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Unmanned Air Systems

The Future of Air & Sea Power?

Paul Rogers

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"Focus stratégique"

Resolving today's security problems requires an integrated approach. Analysis must be cross-cutting and consider the regional and global dimensions of problems, their technological and military aspects, as well as their media linkages and broader human consequences. It must also strive to understand the far reaching and complex dynamics of military transformation, international terrorism or post-conflict stabilization. Through the "**Focus stratégique**" series Ifri's Security Studies Center aims to do so, offering new perspectives on the major international security issues in the world today.

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Abstract

Since their early use for primitive ISR and combined operations, UAS have developed into increasingly multipurpose instruments performing a wide array of missions (from limited strike operations, search and monitoring to time-sensitive targeting) and offering new maneuver options to the armed forces. These improvements in range, speed, endurance, situational awareness and payload, achieved through adaptive use of new information technologies, were catalyzed by the Afghanistan and Iraq testing grounds that proved critical in breaking institutional resistance. Yet for all their contribution to the shaping of a quick learning curve, these developments have occurred in permissive airspace. After tracing back the history of UAS development, this paper argues that the US can overcome the different challenges to UAS brought by contested and denied airspace, as traditional power threats constrain force projection through A2AD strategies. To increase their force multiplier potential, the US will likely improve UAS capabilities in stealth, evasiveness, maneuverability and automation, strengthening both air and sea power.

* * *

De simples appuis à des opérations combinées et de renseignement, surveillance et reconnaissance (ISR) limitées, les drones sont devenus des instruments polyvalents capables d'exécuter un large éventail de missions (qui vont des frappes légères aux missions de surveillance de longue haleine, en passant par des frappes d'opportunité contre des cibles évanescentes) et d'offrir de nouvelles options aux forces armées dans la manœuvre. Ces améliorations portant sur le rayon d'action, la vitesse, l'endurance, l'intelligence situationnelle et la charge utile, rendues possibles grâce à une utilisation adaptée des nouvelles technologies de l'information et de la communication, ont été accélérées par les terrains d'essai afghan et irakien qui se sont révélés essentiels au désarmement des résistances institutionnelles. Cela étant, ces contributions à la « courbe d'apprentissage » de la nouvelle technologie sont intervenues dans des milieux aériens permissifs. Après avoir retracé l'histoire de l'évolution des drones, cet article défend l'idée que les Etats-Unis peuvent surmonter les différents défis auxquels sont confrontés les drones dans des espaces aériens contestés. Ces derniers marquent le retour des menaces de la puissance entravant la projection de forces via des stratégies de déni d'accès. Afin d'augmenter leur potentiel de multiplicateur de force, les Etats-Unis seront amenés à perfectionner les capacités des drones en matière de furtivité, de manœuvrabilité et d'automatisation, renforçant ainsi leur puissance aérienne et maritime.

Introduction

On 4 February 2002, in perhaps the first drone strike in history, a Predator unmanned aerial system (UAS)[1] struck insurgents in Paktia Province, Afghanistan, with a precision-guided Hellfire missile.[2] An operator on the ground piloted the aircraft, found the target using a video camera, and then conducted the strike. A decade later, on 14 May 2013, with calm seas off the coast of Virginia, the United States Navy's USS George H.W. Bush marked the debut of carrier-based unmanned naval aviation when it launched a fighter-sized X-47B Unmanned Combat Air System (UCAS) drone.

The employment of UAS in the wars in Afghanistan and Iraq and the first launch and recovery of the UCAS from an aircraft carrier are part of a trend. The United States armed forces now have thousands of UAS for support and strike missions in permissive air and cyber environments. The US military is building new UAS for combat in contested and denied airspace, and it is inventing new ways to employ them in combined operations with manned platforms. Other states have seen how useful UAS are to America's armed forces, and they are developing UAS for their own militaries.

UAS are weapons systems that consist of unmanned aircraft, a data link segment, and ground control stations to control them, including human operators.[3] Today's UAS fly relatively slowly and are defenseless in the air. Some have reduced radar cross sections (RCS), giving them a degree of stealth. Today they are useful almost exclusively in permissive environments where the enemy has little or no ability to direct fire at them, including kinetic weapons, jamming, and cyber attacks. They are mainly

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The views expressed in this *Focus Stratégique* are those of the author and do not reflect the official policy or position of the United States Navy, Department of Defense, or the United States Government.

[1] "Unmanned aerial systems" include "remotely piloted aircraft (RPA)," "unmanned aerial vehicles (UAV)," and "unmanned combat air vehicles (UCAV)," all of which are often called "drones." The US Air Force prefers the term RPA, and rated pilots fly its unmanned aircraft. The White House, journalists, and scholars typically use the term "drone." This paper uses the term UAS to describe all unmanned aircraft and their associated systems, and the term UCAV to describe certain UAS designed for combat roles, such as strike and fighter missions.

[2] John Sifton, "A Brief History of Drones", *The Nation*, 7 February 2012, available at: http://www.thenation.com/article/166124/brief-history-drones.

[3] There are many definitions of UAS, and this simple definition will be used for this paper. For another definition see Daniel Umpa, "The Pilotless Squadron" *Proceedings Magazine*, Vol. 135/9/1,279, September 2009.

employed for intelligence, surveillance and reconnaissance (ISR)[4] and light strike missions.

In the coming years, the United States and other states will field more advanced UAS, including unmanned *combat* air vehicles (UCAVs) with greater speed, survivability, and more weapons. They will be built specifically for strike and support missions to fight alongside manned aircraft in mixed packages. No state currently fields a fully operational UCAV, but the US Navy and US Air Force have ambitious plans to field them. Great Britain, France, China, Russia, Israel and other states are testing their own new UCAVs.

Like all UAS, UCAVs will have strengths and weaknesses relative to manned aircraft, notably in terms of range, endurance, maneuverability, payload, survivability, sensors, automation, dependence on satellite communications, and costs. New UAS will take over some of the dull and dangerous missions normally flown by manned aircraft, such as surveillance over the ocean. UCAVs will contribute to missions traditionally dominated by manned multi-role fighters. The technology that makes them possible is new, and research and development is necessary to discover what they can do. UAS are already considered to be superior to manned aircraft in many ISR operations in permissive air environments; looking ahead, the technologies already exist to design more capable and lethal UAS, and they shall probably prove critical in maintaining a competitive edge in the military realm.

This analysis will tackle several issues, including how military forces might employ UAS and UCAVs, how they are likely to change warfare, and the challenges to their development. It is divided into two parts. The first part reviews technological developments and military operations that have employed UAS over the past few decades, examining the unique vulnerabilities of UAS and discussing how their use is changing the military profession. The second part reviews future military threats that American and other militaries might face, and it analyzes how new UAS and UCAVs might help combat these threats. It discusses some of the ways that modern air and naval air forces – particularly in the United States but eventually elsewhere – can and likely will integrate and employ UAS with existing conventional military forces, viewing this as both a major opportunity and a challenge.

UAS range in size from the tactical, hand-thrown RQ-11 Raven to the 737-sized MQ-4C Triton. This study is limited in scope to an analysis of

[4] Intelligence, surveillance, and reconnaissance (ISR) is defined as, "…an activity that synchronizes and integrates the planning and operation of sensors, assets, and processing, exploitation, and dissemination systems in direct support of current and future operations. This is an integrated intelligence and operations function." Joint Chief of Staff *Joint Publication 1-02: Department of Defense Dictionary of Military and Associated Terms*, 8 November 2010 (As Amended Through 15 September 2013) p. 139, available at: http://www.dtic.mil/doctrine/new_pubs/jp1_02.pdf p139.

larger UAS that might replace or accompany manned aircraft in ISR, electronic and cyber attack, strike, and ultimately air-to-air combat missions. Such UAS typically fall into the categories of medium altitude long endurance (MALE) and high altitude long endurance (HALE) UAS. Smaller UAS will play important roles in the future of warfare, but they are not discussed in this paper.[5]

Some may be tempted to believe that new UAS will make fighting and winning wars easier in the future. This is not true, as the inherent uncertainty and friction of war will not change. Yet the deployment of UAS and UCAVs for ISR, strike, and eventually fighter missions represents a change in armament on a par with the introduction of some of the most notorious weapons systems in history. One day two states that possess advanced UAS could face each other in conventional war. At that time, they will doubtless be essential weapons and force multipliers in combat. Until then, UAS can contribute to winning wars and perhaps even deterring them from starting. They will form a critical part of modern armed forces necessary to assure victory.

[5] Important ethical questions also need to be posed about the employment of unmanned and robotic systems in warfare. Whether automated weapons systems that use computer algorithms to "think" should have the right to kill people in battle, either by striking offensively or by defending soldiers, sailors, and airmen from attacks from which they would otherwise be unable to protect themselves, is an important question. For the moment, no international agreement to ban their use exists, and many militaries are developing and deploying them.

A Quick and Dirty History of UAS

Unmanned aviation's history began as early as 1919 when Elmer Sperry invented an airplane flyable by remote control[6]. During America's War in Vietnam, UAS conducted ISR and even delivered ordnance[7]. With no integrated "near real-time[8]" airborne sensors and only primitive navigational systems, UAS were difficult to dynamically control, and ground controllers had little situational awareness, especially over the horizon. Signals intelligence (SIGINT) collection systems lacked computing power and communications lacked bandwidth and wet film had to be developed after the aircraft landed, limiting its tactical value. Without precision-guided munitions and live video feeds from the aircraft, launching strikes with UAS was not dependable.

The revolution in information technology over the past 30 years has permitted globally networked and armed UAS to become effective and practical weapons systems. The terrorist attacks of 9/11 and the ensuing wars in Iraq and Afghanistan accelerated the adoption of UAS by the US military. Threatening new weapons systems are driving the development of new UAS for use in high-intensity conventional warfare in contested and denied environments. The following sections illuminate how UAS have developed and been employed from the past few decades to the present day.

UAS and the Revolution in Information Technology

Because of the revolution in information technology, UAS became inexpensive, practical weapons over the past generation. Technological advances at the end of the 20th Century allowed for the creation of miniature computers, high-speed data communications, precise global navigation (the global positioning system, GPS), and tiny digitized sensors. These technologies are now integrated into a typical smartphone that costs

[6] "Kettering Aerial Torpedo 'Bug'," *National Museum of the US Air Force*, available at: http://www.nationalmuseum.af.mil/factsheets/factsheet.asp?id=320.

[7] Gertler, "U.S. Unmanned Aerial Systems," *Congressional Research Service*, Washington, DC, 3 January 2012.

[8] The difference between "real-time" and "near real-time" is a very short time delay, often a couple seconds. Real-time is instant, such as when a pilot physically sees an inbound hostile aircraft. An example of near real-time is when signals intelligence collection systems detect an inbound aircraft and pass the information via a communications relay to an operator on the ground or in a ship. The delay in the latter case is critically important in missile defense and in dogfighting, where seconds mean survival.

some $400; in 1975, the world's fastest supercomputer cost $5 million, was as large as a room, and had the same processing power but none of the other capabilities[9]. All of these technologies are required to operate modern American military UAS.

UAS demonstrated significant military value beginning in the 1970s. The Israeli Defense Force (IDF) revealed a leap forward in UAS technology during the 1973 Yom Kippur War, deploying the new Tadiran Mastiff UAS. With a video camera and a data link, the Mastiff provided near real-time airborne video surveillance to ground controllers for up to 7.5 hours. In the Lebanon War beginning in 1982, the IDF employed Mastiff in sophisticated combined operations with jammers, precision guided bombs, artillery, signals intelligence collection systems and manned strike aircraft. During Operation Peace for Galilee, Israeli UAS collected electronic intelligence on Syrian surface-to-air missile (SAM) radars without being detected. This intelligence was used to program the anti-radiation missiles (ARM) carried by Israeli strike aircraft. Before the ensuing Israeli attack, the UAS were again sent ahead to emit spoofing signals to the Syrian SAM batteries, fooling them into launching most of their missiles. With the Syrian SAM batteries empty and reloading, manned IDF strike aircraft attacked with their pre-programmed ARM missiles, destroying them[10]. The Israelis deserve great credit for their inventiveness in building and employing the first UAS in combined operations to protect their borders and conduct ISR over their local adversaries' frontiers.

