickly and accurately on targeting information.

Although the emergence of a trio of military technologies (wide-area sensors, PGMs, and automated C2 networks) underpinned the development of RSCs, fully exploiting their potential required the development of new operational concepts and new organizations. As Andrew Krepinevich noted in an assessment of the military-technical revolution, "layering new systems on old doctrine merely allows you to become more effective at the margins within the old

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4 For more thorough explorations of the precision-guided weapons regime and its maturation, see: Andrew F. Krepinevich, Jr., *The Military-Technical Revolution: A Preliminary Assessment* (Washington, DC: Center for Strategic and Budgetary Assessments, 2002); Vickers and Martinage, *The Revolution in War*; Barry D. Watts, *Six Decades of Guided Munitions and Battle Networks: Progress and Prospects* (Washington, DC: Center for Strategic and Budgetary Assessments, 2007); and Barry D. Watts, *The Maturing Revolution in Military Affairs* (Washington, DC: Center for Strategic and Budgetary Assessments, 2011). For a more complete history of UAS prior to 2001, see: Thomas P. Ehrhard, *Air Force UAVs: The Secret History* (Washington, DC: Mitchell Institute Press, 2010); and Jeremiah Gertler, *U.S. Unmanned Aerial Systems* (Washington, DC: Congressional Research Service, 2012), pp. 1-7.

5 Watts, The Maturing Revolution in Military Affairs, pp. 1-2.

operational paradigm of conflict.”[6] Krepinevich pointed out that both France and Germany had developed airplanes, tanks, and major weapon systems equipped with radios during the period between the World Wars. What differentiated the *Wehrmacht* and made it so effective during the Battle of France in 1940 was its adoption of the blitzkrieg operational concept and organizational precepts that derived from it, such as combining armor with mechanized infantry and the close collaboration between armored “spearhead” forces and ground-attack aircraft.

Much like tanks, airplanes, and radios in the Second World War, wide-area sensors, PGMs, and automated C2 were the technological *sine qua non* of the late-Cold War MTR. A broad and lasting change in warfare, however, would await the development of new operational concepts and the creation of organizations that would allow militaries to take full advantage of these new technologies. According to Barry Watts, [redacted] believed that operational concepts and new organizations would actually be *more important* to the realization of an RMA than the technologies themselves.[redacted] [redacted] emphasis on the human elements of an RMA led to his observation that the use of long-range precision strikes, wide-area sensors, and automated C2 networks during the First Gulf War was not evidence of a military revolution, but rather a harbinger of greater change to come.[8] Although fully 65 percent of munitions expended by Coalition forces during the Second Gulf War in 2003 were PGMs,[9] [redacted][10] Extending his interwar-period example, [redacted] the U.S. military had only progressed to around 1930 (i.e., before the advent of blitzkrieg and Panzer divisions), despite its adoption of the technological aspects of an RMA. [redacted] America’s wars against third-rate militaries and non-state actors had not necessitated the development of the new operational concepts or organizational structures that were essential to an RMA:

> [redacted]

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6 Krepinevich, The Military-Technical Revolution: A Preliminary Assessment, p. 19.

[redacted]

9 “In 1991 some 92 percent of the more than 230,000 munitions expended in the Operation Desert Storm air campaign were unguided; in 2003, total expenditures in the Operation Iraqi Freedom air campaign were less than 28,000 munitions, of which some 65 percent were guided and included both LGBs as well as all-weather Joint Direct Attack Munitions (JDAMs).” Barry D. Watts, *Six Decades of Guided Munitions and Battle Networks: Progress and Prospects* (Washington, DC: Center for Strategic and Budgetary Assessments, 2007), p. 20; and Watts, *The Maturing Revolution in Military Affairs, p. 6.*

[redacted]

Thus, the introduction of PGMs, wide-area sensors, and automated C2 networks is a necessary but insufficient condition for the emergence of a mature precision-strike RMA, since a true RMA also requires new operational concepts designed specifically to exploit innovative technologies as well as appropriate organizations to implement and advance the operational concepts. Moreover, for this precision-strike RMA to achieve maturity, the U.S. military would need to face a capable opponent wielding its own RSC at the operational level of war. One participant at a 2009 CSBA workshop observed, "without some catalytic event, there would appear to be no strategic imperative for rapid investment in radical change, thus forestalling actual achievement of a true RMA force for decades."[12] In other words, while a peacetime military competition may instigate the maturation of the precision-strike RMA, a major conflict might be needed to push the U.S. military toward fully embracing revolutionary change.

As the first adopter of precision-strike operations on a large scale, the United States created significant advantages in technologies that have come to define the first two decades of the precision-strike regime: airborne and space-based wide-area sensors; standoff and direct-attack PGMs; over-the-horizon C2 networks; position, navigation, and timing (PNT); and stealth aircraft. It is evident that the U.S. military still enjoys a number of these advantages—in particular, its stealth aircraft give it a significant operational advantage compared to non-stealthy air forces fielded by competitors. The last decade, however, has seen the emergence of new areas of competition within the precision-strike regime, such as cyberwarfare and high-power directed-energy (DE) weapons.[13] Today, the U.S. military may lack significant competitive advantages in both cyberwarfare and DE weapons. In the case of the former, the barriers to entry for competitors are extremely low compared to the cost and time needed to operationalize advanced kinetic weapon systems. In the case of the latter, other competitors are actively pursuing non-kinetic capabilities that have the potential to impose costs on the U.S. military.[14]

In summary, it is possible that an emerging UAS competition could follow this pattern. The United States has created the world's largest, and arguably most capable, UAS force, as summarized in the next chapter. Having observed the operational utility of U.S. and Israeli UAS, China, Iran, and other competitors are beginning to capitalize on the potential of robotic technologies to exploit the air domain for military purposes, potentially at less cost than developing and operating fleets of sophisticated manned aircraft. Building on this background,

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12 James FitzSimonds, "Thoughts from the December 11, 2009 RMA Meeting," p. 2.

13 For more information on cyber and directed energy capabilities, see Andrew Krepinevich, *Cyber Warfare: A "Nuclear Option"?* (Washington, DC: Center for Strategic and Budgetary Assessments, 2012); and Mark Gunzinger and Chris Dougherty, *Changing the Game: The Promise of Directed-Energy Weapons* (Washington, DC: Center for Strategic and Budgetary Assessments, 2012).

14 For example, according to DoD China "is developing a multidimensional program to limit or deny the use of space-based assets by adversaries during times of crisis or conflict. In addition to the direct-ascent anti-satellite weapon tested in 2007, these counterspace capabilities also include jamming, laser, microwave, and cyber weapons." Office of the Secretary of Defense, *Annual Report to Congress Military and Security Developments Involving the People's Republic of China 2012* (Washington, DC: Department of Defense, May 2012), p. 9.

this report then addresses how the U.S. military may be at risk of losing its UAS capability advantage over potential enemies, especially if it chooses to forego investments needed to develop a new generation of more capable, multi-mission unmanned aircraft. On the other hand, a UAS competition could help instigate the development of new unmanned aircraft, operational concepts, and organizations that could provide precision-strike capabilities to a larger number of military actors. By helping to diffuse precision-strike capabilities, the emerging UAS competition could also enable the emergence of an MPSR and could eventually alter or subvert the missile-dominated precision-strike regime.

Chapter 2. A Brief History of U.S. Military UAS

Lightning Bugs and Buffalo Hunters

Military UAS prior to the First Gulf War tended to be limited, niche capabilities that were designed to address very specific operational problems. For example, U.S. operations in Vietnam in the 1960s created demand for UAS that could provide tactical reconnaissance and persistent surveillance in contested environments. This led to the development of unmanned aircraft such as the Teledyne Ryan 147B Lightning Bug that were used to act as decoys for B-52 strike packages and conduct “suicide” SIGINT collection missions against North Vietnamese SA-2 surface-to-air missile (SAM) systems.[15] The use of manned aircraft to conduct low-altitude tactical reconnaissance and battle damage assessment (BDA) missions in Vietnam resulted in numerous losses of aircraft and pilots, many of whom became prisoners of war. As a result, RF-4 Phantoms and RF-101 Voodoo reconnaissance aircraft began flying at higher altitudes to avoid ground fire, an operational limitation that reduced their effectiveness during Vietnam’s May through October monsoon season when cloud cover obscured their target areas.[16] In response, the Air Force ordered the conversion of Lightning Bug SIGINT drones to low altitude photoreconnaissance platforms. Despite technological and operational hiccups, the resultant “Buffalo Hunter” UAS proved successful, with one particular highlight being the BDA missions they flew during the 1972 Linebacker II bombing campaign over North Vietnam. Altogether, Lightning Bug and Buffalo Hunter variants were the largest and most successful U.S. unmanned aircraft systems to that point, with a total of approximately 3,500 missions flown[17] at a total program cost of $5.8 billion in Fiscal Year (FY) 2010 dollars.[18]

Although merely a footnote in the Vietnam War, the Lightning Bug program is an excellent case study as it embodies most of the technological, operational, and organizational issues that can influence UAS development. Like many early-generation unmanned aircraft, Lightning Bugs were somewhat more akin to a Rube Goldberg device than a typical U.S. military weapons system. To compensate for the lack of a pilot, the inadequacy of period automated flight controls, and the limitations of line-of-sight radio C2 capabilities, the Lightning Bug was air-launched from a modified C-130 cargo aircraft and recovered in a variety of non-traditional manners including parachute landings, parachute landings damped with air bags (since regular parachute

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[15] Ehrhard, Air Force UAVs: The Secret History, p. 25.

[16] Greg Goebel, “Unmanned Aerial Vehicles: USA,” February 1, 2012, Chapter 3.5-3.7, available at http://www.vectorsite net/twuav html; and Ehrhard, *Air Force UAVs: The Secret History*, pp. 25-26.

[17] Goebel, “Unmanned Aerial Vehicles: USA,” Chapters 3.5-3.7.

[18] Despite its success and these seemingly impressive numbers, Buffalo Hunter drones flew only 3 percent of the Air Force’s combat reconnaissance sorties during the Vietnam War. The Air Force canceled a later attempt to modify the Lightning Bug for duty on the Central Front in Europe when they determined that the operational challenges and costs associated with operating the Lightning Bug in the teeth of the Warsaw Pact’s IADS was not worth the marginal operational gains. See Ehrhard, *Air Force UAVs: The Secret History*, pp. 28-29, 34-36.

landings tended to damage the aircraft), and finally mid-air recovery using a helicopter.[19] These non-traditional launch and recovery methods added significantly to the cost and complexity of Lighting Bug operations.

Command and Control

Once airborne, Lightning Bugs relied on a variety of PNT technologies including Doppler radar and later the Long Range Navigation (LORAN) system to maintain flight paths that would allow them to surveil target areas before returning to their pre-designated recovery locations. As the Lightning Bug program evolved to produce the Buffalo Hunter, navigational accuracy became even more important, since low-level reconnaissance flights presented more obstacles and limited the aircraft's area of regard. Unfortunately, rudimentary PNT capabilities simply were not up to the task:

> The Lightning Bug's navigation system remained a weakness throughout the Vietnam conflict. In support of U.S. combat operations prior to the 1973 cease-fire, Lightning Bug drone operations hit less than 50 percent of the planned reconnaissance targets, mainly due to navigation errors…Location accuracy, a pivotal requirement for effective reconnaissance operations, would continue to plague UAVs until the early 1990s with the advent of the satellite-based GPS.[20]

The lack of reliable, real-time, beyond-line-of sight data networks during the Vietnam War also meant that information collected by Lightning Bugs/Buffalo Hunters could not be processed, exploited, and disseminated until they returned to their bases. Since the aircraft had on-station loiter times of anywhere from five to eight hours (depending on the variant) and recovery could take several additional hours, their exposed films could be over six hours old before they were processed.[21] This significantly reduced their potential to provide tactically useful information on fast-moving enemy forces and other time-sensitive targets.

Other unmanned aircraft of the Vietnam War era had capability shortfalls similar to the Lightning Bug. The Navy's Gyrodyne QH-50 Drone Anti-Submarine Helicopter (DASH) was originally designed to give U.S. destroyers an off-board means to detect and attack Soviet submarines before they could launch their torpedoes or missiles.[22] The Navy's concept of operations (CONOPS) for the DASH involved visually launching the aircraft from a ship's deck before handing their control over to the ship's combat information center. The ship's Mk-25 fire-

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19 Some variants of the Lightning Bug, including the Navy's 147SK, used rocket-assisted take-off (RATO) and then were under airborne radio control until they reached an initial flight checkpoint. See Goebel, "Unmanned Aerial Vehicles: USA," Chapters 3.5-3.7.

20 Ehrhard, Air Force UAVs: The Secret History, p. 24.

21 According to Goebel, the on-station time of the early 147 models was five hours, and stretched to eight for the 147TE and TF Combat Dawn variants, which were outfitted with under-wing fuel tanks, See Goebel, "Unmanned Aerial Vehicles: USA," Chapters 3.5-3.7.

22 Rebecca Maksel, "D.A.S.H. Goes to War," *Air & Space Magazine*, March 2012; and Gyrodyne Helicopter Historical Foundation, "DASH History," available at http://www.gyrodynehelicopters.com/dash_history htm.

control radar and the SPS-10 tracking radar would provide the DASH's position to a controller, who would then guide the aircraft to target coordinates using a line-of-sight FM radio signal.[23] Once a DASH was over a target area, controllers would command the release of either Mk 44 homing torpedoes or Mk 17 nuclear depth charges.[24]

The inability to know precisely where DASH aircraft were located or their airborne orientation, combined with unreliable command and control systems that used commercial hardware and lacked redundancy owing to the need to keep costs low, crippled their operational effectiveness. According to the Gyrodyne Historical Foundation:

> The lack of a "feed-back-loop" from the drone to the controller prevented the operating drone controller from knowing the drone's orientation. This was exacerbated by the low radar profile of the QH-50 to the ships [sic] tracking radar and the lack of transponders resulted in the loss of many drones due to not knowing where the drones were in relation to the ship.[25]

As a result, 25 percent of the first 100 operational DASH aircraft crashed and were lost.[26] In an assessment of the program, the Government Accountability Office (GAO) determined that 80 percent of all DASH aircraft were eventually lost due to electronic system failures.[27]

Illustrating the Cost-Capability-Expendability Conundrum

Although drones like Lightning Bug and DASH were originally desired for their expendability and were designed accordingly, their high attrition rates undermined their operational utility. This, in turn, undermined the U.S. military's confidence in unmanned systems. As UAS evolved, they gradually became larger and acquired more sophisticated navigation equipment, flight controls, and sensors, increasing their unit cost and making them less expendable. This "cost-capability-expendability" conundrum has remained a factor that continues to affect UAS development and employment. Military planners value unmanned aircraft for their ability to perform dull, dirty, and dangerous missions without risk to a pilot, as well as their lower attrition cost compared to manned aircraft. But the need to improve the effectiveness and reliability of UAS has led to the development of sub-systems such radars and other sensors that are often more costly than the aircraft itself. In this manner, although the airframes of large UAS may remain inexpensive relative to manned aircraft, the total unmanned *system* could become too valuable to be expendable, negating one of the original reasons UAS were developed by the U.S. military.

Backed by the vast resources of the National Reconnaissance Office (NRO) and driven by the exigencies of Vietnam, the Lightning Bug program managed to elude this cost-capability-

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[23] Gyrodyne Helicopter Historical Foundation, "DASH History."

[24] Later DASH variants equipped with cameras were used as target spotters for naval gunfire. Gyrodyne Helicopter Historical Foundation, "DASH History;" Goebel, "Unmanned Aerial Vehicles: USA," Chapters 3.5-3.7; and Maksel, "D.A.S.H. Goes to War."

[25] Gyrodyne Helicopter Historical Foundation, "DASH History."

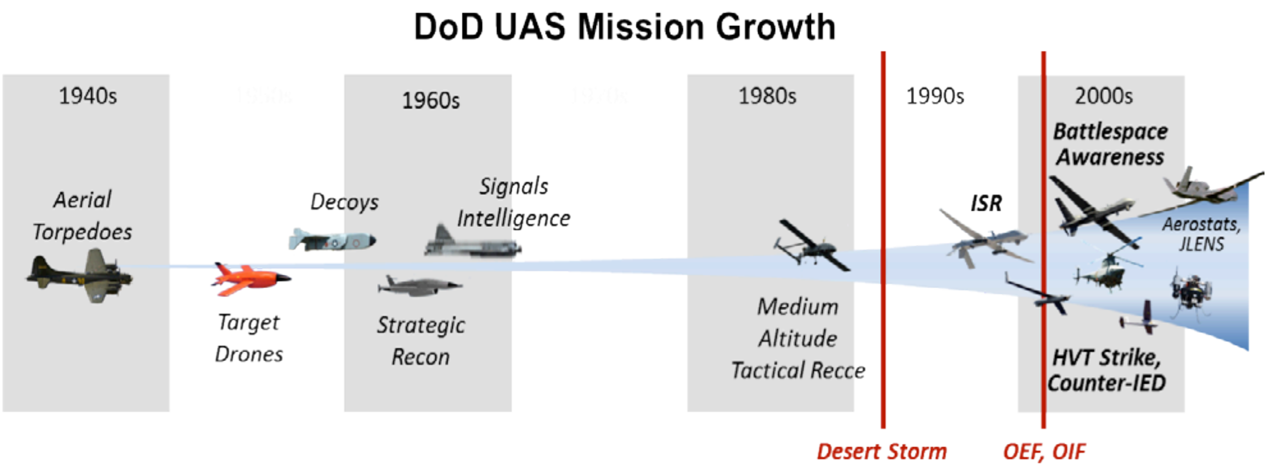
[26] Goebel, "Unmanned Aerial Vehicles: USA," Chapters 3.5-3.7.

[27] Gyrodyne Helicopter Historical Foundation, "DASH History."

expendability conundrum.[28] Other Air Force UAS, such as the D-21 (Senior Bowl), Compass Arrow, Compass Cope, Combat Dawn and Compass Dwell systems were not as fortunate—all were canceled due to rising costs and capability shortfalls. Compass Dwell and Compass Cope were perhaps the most significant of these aircraft, as they were intended to fly surveillance missions for 28-plus hours, a period of time that exceeds the typical duty day of a flight crew.[29] Thus, these programs represented the first U.S. military unmanned aircraft that were created to exploit a unique characteristic of UAS other than expendability, i.e., mission endurance limited only by the aircraft's systems reliability and fuel capacity, instead of crew duty restrictions and physiological limitations of pilots.[30] Ultimately, however, none of these early UAS proved to be a more cost-effective capability than existing manned aircraft or satellite systems.

UAS in the Nascent Precision-Strike Regime

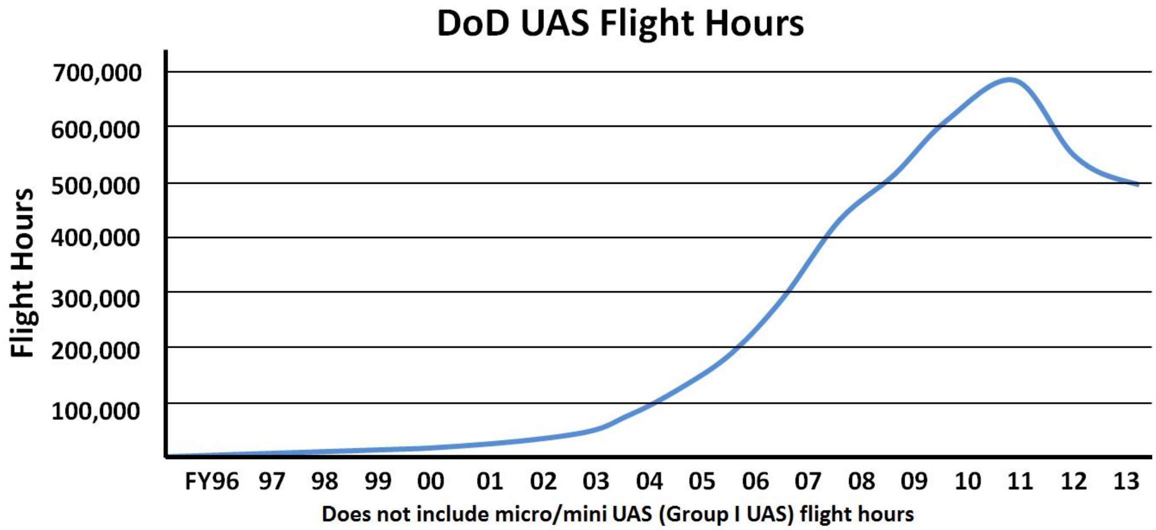
As the following illustrations show, there has been tremendous growth in the U.S. military's UAS force over the last decade.



28 A later variant, the Ryan 147TE/F (AQM-34R) "Combat Dawn" aircraft, was canceled when the Air Force determined that using satellites and manned aircraft for SIGINT missions could be more cost effective. Goebel, "Unmanned Aerial Vehicles: USA," Chapters 3.5-3.7; and Ehrhard, *Air Force UAVs: The Secret History*, pp. 12, 32.

29 Initial Compass Dwell requirements called for a flight endurance of 28 hours, while Compass Cope was to have 30 hours of endurance. Goebel, "Unmanned Aerial Vehicles: USA," Chapters 3.5-3.7.

30 For more background information on these limitations, see Christopher J. Bowie, *The Anti-Access Threat and Theater Air Bases* (Washington, DC: Center for Strategic and Budgetary Assessments, 2002), pp. 11-14.



Today, it is generally accepted that the terrorist attacks of September 11, 2001 and subsequent U.S. military operations in Iraq, Afghanistan, and other areas sparked the growth of Pentagon's current UAS force. In retrospect, however, the First Gulf War in 1991 may have been another critical event that helped instigate the eventual expansion of America's unmanned aircraft capabilities.

UAS in the First Gulf War

The operational challenges of the First Gulf War helped to underscore the U.S. military's need for the kind of persistent surveillance and strike capabilities that unmanned aircraft could provide. Precision strikes in Iraq required accurate targeting data and BDA. Once Coalition air forces established air superiority and began to pummel enemy targets, many Iraqi forces, particularly their mobile SCUD missile units, used a combination of camouflage, deception, and movement to avoid attacks. Persistent airborne surveillance-strike provided by UAS might have helped counter these tactics and help suppress Iraqi missile strikes into Israel and Saudi Arabia. Unfortunately, the cancellation of the aforementioned unmanned aircraft programs left the Air Force without a significant UAS force to support air campaign operations in Iraq and Kuwait. The Navy, however, was able to employ its RQ-2 Pioneers—U.S. built versions of Israel's "Mastiff" unmanned aircraft—as spotters for naval gunfire from *Iowa*-class battleships. It was during one such mission that a Pioneer famously received the surrender of a group of Iraqi soldiers. Despite the historical significance of being the first surrender to an unmanned system, Pioneers in the early 1990s were still technologically immature, as they lacked GPS guidance and beyond-line-of sight command and control.[31] Fortunately, technology was about to catch up with operational demand and, for the first time in the history of aviation, approach a level of maturity sufficient to field a new generation of UAS that could support precision strike operations.

[31] Later versions of the RQ-2 Pioneer were upgraded with GPS navigation. See "Pioneer Short Range (SR) UAV," *Global Security*, available at http://www.globalsecurity.org/intell/systems/pioneer.htm.

The Advent of GPS

UAS development benefited greatly from the same late-twentieth century technological innovations that enabled precision-strike operations during the First Gulf War. Of these technologies, GPS was perhaps the most important to UAS development. The performance of every unmanned aircraft prior to the advent of GPS suffered from their inability to consistently follow predetermined flight paths and payload constraints created by the need to carry large and complex on-board navigation systems. A fully operational GPS constellation permitted the development of UAS with highly accurate PNT systems that used small, lightweight GPS receivers. In combination with increasingly capable on-board computers,[32] GPS-equipped UAS could navigate with a high degree of precision using navigation waypoints, and GPS information could provide remote pilots with accurate information on the location and orientation of remotely piloted vehicles (RPVs).

Satellite Communications

Like the creation of GPS, the development of satellite communications constellations enabled a paradigm shift for unmanned aircraft operations. Major advances in satellite-based communications networks gave rise to beyond-line-of-sight C2 and data links, which in turn supported the development of long-range RPVs and the near-real-time sharing of their ISR information. Early unmanned aircraft such as the aforementioned DASH were limited to line-of-sight operations due to their radio controls, although their operational ranges could be extended somewhat by putting radio controls and a remote pilot aboard an accompanying aircraft.[33] The advent of satellite data links permitted remote operators to control RPVs during all mission phases. Combined with PNT from GPS, beyond-line-of-sight data links permitted RPVs equipped with on-board electro-optical/infrared (EO/IR) sensors or synthetic-aperture radars (SARs) to provide geo-located ISR to all U.S. military echelons in near-real time.

Toward Today's UAS Force

Taking advantage of GPS and satellite communications, the U.S. military developed a new generation of UAS that showed great promise during contingency operations in the decade following the First Gulf War. RQ-1 Predators, developed as an Advanced Capability Technology Demonstration (ACTD) program in the mid-1990s, were pressed into service to provide tactical ISR for operations in the Balkans and were used by the Central Intelligence Agency (CIA) to surveil al Qaeda operating locations prior to September 2001. While Predators were demonstrating their value as tactical ISR platforms, the Air Force, under the direction of the Defense Airborne Reconnaissance Office (DARO), was developing the RQ-3 Darkstar and the

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[32] The same advances in solid-state electronics and computing power also enabled more reliable and accurate on-board flight control systems.

[33] Later Navy versions of the Lightning Bug could be controlled from HC-130 launch aircraft or E-2 Hawkeyes.

RQ-4 Global Hawk for theater-level ISR missions.[34] The Darkstar was a low-observable aircraft that was intended to survive in denied environments. By comparison, the Global Hawk was designed to be a long-endurance, non-stealthy platform that would operate from standoff distances to provide broad-area ISR and act as communication relays.

Non-Standard Development

Despite their obvious differences, the Predator, Darkstar, and Global Hawk programs serve to illustrate how the Pentagon has approached UAS development over the last twenty years. All three systems grew out of ACTD programs that were overseen by DARO. In other words, none of these UAS were developed or procured through the U.S. military's traditional requirements definition and procurement processes. Despite their "demonstrator" status, both the Predator and the Global Hawk were pressed into active service to meet urgent operational requirements.[35] As a result of their ACTD backgrounds and the pressure to make them operational as soon as possible, both lacked capabilities that are typical of modern military aircraft. For instance, early "block zero" Global Hawks did not have an inflight wing de-icing system, while early Predators were not equipped with laser target-designators. The Predator and the Global Hawk force also lacked a complete suite of supporting structures—such as mature CONOPs and reserves of spare parts and tools—that would normally complement fully operational systems.

Although DoD's experiences with UAS during operations in the 1990s were generally positive, UAS were still a very small, niche capability at the turn of the century. In 2001, the Air Force's entire operational fleet of Predators numbered only ten aircraft.[36] Furthermore, costly failures like the Compass Cope, Compass Dwell, and the Army's Aquila UAS program had tamped down the Services' enthusiasm for unmanned platforms. With the Services fighting to preserve manned aircraft modernization programs such as the F-22 and F-35 during the procurement holiday of the 1990s, advocacy for new UAS development fell to other parties, including DARPA, the intelligence community, and Congress. In 2000, Senator John Warner of Virginia mandated that one third of DoD's penetrating aircraft must be unmanned by the year 2010, declaring "every now and then somebody like me has to take out their shotgun and fire it into the heavens to get somebody's attention."[37] Although Warner's edict was never met, the September 11, 2001 terrorist attacks on New York City and Washington, DC proved to be the proverbial shotgun blasts that helped drive a massive expansion of the Pentagon's UAS force.

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[34] The Predator, Darkstar, and Global Hawk were all part of the Air Force's "tiered" UAS development strategy. The Predator's antecedent, the Gnat-750, was a Tier I system, the Predator is a Tier II system, the Global Hawk is a Tier II+ system, and the Darkstar was a Tier III- system.

[35] The Darkstar program was canceled after it experienced crashes during testing.

[36] By 2001, the Air Force had purchased a total of 49 Predator airframes. United States Air Force, *Committee Staff Procurement Backup Book: FY 2002 Amended Budget Submission* (Washington, DC: United States Air Force, 2001), p. 4-85; and P.W. Singer, *Wired for War: The Robotics Revolution and Conflict in the 21st Century* (New York, NY: Penguin Press, 2009), p. 35.

[37] Quoted in Singer, Wired for War: The Robotics Revolution and Conflict in the 21st Century, p. 60.

Chapter 3. Characterizing Today's UAS Force

CIA-operated Predators had tracked Osama bin Laden prior to September 2001 and played a key role designating targets for airstrikes during the U.S. military's initial operations in Afghanistan in 2001 and 2002.[38] Perhaps just as important, these UAS operations helped remove policy obstacles that had previously prevented the use of unmanned aircraft that were armed with guided weapons.[39] However, for all of their early successes in Afghanistan and later in Iraq, the Pentagon's UAS force did not fully hit its stride until the emergence of large-scale insurgencies in both countries.[40] Rising coalition casualty rates after 2004 created a demand for persistent airborne ISR assets that could help detect and counter improvised explosive device (IED) attacks, provide close air support (CAS) to ground forces, and conduct limited strikes on high-value targets. In particular, the Air Force's Predator and Reaper UAS were in high demand due to their ability to loiter for long periods of time and support highly dispersed ground forces operating in a large battlespace. In addition to Predators and Reapers, smaller UAS such as the RQ-7 Shadow and the RQ-11 Raven provided ground forces with on-demand situational awareness.

The Great Ramp-Up

Driven by Joint Urgent Operational Needs Statements (JUONs) and supported by Overseas Contingency Operations (OCO) supplemental funding from Congress, the Pentagon's UAS force experienced dramatic growth in terms of capacity, budget, and operational flight hours in the years following 2001. According to DoD, its annual spending on UAS grew from just $284 million in FY2000 to $3.96 billion for FY2013, while its total fleet increased from 167 UAS to approximately 11,320 unmanned platforms over the same timeframe.[41] Reflecting the post-2004 surge in demand for UAS, unmanned combat air patrols (CAPs) increased by 1,200 percent from 2005 to 2011, while Predator and Reaper combat flight hours grew from 62,000 hours in 2006 to 185,000 hours in 2009.[42]

A Word on UAS Taxonomies

The following table presents the official taxonomy used by DoD to categorize its UAS force. Based on aircraft weights, speeds, and "flight level" altitudes, the taxonomy combines unmanned

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[38] George Tenet, Director of Central Intelligence, "Statement Before the National Commission on Terrorist Attacks Upon the United States," March 24, 2004, pp. 14-16, available at http://www.9-11commission.gov/hearings/hearing8/tenet_statement.pdf.

[39] Although a Predator had test-fired a Hellfire missile in February of 2001, the approval for their operational use did not occur until approximately a month after the attacks on the World Trade Center and the Pentagon. See Tenet, "Statement Before the National Commission on Terrorist Attacks Upon the United States," p. 16.

[40] It is also likely that there was a lag between requests for more UAS and the ability of drone manufacturers such as General Atomics—which largely assembled the Predator by hand—to increase production.

[41] Ed Wolski, *Unmanned Aircraft Systems,* Office of the Undersecretary of Defense for Acquisition, Technology, and Logistics (OUSD/AT&L) briefing, January 9, 2009, slide 6; and Dyke Weatherington, *Unmanned Systems Integrated Roadmap FY2013-2038*, OUSD/AT&L briefing, April 2013, slides 5, 9.

[42] "Unmanned Aerial Warfare: Flight of the Drones," *The Economist,* October 8, 2011; and David Zucchino, "War Zone Drone Crashes Add Up," *Los Angeles Times,* July 6, 2010.

aircraft that have different capabilities in the same groups, e.g., the armed hunter-killer MQ-9 Reaper and unarmed RQ-4 ISR platform are both "Group 5" aircraft.

	Examples	Missions
Group 5 *> 1,320 lbs* *> FL180*	**RQ-4 Global Hawk**	ISR, C2
	MQ-4 Triton (BAMS)	Maritime domain awareness (MDA)
	MQ-9 Reaper	ISR; reconnaissance, strike, target acquisition (RSTA); precision strike (PS); force protection (FP)
Group 4 *> 1,320 lbs* *< FL180*	**MQ-1 Predator, Gray Eagle**	ISR, RSTA, electronic warfare (EW), PS, FP
	MQ-5 Hunter	ISR, RSTA, BDA
	MQ-8 Fire Scout	ISR; RSTA; anti-sub, anti-surface warfare, counter-mine
	UCAS-D	Demonstrator
	A160 Hummingbird	Demonstrator
Group 3 *< 1,320 lbs* *< FL180* *< 250 knots*	**RQ-7 Shadow**	ISR, RSTA, BDA
	RQ-21 Integrator	ISR, FP, explosive ordnance disposal (EOD)
Group 2 *21-55 lbs* *< 3,500 AGL* *< 250 knots*	**RQ-21A ScanEagle**	ISR, RSTA, FP
Group 1 *0-20 lbs* *< 1,200 AGL* *< 100 knots*	**RQ-11 Raven**	ISR, RSTA
	Wasp	ISR, RSTA
	SUAS AECV Puma	ISR, RSTA
	gMAV / T-Hawk	ISR, RSTA, EOD

There does not appear to be a standard taxonomy that is used to categorize non-U.S. unmanned aircraft. For the purposes of clarity, this report will use descriptions that are based on UAS missions or functions, rather than weight, altitude, and speed (see following table).

