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Chasing Autonomy: How Much is Enough and How Much is Too Much?

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UxS have become almost ubiquitous in U.S. military operations today, but many still wonder how they will be effectively integrated into the existing force, to succeed as a force multiplier rather than just a force enabler. To these observers, the DoD *FY 2013-2038 Unmanned Systems Integrated Roadmap*'s vision of "merging unmanned systems from air, ground, and sea domains into teams of unmanned and manned systems" that "beyond autonomous mission *execution* to autonomous mission *performance*," remains a work in progress.

We argue that advanced, effective autonomy is a cornerstone of the *Integrated Roadmap*'s future vision. More than this, budget realities – especially spiraling personnel costs – make autonomy an absolute necessity if unmanned systems are to be sustainably integrated into the joint force. With this imperative, the Department of Defense is making tangible progress; recent technology developments in computational intelligence and multi-sensor data fusion hold the promise of making the military's vision of autonomy a reality.

But as advanced degrees of autonomy are achieved and these systems begin to sense and adapt and allow blue forces to act within an adversary's OODA (Observe, Orient, Decide, and Act) loop, these systems may well have to operate within *our* OODA loop. They may need to adapt to changing environments quickly without waiting for human operator oversight, input, and decision-making. As UxS ultimately provide their own command and control and self-synchronization and become truly autonomous, the U.S. military profession's command and control capabilities must evolve as well.

This paper will explore the urgent need to achieve more autonomy in unmanned systems, show examples of ongoing projects designed to enhance the autonomy of unmanned systems (as well as their ability to better interact with manned systems), and define some of the challenges that will need to be addressed as these unmanned systems begin to operate within our own OODA loops.

Chasing Autonomy: How Much is Enough and How Much is Too Much?

Background

“Tools, or weapons, if only the right ones can be discovered, form 99 percent of victory ... Strategy, command, leadership, courage, discipline, supply, organization and all the moral and physical paraphernalia of war are nothing to a high superiority of weapons – at most they go to form the one percent which makes the whole possible.”

J.F.C. Fuller (1919)
War Made New

While few today would ascribe to Major General J.F.C. Fuller’s contention, quoted in Max Boot’s best-selling book, *War Made New*, the influence of technology on warfare *is* profound. In his best-selling book, *War Made New: Technology, Warfare, and the Course of History 1500 to Today*, military historian Max Boot supports his thesis with historical examples to show how technology has transformed military operations.

One of the most rapidly growing areas of technology adoption involves unmanned systems. In the past ten years alone, the military’s use of unmanned systems (UxS) has exploded. The expanding use of armed unmanned aerial vehicles (UAV) is changing the face of modern warfare, and now unmanned surface vehicles (USV) and unmanned underwater vehicles (UUV) are showing similar promise. This rise has been supported by the equally fast pace of technological research and development taking place within industry, academia, and Department of Defense laboratories.

But the challenge is daunting. For UxS to reach their full potential, important command, control communications, computers, intelligence, surveillance and reconnaissance (C4ISR) considerations must be addressed. The science of building unmanned air, ground, surface, and underwater vehicles is well advanced. Today the soaring costs of military manpower mandate that we must move beyond the current one-man, one-joystick, one-vehicle paradigm.

If the vision of unmanned aircraft systems is to be fully realized, the focus must be on their C4ISR capabilities rather than just on the platforms themselves. This will enable multiple UxS to be controlled by one operator. In the future, unmanned systems must be able to provide their own command and control and self-synchronization, thereby allowing the systems to become truly autonomous.

Dominating the Information Space with UxS

“The Navy is pursuing improved information-based capabilities that will enable it to prevail in the higher-threat, information-intensive combat environments of the 21st Century.”

U.S. Navy Information Dominance Roadmap 2013-2028

The 2014 *Quadrennial Defense Review* embodies the strategic imperatives first articulated in the strategic documents *Sustaining U.S. Global Leadership: Priorities for 21st Century Defense* and its companion, *Budget Priorities and Choices*. These imperatives include sustaining global presence; renewing DoD’s emphasis on Asia together with continued focus on the Middle East;

maintaining DoD's commitments and evolving its presence in Europe; and building innovative, low-cost, small-footprint approaches to partnership around the world. UxS are a fundamental enabler of these imperatives. Additionally, defense leaders including former Secretary Robert Work have been adamant that U.S. forces will remain engaged globally even while budgets decline, thus creating a requirement to do the same – or more – with less.