The United States was the first state to employ UAS for global missions. In the 1990s, as GPS achieved full operational capability and was integrated into military aircraft and ground control stations, and as the revolution in information technologies gained speed, the US deployed UAS with global reach. During the 1991 Gulf War, the US military deployed its new RQ-2A Pioneer UAS, essentially a larger version of the Mastiff, for limited missions. The US Navy employed Pioneer to provide target spotting to its battleships in the Persian Gulf, and the US Marine Corps used it to watch the Iraqi Army along the Iraq-Kuwait border. Pioneer was unarmed, sent infrared and electro-optical video to ground control stations in near real-time, and had an endurance of 5 hours[11]. Mastiff and Pioneer both had relatively short dwell times, small payloads, and no weapons. GPS was new at the outbreak of the 1991 Gulf War, and the computer systems and interfaces that soldiers, sailors, and airmen used to display and portray the

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[9] Peter Bisson, Jacques Bughin, Michael Chui, Richard Dobbs, James Manyika, and Alex Marrs, "Disruptive Technologies: Advances that will transform life, business, and the global economy." *McKinsey Global Institute*, May 2013, available at: http://www.mckinsey.com/insights/business_technology/disruptive_technologies

[10] Carl Otis Schuster, "Arab-Israeli Wars: 60 Years of Conflict," *ABC-Clioi*, available at: http://www.historyandtheheadlines.abc-clio.com/ContentPages/ContentPage.aspx?entryId=1281931&currentSection=1271019&productid=16. See also, Ralph Sanders, "UAS: An Israeli Military Innovation," a report written for the *United States National Defense University* in Washington, DC. 2002, available at: http://www.dtic.mil/dtic/tr/fulltext/u2/a483682.pdf

[11] "RQ-2A Pioneer." *US Navy Fact File*, available at: http://www.navy.mil/navydata/fact_display.asp?cid=1100&tid=2100&ct=1.

combat zone on computer screens were primitive, limiting UAS controllers' situational awareness and the dynamism of UAS operations.

By July 1994, the United States deployed a new UAS that relayed live video feeds directly to the Pentagon via a satellite data link. The MQ-1 Predator UAS was unarmed but could loiter over a target area for a longer period of time while conducting continuous infrared and electro optical surveillance.[12] Then, in 1997, experimentation with existing fighter aircraft led the US Air Force to begin flying unmanned QF-4 "Drones" for air-to-air target practice. The QF-4 was based on a modified F-4 Phantom II, the service's primary fighter-bomber in the 1960s and 1970s.[13] This development proved that fighter aircraft could be flown remotely, if only as targets for the moment.

As the 1990s ended, the US military stood up its Global Information Grid (GIG),[14] including multiple Department of Defense (DOD)-wide intranets, a key enabler in its new Network Centric Warfare.[15] Over the first decade after the turn of the millennium, information technology continued to evolve rapidly: the speed of data communication increased explosively, digital cameras became better, cheaper, and smaller, GPS became banal, lightweight liquid crystal display (LCD) flat screens became common, and the Smartphone appeared. These technologies, so commonplace today, were key to enabling the practical employment of UAS in warfare: this truth cannot be overstated. Even so, defense bureaucracies lacked the agility and budgets to fully adopt these new technologies in a time of relative peace, and institutional resistance slowed change. The terrorist attacks of 11 September 2001 and the wars in Afghanistan and Iraq then galvanized the American Government into action to build and deploy large numbers of armed UAS for ISR and light strike missions.

UAS in ISR and Strike Operations in Afghanistan and Iraq

The US Army sought to regain the strategic initiative against the insurgencies in Afghanistan and Iraq by implementing a new counterinsurgency doctrine, a "surge" of ground forces, and by capitalizing on the "Sunni Awakening" in Iraq. The US Air Force sent squadrons of UAS that had previously been considered experimental or purely a tool of the Central Intelligence Agency to the warzones to improve ISR and speed up

[12] "The Dronefather," *The Economist*, London, 1 December 2013.

[13] "QF-4 UAS," *US Air Force Fact Sheet*, available at: http://www.af.mil/information/factsheets/factsheet.asp?id=13226. As a sign of what the US Air Force now thinks of its older 4th generation strike aircraft, it is now converting F-16s into target drones. See: Allen McDufee, "Aging F-16 Converted Into a Target-Practice Drone." *Wired,* 27 September 2013, available at: http://www.wired.com/dangerroom/2013/09/f16-drone/

[14] Management of the Department of Defense Information Enterprise*, Department of Defense Directive 8000.01, department of defense,* 10 February 2009. See p. 10 for a precise definition of the Global Information Grid, available at: http://www.dtic.mil/whs/directives/corres/pdf/800001p.pdf.

[15], Arthur K. Cebrowski, VADM, and John H. Garstka, "Network-Centric Warfare – Its Origin and Future," *Proceedings Magazine*, Volume 123/1/1, January 1998, p. 139.

the pace of counterterrorism operations.[16] In 2002, a Predator was armed for the first time with two AGM-114 Hellfire missiles, combining continuous ISR with precision light strike on a UAS.[17] An instant success, Predator was deployed in increasing numbers and had an immediate impact in the fight against insurgents and terrorists in Iraq, Afghanistan and elsewhere. The US Air Force then deployed the larger and faster MQ-9 Reaper UAS, armed with 8 Hellfire missiles and with a longer endurance and higher altitude ceiling.[18] The US Air Force also deployed the new RQ-4A Global Hawk HALE UAS to replace the older U-2 Dragon Lady spy plane. Developed to fly for over 28 hours with a significantly longer range but no strike capabilities, the Global Hawk filled strategic ISR and airborne data networking missions.[19]

Armed UAS combined the striking power of light attack aircraft with the ISR capabilities of manned reconnaissance aircraft. They had much longer airborne endurance than manned aircraft, providing what came to be called "orbits" because they allowed for a continuous armed "stare" at ISR targets, reducing intelligence gaps and allowing for time-sensitive targeting of emergent threats. The US Air Force's manned strike aircraft and bombers could carry far more weapons than Predator and Reaper UAS, but in a military campaign against small and unarmored insurgents operating in urban areas where limiting civilian casualties was key to establishing political legitimacy, small and precise weapons were ideal.

Predator and Reaper UAS provided important new military capabilities in the mission sets of tracking suspected insurgents, monitoring safe houses, and searching for improvised explosive devices. From inside of tactical and theater command centers on the ground, the US military

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[16] David F. Ucko, *The New Counterinsurgency Era: Transforming the U.S. Military for Modern Wars*. Washington DC: Georgetown University Press, July 2009. US military UAS strikes have been well documented in the press and acknowledged by the White House. See, for example, *The Long War Journal online,* available at: www.longwarjournal.org/.

[17] "MQ-1B Predator" *US Air Force Fact Sheet*, available at: http://www.af.mil/information/factsheets/factsheet.asp?id=122. The Predator was originally deployed in 1996 and designated the RQ-1, with "R" for reconnaissance and Q for unmanned aircraft system. The "R" was changed to "M" for multi-role when missiles were added to the aircraft in 2002.

[18] "MQ-9 Reaper" *US Air Force Fact Sheet*, available at: http://www.af.mil/AboutUs/FactSheets/Display/tabid/224/Article/104470/mq-9-reaper.aspx.

[19] There are four distinct versions of the Global Hawk, each with different costs and capabilities. Blocks 30 and 40, the two latest versions, offer greater capabilities than the earlier Block 10 and Block 20 versions, demonstrating how much technology changed during the decade when Global Hawk was initially designed. More recently, the US Air Force attempted to cancel parts of the Global Hawk program as it tries to manage budget cuts and competing programs, such as newer UAS and the older U-2 fleet. See, for example: "USAF places order for additional RQ-4 Global Hawk UAVs," *Air force Technology*, 12 November 2013, available at: http://www.airforce-technology.com/news/newsusaf-places-orderfor-additional-rq-4-global-hawk-uavs. See also: "RQ-4 Global Hawk" *US Air Force Fact Sheet*, available at: http://www.af.mil/AboutUs/FactSheets/Display/tabid/224/Article/104516/rq-4-global-hawk.aspx. See also: Gertler, "U.S. Unmanned Aerial Systems," pp. 36-38 contain a summary of the different Global Hawk variants.

could monitor suspected insurgents for days to confirm their hostile intentions and activities, establish their "pattern of life," and learn about their support networks. The soldiers and airmen charged with analyzing the intelligence worked in standardized watch rotations, turning over regularly to reduce fatigue. The intelligence from UAS reduced collateral damage because coalition forces were better able to vet ISR targets to distinguish innocent civilians from dangerous insurgents.[20]

UAS created new maneuver options for coalition ground forces. A Reaper could loiter over an area of interest and transmit near real-time ISR directly to patrolling soldiers, special operations forces (SOF) carrying mobile communications devices on raids, and to command centers monitoring 24-hour operations. According to US Army General Stanley McChrystal, UAS allowed the combat forces under his command "…on the ground in the mud or dirt" to have, "…a bird's-eye view of the battlefield."[21]

> "Traditionally, if we did a raid and we thought we were going to need 20 commandos to actually hit a target, we might take 120, because we had to put security around the site to protect it from enemy reinforcements, and we might have to put a support section and a command-and-control section there, because you need all those things to account for the unexpected. But when you have very good situational awareness and good communications, you only send the 20, because your security comes from being able to see, and then you can maneuver forces if you need them. So suddenly, the 120 commandos aren't doing one raid; they're doing six raids simultaneously, and you start getting the ability to do 300 raids per month."[22]

In Afghanistan and Iraq, more UAS meant more raids, and the speed of counterterrorism operations increased, allowing US SOF to hit Al-Qaeda in more places simultaneously. UAS could also strike independently, and clandestine "drone strikes" allegedly decimated Al-Qaeda's leadership in the Afghanistan-Pakistan border region and elsewhere.[23] Seeing the impact, Secretary of Defense Robert Gates

[20] Alexander Mayer, and Bill Roggio, "Charting the data for us airstrikes in Pakistan, 2004 – 2013." *The Long War Journal*, lasted updated on 29 November 2013, available at: http://www.longwarjournal.org/pakistan-strikes.php. See also: Alex Young, "A Defense of Drones," *Harvard International Review*, 25 February 2013, available at: http://hir.harvard.edu/a-defense-of-drones.

[21] Rose Gideon, "Generation Kill. A Conversation with Stanley McChrystal," *Foreign Affairs*, March/April 2013, pp. 4-5.

[22] Ibid. p 4-5. McChrystal specifically stated that GPS navigation, night-vision goggles, and Predator UAS feeds as three technologies that changed the tactics that his forces employed. More raids could have meant more civilian casualties as well. On one hand, more raids meant more opportunities to make mistakes. Yet thanks to the better intelligence provided by UAS and other the other technologies that McChrystal mentions, the raids might have inflicted fewer civilian casualties.

[23] *The Long War Journal online* is one of the best public references on drone strikes and their impact on al-Qaeda Senior Leadership. See also: Daniel L. Byman, "Why Drones Work: The Case for Washington's Weapon of Choice," *The*

accelerated the purchase and deployment of UAS to the ongoing wars. US Department of Defense (DOD) expenditures on UAS increased from $667 million per fiscal year in 2001 to $3.9 billion per year in 2012. The DOD's inventory of unmanned aircraft increased from 167 in 2002 to nearly 7,500 in 2010.[24] Of note, over 5,000 of them were tactical UAS such as the RQ-11B Raven. Approximately 300 of the systems were HALE and MALE UAS.