Unmanned Combat Air Vehicle (UCAV)	*Stealthy, carries advanced sensors for target acquisition and air-to-ground weapons, controlled by line-of-sight and beyond-line-of-sight data links, can conduct multiple missions such as surveillance, strike, and suppression of enemy air defenses*
Armed	*Mainly tasked to conduct ISR missions but can carry small weapons payloads for strikes, operate at low and medium altitudes, typically low speed and long endurance, unlikely to operate in contested environments*
Lethal	*Designed for expendable / one way attacks, are destroyed upon detonation similar to cruise missiles, and generally carry smaller payloads than cruise missiles*
Strategic Surveillance	*20-plus hours mission endurance, long range, 30,000' to 45,000' operating altitudes, can carry multiple payloads simultaneously*
Tactical Surveillance	*Primary mission for UAS worldwide, limited to line-of-sight ranges (approximately 300 kilometers), operate at low to medium altitudes, carry limited payloads*
Rotary-wing	*Capable of a number of missions, including surveillance, logistics support and resupply, targeting support*
Micro/Mini	*Lightweight and man-portable, operate over short ranges and have limited mission endurance (about an hour), operate at low altitudes, and carry small payloads*

These alternative descriptions[43] are not without their own limitations, since "armed" and "rotary-wing" could encompass unmanned platforms that are capable of similar missions. Still, it may be a more useful taxonomy for describing new UAS that can perform missions other than ISR, and is thus used in the following table that summarizes DoD's FY2013 UAS inventory.[44]

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43 The UCAV description is extracted from *Agencies Could Improve Information Sharing and End-Use Monitoring on Unmanned Aerial Vehicle Exports* (Washington, DC: Government Accountability Office, 2012), p. 18, available at http://www.gao.gov/assets/600/593131.pdf; Michael Franklin, "Unmanned Combat Air Vehicles: Opportunities for the Guided Weapons Industry?," Royal United Services Institute for Defence and Security Studies, September, 2008, pp. 3-4, available at http://www.rusi.org/downloads/assets/Unmanned_Combat_Air_Vehicles.pdf; and Unmanned Combat Air Vehicle, *Director of Operational Test & Evaluation FY2002 Annual Report* (Washington, DC: Department of Defense, 2002), p. 305, available at http://www.dote.osd mil/pub/reports/FY2002/. Descriptions for Armed, Lethal, Tactical Surveillance, and Micro/Mini UAS were extracted from *Agencies Could Improve Information Sharing and End-Use Monitoring on Unmanned Aerial Vehicle Exports*, pp. 3-4, 11, 18. The Strategic Surveillance UAS description was extracted from *Agencies Could Improve Information Sharing and End-Use Monitoring on Unmanned Aerial Vehicle Exports*, p. 4; and Stew Magnuson, Wide Area Surveillance Sensors Prove Value On Battlefields, *National Defense Magazine*, November 2012, available at http://www.nationaldefensemagazine.org/archive/2012/November/Pages/WideAreaSurveillanceSensorsProveValueonBattlefields.aspx.

44 Inventory data extracted from Weatherington, *Unmanned Systems Integrated Roadmap FY2013-2038*. MQ-1B and MQ-9A inventories are updated with data provided by the Air Force on June 20, 2013.

Designation/Name		Type	FY2013 Inventory
Air Force			
MQ-1B	Predator	Armed	141
MQ-9A	Reaper	Armed	135
RQ-4B	Global Hawk	Strategic Surveillance	34
Army			
MQ-5B	Hunter	Armed	43
MQ-1C	Gray Eagle	Armed	91
Navy/Marine Corps			
MQ-4C	BAMS	Strategic Surveillance	2
MQ-8B	Firescout	Rotary Wing	21
RQ-21A	STUAS	Tactical Surveillance	8
	Scan Eagle	Tactical Surveillance	225
X-47B	UCAS-D	UCAV Demonstrator	2
	UCLASS	Future	0
Multi-Service			
RQ-7B	Shadow	Armed	499
RQ-11	Raven	Micro/Mini	7680
RQ-16	T-Hawk	Micro/Mini	306
	WASP	Micro/Mini	1002
RQ-20	Puma	Micro/Mini	1137

Growing Pains

The rapid growth of DoD's unmanned aircraft operations since 2001 was not without its problems. The Predator, Reaper, and Global Hawk force all experienced significant mishap rates during their early deployments. According to *Bloomberg Government Barometer*, these aircraft had a lifetime combined accident rate of 9.31 incidents per 100,000 flight hours, compared to DoD's fleet-wide average of 3.3 incidents per 100,000 flight hours.[45] Although the precise incident rate is disputed, current UAS continue to suffer mishaps at a rate exceeding more mature manned military aircraft.[46]

45 Brendan McGarry, "Drones Most Accident-Prone U.S. Air Force Craft: BGOV Barometer," *Bloomberg Businessweek*, June 18, 2012. Winslow Wheeler and other observers claim that the actual rate is closer to 16 accidents per 100,000 flight hours. See Winslow Wheeler, "Keeping Track of the Drones," *Time Battleland*, March 1, 2012, available at http://nation.time.com/2012/03/01/4-keeping-track-of-the-drones/.

46 The U.S. military's early manned aircraft designs also experienced high mishap rates. UAS incident rates have declined as hardware and software problems are rectified, their CONOPs mature, and pilot training improves. Moreover, their attrition rates may be partly due to the U.S. military's willingness to use them in hazardous environments or missions that are too high a risk for manned aircraft.

Recent mishap rates are attributable to a number of factors, some of which may be “growing pains” and some that may simply be inherent to UAS operations. Commercial-off-the-shelf (COTS) unmanned systems or demonstrator aircraft that were quickly adapted for operational use, including the MQ-1B Predator, typically lack the maturity of manned military aircraft that are developed by traditional (and more lengthy) procurement processes. For example, early variants of the Global Hawk lacked de-icing equipment, and other current-generation UAS lack automated sense-and-avoid capabilities that would permit them to sidestep hazardous weather without the intervention of a human controller. Instead of undergoing rigorous flight-testing during development, UAS that were rapidly deployed to meet urgent operational needs had shortcomings that were only revealed during combat operations. Since DoD is now beginning to develop UAS using more rigorous requirements and acquisition and testing processes, these shortfalls may be short-lived.[47]

The dependence of some current-generation UAS on long-distance C2 may also contribute to their mishap rates. The time it takes for a command from a remote ground station to reach an aircraft via satellite introduces a degree of latency between the remote pilot’s action and the aircraft’s response. Moreover, pilots sitting in UAS ground-control stations lack the cues that pilots in a cockpit use to “feel” the orientation and performance of an aircraft. Using narrow-field-of-view EO/IR sensors (what pilots describe as “looking through a soda straw”) to command in-flight actions may exacerbate this problem. According to a 2007 Air Force study, as many as 80 percent of Predator crashes involved human error.[48]

UAS that are reliant on current-generation C2 networks are also susceptible to jamming or other attempts to disrupt their operations. Such attacks are more than hypothetical, as insurgents in Iraq and Afghanistan used off-the-shelf technology in attempts to disrupt UAS data links.[49] The relatively weak signals emitted by GPS satellites are also susceptible to attacks, and even in uncontested electromagnetic (EM) environments, information from satellite-based systems may be disrupted by hardware or software glitches and certain types of weather.

Bandwidth Limitations

Satellite bandwidth capacity was not a significant limitation for unmanned aircraft operations when UAS were a niche capability controlled with line-of-sight communications. As the Pentagon responded to the increase in demand for information provided by the “unblinking eye” of unmanned aircraft sensors, satellite bandwidth became a significant operational bottleneck. To illustrate how UAS bandwidth requirements have increased over time, a single Global Hawk can require 500 megabits per second (Mbps), which is roughly equivalent to the bandwidth needs of

[47] For example, the Navy’s MQ-4Cs will be equipped with anti-icing capabilities.

[48] David Zucchino, “War Zone Drone Crashes Add Up,” *Los Angeles Times*, July 6, 2010.

[49] Siobhan Gorman, Yochi J. Dreazen, and August Cole, “Insurgents Hack U.S. Drones,” *Wall Street Journal*, December 17, 2009.

the entire U.S. military during the First Gulf War.[50] Innovations intended to improve the utility of UAS, such as the use of high-definition, full-motion video (FMV) sensors, wide-area sensors, and remote-split UAS operations, have exacerbated the bandwidth problem.[51]

Perhaps the most significant driver of bandwidth demand has been the rapid improvement over the last decade in the quality and quantity of sensors carried by unmanned aircraft. This improvement is almost entirely the result of the unique demands stemming from the conduct of counterinsurgency (COIN) and counterterrorism (CT) operations in remote areas and urban environments. UAS equipped with FMV sensors to support COIN and CT operations were initially limited by the low resolution and narrow area of regard of their sensors. These limitations hampered the ability of analysts to isolate and positively identify small, discrete high-value targets (HVTs) such as individual terrorists.

The integration of high-definition FMV sensors on unmanned aircraft improved the U.S. military's ability to identify hostile activities and helped enable UAS strikes on individual HVTs.[52] U.S. forces conducting COIN and CT operations also needed capabilities that could help them locate and track groups of enemy personnel across a broad area. For example, when groups of enemy fighters suddenly dispersed, Predators with narrow field of view FMV sensors could only follow one or two individuals at a time. This "squirter" problem and other issues with tracking groups in urban terrain prompted DoD to integrate wide-area airborne surveillance (WAAS) systems on UAS. New sensors, such as Gorgon Stare, the Autonomous Real-Time Ground Ubiquitous Surveillance Imaging System (ARGUS-IS), and the Autonomous Real-Time Ground Ubiquitous Surveillance–Infrared (ARGUS-IR) use multi-lens camera arrays controlled by sophisticated software to provide a wide field of view from a single sensor pod (see figure below). Although the images they produce are at a lower frame-rate and resolution than high-definition FMV, these sensors can track small targets such as dismounted personnel over areas as large as forty square kilometers.[53]

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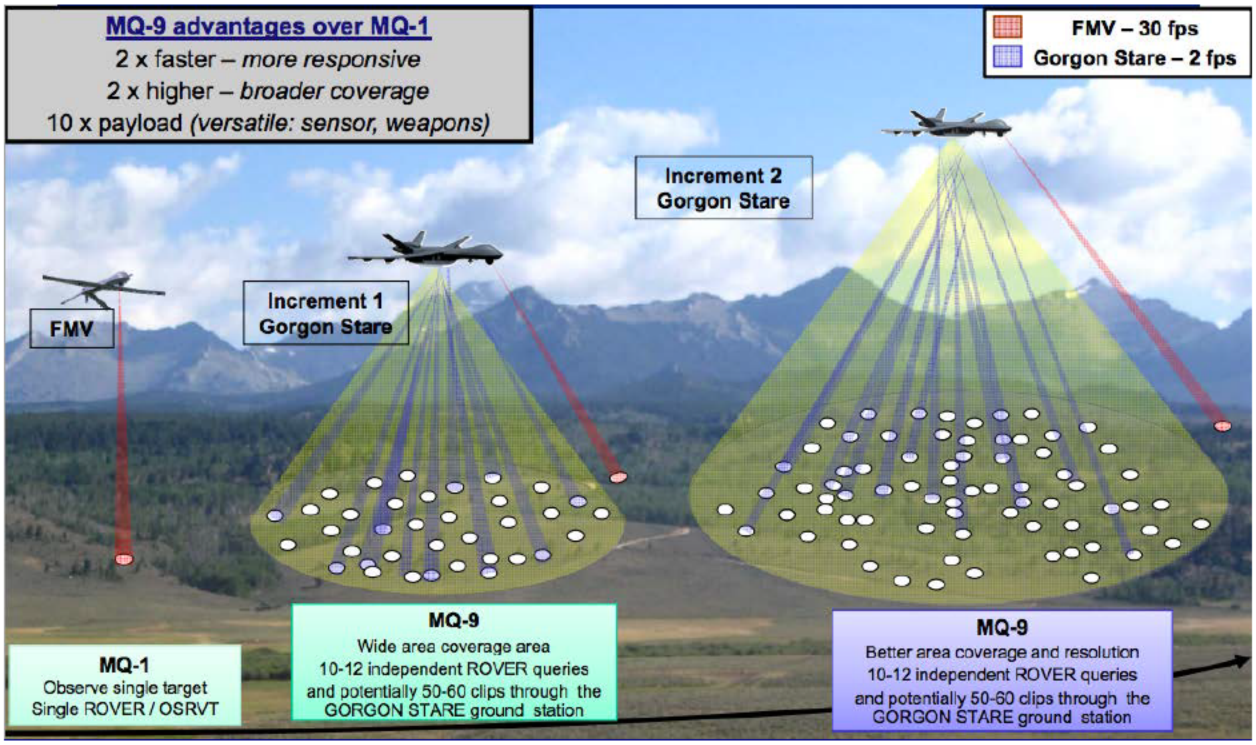
50 Gertler, *U.S. Unmanned Aerial Systems*, p. 17; and Department of the Navy Chief Information Officer Spectrum/Telecommunications Team, "Transformational Communications," *CHIPS*, January-March 2005.

51 Briefing by Colonel J.R. Gear, Director, Air Force RPA Task Force, "USAF RPA Update–Looking to the Future," June 3, 2011, slide 43.

52 Most HVT strikes are against known enemy personnel and are called "personality strikes." Signature strikes are made against a person based on their activity, affiliation, location, or what they are carrying.

53 The software stitching these images together can also "unravel" them, allowing analysts to focus on an individual area or track.



CONOPs for current-generation UAS have added to the bandwidth problem. Remote-split operations for UAS involve deploying a small launch and recovery team forward to maintain the UAS and control takeoffs and landings via line-of-sight control. Other flight control operations and the processing, exploitation, and dissemination (PED) of intelligence typically occur at remote sites (usually in the continental United States) via satellite links. While this drastically decreases the physical footprints of UAS units in forward operating locations, it also increases demand for satellite bandwidth.

This deluge of data has strained DoD's ability to monitor, process, exploit, and disseminate information from UAS sensors, which is a personnel-intensive mission. A single 24-hour, 7-day a week, 365-day per year combat air patrol of MQ-9 or MQ-1 aircraft requires the support of nearly 200 personnel.[54] Out of that total, 84 personnel are in the PED element, 49 are in the mission control element (i.e., they pilot the aircraft and monitor their sensors), and the remaining 59 are in the forward launch and recovery element. DoD has responded to this problem in part by spending almost $2 billion a year to lease bandwidth from commercial satellite companies.[55] Much as DoD addressed the bandwidth issue by renting satellite capacity, it also sought to

54 Gear, Director, "USAF RPA Update–Looking to the Future," slide 43.

55 Debra Werner, "The Military's Second Chance For a Bandwidth Fix," *Defense News*, April 19, 2013. According to Werner, "worldwide, only about 20 percent of U.S. military communications travel over U.S. military satellites. For the other 80 percent, defense agencies spend $1 billion to $2 billion a year buying excess capacity on the same commercial satellites that give the world direct-to-home television and networks for mobile devices. In 15 years, the cost of that satellite service could rise to $5 billion annually, according to the Defense Business Board."

mitigate its human resource problems—and particularly its PED analyst shortfall—by "renting" personnel in the form of civilian contractors. The Air Force Special Operations Command (AFSOC) employed 165 contractor intelligence analysts to support UAS intelligence operations as of 2011, and the Air Force acknowledged it had deployed 300 civilians to support drone operations at forward locations.[56] The total number of contractor personnel supporting the PED process at the height of UAS operations in Iraq and Afghanistan was likely much higher.

Despite these expenditures, the Air Force and Army personnel systems have struggled to keep up with the demand for sensor operators, intelligence analysts, and pilots. According to a 2012 Defense Department report, the Air Force alone had the following shortfalls:[57]

RPA Crew Manpower Requirements

	MQ-1	MQ-9	RQ-4	Total
Pilots	1012	529	155	1696
Sensor Operators	730	401	63	1194

RPA Crew Manning Availability

	MQ-1	MQ-9	RQ-4	Total	Current Shortfall
Pilots	726	455	177	1358	-338
Sensor Operators	610	291	48	949	-245

Persistent RPA manning issues have prompted Congress to request the Government Accountability Office (GAO) to look into the matter. The GAO determined that:

> Several factors have contributed to a lag in Air Force and Army planning for the personnel, facilities, and some communications infrastructure that are integral to the operation of UAS. For example, although DOD's primary requirements definition process—termed the Joint Capabilities Integration and Development System—encourages acquisition personnel to develop cost estimates for its new weapon systems programs, including consideration of various support factors, the Air Force's current UAS programs were, for the most part, initially developed and fielded as technology demonstrations… Further, to meet near-term warfighter demands for these capabilities, several UAS programs have been expanded beyond planned force structure levels and, in some cases, have been fielded more rapidly than originally planned.[58]

Despite the growth in uniformed and contractor personnel dedicated to drone operations, the data generated by the current UAS fleet continues to far outstrip DoD's ability to process it. Instead

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56 David S. Cloud, "Civilian Contractors Playing Key Roles in U.S. Drone Operations," *Los Angeles Times*, December 29, 2011.

57 Department of Defense, Report to Congress on Future Unmanned Aircraft Systems Training, Operations, and Sustainability (Washington, DC: DoD, 2012), p. 3.

58 Unmanned Aircraft Systems: Comprehensive Planning and a Results-Oriented Training Strategy Are Needed to Support Growing Inventories (Washington, DC: United States Government Accountability Office, 2010), p. 21.

of simply increasing the number of intelligence analysts, the development of new, possibly more autonomous PED technologies may be needed to manage the explosion in multi-intelligence information from the Pentagon's next generation of UAS. According to Major General Bradley A. Heithold, commander of the Air Force ISR Agency, "the answer isn't throwing more manpower at it because in DoD, we don't have it…it's easier for me to get money than it is to get manpower. We're going to have to use technology, smart systems that cipher through the intelligence."[59]

Optimized for Today's Operations

The rapid growth of DoD's UAS force since 2001 did not occur without resistance from the Services, especially as unmanned aircraft programs such as the Predator and Reaper began to crowd out funding for new manned aircraft and other modernization priorities. The Air Force's wartime budget requests for UAS, for example, were often less than funding provided by Congress, which authorized 109 additional MQ-1 and MQ-9 aircraft beyond what the Air Force requested from 2002 through 2008.[60]

By 2008, the apparent reluctance to increase resources for UAS and other capabilities needed for overseas contingency operations had become a source of friction between the Services and the Office of the Secretary of Defense (OSD). In April of 2008, Secretary of Defense Robert Gates publicly chastised the Services' unwillingness to place a higher priority on immediate wartime needs, including more UAS assets for ISR missions, over modernization programs:

> I've been wrestling for months to get more intelligence, surveillance, and reconnaissance assets into the theatre. Because people were stuck in old ways of doing business, it's been like pulling teeth… My concern is that our services are still not moving aggressively in wartime to provide resources needed now on the battlefield.[61]

Less than a year later, Gates redirected funding toward capabilities to support war operations. In particular, he directed the Air Force to cap its F-22 5th generation fighter program at 187 aircraft

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59 Magnuson, "Military 'Swimming in Sensors and Drowning in Data.'"

60 FY2003 Budget Estimates: Aircraft Procurement, Air Force Volume I (Washington, DC: United States Air Force, 2002), p. 4-79; FY2004/2005 Biennial Budget Estimates: Aircraft Procurement, Air Force Volume I (Washington, DC: United States Air Force, 2003), p. 4-73; FY2005 Budget Estimates: Aircraft Procurement, Air Force Volume I (Washington, DC: United States Air Force, 2004), p. 4-63; FY2006/2007 Budget Estimates: Aircraft Procurement, Air Force Volume I (Washington, DC: United States Air Force, 2005), p. 4-49; FY2007 Budget Estimates: Aircraft Procurement, Air Force Volume I (Washington, DC: United States Air Force, 2006), p. 4-63; FY2008/2009 Budget Estimates: Aircraft Procurement, Air Force Volume I (Washington, DC: United States Air Force, 2007), p. 4-82; FY2009 Budget Estimates: Aircraft Procurement, Air Force Volume I (Washington, DC: United States Air Force, 2008), pp. 4-73, 4-103; FY2010 Budget Estimates: Aircraft Procurement, Air Force Volume I (Washington, DC: United States Air Force, 2009), pp. 4-75, 4-97; and FY2011 Budget Estimates: Aircraft Procurement, Air Force Volume I (Washington, DC: United States Air Force, 2010), pp. 4-117, 4-121.

61 Michael Hoffman, "Gates puts pressure on call for more UAVs," *ArmyTimes*, April 21, 2008.

and increase funding for unmanned aircraft. Tellingly, from FY2009 through FY2012 the Air Force's requests for MQ-1s and MQ-9s met or exceeded the number authorized by Congress.[62]

A Persistent Focus on Current Operations

Although Gates' focus on Iraq and Afghanistan was understandable, his priorities left the Air Force, and DoD more broadly, with a UAS force that is optimized for supporting COIN and CT operations in permissive environments. As the inventory tables earlier in this chapter illustrate, the vast majority of the Pentagon's UAS are oriented toward ISR missions with some capability to support counter-IED and HVT strike missions. In other words, the preponderance of the Pentagon's UAS force consists of platforms that are best suited for gathering information, as Lt Gen David Deptula noted in 2010: "97 percent of the remotely piloted aircraft today are used to acquire intelligence, surveillance and reconnaissance."[63] Even the low-observable RQ-170 is officially acknowledged as a surveillance and reconnaissance aircraft. Moreover, it is not readily apparent that the Services are eager to develop a new generation of UAS that would be capable of a wider range of missions in contested environments. In particular, it appears unlikely that the Navy will transition from its Unmanned Combat Air Systems Demonstrator (UCAS-D) program to a program of record that will develop a stealthy, multi-mission Naval-UCAS (N-UCAS) capable of operating from its aircraft carriers.[64]

The Pentagon's reactive expansion of its unmanned aircraft capabilities has created a force that is awash in contradictions. DoD capitalized on its late-Cold War investments in space-based C2 and PNT capabilities, the research and development of DARPA, and wartime budgets to field the world's largest and most battle-tested UAS force. At the same time, DoD's operational UAS largely consist of demonstrator aircraft that were rushed into service before they fully matured. Although shortcutting traditional acquisition processes helped the Pentagon to field new unmanned aircraft rapidly, it has done so at the expense of developing mature unmanned aircraft *systems*. As a result, today's force lacks fully developed CONOPs, robust support networks, and sufficient cross-Service and cross-systems integration. Furthermore, relentless and urgent demand for near-real-time ISR has led to the creation of improvised UAS support networks that are heavily dependent on expensive commercial satellite bandwidth and personnel-intensive PED architectures. In many ways, today's UAS force is analogous to the Mine Resistant Ambush Protected (MRAP) armored vehicle fleet of the Army and Marine Corps. Both were procured in

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[62] FY2009 Budget Estimates: Aircraft Procurement, Air Force Volume I (Washington, DC: United States Air Force, 2008), pp. 4-73, 4-103; FY2010 Budget Estimates: Aircraft Procurement, Air Force Volume I (Washington, DC: United States Air Force, 2009), pp. 4-75, 4-97; and FY2011 Budget Estimates: Aircraft Procurement, Air Force Volume I (Washington, DC: United States Air Force, 2010), pp. 4-117, 4-121.

[63] "Crafting a New Paradigm for Manned-Unmanned Systems: Lieutenant General Deptula Reflects on the MQ-X," *Second Line of Defense,* May 2010. At the time of this article, Deptula was the Air Force's Deputy Chief of Staff for Intelligence, Surveillance, and Reconnaissance.

[64] See Chapter 6 for a case study on the UCAS-D and the potential that the Navy will develop an Unmanned Carrier Launched Airborne Surveillance and Strike System **(**UCLASS**)** that may be little more than another non-stealthy ISR platform.

response to urgent operational needs through rapid-acquisition programs using commercial-off-the-shelf systems (COTS) and developmental technologies. Both were expensive and crowded out investments in modernization programs. Finally and perhaps most importantly, both appear to be of questionable utility in future operational environments.

Looking Beyond the Present

The U.S. military has employed its UAS against opponents that lacked countervailing capabilities, a factor that may have contributed to its failure to advance toward a more capable, multi-mission unmanned force as part of an MPSR. America's dominance of the air domain has been nearly unchallenged over the last decade, permitting it to operate "low and slow" non-stealthy unmanned and manned aircraft in Iraq, Afghanistan, Yemen, Libya, the Horn of Africa, and elsewhere. The availability of a secure network of forward bases in and around the immediate battlespace has allowed deployed forces to launch and recover UAS close to their operating areas, thereby minimizing transit times and maximizing time on station. The inability of hostile forces to strike these bases has made them sanctuaries for UAS operations. Irregular forces the United States has fought since 2001 have also lacked effective counter-network and electronic warfare (EW) capabilities, a fact that has granted U.S. power-projection forces virtual sanctuaries in the electronic spectrum, to include cyberspace.

In the future, it is highly unlikely that U.S. power-projection forces will always enjoy control of the air, unfettered access to close-in regional bases, and secure PNT and C2 networks. States such as China, Iran, and non-state actors such as Hezbollah, are seeking to develop capabilities and operational concepts that are intended to turn U.S. strengths into vulnerabilities by attacking American forces in areas where they have traditionally found sanctuary.[65]

Challenging America's Air Dominance

State and non-state competitors are investing in systems to contest the air dominance that is a *sine qua non* of U.S. power-projection operations. At the high end, competitors such as China are fielding advanced integrated air defense systems (IADS) designed to deny U.S. aircraft the ability to penetrate their airspace. These IADS include advanced systems such as Russian "triple-digit" SAMs (the S-300 and S-400) and their derivatives; 4th and 5th generation combat aircraft; long-range air-search sensors, including ground-based early-warning radars and airborne early warning (AEW) platforms; and dedicated, hardened, and buried fiber-optic C2 networks.

Other competitors that lack the requisite technologies and resources to field a capable IADS are instead opting for a mix of obsolescent fighters and SAMs, interspersed with more advanced

[65] For more detailed assessments of emerging anti-access/area-denial strategies, see Andrew F. Krepinevich, *Why AirSea Battle?* (Washington, DC: Center for Strategic and Budgetary Assessments, 2010); Jan van Tol with Mark Gunzinger, Andrew Krepinevich, and Jim Thomas, *AirSea Battle: A Point-of-Departure Operational Concept* (Washington, DC: Center For Strategic and Budgetary Assessments, 2010); and Mark Gunzinger with Chris Dougherty, *Outside-In: Operating from Range to Defeat Iran's Anti-Access and Area-Denial Threats* (Washington, DC: Center For Strategic And Budgetary Assessments, 2011).

mobile (and therefore harder to find and kill) SAM launchers. Operations in the Balkans during the 1990s demonstrated that even a technologically unsophisticated air defense system could pose a serious threat to non-stealthy UAVs. According to General Roger Brady, then Commander of U.S. Air Forces in Europe, fifteen of the seventeen aircraft shot down by Serbian forces during Operation Allied Force in 1999 were UAVs.[66] The Serbs achieved these successes with mostly outdated Russian systems and by using "smart" tactics such as activating their search and targeting radars only when absolutely necessary to avoid being detected by Coalition air forces.[67] The U.S. military's current generation of UAS—with the possible exception of the RQ-170—also remains highly vulnerable to air-to-air attacks, as demonstrated in 2002 when an Iraqi MiG-25 intercepted and shot down a Predator.[68]

Today, most U.S. manned combat aircraft can use speed, altitude, maneuverability, and on-board countermeasures to evade man-portable air defense systems (MANPADS). MANPADS pose a serious threat to aircraft such as non-stealthy UAS that operate at slow airspeeds and low altitudes in order to maximize the effectiveness of their sensors, lack autonomous capability to detect missile launches and take evasive action or alert their remote pilots, and are not equipped with on-board countermeasures. UAS vulnerability to MANPADS, older air interceptors, SAMs, and even aimed anti-aircraft artillery fires suggests they would lack survivability in an MPSR, which will likely find non-state actors such as Hezbollah, the Movement for the Emancipation of the Niger Delta (MEND), and even drug cartels possessing MANPADS and other means to shoot down UAS.

Denying Access to Close-In Bases

DoD is heavily dependent on secure forward bases that it can use as staging areas for UAS operations. Using bases located close to an enemy allow UAS that are incapable of autonomous air refueling to spend less time in transit and more time over target areas. Moreover, given the slow airspeeds of Predators, Reapers, and other current-generation UAS,[69] the ability to launch and recover close to areas of interest is of significant operational value.

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66 Scott Fontaine, "USAFE chief: Don't rely on UAVs," *Air Force Times*, July 30, 2010.

67 According to DoD, the Serbian military possessed: 100 surface-to-air missiles (a mix of SA-2, SA-3, SA-6, SA-7, SA-9, SA-13, SA-14 and SA-16), 240 combat aircraft (mostly MiG-21s and MiG-29s), and 1,850 air defense artillery pieces. The SA-2, SA-3, and SA-6 are obsolete, "legacy" Cold War systems designed to intercept aircraft at high, medium, and low altitudes, respectively. The SA-9 and SA-13 are highly mobile, short-range, low-altitude, heat-seeking SAM systems. The SA-7, SA-14, and SA-16 are all older MANPADS.

68 In what appears to be the first instance of air-to-air combat between a UAV and a manned aircraft, the Iraqi MiG and the Predator both fired air-to-air missiles. The Predator's FIM-92 Stinger missed. The MiG's did not. Walter J. Boyne, "How the Predator Grew Teeth," *Air Force Magazine*, July 2009.

69 The Air Force lists the Predator's speed as "up to 135" miles per hour, while the Reaper is capable of 230 miles per hour. By comparison, the manned, turboprop MC-12 ISR aircraft flies at 360 miles per hour, while the manned U-2 flies at over 410 miles per hour. See official Air Force fact sheets "U-2S/TU-2S," available at http://www.af mil/information/factsheets/factsheet_print.asp?fsID=129&page=2; "MQ-1B Predator," available at http://www.af.mil/information/factsheets/factsheet.asp?fsID=122; "MQ-9 Reaper," available at

In addition to preparing to use precision weapons to defend their airspace, military competitors are making investments to deny U.S. power-projection forces the ability to operate effectively from close-in theater bases. In particular, competitors have realized that, over the near- to medium-term, offensive ballistic missiles are both more effective and far less expensive than the kinetic missile defenses the United States now relies on almost exclusively to defend its overseas operating locations. The hypersonic speeds achieved by reentry vehicles force defenders to "hit a bullet with another bullet," a difficult task even if incoming missiles do not use maneuverable reentry vehicles (MaRVs) and/or decoy warheads (which many do). Each offensive missile a competitor acquires therefore has the potential to impose even greater costs on defenders who are reliant on kinetic interceptor missiles that can cost millions of dollars each, and which will likely require shooting at least two interceptors to defeat every incoming missile.[70]

China again leads the way in this effort. The People's Liberation Army (PLA) 2nd Artillery Corps has assembled an arsenal of precision-guided conventional and nuclear-tipped ballistic missiles, as well as land-attack cruise missiles that can be fired from land-, air-, sea-, and undersea-based platforms. The PLA could employ these weapons in an attempt to deny U.S. forces access to Western Pacific bases and significantly degrade the bases' ability to support a high tempo of operations.[71] Freed from the threat of prompt, effective U.S. intervention, the PLA could then use its short-range ballistic and cruise missiles or strike aircraft to batter Taiwan or another target state to force them to capitulate.

Iran, North Korea, and other states have fielded their own missile forces. Their ballistic and cruise missiles lack the accuracy of the PLA's systems, thus limiting their effectiveness against small targets such as hardened aircraft shelters. However, the rapid proliferation of space constellations capable of providing precise PNT, like Russia's GLONASS, China's Beidou, and the European Galileo constellation could enable less advanced states like Iran and North Korea to improve substantially the accuracy of their long-range strike missile forces.

Even small-states and non-state actors could use tactical guided rockets, artillery, mortars, and missiles (G-RAMM) to strike U.S. forward bases and deployed forces with accuracy. Relatively affordable and easy-to-use weapons equipped with GPS, laser, infrared, or even anti-radiation seekers could wreak havoc on U.S. bases and other rear-area facilities. Though mortars and rockets were used against coalition facilities in Iraq and Afghanistan, they were little more than barely-aimed harassment attacks. G-RAMM attacks on bases would likely be far more destructive and produce greater casualties. G-RAMM also pose a significant threat to ground maneuver forces; anti-tank guided munitions (ATGMs) proved exceptionally lethal to Israeli ground forces during the 2006 war between Israel and Hezbollah. In a future environment where

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http://www.af mil/information/factsheets/factsheet.asp?fsID=6405; and "MC-12," available at http://www.af mil/information/factsheets/factsheet.asp?id=15202.

70 This is a tactic known as "shoot-look-shoot."

71 van Tol, Gunzinger, Krepinevich, and Thomas, *AirSea Battle: A Point-of-Departure Operational Concept,* pp. 19-21.

these weapons are highly proliferated, U.S. ground forces would operate at significant risk absent the development of effective capabilities and CONOPs to counter them, which at present appears problematic.

Threats to America's Seabase

Since World War II the U.S. military has capitalized on its dominance of the maritime domain—and especially the open ocean—to project power into areas where land bases are unavailable or inadequate. The PLA witnessed this capability first-hand in 1996 when, during a tense standoff between mainland China and Taiwan over the latter's flirtation with independence and diplomatic outreach to the United States, the United States sailed two Carrier Strike Groups (CSGs) into or near the Taiwan Strait. Recognizing the pivotal role aircraft carriers in U.S. foreign policy, the PLA began pursuing a multi-pronged approach to harass and eventually deny carriers from being able to operate within China's maritime sphere of influence in East Asia.[72]

China is now developing a diverse array of anti-surface warfare (ASuW) capabilities. From the U.S. Navy's perspective, PLA anti-ship ballistic missiles (ASBMs) are one of the most problematic threats to its aircraft carriers. Using targeting data from over-the-horizon radars (OTH-R), reconnaissance satellites, and possibly manned—or in future unmanned—maritime patrol aircraft (MPA), ASBMs exploit the fundamental offensive advantage conferred by a combination of their extreme speed and hardened warheads to reduce the likelihood of successful interception by defenses surrounding aircraft carriers, while their terminal guidance and maneuverable reentry vehicles decrease the potential for slow-moving carriers to evade strikes. Not only is the PLA's DF-21 ASBM, now in development, designed to be difficult to intercept or avoid, but it may also be capable of striking CSGs as far as 1,000 nautical miles from mainland China.

China could also use its nuclear submarines and long-range maritime strike aircraft carrying anti-ship cruise missiles (ASCMs) to harass U.S. carriers and their supporting Combat Logistics Force (CLF) ships en route to the theater of operations. Closer to China, U.S. CSGs might encounter medium-range fighter/bombers such as the recently unveiled, purportedly low-observable J-20 which could be outfitted with ASCMs or beyond-visual-range air-to-air missiles for attacking E-2D Hawkeye AEW aircraft. As they pass through the first island chain, U.S. CSGs would begin to encounter diesel attack submarine (SSK) ambushes at choke points such as the Strait of Luzon. Myriad land, air, surface, and undersea threats would await the CSG inside the first island chain, including land-based ASCMs, huge numbers of fighter aircraft, numerous small fast-attack craft armed with ASCMs, and SSKs.

Although no other non-U.S. state or non-state actor currently possesses the means to match China's open-ocean ASuW capabilities, Iran is deploying more limited sea denial capabilities

[72] China includes areas of the Pacific Ocean and South China Sea that are within "the first island chain" as part of its self-proclaimed sphere of influence.

around the Strait of Hormuz. While Iran is unlikely to acquire a precise over-the-horizon reconnaissance-strike capability any time soon, the geographic constraints of the Strait of Hormuz and Persian Gulf enable it to rely on sea mines and short-range weapons, including coastal ASCMs and possibly G-RAMM. Rather than seeking to establish full control over the Strait of Hormuz indefinitely, Iran could seek to deter an intervention by significantly raising the costs and stretching out the timelines of U.S. power-projection operations.[73] Similarly, Iranian proxies such as Hezbollah may only need to demonstrate their ability to conduct anti-ship strikes (which they did in 2006 with their C-802 attack on the INS *Hanit*) to force U.S. warships to operate further from land and dedicate more resources to defending the fleet instead of projecting power ashore.