The U.S. Navy is at the forefront of these efforts. To enable effective maritime superiority and maintain global maritime awareness, the U.S. Navy has made information a “main battery” of its arsenal. A key focus area for the Navy is to fully leverage the rapid evolution of information technology, which presents simultaneous opportunities and challenges in pursuing the missions outlined above. As stated in the Navy's *Vision for Information Dominance*, the role of information is fundamentally changing from its traditional function as a combat enabler to being deployed as a weapon itself.

At the tactical level, UxS will support the strategies outlined above, and if key developments are achieved they have the potential be a crucial force multiplier. As noted in the QDR, “The increasing precision, persistence, and autonomy of unmanned systems hold great promise.” This is particularly true in the Middle East and Asia Pacific regions, which will be the two major “hubs” for the U.S. Navy going forward.

In his June 2013 article in *Foreign Policy* entitled, “The New Triad,” the recently-retired Supreme Allied Commander Europe, Admiral James Stavridis, identified UxS as one of the three pillars of this New Triad, writing:

The second capability in the New Triad is unmanned vehicles and sensors. This branch of the triad includes not only the airborne attack "drones" that are endlessly debated at the moment, but unmanned surveillance vehicles in the air, on the ground, and on the ocean's surface...While expensive, such systems have the obvious advantage of not requiring the most costly component of all: people. Also, without people operating them, they can perform in far harsher environments and hold a higher degree of political deniability for covert and clandestine operations.

It is increasingly evident that UxS have an integral role to play in achieving the DoD's and Navy's strategic goals ... although this role may not be fully realized until UxS reach their full potential with advancements in their intelligence, autonomy, and perception capabilities.

The U.S. Military Plan for UxS Development

“The Department of Defense's vision for unmanned systems is the integration of diverse unmanned capabilities that provide flexible options for Joint Warfighters while exploiting the inherent advantages of unmanned technologies, including persistence, size, speed, maneuverability, and reduced risk to human life.”

FY 2013-2038 Unmanned Systems Integrated Roadmap

On Dec. 23, 2013, the Defense Department released its *Fiscal Year 2013-2038 Unmanned Systems Integrated Roadmap*, the latest iteration of this biennial report to Congress. Dyke Weatherington, Director, Unmanned Warfare and Intelligence, Surveillance And Reconnaissance at USD(AT&L), noted that the roadmap “articulates a vision and strategy for the continued development, production, test, training, operation and sustainment of unmanned systems technology across DoD ... This road map establishes a technological vision for the next 25 years and outlines the actions and technologies for DOD and industry to pursue to intelligently and affordably align with this vision.” The technical vision outlined in the Roadmap is shaped by the strategic environment, and in particular by constrained budgets and the rebalance to the Asia-Pacific region.

The previous, FY 2011 – 2036 *Integrated Roadmap* also responded to DoD’s budgetary constraints, emphasizing that “affordability will be treated as a key performance parameter (KPP) equal to, if not more important than, schedule and technical performance.” The current version of the Roadmap focuses on the fact that, as Mr. Weatherington put it, DoD “can’t start programs that we can’t afford.”

The Roadmap also delves into the reduction in budget over the next five years, beginning with the President’s Budget request for \$5.6 billion in unmanned systems in FY 2013. One approach the Roadmap presents for adapting to austere budgets is “selective innovation.” “Future mission needs will have to be met by funding capability improvements that exploit existing systems with innovative improvements to their indigenous technologies. This approach might be as simple as modifying a sensor to improve data flow or applying standard message set architectures to improve interoperability,” the Roadmap explains.

Another focus area guiding the Roadmap’s vision is the strategic focus on the Asia-Pacific region. Unlike the past decade, in which UxV have operated in relatively uncontested environments, future operations are expected to contend with significant anti-access/area denial (A2/AD) challenges. The Roadmap explains that this will create a need to build smaller and more agile systems, and also to enhance manned-unmanned integration.

Chapter 4 of the Roadmap discusses six “Technologies for Unmanned Systems” that reflect DoD’s shift in strategic priorities and address the need to reduce lifecycle costs. It also describes how limited science and technology funding will potentially impact these emerging technology solutions. The nine technology areas of interest are:

- Interoperability and Modularity
- Communication Systems, Spectrum, and Resilience
- Security: Research and Intelligence/Technology Protection (RITP)
- Persistent Resilience
- Autonomy and Cognitive Behavior
- Weaponry
- Sensor Air Drop
- Weather Sensing
- High Performance Computing

In each of these areas, near-, middle-, and long-term goals are identified.

Summarizing the report, Mr. Weatherington stated that, “the road map describes the challenges of logistics and sustainment, training and international cooperation while providing insight on the strategic planning and policy, capability needs, technology development and operational environments relevant to the spectrum of unmanned systems.”