Inventories of American Military UAS

Designation	Name	FY11	FY12	FY13	FY14	FY15	FY16	FY17
Air Force								
MQ-1B	Predator	163	152	141	130	121	115	110
MQ-9A	Reaper	70	96	135	167	199	229	256
RQ-4B	Global Hawk	23	23	15	15	15	15	15
Army								
RQ-11B	Raven	5394	6294	6528	6717	6921	7074	7074
RQ-7B	Shadow	408	408	408	408	408	408	408
MQ-5B	Hunter	45	45	45	45	45	45	45
MQ-1C	Gray Eagle	19	45	74	110	138	152	152
Navy								
RQ-4A	Global Hawk	5	5	0	0	0	0	0
MQ-4C	BAMS	0	0	2	2	5	9	13
MQ-8B	Fire Scout/VT UAS	5	9	14	18	25	32	37
RQ-21A	STUAS	0	1	2	3	4	4	4
	Scan Eagle	122	122	122	122	122	122	122
X-47B	UCAS-D	2	2	2	2	0	0	0
	UCLASS	0	0	0	0	2	2	4
Marine Corps								
RQ-7B	Shadow	52	52	52	52	52	52	52
RQ-21A	STUAS	8	8	8	23	48	73	100
*Reflects RQ-4B Block 20/40 inventory remaining after FY 2012 (Block 30 cancelled in President's 2013 Budget submission, but the US Congress has lobbied to continue production.								

Source: Department of Defense Report to Congress on Future Unmanned Aircraft Systems Training, Operations, and Sustainability, by the Under Secretary of Defense for Acquisition, Technology and Logistics, April 2012.

Brookings Institution online, July/August 2013, available at: http://www.brookings.edu/research/articles/2013/06/17-drones-obama-weapon-choice-us-counterterrorism-byman.

[24] Gertler, "U.S. Unmanned Aerial Systems;" and Under Secretary of Defense for Acquisition, Technology and Logistics, *Department of Defense Report to Congress on Future Unmanned Aircraft Systems Training, Operations, and Sustainability*, April 2012.

New Vulnerabilities

Afghanistan and Iraq were the first major wartime deployments of and therefore testing grounds for massive numbers of modern UAS. The post-invasion air environments in the two countries were highly permissive as there was no air-to-air fighter enemy and little SAM threat. The circumstances allowed UAS to operate with impunity. At the same time, UAS revealed some of their unique weaknesses. Predator and Reaper UAS are slow and have no radar-evading stealth. They have no defensive weapons or countermeasures. Above all, UAS are dependent on communications links, including for piloting and navigating the aircraft and for feeding ISR and targeting information to ground control stations and manned aircraft. These communications links must be assured and protected from jamming and hacking. Beyond that, operations in Afghanistan and Iraq revealed that UAS cannot fully substitute for having trained operators on the ground to observe the enemy and foil camouflage and concealment efforts.[25]

No doubt wishing to reduce some of these vulnerabilities, the US Air Force deployed another important UAS sometime in the early 2000's, the wing-shaped RQ-170 Sentinel.[26] A reduced radar cross section provides it some radar-evading stealth, and a jet engine propels it with greater speed than other MALE UAS. Sentinel can conduct ISR over contested and perhaps some denied areas without being detected, but it apparently does not carry any weapons. Journalists report that Sentinels flew over Pakistan during the Bin Laden raid in 2011 and that they may have flown over the Korean Peninsula.[27]

In December 2011, Iran displayed a mostly intact Sentinel on public television and claimed to have forced it to land. The White House confirmed that a UAS crashed in Iran but did not disclosed how or why.[28] The Sentinel could have crashed because of a mechanical or computer malfunction, because of operator error; or the Iranians could have forced it to land, perhaps via jamming, a cyber attack, or by GPS spoofing. Reports indicate

[25] Pete Blaber, *The Mission, The Men, and Me: Lessons from a Former Delta Force Commander*, New York, The Penguin Group, 2008. Blaber notes that the men on his team had to infiltrated on the ground to confirm the presence of several hundred al-Qaeda and foreign fighters in the Shahi Kot Valley. Old-fashioned tarps and camouflage had completely concealed the al-Qaeda fighters from satellite imagery and UAS reconnaissance.

[26] "RQ-170 Sentinel," *US Air Force fact sheet*, available at: http://www.af.mil/information/factsheets/factsheet.asp?id=16001.

[27] Noah Shachtman, "Secret Stealth Drone Spied on Osama, Dodged Pakistanis", *The Danger Room* on *Wired*, 18 May 2011, available at: http://www.wired.com/dangerroom/2011/05/secret-stealth-drone-spied-on-osama-dodged-pakistanis/. Greg Miller, "CIA flew stealth drones into Pakistan to monitor bin Laden house," *The Washington Post*. 17 May 2011, available at: http://articles.washingtonpost.com/2011-05-17/world/35233221_1_stealth-drone-bin-laden-house-new-stealth.

[28] Elisha Maldonado, "Iran Denies US Request for Drone Return, Demands Apology" *International Business Times*, 13 December 2011, available at: http://www.ibtimes.com/iran-denies-us-request-drone-return-demands-apology-382694.

that it likely landed due to a navigational failure.[29] If it was brought down by an electronic or cyber attack, then the incident may represent the first kill of a military aircraft by cyber attack.

Perhaps not coincidentally, on at least one occasion in Iraq, Shiite insurgents successfully hacked into a Predator UAS video feed.[30] The US military claims to have addressed the problem by securing its ISR communications, but the incident revealed a fundamental tradeoff between better data encryption and data transmission speed.

For a UAS with radar-evading stealth like the Sentinel to avoid detection over contested airspace, it must control its electronic emissions. How strictly it must do so depends on the nature of the environment, namely the enemy's SIGINT collection capabilities. A reduced radar cross section is only one factor in stealth; an aircraft that has to communicate constantly with an off-board ground control station could still be detectable by its electronic signature. This was a relatively inconsequential matter in Afghanistan and Iraq, was potentially critical in the case of the Sentinel, and will be a big problem for UAS operations in contested and denied areas, where potential adversaries might wield capable SIGINT collection suites that can cue SAM batteries and fighter aircraft, and where enemies will likely be ready to jam UAS communications.

UAS can be vulnerable to spoofing, the sending of false signals to confuse and cause them to fail their missions. Hobbyists have demonstrated that military UAS are vulnerable to GPS spoofing that can force them to crash or land.[31] The US military encrypts its GPS signals, but one is forced to wonder how strong the encryption is given hobbyists' success in spoofing UAS in controlled experiments.

Satellite and ground command and control architectures are a prerequisite for global UAS operations. The costs of these systems, such as satellites, are high and a serious barrier to entry for some countries. They can also be attacked directly. Protecting GPS satellites from exploitation or destruction is imperative as they are the backbone of UAS global navigation systems. Networked connectivity with other aircraft, ships, and ground vehicles in the immediate area can allow UAS and other aircraft to maintain situational awareness in the event of satellite degradation,

[29] Marc Ambinder, "Officials: Navigation System Failure Probable Cause of Drone Crash." *National Journal*, 8 December 2011, available at: http://www.nationaljournal.com/nationalsecurity/officials-navigation-system-failure-probable-cause-of-drone-crash-20111208. See also: "Iran's captured RQ-170: How bad is the damage?" *Air Force Times*, 9 December 2011, available at: http://www.airforcetimes.com/article/20111209/NEWS/112090311/Iran-s-captured-RQ-170-How-bad-damage-.

[30] Mike Mount and Elaine Quijano, "Iraqi insurgents hacked Predator drone feeds, U.S. official indicates." *CNN News online*, December 17, 2009, available at: http://www.cnn.com/2009/US/12/17/drone.video.hacked/.

[31] Lorenzo Franceschi-Bicchierai, "Drone Hijacking? That's Just the Start of GPS Troubles," *The Danger Room* on *Wired*, 6 July 2012, available at: http://www.wired.com/dangerroom/2012/07/drone-hijacking/.

including through the provision of navigational information in the event of a GPS failure. HALE UAS such as Global Hawk specialize in transmitting and repeating data links across communications architectures to expand networking over long distances. UAS can therefore create networking redundancy by serving as backup nodes to satellites in military kill chains. Militaries will want to integrate UAS with other weapons systems as part of a larger network of systems with multiple backup nodes and links on the battle network.[32]

UAS present the problem of creating huge communications or electronic signatures. They are reliant on communications with ground controllers, especially if they are not fully autonomous. Manned aircraft simply operate under strict emissions control when they are flying missions into contested or denied areas. Their silence helps them avoid being detected by the enemy. UAS must continuously communicate with their ground stations via satellite or line of sight communications in order to keep the off-board control appraised of the aircraft's status and vector. Future UAS will need to overcome this problem through automation that allows them to cease to communicate with their home base or through stealthy communications. Otherwise, UAS will not be any more survivable in non-permissive environments than manned aircraft as their large electronic signatures will make them easy targets.

One day, an enemy employing a cyber attack could possibly take control of a UAS and employ it against its own military via either the uplink to the aircraft or the downlink to the ground control station. This has never actually happened, likely because the cyber environments where UAS have been employed over the past decades have been highly permissive, but the future will offer more difficult operating environments. Modern manned aircraft could possibly also face this threat given that they are computerized and networked, but in this case a human operator still controls the aircraft.

Finally, UAS downed on enemy territory do not create the same liability as manned aircraft. The combat search and rescue resource requirements are significantly less. Politically, the scandal that followed the Sentinel crash was miniscule compared to those that ensued when the US Air Force lost a U-2 Dragon Lady over the Soviet Union in 1960 and when the US Navy lost an EP-3E Aries II on Hainan Island, China, in 2001. In the latter two cases, humiliating public negotiations were necessary to recover the lost pilots. In all three cases, significant technology was lost to another state, yet with the Sentinel, no negotiations for a pilot were required after the crash. Given the difficulty that the US had in negotiating the release of its embassy personnel from Tehran in 1979, it is unlikely that obtaining the release of a spy plane pilot would have been simple and painless.

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[32] "Air-Sea Battle Doctrine: A Discussion with the Chief of Staff of the Air Force and Chief of Naval Operations," Moderated by Michael O'Hanlon, *The Brookings Institution*, 16 May 2012, available at: http://www.brookings.edu/~/media/events/2012/5/16-air-sea-battle/20120516_air_sea_doctrine_corrected_transcript.pdf.

Evolving Military Professions

Several groups of military professionals are being particularly affected by the adoption of UAS and their technological support systems. Pilots who are being displaced from aircraft to ground control stations are clearly feeling the biggest impact. As of January 2013, there were approximately 1,300 UAS pilots in the US Air Force (8.5% of total Air Force pilots, up from 3.3% in 2008).[33] The US military has been re-tasking its aviators to fly UAS from within ground control stations, often meeting stiff resistance from pilots who do not want to fly UAS.[34] There are probably a variety of reasons why pilots do not wish to transition from flying manned aircraft to flying UAS, including issues of prestige, salary bonuses, the difficulty of transitioning UAS skills to civilian pilot jobs, and a general belief that flying UAS is not as enjoyable and satisfying as flying manned aircraft. More thoughtful officers may also have moral qualms with flying armed UAS. Yet if UAS are essential future weapons in war, there is perhaps therefore a disconnect between what is best for the future of the military and what pilots would prefer as individuals. Given that enemy forces will no doubt develop their own highly capable UAS to obtain a military advantage, this disconnect will likely be temporary as pilots will ultimately realize exactly how essential UAS are to winning future wars.

UAS operators do not need to deploy to warzones. They can fly their missions from bases in the United States, reducing their exposure to danger and limiting costs associated with travel and deployment. This protected soldiers from harm, but it also brought new risks of confusing command and control relationships.[35]

Meanwhile, intelligence, communications, and cryptology professionals have found that they have new roles in warfare. As a result of the deployment of UAS around the world, airborne sensors now send huge amounts of ISR information to tactical and strategic command centers where such information did not use to be available. The increased volume of ISR data has created a strong demand for more intelligence analysts to process the information and for computer, cryptology, and communications specialists to run and maintain the UAS systems architecture. More information has become available to make combat decisions, and these personnel have never had such direct roles in assisting operators to make

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[33] Bradley T. Hoagland, Col, USAF. "Manning the Next Unmanned Air Force: Developing RPA Pilots of the Future." *Policy Paper*, Center for 21st Century Security and Intelligence, Foreign Policy at the Brookings Institution, August 2013, p. 9.

[34] Jeff Schogol, "Demand grows for UAS pilots, sensor operators." *Air Force Times*, 21 April 2013, available at: http://www.airforcetimes.com/article/20120421/NEWS/204210318/. See also Kelsey Atherton, "No One Wants To Be A Drone Pilot, U.S. Air Force Discovers", *Popular Science*, 21 August 2013, available at: http://www.popsci.com/technology/article/2013-08/air-force-drone-program-too-unmanned-its-own-good.