Threats to Operations in Virtual Domains

Challenges to future UAS operations in an MPSR extend beyond the terrestrial and physical domains. In the future, it is quite possible that UAS operations may prove to be far more vulnerable to attacks on their supporting networks rather than attacks on individual aircraft. As described in previous sections, DoD's current UAS fleet is almost entirely dependent on space-based C2 and PNT. Satellite C2 links are susceptible to an array of EW and cyber attacks. The satellites themselves are vulnerable to being disrupted, degraded, or destroyed by kinetic threats such as direct-ascent anti-satellite (ASAT) weapons and non-kinetic (directed-energy and cyber) attacks. Given the technological challenges involved, destroying a U.S. GPS satellite would prove difficult for most military competitors, save for China and perhaps Russia. Low-power satellite GPS signals, however, could be disrupted by even small mobile jammers, which are proliferating. According to the Defense Science Board:

> The ability for our military forces to be able to navigate and determine positions in the presence of hostile jamming is essential. The principal vulnerability to be addressed is the threat of widely proliferated, mobile, inexpensive, relatively low-power jammers. The optimal configuration for such jammers is in an extensive array, in which the jammers blink on and off. Worldwide, we can foresee GPS jammers available in the 100 Watt size. This size jammer is relatively easy to manufacture and can be widely proliferated.[74]

EW and cyber attacks are likely to become a preferred means for disrupting and degrading U.S. military UAS operations in the future, especially given their potential to do so en masse at relatively low cost compared to attacking unmanned aircraft individually with kinetic weapons.

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[73] For additional information on Iran's A2/AD strategy, see Gunzinger and Dougherty, *Outside-In: Operating from Range to Defeat Iran's Anti-Access and Area-Denial Threats*, pp. 21-52.

[74] Defense Science Board, *The Future of the Global Positioning System* (Washington, DC: Department of Defense, 2005) p. 56.

Summary

In summary, most of DoD's current and planned UAS fleet would be at significant risk of incurring large-scale attrition *at present* during operations against mid-range military competitors such as Iran or North Korea, to say nothing of their vulnerability against the weapons systems of near-peer competitors like China and Russia. As an MPSR progresses and advanced military technologies diffuse to increasingly less-advanced states and non-state actors, DoD's current UAS may reach obsolescence even for missions which are today considered low-end, such as COIN, CT, and counter-narcotics operations.

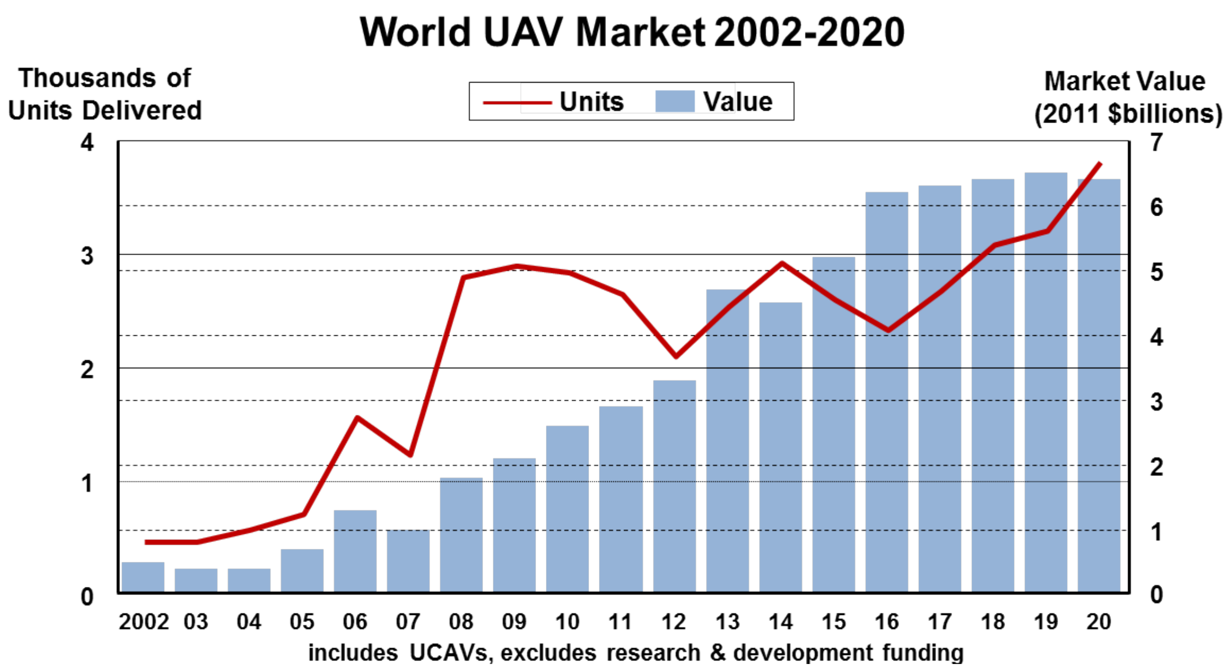
Adjusting to the far less permissive environment of an MPSR may require an alternative vision to guide DoD's development of its next UAS force, a vision that diverges from the path it has followed since 2001. Unlike today's force, it would seem logical that future UAS should have greater unrefueled ranges than current land- and carrier-based fighters to enable them to outrange enemy strike systems; stealth characteristics to survive in contested airspace; and the flexibility to conduct multiple missions, including ISR, precision strike, and airborne electronic attack. The Navy in particular has an opportunity to develop new, long-range weapon systems that would enable it to conduct initial combat operations from more secure standoff distances. These could include manned and unmanned undersea warfare capabilities, air- and sea-launched standoff attack weapons, and a new generation of carrier-based UAS that combines the aircraft's extended range and persistence with the strategic mobility provided by the carrier strike group.[75]

The next two chapters address competitor investments in UAS technologies before turning to address potential priorities of a new UAS development path that could help the Defense Department maintain its robotic aviation advantage in an emerging MPSR.

[75] UAS that stage from Navy warships are now primarily tactical reconnaissance systems designed to provide situational awareness. The Navy is in the process of arming the MQ-8B Firescout VTUAV and the larger MQ-8C (sometimes referred to as the Fire-X) with the Advanced Precision Kill Weapons System (APKWS), which is a laser-guided 70 mm rocket based on the unguided Hydra 70. See "APKWS II: Laser-Guided Hydra Rockets in Production At Last," *Defense Industry Daily*, March 4, 2013.

Chapter 4. Global UAS Trends and Competitors' Paths

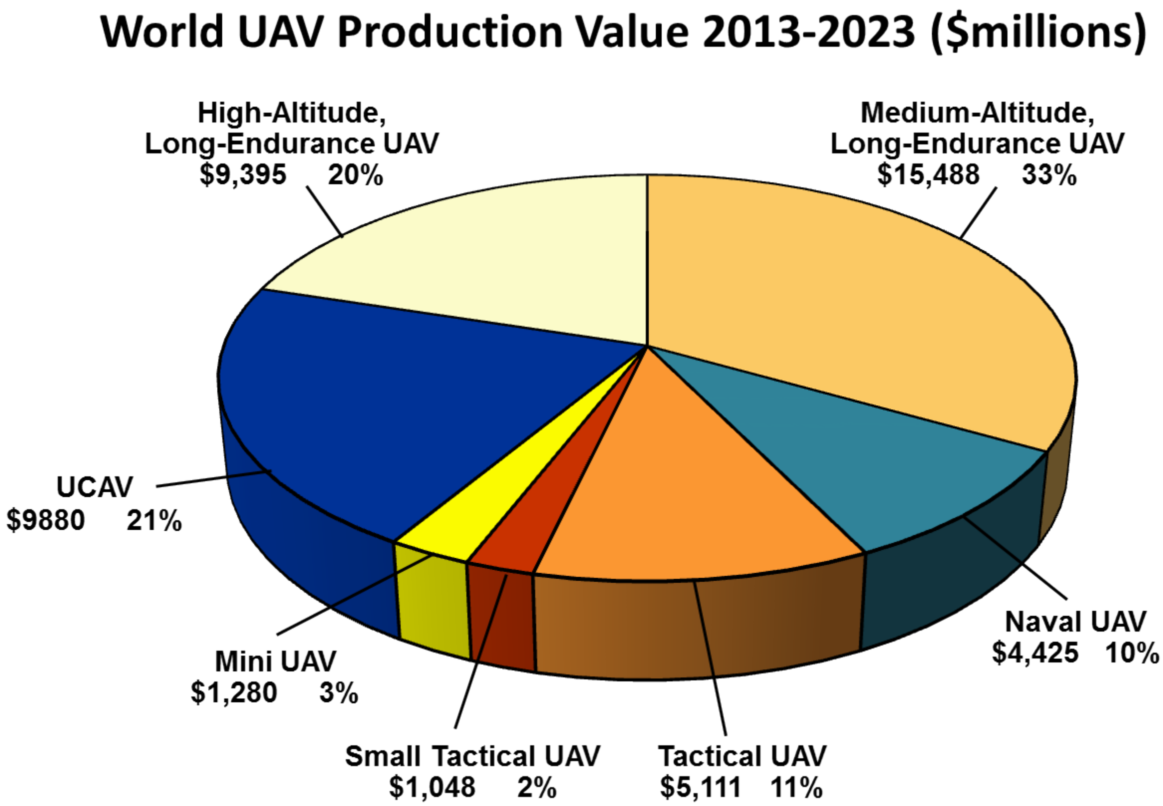
The success of UAS operations over the last decade has sparked enormous growth in global demand for unmanned aircraft (see figure below).[76] In 2004, the Government Accountability Office (GAO) estimated that approximately 41 countries had acquired UAS capabilities; by July of 2012, this number had roughly doubled to over 76 states.[77] This growth has been stimulated by a number of other factors, including lower barriers to entry for manufacturers and the increased affordability of buying and operating some unmanned aircraft variants compared to manned aircraft.



Although global investment in medium-altitude, long-endurance (MALE) and high-altitude, long-endurance (HALE) UAV programs outstrips estimated funding for other UAV classes (see figure below), measured by platform numbers, the vast majority of UAS today consist of mini, small, and tactical aircraft that are capable of conducting surveillance missions. This reflects both the lower cost and relative technological simplicity of these systems as well as the particular operational needs of most militaries.

76 "2012 Aircraft Industry Study Outbrief," National Defense University Industrial College of the Armed Forces, May 23, 2012, slide 12. The figure is derived from a briefing provided to CSBA by Dr. Sorin Lungu, faculty lead for the study.

77 *Nonproliferation: Agencies Could Improve Information Sharing and End-Use Monitoring on Unmanned Aerial Vehicle Exports* (Washington, DC: Government Accountability Office, 2012), p. 9. Global UAS programs have expanded from under 200 in 2005 to around 700 by 2013.



From a defense requirements perspective, most states focus on unmanned capabilities that could help them to maintain their internal security and protect their borders or littoral regions, missions for which smaller, short-range ISR UAS are generally sufficient. From a technology and cost perspective, unmanned aircraft with line-of-sight radio controls can be built and operated by unsophisticated military-technological complexes, while larger armed or strategic surveillance UAS are more costly and more difficult to develop indigenously. Since most nations that produce large UAS are either signatories of the Missile Technology Control Regime (MTCR) or adhere to its guidelines, which restrict the export of UAVs capable of carrying a payload of 500 kilograms further than 300 kilometers, proliferation of more capable (and more expensive) systems has been limited.[78] Beyond-line-of-sight C2, which presently requires access to space-based PNT and communications, is another limiting factor for states and non-state actors who aspire to operate long-range UAS.

[78] The MTCR was created to control transfers of WMD and systems that could deliver WMD other than manned aircraft. See Arms Control Association, "Missile Technology Control Regime," available at http://www.armscontrol.org. According to a 2012 study, "Despite growing worldwide interest in UAS for military, civilian and commercial purposes, U.S. application of its overly restrictive Missile Technology Control Regime (MTCR) obligations hampers consistent UAS exports." The Industrial College of the Armed Services, *Final Report: Aircraft Industry* (Washington, DC: National Defense University, 2012), p. 30. The Wassenaar Arrangement on Export Controls for Conventional Arms and Dual-Use Goods and Technologies places further voluntary restrictions on UAS exports.

World UAV Budget Forecast

A 2013 Teal Group market outlook assessment predicts the current global investment of $5.2 billion in UAV programs will more than double over the next ten years.[79] Although the forecast indicates the United States will continue to be responsible for most of this spending in the near term, the rest of the world's UAS investments may begin to outpace the United States by the mid-2020s (see figures below).[80]

World UAV Budget Forecast

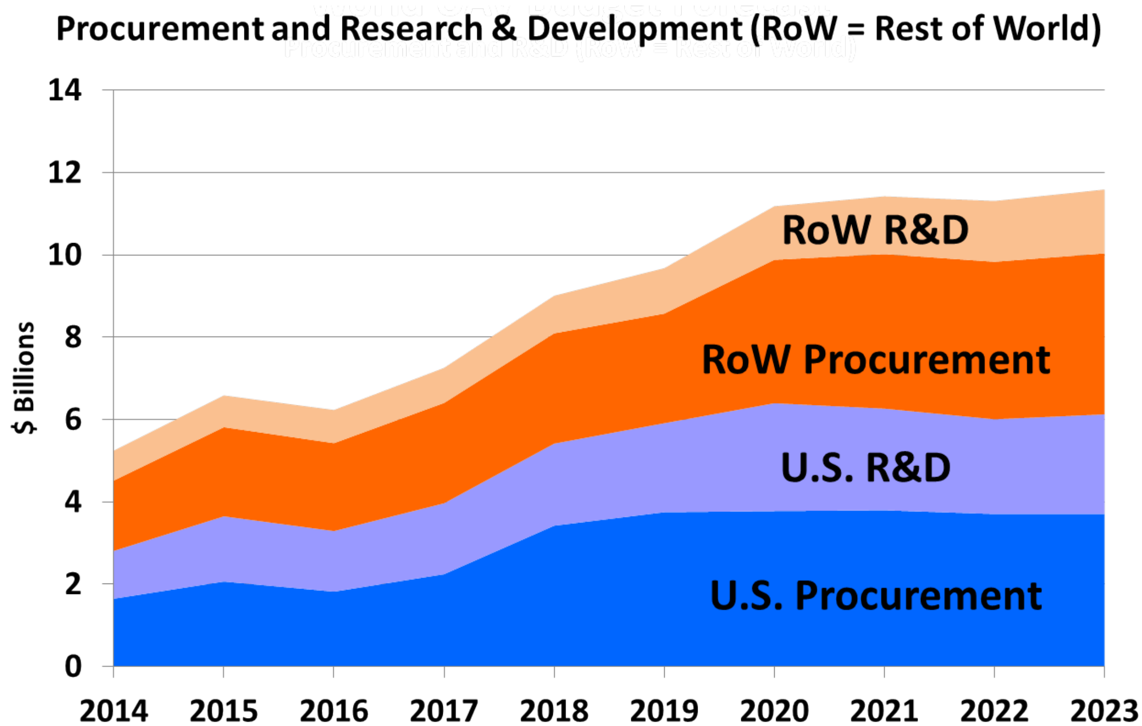
R&D ($ Millions)	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	Total
USA	1,161	1,585	1,471	1,722	1,992	2,162	2,620	2,470	2,303	2,416	19,902
Rest of World (RoW)	725	770	805	850	910	1,100	1,300	1,400	1,475	1,550	10,885
Total R&D	**1,886**	**2,355**	**2,276**	**2,572**	**2,902**	**3,262**	**3,920**	**3,870**	**3,778**	**3,966**	**30,787**

Procurement ($ Millions)	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	Total
USA (less UCAV)	1,649	2,066	1,821	2,245	3,424	3,750	3,777	3,797	3,706	3,711	29,945
RoW (less UCAV)	1,710	2,165	2,135	2,438	2,681	2,663	3,484	3,754	3,825	3,910	28,765
Total Procurement	**3,359**	**4,231**	**3,956**	**4,683**	**6,105**	**6,412**	**7,261**	**7,551**	**7,531**	**7,621**	**58,710**

($ Millions)	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	Total
World R&D	1,886	2,355	2,276	2,572	2,902	3,262	3,920	3,870	3,778	3,966	30,787
World Procurement	3,359	4,231	3,956	4,683	6,105	6,412	7,261	7,551	7,531	7,621	58,710
Total	**5,245**	**6,586**	**6,232**	**7,255**	**9,007**	**9,674**	**11,181**	**11,421**	**11,309**	**11,587**	**89,497**

79 Steven J. Zaloga, Dr. David Rockwell, and Philip Finnegan, *World Unmanned Aerial Vehicle Systems* (Fairfax, VA: Teal Group Corporation, 2013), p. 1. For another analysis of the UAS industry, see also Glennon J. Harrison, *Unmanned Aircraft Systems (UAS): Manufacturing Trends* (Washington, DC: Congressional Research Service, 2013).

80 Zaloga, Rockwell, and Finnegan, *World Unmanned Aerial Vehicle Systems*, p. 2. Owing to classification levels and lack of transparency into national military plans, yearly costs for UCAV programs were not included in the forecast. As one of the larger and more technologically advanced forms of UAS, UCAV programs will likely require large R&D and procurement budgets.



The assessment also predicts that global UAS investment and proliferation will follow patterns previously demonstrated by other advanced defense capabilities. Specifically, China, Japan, and other Asia-Pacific states will be global leaders in UAS investments, followed closely by European states which will develop both national and multi-national UAS programs.

Following in America's Footsteps…or Not?

A desire to emulate the U.S. military's UAS force may have led to a certain degree of mimicry in foreign aircraft designs. In particular, the MALE UAS typified by the Predator has become a popular model to copy, with some Chinese designs such as the Chengdu "Wing Loong" and CASC CH-4 bordering on being out-and-out knock-offs.

The actual motivations behind UAS designs are much more diverse, however. While DoD has been building a UAS fleet primarily to support large-scale ground operations, other states see unmanned systems as a means to offset manpower shortages (Israel), substitutes for the lack of a manned aircraft industrial base (Iran), capabilities that can provide situational awareness to a technologically outdated force (Russia), systems that can help enable new operational concepts (China), or as a means of tapping into the growing UAS export market (Israel, Iran, China, and Russia). These diverse motives help explain why states may be motivated to adopt alternative paths for developing future UAS forces that move beyond counterfeit Predators and toward capabilities and concepts of operation that could eventually surpass the United States and spur the onset of a "robotic revolution."

The following sections assess the ability of four states—China, Israel, Iran, and Russia—to develop operational UAS. These assessments examine each country's current forces, developmental programs, and industrial-technical base for developing and building UAS. Due to the size of their apparent programs, the sections on China and Israel also explore their future UAS requirements. All four sections conclude with an assessment of how each country may adopt an alternative vision for UAS, and whether that means different unmanned systems and operational concepts will populate an MPSR.

China's UAS Development Path

> It is difficult to establish the extent to which China's unmanned systems are operational, and it appears today that China is technologically lagging behind U.S. and other international efforts. Nevertheless, the military significance of China's move into unmanned systems is alarming. The country has a great deal of technology, seemingly unlimited resources and clearly is leveraging all available information on Western unmanned systems development. China might easily match or outpace U.S. spending on unmanned systems, rapidly close the technology gaps and become a formidable global competitor in unmanned systems.
>
> — DoD Defense Science Board[81]

The history of China's UAS capabilities is not an illustrious one. Until very recently, the PLA's unmanned aviation fleet consisted of reverse-engineered copies of old AQM-34 Firebee drones and a handful of even older and more obsolete Russian drones. Despite this inauspicious beginning, China now clearly views unmanned aviation as a military-technological sector that could "support the expansion of the PLA's operational envelope, pushing its reconnaissance strike complex farther out into the Western Pacific" [82] and help offset the U.S. military's power-projection capabilities.

Crucially, the PRC is approaching the development of new UAS capabilities from a fundamentally different perspective than the United States. Whereas the U.S. military has long viewed UAS as adjuncts to manned aircraft and has only acquired them in earnest to support recent combat operations, China is relatively unburdened by a long history of excellence in manned aviation. This could allow China to follow development paths that may, for reasons of Service cultures and institutional resistance, be difficult for the Pentagon to adopt.

Current UAS Fleet and Developmental Programs

China's UAS capabilities are modest relative to the United States.[83] Most PLA operational UAS (see table below) are piston-engine, propeller-driven tactical reconnaissance aircraft akin to the

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81 Defense Science Board, *The Role of Autonomy in DoD Systems* (Washington, DC: Department of Defense, 2012), p. 71.

82 Ian M. Easton and L.C. Russell Hsiao, The Chinese People's Liberation Army's Unmanned Aerial Vehicle Project: Organizational Capacities and Operational Capabilities (Arlington, VA: Project 2049, March 2013), pp. 13-14.

83 Kimberly Hsu, with Craig Murray, Jeremy Cook, Amalia Feld, *China's Military Unmanned Aerial Vehicle Industry* (U.S.-China Economic and Security Review Commission, 2013), p. 6.

RQ-2 Pioneer aircraft operated by the U.S. military in the First Gulf War, or the slightly more advanced RQ-5 Hunter. These systems typically have line-of-sight C2 and limited payloads, range/endurance, and flight ceilings. The PLA Air Force's (PLAAF) largest and most advanced operational UAS may be the BZK-005, which some analysts surmise is in the Predator/MALE class of UAS. The PLA Navy (PLAN) also operates UAS and recently used one to shadow Japanese Maritime Self Defence Force ships in the East China Sea.[84]

Information at the unclassified level on its operational status and indeed the status of many of China's UAS programs is often vague and derived from speculation on the Internet. The BZK, for example, is assumed to be operational because it was spotted at an active PLAAF airfield in 2009.[85] As defense journalist David Axe notes, even if the BZK-005, or the PRC's developmental "Xianglong/Soaring Dragon" and "Soar Eagle" Global Hawk-like strategic surveillance UAS are operational, these platforms would still be almost two decades behind their U.S. and Israeli counterparts in terms of technological sophistication and operational experience.[86]

84 James Simpson, "Chinese UAV spotted by MSDF Aircraft," *Japan Security Watch: New Pacific Institute*, June 23, 2011, available at http://jsw.newpacificinstitute.org/?p=6844.

85 See David Axe, "U.S. Drones Trump China Theatrics," *The Diplomat*, February 7, 2011, available at http://thediplomat.com/2011/02/07/us-drones-trump-china-theatrics/.

86 Ibid.

China's Key Operational UAVs by Function

Function	Developer/ Manufacturer	Designator	Est. Date in Service
Target Drones. Used for target training			
Target drone, air sampling for nuclear tests	Nanjing University of Aeronautics and Astronautics (based on Soviet La-17)	Chang Kong-1	Late 1970s
Target drone, cruise missile simulation	Nanjing Research Institute on Simulation Technique/PLA General Staff Department (GSD) 60th Institute[10]	Tian Jian 1	~2005
Target drone, multipurpose	Northwestern Polytechnic University (precursor to Xi'an ASN Technology Group)	Ba-2	Early 1970s
Target drone, naval anti-aircraft artillery	Xi'an ASN Technology Group	Ba-9	?
MINI: Micro, Mini, and Short-Range. Ranges from handheld platforms with a range of less than 10 km to those with a range of approximately 70 km			
Micro and mini models for reconnaissance	Beijing Wisewell Avionics Science and Technology Company	AW series	Mid-2000s
Short-range rotary wing reconnaissance, communication relay[11]	Nanjing Research Institute on Simulation Technique/PLA GSD 60th Institute	Z series, (I-Z, Z-2, Z-3, Z-5)	Early 2000s
Short- and medium-range reconnaissance	Nanjing Research Institute on Simulation Technique/PLA GSD 60th Institute	W/PW series (W-30, W-50, PW-1, PW-2)	?
TACTICAL: Medium-Range. Approximate max range 150 km-200 km			
Medium-range, real-time reconnaissance	Xi'an ASN Technology Group	ASN 104/105	Late 1980s
Medium-range multirole	Xi'an ASN Technology Group	ASN 206	Mid-1990s
Medium-range endurance multirole	Xi'an ASN Technology Group	ASN 207	Early 2000s
Medium-range, naval use	Xi'an ASN Technology Group	ASN 209	~2011
TACTICAL: Medium-Range, antiradiation. Targets ground-based radar, approximate max range 500 km			
Antiradiation destruction of ground-based radar	Israel-exported: Israel Aerospace Industries	Harpy	Early 2000s
STRATEGIC: Low-altitude deep penetration. Max range 2500 km, max endurance 3 hours for reconnaissance missions			
Low-altitude deep-penetration reconnaissance	Beijing University of Aeronautics and Astronautics (based on U.S. Firebee)	WZ-5 (exported as CH-1)	~1981
STRATEGIC: Medium-altitude long-endurance. Reported max range 2400, max endurance 40 hours for reconnaissance and other missions			
Medium-altitude long-endurance multirole	Beijing University of Aeronautics and Astronautics	BZK-005	Mid- to late 2000s

Chinese analysts see unmanned aircraft as having the potential to enable new methods of operation. These analysts point to advantages that are often cited by Western UAS advocates: weight and space saved by dispensing with aircrew support systems, mission duration and maneuverability unconstrained by human physiology, and the ability of UAS to perform missions considered too difficult or too dangerous for manned aircraft. Chinese sources have also observed that UAS may be less expensive to manufacture and operate than manned aircraft.[87]

Consequently, China has made considerable progress in developing UAS technologies in the last decade as evidenced by its programs to design unmanned platforms that could have greater range and mission endurance (up to 40 hours) compared to its current UAS, hard points for weapons, and low-observable characteristics. Although many of China's unmanned aircraft prototypes appear to be little more than scale model aircraft, the sheer number and scope of its developmental UAS programs are impressive. This is consistent with the Chinese military's practice of experimenting with large numbers of prototype/demonstrator systems before settling on one or a handful of designs that work. In addition to smaller unmanned aircraft and its Predator, Reaper, and Global Hawk knock-offs, the PRC is pursuing low-observable UCAV designs, lethal UAS, maritime-patrol UAS, rotary-wing UAS, and armed UAS.

China has many of the necessary components in place to support its ambitious UAS development plans. In addition to its increasingly large and sophisticated aerospace industry, the PRC has tapped into its broad base of academic and research institutes to explore and develop UAS technologies.[88] Reflecting the lower barriers to entry into the UAS market, this broad development base exists alongside (and often affiliated with) established suppliers such as the Aviation Industry Corporation of China (AVIC), and the China Aerospace Science and Industry Corporation (CASIC), in much the same way that unmanned aircraft manufacturers General Atomics, AeroVironment, and InSitu have coexisted with U.S. prime contractors Northrop Grumman, Lockheed Martin, and Boeing.[89] China's military-industrial-academic complex has also sought to tap into individuals and groups who possess robotics expertise but may not typically conduct military research. Similar to how the DARPA Grand Challenge spurred research and development of autonomous ground vehicles by robotics researchers in the United States, the AVIC Cup UAV Innovation Grand Prix encouraged China's development of unmanned aviation. Tellingly, the competition involved unmanned aircraft performing a number of tasks, including taking off and landing on a scaled-down simulated aircraft carrier deck complete with arrester wires.

From a technological perspective, the PRC has sufficient space-based infrastructure to support regional over-the-horizon UAS operations. The Beidou satellite constellation provides GPS-like coverage of much of East Asia and the Western Pacific region, and China is rapidly expanding

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[87] Insights extracted from a briefing by Roger Cliff entitled "Future Chinese UAS Capabilities and Missions," developed in support of this research project. The briefing is based on an extensive literature search of Chinese military and technical periodicals published from 2002 to 2012.

[88] For more on China's UAS research, development, and manufacturing base, see Kimberly Hsu, with Craig Murray, Jeremy Cook, Amalia Feld, *China's Military Unmanned Aerial Vehicle Industry*; and Easton and Hsiao, *The Chinese People's Liberation Army's Unmanned Aerial Vehicle Project: Organizational Capacities and Operational Capabilities*.

[89] Boeing acquired InSitu in 2008.

the system to provide global PNT coverage by 2020.[90] The PRC is aware of the communications challenges inherent in beyond-line-of-sight C2 and has been working to develop and deploy data links with greater bandwidth and increased resistance to electronic jamming. Accordingly, the PRC is expanding its space-based C4ISR infrastructure, having launched eleven ISR satellites and three C2 satellites in 2012.[91]

Potential Operational Requirements for UAS

Like the United States, the PRC's initial UAS operational requirements focused primarily on providing tactical ISR to ground forces, hence the reverse-engineered clones of Firebees. However, the PRC's UAS needs evolved as it incorporated PGMs and other advanced military systems into an "informationalized" operational concept that includes its A2/AD strategy. In addition to the need to meet demand for ISR to support future precision strike operations, the PRC now faces two key, interrelated challenges: operating over the vast distances of the Western Pacific, and confronting potential adversaries, such as the United States and Japan, that will likely continue to possess a qualitative advantage in manned aviation and many other military systems over the near-to-medium term. The PRC also lacks air refueling capacity, which could incentivize its pursuit of aircraft with greater unrefueled ranges and endurance—attributes for which UAS may have an inherent advantage over manned platforms.

Domain awareness

Long-range ISR and maritime domain awareness (MDA) missions performed by the U.S. Global Hawk and Triton Broad-Area Maritime Surveillance (BAMS) system are two areas of particular interest for China's UAS development plans. While the PRC has been expanding its space-based ISR capacity to augment its shore-based OTH-R surveillance stations, both capabilities have operational limitations. Satellites in low-earth orbit (LEO) can provide reconnaissance support (i.e., a snapshot of a moment in time), but not surveillance information (i.e., a "stare" at a location or target over time) which is crucial for tracking warships or locating submarines in the open ocean. OTH-Rs, on the other hand, can conduct surveillance-like tracking but use long wavelengths that are not optimal for identifying targets with high levels of precision, especially in cluttered environments. LEO ISR satellite and OTH-R operations are also subject to atmospheric conditions. Thus, it is no surprise that China is interested in developing long-range UAS to provide persistent maritime surveillance for ballistic and cruise missile targeting and BDA. Chinese frigates have also been observed testing an unmanned helicopter, and China's State Oceanic Administration has announced that it intends fly UAV patrols out of eleven coastal

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90 China launched six Beidou satellites in 2012. See "Beidou Development Plan," *Beidou Navigation System*, available at http://en.beidou.gov.cn/; and Office of the Secretary of Defense, *Annual Report to Congress: Military and Security Developments Involving the People's Republic of China 2013* (Washington, DC: Department of Defense, 2013) p. 9.

91 Ibid.

bases to enhance maritime surveillance and monitor disputed islands and territories in the South China Sea.[92]

Low observability and long ranges

Perhaps more so than the United States, the PRC seems enamored of low-observable UCAVs, such as the "Lijian/Sharp Sword"[93] or the "Dark Sword" model shown at the 2006 Zhuhai air show. These aircraft could be used to suppress enemy air defenses (SEAD), conduct EW and potentially air-to-air combat missions, and provide close air support (CAS). The PRC has a particular interest in disrupting capabilities that are essential to U.S. power-projection operations in the Western Pacific, such as air refueling aircraft, AEW and Airborne Warning and Control System (AWACS) aircraft, the Joint Surveillance Target Attack Radar System (J-STARS), and Combat Logistics Force (CLF) ships. Long-range UCAVs, operating independently or from manned "mothership" aircraft and equipped with kinetic weapons or EW systems, could be an effective means of placing these key assets at risk even when operating far from the Chinese mainland.

Imposing costs

While the PRC is researching and developing advanced, long-range UAS, it is also procuring large numbers of smaller, cheaper UAS designed to impose costs on a military competitor. The best example of this is the Harpy lethal UAS. An anti-radiation UAS designed to suppress enemy air defenses by loitering above the battlespace until its sensors detect an air-search or targeting radar then conducting a kamikaze attack on the source of the radiation, the Harpy would technically not fall under the DoD definition of a UAS (since it is not designed to be recovered). Nevertheless, this type of simple, affordable capability could impose costs by forcing an opposing enemy's defensive systems to operate without active radars, or by forcing it to waste precious kinetic defensive rounds to counter relatively cheap UAS.

In the eyes of Chinese military strategists, the expendability of low-cost UAS and perception that incidents with unmanned systems may be less provocative than those involving the potential loss of life may be more marks in their favor. As China's military, economic, and political power in East Asia has waxed, it has demonstrated a willingness to take a more confrontational approach when dealing with neighbors and rivals such as the United States. The collision between a PLAAN fighter and a U.S. Navy EP-3 in April of 2001 was just one example of China's occasional forays into reckless behavior. While collisions between manned platforms such as this typically become diplomatic incidents, even intentional attacks on unmanned platforms may be overlooked. UAS may therefore become a means for China to "deniably" coerce its neighbors and rivals with less risk.

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[92] Michael Standaer, "Stage set for drone chess match in Asia-Pacific," *Global Post*, November 5, 2012, available at http://www.globalpost.com/dispatch/news/regions/asia-pacific/121102/china-drone-UAV-proliferation.

[93] The Lijian/Sharp Sword may be a clone of the U.S. Navy's experimental X-47B.

Potential UAS Development Path

China's unmanned aircraft and its expressed interest in developing future robotic capabilities for a range of missions suggest that it has a fundamentally different vision for UAS than the United States. Whereas the U.S. military has often seen unmanned systems as a subordinate adjunct to manned operations, the PLA seems to view UAS as a co-equal means to enable new operational concepts. The potential for UAS to provide targeting and BDA information as part of China's emerging long-range surveillance-strike complex is a good example, as is the inclination of the PRC to explore using UAS in missions traditionally dominated by manned platforms. Furthermore, barring a malfunction or enemy interference, unmanned systems always obey orders—an attribute that meshes well with the PRC's historically centralized command-order military doctrine.

The PLA's desire to develop a robust UAS force may also stem from the influence of the Second Artillery Corps, which commands a large inventory of conventional ballistic and cruise missiles and all of China's nuclear forces. As such, it wields great influence within the PLA. Its need for persistent long-range ISR support for targeting and BDA in denied or politically sensitive areas, combined with the lack of a manned aircraft for these missions or the aerial refueling capacity to support them, could motivate the Second Artillery Corps to support development of new UAS.

The combination of China's improving technical-industrial base, geo-strategic position, operational requirements, and institutional-cultural-political proclivities suggests that it may adopt a four "talon" vision to guide its UAS development. The first talon will likely be continued development and fielding of micro, mini, tactical surveillance, and armed UAS—similar to what DoD has been procuring for operations in Afghanistan and Iraq—to support the PLA's considerable ground forces as well as China's large internal security forces. The PRC faces military competitors—India and Russia—on at least two of its land borders, instability in North Korea and Myanmar, and internal instability in its western provinces. Low-cost airborne systems that can provide security forces with enhanced situational awareness over wide areas and in urban terrain should therefore remain a priority for China.

The second talon is likely to be the development of expendable UAS designed to coerce its neighbors while imposing costs on U.S. power-projection forces. This talon may be closely related to the first, as it could involve some of the same smaller unmanned systems designed to support the PLA and internal security forces. In some situations, these platforms could be used to skirt or even penetrate a competitor's airspace to collect ISR—and especially SIGINT—much as the U.S. military once operated Firebee and Lightning Bug drones. Alternatively, the PRC could use these assets to conduct persistent surveillance of disputed borders or maritime areas and, should China perceive a violation of its sovereignty, to harass intruders at lower levels of escalatory risk than with manned aircraft. Against a more advanced rival like the United States or Japan, smaller expendable UAS could be used as decoys to compel air defense forces to reveal themselves and possibly expend expensive defensive weapons against non-essential targets.

The third talon of the PRC's vision, and perhaps the most significant from the standpoint of this assessment, may be the desire to "leap ahead" of U.S. aerospace capabilities by exploiting the unique advantages of robotic systems. Platforms with excellent endurance and range, attributes where, *ceteris paribus,* unmanned aircraft are superior to manned aircraft, could help China to overcome the challenge of operating across the extreme distances of the Western Pacific. By combining long-range/long-endurance unmanned platforms with land-based ballistic and cruise missiles, the PRC could hope to qualitatively surpass U.S. forces in their ability to mass sensors and striking power at range. It has also been reported that Chinese "operational thinkers and scientists envision attacking U.S. aircraft-carrier battle groups with swarms of multimission UAVs in the event of conflict."[94] Moreover, Chinese analysts have discussed how the PRC could field UAS at lower cost than equivalent manned platforms, thereby allowing it to also establish a quantitative edge over competing militaries.[95] The cost factor also helps explain why the PLA is interested in unmanned aircraft that "can fly in formations, engage in aerial refueling, and take-off and land autonomously."[96] China's interest in autonomous technologies is part of its vision for developing an unmanned force that reduces the number of highly trained personnel needed to support UAS operations.

The fourth and final prong of the PRC's UAS development vision is its concerted effort to export UAS technology. Long before China became an export-driven, economic "Asian Tiger," it relied on arms exports to help fill its coffers with foreign reserves. More recently, the PRC has sought to become one of the world's premier exporters of advanced weaponry, particularly UAS. According to a recent report by Kimberly Hsu, an analyst for the U.S.-China Economic and Security Review Commission,

> Surging domestic and international market demand for UAVs, from both military and civilian customers, will continue to buoy growth of the Chinese industry. Chinese defense firms do not face the same export restrictions as top UAV-exporting countries, such as the United States and Israel. As a result, China could become a key UAV proliferator, particularly to developing countries.[97]

China's desire to build its UAS export industry could have a significant impact on the characteristics of an MPSR. First, penetrating the large global UAS market could increase the number of Chinese firms developing and manufacturing UAS and encourage them to develop innovative unmanned technologies in an effort to capture a wide range of market segments. Second, it could help Chinese firms to achieve greater economies of scale and thereby reduce unit costs of unmanned aircraft produced for the PLA. Finally, by targeting sales of its UAS to

94 Easton and Hsiao, The Chinese People's Liberation Army's Unmanned Aerial Vehicle Project: Organizational Capacities and Operational Capabilities, p. 14.
95 Cliff, "Future Chinese UAS Capabilities and Missions."
96 Easton and Hsiao, The Chinese People's Liberation Army's Unmanned Aerial Vehicle Project: Organizational Capacities and Operational Capabilities, p. 12.
97 Kimberly Hsu, et al., *China's Military Unmanned Aerial Vehicle Industry*, p. 3.

developing states (including the United Arab Emirates, Uzbekistan, Pakistan, and Myanmar),[98] China could seek to influence regional balance-of-power competitions and encourage foreign policies that create problems for U.S. military power-projection operations.

Obstacles

The outlook for China's UAS development is not entirely positive. Despite formidable industrial espionage efforts, technological challenges in the areas of automated flight control systems and propulsion—specifically advanced jet engines—are likely to continue to hamper its development of UCAVs and other advanced unmanned systems. Until such a time as autonomy and non-space-based PNT become commonplace, China's long-range UAS will likely remain just as dependent on vulnerable space-based C2 capabilities, data links, and PNT as U.S. unmanned systems.

Israel's UAS Development Path

Along with the United States, Israel has been a leader in the development and use of UAS. Its early adoption of unmanned aircraft was rooted in its need for military capabilities that could give it an advantage over larger, more populous Arab states that were armed with heavy weaponry and dedicated to the destruction of Israel.

By combining the deft use of operational art with modern military weapons systems (particularly aircraft and anti-armor capabilities), highly trained forces, and innovative operational concepts, Israel has repeatedly prevailed over its enemies over the last 50 years. Israel's ability to defeat numerically superior forces has depended in no small part on its ability to obtain superior intelligence on enemy capabilities, dispositions, and movements, which in turn required airborne ISR capabilities. Following Israel's victory during the "Six Day" Arab-Israeli War of 1967, Egypt, Syria, and other Arab states began to acquire Soviet SAM systems such as the SA-2, which were responsible for downing U.S. aircraft in Vietnam. Israel simply could not afford to suffer significant attrition from SAM attacks to either its manned aircraft or its elite cadre of pilots. During the ensuing 1967-1970 War of Attrition, Israeli losses to SAM attacks pushed it to purchase UAVs to fly reconnaissance missions over Egyptian territory. The Israeli Air Force (IAF) outfitted their newly created First UAV Squadron with the Teledyne-Ryan AQM-34 Firebee, which was the most advanced reconnaissance UAS then in operation.[99] The Firebee, renamed "Mabat" by Israel, was pressed into service in late 1971 and was followed shortly thereafter by Northrop's Chukar decoy drone, which the Israelis dubbed "Telem."

Together with manned aircraft, the Firebee and Chukar provided Israel with a potent force to counter enemy air defense systems. Israel used Firebees to collect intelligence on enemy positions and radar frequencies prior to planned airstrikes. Armed with this knowledge, the IAF

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98 Christopher Bodeen, "China Emerging as a New Force in Drone Warfare," *Associated Press*, May 3, 2013.

99 *First UAV Squadron: History* (Tel Aviv, Israel: Israeli Air Force), available at http://www.iaf.org.il/4968-33518-en/IAF.aspx.

would launch Chukar decoys to induce SAM sites to fire their weapons at what they believed to be an Israeli strike package. Israeli strike aircraft would then use air-to-ground and anti-radiation missiles to destroy the SAM launchers. The IAF refined and enhanced these tactics with the addition of the Israeli Aerospace Industries (IAI) Scout, a domestically produced UAS that used an early type of datalink to provide Israeli commanders with real-time intelligence. Firebees, Chukars, Scouts, and manned aircraft proved to be a devastating combination during the First Lebanon War in 1982. During one engagement over the Bekaa Valley, IAF manned and unmanned aircraft working in unison disabled nineteen Syrian SAM batteries, which allowed follow-on Israeli fighters to destroy twenty-two Syrian fighters without the loss of a single IAF manned aircraft.[100] These operational successes helped renew the U.S. military's interest in unmanned aircraft and led it to purchase from Israel what was to become the RQ-2 Pioneer.

Since the First Lebanon War, Israel has increased the use of UAS to support ground operations, including the invasions of Lebanon in 2006, Operation Cast Lead in Gaza in 2008-2009, and military responses to various Palestinian *intifadas* and harassment from terrorist groups such as Hamas, Islamic Jihad, and Hezbollah.

Current UAS Fleet and Developmental Programs

Given that the success of Israel's UAS operations influenced the development of the U.S. military's UAS force, and the fact that both states have procured UAS primarily for ISR missions, it is not surprising that the characteristics of their current forces are remarkably similar.

Today, the IAI Eitan is Israel's largest and most advanced UAS.[101] The Eitan, which purportedly has an endurance of thirty-six hours,[102] is slightly larger than the MQ-9 Reaper and smaller than the RQ-4B Global Hawk. Its predecessor the IAI Heron, which splits the difference in size between and MQ-9 and MQ-1 Predator, has greater persistence than either with over forty hours of endurance.[103] The Elbit Hermes 450 is UAS smaller than the Predator and can fly for seventeen hours.[104] The IAF is procuring Elbit's larger variant of the Hermes, the 900 model,

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[100] Ralph Sanders, "UAVs: An Israeli Military Innovation," *Joint Forces Quarterly*, Winter 2002-2003, p. 115.

[101] Confusingly, the Eitan is referred to as the Heron TP when sold internationally, as it is in many ways an evolved and enlarged Heron, much like the MQ-9 Reaper was initially dubbed the "Predator-B."

[102] "Heron TP MALE UAV System," *Israel Aerospace Industries*, p. 1, available at http://www.iai.co.il/sip_storage/FILES/6/35766.pdf. Other sources list considerably longer endurance of up to seventy hours. See Arie Egozi, "Israeli Heron TP crashes as test flight goes wrong," *Flight International*, January 30, 2012, available at http://www flightglobal.com/news/articles/israeli-heron-tp-crashes-as-test-flight-goes-wrong-367527/.

[103] "Heron Family," *Israel Aerospace Industries*, available at http://www.iai.co.il/18900-en/BusinessAreas_UnmannedAirSystems_HeronFamily.aspx. Again, other sources list greater endurance for the Heron. See "UAVs at the Forefront of Future Warfare," *Airforce-Technology*, October 6, 2009, available at http://www.airforce-technology.com/features/feature65494/; and Greg Goebels, "Unmanned Aerial Vehicles: Israel," available at http://www.vectorsite net/twuavi html.

[104] "Hermes 450 Multi-role High Performance Tactical UAS," *Elbit Systems – Unmanned Aircraft Systems*, 2012, available at http://62.0.44.103/Elbitmain/files/Hermes_450_(2012).pdf.

which will be similar in size and shape to the Predator and have an endurance of thirty-six hours similar to the Reaper. Israel also operates a variety of mini and micro UAS and the Harpy lethal UAS that can autonomously hone on and strike radar emitters.

In addition to their similar design characteristics, Israeli and U.S. unmanned aircraft carry comparable sensors, e.g., EO/IR, SAR, ground moving target indicators (GMTI), and signals intelligence, and use similar methods of command and control. Israeli unmanned aircraft operations therefore suffer from some of the same problems experienced by the United States, including personnel shortages which have led some observers to suggest that the IAF should hire contractors much as DoD did as it grew its UAS force.[105]

Operational Requirements for UAS

Like the United States, Israel has acquired its current UAS fleet largely to support ground operations and persistent CT operations in relatively permissive air environments. UAS have therefore helped to meet operational requirements for persistent overhead ISR coverage and, although Israel does not officially confirm this, CT strike missions.[106] There are a number of potential applications for Israel's UAS beyond ISR and limited strikes.

Long-range strike

Iran has long posed a threat to Israel via its support of proxies such as the terrorist groups Hezbollah and Hamas, but its burgeoning inventory of ballistic missiles combined with its nuclear weapons program could pose an existential threat to Israel. Should Israel attack Iran's nuclear program directly, Israeli air forces would need to be able to reach targets deep inside Iran, penetrate the air defenses that Iran has erected around its nuclear facilities, and be able to carry heavy munitions such as the GBU-28 bunker-buster to penetrate hardened and deeply buried WMD facilities. Given the risk of losing pilots over hostile territory and the political fallout that

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105 Major Kevin Gambold, Royal Air Force, quoted in "Operator overload to blame for Israel's UAV problems," *Defence Report*, February 12, 2012, available at http://defencereport.com/operator-overload-to-blame-for-israels-uav-problems/.

106 Associated Press, "Israel's air force developing drones to replace aircraft," *Fox News*, April 21, 2013, available at http://www foxnews.com/world/2013/04/21/israel-military-official-says-drones-to-replace-piloted-warplanes-within/. Some have speculated that Israel fielded armed UAS during the 2006 war with Lebanon. See Peter La Franchi, "Israel fields armed UAVs in Lebanon," *Flight International*, August 8, 2006, available at http://www.flightglobal.com/news/articles/israel-fields-armed-uavs-in-lebanon-208315/. Numerous sources cite videos taken from the sensors of Israeli "drone strikes" without conclusive proof that the weapon(s) in question were actually launched from UAS. See Fares Akram and Isabel Kershner, "Israeli Drone Strike Kills Militants in Southern Gaza," *New York Times*, October 29, 2011, available at http://www.nytimes.com/2011/10/30/world/middleeast/israeli-drone-strike-kills-militants-in-gaza.html; Nick Meo, "How Israel killed Ahmed Jabari, its toughest enemy in Gaza," *The Telegraph*, November 17, 2012; and Noah Schachtman, "Israel Kills Hamas Leader, Instantly Posts It to YouTube," *Wired Danger Room*, November 14, 2012. Given the military necessity to shorten the sensor-shooter loop to hit time sensitive targets, and size, payload capacity, and wing hardpoints of Israeli UAS, it would be surprising if Israel had *not* armed its unmanned aircraft.

would ensue, using unmanned aircraft to support or execute long-range strikes would seem to be of great interest for Israel.

Israel's current UAS, however, are not well suited for supporting long-range strike operations into contested airspace. Although the Eitan, Heron, and perhaps the forthcoming Elbit 900 have the range to reach Iran and return, their lack of stealth would make it nearly impossible for them to slip undetected through neighboring airspace. Even if they were able to reach Iran, their non-stealthy signatures would likely be detected by Iranian air defenses. Unlike manned aircraft, these UAS are unable to autonomously fly low to the ground and use terrain to mask themselves, or to maneuver around pop-up air defense threats. Thus, while Israel's current UAS have the on-board sensors needed to provide ISR and BDA support for strikes on Iran and other potential regional opponents, using them could deny IAF strike packages the critical advantage of surprise.[107] Moreover, the Eitan, Heron, and Elbit lack the payload capacity to carry bunker busting PGMs that could be needed to destroy fortified targets such as Iran's WMD facilities.

It is also conceivable that UAS equipped with EW systems could support future Israeli air operations. Israel has long used sophisticated EW weapons and tactics to compensate for its lack of low-observable aircraft. Some of Israel's current UAS may not be well suited for these missions, since they lack sufficient power for EW jammers.[108] IAI's anti-radiation lethal Harpy and its successor the Harop, on the other hand, are designed for SEAD missions. Interestingly, the Harop is purported to be air-launchable.[109] With a range of 1000 km[110] and a weight of approximately 300 pounds,[111] multiple Harops could be mounted aboard an Eitan UAS (which has a payload of roughly 2,200 pounds) or a manned aircraft, thereby giving Israel a long-range

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[107] According to various reports, Israel has used its UAS to support strikes against weapons shipments in Sudan. Sudan's airspace is undefended relative to Iran, however, and the strike packages were accompanied by EW jammers and followed flight paths over the Red Sea that were out of the range of Egyptian radars. See "Report: Israel used unmanned drones to attack Sudan convoys," *Haaretz*, March 29, 2009, available at http://www.haaretz.com/news/report-israel-used-unmanned-drones-to-attack-sudan-convoys-1.273099; and "How Israel Foiled an Arms Convoy Bound for Hamas," *Time*, March 30, 2009.

[108] Barbara Opall-Rome, "Israel's Heavy-Hauling UAVs Are Ready for Battle," *Defense News*, January 25, 2010, available at http://www.defensenews.com/article/20100125/DEFSECT01/1250301/Israel-s-Heavy-Hauling-UAVs-Ready-Battle.

[109] "Harop Loitering Munitions UCAV System, Israel," *Airforce-Technology*, available at http://www.airforce-technology.com/projects/haroploiteringmuniti/.

[110] The cited endurance for both the Harpy and the Harop is six hours. A speed of 185 kilometers per hour (equivalent to that of the Harpy) would give the Harop a range of approximately 1,110 kilometers. Although achieving the aircraft's maximum endurance is unlikely at top speeds, a range near 1,000 kilometers is not impossible, particularly if the system is air-launched and does not have to waste power gaining speed or altitude. See "Harop Loitering Munitions UCAV System, Israel," *Airforce-Technology*; and "Israel special - IAI's Harop ups the stakes on SEAD missions," *Flight International*, February 11, 2008, available at http://www.flightglobal.com/news/articles/israel-special-iais-harop-ups-the-stakes-on-sead-missions-221439/).

[111] "Harop Loitering Munitions UCAV System, Israel," *Airforce-Technology*. The weight of the Harop is similar to that of the Harpy, which weighs 135 kilograms, or approximately 300 pounds. See Greg Goebel, "Unmanned Aerial Vehicles: Israel."

SEAD capability. This could free up limited manned aircraft for offensive operations rather than suppressing air defenses.

Counter-missile operations

Although the manned air threat to Israel has decreased since the 1970s, threats from ballistic and cruise missile attacks as well as G-RAMM strikes have multiplied and are likely to increase in an MPSR. Apparently, Israeli has considered using loitering UAS armed with missiles to attack ballistic missiles in their boost phases,[112] although their current UAS may lack the capability attributes needed for this CONOPs. Intercepting a ballistic missile during its boost phase requires the ability to detect its launch and then almost immediately fire an interceptor on a trajectory that does not require it to “chase” the target. To intercept missiles launched from border areas in Iran, for instance, a UAS would need to loiter very close to Iranian airspace and carry a large air-to-air missile. The Eitan, Israel’s largest UAS, lacks the stealth to loiter over defended airspace and has a maximum payload capacity of 2,200 pounds, which would limit the size and number of interceptors it could carry. It is possible that future armed UAS could be used to counter short-range rockets and missiles fired by Hezbollah and Hamas, since this mission would allow IAF aircraft to loiter within range of potential launch sites.

Offshore defense

Finally, while maintaining a decisive advantage in the air and ground domains has dominated Israeli strategic thinking over the last fifty years, the maritime domain of the Eastern Mediterranean is increasingly becoming more vital for Israel’s economy. The discovery in 2009 and 2010 of the Tamar and Leviathan gas fields underneath Israeli waters in the Eastern Mediterranean (see illustration below)[113] prompted Eli Glickman, chief operating officer of Israel electric, to claim that "Israel was a state from the bible of milk and honey, now we're going to be a state of milk, honey and gas."[114]

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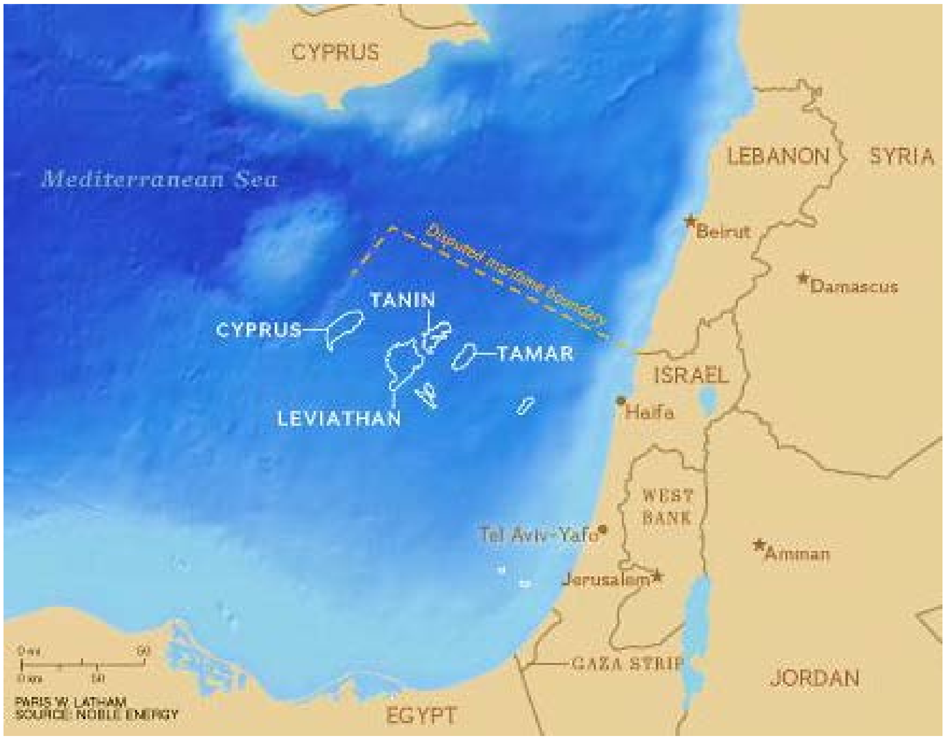
[112] Sanders, “UAVS: an Israeli Military Innovation,” p. 117; and David A. Fulghum, “UAV-based Missile Interceptors Reconsidered,” *Aviation Week: Ares, a Defense Technology Blog*, June 4, 2009; and Joe Pappalardo, “How Israel's Biggest Drone Could Take Out Iranian Nukes,” *Popular Mechanics*, February 23, 2010.

[113] Sharon Udasin, "New Natural Gas Wealth Means Historic Change for Israel," *National Geographic News*, July 3, 2012, available at http://news nationalgeographic.com/news/energy/2012/07/120703-israel-new-natural-gas/.

[114] Quoted in Sam Kiley, “Israel Gas Bonanza: New Field Discovered,” *Sky News*, May 26, 2013.



The fields, which are estimated to contain roughly 26 trillion cubic feet of natural gas, could supply Israel with domestic energy for decades with ample supply left over for export.[115] Not surprisingly, Israel's neighbors Cyprus, Lebanon, and Turkey have all made claims on the natural gas finds in the Eastern Mediterranean, and the Palestinian Authority has started negotiations over exploration and drilling off the coast of Hamas-controlled Gaza.[116]

While understandably jubilant over this energy windfall, the Israeli government is deeply concerned about defending expensive and strategically vital infrastructure associated with the development and production of liquid natural gas.[117] According to Captain Ilan Lavi, head of the Israeli Navy's planning department, "We have to build an entire new defensive envelope… But you can't have a defence system that costs more to build than the gas itself."[118] The proximity of

115 Isabel Kershner, "Israel Taps an Offshore Natural Gas Field," *New York Times*, March 31, 2013, available at http://www.nytimes.com/2013/04/01/world/middleeast/israel-turns-on-natural-gas-flow-at-offshore-site html?_r=0; Sharon Udasin, "New Natural Gas Wealth Means Historic Change for Israel;" and Calev Ben-David, "Gas Adds Energy to Israeli Diplomacy Dominated by Conflicts," *Bloomberg*, June 12, 2013, available at http://www.bloomberg.com/news/2013-06-11/israeli-gas-adds-energy-to-foreign-policy-dominated-by-conflicts.html.

116 Calev Ben-David, "Gas Adds Energy to Israeli Diplomacy Dominated by Conflicts;" and "Israel and PA discuss Gaza offshore gas plans," *al-Jazeera*, September 23, 2012, available at http://www.aljazeera.com/news/middleeast/2012/09/201292316466184221.html.

117 The eighteen wells built by the end of 2013 are estimated to cost $1.8 billion. Ari Rabinovitch, "Israel's navy gears up for new job of protecting gas fields," *Reuters*, April 1, 2013, available at http://www.reuters.com/article/2013/04/01/israel-navy-natgas-idUSL5N0CN01P20130401.

118 Rabinovitch, "Israel's navy gears up for new job of protecting gas fields."

oil rigs to the shore, as well as the need for transfer stations and pipelines on land, places this critical infrastructure within range of Hezbollah and Hamas rockets and missiles, to say nothing of the cruise missiles now in Syria's arsenal, such as the Yakhont/P-800 Oniks supersonic ASCM.[119]

Given the small size of the Israeli Navy and the inherent difficulty of protecting large areas with point air and missile defenses such as the David's Sling or the Barak-8, UAS are likely to play a key role in monitoring and defending Israel's dispersed offshore infrastructure.[120] With point defenses at key nodes and mobile quick-reaction forces as backstops, loitering armed UAS could work as missile hunter/killers, monitoring the coastline and negating threats with precision strikes before they can be launched or once they are in flight.

Potential UAS Development Path

The fact that Israel's current UAS fleet was developed to support requirements similar to the U.S. military's urgent operational needs over the last decade—i.e., ground combat against irregular forces—would seem to suggest that its UAS development path would continue to parallel that of the United States. A deeper analysis indicates that Israel may have a fundamentally different attitude toward the future potential of UAS, borne largely out of strategic necessity.

Israel has a clear understanding that UAS (and unmanned systems generally) can act as force-multipliers for its demographically and financially challenged military. Its early adoption of UAS, interest in alternative UAS missions such as BMD, and apparent willingness to replace manned platforms with unmanned aircraft suggests it will continue to pursue UAS and related operational concepts that could enhance its military posture. Given the aforementioned inability of Israel's current UAS to avoid detection by modern air defenses, for example, it makes sense that it would develop new low-observable unmanned platforms for a range of missions. Whenever technologically feasible, the IAF appears willing to replace manned platforms with UAS. According to a high-ranking Israeli officer, "there is a process happening now of transferring tasks from manned to unmanned vehicles…this trend will continue to become stronger."[121] To illustrate this trend, by 2011 IAF UAS were flying more hours than manned aircraft and, as of

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119 Michael R. Gordon and Eric Schmitt, "Russia Sends More Advanced Missiles to Aid Assad in Syria," *New York Times*, May 16, 2013, available at http://www nytimes.com/2013/05/17/world/middleeast/russia-provides-syria-with-advanced-missiles.html?pagewanted=all.

120 "Israel mulls missile defense for gas rigs," *United Press International*, April 10, 2012, available at http://www.upi.com/Business_News/Security-Industry/2012/04/10/Israel-mulls-missile-defense-for-gas-rigs/UPI-17141334075177/.

121 As one U.S. government official has noted, "You would expect that stealth is something they'd be interested in, particularly in light of the threats they face." See "Israel's air force developing drones to replace aircraft," *Fox News*, April 21, 2013, available at http://www foxnews.com/world/2013/04/21/israel-military-official-says-drones-to-replace-piloted-warplanes-within/.

July 2013, they were flying more sorties as well.[122] By 2030, it is possible that the IAF will operate more UAS than manned aircraft as a total percentage of their fleet.[123]

What Israel may lack, however, is the means to fund large-scale UAS experimentation and the strategic breathing space to pursue innovations that do not promise immediate payoffs. Israel's defense budget is undergoing cuts at the same time that political instability in the Levant and Iran's pursuit of nuclear weapons are threatening its security. Israel could subsidize its future UAS investments by taking advantage of the export market. Israel's UAS exports, which totaled $4.6 billion from 2005 to 2012, may grow to be roughly twice the value of U.S. unmanned aircraft exports by 2014.[124] Israel might therefore continue to invest in UAS technologies that it may be able to market globally, including greater autonomy for unmanned aircraft and supporting PED architectures that could reduce manpower costs. Over time, Israeli exports could help proliferate UAS and contribute to the emergence of a robotic revolution. At the same time, Israel may have little interest in exporting more sophisticated low-observable, long-range UAS, since proliferation of these capabilities could constitute a significant threat to its own security.

Iran's UAS Development Path

Despite its bombastic propaganda, Iran's UAS capabilities are quite modest. Most of its current UAS, including the Mohajer and Ababil models, may be best suited for performing tactical ISR missions or acting as "guided" lethal UAS (i.e., as land-attack cruise missiles). It is apparent, however, that UAS are increasingly becoming a key part of the mix of military capabilities that Iran is pursuing to support its "hybrid" A2/AD strategy.[125] In particular, new unmanned aircraft could supplement Iran's rapidly deteriorating manned aircraft and provide better targeting information for its ballistic missiles and land- and sea-based maritime exclusion capabilities.

Current UAS Fleet and Developmental Programs

Reflecting the lower cost and technological barriers to developing and manufacturing UAS, Iran's unmanned aircraft industrial base far outstrips that for manned aircraft. According to the unmanned systems trade group UVS International, Iran has approximately 41 civil, military, or

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[122] "Age of drones: Israeli Air Force now flying more unmanned than manned sorties," *World Tribune*, July 5, 2013, available at http://www.worldtribune.com/2013/07/05/age-of-drones-israeli-air-force-now-flying-more-unmanned-than-manned-sorties/.

[123] Arie Egozi, "Israel increases use of unmanned systems," *Flight International*, November 3, 2011, available at http://www.flightglobal.com/news/articles/israel-increases-use-of-unmanned-systems-364194/.

[124] Israeli UAS exports between 2005 and 2012 totaled $4.6 billion, whereas U.S. exports fell between $2 and $3 billion. See Tia Goldenberg, "Israel leads global drone exports as demand grows," *Yahoo News*, June 5, 2013, available at http://news.yahoo.com/israel-leads-global-drone-exports-demand-grows-194424173.html. Also see Jane Wells, "US leads in arming world; but China, Russia defense business rising," *CNBC*, June 26, 2013, available at http://www.nbcnews.com/business/us-leads-arming-world-china-russia-defense-business-rising-6C10457030.

[125] For a more detailed analysis of Iran's emerging "mosaic" A2/AD strategy and its potential impact on future U.S. power-projection operations in the Persian Gulf, see Gunzinger and Dougherty, *Outside-In: Operating from Range to Defeat Iran's Anti-Access and Area-Denial Threats*, pp. 21-52.

dual-use UAS variants fielded or in development. Of those, 30 are micro/mini UAS while the remaining 11 are short-range tactical surveillance, armed, or lethal UAS.[126]

Ironically, Iran's larger UAS seem to be heavily influenced by unmanned aircraft designed by Israel and the United States. Iran's Hamaseh, Shahed, and Sarir UAS appear to be modeled on the Tadiran Electronic Industries Tadiran Mastiff (a progenitor of the RQ-2 Pioneer), the Elbit Systems Hermes 750, and Israeli Air Industries' RQ-5 Hunter UAS, respectively.[127] Iran has also developed the "Karrar" unmanned aircraft which bears a superficial resemblance to older U.S. target drones. The mission of the Karrar is unknown, but Iran claims that it will carry up to 500 kilograms of weapons including cruise missiles, and have a range of approximately 1,000 kilometers.[128]

Future UAS Development Path

Iran's A2/AD strategy hinges on the use of ballistic and cruise missiles, irregular proxy forces, maritime denial systems, and possibly WMD. Not surprisingly, it is developing UAS that could improve the effectiveness of these capabilities.

Iran's ballistic missile arsenal provides the bulk of its conventional capacity to strike targets outside of its borders. In a regional conflict, Iran could use its short- and medium-range ballistic missiles to attack population centers and other counter-value targets as a means of coercing states that might consider hosting U.S. power-projection forces. Unlike China, Iran's ballistic missiles currently lack the accuracy needed to strike military bases and forces effectively. DoD reports suggest that Iran is attempting to address this shortfall.[129] Iran may be able to use UAS to acquire targeting information and post-strike BDA in support of a missile offensive. For Iran to fully develop an RSC that integrates UAS and ballistic missile operations, however, it will need to substantially upgrade its long-range C2 and PNT capabilities as well as its missile guidance systems. To provide the former, Iran could deploy high-altitude UAS to act as C2 relays for missile guidance corrections. For the latter, it could eventually install maneuverable warheads with multi-modal seekers on its ballistic missiles. Iran could also arm its UAS to conduct long-range strikes, as the Karrar variant suggests, or use large numbers of low-cost, "expendable" UAS as de-facto land-attack cruise missiles.

Evidence gleaned from conflicts in Lebanon in 2006 and Syria during the past several years suggests that Iran, likely via the Quds Force of the Iranian Revolutionary Guard Corps (IRGC),

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[126] UVS International uses a slightly different taxonomy than that used in this paper. See *2013 RPA Yearbook – UAS: The Global Perspective* (Paris, France: UVS International, 2013), pp. 179-180.

[127] "Teherans' Drone Fever," *Defense Update*, May 11, 2013, available at http://defense-update.com/20130511_teherans-drone-fever.html.

[128] Robert Wall, "Iran Unveils Karrar UAV," *Aviation Week: Ares, a Defense Technology Blog*, August 23, 2010; "Iran Unveils Domestically-Built Drone," *Voice of America*, August 21, 2010; and "Iran unveils first bomber drone," *BBC News*, August 22, 2010.

[129] *2012 Annual Report on the Military Power of Iran* (Washington, DC: United States Department of Defense, 2012), p. 1.

has equipped its proxies with unmanned aircraft.[130] Reports from both conflicts suggest that Iranian-supplied UAS provided vital ISR information regarding the movement of opposing forces to Hezbollah and Syria's Assad regime. Should Iran continue to develop more sophisticated armed and lethal UAS, it is possible that its proxies could use them to expand their use of the air domain. The presence of UAS in the hands of Iranian state and non-state proxies may increase the need for the United States and its regional partners to develop the means to counter them.

Iran has indicated it will use UAS to improve its sea-denial capability and extend it out into the Gulf of Oman and the Arabian Sea. Within the confined and cluttered waters of the Strait of Hormuz or the Persian Gulf, UAS could give Iranian fast-attack craft and sea- and shore-based ASCM launchers better situational awareness and enable coordinated attacks on discrete targets. UAS could provide maritime domain awareness and target cueing for longer-range ASCM strikes. Iran has also made the dubious claim that it is developing an ASBM capability akin to that deployed by China. Should this capability become operational, UAS could become a key means of providing targeting information for attacks on military and commercial vessels located hundreds of miles off the coast of Iran.

Iran's current lack of beyond-line-of-sight C2 and PNT would hamper UAS operations that extend beyond its littoral areas. UAS with improved guidance systems and autonomy could execute independent missions rather than act as "spotters" for missile attacks and manned aircraft. For instance, Iran might arm low-cost UAS with ASCMs, or turn them into "kamikaze" weapons to strike at ships directly. Should Iran field sufficient numbers of these UAS, they could be used in swarm attacks to overwhelm the air defenses of U.S. warships.

Iran has long sought to augment its defenses against enemy aircraft. In the near term, it is possible that Iran may attempt to supplement its aging fighter force by arming UAS with heat-seeking air-to-air missiles much as the United States once armed an MQ-1 Predator with Stinger missiles. While these UAS would individually be easy kills for a modern manned fighter, if deployed in sufficient numbers, swarms of UAS armed with air-to-air weapons might be able to greatly complicate enemy air operations at relatively low cost. Future UAS armed with non-kinetic systems such as EW jammers and high-power microwave weapons could provide the Iranian regime with the means to degrade an enemy's use of the electromagnetic spectrum.

In summary, Iran appears to be pursuing a UAS force as an alternative to manned aerospace capabilities that are currently beyond its means. Iran's air force is aging, as most of its manned aircraft were purchased from the United States during the Shah's regime or acquired serendipitously when Iraq evacuated some of its MiG-29s to Iran during the First Gulf War.

[130] See Peter La Franchi, "Iranian-made Ababil-T Hezbollah UAV shot down by Israeli fighter in Lebanon crisis," *Flight International*, August 15, 2006; Nick Paton Walsh, "Iranian drones guiding Syrian attacks, rebels say," *CNN*, October 31, 2012; and David Axe, "Satellite Spots Syria's Iranian-Made Drones," *Wired Danger Room*, July 23, 2012.