[35] Martin Van Creveld, *Command in War*, New Haven, Harvard University Press, 1987. New technology does not by itself make a military more effective or powerful if command relationships are not appropriately adjusted to compensate for the change.

tactical decisions about the employment of deadly force. This has blurred the traditional line between operations and intelligence.

There has always been and will likely remain a division between operators and intelligence support personnel. UAS vehicle operators receive training on weapons employment and are responsible for making final weapons employment decisions. Intelligence professionals remain responsible for putting information on current and future enemy actions into the hands of operators and for providing operators with an information advantage in war. Yet before, when a pilot was sitting alone in an aircraft somewhere over a dangerous warzone, it was obvious that an intelligence analyst staying behind in the command center was a support asset. In UAS ground control stations, where both pilot and intelligence specialist sit side-by-side, weapons employment becomes more of joint decision despite the formal authority of the UAS operator. This is especially true if an operator's main criterion for the employment of deadly force is an intelligence analyst's assessment of a target. The matter becomes more complicated if the weapon to be employed is electronic in nature, such as a jammer or cyber attack, as these weapons sometimes fall under the control of military intelligence corps.[36] These new realities may call established roles into question.

Equally importantly, the rise of UAS and of computer-enabled warfare has created a need for cyber warfare and communications professionals like never before. There is a strong demand for more communications professionals including network administrators and computer technicians to run the control systems and data link segments of UAS. Another requirement has been created for cyber professionals to actually protect these systems from hostile computer network attacks. The standup of the US Cyber Command and the creation of new corps of cyber engineers and officers within the various US military services indicates that the US military leadership is aware of the scope of this problem.[37]

The first part of this study examined the recent history of UAS, including the technology that allowed for their emergence as modern weapons, and their early use in combined military operations. It then examined some of the vulnerabilities of UAS and how militaries professionals are adapting to successfully integrate them into their forces. The next part of this study will examine the capabilities of a new generation of UAS currently being developed for combat against more sophisticated military threats, and how they might be integrated into modern armed forces.

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[36] For example, the commander of the US Cyber Command is a US Army general officer. Also, the US Navy recently merged its intelligence, communications, cryptology, cyber, and meteorological officer and enlisted communities into one single "Information Dominance Corps" in recognition of these new realities.

[37] "US Cyber Command." *US Strategic Command's* website, available at: http://www.stratcom.mil/factsheets/Cyber_Command/.

Future UAS for Contested Environments

"Inside of 40 years, from World War I to the Korean conflict, pilots went from shooting at each other with pistols from propeller-driven biplanes to dueling with cannons and missiles in jet aircraft moving faster than sound."[38]

Military technologies and tactics change, and change always has its heralds and doubters. One of the US Air Force's great thinkers, Colonel John R. Boyd, believed that well-trained pilots flying old F-4 Phantom II's carrying guns and infrared guided missiles could always defeat new F-15 Eagle fighters with radar-guided missiles. The development of radar-guided advanced medium range air-to-air missiles (AMRAAM) proved him to be very wrong.[39]

One aviation expert noted that the current state of technological development of unmanned aircraft is analogous to the state of manned aviation in the era of biplanes.[40] Unmanned airframes and components are new, and with experimentation they will change dramatically over coming decades. It does not take great imagination to see how the slow, defenseless UAS employed by the US Air Force in Afghanistan and Iraq could be modified with largely existing technology such as jet engines, radars, and stealthy airframes to build UCAVs capable of some measure of self-defense in non-permissive environments. Engineering, software code writing, testing, and operational integration need to be tackled. These problems are formidable but concrete.

This chapter examines what new capabilities new UAS and UCAVs can be expected to have and how they might be integrated into existing military forces. The American military is notable because as in the recent past, it appears that Americans will remain at the forefront in UAS development in the immediate future thanks to a lead in key technologies

[38] Mark Bowden, "The Last Ace", *The Atlantic Monthly*, March 2009, available at: http://www.theatlantic.com/magazine/archive/2009/03/the-last-ace/307291/.

[39] John T. Correll, "The Reformers" *Air Force Magazine*, February 2008, available at: http://www.airforcemag.com/MagazineArchive/Pages/2008/February%202008/0208reformers.aspx

[40] NOVA, "Rise of the Drones." An online film, *PBS*, 2013, available at: http://www.pbs.org/wgbh/nova/military/rise-of-the-drones.html.

and high, even if diminishing, defense budgets, including for research and development.

Future Warfare Requirements in Contested and Denied Areas

The wars in Afghanistan and Iraq were not the DOD's only military commitments around the globe over the past decade. The diffusion of terrorist cells, nuclear proliferation in North Korea and Iran, and the rapid modernization of China's armed forces also occupy minds at the Pentagon. Accordingly, the DOD and several Washington think tanks have been considering how UAS could be useful in other contexts.[41] The current generation of Predators and Reaper UAS and even Global Hawk UAS would be defenseless and therefore useless in contested airspace, but new types of survivable UAS could be useful against sophisticated military adversaries. The US Air Force and US Navy leaders are therefore working with US defense contractors to invent UAS with longer range, speed, greater stealth, and larger weapons and sensor payloads.

As noted, over the past ten years, the US military fought its wars in amazingly permissive air environments. The threat from al-Qaeda remains, but other threats are emerging. More states possess advanced cruise, ballistic, anti-ship, and surface-to-air missiles (SAMs), as well as over-the-horizon targeting (OTH-T) radars, ISR and strike aircraft, cyber weapons, and submarines.[42] The employment of such weapons systems to prevent force projection and to reduce the ability of an opposing state's military forces to enter or traverse on land, at sea, and in the air is often referred to as "anti-access" and "area-denial" (A2AD):

Anti-access strategies deny an adversary *entry into* the region of conflict. Area-denial strategies deny an adversary movement and *operations within* the region of conflict. Often, the two are pursued simultaneously using similar weapons.[43]

Several countries are organizing and equipping their military forces to create layered defenses capable of overwhelming opposing forces in their territorial waters, the adjacent international waters, and the airspace above, particularly through volleys of missiles. Iran, with cruise and ballistic missiles, swarms of small boats, and mini-submarines, presents this threat

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[41] Andrew Krepinevich, "Why AirSea Battle?", *Center for Strategic and Budgetary Assessments*, 2010; Thomas P. Ehrhard, and Robert O. Work, "Range, Persistence, Stealth, and Networking: The Case for a Carrier-Based Unmanned Combat Air System," *The Center for Strategic and Budgetary Assessments*, 2008.
[42] Ibid.
[43] Jonathan W. Greenert, ADM, USN, and Norton A. Schwartz, Gen, USAF. **"**Air-Sea Battle Promoting Stability in an Era of Uncertainty." *The American Interest*, 20 February 2012, available at: http://www.the-american-interest.com/articles/2012/02/20/air-sea-battle/; "Air-Sea Battle: Service Collaboration to Address Anti-Access and Area Denial Challenges," *Department of Defense Air-Sea Battle Office*, May 2013, available at: http://www.defense.gov/pubs/ASB-ConceptImplementation-Summary-May-2013.pdf.

in the geographically confined Strait of Hormuz and Arabian Sea.[44] China presents this threat on a much larger scale out to the first island chain adjacent to its coast, deploying hundreds of ballistic missiles capable of striking American airfields in East Asia. China's DF-21D missiles can supposedly target and strike aircraft carriers at sea.[45] China fields capable, long range "double digit" SAMs, such as SA-10s (HQ-9s), SA-12s and SA-20s, and its best naval combatants carry HHQ-9 SAMs, extending a formidable air defense umbrella out to sea.[46] Russia has reportedly closed deals to sell long-range double digit SAMs to Syria and to Iran, even though no actual transfer has apparently occurred. If one of these states obtains such systems, the United States and her allies will find strike planning against them much more complicated.[47]

In the face of these emerging threats, combined operations employing air, ground and sea-based missile strikes, jamming, and cyber attacks, supported by networked communications and ISR, can still penetrate a state's defenses.[48] The key will be to employ multiple platforms of weapons systems in combined operations to exploit an enemy's weaknesses and break through its defenses. UAS and UCAVs in particular offer promising capabilities as force multipliers in aerial combat.[49]

To penetrate double digit SAM envelopes, combat aircraft must have extended range, speed, stealth, maneuverability, accurate targeting information from networked ISR, and striking power. On a network-centric battlefield, cyber and electronic warfare will be crucial to victory in combined operations. Manned 4th generation multi-role fighter aircraft increasingly are unsuited to the mission, given their lack of stealth and range. Aerial refueling can extend their range, but over long distances where many combat sorties are required, it is slow, and pilots must turnover between missions. This is especially true in the Pacific where there are few hardened air bases near potential conflict zones. 5th generation manned

44 Caitlin Talmadge, "Closing Time: Assessing the Iranian Threat to the Strait of Hormuz." *International Security,* Vol. 33, No.1, Summer 2009, pp. 82-117.

45 Henry J. Hendrix, CAPT, USN, "At What Cost a Carrier", *Disruptive Defense Papers, The Center for a New American Security*, March 2013, available at: http://www.cnas.org/files/documents/publications/CNAS%20Carrier_Hendrix_FINAL.pdf.

46 Krepinevich, "Why AirSea Battle?;" Corentin Brustlein, "Toward the End of Force Projection ? I. The Antiaccess Threat," *Focus Stratégique*, No. 20 *bis*, Ifri, July 2011.

47 Regarding the proliferation of advanced "double digit" SAM systems, see International Institute of Strategic Studies, *The Military Balance 2013,* London, Routledge, 2013.

48 The US Navy's new EA-18G Growler is capable of electronic attack and of launching high-speed anti-radiation missiles (HARM), and the US Air Force has a variant of the F-16 that is also capable of launching HARM. These aircraft are currently critical in strike missions.

49 "Air-Sea Battle: Service Collaboration to Address Anti-Access and Area Denial Challenges," *Department of Defense*; Jan Van Tol, with Mark Gunzinger, Andrew Krepinevich, and Jim Thomas, "AirSea Battle: A Point-of-Departure Operational Concept," *Center for Strategic and Budgetary Assessments*, 2010, available at: http://www.csbaonline.org/publications/2010/05/airsea-battle-concept/.

fighter aircraft are stealthy but still suffer from short ranges and moreover, high costs. One solution could be to acquire many more inexpensive 4th generation strike aircraft to swarm and overwhelm layered defenses, but many aircraft and pilots might be lost in such strike missions. Some of these 4th generation strike aircraft could be converted into UAS, reducing human losses. Another option is to develop UCAVs. They could offer new capabilities such as longer ranges, could be cheaper than 5th generation strike aircraft, and do not run the risk of losing pilots. UCAVs could be useful both in penetrating sophisticated air defenses for long-range strikes against conventional opponents and useful in enduring time-sensitive targeting missions where the air environment is permissive but endurance is required to carefully examine and confirm valid targets. Yet if UCAVs and UAS in general are to be successful in contested and denied environments, they also have to deal with emerging electronic and cyber threats.

The continuing rapid advance of UAS-related information technologies and the emergence of sophisticated new A2AD threats is driving a requirement for more advanced UAS and UCAVs. How such UAS can integrate into and support existing military forces by partnering with ground, naval and manned air forces in combined operations is the next great challenge.

New Capabilities on the Horizon

Without a cockpit or human life support systems, UAS design opens new horizons for aeronautical engineers. Weapons bays, fuel tanks, ordnance, and engines can be relocated, allowing for new aerodynamic characteristics and a reduced radar cross section. Jet-powered UAS will burn fuel faster than today's propeller-driven UAS, and they may likely burn fuel faster than manned strike aircraft, as they will have the capability to fly far faster and maneuver more aggressively without the burden of a human pilot. Yet this will be a boon for evading missiles. Today's UAS can fly for longer than manned aircraft, and UCAVs with engines and payloads similar in size to today's manned jet aircraft will have more endurance and range because the cockpit could be used for additional fuel capacity, bigger engines, and more ordnance.