Keeping its combat aircraft ready to fly and its pilots trained are major challenges for Iran given United Nations sanctions that nearly prevent it from acquiring spare parts from foreign sources.

The lower technological and cost barriers to developing and fielding UAS compared to manned military aircraft and space-based systems could allow Iran to create new offensive and defensive capabilities. In the near term, Iran is likely to use unmanned capabilities to support its current operational concepts. As Iran's UAS become more advanced, they may play a more central role in Iran's military doctrine. This transition would likely accelerate were Iran to develop or acquire more advanced PNT, C2, and autonomous capabilities that would permit it to field UAS that can strike with precision at beyond-line-of-sight ranges.

Russia's UAS Development Path

Given that the former Soviet Union intellectually fathered what is now known as the RMA, one might expect to see significant Russian interest in pursuing the advantages of UAS as a means of "fundamentally changing the character of future warfare."[131] At the time of the Soviet Union's collapse, it possessed some of the world's most advanced manned aircraft, but it was also decades behind the West in the development of microprocessors and other technologies that could help it to develop and operate a force of UAS. Thus, while unmanned aircraft have the potential to become critical enablers of reconnaissance-strike operations, until recently they remained a niche capability for Russia's military.

Current UAS Fleet and Developmental Programs

Post-Soviet Russian military theorists have posited that Russia must adopt asymmetric operational concepts and tactics to counter the conventional aerospace-strike superiority of the United States and North Atlantic Treaty Organization (NATO). Russian analysts and industrialists have argued that 90 percent of the outcome of future conventional armed conflicts will hinge on the success of air operations.[132] This school of thought may help explain why Russia's current rearmament priorities (nuclear systems are prioritized above all else) include new space, air defense, and air capabilities, including UAVs.

Two factors in particular may have sparked Russia to change its opinion on UAS: the success of U.S. and Israeli unmanned aircraft operations throughout the 2000s, and the shocking problems Russia encountered during its 2008 invasion of Georgia. As to the latter, although Russian forces

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[131] As Barry Watts has explained, "prominent Soviet military leaders and theorists had accepted that the integration of accurate conventional munitions, wide-area sensors, and automated control systems would enable reconnaissance-strike complexes to approach the effectiveness of nuclear weapons against many targets, thereby fundamentally changing the character of future warfare." Barry D. Watts, *Broader Implications of a Maturing Precision-Strike Regime* (Washington, DC: Center for Strategic and Budgetary Assessments, 2012), pp. 5-6.

[132] From a briefing entitled "Russian UAS Development" by Dr. Steven Blank, Research Professor of National Security Affairs at the Strategic Studies Institute, U.S. Army War College, developed for the second UAS workshop supporting this project.

quickly defeated their opponent, the operation exposed how decrepit Russia's post-Soviet military had become. Perhaps nothing illustrated this better than the fact that Georgia, a country with a population of 4.4 million people and a gross domestic product (GDP) of $12.7993 billion in 2008, fielded a more capable UAS fleet than Russia, a nation of 142 million people and a GDP of $1.66 trillion.[133] According to Ariel Cohen and Robert E. Hamilton, authors of a Strategic Studies Institute assessment of the conflict:

> Russian commanders said the images [the Russian-made Pchela UAV] sent were so poor, they were useless and it [the UAV] "flew so low you could hit it with a slingshot and it roared like a BTR [armored vehicle].[134]

To address this sorry state of affairs, Russia signed a contract with Israel in 2009 to acquire an estimated 60 Israeli-built short-range Bird Eye 400, I-View Mk150, and Searcher II UAS. These systems were already borderline obsolescent at that time, and it is so far unclear if Israel will sell Russia its more advanced Heron TP/Eitan UAS.[135] Russia is also beginning to develop its own UAS models, apparently with mixed results. In 2010, a Russian-designed tactical surveillance UAS called the Vega Stork crashed spectacularly on takeoff, thereby ending the program.[136] More recently, Russia announced that it will field a "strike UAV" by 2014.[137] This aircraft is believed to be the Tranzas-Sokol Altius, a dual-engine, turboprop aircraft roughly comparable to the MQ-9 Reaper.

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133 Population and GDP data from the World Bank, June 9, 2013, available at https://www.google.com/publicdata/explore?ds=d5bncppjof8f9_&met_y=sp_pop_totl&hl=en&dl=en&idim=country:GEO:ARM#!ctype=l&strail=false&bcs=d&nselm=h&met_y=sp_pop_totl&scale_y=lin&ind_y=false&rdim=region&idim=country:GEO:RUS&ifdim=region&hl=en_US&dl=en&ind=false, and https://www.google.com/publicdata/explore?ds=d5bncppjof8f9_&met_y=ny_gdp_mktp_cd&hl=en&dl=en&idim=country:GEO:ARM#!ctype=l&strail=false&bcs=d&nselm=h&met_y=ny_gdp_mktp_cd&scale_y=lin&ind_y=false&rdim=region&idim=country:GEO:RUS&ifdim=region&hl=en_US&dl=en&ind=false.

134 Ariel Cohen and Robert E. Hamilton, *The Russian Military and the Georgia War: Lessons and Implications* (Carlisle, PA: Strategic Studies Institute, 2011), p. 73.

135 See David Axe, "Russian Drones Lag U.S. Models by 20 Years," *Wired Danger Room*, August 6, 2012, available at http://www.wired.com/dangerroom/2012/08/russian-drones/; Spencer Ackerman, "Will Israel Sell Russia Its Prized Monster Drone?" *Wired Danger Room*, January 18, 2011, available at http://www.wired.com/dangerroom/2011/01/will-israel-sell-russia-its-prized-monster-drone/; and "Israel and Russia in UAV Deal," *Defense Industry Daily*, May 30, 2011.

136 Vega has other mini-UAS and tactical surveillance UAS that look suspiciously similar to the Israeli UAS that Russia has been importing since 2009. See Stephen Trimble, "Crash that dashed Russia's UAV hopes finally revealed," *Flightglobal: DEW Line*, September 18, 2011, available at http://www.flightglobal.com/blogs/the-dewline/2011/09/video-crash-that-dashed-russia html.

137 Russia's Ministry of Defense has claimed the system would be in service by the end of 2014. See "Russian Army to Receive First Indigenous Strike UAV in 2014," *RIA Novosti*, June 28, 2012, available at http://en.rian.ru/military_news/20120628/174289204 html. More recent reporting suggests the aircraft will begin flight testing in 2014. See Alexander Zudin, "Secret Russian UAV design revealed," *Flight International*, February 13, 2013, available at http://www flightglobal.com/news/articles/pictures-secret-russian-uav-design-revealed-382274/.

Potential Future UAS Development Path

In the near-term, Russia will likely continue to develop of mini/micro, tactical surveillance, and armed UAS suitable to support its internal security forces and limited power-projection operations similar to the invasion of Georgia.[138] In the long run, it is probable that Russia will invest in programs that will help it to catch up with the unmanned systems technologies of its competitors. President Vladimir Putin has declared his personal support for this more capable UAS force:

> We need a program for unmanned aircraft. Experts say this is a most important area of development in aviation… [We] need a range of all types, including automated strike aircraft, reconnaissance and other types.[139]

Accordingly, Russia intends to invest $13 billion over the next eight years as part of a large-scale effort to develop:

- a series of light, medium and heavy-weight MALE UAS for reconnaissance, strike, and transport missions including the Tranzas-Sokol Reaper-class UAS and the Tranzas-Sokol Inokhodyets Predator-class UAS;
- a strategic surveillance UAS capable of flying 350 miles and equipped with advanced datalinks;
- a rotary-wing UAS intended for transportation and assault missions; and
- an unmanned design for the follow-on to Russia's PAK-DA strategic bomber, with a projected 2040 fielding date.[140]

Russia's growing interest in robotic systems could lead to the development of advanced, long-range UAS and UCAVs as components of a new reconnaissance-strike complex that leverages Russia's large constellations of communications and PNT satellites. Supporting precise air and missile strikes with discrete sensors and C2 systems was the embodiment of the original Soviet RSC concept. Operational experience has shown that co-locating sensors and strike capabilities—i.e., by arming sensor-equipped UAS with PGMs or operating ISR UAS and manned strike aircraft in hunter/killer pairs—can shorten the "find, fix, track, target, engage, and assess" targeting chain. By deploying penetrating UCAVs or stealthy strategic surveillance UAS that can communicate directly with manned or unmanned strike platforms, Russia could gain an

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138 Blank, "Russian UAS Development."

139 "Putin Calls for New Long-Range Bomber and UAVs," *RIA Novosti*, June 14, 2012, available at http://en.rian.ru/military_news/20120614/174031126 html.

140 See "Russia Could Deploy Unmanned Bomber After 2040 - Air Force," *RIA Novosti*, August 2, 2012, available at http://en.ria ru/military_news/20120802/174929681.html; and Dave Majumdar, "Russia considering unmanned strategic bomber for deployment in the 2040s," *Flightglobal: DEW Line*, August 28, 2012, available at http://www.flightglobal.com/blogs/the-dewline/2012/08/russia-considering-unmanned-st.html.

advantage over UAS forces that are optimized for ISR operations in permissive conditions around its "near abroad" periphery in the Caucasus and Central Asia.

Thus, while Russia's near-term plans for its UAS force seems modest, over the long term, Russian UAS could prove to be "wildcards" that help stimulate the eventual maturation of a robotic regime. Russia possesses the space-based C2 and PNT capabilities needed to support long-range UAS operations, and its aerospace industry has the talent and experience needed to design advanced military aircraft. If Russia is successful in its push to field a new generation of UAS, it could achieve its informal goal of capturing 3 to 5 percent of the global UAS market by the early 2020s.[141] Contracts with Vietnam to build mini-UAVs, ostensibly for civilian use, and more lethal unmanned systems designated for sale to Belarus and Kazakhstan, are examples of Russia's continuing interest in expanding its UAS sales.[142] Finally, it is entirely possible that Russia could advance the sophistication of its own unmanned systems in exchange for exports or technology transfers in other areas—such as SAMs, propulsion, avionics, and stealth, and ballistic missiles—where Russian technology remains state-of-the art.[143]

Summary

Competitor militaries are pursuing unmanned systems that could allow them to develop an airborne precision-strike capability potentially at lower cost than creating sophisticated manned air forces. Global trends in UAS programs illustrate that America's military competitors may not view unmanned systems as capabilities to be used only as information gatherers in support of manned aircraft and other weapons systems. Iran in particular sees UAS as a means of overcoming its current limitations in long-range ISR, command and control, and precision strike, while China has already developed "an extensive and organizationally complex UAV infrastructure" to further its designs to "become a world-class leader in unmanned technology."[144]

While the U.S. military's advantages in UAS design and employment are significant at present, they are not insurmountable. Absent investments in a different mix of UAS capabilities, DoD

[141] According to Sergey Kornev, head of Rosoboronexport's Department of Air Forces, proper project management of Russia's UAS programs may allow it to capture "3-5% of the global market over the next ten years." *Russian Aviation*, November 13, 2012, available at http://www.ruaviation.com/news/2012/11/13/1336/.

[142] "Russia to Build Mini Drone for Vietnam," *RIA Novosti*, March 15, 2012, available at http://en rian ru/military_news/20120315/172178844 html; and "The Ministry of Defense of Kazakhstan will purchase UAVs from Irkut Corporation," *Russian Aviation,* October 3, 2012, available at http://www.ruaviation.com/news/2012/10/3/1242/.

[143] Russia's recent dealings with Israel suggest that this may be a likely course of action. Mark N. Katz has suggested that Russia and Israel have come to an arrangement whereby Israel supplies Russia with, among other things, UAS technology. Notably, this speculation predates the recent conflict in Syria. See Mark N. Katz, "Implications of the Georgian Crisis for Israel, Iran, and the West," *Middle East Review of International Affairs*, Vol. 12, No. 4, 2008.

[144] Easton and Hsiao, The Chinese People's Liberation Army's Unmanned Aerial Vehicle Project: Organizational Capacities and Operational Capabilities, p. 2.

may be in danger of squandering its lead. It is highly likely that staying on a “more of the same” UAS development path would lead to a future force that will have significant shortfalls in an MPSR.

The next chapter addresses alternative development paths that could lead to a “high-low” mix of UAS for DoD which could, in combination with new UAS CONOPs and organizations, help instigate a robotic revolution in air power.

Chapter 5. Thinking About DoD's Next UAS Force

> Few now question that ISR has been 'the centerpiece of our global war on terrorism,' but a 'pivot to Asia' and potential future operations in anti-access/area-denial (A2/AD) environments will lead to a need for … a variety of new and legacy UAV platforms.[145]
>
> — Dr. David Rockwell, Teal Group

The Need for a New Path

Over the last decade, the U.S. military's UAS force has helped it to sustain situational awareness of the battlespace that has been unmatched by its adversaries. Looking to the future, the proliferation of robotic technologies will enable competitors such as China and Iran to develop their own UAS forces for ISR, precision strike, AEA, swarming attacks, and possibly other missions that could impose costs on U.S. power-projection forces. It is likely that this emerging UAS competition will also include the development of capabilities to counter current-generation unmanned aircraft, much as competitors now seek to offset the U.S. military's precision strike advantage.

The diffusion of UAS and counter-UAS capabilities as part of an MPSR could render much of America's existing unmanned aircraft force obsolete, especially if DoD fails to pursue a new path that could help it to maintain its robotic air warfare advantage. This does not have to be the case, since the U.S. military could build on maturing UAS technologies as well as its existing cadre of world-class experts in unmanned aircraft operations. Of the countries included in this assessment, only the United States and Israel have tested their UAS capabilities in the fog and friction of war, a factor that should give them a head start toward developing UAS that could prove to be "the game changer for the coming decades"[146] in the Asia-Pacific and other critical regions. The U.S. industrial base, fueled by billions of dollars of investments in unmanned aircraft over the last decade, is similarly poised to support the creation of a UAS force that could provide commanders with new advantages in an MPSR.

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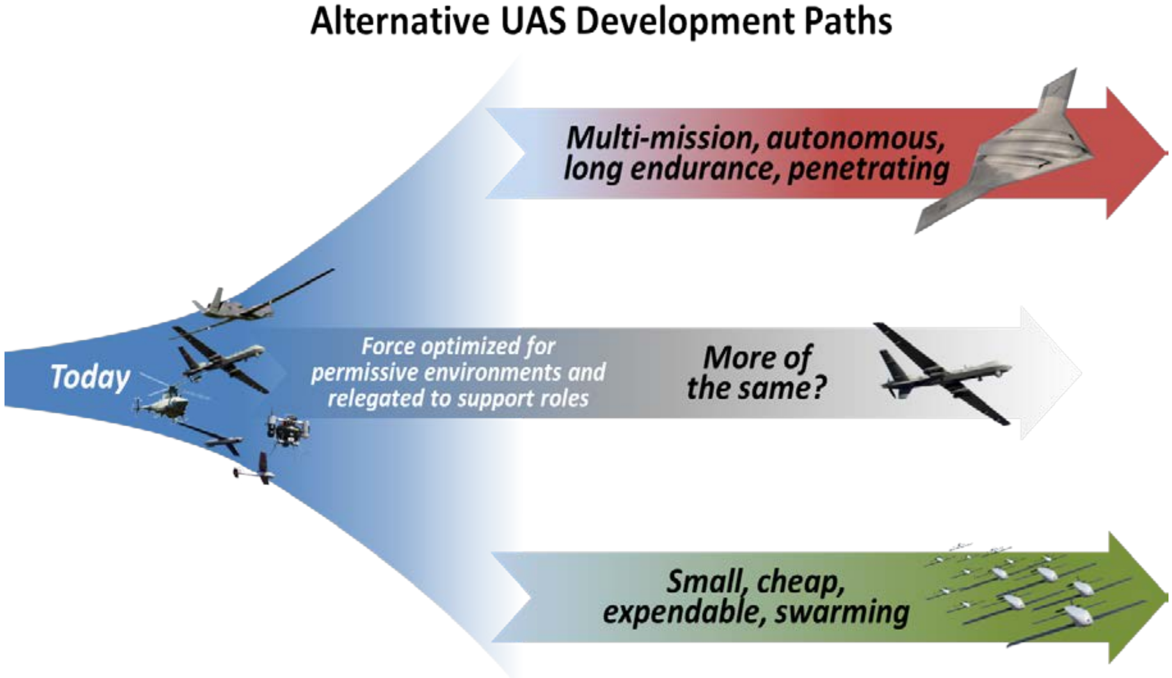
145 "Teal Group Predicts Worldwide UAV Market Will Total $89 Billion In Its 2013 UAV Market Profile and Forecast," *PR Newswire*, June 17, 2013, available at http://www.prnewswire.com/news-releases/teal-group-predicts-worldwide-uav-market-will-total-89-billion-in-its-2013-uav-market-profile-and-forecast-211776631.html.

146 During congressional testimony on capabilities needed in the Pacific, Admiral Gary Roughead observed, "And I would say we have to look at the vastness of the region. And you can talk about capabilities, but capacity in the Pacific matters a lot. That's why I believe that a very, very thoughtful approach to our unmanned strategy in the Pacific, both air and subsurface, is required because that will be the game-changer for the coming decades, in my view. And we have the lead in that technology and our operational experience, and we should jump on that and move as quickly as we possibly can." *Hearing of the House Armed Services Committee on Rebalancing to the Asia-Pacific Region and Implications for U.S. National Security* (Washington, DC: Federal News Service, 2013), pp. 16-17.

Toward a New Vision

Given trends in the operational environment and possible emergence of a UAS competition, it is unlikely that DoD will sustain its UAS advantage by simply extrapolating its current capabilities and CONOPs into the future. Rather, if it is to extend its lead in this competition, DoD will need to shift from building UAS primarily to conduct dull, dirty, and dangerous missions such as tactical and strategic reconnaissance toward creating a robotic force capable of a wider range of operations in all threat regimes. In lieu of a "more of the same" path, DoD could explore developing a different, high-low mix of UAS capabilities (see illustration below) to help achieve this objective.



One Possible Alternative Path

The "high" part of a future force mix could include UAS capable of penetrating and persisting deep in contested airspace to conduct strike, ISR, EW, and offensive counter-air operations. Using stealthy, land- and sea-based UAS to degrade and destroy enemy C4ISR networks and IADS early in an air campaign would help pave the way for other penetrating capabilities while reducing overall risk to U.S. pilots. Working in cooperation with manned penetrators such as a new bomber, long-range unmanned *combat* air vehicles equipped with ground moving target indicator (GMTI) radars and PGMs could sustain CAPs to help suppress enemy air defenses and ballistic missile transporter-erector-launchers (TELs). Arming these UCAVs with non-kinetic weapons would allow them to take full advantage of the mission persistence of unmanned aircraft by giving them self-replenishing magazines that are limited only by the aircraft's ability to generate and store power while airborne.[147]

Other high-end capabilities might include long-range, extremely persistent UAS for ISR, wide-area maritime surveillance, C2, and airborne early warning and control. The recent decision to shift the U.S. military's planning focus toward the Asia-Pacific will place a premium on aircraft that can surveil large maritime areas in a single sortie. Collectively, a new generation of multi-mission UAS may reduce opportunities for future enemies to cripple the U.S. military's freedom of action by striking a small number of critical nodes in its C4ISR networks. Future UAS that operate at very high altitudes for mission durations measured by days instead of hours could provide true "aerospace" surveillance and C2 support over large areas of the operational battlespace and help offset the effects of enemy attacks on U.S. space-based networks. Creating new, long-range UAS for ISR, maritime surveillance, and AEW could reduce the need to endanger aircraft that typically carry at least two pilots and multiple mission support crewmembers.[148] Future penetrating UAS could also support manned and unmanned aircraft operations in contested airspace by providing threat warning and targeting information. Ideally, these aircraft would be equipped with highly directional and difficult to detect data links such as laser communications systems that could provide "high-bandwidth connectivity between airborne sensor platforms and the end users of sensor data."[149]

Next-generation UAS could also offer advantages in operational environments that constrain the performance characteristics of aircraft. For example, the physical dimensions of carrier decks and the limitations of catapult systems bound the size, weight, and therefore unrefueled ranges and useful payloads of carrier aircraft.[150] Unlike aircraft that operate from large, terrestrial airfields, it is not possible to increase the range, persistence, and payload capacity of carrier aircraft by simply increasing their size.[151] Thus, cockpits that weigh approximately 3,000 pounds

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147 For example, current technology would support the development of a high-power microwave weapon that could be carried by UAS and cruise missiles. See Gunzinger and Dougherty, *Changing the Game: the Promise of Directed-Energy Weapons,* pp. 28-30.

148 The E-8C Joint Surveillance Target Attack Radar System (JSTARS) can carry a crew of over nineteen personnel, the E-3 Sentry can carry up to twenty-three crewmembers, and the P-8A carries a crew of nine.

149 "MIT Lincoln Laboratory Demonstrates Reliable Air-to-ground Laser Communications," Massachusetts Institute of Technology Lincoln Laboratory, June 2010, available at http://www.ll mit.edu/news/airgroundlasercom.html. Laser communications systems could have a bandwidth of "two gigabytes per second and upwards of 20 gigabytes per second" compared to "radio frequency transmissions [that] can go to 200 megabytes per second." See Stew Magnuson, "Game-Changing Laser Communications Ready For Fielding, Vendors Say," National Defense Magazine, January 2013, available at http://www.nationaldefensemagazine.org/archive/2013/January/Pages/Game-ChangingLaserCommunicationsReadyForFielding,VendorsSay.aspx.

150 Carrier-based aircraft are also limited to a wingspan of approximately seventy feet to ensure they can safely takeoff and land on a carrier deck.

151 Aircraft that land on carriers also require heavier landing gear and more robust designs than land-based aircraft. As a result "carrier aircraft generally have a shorter unrefueled combat radius, or can carry less weight over

for a single pilot are a significant design factor for aircraft that are the size and weight of the Navy's F/A-18 and F-35C.[152] By comparison, a 3,000 pound cockpit or even a 6,000 pound cockpit for two crewmembers is a negligible factor for land-based combat aircraft that have empty weights of 160,000 or more pounds, such as B-2 and B-1 bombers.

Although the UAS force mix suggested above would include a number of new aircraft designs, it may be possible to save time and reduce overall program costs by building on other developmental programs. A new carrier-based, multi-mission UCAV, for example, could capitalize on the J-UCAS, N-UCAS, and UCAS-D programs. A scaled-up version of an N-UCAS planform, without carrier-specific capabilities such as a tailhook, could also provide the Air Force with a land-based combat aircraft that has greater range, endurance, and mission payloads compared to its carrier-based cousin. It may even be possible to achieve economies of scale by using the same basic UCAV design, engines, and mission control systems to develop a UAS tanker to refuel manned and unmanned aircraft. Development of an extremely long-endurance, high-altitude UAS for wide-area ISR and C2 could leverage technologies developed for the experimental Global Observer and Phantom Eye UAS, both of which were designed to fly at 65,000 feet for four to seven days and carry payloads of up to 450 pounds.[153] Modifying the Navy's MQ-4C Triton to carry weapons as well sensors could also reduce costs.

Small, Cheap, Expendable, Swarming?

For the "low-end" of a future force mix, DoD could maintain some portion of its current UAS while developing new, low-cost systems that could counter A2/AD threats and impose costs on future enemies.

UAS to counter G-RAMM

The need to counter G-RAMM may increasingly drive UAS requirements in much the same way that unmanned aircraft were adapted to help counter successful IED attacks in Iraq and Afghanistan. Instead of providing an unblinking eye to detect IED teams and emplacements, however, new UAS with sensors and miniaturized PGMs such as the Viper Strike standoff attack weapon could act as G-RAMM hunter-killers. Within five years, it may be possible to arm

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similar ranges, than comparably-sized land-based planes." See Thomas P. Ehrhard and Robert O. Work, *Range, Persistence, Stealth, and Networking: The Case for a Carrier-Based Unmanned Combat Air System* (Washington, DC: Center for Strategic and Budgetary Assessments, 2008), p. 47.

152 Mark Gunzinger and Chris Dougherty, *Sustaining America's Strategic Advantage in Long-Range Strike* (Washington, DC: Center for Strategic and Budgetary Assessments, 2010), pp. 43-44. The empty weight of a carrier-based F-35C is approximately 34,800 pounds. Lockheed Martin, "F-35C Carrier Variant," 2013, available at http://www.lockheedmartin.com/us/products/f35/f-35c-carrier-variant html.

153 Powered by hydrogen fuel cells, the Global Observer has a claimed endurance of up to seven days while carrying a payload of 400 pounds. See "Global Observer UAS Overview Data Sheet," *Aerovironment*, 2013, available at http://www.avinc.com/images/go_site/GO_Data_Sheet.pdf. The Phantom Eye uses internal combustion engines powered by liquid hydrogen to achieve an endurance of four days carrying a payload of 450 pounds. See "Backgrounder Phantom Eye (HALE)," January 2013, available at http://www.boeing.com/assets/pdf/bds/phantom_works/docs/bkgd_phantom_eye.pdf.

Predator-sized UAS with pods that contain high-power lasers capable of countering G-RAMM fire teams and soft, unarmored targets. Laser-equipped UAS capable of loitering in the battlespace for twelve or more hours at a time could augment manned Air Force Special Operations Command AC-130 gunships.[154] It may even be feasible to arm rotary-wing UAS, such as the K-MAX, MQ-8 Fire Scout, or A160 Hummingbird, to suppress threats as well as fly more mundane ISR and logistics resupply missions.

Of course, the survivability of non-stealthy UAS in G-RAMM environments will depend a great deal on how they are operated. For instance, UAS flown at altitudes above 20,000 feet would be above the effective reach of many MANPADS.[155] It may also be possible to partially mitigate threats from MANPADS and other surface fires by adopting innovative tactics. During the 2011 intervention in Libya, DoD claimed to have used a new armed Predator tactic that significantly reduced the threat from MANPADS.[156]

Expendable/optionally expendable UAS

The future UAS force mix could include expendable lethal and "optionally expendable" systems that could enhance the U.S. military's ability to impose costs on future enemies. Unlike lethal UAS, optionally expendable aircraft could conduct ISR missions or strike enemy air defenses at cost/exchange ratios that favor the United States. Low-cost, optionally expendable UAS could be used in a manner similar to how Israel employed Chukar drones against Syrian air defenses in 1982. New lethal UAS akin to Israel's Harpy and Harop[157] could help defeat enemy SAM batteries with reduced risk to U.S. aircrews and aircraft. This CONOP would force enemies with a limited number of SAMs to make an unpleasant choice: either expend valuable missiles and expose the locations of SAM launchers, or allow the optionally expendable UAS to strike or relay targeting information to other U.S. combat aircraft.

A "Chukar" CONOP is not wholly foreign to the U.S. military. Prior to the Second Gulf War, Predators operating in and around the no-fly zone imposed by the United States and other coalition forces over southern Iraq, tempted the Iraqi Air Force to launch MiG fighters to intercept them. This allowed the U.S. Air Force to develop a better understanding of Iraq's air defense system and response times.[158] During the Second Gulf War's initial air campaign, the

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154 Secretary of Defense Robert Gates claimed armed Predators "give you a capability that even the A-10s and the AC-130s couldn't provide." David A. Fulghum, "Armed Predators Back In Libya," *Aviation Week Ares: a Defense Technology Blog*, April 22, 2011, available at http://www.aviationweek.com/Blogs.aspx?plckBlogId=Blog%3a27ec4a53-dcc8-42d0-bd3a-01329aef79a7&plckPostId=Blog%3a27ec4a53-dcc8-42d0-bd3a-01329aef79a7Post%3a161e712a-a94b-4fd2-921b-399a34677c59.

155 For example, the SA-24 Grinch MANPAD has a maximum effective altitude of 11,000 feet.

156 Fulghum, "Armed Predators Back In Libya."

157 Based on DoD's official definition for UAS, these systems would likely be considered loitering munitions instead of unmanned aircraft systems.

158 Jim Krane, "Pilotless Warriors Soar To Success," *CBS News*, February 11, 2009, available at http://www.cbsnews.com/2100-205_162-551126.html.

Air Force flew two Predators stripped of their sensitive equipment on suicide missions over Baghdad to act as decoys to draw fire from Iraqi air defenses and thus reveal their locations to manned strike aircraft.[159]

Swarming UAS

Swarming UAS are often thought of as an amorphous mass of tiny micro- and nano-sized UAS similar to a swarm of bees. Lieutenant General Larry James, the Air Force's intelligence chief, alluded to this when he asked:

> Are there places for nano-UAVs that can be survivable or throwaway, networked small UAVs that can perhaps penetrate and operate for some period of time? Those are things technologists need to look at.[160]

The development of small UAS that are capable of coordinated operations could lead to the creation of new concepts of operation for imposing costs on future enemies. For example, low-cost, expendable UAS could be used to launch swarming attacks that could overwhelm enemy defensive systems through their sheer numbers161 Theoretically they could also be designed to loiter for some period of time above a battlespace waiting for enemy systems to move, emit, or otherwise reveal their locations. These expendable UAS could then quickly strike from multiple axes with little prior warning and without the need for U.S. manned combat aircraft to expose themselves to possible enemy attacks by directly dispensing munitions in high-threat areas.

Unfortunately, while developing micro- and nano-UAS for swarming operations is technologically feasible, their small sizes and payload constraints could limit them to operating over extremely short ranges and prevent them from carrying sophisticated sensors or warheads that would be effective on reinforced targets. These limitations suggest that micro- and nano-UAS swarms might best be used to support ground maneuver units that are operating in close proximity to enemy threats, at least in the near-term. In the future, it may be possible for "motherships" such as penetrating bombers, large UAS, or even cargo aircraft (in permissive operating conditions) to "seed" small, expendable UAS over a battlespace. New concepts of operation for cost-imposing swarming attacks might also include launching ballistic or cruise missiles from standoff ranges that carry munitions dispensers filled with small, loitering UAS.

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[159] Krane, "Pilotless Warriors Soar To Success;" and Matt J. Martin, *Predator: The Remote-Control Air War Over Iraq and Afghanistan: A Pilot's Story* (Minneapolis, MN: Zenith Press, 2010), p. 22.

[160] Quoted in Dave Majumdar, "Future nano-UAVs could collect ISR in heavily defended airspace alongside Raptors and F-35s," *Flight International*, April 26, 2012, available at http://www.flightglobal.com/news/articles/future-nano-uavs-could-collect-isr-in-heavily-defended-airspace-alongside-raptors-and-f-35s-371189/.

[161] John Arquilla and David Ronfelt defined swarming as, "engaging an adversary from all directions simultaneously, either with fire or in force." See John Arquilla and David Ronfelt, *Swarming and the Future of Conflict* (Washington, DC: RAND, 2000), p. vii.

Key UAS Technology Opportunities

There are important technological gaps to be bridged if DoD is to develop a future high-low UAS mix as suggested in preceding paragraphs. Closing these gaps should be a key part of developing unmanned aircraft with "revolutionary" capabilities within an MPSR, rather than continuing to field UAS that are primarily information-gathering enablers as is presently the case. Participants in UAS workshops led by CSBA to support this assessment concurred that the following technologies will be critical to the development of a next-generation, multi-mission UAS force:

- Alternatives to space-based PNT and C2. Reliance on space-based PNT and C2 networks is a critical vulnerability of today's UAS force. Future UAS will need alternatives to space-based systems for operations in scenarios where U.S. space capabilities may be degraded or temporarily unavailable.

- Automation and autonomy. Increased mission automation and autonomy may be the single most significant technological area that could help enable the future UAS force to achieve its full potential. Operating in fast-moving, degraded- or denied-communications environments will require UAS with greater levels of on-board automation and autonomy, to include automated sense-and-avoid capabilities and the ability to find, fix, track, target, and strike targets without a man in the loop. Automated mission management and PED could simultaneously reduce the manpower and bandwidth required to support UAS operations.

- Integrating unmanned aircraft operations. As DoD develops increasingly autonomous UAS, it will need to ensure they are capable of operating seamlessly with other unmanned and manned systems.

- Stealth. Stealth technologies will be particularly important for future UAS of all classes that are intended to operate in contested environments.[162] Stealth, while not an end in and of itself, remains an enabling attribute that determines if unmanned capabilities (including cruise missiles as well as UAS) and manned penetrating aircraft will be able to persist in the future battlespace. Low observability is increasingly becoming the price of admission to future combat operations. Without stealth attributes, it is highly likely that combat and combat support aircraft will be relegated to operating in secure rear areas until enemy air defense networks are suppressed.

- Miniaturization and alternative weapons. To take full advantage of unmanned systems that can persist in the battlespace for many hours or even days, DoD should develop miniaturized sensors and small, expendable PGMs and non-kinetic weapon systems that will allow UAS to strike multiple targets per sortie.

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[162] Bill Sweetman, "Reading Secret USAF Bomber, ISR Plans," *Aviation Week & Space Technology*, December 3, 2012, available at http://www.aviationweek.com/Article.aspx?id=/article-xml/AW_12_03_2012_p04-520329.xml.

- Next-generation power plants. As noted throughout this assessment, current UAS may have a limited capability to perform EW and other missions due to the power outputs of their generators. The development of next-generation, fuel-efficient power plants could lead to UAS that produce enough power to operate standoff jammers and long-range sensors, while also increasing their mission endurance and unrefueled combat radius.

The remainder of Chapter 5 addresses these technology areas and suggests initiatives that could lead to the development of a future force that will sustain the U.S. military's UAS advantage in an MPSR.

Potential PNT Alternatives

Space-based PNT and C2 helped enable the development of today's UAS force. The next two sections identify some of the existing and emerging threats to the U.S. military's GPS and satellite communications (SATCOM) networks, and suggest capability enhancements and alternatives that might help mitigate the impact of these threats on future UAS operations.

Vulnerabilities

The completion of the initial U.S. Global Positioning Satellite constellation in 1994 enabled the effective C2 of UAS at beyond-line-of-sight ranges. According to DARPA director Arati Prabhakar, GPS-provided PNT is now so central to U.S. military operations that it has become a major vulnerability.[163] This is partially due to the fact that signals from GPS satellites are weak (roughly 10^{-16} watts),[164] which makes them vulnerable to jamming. Even low-power jammers have the potential to disrupt GPS signals in localized areas.[165] More sophisticated, higher power jammers may prove an even greater danger to satellite-provided PNT. One North Korean jamming incident in 2012 reportedly interfered with the navigation of 1,016 aircraft and 254

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163 "Sometimes a capability is so powerful that our reliance on it, in itself, becomes a vulnerability… I think that's where we are today with GPS." Quoted in Agence France-Presse, "US army seeks new technology to replace GPS," *The Telegraph*, April 25, 2013, available at http://www.telegraph.co.uk/news/worldnews/northamerica/usa/10017306/US-army-seeks-new-technology-to-replace-GPS.html.

164 Scott Pace, Gerald P. Frost, Irving Lachow, David R. Frelinger, Donna Fossum, Don Wassem, Monica M. Pinto, *The Global Positioning System: Assessing National Policies* (Santa Monica, CA: RAND, 1995), p. 48.

165 Early testing of the GPS system showed that a one-Watt jammer could completely disrupt commercial GPS reception at a range of twenty-two kilometers. "Jamming Danger Raises Doubts About GPS," *Aviation Week & Space Technology*, October 19, 1992, p. 61. Cited in Pace et al., *The Global Positioning System: Assessing National Policies*, p. 48. More recently, a commercial truck driver in northern New Jersey demonstrated this in the real world when the GPS jammer he'd installed in his truck to block his company from monitoring his movements interfered with navigation equipment at Newark Airport. "No jam tomorrow," *The Economist*, March 10, 2011, available at http://www.economist.com/node/18304246.

ships in and around South Korea.[166] GPS "spoofing," i.e., feeding false signals to GPS receivers, also presents a potential threat to UAS operations.[167]

DoD is well aware of these threats and is now in the process of replacing current GPS II satellites with GPS III models that use of the encrypted, military "M-code" signals to provide "an order of magnitude improvement in jamming resistance."[168] In addition to the M-code, GPS III satellites will use stronger signals and have the ability to transmit "spot beams" of even higher signal strength to military users in areas where jamming may occur.

Potential PNT Alternatives

Even with GPS III enhancements, it is likely that some future enemies will be able to degrade or temporarily deny satellite-provided PNT. It would therefore seem prudent to develop alternatives to GPS, such as improved inertial navigation and timing systems and other avionics that could provide UAS with precision navigation and timing information should GPS be degraded or denied.

Enhanced inertial navigation systems (INS)[169] may become adjuncts to, or temporary replacements for GPS in high-threat jamming environments. Typical inertial navigation systems suffer from three disadvantages relative to GPS. First, since they use three gyroscopes and three accelerometers, one for each dimension in which a weapon system might move, they can be rather large and consume power that is in short supply in some smaller aircraft and cruise missiles.[170] Second, the accuracy of current INS tends to "drift" by more than a nautical mile per

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166 "Out of sight," *The Economist*, July 27, 2013, available at http://www.economist.com/news/international/21582288-satellite-positioning-data-are-vitalbut-signal-surprisingly-easy-disrupt-out.

167 See, for example, Adam Rawnsley, "Iran's Alleged Drone Hack: Tough, but Possible," *Wired Danger Room*, December 16, 2011, available at http://www.wired.com/dangerroom/2011/12/iran-drone-hack-gps/. Although an experiment at the University of Texas-Austin demonstrated that a UAV could be controlled via the introduction of false GPS coordinates, this would likely not be possible with military aircraft using encrypted GPS P(Y) code signals. See David Sydiongco, "Research Team Hacks Surveillance Drone With Less than $1,000 in Equipment," *Slate Future Tense*, July 2, 2012, available at http://www.slate.com/blogs/future_tense/2012/07/02/hacked_surveillance_drone_with_spoofed_gps_system_demonstrates_uav_security_flaws_.html; and John Roberts, "EXCLUSIVE: Drones vulnerable to terrorist hijacking, researchers say," *Fox News*, June 25, 2012, available at http://www.foxnews.com/tech/2012/06/25/drones-vulnerable-to-terrorist-hijacking-researchers-say/.

168 Dr. Donald G. DeGryse, Vice President of Navigation Systems at Lockheed Martin Space Systems, "Bringing New Capabilities to Military and Civil Users Worldwide," *High Frontier: The Journal for Space and Missile Professionals*, 4, No. 3, 2008, p. 17.

169 Inertial navigation systems measure acceleration vectors and heading and therefore provide information on the location of a moving vehicle relative to a known starting position.

170 Second Lieutenant Aaron Canciani, *Integration of Cold Atom Interferometry INS With Other Sensors* (Wright-Patterson Air Force Base, OH: Air Force Institute of Technology, 2012), p. 1, available at http://www.dtic.mil/dtic/tr/fulltext/u2/a558235.pdf.

hour, making accurate long-range navigation difficult.[171] Third, typical INS can cost tens of thousands of dollars.[172] The combination of size, power requirements, drift errors, and cost reduce the practicality of using current-generation INS to provide guidance for small air vehicles (such as mini-UAS and guided weapons) or unmanned aircraft that need to fly for very long periods of time.[173]

New, more accurate gyroscopes, combined with smaller and less costly precision accelerometers and atomic clocks could lead to next-generation INS that could help reduce UAS dependence on vulnerable satellite PNT networks. DARPA, in particular, has been exploring and developing these cutting-edge technologies through its Micro-Technology for Positioning, Navigation and Timing (Micro-PNT), Precision Inertial Navigation Systems, and All Source Positioning and Navigation programs.

The Micro-PNT program has made major advancements in the integration of miniaturized gyroscopes, accelerometers, and chip-scale atomic clocks to create the "Timing and Inertial Navigation Unit," or TIMU, which contains three gyroscopes, three accelerometers, and a chip-scale atomic clock in a chip with a total volume of approximately ten cubic millimeters.[174] While the TIMU would be adequate as a temporary substitute for GPS, it would not provide precision PNT during prolonged GPS outages. To address this issue, the Precision Inertial Navigation Systems program is developing cold-atom interferometers that could reduce the drift error of INS to a meter per hour.[175] DARPA's All Source Positioning and Navigation program seeks to further improve on this accuracy by using cell-phone, radio, and television signals of opportunity to help update position information for platform navigation systems.[176] The Navigation via Signals of Opportunity, or NAVSOP, program is investigating a similar approach that would use cell phone, television, radio, wi-fi, air-traffic control, and even GPS jammers to provide PNT that may be on par with GPS information.[177]

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171 Canciani, Integration of Cold Atom Interferometry INS With Other Sensors, p. 1.

172 Ibid.

173 Major Mike Veth and John Raquet, *Fusion of Low-Cost Imaging and Inertial Sensors for Navigation* (Wright-Patterson Air Force Base, OH: Air Force Institute of Technology, 2007), p. 1, available at http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA462964.

174 Defense Advanced Research Projects Agency, "Extreme Miniaturization: Seven Devices, One Chip to Navigate Without GPS," April 10, 2013, available at http://www.darpa.mil/NewsEvents/Releases/2013/04/10.aspx.

175 Canciani, Integration of Cold Atom Interferometry INS With Other Sensors, p. 2.

176 Defense Advanced Research Projects Agency, "Adaptable Navigation Systems," available at http://www.darpa.mil/Our_Work/STO/Programs/Adaptable_Navigation_Systems_(ANS).aspx.

177 Callan James, "What Will Follow GPS?," *Avionics Today*, September 1, 2012, available at http://www.aviationtoday.com/av/military/What-Will-Follow-GPS_77077 html#.UfL2OWSY4cU.

Vulnerabilities

Current beyond-line-of-sight UAS operations are also highly dependent on military and commercial SATCOM networks that could be degraded by direct and indirect attacks. Since most communications satellites occupy geostationary orbits at over 22,000 miles above the earth, it is likely that only the most advanced militaries are presently capable of launching direct ascent anti-satellite (ASAT) weapons against them.[178] For states that do not have sophisticated ASAT capabilities, radio frequency (RF) jamming is, and in the near term will most likely remain, the most feasible means of interfering with SATCOM links.

Jamming

Given the distance between transmitters and UAS receivers, satellite signals are weak and therefore relatively easy to jam with ground-based emitters. Uplinks—either from an aircraft or a ground station to the satellite—may be particularly vulnerable to ground-based jamming.[179] According to Todd Harrison of CSBA:

> An uplink jammer must be roughly as powerful as the signal it is attempting to jam, and it must be within the footprint of the satellite antenna it is targeting. Neither of these factors is particularly challenging, especially considering that the footprint of a satellite antenna typically ranges from a few hundred miles to more than 1,000 miles in diameter.[180]

Uplink jamming could interfere with the remote piloting of UAS by degrading or disrupting C2 signals from ground-control stations to satellites, or by jamming links from UAS to their remote crews. According to the Air Force, uplink jammers have been used against U.S. satellite systems during operations in Southwest Asia.[181] Countering uplink jamming can be difficult, especially if opponents use highly mobile jammers, operate their jammers intermittently in order to avoid detection, or conduct operations from dispersed locations that are within the large areas of regard ("footprints") of target satellites.

Cyber attacks

Rather than using jammers that create detectable signals, enemies could use offensive cyber capabilities to infiltrate malicious data into U.S. satellite networks. Cyber attacks could interfere

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[178] The potential for ASAT strikes to create debris that could degrade an enemy's own satellites is a mitigating factor, especially since attacks against U.S. ground-based space infrastructure could be far easier, more deniable (if covert forces are used), and would have less risk of collateral damage.

[179] Jamming downlinks to air or surface receivers, while possible, is more difficult than jamming uplinks because jamming transmitters must be located within the area of regard of receivers' directional target antennas. In other words, this would require jamming platforms to fly above their target aircraft and ground stations.

[180] Todd Harrison, *The Future of MILSATCOM* (Washington, DC: Center for Strategic and Budgetary Assessments, 2013), p. 10.

[181] Lt. Gen. C. Robert Kehler, Deputy Commander, United States Strategic Command, statement before the Strategic Forces Subcommittee, House Armed Services Committee, *Hearing on Space and National Power,* June 21, 2006, p. 7, available at http://www.hsdl.org/?view&did=466614.

with UAS operations by introducing false or corrupt data to UAS ground-control elements, sending false commands to UAVs, or even gaining partial control over satellites to reduce their operational effectiveness. Infiltration attacks could come in the form of computer network attacks, tapping the fiber optics networks that provide terrestrial links between download terminals and ground-control stations, or emitting EW signals containing malicious codes that could be received by satellites, UAS, or UAS ground terminals. In light of the fact that "all command and control runs through cyber now…not a single [UAV] mission would be possible without a functioning and secure cyber domain,"182 cyber attacks could cripple UAS operations.

Alternatives to Space-Based C2 for UAS Operations

UAS that continue to rely almost exclusively on SATCOM-based C2 may present future adversaries with an "exposed flank" that could that could greatly impact U.S. unmanned aircraft operations at beyond line-of-sight ranges. Increasing the U.S. military's protected SATCOM capacity would help reduce this exposure. Even with additional protected SATCOM, however, it is likely that capable enemies will be able to degrade or disrupt—if only temporarily in localized areas—space-based C2. Thus, it would also seem important to develop alternative CONOPS that could help decrease UAS dependence on military and commercial satellite communications.

Protected SATCOM

Military SATCOM (MILSATCOM) systems such as the Wideband Global Satellite (WGS) and Mobile User Objective System (MUOS) use a number of techniques and technologies to counter jamming, including frequency hopping (rapidly switching frequencies in a pattern known only to the sender and the receiver); antenna notching (blocking all communications in a given frequency band); antenna nulling (blocking all communications from a given location); interleaving (scrambling data to minimize the errors caused by burst jamming); and processing onboard the satellite (which helps to minimize the retransmission of errors caused by jamming).[183] Other protected MILSATCOM systems, such as the Advanced Extremely High Frequency (AEHF) constellation, are hardened against nuclear radiation and electromagnetic pulses and use direct links between satellites to reduce satellite-to-ground links that may be vulnerable to jamming.

Unfortunately, frequency hopping, antenna notching, interleaving, and additional processing tend to limit bandwidth or decrease data throughput. Moreover, satellite hardening and other protective measures can be costly. New AEHF satellites are approximately five times more expensive than less-protected WGS satellites,[184] while the laser communications-based Transformational Satellite Communications System (TSAT) that promised to provide even

[182] Maj Gen Earl Matthews, Director, Cyberspace Operations, Office of Information Dominance and Chief Information Officer, Office of the Secretary of the Air Force, quoted in John Reed, "It's the data, stupid," *Foreign Policy: Killer Apps*, September 21, 2012, available at http://killerapps.foreignpolicy.com/posts/2012/09/21/its_the_cyber_data_stupid.

[183] Harrison, *The Future of MILSATCOM*, pp. 25-26.

[184] Harrison, The Future of MILSATCOM, p. 17.

greater resistance to jamming was canceled primarily due to its high development costs. Higher costs can translate into fewer satellites on-orbit, which in turn reduces bandwidth available to support over-the-horizon operations of unmanned and manned weapons systems.

Commercial SATCOM

Today, as much as 80 percent of U.S. space-based communications use commercial SATCOM networks that lack the same degree of protection against jamming as MILSATCOM systems.[185] This dependency on unprotected commercial SATCOM increases the risk to future UAS operations.[186] Replacing commercial systems with military satellites may not be an economically viable solution, however, given the high cost of protected wideband satellites and the fact that MILSATCOM capacity has only been capable of meeting 20 percent of the U.S. military's bandwidth requirements in recent years.

It may be possible, however, to increase DoD's MILSATCOM capacity at less cost by using "hosted payloads" rather than buying new satellites. As the name implies, hosted payloads are military communications transmitters placed aboard commercial satellites. Although hosted payloads may lack the full protection of dedicated MILSATCOM satellites, they have the potential to help expand C2 capacity for less than it would cost to buy new satellites.[187] It may also be possible to encourage U.S. partners to share in the cost of building, launching, and maintaining new MILSATCOMs. Partnering with allies such as Japan and Australia to increase MILSATCOM coverage in regions of particular interest could both reduce costs and potentially deter hostile actions by future adversaries by introducing the risk of horizontal escalation since an attack on "shared" satellites might provoke a regional response.[188]

New CONOPs

Alternative CONOPs may help reduce the U.S. military's dependence on space-based networks for long-range UAS C2. In the relatively permissive operating environments of the last decade, SATCOM was used to "reach-back" to UAS pilots, sensor operators, and intelligence analysts based at overseas and U.S. locations. In more contested threat environments, UAS may need to operate effectively without the benefit of these long-range tethers, relying instead on shorter range C2 and data networks that are more difficult for adversaries disrupt. For example, current U.S. military aircraft equipped with targeting pods are able to pass their EO/IR sensor feeds to ground forces using the Remotely Operated Video Enhanced Receiver (ROVER) system. Newer ROVER versions permit maneuver units to communicate with remote pilots and enable Joint Terminal Attack Controllers (JTACs) to mark targets and highlight the locations of friendly

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[185] Barry Rosenberg, "DOD's reliance on commercial satellites hits new zenith," *Defense Systems*, February 25, 2010, available at http://www.defensesystems.com/Articles/2010/03/11/Cover-story-The-Satcom-Challenge.aspx.

[186] It is also expensive. The annual cost of leasing commercial satellite bandwidth is projected to increase to approximately $5 billion. See Werner, "The Military's Second Chance for a Bandwidth Fix."

[187] Harrison, The Future of MILSATCOM, p. 30.

[188] Ibid.

forces and non-combatants for air attacks. A ROVER-UAS combination might be a model for new CONOPs that shift tactical command over UAS to controllers in the *forward* battlespace rather than in remote rear areas, thus reducing reliance on long-range UAS tethers.

The following tactical vignettes describe possible "forward controlled" CONOPs for four mission areas: persistent ISR and strike; suppression of enemy air defenses; maritime domain awareness; and anti-submarine warfare.

Persistent ISR and strike

Power-projection operations in a mature precision-strike regime will require capabilities that can conduct persistent ISR and strike in contested airspace without the benefit of continuous, secure long-range communications. Suppressing mobile targets such as ballistic missile TELs could be one particular mission that would benefit from the persistence that stealthy, long-endurance, multi-mission UAS could provide. Problematically, however, finding, fixing, tracking, targeting, and attacking mobile targets without a human in the loop will require substantial improvements in automated target recognition technologies.

New CONOPS that integrate penetrating manned and forward-controlled unmanned combat aircraft could reduce risk for future strike operations in contested airspace. For example, manned combat aircraft could escort multiple UAS to target areas, thereby helping them to avoid previously unknown air defense threats. UAS could then establish ISR orbits to find mobile targets and transmit targeting data using jam-resistant, short-range data links to other platforms carrying large PGM payloads, such as the Long Range Strike-Bomber (LRS-B). Ideally, these "scouting" UAS could remain on-station for long periods of time, passing their targeting data to a string of bombers ferrying PGMs to the target area. This CONOP could maximize the persistence of UAS, capitalize on the large payload of bombers and the decision-making ability of their pilots, and reduce the need to rely on vulnerable SATCOM links.

Suppressing air defenses in contested areas

Forward-controlled, multi-mission UAS could perform high-risk tasks in support of SEAD missions. Future SEAD packages could consist of long-range, stealthy manned aircraft that use secure, highly directional data links such as the Multifunction Advanced Data Link (MADL) to orchestrate the operations of UAS "wingmen." Other, optionally expendable UAS could precede the main SEAD package to collect ISR and lure enemy air defenses to activate their radars and possibly expend weapons that would help reveal their locations. Lethal UAS could then attack radar emitters, while other UAS armed with HPM weapons disrupt air defense computer systems and networks. Low-observable UCAVs could also augment manned aircraft strikes and provide ISR for BDA and follow-on strikes as needed.

Maritime domain awareness and anti-surface/anti-submarine warfare

In a future MPSR, advantages are likely to accrue to combatants that can acquire, process, and disseminate ISR information more rapidly than their opposition. Since enemies are likely to be cognizant of the advantages provided by each other's ISR and C2 networks, it should be expected that they would be priority targets from the onset of a conflict. In particular, it should be assumed that space-based, airborne, and terrestrial sensors needed for the U.S. military to maintain an effective operational picture of the maritime domain would be attacked. CONOPs that combine forward-controlled UAS with manned platforms as part of a new normal for maritime operations could provide the U.S. military with a number of advantages in a mature precision-strike regime. For example,

- UAS, such as the long-endurance BAMS and future multi-mission UCAVs, could help the Navy to offset the effects of an enemy's "blinding campaign"[189] and maintain its situational awareness over large maritime areas while reducing or possibly eliminating the need for long-range SATCOM tethers to remote C2 centers.

- Information from UAS provided directly to airborne ISR, anti-submarine warfare, and anti-surface warfare manned aircraft such as the P-8A Poseidon could greatly extend the effective "reach" of their sensors.

- A future UCAV could provide Navy carriers with a highly responsive strike capability, especially if they can deliver sonobuoys, torpedoes, and next-generation PGMs such as the Long-Range Anti-Ship Missile (LRASM).[190] Extremely long-endurance, high-altitude UAS acting as communications relays could help network these aircraft together and extend their effective coverage.

There are downsides to these "forward controlled UAS" CONOPs, such as the risk that the sheer volume of information from UAS wingmen could threaten to overwhelm the processing ability of forward C2 centers and operators. Even with effective C2 from airborne manned aircraft, forward control would likely require UAS to have increased automation and autonomy.[191] Over time, the need for human controllers may decrease as maturing automation and autonomous technologies lead to the development of "remotely managed aircraft" and eventually "remotely directed aircraft" that conduct operations with only general mission-type orders from human commanders. The development of this sort of automation and autonomy is the subject of the next section.

UAS Automation and Autonomy

Compared to other technology areas addressed by this report, increased automation and autonomy may have the greatest potential to reshape UAS operations and in so doing help bring

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189 For more on blinding campaigns, see van Tol et al, *AirSea Battle*, p. 56.

190 The LRASM-A is a variant of the Joint Air-to-Surface Standoff Missile (JASSM).

191 For this CONOPS to be effective, new UAS may need to be able to conduct discrete operations with less cueing from human controllers. For example, controllers should be able to order networked UAS to monitor given areas of ocean for a certain period of time and alert manned battlespace control aircraft when they detect a vessel that meets certain criteria (e.g., size, shape, speed, or emissions).

about a robotic revolution in airpower. In particular, improved automation and autonomy could help overcome the most pressing operational shortfalls of DoD's current UAS force by:

- decreasing UAS reliance on vulnerable C2 networks;
- saving resources by reducing crew requirements for UAS operations;
- accelerating the processing, exploitation, and dissemination (PED) process and targeting cycles; and
- enabling UAS to find, fix, track, target, and attack movable and moving targets autonomously or with minimal or no cueing from off-board sources.

In effect, automation and autonomous technologies promise to shift the UAS paradigm from the current "remotely piloted" era in which many pilots and sensor operators are needed to control and monitor single unmanned aircraft, to a "remotely managed" regime in which small numbers of operators—some of whom may be located in forward areas—control multiple UAS. As automation and autonomous technologies mature, they could even lead to a UAS force that is able to operate using mission-type orders wherein they pursue a commander's intent without direct human control.

Autonomy and Automation

There is a great deal of confusion over what is meant by the various levels of autonomy for UAS.[192] While precise definitions for autonomous functions may be important from a technological perspective, attempting to define discrete levels of autonomy (see table below) may actually be counterproductive. According to the Defense Science Board:

> DoD-funded studies on "levels of autonomy"…are not particularly helpful to the autonomy design process. They are counter-productive because they focus too much attention on the computer rather than on the collaboration between the computer and its operator/supervisor to achieve the desired capabilities and effects. Further, these taxonomies imply that there are discrete levels of intelligence for autonomous systems, and that classes of vehicle systems can be designed to operate at a specific level for the entire mission.[193]

[192] This is not an uncommon response to new military technologies, as demonstrated by hyperbole related to the emergence of cyber warfare and directed energy technologies.

[193] Defense Science Board, The Role of Autonomy in DoD Systems, p. 4.

Level	Name	Description
4	Fully Autonomous	The system receives goals from humans and translates them into tasks to be performed without human interaction. A human could still enter the loop in an emergency or change the goals, although in practice there may be significant time delays before human intervention occurs.
3	Human Supervised	The system can perform a wide variety of activities when given top-level permissions or direction by a human. Both the human and the system can initiate behaviors based on sensed data, but the system can do so only if within the scope of its currently directed tasks.
2	Human Delegated	The vehicle can perform many functions independently of human control when delegated to do so. This level encompasses automatic controls, engine controls, and other low-level automation that must be activated or deactivated by human input and must act in mutual exclusion of human operation.
1	Human Operated	A human operator makes all decisions. The system has no autonomous control of its environment although it may have information-only responses to sensed data.

In fact, some functions that are referred to as "autonomy" may actually be "automation," as explained by another 2012 DoD report:

> Automatic systems are fully preprogrammed and act repeatedly and independently of external influence or control. An automatic system can be described as self-steering or self-regulating and is able to follow an externally given path while compensating for small deviations caused by external disturbances. However, the automatic system is not able to define the path according to some given goal or to choose the goal dictating its path…By contrast, autonomous systems are self-directed toward a goal in that they do not require outside control, but rather are governed by laws and strategies that direct their behavior…to reach a human-directed goal…*The special feature of an autonomous system is its ability to be goal-directed in unpredictable situations* [emphasis added].[194]

Perhaps more simply stated, automation and autonomous technologies promise to reduce UAS dependence on vulnerable communications links and human controllers that may be otherwise cognitively engaged. Thus, instead of seeking to achieve various levels of autonomy, developers should focus on creating UAS capable of automatically or autonomously accomplishing key operational tasks in a range of threat environments. As they do so, UAS developers should also take into account the degree of human and machine integration that is needed to accomplish future missions. Just as aerospace engineers concentrate on developing unmanned platforms that exploit the advantages of not having a cockpit, software development could focus on how the unique cognitive capabilities of computers (e.g., rapid computation) and humans (e.g., the ability to respond to ambiguous situations) can best be integrated to achieve operational tasks.

[194] Department of Defense, *Unmanned Systems Integrated Roadmap 2011-2036* (Washington, DC: Department of Defense, 2011), p. 43. By this definition, the X-47 landing on the deck of the *USS George H.W. Bush* was not acting autonomously, but rather demonstrating sophisticated automation.

Promising Initiatives

The challenges of the emerging security environment will increase the need for unmanned aircraft *systems* that are less dependent on satellite C2 networks and are more capable of cooperating with other unmanned and manned weapons systems in complex operations. A shrinking defense budget will also necessitate developing a next-generation UAS force that is more reliable, affordable, and less dependent on expensive manpower for data-intensive tasks such as PED. DoD could pursue these objectives by improving UAS flight automation, developing technologies to better integrate manned and unmanned operations, automating PED functions, enhancing automated/autonomous target recognition (ATR), and eventually creating a mature autonomous UAS force. The following paragraphs address each of these areas.

Flight automation

Although some automated functions are incorporated in UAS that have been fielded over the last decade, the urgent needs that drove their procurement prioritized pushing platforms and sensors into the field at the expense of incorporating software and doctrine for automated operations in their designs. Today, Air Force pilots remotely control current-generation MQ-1 Predators and MQ-9 Reapers during all flight phases including launch and recovery, while the Army's new MQ-1C Warrior, the Air Force's MQ-4 Global Hawk, and the Navy's UCAS-D demonstrator are able to take off and land automatically.[195]

According to U.S. Air Force experts, automation promises to reduce the number of pilots required to sustain UAS combat air patrols by more than two-thirds and may eventually lead to a CONOPs where one pilot is capable of controlling multiple UAS.[196] In the near term, greater automation could free pilots from commanding routine UAS actions so they can better focus on more critical mission functions. In the more distant future, long-endurance UAS with improved flight automation might be able to launch from remote airfields and then independently follow formations of friendly ground units and convoys, or automatically accept cues from ground forces to guide them toward areas of interest. This would help alleviate UAS pilots of some of their more mundane tasks and allow them to focus on monitoring sensors and aircraft functions.

Similar technologies could be applied to smaller tactical and micro/mini UAS. Some of these systems now have the ability to navigate by using GPS coordinates. For the most part, however, when a ground unit wants to "see over the next ridgeline," it must first stop to deploy and then

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195 Israel plans to have all of its UAS perform automatic takeoffs and landings by 2015. Arie Egozi, "Israeli air force to phase out piloted take-offs for UAS," *Flight International*, March 28, 2012, available at http://www.flightglobal.com/news/articles/israeli-air-force-to-phase-out-piloted-take-offs-for-uas-369993/.

196 According to Colonel J.R. Gear, automation could reduce the number of pilots required to support 50 UAS CAPs from 570 to 150. Gear also argues that such a reduction would reduce the flexibility and responsiveness of UAS. Quoted in Scott Fontaine, "UAV autonomy limits flexibility, officer says," *Air Force Times*, October 16, 2010, available at http://www.airforcetimes.com/article/20101016/NEWS/10160308/UAV-autonomy-limits-flexibility-officer-says.

pilot its UAS to the area of interest.[197] By contrast, UAS that are able to automatically follow troop movements could simultaneously increase a unit's situational awareness and free controllers to perform other tasks.

Automated sense-and-avoid

As self-piloted UAS become commonplace, it will be essential that they have the ability to operate safely in airspace that is crowded with other aircraft. The U.S. military has already experienced one mid-air collision between a UAS and a manned aircraft, and "near-misses" are not uncommon.[198]Automated sense-and-avoid systems now in development use radar, lidar, or some combination of sensors to detect other aircraft and help guide aircraft to avoid collisions. Integrating these technologies on UAS appears to be achievable in the near term, given sufficient funding.[199] Doing so could help open forward areas and civil airspace to UAS, decrease workloads on UAS controllers, and increase the availability of military training areas for UAS operations. Over time, it is possible that these technologies could be adapted for other uses such as helping unmanned and manned aircraft to avoid areas of inclement weather automatically and possibly detect and avoid previously unknown, pop-up surface-to-air and air-to-air threats in contested areas.

Automated PED

Automation could reduce bandwidth, manpower, and other resources needed to process, exploit, and disseminate ISR information from UAS. Current CONOPs for UAS ISR operations involve collecting vast amounts of unfiltered data and pushing it via SATCOM links to large cadres of personnel who monitor and process it into actionable information before it is then disseminated

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197 "Small, soldier-operated UAVs are an example of systems that underutilize autonomy. Such fielded systems operate either through direct teleoperation or with a handful of Global Positioning System GPS waypoints. Users are interested in information from the UAV sensors for a given mission objective. These systems are often operated by two people, one flies the UAV and the other monitors the raw video returns." From *The Role of Autonomy in DoD Systems*, pp. 31-32.

198 See Stephen Trimble, "AUVSI: RQ-7 likely not to blame for C-130 collision," *Flight Daily News*, August 19, 2011, available at http://www flightglobal.com/news/articles/auvsi-rq-7-likely-not-to-blame-for-c-130-collision-360993/; and John Reed, "Midair Collision Between a C-130 and a UAV," *Defense Tech*, August 17, 2011.

199 See John Croft, "UAV Autonomy - Flying sense," *Flight International*, May 30, 2008, available at http://www.flightglobal.com/news/articles/uav-autonomy-flying-sense-224349/; Dan Thisdell, "European UAV sense-and-avoid system to begin trial flights by year-end," *Flight International*, October 25, 2012, available at http://www.flightglobal.com/news/articles/european-uav-sense-and-avoid-system-to-begin-trial-flights-by-year-end-378078/; Graham Warwick, "Sense-And-Avoid System To Transition To Global Hawk," *Aerospace Daily & Defense Report*, July 30, 2012, available at http://www.aviationweek.com/Article.aspx?id=/article-xml/asd_07_30_2012_p03-01-481223.xml&p=1; Craig Hoyle, "EMT offers LIDAR fit for UAV sense and avoid," *Flight International*, March 15, 2013, available at http://www flightglobal.com/news/articles/emt-offers-lidar-fit-for-uav-sense-and-avoid-383493/; John Keller, "Northrop Grumman to provide BAMS maritime surveillance UAV with ability to sense and avoid other aircraft," *Military & Aerospace Electronics*, March 1, 2011, available at http://www militaryaerospace.com/articles/print/volume-22/issue-30/news/news/northrop-grumman-to-provide-bams-maritime-surveillance-uav-with-ability-to-sense-and-avoid-other-aircraft.html; and *The Role of Autonomy in DoD Systems*, pp. 36-37.

to relevant units. These CONOPs, developed to support operations in Iraq and Afghanistan, are resource intensive and may not be sustainable in the future. As one Air Force UAS expert has observed:

> We're moving from megabytes to terabytes to petabytes of data being collected… We've solved that by moving people overseas because we don't have the bandwidth to move all that information back and store it. … We're going to have to be able to filter this information, automate the ability to locate those items of interest so that they're on demand instead of moving all that information back."[200]

This quote describes a CONOPs shift that is roughly analogous to moving from a television broadcast infrastructure that beams signals over wide areas to an "on-demand" viewing model. Instead of beaming back high-definition FMV to ground stations where sensor operators and intelligence analysts must monitor feeds and extract relevant information, UAS with automated on-board PED processing systems could filter and then transmit items of interest.[201] In addition to reducing PED manpower needs, such an approach could significantly decrease UAS bandwidth requirements and dependence on vulnerable data links. According to the Defense Science Board:

> If more processing and exploitation processes can be accomplished onboard a UAS…the system can disseminate actionable intelligence for immediate use and reduce bandwidth requirements. FMV ISR, for example, uses roughly an order of magnitude more bandwidth than the C2 data for a UA. By accomplishing more of the TPED process onboard the unmanned system, the link bandwidth can then be focused on transmitting only what's needed, and the overall bandwidth requirements can be reduced.[202]

Advances in processing power and data storage capacity (as well as concomitant reductions in the cost of requisite hardware) could enable this shift from constant-broadcast to on-board processing and on-demand delivery. Future UAS with multi-intelligence sensors, enhanced processing power, increased data storage, and advanced capabilities such as automated facial recognition and coherent change detection could provide warfighters with on-demand targeting information.[203] By reducing human workloads and streamlining the PED process, this on-board/on-demand model would help compress the operations-intelligence cycle. Networking multiple UAS with on-board processing together (and potentially integrating manned platforms with significant on-board processing power such as the F-35) could further improve both the accuracy and the speed of the PED process.[204]

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200 Quoted in Scott Fontaine, "UAV autonomy limits flexibility, officer says," *Air Force Times*, October 16, 2010, available at http://www.airforcetimes.com/article/20101016/NEWS/10160308/UAV-autonomy-limits-flexibility-officer-says.

201 The Role of Autonomy in DoD Systems, pp. 31-32.

202 Unmanned Systems Integrated Roadmap 2011-2036, p. 49.

203 Ibid.

204 Ibid.

Automated PED may be possible in the near term.[205] As the quality of artificial intelligence improves, analysts and sensor operators may be able to "teach" UAS PED programs by providing feedback on the relevancy and usefulness of automated reports. This would allow PED programs to refine their capabilities over time and use sensors and bandwidth more judiciously.

Automated/autonomous target recognition

Automated or autonomous target recognition (ATR) is in many ways closely related to automated PED. Both functions require UAS systems capable of detecting something of significance, characterizing it, and gathering additional information to determine if further action is warranted. In all likelihood, the two will be complementary, as the persistent collection and PED of information can support more rapid ATR, and the ability to rapidly detect and assess potential targets/items of interest will improve the ability of automated PED to separate signals from noise.

An example scenario might better illustrate this relationship. In a future conflict, the U.S. military may need to counter sophisticated ballistic missile forces. In the past, the U.S. military has generally tried to "shoot the archer, not the arrow," i.e., attack relatively vulnerable missile C2 networks and launch platforms instead of relying completely on defenses that use missiles to hit missiles that are in flight.[206] Unfortunately, mobile ballistic missile TELs proved difficult to detect and kill in past conflicts—Coalition forces were conspicuously unable to stop the Iraqi Army from launching SCUD missiles throughout the First Gulf War:

> In 1991 the U.S. dedicated 2,493 missions to what came to be called the "Great Scud Hunt." But it did not score one confirmable kill against a mobile missile or its launcher in Iraq — though it did destroy what turned out to be a few fuel trucks as well as some East German decoys that looked like the real thing.[207]

Penetrating UCAS with automated PED and ATR may be able to help DoD address this operational challenge. UCAS with wide-area motion sensors such as ARGUS-IS could provide persistent ISR coverage of known ballistic missile launch areas. When a missile launch is detected using passive sensors, UCAS on-board PED systems could "rewind" recordings of the battlespace, fuse this information with other available intelligence sources, and track the missile

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[205] According to the Defense Science Board, "The state of the art in mission sensing can be summarized as follows: well-specified objects or events can be autonomously recognized under favorable conditions, while cues and indicators of areas of interest can be generated under less-constrained conditions for rapid disambiguation by human analysts. Significant progress has been made in fusing geolocated imagery from multiple sources, most notably the open source Photosynth, which was developed for public imagery. *The Role of Autonomy in DoD Systems*, p. 35. See also *Unmanned Systems Integrated Roadmap 2011-2036*, p. 48.

[206] The Navy's "outer air battle" concept—wherein F-14 Tomcats armed with long-range Phoenix air-to-air missiles attempted to intercept Soviet aircraft before they could launch their advanced ASCMs toward a Carrier Strike Group—is one such example.