UCAVs could be more "attritable" than manned aircraft if the loss of a UCAV airframe were less costly for a military force than the loss of a similar manned aircraft. No pilot would be at risk, and there would be a reduced need for combat search and rescue support assets. If a UCAV were destroyed in combat, the pilot would be unaffected and could immediately control another aircraft, possibly already in the air. It takes years to train pilots to operate their combat aircraft and longer to teach them to lead complex operations involving multiple types of aircraft and support systems. Such training is expensive, and as pilots are captured or killed, an air force becomes ineffective. Modern air forces are very standoff-oriented – they prefer to release their weapons from a safe distance from hostile enemy forces – because aircraft and pilots are so expensive and politically valuable that practically no losses are tolerated. The F-15 has never been shot down in aerial combat,[50] speaking to the quality of the aircraft and pilot training, but probably as much as anything to the fact that the aircraft is employed very carefully in large, complex mission packages. As double digit SAMs, advanced combat aircraft, and air-to-air missiles proliferate, military objectives may require more risk-taking from strike aircraft. UCAVs could help preserve a valuable and expensive input in the air power equation.

If they could be developed, it would be logical to field advanced, expensive, survivable UCAVs for ISR and combat missions. It would also be clever to design less expensive, expendable UCAVs. They could be destroyed while completing particularly dangerous missions, such as swarming and overwhelming enemy air defense systems that would be expected to inflict heavy losses, such as SA-20s. Expensive Tomahawk Land Attack Cruise Missiles (TLAM) are already expended generously to pierce enemy air defenses. TLAMs may have offered adequate firepower against the Libyan integrated air defense system (IADS) in 2011, but against robust IADS comprised of double-digit SAMs and redundant communications networks, a combination of TLAMs, expendable UAS, and perhaps survivable UCAVs could provide a first punch of firepower to allow manned strike aircraft to follow and break down enemy air defenses. The destroyers, cruisers, and submarines of the US Navy that carry TLAMs cannot reload at sea so they cannot generate the sustained firepower of aircraft carriers, which could carry both UCAVs and manned strike aircraft. Both expendable and survivable UCAVs could have critical roles in collecting time-sensitive targeting information to track mobile SAM launchers and to jam and strike targets to suppress enemy air defenses before manned aircraft arrive.[51] The question remains as to what would be "too costly" to accept in terms of lost expendable UCAVs, and that question would need to be analyzed both in terms of battlefield costs and in terms of development and acquisition costs.

Maneuverability

UCAVs will be more maneuverable and evasive than manned aircraft. A main limitation of manned aircraft is the number of g-forces a human pilot can withstand before fainting or being killed. Technologies will undoubtedly exist one day to allow UCAVs to maneuver at g-forces near or higher than 20 times the force of gravity in dogfights and to evade threats. At that point, UCAVs will have a massive maneuver advantage over manned fighters. This technology seems to be far from deployment, but air forces are exploring possibilities.[52]

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[50] Correll, "The Reformers."

[51] Owen R. Cote Jr., "Submarines in Air Sea Battle." *Massachusetts Institute of Technology, Security Studies Program*, 2010. While Cote's paper is about using small submarine-launched UAS as targeting platforms for TLAM strikes, his concepts are applicable to all sorts of future UAS designs, particularly stealthy UAS.

[52] "United States Department of Defense Fiscal Year 2009 – 2034 Unmanned Systems Integrated Roadmap," *US Department of Defense*, Washington, DC, April 2009, p. 30; Robert B. Trsek, Maj, USAF, "The Last Manned Fighter:

UCAVs can be expected to take off and land more quickly and suddenly than today's aircraft. With no human pilot, the limit on how an aircraft could land would be based solely on aircraft and runway material strength and the geometry of the landing and takeoff. Material integrity would remain an important constraint, especially for aircraft made of sensitive, stealthy material and carrying electronics and ordnance payloads. Of particular interest to navies, it should be possible to launch aircraft using more powerful catapults from ships and airfields, shortening minimum runway lengths and perhaps increasing the sortie generation of aircraft carriers. This could obviate the need for aircraft carriers to steam into the wind to launch fixed wing aircraft. It may allow for the construction of smaller, more maneuverable carriers. A limit for aircraft carriers today is that aircraft cannot weigh above a certain tonnage before landing on a carrier flight deck so stronger arresting wires and deck materials would be required. Farther into the future, automated, robotic systems could even retrieve UCAVs from hangers or "racks," to arm, and launch and recover them. In the case of ground based UCAVs, they could possibly be launched and recovered from small, expeditionary airfields using special launchers and arresting equipment.[53]

Automation

Automation could be a key advance for UAS employment. UAS may soon be capable of making intelligent, independent choices, even learning as they operate, without human intervention. According to the US DOD's *Unmanned Systems Integration Roadmap for FY2011,*

"Dramatic progress in supporting technologies suggests that unprecedented levels of autonomy can be introduced into current and future unmanned systems. This advancement could presage dramatic changes in military capability and force composition comparable to the introduction of 'net-centricity'."[54]

The DOD categorizes autonomy for unmanned aerial systems using a four-level scale. At the lowest level, a human operator makes all decisions; at the highest level, "[t]he system receives goals from humans and translates them into tasks to be performed without human interaction."[55] Human operators could essentially allow automated UCAVs to fight using algorithms to make combat decisions. This could be highly effective and deadly against enemies and perhaps dangerous to innocent civilians and friendly forces. Trained operators guided by pre-established protocols would be key to controlling such systems. The employment of

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Replacing Manned Fighters with UCAVS," *Air Command and Staff College Air University,* Maxwell Air Force Base, 2007, available at: http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA515443

[53] Bisson and all, "Disruptive Technologie;" Peter W. Singer, *Wired for War: The Robotics Revolution and Conflict in the 21st Century*, Penguin Books, London, 2009.

[54] US Department of Defense *United States Department of Defense Fiscal Year 2011 – 2036 Unmanned Systems Integrated Roadmap*, Washington, DC, 2011, p. 43.

[55] Ibid. p. 46.

automated UAS would need to follow an escalatory model where operators have the option to increase automation levels step-by-step in line with the danger and gravity of a threat. For a time-sensitive targeting counterterrorism mission, for example, human operators would want to directly control targeting and ordnance employment to be certain to hit the right target and avoid collateral damage. In a high-intensity conventional war, pilots and ground control stations might need to almost fully automate UCAVs: the speed of aerial warfare could be too fast and pilots' and ground controllers' situational awareness too limited to intervene fast enough to make full use of UCAV capabilities.

If UAS were automated, then the number of pilots needed to control them could decrease. The limiting factors in mission execution would become the quality of the automation systems controlling the aircraft, intelligence, the number of mission planners, the number of aircraft, and the availability of fuel and ordnance. The US Navy, at least, is heading in this direction, and is seeking to control multiple UCAVs from aircraft carriers via keyboard and mouse.[56] With only a mouse and keyboard, operators would assign tasks and waypoints to UAS and tweak their performance, but they would not directly control the aircraft the way a pilot does. The US Air Force, for its part, is thinking about having its 6th generation fighter pilots control several UAS from within their aircraft.

Automating aircraft is particularly attractive for long missions because pilots commit more errors when they are tired from having flown for too long. Air forces strictly define the number of hours that pilots are allowed to fly and the number of hours they are required to rest. Displacing pilots from the cockpit could reduce mission errors and mishaps on missions lasting longer than 24 or 48 hours. This could be important for lengthy armed reconnaissance, maritime, and intercontinental missions. For example, currently, when the US Air Force needs a heavy bomber, a team of pilots flies a B-2 Spirit from the Continental United States or Guam to a combat zone on the other side of the world, completes its mission, and then flies back to the Continental United States. The same team of pilots completes the entire mission, even if they set the aircraft on autopilot for certain traverses during the mission. In the future, the US Air Force could develop heavy bombers UCAVs that could fly the same mission from the Continental United States to a target on the other side of the world, but the mission would be largely automated and monitored from a ground control station.

Teams of UAS operators in an air operations center could rotate through four or six hour mission control watches to command the aircraft. These pilot controllers would be less fatigued during the mission, especially when the UAS arrived in combat and returned to base. The pilot controllers would rest frequently, eat regularly, and perhaps spend more time reviewing current intelligence to stay mission-focused. Such a change

[56] Spencer Ackerman, "Navy's Historic UAS Launch From an Aircraft Carrier Has an Asterisk," *Wired*, 14 May 2013, available at: http://www.wired.com/dangerroom/2013/05/drone-carrier/.

would have several positive benefits during a given mission: the pilots would commit fewer errors due to fatigue, would be less exposed to danger, and if the UAS had dynamic automation, the UAS operators could control several aircraft at once, decreasing manpower requirements. Moreover, design and technology allowing, the UAS aircraft could be built for better stealth and more evasive maneuverability. Meanwhile, several manned aircraft could still accompany the mission to ensure that human eyes remained on scene in combat and to control the UCAV as needed.

Improving Sensors

One major problem for both autonomous and piloted UAS is to ensure that they have adequate "sense and avoid" capabilities as they lack human eyes to scan from left to right across the horizon to avoid collisions. Electro-optical sensors, television screens and control consoles can replicate much of the sense of being in an aircraft, but such interfaces de not fully replicate actually having a pilot in the aircraft. This resistance to change may be due as much to fear of the unknown and unfamiliar as to reasonable data analysis. While mishap rates for UAS in the US military were initially high following their initial deployment to combat and to the field, they have fallen in recent years. According to the US Air Force, in 2009, the Predator Class A mishap[57] rate was comparable to that of the F-16 fighter at the same stage, and the Predator mishap rate was under that of small, single-engine private airplanes flown in the United States.[58] The risk of collision while flying UAS is therefore already proving to be similar to the risk for manned aircraft. The DOD continues to put great emphasis on decreasing UAS mishap rates.

Looking ahead, the United States Congress has mandated that the DOD and the Federal Aviation Administration (FAA) work together to develop the technology, rules, and certifications to safely operate UAS in domestic airspace. Significant commercial and consumer demand for UAS and for automated automobiles could help the American Government bear these costs. Google's retrofitted autonomous self-driving cars have already logged 800,000 kilometers on American roads, and now General Motors, Toyota, and Volkswagen are all developing autonomous cars. General Motors hopes to introduce one into the American consumer market by the end of the decade. [59] Other countries may or may not follow suit. If they do not, they may miss a major technological leap and corresponding opportunities. Some combination of sensors, data links, pre-determined air

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[57] The US Air Force defines a Class A Mishap as, "Reportable damage of $1,000,000 or more; a fatality or permanent total disability; or destruction of an Air Force aircraft, spacecraft, or missile during launch." See *US Air Force Instruction 91-204*, 20 February 1998, p. 32, available at: http://library.ndmctsgh.edu.tw/milmed/avitation/file-air/AFI-91-204%28safety-investig-report%29.pdf.

[58] Gertler, "U.S. Unmanned Aerial Systems," p. 18.

[59] Angela Greiling Keane, "Google's Self Driving Cars get Boost from US Agency," Bloomberg News, May 30, 2013, available at: http://www.bloomberg.com/news/2013-05-30/google-s-self-driving-cars-get-boost-from-u-s-agency.html. See also Sebastian Thrun, "La voiture sans chauffeur de Google," *Ted Talks*, March 2011, available at: http://www.ted.com/talks/sebastian_thrun_google_s_driverless_car.html.

corridors, automation, and piloting will be needed to keep UAS and manned aircraft from colliding in the air, on the ground, and on aircraft carrier flight decks.

Other solutions, at least for remotely piloted aircraft, could come from improved UAS cockpits and helmets. In 2006, Raytheon unveiled a cockpit to improve the situational awareness of UAS pilots.[60] Separately, the new helmet of the F-35 Lightning II could bring significant new capabilities to both manned and unmanned piloting. The F-35 has six electro-optical sensors facing in all directions around the aircraft, and an integrated 360-degree view is projected directly into the visor of the pilot's helmet. When looking down and around, the pilot sees "through" the aircraft via the cameras. The system is designed to work equally well at night and during the day, without night vision goggles. With the F-35's integrated helmet and targeting system, the aircraft does not need to maneuver to fire missiles behind itself: sensors redirect weapons 180 degrees off bore-sight at targets seen with the aircraft's cameras and other sensors.[61] The helmet has technical problems, particularly with its software, but the technology is new and promising.[62] Moreover, if the pilots of the next manned American strike aircraft will navigate and fight wearing helmets that view a virtual digital camera world anyway, the same helmet should also be wearable by a ground control station operator flying a UAS. Communications between a UCAV and ground controller would have to be instantaneous to make the comparison perfect, however, and for the moment communications relays still suffer from short delays.