[207] Mark Thompson, "The Great Scud Hunt," *Time*, December 15, 2002, available at http://www.time.com/time/magazine/article/0,9171,400021,00.html.

launcher to its loading area. Other armed UCAVs could draw on this information to automatically target missile launchers with a matching "signature," i.e., vehicles that have the correct size and shape, are emitting in the same manner as previous TELs, and are moving on routes known to be frequented by TELs.

As is the case with automated PED and automated sense-and-avoid, ATR systems could gradually evolve into *autonomous* target recognition systems as artificial intelligence technologies improve. In the meantime, humans may be able to provide guidance that could help these systems "learn" how to detect and assess targets automatically.

Mature autonomous operations

As the aforementioned technologies are integrated into systems, they will help enable the development of UAS that are increasingly capable of autonomous tasks. Initially, these tasks are likely to be heavily bounded and require some human oversight. For example, manned combat aircraft operating in concert with UAS may need to designate targets for UAS strikes and digitally "approve" their use of lethal force. As these tasks become more complex and open-ended—i.e., they transition from "destroy or disable this SAM site" to "suppress enemy air defenses in this sector for a given period of time"—they will require UAS with the ability to assess and respond to non-binary, uncertain situations. In turn, this will free humans from the time-consuming task of acting as managers of UAS, permitting them instead to perform as commanders of unmanned subordinates that can adapt to unforeseen events.

In some cases, increased UAS autonomy may actually be misnomer for what is actually a system of complex integrated automation, but the end result will be the same from an operational perspective: unmanned aircraft will be able to conduct missions and tasks relying solely on mission-type orders based on the commander's intent and rules of engagement.

Integrating Unmanned Operations

The need for new CONOPS

The next-generation UAS force envisioned in this assessment will need to interact effectively with manned weapons systems as well as other unmanned aircraft. This will require DoD to develop the new concepts of operation. For convenience, the term "unmanned^n" is used to describe the coordinated operations of an indeterminate number of UAS.

One possible CONOPs might address how groups of networked, autonomous UAS could independently conduct human-designated tasks such as suppressing enemy SAM sites. This would require a sort of collective, bounded task autonomy wherein multiple UAS decide how they will operate together before each automatically executes its individual tasks. The Navy's UCAS-D program has developed state-of-the-art unmanned software that would allow groups of UAS to determine how they should perform given tasks autonomously. As artificial intelligence improves, the range and complexity of UAS CONOPs could provide significant new advantages to warfighters. In the future, groups or "swarms" of autonomous UCAS may be able to overwhelm an enemy's air defense systems and conduct cooperative precision strikes on C2 facilities, weapons storage complexes, and other large target sets.[208]

Secure data links

In addition to new CONOPs, the effective integration of manned and unmanned aircraft operations will require secure data links that permit the sharing of C2 and ISR information. Today's UAS lack secure, jam-resistant data links that would allow them to share information with manned and unmanned platforms. According to one Marine Corps UAS squadron commander, "the biggest number-one issue is we can't talk to the people we need to…digitally…[as there are] no encrypted data links."[209]

The Tactical Common Data Link (TCDL), the primary data link for UAS, uses a common waveform and protocol for communications between aircraft, ground stations, and surface vessels.[210] The unmanned aerial systems tactical common data link assembly (UTA) allows AH-64D Longbow Apache helicopters to use the TCDL to view sensor feeds from UAS, as well as control its sensors and even the UAS itself.[211] TCDL is, however, vulnerable to detection and jamming. According to Vice Admiral William Burke, DoD must therefore "develop a robust communications suite to operate in the A2/AD environment…it must be jam-resistant, yet have ample bandwidth for the drone to transmit back the data it collects."[212]

Fortunately, such data links already exist. MADL is one such link that is being developed for stealth aircraft and could allow for rapid, automated sharing of information between manned and unmanned platforms and potentially between UAS.[213] Equipping future UAS with MADL may be "more like an engineering challenge than an impossible task."[214] MADL's cost is another issue. In 2011, the Air Force canceled a program to equip F-22 Raptors with MADL due to

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208 It is important to note, however, that swarming in this sense refers to a tactic to be used by UAS generally, and not to a "swarm" of tiny UAS meant to bio-mimetically replicate a swarm of insects or birds. As noted previously, swarms of tiny UAS are likely to be of limited operational utility.

209 Quoted in Sydney J. Freedberg, "Drones Need Secure Datalinks To Survive Vs. Iran, China," *Breaking Defense*, August 10, 2012, available at http://breakingdefense.com/2012/08/10/drones-need-secure-datalinks-to-survive-vs-iran-china/.

210 Michael Hoffman and Kris Osborn, "Sharing UAV feeds easier with new data link," *Air Force Times*, January 22, 2009. TCDL also enables pilots to directly control UAS without the need to pass commands through ground control stations.

211 Stephen Trimble, "New Apache-UAV datalink completes first flight," *Flight International*, January 29, 2009, available at http://www flightglobal.com/news/articles/new-apache-uav-datalink-completes-first-flight-321814/

212 Quoted in Sydney J. Freedberg, "Drones Need Secure Datalinks To Survive vs. Iran, China," *Breaking Defense*, August 10, 2012, available at http://breakingdefense.com/2012/08/10/drones-need-secure-datalinks-to-survive-vs-iran-china/.

213 Aaron Mehta, "New data link enables stealthy comms for F-35," *Air Force Times*, July 19, 2013, available at http://www.airforcetimes.com/article/20130719/NEWS04/307190027/New-data-link-enables-stealthy-comms-F-35.

214 Vice Admiral William Burke, as quoted by Freedberg, "Drones Need Secure Datalinks To Survive Vs. Iran, China."

concerns about cost and risk.[215] While it is likely that integrating MADL in clean-sheet UAS designs could be less expensive and risky than retrofitting it into existing stealth aircraft, cost will certainly remain an issue. Semi-expendable or lethal UAS, for example, may not warrant the expense of MADL and would therefore need more cost-effective means of communicating in contested areas.

Data and control interfaces

The control interfaces of most current-generation UAS were designed around remotely piloting and monitoring UAS from ground stations or, in the case of smaller, tactical UAS, laptops. CONOPs that use forward-located operators to control multiple automated/autonomous aircraft, monitor the data they collect, and assign tasks will need new interfaces that maximize operators' access to critical information and reduce data overload.

Sensor operators and intelligence analysts have struggled to cope with the deluge of data provided by DoD's expanding fleet of UAS equipped with increasingly capable, multi-spectral sensors. Along with throwing more manpower at the problem, DoD has explored alternative technical means to process huge volumes of data. One approach has been to use techniques borrowed from television coverage of professional football that tag clips of video with keywords that can be searched to create interesting highlights.[216] Future iterations of this capability could tag data automatically and compose fused ISR "highlight reels" for various users and weapons systems. Continuing the football analogy, the National Football League's "RedZone" is a rough example of this approach. Rather than broadcasting a single professional football game, RedZone covers nearly every key play in the league by jumping between games and dedicating air time to teams that are within the opponent's 20-yard line "red zone" and thus have a relatively high probability of scoring.

In the future, operators may not have the time or the ability to monitor large numbers of UAS continuously and thus may require some type of automated "redzone" capability that would show crucial, time-critical information. Moreover, their UAS C2 systems will need to move beyond joysticks, keyboards, and computer mice to more advanced systems such as touchpads, voice recognition, or ocular tracking. Given the rapid advancement of these systems in commercial sectors, DoD may wish to adopt an open architecture that would allow it to rapidly incorporate new or modified off-the-shelf capabilities as they become available.

Stealth

The proliferation of advanced air defenses to state and non-state actors will place a premium on aircraft and cruise missiles that are capable of penetrating and persisting in contested airspace. This capability, which is usually represented by the catchall terms "low-observable" or "stealth,"

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215 David Majumdar, "Cost, risk scuttle planned Raptor data upgrade," *Air Force Times*, March 31, 2011.

216 Christopher Drew, "Military Is Awash in Data From Drones," *New York Times*, January 10, 2010, available at http://www.nytimes.com/2010/01/11/business/11drone.html?adxnnl=1&pagewanted=1&adxnnlx=1266073201-KIL+Qc4vJ3hI/2wec9b0fA&_r=0.

is actually the product of a suite of technologies designed to avoid threats and reduce the spectral and sonic signatures of aircraft.

The development of next-generation, stealthy UAS should be informed by mission requirements and considerations of their cost and expendability. Today, DoD's UAS force lacks sufficient survivability. This is a critical shortfall, since stealth will remain a threshold capability for aircraft of all classes that are required to operate in contested airspace. At the same time, building an *all* stealth UAS fleet would be prohibitively expensive and capability overkill for low-end contingencies such as Operation Odyssey Dawn.[217] Given the operational challenges inherent in an MPSR, as well as future missions envisioned for UAS by this report, it may be more appropriate to pursue a "high-low" mix of stealth and non-stealth designs.

The high end

DoD has the opportunity to use known, highly mature technologies to develop multi-mission UAS and UCAVs with all-aspect, broadband stealth characteristics. Future tailless UAS designs, such as the X-47B with its "cranked kite" flying wing planform, could be difficult to detect by low-frequency search radars and high-frequency tracking radars.[218] Moreover, all-aspect stealth would reduce the need for UAS to maneuver to avoid detection by enemy radars, as opposed to "single-aspect" stealth aircraft that are low-observable from only one direction.

Stealthy UCAVs could conduct ISR, EW, strike, and counterair missions to help "knock down the door" for non-stealthy aircraft and cruise missiles. Counter-air missions could include offensive counter-air (OCA) operations to defeat airborne threats as well as surface-to-air missiles. Some analysts have suggested that future air superiority UAS could have greater maneuverability compared to manned aircraft that are constrained by the physiological limitations of their pilots.[219] While this is technically true, the cost of building UAS airframes capable of withstanding extreme gravitational forces (G-forces) would likely render them prohibitively expensive. Furthermore, advanced, long-range, air-to-air missiles are rapidly becoming a dominant counter-air capability. Thus, it would seem appropriate to design stealthy UCAVs as counter-air sensor platforms and weapons carriers—possibly including air-to-air missiles and counterair directed energy weapons—with a modicum of maneuverability, while leaving extreme maneuvers to air-to-air missiles.

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217 During Operation Odyssey Dawn in 2011, manned aircraft and cruise missile strikes destroyed the remnants of Libya's air defenses, allowing non-stealthy Predators and Reapers to operate nearly unchallenged.

218 See "U.S. Navy's Unmanned Combat Air System Demonstration (UCAS-D) Program," available at http://www.northropgrumman.com/review/005-us-navy-ucas-d-program html#. Also see David A. Fulghum, "Northrop Crafts Multimission N-UCAS," *Aerospace Daily and Defense Report*, March 21, 2008, available at http://www.aviationweek.com/ aw/generic/story_generic.jsp?channel=defense&id=news/NUCAS032108.xml&headline= Northrop%20Crafts%20Multimission%20N-UCAS.

219 See Robert Haffa and Anand Datla, "Commentary: 6 Ways to Improve UAVs," *Defense News*, March 22, 2012.

The "low end"

The remainder of DoD's future UAS fleet could be comprised of so-called low-end capabilities with little consideration given to incorporating low-observable features in their designs.[220] There are at least two significant reasons why DoD might choose this bifurcated UAS development path. First, stealth aircraft are costly to develop, procure, and maintain. Attempting to replace every Predator, Reaper, Global Hawk, and BAMS with low-observable platforms would be prohibitively expensive. Second, while stealth aircraft may be vital capabilities in an MPSR, there will remain numerous operational scenarios for which highly stealthy UAS would either be capability overkill or incompatible with missions that require UAS to actively emit energy.[221]

Directed Energy Weapons for UAS

Within an emerging MPSR, DE weapons may have great potential to help reverse the cost-imposition dynamic of the missile versus missile-defense competition and instead impose costs on adversaries whose anti-access strategies are anchored by electronics-based networks. Directed-energy weapons encompass various forms of high- and low-power lasers, high-power microwave weapons, and non-lethal uses of concentrated electromagnetic energy.[222] Two forms of DE technologies—high-power, solid-state lasers (HPSSLs) and HPMs—may be particularly well suited as weapons systems carried by long-endurance UAS, as they could provide "self-renewing" payloads that would reduce the need for the aircraft to land and be rearmed.

HPSSLs use doped glass or ceramic lasing media to create a highly accurate coherent beam of light. Unlike chemical lasers, which use chemical gas lasing media that must be replenished after a number of shots, SSLs are capable of firing nearly indefinitely if provided with sufficient cooling and power from generators and battery systems.[223] Moreover, the low cost-per-shot of an SSL weapon is exceedingly low as it is determined by the cost of the electricity required to generate its laser beam. The combination of precision, a self-replenishing magazine, and low cost-per-shot make HPSSLs promising candidates as weapons for countering cruise missiles, air-

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220 Although not stealthy, high-altitude, long-endurance multi-mission platforms such as the RQ-4 Global Hawk and the MQ-4C Triton, and extremely long-endurance, very high-altitude UAS designed to augment space-based ISR and C2 capabilities may also qualify as "high-end" capabilities given the critical nature of their missions and the sophistication and cost of their sensors. Nevertheless, these capabilities would be "low-end" with regard to stealth.

221 Such as UAS acting as high-altitude, long-endurance communications relays.

222 Directed energy is used by DoD to describe non-kinetic capabilities that produce "a beam of concentrated electromagnetic energy or atomic or subatomic particles" to "damage or destroy enemy equipment, facilities, and personnel" in the air, sea, space, and land domains. DE devices are defined as systems "using directed energy primarily for a purpose other than as a weapon" that may include laser rangefinders and designators used against sensors that are sensitive to light. Finally, DE warfare includes "actions taken to protect friendly equipment, facilities, and personnel and retain friendly use of the electromagnetic spectrum." See Joint Publication 1-02, "Department of Defense Dictionary of Military and Associated Terms," November 8, 2010, pp. 99-100.

223 See Gunzinger and Dougherty, Changing the Game: the Promise of Directed-Energy Weapons, pp. 16, 17.

to-air missiles, G-RAMM, and even other aircraft, particularly given the high cost of current-generation kinetic missile interceptors.[224]

There are, however, technological challenges that must be overcome before SSLs mature as practical weapons for fighter-sized unmanned or manned aircraft. Although SSLs are improving their efficiency and power outputs, additional work is needed to ensure they will be capable of generating laser beams with sufficient power to be effective against fast-moving targets over operationally useful ranges. Since the highest electro-optical efficiency that can theoretically be achieved from HPSSLs is approximately thirty to thirty-five percent and the most efficient HPSSLs are currently only nineteen to twenty-three percent efficient, a significant amount of waste heat is generated.[225] Unless the laser system is cooled, this waste heat could damage many components of the laser system. Active cooling of the laser system increases the power demands on an aircraft's on-board systems. Although programs such as DARPA's High-Energy Liquid Laser Air Defense System (HELLADS) program and the High Energy Laser Joint Technology Office's Robust Electric Laser Initiative seek to create HPSSLs that are more efficient, smaller, and lighter, an operational laser weapon suitable for fighter-sized aircraft will not be available in the near term.[226]

In the near term, current technology could support the development of HPM weapon packages for UAS the size of today's Predator or even smaller. As their name implies, HPM weapons use extremely short, high-power bursts of microwave radiation to disrupt or destroy unshielded electronic systems. Like HPSSLs, HPMs can be fired nearly indefinitely if supplied with sufficient power and cooling. Unlike HPSSLs, HPM weapons could be integrated onto existing or new UAS in the next several years.[227] Mounted in stealthy, long-endurance UCAVs that use on-board generators and batteries to power weapons systems, HPM weapons could be a potent

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224 These include interceptors such as the $3.3 million Patriot Advanced Capability-3 (PAC-3) missile, $9 million Terminal High Altitude Area Defense (THAAD) missile, and $10-15 million Standard Missile-3 (SM-3).

225 The electro-optical (E-O) efficiency of electric lasers is measured as the ratio of the optical power out of a laser to the electrical power input to the laser. State-of-the-art electric lasers have E-O efficiencies that range around 20 percent or slightly more. An SSL with an output of 100 kilowatts and an E-O efficiency of 20 percent would require 500 kilowatts of power and would produce 400 kilowatts of wasted power that would need to be dissipated by a cooling system.

226 See the HELLADS description provided by DARPA's Strategic Technology Office, available at http://www.darpa.mil/Our_Work/STO/Programs/High_Energy_Liquid_Laser_Area_Defense_System_(HELLADS).aspx. Larger platforms such as a manned or optionally manned version of the Long Range Strike-Bomber may have sufficient space, weight, and power to carry SSL weapons.

227 The Air Force's now-completed Counter-Electronics High Power Microwave Advanced Missile Project Joint Capability Technology Demonstration (CHAMP JCTD) had the objective of developing an HPM package that "could be carried aboard cruise missiles, small aircraft, or UAS. See "Counter-Electronics High Power Microwave Advanced Missile Project (CHAMP) JCTD," United States Air Force Official Solicitation Notice, available at https://www.fbo.gov/index?s=opportunity&mode=form&id=e2daa9dccf59c9887810286dc9909d54&tab=core&_cview=1.

means of countering target-acquisition radars, SAM launchers, and the computers and communications networks that serve as the synapses of an A2/AD complex.

Integrating DE weapons on UAS could provide U.S. power-projection forces with important advantages in an MPSR. First, UAS capable of generating sufficient power could carry "self-replenishing" SSL and HPM payloads that complement their long mission endurance. Second, and perhaps most importantly, SSL and HPM weapons could help create a cost-imposition dynamic in the emerging MPSR that favors U.S. power-projection forces. The continued proliferation of precision-guided missiles is giving military competitors the means to strike military bases and forces with accuracy over long ranges. Countering these threats with kinetic interceptors that cost millions of dollars each creates a cost imposition dynamic that favors the offense. HPSSLs that could disable or destroy incoming cruise missiles, aircraft, and other airborne threats for a negligible cost-per-shot could reverse this cost-imposition calculus. Third, near-future DE weapons could lead to another leap-ahead in the U.S. military's ability to "strike" with precision. During the Second World War, hundreds of conventional unguided bombs were needed to destroy single targets. Today, "one PGM, one target" is an everyday assumption for air campaign planners. In the future, unmanned platforms could carry HPMs and possibly other DE systems that could be effective against many targets in a single pass. To counter a U.S. fleet of UAS armed with HPM weapons, adversaries would need to invest in measures to harden their key weapons systems, possibly at the expense of investments in offensive capabilities. The alternative would be to accept that they might suffer the temporary or even permanent loss of capabilities that are critical to their operations.

Powerplants for Future UAS

Taking full advantage of the robotic revolution may require equipping the next generation of UAS with new powerplants to enable a wider range of missions compared to current unmanned aircraft. Most UAS designs now use engines that prioritize cost, fuel efficiency, range, and endurance over aircraft thrust, speed, and the generation of electricity to power sensors and weapons systems. Future unmanned aircraft that are designed to carry larger and more diverse weapons payloads may need to establish a better balance between these performance characteristics.

Under the Air Force Research Laboratory's broader Versatile Affordable Advanced Turbine Engines (VAATE) program, efforts such as the Adaptive Versatile Engine Technology (ADVENT), Highly Efficient Embedded Turbine Engine (HEETE) and efficient small-scale propulsion (ESSP) have sought to develop more fuel-efficient engines that could also provide aircraft with greater thrust and power generation capacity. The Air Force's Adaptive Engine Technology Development (AETD) program received $216.3 million to develop variable cycle propulsion systems that could reduce specific fuel consumption by 25 percent or more while providing thrust to allow aircraft to cruise at higher speeds.[228]

For smaller, tactical UAS, substantial gains in endurance and range may become possible as advanced batteries become available and fuel cell technologies mature. Aircraft designers are interested in developing alternatives to nickel cadmium (Ni-cad) batteries that are currently incorporated in many small UAS. Lithium Ion (Li-ion)–based batteries, which are more efficient and lighter than Ni-cad batteries, are used in the new Boeing 787 "Dreamliner."[229] Extremely long-endurance, high-altitude UAS could also benefit from advances in non-traditional powerplants similar to the liquid hydrogen engine developed for the Phantom Eye demonstrator.[230]

Miniaturization, Additive Manufacturing, and Novel Materials

The design characteristics of current-generation UAS are greatly influenced by the size and shape of their engines, sensors, and other major components, while their airframes are, for the most part, built using methods and materials that may not be fully optimized for the production of unmanned aircraft. In the future, it may be possible for the defense industrial base to capitalize on advances in miniaturization, new manufacturing techniques such as "3-D printing," and novel materials (e.g., graphene) to create UAS with significantly improved capabilities for less cost compared to current-generation aircraft development approaches.

The rapid expansion of demand for UAS sparked by the wars in Iraq and Afghanistan and subsequent global interest in unmanned aircraft helped drive the development of mini/micro and tactical UAS designs that could be carried by small squads in the field. Befitting their roots as demonstrator or rapid-development programs, current UAS incorporate many off-the-shelf components. While this reduced the time and cost needed to field them, it also led to systems that do not take full advantage of emerging miniaturization technologies. As urgent operational requirements for UAS decrease, DoD's focus is beginning to shift from reducing the size of unmanned aircraft platforms toward reducing the size and weight of their payloads. This could free up space for next-generation UAS to carry additional fuel (and therefore increase their unrefueled range and endurance), weapons, sensors, or avionics systems needed for automated or autonomous functions.

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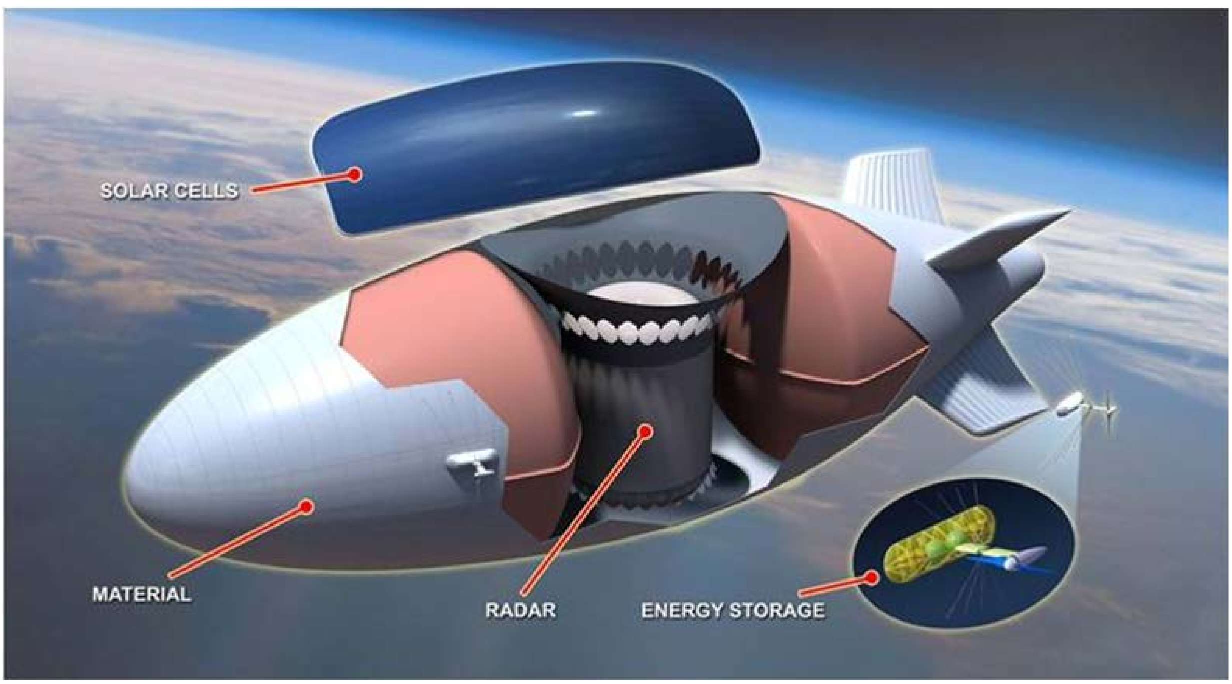
228 Rebecca Grant, "Adaptive Engines," *Air Force Magazine*, September 2012, available at http://www.airforcemag.com/MagazineArchive/Pages/2012/September%202012/0912engines.aspx.

229 Sodium-based batteries are also leading contenders for future commercial and military aircraft.

230 Engine designs for UAS intended to fly very long periods of time will also need to account for other factors that could limit mission endurance, such as the depletion of engine lubricants and coolants. Craig L. Nickol, Mark D. Guynn, Lisa L. Kohout, and Thomas A. Ozoroski, *High Altitude Long Endurance UAV Analysis of Alternatives and Technology Requirements Development* (Washington, DC: National Aeronautics and Space Administration, 2007), p. 65.

Certain components, such as antennas and optical sensors, are presently difficult to miniaturize because their effectiveness depends to a large extent on their size. This may change as digital sensors, digital signal processing power, and novel construction techniques enable the development of new sensors. For instance, instead of concentrating components in single large radar antennas or EO/IR cameras, it may be possible to integrate large numbers of tiny, dispersed digital sensors directly into UAS structures. Information generated by a networked system of mini-sensors could be integrated using on-board advanced digital signal processors to create unified "virtual sensors" with large areas of regard. Similar technologies already exist. The F-35's infrared search and track (IRST) system uses networked IR sensors mounted around the aircraft to provide pilots with 360-degree situational awareness. Additionally, DARPA has funded the development of a prototype Integrated Sensor Is Structure (ISIS) airship that incorporates a radar system designed to provide "wide-area surveillance, tracking, and engagement for hundreds of time-critical air and ground targets"[231] as part of its structure (see cutaway illustration below).

Integrated Sensor Is Structure (ISIS) Developmental Airship



Building sensors into airframes is presently a costly and technologically challenging process. The advent of "additive manufacturing" and other advanced production techniques may help to reduce these challenges. Additive manufacturing, which is commonly referred to as 3D printing, is a method that combines digital technologies with materials that can be combined layer-by-layer to rapidly create three-dimensional objects. Using this technique, it may be possible to

[231] DARPA Strategic Technology Office, "Integrated Sensor is Structure (ISIS)," available at http://www.darpa.mil/Our_Work/STO/Programs/Integrated_Sensor_is_Structure_(ISIS).aspx.

"print" airframe pieces that are with impregnated with sensors and integrated circuits at much less cost than conventional manufacturing practices. 3D printing is rapidly becoming science fact, rather than science fiction. According to one report, current-generation F/A-18s are "likely to contain some 90 3D-printed parts," and the F-35 may have "around 900 parts that have been identified as suitable for additive manufacturing."[232]

It may also be possible to combine additive manufacturing with the use of novel materials to create other UAS components. Graphene, for instance, has a unique structure consisting of a near-perfect crystal lattice of carbon atoms that gives it properties scientists are only beginning to exploit. According to experts from the University of Manchester where graphene was first isolated, the material is very light and "harder than diamond and 300 times harder than steel."[233] Graphene is also a more efficient conductor of electricity than copper. This makes it an excellent candidate for supercapacitors whose energy density (storage capacity per unit volume) rivals advanced batteries but weigh far less.[234] Supercapacitors developed from graphene could become a much lighter, more inexpensive, and more effective means than conventional batteries for storing and then quickly releasing energy to power UAS weapons systems.

Summary

UAS technologies are on the brink of enormous change. In lieu of sustaining a fleet that has been sized and shaped to support irregular warfare in Iraq and Afghanistan, DoD has the opportunity to leverage advances in precision navigation and timing, C2, autonomy, and new materials to create a high-low mix of UAS that is both affordable and relevant in all threat environments. To use a historical analogy, early, pre-GPS and SATCOM UAS were akin to the military aircraft used in the First World War: they were interesting capabilities that showed promise but were unable to affect operational outcomes in a meaningful way due to their technological immaturity. Today's UAS may be akin to Second World War piston-engine, propeller-driven aircraft: although far more capable than their predecessors, they were about to be eclipsed by a new generation of systems that took advantage of new sensors, weapons, powerplants, and materials.

Following this analogy, new UAS such as the Navy's UCLASS could become a harbinger of technological change as far removed from the First Gulf War's RQ-2 Pioneer as the Messerschmitt Me-262, the world's first jet-powered combat fighter, was from the Fokker Dr.I triplane. Leveraging mature and maturing technologies, UAS could be highly automated systems that are capable of bounded task autonomy, automatic air refueling, and unmanned^n cooperation.

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232 "3D Printing Scales Up," *The Economist*, September 7-13, 2013, p. 12.

233 "Properties of Graphene," The University of Manchester, available at http://www.graphene manchester.ac.uk/story/properties/. See also "The Story of Graphene," The University of Manchester, available at http://www.graphene manchester.ac.uk/story/.

234 Farhad Manjoo, "Unexpectedly Amazing Carbon-Based Energy Form," *Slate*, March 22, 2013, available at http://www.slate.com/articles/health_and_science/alternative_energy/2013/03/graphene_supercapacitors_small_cheap_energy_dense_replacements_for_batteries.html.

What is most striking, however, is that this technology exists today, as demonstrated by the Navy's UCAS-D program.

Admittedly, there are still significant hurdles that must be overcome before DoD is able to develop its next-generation UAS force. Some of these hurdles are at the engineering or manufacturing level, while others—such as artificial intelligence sophisticated enough to enable fully autonomous operations for all UAS mission functions—will require the invention of some new technology. Nevertheless, designs created in support of the Navy's UCLASS initiative are tangible proof that a substantial number of the technologies needed to support an alternative UAS development path are sufficiently mature. Other, perhaps more significant barriers to this new path are the subject of Chapter 6.

Chapter 6. Possible Barriers to a New UAS Path

Technological Barriers

It is clear that most of the U.S. military's current UAS fall short of the capabilities that are needed to operate effectively in an MPSR. However, nearly all of these shortfalls—large passive signatures, limited mission capabilities, lack of secure and jam-resistant data links, overreliance on GPS, and dependence on human controllers for most mission functions—can be overcome by existing technologies and engineering solutions rather than the wholesale inventions of new technologies.

Overcoming other challenges, such as providing UAS with some advanced autonomous functions or effective DE weapons, will require continued research and development. In the case of autonomy, however, it appears that operators and technologists may be talking past one another. Operators desire UAS that require a far lower degree of human interaction, and thus ask for "autonomous" UAS, despite the fact that advanced automation or bounded, low-level autonomy would suffice in many cases. The science and technology (S&T) community, for their part, sometimes interpret "autonomous UAS" to mean self-directed and self-aware robotic systems that are capable of conducting complex tasks in highly uncertain situations and learning by doing with minimal human direction. They then (correctly) argue that such autonomy may not be possible in the near term. Both operators and the S&T community sometimes miss that difficult UAS tasks[235] can be accomplished automatically and that some autonomous functions are possible today if the tasks and conditions are sufficiently bounded. For example, although the U.S. Navy's X-47B may not be fully autonomous, it does possess sufficient automation and autonomy to perform missions with a much lower level of human control compared to other UAS now flying today.

Funding for Next-Generation UAS

While a UAS development path that would lead to a far more capable force in the future may be technologically feasible, it will be difficult from a budget perspective in a post-war period when funding for new defense programs will be a tough sell in Congress. Similar to manned aircraft, UAS with stealth capabilities and greater range and useful payloads compared to current systems will not be inexpensive. Developing the "high" part of a high-low UAS future force mix may not be possible should DoD or Congress significantly decrease funding for unmanned aircraft development. Major cuts to the defense budget are already underway as shown by the table below,[236] which does not include "sequestration" cuts required by the Budget Control Act (BCA)

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[235] For instance, in July 2013 the Navy's UCAS-D performed the very difficult tasks of taking off and landing on an aircraft carrier deck without human direction.

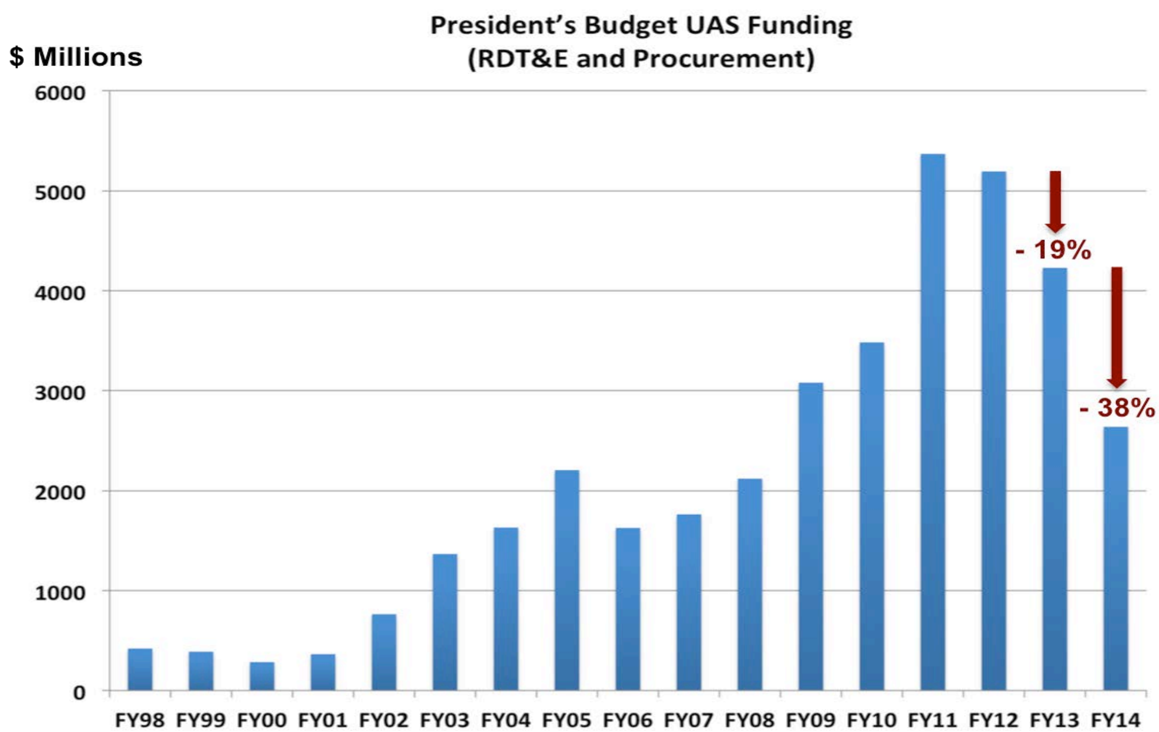
[236] The table is extracted from *United States Department of Defense Fiscal Year 2014 Budget Request* (Washington, DC: Department of Defense, 2013), p. 1-3.

of 2011. Budget sequestration has already led to a 12 percent reduction in the overall defense budget, the largest year-on-year decrease since the drawdown following the Korean War.[237]

DoD Topline Since September 11, 2001 Terrorist Attacks (in $billions)

	FY01	FY02	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14
Base	287.4	328.2	364.9	376.5	400.1	410.6	431.5	479.0	513.2	527.9	528.2	529.9	527.5	526.6
OCO	22.9	16.9	72.5	90.8	75.6	115.8	166.3	186.9	145.7	162.4	158.8	115.1	87.2	88.5
Other	5.8	--	--	0.3	3.2	8.2	3.1	--	7.4	0.7	--	--	0.1	--
Total	**316.2**	**345.1**	**437.5**	**467.6**	**478.9**	**534.5**	**600.9**	**665.9**	**666.3**	**691.0**	**687.0**	**645.0**	**614.8**	**615.1**

At a more granular level, UAS research, development, and procurement investments have come to be seen as a source of savings for the Services. The President's Budget Request for FY2013 reduced UAS research, development, and procurement spending by 19 percent from the previous year, and the FY2014 budget request cut UAS funding yet another 38 percent. The chart below[238] illustrates that DoD has cut its proposed annual spending for new UAS by nearly 50 percent in the space of three years.