Sensors continue to improve by leaps and bounds, aided by artificial intelligence. Electro-optical sensors used to provide limited, "soda straw" views of the ground or sea. They now allow for wide-angled views with subsection cutouts. For example, the Autonomous Real-Time Ground Ubiquitous Surveillance Imaging System (ARGUS) is a 1.8 gigapixel camera that takes detailed, wide-angled pictures the size of half of Manhattan Island twice per second. By touching the television display screen, an operator can zoom in to watch streaming video of up to 65 sub-regions in the target area with enough detail to see a person waving their arms and birds flying from over 5,000 meters above the ground. The data is streamed to ground stations for real-time analysis and stored for future exploitation, as needed.[63] ARGUS is the equivalent of

[60] "Advanced Multi-Unmanned Aerial System's Cockpit," *Defense Update International Online Defense Magazine*, available at: http://defense-update.com/products/u/UCS.htm.

[61] Some herald the helmet as a revolutionary technology and others as a bust. See, for example, Rob Taylor, "Australia heaps praise on F-35, says rivals years behind," *Reuters*, 16 May 2013, available at: http://www.reuters.com/article/2013/05/16/lockheed-fighter-australia-idUSL3N0DX17I20130516.

[62] Bill Carey and Chris Pocock, "Software Is Biggest F-35 Risk, Says Program Executive Officer," *AIN Online*, 27 September 2013, available at: http://www.ainonline.com/aviation-news/ain-defense-perspective/2013-09-27/software-biggest-f-35-risk-says-program-executive-officer.

[63] NOVA, "What UAS Can See, An engineer describes the next-generation surveillance sensor for UAS, called ARGUS," *PBS,* aired on 17 January 2013, available at: http://video.pbs.org/video/2325492143/; Paul Szoldra, "UAS Spying

having 200 Predators over a target area all at the same time, except that it sits under the fuselage of a single Reaper. Electro-optical sensors can also be fused with infrared and radar images to provide clear imagery both during the day and at night. Such cameras may eventually allow multi-role fighter aircraft to detect and target other aircraft far beyond visual range.

The Issue of Costs

The development of new UAS will be expensive in proportion to the requirements of their capabilities. The communications architecture that sustains them come with unavoidable costs. It is difficult to make reasonable cost comparisons between manned aircraft and UAS because they are so different.[64] Predator and Reaper UAS resemble nothing else in the US Air Force aircraft inventory. Comparing UAS to manned ISR aircraft is a farce. "One" Reaper UAS provides four aircraft and a ground control station and data link that can provide a non-stop, continuous combat air patrol over an area of interest. There is no manned aircraft in the US Air Force inventory with a similar capability and similar data and support requirements. Yet cost-benefit analyses will be necessary because if hundreds of expendable UCAVs are too expensive to procure, then they will not be an attritable force. Furthermore, if manned aircraft can provide the same or better capabilities for a cheaper price, then UAS and UCAVs should not be pursued.

Current UAS are incomparably less capable than 4th and 5th generation manned strike aircraft, but they were not designed with similar capabilities in mind. To make a reasonable cost comparison, it will be necessary to design, build, and experiment with UCAVs that incorporate the characteristics of fighter aircraft, such as a larger payload, speed, and stealth. It will take time to see the true costs of UCAVs vis-à-vis manned aircraft, but they will never be perfectly comparable. Meanwhile, there is a temptation to add more and more capabilities to weapons systems under development. A good example of this is the increasing capability requirements and newer and better ISR payloads that have been added to the Global Hawk, causing its price tag to increase exorbitantly. The ISR payload accounts for some 53% of the UAS's price, and the wings of the MQ-4B had to be made larger to carry the larger ISR payload.[65] Affordable solutions are needed given today's budgetary realities.[66]

Two competing trends indicate that UAS and UCAVS are affordable and will become more cost efficient in the future. The first trend is the continuing fall in the cost of information technology, sensors, and

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Capabilities Are About To Take Another Huge Leap," *Business Insider*, 29 January 2013, available at: http://www.businessinsider.com/darpa-argus-mega-camera-most-detailed-surveillance-camera-in-world-2013-1?op=1.

[64] Gertler, "U.S. Unmanned Aerial Systems;" Ashley Boyle, "The US and its UAVs: A Cost-Benefit Analysis," *American Security Project online*, 24 July 2012, available at: http://americansecurityproject.org/blog/2012/the-us-and-its-uavs-a-cost-benefit-analysis/.

[65] Ibid.

[66] See Department of Defense, *Defense Budget Priorities Choices Fiscal Year 2014*, Washington DC, April 2013.

communications bandwidth per unit of computing power, image, and transmission. The second trend is the fact that even in the face of new and expensive design problems, states around the world continue to push the limits of what is technologically possible in the military realm. UAS technology is becoming cheaper and more affordable for average consumers in America, and there is no reason to believe that the US military will stop experimenting with new and improved UAS.

Today, private consumer demand drives the market for electronics and computers. Governments provide significant money for research and development, and commercial technologies do need to be adapted to military specifications and requirements, often at significant costs. Analysts believe that in the United States, private commercial unmanned aviation will be a huge market, helping to defray many of the costs associated with the development of unmanned aircraft systems.[67] These facts imply that market forces will help drive advances in unmanned aircraft technology for the foreseeable future.

While there is no reason why UAS will not fall prey to modern military procurement's tendency to suffer from price inflation, there is grounds for some cautious optimism. One area where UAS and UCAVs offer the possibility of cost savings over manned aircraft is in training. According to one non-commissioned officer at the Directorate of Evaluation and Standards of the US Army Aviation Center of Excellence, at Fort Rucker:

> "…UAS (unmanned aerial systems) operators advised that the use of simulation is critical to their preparation for combat. UAS simulation is so accurate and realistic that, specifically for the Shadow UAS, it is hard to tell the difference between the simulator and actual flight.[68]"

The RQ-7B Shadow is a small MALE UAS, and the question needs to be posed whether the same logic will hold true for all UAS training. Experience from past UAS training and operations offers the hope that fuel savings and airframe maintenance reductions resulting from relying on simulation-based training for UAS and UCAV pilots and payload operators can offer significant cost savings.

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[67] The US Congress had mandated that the Federal Aviation Administration prepares US domestic airspace for civilian commercial UAS usage by 2015. See Bart Elias, "Pilotless Drones: Background and Considerations for Congress Regarding Unmanned Aircraft Operations in the National Airspace System," *Congressional Research Service*, 10 September 2012, p. 2. See also Teal Group Corporation, "Teal Group Predicts Worldwide UAS Market Will Total $89 Billion in Its 2013 UAS Market Profile and Forecast," 17 June 2013, available at: http://tealgroup.com/index.php/about-teal-group-corporation/press-releases/94-2013-uav-press-release.

[68] "United States Department of Defense Fiscal Year 2011 – 2036 Unmanned Systems Integrated Roadmap," *US Department of Defense*, p. 75.

Having discussed some likely new UAS and UCAV capabilities, this paper will pass to an examination of how they could fit in with existing military forces and what missions they could perform. Some of these new combat missions are likely to be fulfilled with current capabilities, while others will probably only be fulfilled in a more distant future.

Combat Missions

UAS and UCAVs can operate alone or they can fill special roles as force multipliers in mixed packages with other aircraft. Even when operating alone on missions, UAS should practically always form part of a larger network of weapons systems being employed in combined operations. UAS can be potent allies alongside manned aircraft when attacking dangerous enemy air defenses. Ground forces can employ UAS to prevent operational surprise and to increase awareness of the enemy's activity over the horizon. The number of possible mixes of capabilities that UAS and UCAVs might have is as limitless as it is for manned aircraft, except that maneuverability and speed should know even fewer limits.

UCAVs will be well suited to long-range strike missions. Their speed will make them ill-suited to the role of establishing insurgents' patterns of life, yet their speed and perhaps stealth, armament, and defensive countermeasures should make them excellent candidates to accompany manned aircraft in non-permissive environments, such as against A2AD threats. UCAVs could fulfill supporting roles in the suppression of enemy air defenses, such as in jamming.[69] UCAVs might also attack difficult and dangerous targets such as double-digit SAMs thanks to some combination of increased evasiveness, stealth, and higher expendability. With aerial refueling, they will likely be capable of flying long distances to complete their missions. States with stealthy UCAVs may become capable of launching long-range strike missions from their home territory without warning, increasing the chance of successfully achieving surprise and of completing their mission. Such a capability will also necessitate a secure global communications grid, and few states possess all of these capabilities.

The US Air Force is probably already developing advanced UAS and UCAVs. It has not unveiled any new UAS air frames since the RQ-170 Sentinel, but it is highly unlikely that the US military's primary air power service would stop designing and testing new UAS at such a pivotal moment in history. Additionally, US Air Force officials and planning documents stated their objectives to build new UAS for ISR and missions as well as a new optionally manned long range strike bomber. These projects are likely ongoing, and some will doubtless come to fruition before others.[70] Moreover, aviation journalists have recently reported that the US

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[69] Mark J. Mears, "Cooperative Electronic Attack Using Electronic Aerial Vehicles," *Air Force Research Laboratory, Air Vehicles Directorate*, Wright Patterson AFB, 2006, available at: http://www.dtic.mil/dtic/tr/fulltext/u2/a444985.pdf.

[70] US Air Force Headquarters, *United States Air Force Unmanned Aerial Systems Flight Plan, 2009-2047*, 18 May 2009. Annex 4 beginning on p. 33 contains information on the US Air Force's "family of systems" approach and on some of the

Air Force is already testing a new ISR UAS that shows significant advances in stealth and maneuverability.[71]

The US military has no lack of appetite for new UAS capabilities, but a few are most urgent. There is a need for a UAS that can perform sustained ISR near and in contested and denied airspace. A UAS that could do this would need a stealthy radar cross-section and to be capable of flying at high altitudes to peer down on ISR targets while maintaining standoff over long periods of time. It would also ideally have stealthy communications because a crafty adversary would otherwise quickly learn to track and target it by its electronic signature, which could be significant as the UAS would likely feed continuous ISR collection to its ground control station and other aircraft via satellite or line of site communication. Ideally the UAS would be fast and maneuverable enough to avoid some missile threats but perhaps not double-digit SAMs, for the moment.

Another important American requirement is for a long-range penetrating strike aircraft to replace the US Air Force's aging bomber fleet. This mission could potentially be filled by a UCAV. Such a UCAV would ideally be fast, stealthy, and survivable enough to strike double-digit SAMs and escape unharmed. As its mission would be to strike and then depart an area of operations, it would ideally be capable of operating autonomously and under radio silence in denied airspace. Such a strike UCAV could perhaps follow a preplanned flight path to its targets or receive updated navigational and targeting data via encrypted communications broadcasts or passive sensors. The US Air Force's planned long range strike bomber might fill this role. Since UAS technology is evolving rapidly, the air service may produce multiple small runs of long range strike UAS aircraft to attempt to capitalize on state of the art capability advances.

A key question is whether UCAVs can fulfill the fighter mission of air-to-air combat. This is probably the last capability that will be developed for UCAVs because it is so complicated and important, and because manned fighter pilots are so dependable. To fulfill this mission, UCAVs must be able to accurately distinguish friendly from hostile aircraft, and their sensors must be able to do this independently. Beyond that, there are two situations to consider: beyond visual range (BVR) and within visual range (WVR) aerial combat.

Whether controlled by a man in the loop or totally automated, UCAVs should eventually be able to fulfill the mission of BVR air-to-air

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UAS the service hopes to produce over the coming thirty years, available at: http://www.fas.org/irp/program/collect/uas_2009.pdf. For information on the Long Range Strike Bomber program, see, Bill Sweetman, "Boeing, Lockheed Form New Bomber Team," *Aviation Week*, 4 November 2013, available at: http://www.aviationweek.com/Article.aspx?id=/articlexml/AW_11_04_2013_p22-631732.xml.