237 Todd Harrison, *Looking Beyond the Fog Bank: Fiscal Challenges Facing Defense* (Washington, DC: Center for Strategic and Budgetary Assessments, 2013), p. 3.

238 Data extracted from Weatherington, Unmanned Systems Integrated Roadmap FY2013-2038.

The growth of America's UAS force over the last decade was fueled in part by wartime budgets and DoD's ability to rapidly adapt developmental systems to support current operations. The cost of buying and maintaining DoD's UAS force and other systems needed to meet operational needs also had the effect of crowding out Service investments in modernization programs needed to operate effectively in A2/AD environments, such as a new bomber, undersea warfare systems, and missile defenses. The residual effects of this crowding out, coupled with a reduced defense spending and not the entirely groundless perception that wartime UAS investments were mandated by DoD's civilian leadership, is likely to reduce the Services' enthusiasm for developing a new generation of unmanned aircraft in the near term.

To partially offset the cost of the next-generation unmanned force, DoD may need to retire some of its current UAS and possibly replace some manned aircraft with unmanned platforms. This latter action also could help reduce the cost of replacing aging manned aircraft. According to DoD's latest UAS roadmap:

> It is possible that advances in UAS designs will allow unmanned systems to replace…the E-3 Airborne Warning and Control System (AWACS) and RC-135 Rivet Joint ISR aircraft [that] will reach the end of their service lives prior to FY 2041.[239]

To date, the Services have been averse to completely replacing manned aircraft with UAS for any particular mission, although the jury is still out on the possibility that Global Hawk Block 30 variants will replace the Air Force's U-2s. The next section addresses the role that institutional factors may play in the adoption of UAS for new missions.

Institutional Barriers?

> Among many myths [surrounding UAS], however, none has been as persistent that the legend of the "white scarf syndrome"—that is, the proposition that USAF pilots culturally resisted UAVs because they wanted to protect their jobs and way of life… In fact, Air Force leaders seem to habitually, even reflexively pursued [sic] aerospace technology of all kinds, even that which might reduce cockpit numbers.[240]
>
> — Colonel Tom Ehrhard (USAF, retired)

> You see a cultural resistance [to UAS]…it's the same thing with the horse cavalry during the introduction of the tank.[241]
>
> — Colonel Eric Mathewson, Air Force UAS Task Force Director

239 *Aircraft Procurement Plan: Fiscal Years (FY) 2012-2041* (Washington, DC: Department of Defense, 2011), p. 19.

240 Ehrhard, Air Force UAVs: The Secret History, p. 45.

241 Quoted in Joe Pappalardo, "The Future For UAVs in the U.S. Air Force," *Popular Mechanics*, February 26, 2010.

As these quotes suggest, there may be a range of attitudes within the Services toward developing a new generation of more capable UAS. A surfeit of anecdotal and programmatic evidence suggests that there may be significant resistance within the Services to fielding new UAS that could perform strike, airborne electronic attack, and other combat missions in high-end conflicts.[242] Fitzsimonds and Mahnken have also suggested that Service attitudes toward UAS were generally more favorable when unmanned aircraft were used to support manned operations (e.g., by providing targeting data for manned strike aircraft), or when the UAS missions were excessively dull (e.g., escorting ground convoys).[243] As UAS have become more capable of performing "real" combat missions, it is possible that they could be perceived as competing, rather than complementary capabilities to manned aircraft.[244]

This dynamic could engender resistance to developing a new generation of more capable UAS. The Air Force, in particular, has been a proponent of unmanned aircraft long before the requisite technologies were sufficiently mature to support development of UAS. By 2008, however, UAS technologies had matured to the point where unmanned systems—such as the Global Hawk Block 30—had the potential to replace, rather than complement, some manned aircraft. It is likely that the leading role of UAS for CT and COIN combat missions in Afghanistan, Pakistan, the Horn of Africa, and elsewhere has reinforced the point that UAS are becoming headlining acts rather than supporting actors in air combat operations. History may eventually show that DoD is now at a "tipping point" for its UAS force. Whereas previously, technological maturity has been a primary obstacle to unmanned aircraft development, hereafter reluctance to creating a new generation of UAS and developing new CONOPs for their employment may stem from institutional factors.

The following case study examines how cultural and institutional barriers may be difficult to overcome for one potentially disruptive unmanned system, the Navy's future UCLASS.

Case study: UCLASS, One Step Forward, Two Steps Back?

Historically, the Navy has had an uneven relationship with unmanned aviation. According to Ehrhard and Work, the relationship between Navy aviators and UAS has been "an uneasy match."[245] This case study addresses how institutional concerns (as well as fiscal challenges)

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242 James R. Fitzsimonds and Thomas G. Mahnken, "Military Officer Attitudes Toward UAV Adoption: Exploring Institutional Impediments to Innovation," *Joint Forces Quarterly*, Summer 2007, pp. 97, 102, 103. On the other hand, their research suggests that many Air Force and Navy officers believe that the pace of UAS integration into the force has been "about right."

243 It is worth noting that Fitzsimonds and Mahnken suggested that "institutionally based opposition will emerge when major organizational and professional changes wrought by growing numbers of unmanned systems actually begin to ripple through the Services." Ibid., p. 103.

244 It is interesting to note there appears to be little resistance within the Army to procuring the MQ-1C Gray Eagle UAS. In part, this may be because the MQ-1C will help fill a known capability gap and will not displace an existing manned platform.

245 See Ehrhard and Work, Range, Persistence, Stealth, and Networking: The Case for a Carrier-Based Unmanned Combat Air System, p. 15.

may have affected the evolution of the Navy's UCLASS program. Beginning with a brief history of Navy UAS, the case study examines the UCAS-D program before finishing with an analysis of the shifting capability attributes desired for the UCLASS.

Background

The Navy's development of the armed DASH UAS in the 1950s and 1960s raised the possibility that the Service could become an early adopter of armed UAS. The abject failure of the DASH program—primarily caused by immature technology—dampened the Navy's enthusiasm for UAS. It was not until after the U.S. intervention in Lebanon in 1983 that the Navy procured the RQ-2 Pioneer to meet urgent operational needs for UAS to act as spotters for naval gunfire.[246]

After the Pioneer, the Navy participated in several joint UAS development programs with the Air Force and the Army, none of which led to an operational Navy UAS. At the turn of the century, the Navy developed and tested the first version of the RQ-8A Fire Scout, but cancelled it almost immediately. The Army's interest in an improved variant, the MQ-8B, combined with Congressional pressure and the need to develop a vertical takeoff and landing (VTOL) system for use aboard Littoral Combat Ships, helped resurrect the Fire Scout program.[247] Today, the Navy's largest, most advanced UAS program is the BAMS, a variant of the Air Force's Global Hawk. Thus, the Navy's two active programs[248] for large UAS—the BAMS and FireScout—owe their existence in part to other Services and Congress.

While the Navy's UAS history reflects a certain amount of skepticism toward unmanned aircraft, much of this may be rooted in concerns over flight safety, as noted by Ehrhard and Work:

> Of all the naval warfighting communities, support for unmanned aircraft has been weakest in the carrier aviation force. This has been primarily due to widespread—and, until now, perhaps justified (if largely untested)—skepticism that unmanned systems could be safely integrated into carrier flight deck operations.[249]

Given this skepticism, it seems improbable that the Navy would fund the development of one of the most advanced UAS developed to date as part of its UCAS-D program.

The UCAS-D program

To counter the emergence of advanced double-digit Russian SAMs in the 1990s, the Air Force and DARPA developed a UCAV—the X-45A—to suppress enemy air defenses.[250] The Navy

[246] This echoes the U.S. Army's procurement of fixed-wing aircraft to act as artillery spotters during the First World War.

[247] Ehrhard and Work, Range, Persistence, Stealth, and Networking: The Case for a Carrier-Based Unmanned Combat Air System, p. 25.

[248] Counting the MQ-8B and MQ-8C as one program, and excluding smaller systems such as the RQ-21A Scan Eagle.

[249] Ehrhard and Work, Range, Persistence, Stealth, and Networking: The Case for a Carrier-Based Unmanned Combat Air System, p. 27.

[250] Ibid., p. 119.

decided that it wanted its own UCAV, one that was designed specifically to operate from a carrier.[251] After requesting concepts from industry, the Navy settled on the X-47A Pegasus in part because the X-45A was not designed for carrier operations.[252]

As the Air Force and Navy programs moved toward producing flying demonstrators, DoD decided to consolidate them under a single Joint Unmanned Combat Air Systems (J-UCAS) initiative in order to reduce program redundancy, cut costs, and foster the development of a common software operating system that would be capable of controlling multiple UCAS. Perhaps more importantly for this case study, DoD leadership also believed that creating the J-UCAS program would protect these fledgling aircraft from "defense infanticide" where funding would be siphoned off to pay for more established programs and thus kill potential threats to the program of record. [253]

The J-UCAS program made significant progress in UAS technologies, particularly in the areas of flight controls and automation/autonomy. In 2004 and 2005, X-45A test aircraft:

- struck a target with an inert, precision-guided, Joint Direct Attack Munition (JDAM);
- flew in formation with a manned aircraft and another unmanned X-45A;
- demonstrated "remotely managed" operations, in which a single ground operator controlled two X-45As;
- automatically detected and avoided a pop-up threat;
- automatically coordinated with another X-45A to achieve simultaneous time-on-target;
- performed a simulated mission in which two X-45As engaged pre-determined ground targets before autonomously detecting, evading, and then destroying two pop-up threats in a coordinated fashion.[254]

The 2006 QDR discontinued the J-UCAS program and channeled its funding to the Navy so that it could "develop an unmanned longer-range carrier-based aircraft capable of being air-refueled to provide greater standoff capability, to expand payload and launch options, and to increase

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[251] Richard R. Burgess, "Mother Ship," Sea Power, July 2005, available at http://findarticles.com/p/articles/mi_qa3738/is_200507/ai_n14687817.

[252] See X-47A Pegasus," *Global Security*, available at http://www.globalsecurity.org/military/systems/aircraft/x-47a htm; and "Naval Unmanned Combat Air Vehicle (UCAV-N)," *Global* Security, available at http://www.globalsecurity.org/military/systems/aircraft/ucav-n.htm.

[253] Ehrhard and Work, Range, Persistence, Stealth, and Networking: The Case for a Carrier-Based Unmanned Combat Air System, pp. 6, 122.

[254] "Ride on the Ray: Boeing's X-45 UCAVs," *Defense Industry Daily*, May 8, 2011, available at http://www.defenseindustrydaily.com/ride-on-the-ray-boeings-x-45-ucavs-05421/.

naval reach and persistence."[255] The Navy's subsequent UCAS-D program was intended to build the foundation for a follow-on operational N-UCAS that would reach initial operating capability (IOC) in 2015.[256] Early plans suggested that carrier air wings would include four to twelve UCAS by 2020.[257] The Navy chose the X-47B (a newer more capable version of the X-47A) for the UCAS-D program and embarked on a development and testing schedule that has "been one of the Navy's most successful, meeting all required objectives within budget and on time."[258]

The Navy's vision for a carrier-based N-UCAS has been in constant flux. In hindsight, the 2006 QDR may have been the high-water mark in terms of developing a true multi-mission N-UCAS. Shortly after the UCAS-D program began, the Navy released its *Navy Aviation Plan Guidance* which stated:

> The N-UCAS program will be refocused…from a carrier-based penetrating, persistent ISR/Tactical Support Team Capability to a 6th generation strike-fighter capability that will recapitalize the F/A-18E/F [around] 2025. It will be renamed F/A-XX and will incorporate…manned/unmanned decision points in the Technical Development phase.[259]

This guidance raised the possibility that the Navy intended to choose between a manned and unmanned platform for its F/A-XX. In other words, it was an indicator that there was a shift in the program's focus toward developing a strike *fighter,* a role for which manned aircraft could have an advantage. This set the N-UCAS on a collision course with a new manned design and may have helped set in motion actions that have affected its successor, the UCLASS.

UCLASS

While the Navy's decision to develop a UCLASS initially appeared to be a step toward a real UCAS, a debate has emerged over its specific capability attributes. In March 2010 the Navy issued a UCLASS request for information (RFI) to industry that did little to clarify if the desired aircraft would be a multi-mission penetrating combat aircraft, or another platform that would primarily provide ISR information:

> The Navy is interested in information on carrier based, low observable Unmanned Air Systems concepts optimized for Irregular and Hybrid Warfare scenarios, capable of integrating with manned platforms as part of the Carrier Air Wing by the end of 2018 to support limited operations in contested scenarios. The UAS should enhance situational

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255 *2006 Quadrennial Defense Review* (Washington, DC: Department of Defense, 2006), p. 46. The 2006 QDR also directed the Air Force to develop a new bomber.

256 *Naval Aviation Vision 2020* (Washington, DC: Department of the Navy, 2005), p. 42.

257 Ibid., p. 38.

258 Secretary of the Navy Ray Mabus, "Unmanned aircraft at sea greatly extend the Navy's reach and sustainability," *U-T San Diego*, July 14, 2013, p. 25.

259 Vice Admiral J. W. Greenert, *Navy Aviation Plan (NAVPLAN 2030) Guidance* (Washington, DC: Office of the Chief of Naval Operations, 2007), pp. 4–5.

> awareness and shorten the time it takes to find, fix, track, target, engage, and assess time sensitive targets. [260]

The RFI did not clarify if the UCLASS should be a stealthy, multi-mission platform suitable to penetrate highly contested airspace, or if it would fall into the mold established by the Predator, Reaper, and other current-generation UAS. Other reports indicate the original vision of developing an air-refuelable, stealthy UCAV capable of conducting long-range ISR and penetrating strike missions from carrier decks was watered down to the point where the UCLASS might be a persistent ISR platform for irregular warfare similar to other contemporary UAS:

> The UCLASS system is to provide [aircraft-carrier]-based persistent intelligence, surveillance reconnaissance, and targeting with precision-strike capability in permissive environments. The use of self-protection payload and/or standoff electronic attack should be considered if operating in a contested environment.[261]

The Navy's attempt to abandon UCAS-D inflight autonomous aerial refueling demonstrations and its 2013 draft UCLASS Request for Proposals (RFP) document are additional indicators that it may have retreated from its original N-UCAS vision. According to the RFP, the UCLASS is now envisioned as a platform that should be capable of maintaining two unrefueled orbits at 600 nautical miles from a carrier, one unrefueled orbit at 1,200 nautical miles, or conducting unrefueled strike missions at 2,000 nautical miles from a carrier while carrying 1,000 pounds of munitions.[262] Reportedly, the RFP also emphasizes affordability over capability, requiring that the 600 nautical mile orbit system cost no more than $150 million while at the same time compromising on aerial refueling and stealth—critical attributes for a penetrating, persistent UCAV that would need to operate in the contested environments of an MPSR.[263]

Thus, instead of a new capability that could greatly extend the offensive reach of the Navy's carrier air wings in contested areas (see figure below),[264] the UCLASS program could produce a

260 "Request for Information for Unmanned Carrier Launched Airborne Surveillance and Strike (UCLASS) System Key Capabilities," Department of the Navy, May 3, 2010, p. 1, available at https://www.fbo.gov/index?s=opportunity&mode=form&id=3c621aa3f10b785132ca7c2abdabf75f&tab=core&_cview=1.

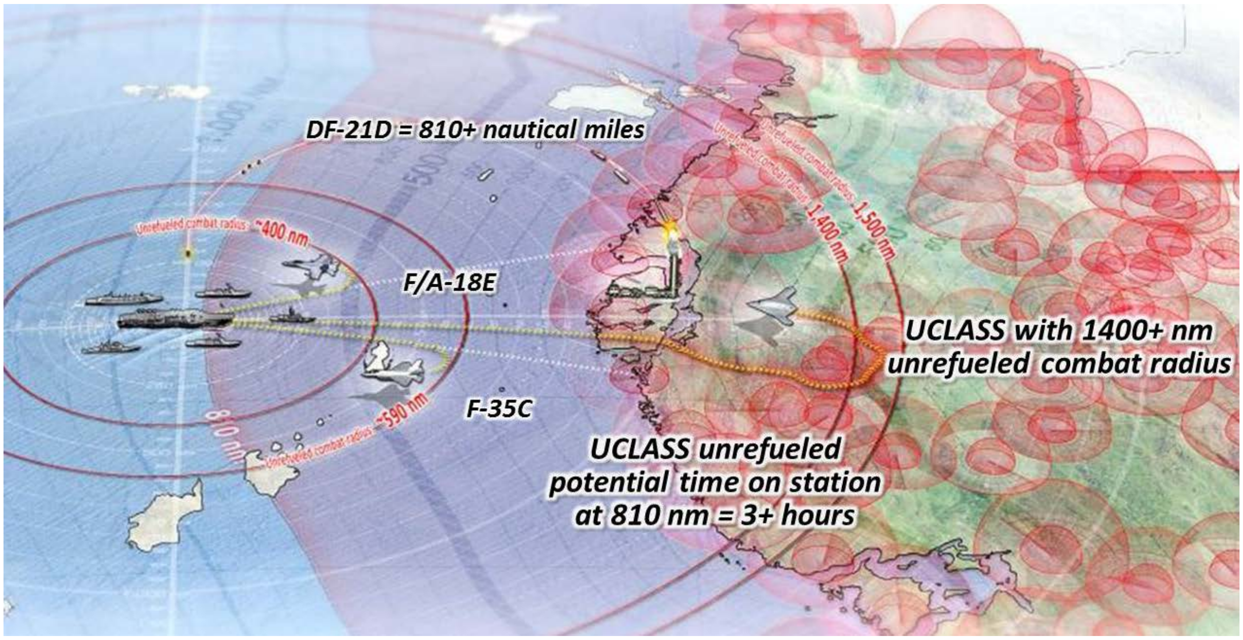
261 "JROC Revises UCLASS Requirements, Calls for Relook of Analysis of Alternatives," *InsideDefense.com*, March 25, 2013, available at http://insidedefense.com/201303252428831/Inside-Defense-Daily-News/DefenseAlert/jroc-revises-uclass-requirements-calls-for-relook-of-analysis-of-alternatives/menu-id-61.html.

262 "Navy Docs Reveal UCLASS Minimum Ranges and Maximum Costs," *U.S. Naval Institute News*, June 26, 2013, available at http://news.usni.org/2013/06/26/navy-docs-reveal-uclass-minimum-ranges-and-maximum-costs.

263 Ibid.

264 This chart is a slight variation on the chart shown during an April 16, 2013 House Armed Services Committee hearing on the Navy's FY2014 budget proposal.

UAS that will be more of a supporting capability for manned aircraft operations in permissive environments.



This is reinforced by a representative from the Office of the Chief of Naval Operations who said, “our primary use for this asset is organic persistent ISR which the strike group doesn’t possess right now—especially at the range and speed that this thing will be able to execute.”[265]

Budget or institutional pressures?

As post-war defense budget cuts began to affect DoD’s modernization programs, it is not surprising that holding the line on cost is a priority for the UCLASS program. DoD’s 2012 budget submission to Congress reported the program would “prioritize cost and effectiveness trades to include, but are not limited to, endurance, payload, speed, sensors, and survivability to maintain affordability.”[266]

Although budget cuts have been cited as the reason why the UCLASS appears to be a capability downgrade from the original N-UCAS concept,[267] institutional resistance to deviating from established CONOPs centered on manned aviation could also be a factor. In 2005, well prior to the Budget Control Act, the Navy’s Deputy Director for Air Warfare Requirements declared that “the primary focus for developing naval [unmanned aircraft] capabilities is centered around

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[265] As quoted in “Navy Docs Reveal UCLASS Minimum Ranges and Maximum Costs.”

[266] *Fiscal Year (FY) 2013 President's Budget Submission: Research, Development, Test & Evaluation, Navy Budget Activity 5* (Washington, DC: Department of Defense, 2012), p. 551, available at http://www.finance.hq navy mil/FMB/13pres/RDTEN_BA5_BOOK.pdf.

[267] “AUVSI 2013: UCLASS Requirements Modified Due to Budget Pressure,” *U.S. Naval Institute News*, August 14, 2013, available at http://news.usni.org/2013/08/14/auvsi-2013-uclass-requirements-modified-due-to-budget-pressure.

providing intelligence, surveillance and reconnaissance (ISR) capabilities. Our whole strategy is focused on ISR."[268] Other evidence, such as the 2010 UCLASS RFI, likewise predates BCA-mandated budget cuts. With the benefit of hindsight, it appears that institutional resistance may be a significant factor in the debate over whether the Navy should develop a UCLASS that could "radically change the way presence and combat power is delivered from aircraft carriers"[269] or another ISR-oriented UAS that could have little operational utility in an MPSR.

Summary

In 1909, the U.S. Army purchased a Wright Military Flyer, the world's first fixed-wing military aircraft. In the ensuing 114 years, aviation technologies have overcome seemingly "impossible" challenges such as aerial refueling, flying at very high altitudes and over long ranges, flying faster than the speed of sound, conducting precision strikes in all weather conditions, and penetrating enemy air defenses undetected. Each of these steps was the result of new technologies developed by the U.S. military and the American defense industry.

Today, unmanned aircraft are operated by all four military services as well as other government agencies. They have become an accepted part of the Joint Force and fly every day in support of global deterrence, counterterrorism, and disaster relief missions. Unmanned aircraft now face a number of technological, resource, and institutional barriers that must be overcome before they can reach their full warfighting potential. Looking to the future, DoD has an opportunity to fund research and development efforts that will lead to an increasingly autonomous, multi-mission UAS fleet that is better able to support power-projection operations in an MPSR. Absent a new vision and support from DoD leadership and Congress, however, America's unmanned systems advantage could be overtaken by others who are willing to explore the potential for UAS to empower new concepts of operation, rather force them into the mold of supporting current ways of doing business.

[268] The comment was made by Rear Admiral Anthony L. Winns, as quoted in Burgess, "Mother Ship."

[269] After observing the successful carrier launch and landings of the X-47B, Secretary of the Navy Mabus wrote: "The operational aircraft that follow it [the X-47B] will radically change the way presence and combat power is delivered from aircraft carriers by conducting surveillance and strike missions at extreme distances and over very long periods of time. With this advanced technology, we will put fewer sailors and Marines in harm's way, and we will push the area of potential action even further from the decks of our ships." Mabus, "Unmanned aircraft at sea greatly extend the Navy's reach and sustainability," p. 25.

Conclusion and Possible Follow-On Analyses

> We have just won a war with a lot of heroes flying around in planes. The next war may be fought by airplanes with no men in them at all... Take everything you've learned about aviation in war, throw it out of the window, and let's go to work on tomorrow's aviation. It will be different from anything the world has ever seen.
>
> — General Henry H. "Hap" Arnold[270]

Since 2001, DoD's UAS have become legitimate warfighting capabilities. The fielding of a UAS fleet capable of supporting more than fifty continuous CAPs,[271] the integration of small UAS into tactical ground units, and the automatic landing of a developmental UCAV on an aircraft carrier are evidence that unmanned systems technologies are maturing rapidly. Today, the United States is on the cusp of realizing significant new advances in C2 systems, automation and autonomy, stealth, propulsion, and novel weapons systems that could help unleash the full potential of UAS. Rather than a distant promise, many of these technologies are incorporated in UAS that are now joining the force—the Global Hawk and BAMS—or could be incorporated in designs that are about to become part of DoD's program of record, such as the UCLASS.

Despite the potential for another leap-ahead in airborne robotic systems, the future for DoD's UAS force appears to be precarious. The U.S. military acquired its current UAS during a period when wartime budgets could support the fielding of multiple new aircraft designs. Shrinking budgets and pressures to modernize fighters, bombers, surface ships, and other capabilities have already led DoD to cut its requests for UAS development and procurement funding. Global Hawk Block 30s are in danger of being mothballed, and in the name of affordability, UCLASS requirements could be diluted to the point where the aircraft could become little more than another flying ISR sensor for irregular warfare scenarios. After a decade of rapid expansion and technology development, it appears as though DoD has yet to define the path it will take to develop its next-generation UAS force, and in some cases may even be retreating. In the words of one former Air Force pilot and combat veteran, "unmanned aircraft development within the Air Force can best be described as driven by short bursts of technological progress spurred by wartime needs and inter-service rivalry, followed by periods of neglect, disinterest and occasional hostility."[272] Based on the evidence, it is possible that this description could apply more broadly to the Defense Department in a post-Iraq, post-Afghanistan world.

The recent operational successes of American and Israeli UAS have unleashed a global wave of interest in the potential of unmanned aircraft. States and non-state actors are developing or acquiring UAS that could enable them to exploit the air domain, possibly at much lower cost than manned aircraft. Just as is the case with the continuing proliferation of guided munitions,

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[270] As quoted in Spinetta, "The Rise of Unmanned Aircraft."
[271] Compared to one UAS orbit in 2003.
[272] Spinetta, "The Rise of Unmanned Aircraft."

competitors are taking advantage of unmanned systems technologies to develop aircraft for a wide array of offensive and defensive missions. Moreover, while smaller budgets and resistance to change may cause the U.S. military to hunker down in defense of existing aircraft programs, other militaries that lack institutional preferences for manned aircraft may be far more willing to embrace the revolutionary potential of UAS. While DoD is not pursuing a program that could lead to a penetrating UCAV, carrier-based or otherwise, China, Russia, France, and Great Britain are all moving forward with programs for multi-mission combat aircraft.

A competition is now underway in unmanned aviation in which barriers to entry may be far lower and traditional U.S. advantages in pilot training and aircraft manufacturing may be less relevant. This emerging competition in robotic aviation could contribute to the maturation of a precision-strike regime, and, over time, lead to the emergence of an actual robotic revolution. However, should DoD choose to slow its UAS development as others continue or accelerate their programs, the potential for disruptive change and technological surprise in this competition could be high. At the very least, America's advantage could erode if DoD were to pursue "more-of-the-same" unmanned systems.

Enabling the MPSR

As noted in Chapter 1, the emergence of an MPSR requires innovative technologies complemented by new operational concepts and organizations, and a competition between competent adversaries possessing similar capabilities.

From a technological perspective, unmanned systems along with G-RAMM could help less-developed countries field precision-strike capabilities. Used creatively, UAS could serve as substitutes for expensive or technologically advanced systems such as space-based ISR and C2 networks, the lack of which now hobbles the ambitions of nations like Iran to strike over long distances with precision. There also may be a substantial "second-mover" advantage for countries like China, Iran, and Russia that have observed DoD's UAS build-up and learned from its technological successes and failures.

From an operational perspective, the U.S. military, which possesses a large piloted combat aircraft force, has developed UAS CONOPs that are predominately oriented toward gathering information to enable manned systems. In other words, the U.S. military has used UAS to improve the way it prefers to conduct operations today, rather than explore how they could underpin new operational concepts to maintain its dominance of the air domain and impose costs on future enemies. Other nations that lack large, sophisticated manned air forces may be more willing to develop innovative operational concepts and organizations designed specifically to take advantage of UAS technologies. This could improve competitors' ability to develop a better picture of the battlespace, strike forward bases needed by U.S. power-projection forces, impose costs by using UAS to saturate air defense networks, and even deliver weapons of mass destruction.

If the United States is in the midst of a nascent UAS competition, the question then becomes how should DoD prepare to maintain its advantage in an MPSR when other have developed their own fleets of unmanned aircraft? Although implementing a new vision for developing a far more capable future unmanned force is part of the answer, it may also require DoD to takes steps to counter emerging UAS threats. According to the Defense Science Board, at present there is:

> …little evidence of planning to counter adversary use of autonomy and unmanned systems against the U.S. Unless this situation is addressed, adversary use of autonomous systems may be the next "knowable" capability surprise.[273]

To address this challenge, the DSB recommended that DoD should begin to assess how enemies could use UAS, establish red teams to look at how enemies might attack DoD's UAS vulnerabilities, develop tactics, techniques, and procedures to counter enemy unmanned systems, and "include adversary use of autonomous systems in war games, simulations and exercises" unconstrained by "U.S. systems or rules of engagement."[274]

A Robotic Revolution?

Future UAS have the potential to augment if not replace some elements of DoD's warfighting capabilities and likewise enable other militaries to develop precision-strike complexes. As capable as UAS may become over the next decade, they are unlikely to "render obsolete or subordinate existing means for conducting war" to use Michael Vickers' and Robert Martinage's definition of an RMA.[275] Rather, over the next ten or even twenty years, UAS are likely to increase, extend, and mature the capabilities of the existing precision-strike regime, rather than subvert it and lead to wars that are "fought by airplanes with no men in them at all."[276]

In the long term, it is possible that advances in artificial intelligence could create UAS that fundamentally alter or subvert the missile-dominated precision-strike regime. Fully autonomous aircraft with advanced AI and powerful directed-energy weapons could maneuver and respond to enemy threats and target opportunities so quickly that even large salvos of anti-aircraft missiles may not be sufficient to saturate their defenses. The primary obstacles to the development of such aircraft, as ever, is likely to be cost and institutional resistance to developing new capabilities that might threaten more established programs of record.

Possible Follow-On Analyses

The emerging competition in robotic aviation suggests that there may be value in conducting several follow-on analyses.

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273 Defense Science Board, The Role of Autonomy in DoD Systems, p. 14.

274 Ibid.

275 Vickers and Martinage, *The Revolution In War*, p. 2.

276 Spinetta, "The Rise of Unmanned Aircraft."

Robotic Capabilities in Other Warfighting Domains

While robotic systems may be most prevalent in the air domain, unmanned ground, surface, and undersea systems have also begun to proliferate over the last decade. A series of workshops with experts in the field of robotics from the Defense Department, industry, and academia could explore the art of the possible for unmanned systems in each of these warfighting domains.

Emergence of a Mature Robotic Regime

This assessment began with an examination of the recent history of UAS and the potential role of future UAS in an MPSR. The “vision” of an MPSR is still largely based on a worldview in which manned systems predominate and unmanned systems are in the minority. This project would build on work done for this report to explore what military competitions might look like in a future where unmanned systems that operate in the air, at sea, undersea, and on land have become the dominant form of warfare.

The initial foray would consist of workshops with technologists and operators akin to the 20XX workshops previously sponsored by OSD/NA. From these workshops, a hypothesis could be developed regarding the characteristics of a robotic regime. This hypothesis could then be tested using seminar-style wargames which use tactical/operational vignettes to explore the interactions and competitions between unmanned systems.

Glossary

A2/AD	Anti-Access/Area Denial
ACTD	Advanced Capability Technology Demonstration
ADVENT	Adaptive Versatile Engine Technology
AEA	Airborne Electronic Attack
AETD	Adaptive Engine Technology Development
ASAT	Anti-Satellite (Weapon)
ASBM	Anti-Ship Ballistic Missile
ASCM	Anti-Ship Cruise Missile
ASIP	Airborne Signals Intelligence Payload
ATGM	Anti-Tank Guided Munitions
ATR	Automated/Autonomous Target Recognition
AWACS	Airborne Warning and Control System
BAMS	Broad Area Maritime Surveillance
BCA	Budget Control Act
BDA	Battle Damage Assessment
C2	Command and Control
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance
CAS	Close Air Support
CLF	Combat Logistics Force
CONOPs	Concept of Operations
COTS	Commercial-off-the-Shelf
CSG	Carrier Strike Group
DE	Directed Energy
EM	Electromagnetic
EO/IR	Electro-Optical/Infrared
EW	Electronic Warfare
FMV	Full Motion Video
FY	Fiscal Year
G-RAMM	Guided Rockets, Artillery, Missiles, and Mortars
GMTI	Ground Moving Target Indicator
HALE	High-Altitude, Long-Endurance
HEETE	Highly Efficient Embedded Turbine Engine
HPM	High-Power Microwave (Weapons)
HVT	High-Value Target
IAF	Israeli Air Force
IAI	Israeli Aerospace Industries
INS	Inertial Navigation System

IRGC	Iranian Revolutionary Guard Corps
IRST	Infrared Search and Track
ISIS	Integrated Sensor is Structure
ISR	Intelligence, Surveillance, and Reconnaissance
JDAM	Joint Direct Attack Munitions
JUONS	Joint Urgent Operational Needs Statement
LEO	Low Earth Orbit
LRASM	Long-Range Anti-Ship Missile
MALE	Medium-Altitude, Long-Endurance
MANPADS	Man-Portable Air Defense Systems
MDA	Maritime Domain Awareness
MPSR	Mature Precision-Strike Regime
MTCR	Missile Technology Control Regime
MTR	Military-Technical Revolution
MUOS	Mobile User Objective System
N-UCAS	Navy Unmanned Combat Air System
NDAA	National Defense Authorization Act
NRO	National Reconnaissance Office
OCO	Overseas Contingency Operations
OTH-R	Over-the-Horizon Radar
PED	Processing, Exploitation, and Dissemination
PGM	Precision Guided Munition
PLA	People’s Liberation Army
PLAAF	People’s Liberation Army Air Force
PLAN	People’s Liberation Army Navy
PNT	Position, Navigation, and Timing
RF	Radio Frequency
RFC	Reconnaissance-Fire Complex
RFI	Request for Information
RFP	Request for Proposals
RMA	Revolution in Military Affairs
RPV	Remotely Piloted Vehicles
RSC	Reconnaissance-Strike Complex
SAM	Surface-to-Air Missile
SAR	Synthetic Aperture Radar
SATCOM	Satellite Communications
SEAD	Suppression of Enemy Air Defenses
SSL	Solid-State Lasers
SYERS	Senior Year Electro-Optical Reconnaissance Sensor
TCDL	Tactical Common Data Link

TIMU	Timing and Inertial Navigation Unit
UAS	Unmanned Aircraft Systems
UCAS	Unmanned Combat Air Systems
UCAS-D	Unmanned Combat Air Systems Demonstrator
UCAV	Unmanned Combat Air Vehicle
UCLASS	Unmanned Carrier Launched Airborne Surveillance and Strike System
VAATE	Versatile Affordable Advanced Turbine Engines
WAAS	Wide-Area Airborne Surveillance
WMD	Weapons of Mass Destruction