[71] Amy Butler and Bill Sweetman, "EXCLUSIVE: Secret New UAS Shows Stealth, Efficiency Advances." *Aviation Week*, 6 December 2013, available at: http://www.aviationweek.com/Article.aspx?id=/article-xml/awx_12_06_2013_p0-643783.xml.

combat, even with a short communications time delay from operator to air vehicle. In such scenarios, pilots already depend on sensors to distinguish friend from foe, and missiles are fired before an assumed enemy aircraft comes within visual range, ideally before coming within an enemy's weapons engagement zone. In BVR aerial combat, fighter pilots rely upon their instruments and computers to make decisions and release weapons, and ground controllers piloting UCAVs should be able to do the same thing.

In the case of within visual range (WVR) air-to-air combat, the situation is more complicated. At the merge, dogfighting aircraft must react immediately. The communications relay between UCAVs and ground controllers takes time, currently up to about two seconds,[72] whereas a pilot's reaction time is estimated to be around 200 milliseconds.[73] In WVR combat, UCAV piloted by a ground operator would therefore be at a disadvantage against a manned fighter given today's communication technology: a manned aircraft will react to the evolving situation faster to maneuver and defeat a UCAV. Advanced optics and sensors that can see far into the distance even in poor weather and at night could potentially make the difference between BVR and WVR combat irrelevant to UCAVs. Experiences since Vietnam give pause to such optimism, however, as most air-to-air engagements have continued to take place within visual range. Yet since the deployment of the advanced medium range air-to-air missile (AMRAAM), BVR's "share" of kills has increased 43 fold.[74]

Also, automation may solve the problem if UCAVs can be made to dogfight autonomously using artificial intelligence. Automated UCAVs would likely be able to calculate and execute maneuvers faster and more aggressively (turning at higher g's), with fewer stress errors than human pilots. In aerial combat, pilots run through complex checklists under pressure, reacting to what they see in the air and on their computer screens; such procedures and maneuvers should eventually be writable as computer algorithms. A couple decades ago the chess master Kasparov could still defeat IBM's Deep Blue computer, but not following software updates allowed Deep Blue to avoid Kasparov's signature traps. Automating UCAVs to be controlled by artificial intelligence is potentially revolutionary thanks to the possibility of coding the best knowledge and experience of all the best fighter pilots into every UCAV, with no training required.[75]

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[72] Trsek, "The Last Manned Fighter."

[73] Brien Alkire, James G. Kallilmani, Peter A.Wilson, and Louis R. Moore, "Applications for Navy Unmanned Aircraft Systems." *The Rand Corporation National Defense Research Institute*, Santa Monica, 2010.

[74] Scott Perdue and John Stillion, "Air Combat Past, Present and Future." Project Air Force, *The Rand Corporation*, August 2008, Slide 24, available at: http://www.mossekongen.no/downloads/2008_RAND_Pacific_View_Air_Combat_Briefing.pdf.

[75] Trsek, "The Last Manned Fighter."

UAS and the Sea

> "Our frontiers are the coasts of the enemy and we ought to be there five minutes after war is declared." - *Admiral Jacky Fisher*

The sea is an international commons where navies and naval aircraft have the right to freely loiter in and above international waters to patrol, send a political message, prepare to project force ashore, or wage war at sea. By nature of their endurance, range and automation, UAS are ideal for lengthy maritime ISR missions in the littorals and on the open ocean, both for surveillance and to extend fleet defense and striking power. An examination of some US Navy ground-based and carrier-based maritime UAS currently under development reveals how they are going to change naval operations.

The most important ground-based US Navy UAS system under development is the MQ-4B Triton Broad Area Maritime Surveillance (BAMS) UAS. Based on the Global Hawk airframe, Triton flies at altitudes of 18,000 – 21,000 meters at speeds up to 575 kilometers per hour and has an endurance of 30 hours and ranges up to 3,000 kilometers. It is unarmed. The Navy plans to buy 68 Tritons to run daily 24-hour operations from five bases around the world. Triton will provide strategic ISR including electro-optical, infrared, SIGINT, and radar ISR collection, and it will provide communications networking to the fleet at sea.[76] Triton could be a valuable asset as a regional back-up system to neutralize US satellites in wartime scenarios, ensuring that dispersed ships in a region stay networked and in communication. Triton made its first flights in June of 2013, and the program appears to be moving ahead for an initial operational capability in December 2015.[77]

Air power is of fundamental importance for navies. Even with sophisticated missile defense systems, navies that expect to face serious maritime air threats must quickly and independently generate fighter sorties for fleet defense. Attacking aircraft will otherwise rapidly overwhelm fleet defenses with volleys of anti-ship missiles. Attacking aircraft must be intercepted and destroyed far from a fleet's ships; the farther from the fleet that attacking enemy aircraft launch their missiles, the more time and space the fleet has to intercept the missiles. Navies cannot rely upon far away ground-based aircraft for fleet defense, especially if the fleet is deployed far from home shores. Furthermore, navies rely on specialized sensors, radars, missiles, torpedoes, and other weapons systems to fight in the maritime domain, and air force sensors cannot adequately fulfill these technical missions.

Carrier-based UCAVs could significantly expand the umbrella of fleet defense and the range of fleet striking power. They can help maintain

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[76] Gertler, "U.S. Unmanned Aerial Systems."

[77] Robert Johnson, "New Triton Drone Makes First Flight: Will Keep Tabs on China, North Korea," *The Business Insider*, 23 May 2013, available at: http://www.businessinsider.com/the-mq-c4-triton-first-flight-2013-5?op=1.

standoff far from the fleet by conducting combat air patrols several hundred or even thousands of nautical miles from their carriers, much farther than manned aircraft can patrol. UCAVs armed with anti-ship missiles, AMRAAM, guided bombs, and torpedoes could provide an outer ring of ISR and fleet defense, supplementing manned fighter aircraft operating closer to the carrier. UCAVs would probably be at a distinct disadvantage in air-to-air combat against manned aircraft because of their dependence on off-board communication and slow reaction times, but when controlled by manned strike or command and control aircraft nearby, or by shipboard operators, that time delay could potentially be reduced to irrelevancy, if the UCAV controllers were able to launch AMRAAM beyond the weapons engagement zone of the enemy, for example. Several UCAVs could be in the air at the same time, networked directly to each other and to manned aircraft and the ships of the fleet, dramatically improving the fleet's networked view of the battle area and providing more targeting solutions. Carrier-based ISR capabilities to see over the horizon and search for enemies trying to hide themselves in the vastness of the sea would be dramatically improved by the addition of carrier-based UCAVs orbits.

UCAVs could give carrier air wings new tactical options. The aircraft of today's carrier air wings have relatively short unrefueled ranges, restricting their ability to maneuver towards an enemy over the water.[78] UCAVs could conduct feinting movements to confuse an enemy and loiter hundreds of miles away from the fleet to attack from unexpected directions, greatly complicating an enemy's force deployment and battle planning. Longer-range UCAVs could also be deployable to stations away from the fleet as ISR pickets to watch for incoming threats. UCAVs could be the eyes of the fleet, searching over the horizon, function as cavalry, attack in swarms, and carrier extra munitions for manned fighters.[79]

Unmanned Carrier-Launched Airborne Surveillance and Strike (UCLASS)

The UCAV test program that marks a rupture in naval aviation history is the US Navy's carrier-based X-47B Unmanned Combat Air System (UCAS). In May 2013, UCAS was launched by catapult from the flight deck of the USS George H. W. Bush, like a manned aircraft. It later conducted a successful landing on a carrier.[80] The jet-powered UCAS is a test bed, and the program will end in the coming years after tests of UCAS's ability to conduct air-to-air refueling and to land on a carrier flight deck under increasingly difficult conditions.[81] Based on its experience with UCAS, the US Navy is now planning to acquire the world's first operational carrier-based UCAV, the Unmanned Carrier-Launched Airborne Surveillance and Strike (UCLASS) system.

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[78] Krepinevich, "Why AirSea Battle?".
[79] Robert C. Rubel, "The Future of Aircraft Carriers," *Naval War College Review*, Vol. 64, No. 4, Autumn 2011, pp. 13-27.
[80] Ackerman, "Navy's Historic UAS Launch."
[81] "Unmanned Combat Air System Demonstration," *Naval Air Systems Command online*, Aircraft and Weapons page, available at: http://www.navair.navy.mil/index.cfm?fuseaction=home.display&key=7468CDCC-8A55-4D30-95E3-761683359B26.

The US Navy ambitiously plans to bring UCLASS to the fleet sometime around 2020. Four major US defense contractors will have the technology from the UCAS program at their disposal to develop proposals for UCLASS. The idea has been put forward to have one squadron of six UCLASS in each aircraft carrier air wing.[82] The requirements for UCLASS have changed significantly over time, but as of December 2013, the Navy was planning on building an aircraft that would weigh about 70,000 – 80,000 pounds, the size of an F-14 Tomcat. That would make UCLASS twice the size of the UCAS, and considerably larger than the F/A-18 Super Hornet. It will, "have heavy-end ISR and strike capabilities with some growth in the ability to carry weapons and some growth in the sensor package," according to one US Navy admiral.[83] UCLASS will also supposedly have some degree of radar-evading stealth but less than the F-35 Lightning II. With such size, UCLASS could make an excellent aerial refueling platform, it could function as a weapons truck to support manned strike aircraft, or it could wield formidable striking power on its own.[84]

US Navy documents released earlier in 2013 defined some of the UCLASS program's key requirements even though an airframe has not been selected. They may no longer be exactly valid, but they provide an idea of the Navy's goals for its first carrier-based UCAV. The Navy wants UCLASS to "be able to conduct two orbits at 600 nautical miles or one orbit at 1,200 nautical miles. The system should also be able to conduct a strike mission at 2,000 nautical miles."[85] UCLASS could therefore provide a longer patrol and strike range than the carrier's F/A-18 E/F Super Hornet, which has a 1,660 nautical mile range carrying two AIM-9 air-to-air missiles, three 480-gallon fuel tanks, and no strike weapons.[86] UCLASS offers the possibility of intercepting enemy missile threats before they become a danger by extending the fleet's ISR and strike umbrella. If UCLASS is to be

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[82] Graham Warwick, "U.S. Navy Is Cautious On Carrier-Launched UAS," *Aviation Week*, 24 June 2013, available at: http://www.aviationweek.com/Article.aspx?id=/article-xml/AW_06_24_2013_p44-588836.xml&p=1.

[83] Sam LaGrone and Dave Majumdar, "Navy: UCLASS Will be Stealthy and 'Tom-cat Size.'" *USNI News* online, 23 December 2013, available at: http://news.usni.org/2013/12/23/navy-uclass-will-stealthy-tomcat-size.

[84] Ibid.

[85] "UCLASS By the Numbers," *USNI News*, 26 June 2013, available at: http://news.usni.org/2013/06/26/uclass-by-the-numbers; "Navy Docs Reveal UCLASS Minimum Ranges and Maximum Costs." *USNI News*, 29 August 2013, available at: http://news.usni.org/2013/06/26/navy-docs-reveal-uclass-minimum-ranges-and-maximum-costs. To reiterate, an orbit means a 24-hour airborne presence. Two orbits would mean that two aircraft would always be airborne at the same time, and one orbit would mean that one aircraft would be airborne. The longer-range orbit would be harder to sustain for a variety of reasons, including satellite communications bandwidth requirements and fuel. One Reaper UAS system consists of four aircraft that are capable of sustaining one continuous orbit. Reaper UAS costs are discussed in terms of a whole system of four aircraft plus the ground equipment and data links, and theoretically UCLASS should be analyzed in a similar way.

[86] "F/A-18 Hornet strike fighter," *US Navy Fact Sheet*. The fact sheet includes information on both the Hornet and Super Hornet, actually two distinct aircraft, available at: http://www.navy.mil/navydata/fact_print.asp?cid=1100&tid=1200&ct=1&page=3.

as large as reported, then it could add a particularly useful long-range refueling and strike aircraft to the carrier air wing, one that could also perhaps aerially refuel manned strike aircraft on the way to battle, particularly useful in supporting sea-based strike missions in contested and denied areas. If it is stealthy, then it could join the battle on more demanding missions after conducting refueling accompanying manned aircraft. It would be prudent, however, to strike a cautious tone regarding UCLASS's final capabilities. In mid-2013, it appeared that the Navy only wanted UCLASS to carry 1,000 pounds of munitions, far less than the almost 18,000 pounds carried by the F/A-18 Super Hornet.[87] Now it appears that the service wants to design UCLASS to carry more payload than the Super Hornet.

With its long range and ability to conduct ISR for up to 50 hours at a time with aerial refueling, or to loiter over a target area waiting to conduct a strike, UCLASS will break carrier flight operations cycle and shipboard intelligence collection and processing paradigms. No aircraft currently onboard carriers can fly for remotely as long. Air operations on the flight deck will have to be re-imagined and reorganized to take advantage. UCAVs will be able to remain on station for longer, and carrier air wing sortie generation could potentially be increased.

UCLASS could be a potent weapon for time-sensitive targeting missions, loitering and conducting ISR until the right moment to strike. It would also be interesting for littoral and inland ISR in areas where the US has no airfields. Depending on its stealth and armament, UCLAS could conduct long-range strikes from the sea, provide jamming support to other aircraft, and perhaps even contribute to air-to-air combat as missile trucks. UCLASS could also provide a significant additional degree of safety to naval aviators having difficulty landing on a pitching flight deck as the UCAV could provide an almost limitless aerial refueling source organic to the carrier during blue water carrier operations.

The aircraft carrier has long been the capital ship of modern navies. There is currently a vibrant debate about the value, role, cost, and vulnerability of aircraft carriers, in the US Navy and in the United Kingdom, France, Russia, and even now in China and other countries. Ship construction and aircraft costs have strengthened arguments that carriers are too expensive; the proliferation of quiet submarines and advanced missiles argue that they are too easy of a target.[88] As of mid-2013, the Navy wanted UCLASS to cost no more than $150 million per orbit. The F/A-

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[87] "Navy Docs Reveal UCLASS Minimum Ranges and Maximum Costs," *USNI News*.

[88] For two articles published by US Navy officers in the first few months of 2013 alone, see: Hendrix, "At What Cost a Carrier?" and David H. Buss, VADM, USN, William F. Moran, RADM, USN, and Thomas J. Moore, RADM, USN, "Why America Still Needs Aircraft Carriers," *Foreign Policy*, 26 April 2013, available at: http://www.foreignpolicy.com/articles/2013/04/26/why_america_still_needs_aircraft_carriers

18 Super Hornet has a fly away cost of $66.9 million per aircraft[89] – cheaper – but with a totally different capability. The Super Hornet is a reliable platform for fighter and strike missions, but UCLASS has the potential to fulfill some of these missions while adding endurance, range, and maneuverability, and other capabilities.

Most importantly, if UCLASS, F-35 Lightning IIs, F/A-18 Super Hornets, Growlers, and E2-D Hawkeyes can operate together from aircraft carriers with the surface fleet and other fleet force multipliers such as Tritons, the lethality of these weapons systems when employed in combined operations will far outweigh their individual values, helping preserve the aircraft carrier's role as the dominant capital ship for the foreseeable future. Adding UCAVs to aircraft carriers is common sense.

[89] "Navy Docs Reveal UCLASS Minimum Ranges and Maximum Costs," *USNI News*; Dave Majumdar, "Navy Shifts Plans to Acquire a Tougher UCLASS," *USNI News* online, 12 November 2013, available at: http://news.usni.org/2013/11/12/navy-shifted-plans-acquire-tougher-uclass.

Conclusion

Over the past generation, first Israel and then the United States demonstrated the value of UAS in warfare. The Israeli Defense Force employed UAS in innovative combined operations in contested environments in regional conflicts. Using new technologies and its Global Information Grid, the United States military then employed armed UAS in largely permissive air environments in counterinsurgency operations around the globe as well as for a variety of ISR missions, including some in denied airspace. In the coming years, increasingly capable UAS will proliferate around the world, even as the US will remain the leader in their development and employment in the near-term. With their range, endurance, maneuverability, stealth, and other new capabilities, and in spite of some significant vulnerabilities, particularly in the cyber realm, new UAS will have an enduring impact on military tactics.

The next generation of UAS is being built for ISR, refueling, jamming, strike, and eventually fighter missions as complements to and as replacements for manned aircraft in contested and denied airspace. Multi-role UCAVs for combat missions will become increasingly prevalent in modern military forces. Advances in information technology, including automation, combined with the natural desire to seek tactical and strategic military advantages will drive this development. Indeed, aircraft procurement programs, which take years to mature, lag in leveraging new information technologies, indicating that the biggest changes are still in the future. The UCLASS program demonstrates one possible major leap forward in UCAV capabilities, and classified US Air Force programs have probably already developed other new UAS. Ultimately, the adoption of UAS may transform military operations on a par with some of the great armament revolutions in history. Meanwhile, mastery of the cyber domain will be essential to their operation.

In the current operating environment, UAS offer ways for the United States and other Western States to combat emerging A2AD threats, particularly those posed by missiles. The states adopting A2AD postures are also integrating UAS into their armed forces. Given how dangerous surface-to-air missiles have become and how rapidly UAS are advancing in capability, the challenges that pilots face today are similar to those faced by horse-mounted cavalry officers in the 19th century. Outgunned by machine guns, automatic rifles, armored vehicles, and aircraft, the cavalry officer disappeared after thousands of years as a dominant soldier.[90] This

[90] Edward L. Katzenbach Jr., "The Horse Cavalry in the Twentieth Century: A Study in Policy Response," *Public Policy,* vol. 7 1958, pp. 120-149.

comparison should not yet be overstated – cavalrymen did not have stealth, for example – but it bears consideration. Moreover, armed UAS teamed with manned aircraft can make manned aircraft more survivable and lethal in combat.

Meanwhile, certain people may be fooled into believing that UAS will allow for almost video game-like, risk-free warfare. Leaders will be tempted to think that UAS strikes can provide easy solutions to complex overseas conflicts. While UAS have added capability to the US and Israeli militaries on the battlefield, and while they have helped decimate al-Qaeda's senior leadership, they still cause collateral damage, and they do not mitigate against the inherent risks of war. Also, UAS have been unable to find elusive targets, including the current leader of al-Qaeda, Ayman al-Zawahiri, and the leader of the Taliban, Mullah Muhammad Omar, both in hiding since 2001. However profound their organizational impact, UAS are only weapons systems so they will not be able to make and win wars by themselves. In the end, the introduction of UAS may prove to be more a revolution inside military organizations than a revolution in warfare itself.

Annexes

Annex 1: Department of Defense levels of autonomy for UAS

Inventories of American Military UAS

Four Levels of Autonomy		
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.
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.
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.
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.

Source: DOD's Unmanned Aerial Systems Integrated Roadmap 2011 - 2036, p. 57.

Annex 2: The Proliferation of UAS

Israel and the United States are leading the way in developing and deploying UAS. China, Russia the United Kingdom and France are variously conducting research and development to and experimenting with their own advanced UAS. Some of these countries have either purchased or copied Israeli and American UAS designs. Other countries can be expected to obtain UAS as time passes, through domestic development and international arms sales. Israel's approach to the use of UAS is focused on its region whereas the United States' approach is based on global presence and interests. A state's requirements will determine the capabilities of the UAS it chooses to design or purchase.

States have every reason to believe that they will need to invest in UAS in order to be competitive in future wars and to make meaningful contributions in future coalitions. For Israel, the constant threat of war and asymmetric attacks on its borders drove the requirements that sped the development of increasingly sophisticated military UAS. For the United States, the wars in Afghanistan and Iraq galvanized the effort to develop UAS. For France, operations like Mali appeared to have had a similar effect. France's decision to purchase Reapers from the United States will allow it to support its military operations in Mali and elsewhere in Africa, an important consideration given the continuing threat of terrorism in Northern and Western Africa. Current UAS are well-suited to combating insurgents and to counterterrorism missions; France's armed forces will use their experience with Reapers to quickly adopt the tactics and technologies for their own UAS development programs. The first flights of the Neuron in late 2012 and this early 2013 indicate that Europe is well on its way to developing UCAVs,[91] as do the flights of the Tarantis indicate the same for the United Kingdom.[92] Yet continuing military budget cuts seriously threaten the viability of both future UAS programs, and as the United States, Israel and other states are pushing ahead with new UAS designs, this implies a relative loss of national power. In the maritime domain, France and the United Kingdom will probably want to carefully consider if and how carrier-based UCAVs can meet their military requirements. France and the United Kingdom will likely wait to purchase maritime UCAVs, and naval strategists everywhere will watch the development of UCLASS. Both land-based and carrier-based unmanned aerial systems could be particularly attractive to France to patrol the international airspace and waters of the Western Mediterranean that border the country's southern coast. Meanwhile the French will have to weigh UCAVs against the country's need to replace its Rafale.[93]

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[91] Dominic Perry, "Neuron partners show off future-fighter know-how," *Flight Global online*, 8 February 2013, available at: http://www.flightglobal.com/news/articles/neuron-partners-show-off-future-fighter-know-how-382100/.

[92] Anthony Osborne, "Parliamentary Documents Reveal Beginning Of Taranis Test Flights," *Aviation Week*, 25 October 2013, available at: http://www.aviationweek.com/Article.aspx?id=/article-xml/awx_10_25_2013_p0-630512.xml

[93] John Reed, "Semi-autonomous killer UAS from around the globe," *Danger Room*, *Foreign Policy,* 29 May 2013, available at: http://killerapps.foreignpolicy.com/posts/2013/05/29/killer_UAS_from_around_the_globe.

Emerging powers such as China and India can be expected to invest heavily in unmanned aircraft and to employ them to their own advantage. China could even outpace the United States in UAS development in the future.[94] The Chinese may succeed in jumping straight to carrier- and ground-based maritime surveillance and strike UCAVs. Adding unmanned ISR and strike aircraft into its A2AD strategy makes perfect sense for China. Armed UAS would threaten the US Navy, show force to Japan during heightened tensions over disputed East Asian Islands, and provide China with a way to significantly increase its over the horizon targeting capabilities. This argues more strongly for the US Navy to develop its own UCAVs to increase the standoff of its carrier air wing and make targeting for China even more difficult. The mixing of Chinese unmanned strike aircraft with American and Japanese ships, combat aircraft, and unmanned combat aircraft could lead to an unintended escalation of military tensions to nobody's benefit. This scenario is certainly not out of the question in the next 10 years, especially if all of the aircraft concerned are stealthy and they suddenly cross paths in the air.

Unmanned aircraft can be expected to proliferate to other developing countries through international arms sales. Potential customers are limited only by their funds and access to communications bandwidth. In the Mediterranean, Algeria could one day be a customer for Russian or Chinese UAS. It is easy to imagine how Libya, Egypt, and Turkey could increase their maritime domain awareness and coastal strike capabilities by investing in unmanned aircraft. Iran already employs some basic unmanned aircraft to survey the Strait of Hormuz. Iran's UAS are basic, but it is not unimaginable to think that Iran could one day obtain UAS that allow the country to increase it's over the horizon targeting capabilities, especially of anti-ship cruise missiles and coastal defense cruise missiles, a department in which Iran's abilities are in doubt.[95] Iran would need satellite communications to operate UAS beyond line of site, however, and it is doubtful that it has or will soon possess such capabilities. For the moment, Iran could control UAS from ships in the Persian Gulf and from ground control stations ashore. Southeast Asia could also be a big market for unmanned aircraft sales, especially with Vietnam, the Philippines, Taiwan, Malaysia, Singapore, and other countries in the area, not to mention the United States, increasingly concerned about China's claims of maritime sovereignty in the South China Sea. Maritime UAS could give these countries heightened situational awareness and lead to regional intelligence sharing and cooperation with the United States to attempt to counter Chinese power projection.

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[94] Minnick, Wendell, "Chinese UAS Development Slowly Outpacing West," *Defense News*, 30 April 2013, available at: http://www.defensenews.com/article/20130430/DEFREG03/304300019/Chinese-UAS-Development-Slowly-Outpacing-West.

[95] Talmadge, "Closing Time: Assessing the Iranian Threat to the Strait of Hormuz."

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