A 2012 Defense Science Board Task Force report examined DoD’s use of unmanned systems and their contribution to overall DoD strategy. The report found that autonomy technology is being underutilized due to internal inefficiencies. However, the Task Force was also optimistic about the potential contributions of autonomy technology, noting that “increased autonomy can enable humans to delegate those tasks that are more effectively done by computer, including synchronizing activities between multiple unmanned systems, software agents and warfighters--thus freeing humans to focus on more complex decision making.”

Echoing the DoD’s emphasis on the need for increased levels of autonomy, the U.S. Air Force vision statement for remotely piloted aircraft highlights the goal of achieving “widespread use of highly adaptable and flexible autonomous systems and processes to provide significant time efficiencies and operational advantages over adversaries.”¹ The Air Force’s *RPA Vector* report goes on to discuss Autonomy as a key enabling concept, stressing the need for developments in “multi-aircraft control technology improvements” – specifically in the areas of swarming technology and manned-unmanned teaming (MUM-T).²

In many ways, the U.S. Navy has been on the forefront of UxS development. For example, the 28th Chief of Naval Operations (CNO) Strategic Studies Group (SSG) spent one year examining this issue. Leveraging the SSG’s work, the Navy is now addressing how it integrates UxS into its force structure, emphasizing in particular the need to enhance C2 capabilities to lower Total Ownership Costs. This link between increased autonomy and decreased TOC has made the revolutionary, rather than simply evolutionary, development of unmanned aircraft systems imperative.

The Office of Naval Research has aligned its priorities with this DoD and Navy guidance. In the latest Naval Science and Technology Strategic Plan, autonomy and unmanned systems are identified as one of nine key focus areas. This plan includes four objectives: human and unmanned systems collaboration; perception and intelligent decision-making; scalable and robust distributed collaboration; and intelligence enablers and architectures.

UxS Budget Outlook

“This roadmap is two years since the last one. We knew budgets would be declining. I don’t think two years ago we understood how significant the down slope was going to be so this roadmap much more clearly addresses the fiscal challenges.”³

Mr. Dyke Weatherington,

¹ U.S. Air Force, *RPA Vector: Vision and Enabling Concepts 2013 – 2038*, 2014, pg. 12. Accessed at: <<http://www.af.mil/Portals/1/documents/news/USAFRPAVectorVisionandEnablingConcepts2013-2038.pdf>>

² U.S. Air Force, *RPA Vector: Vision and Enabling Concepts 2013 – 2038*, 2014, pg. 76. Accessed at: <<http://www.af.mil/Portals/1/documents/news/USAFRPAVectorVisionandEnablingConcepts2013-2038.pdf>>

³ Kris Osborn, “Pentagon Plans for Cuts to Drone Budgets,” DoDBuzz.com, January 2, 2014, accessed at: <<http://www.dodbuzz.com/2014/01/02/pentagon-plans-for-cuts-to-drone-budgets/>>.

Table 1. DoD Unmanned Systems Funding (\$ mil/PB14)

FYDP		2014	2015	2016	2017	2018	Total
Air	RDTE	1189.4	1674.0	1521.4	1189.4	1087.9	6662.2
	Proc	1505.5	2010.2	1843.5	1870.7	2152.8	9382.7
	OM	1080.9	1135.2	1102.7	1156.9	1178.5	5654.1
Domain Total		3775.9	4819.4	4467.6	4217.0	4419.3	21699.1
FYDP		2014	2015	2016	2017	2018	Total
Ground	RDTE	6.5	19.1	13.6	11.1	10.6	60.9
	Proc	6.5	27.9	30.7	42.6	55.4	163.1
	OM	0.0	0.0	0.0	0.0	0.0	0.0
Domain Total		13.0	47.0	44.3	53.7	66.0	223.9
FYDP		2014	2015	2016	2017	2018	Total
Maritime	RDTE	62.8	54.8	66.1	81.0	87.2	351.9
	Proc	104.0	184.8	160.1	158.1	101.1	708.2
	OM	163.4	170.3	182.4	190.5	193.6	900.2
Domain Total		330.2	409.8	408.6	429.7	381.8	1960.2
FYDP		2014	2015	2016	2017	2018	Total
All Unmanned Systems	RDTE	1,258.7	1,747.9	1,601.1	1,281.5	1,185.7	7,075.0
	Proc	1,616.0	2,222.9	2,034.3	2,071.4	2,309.3	10,253.9
	OM	1,244.3	1,305.4	1,285.1	1,347.4	1,372.1	6,554.3
Domain Total		4,119.1	5,276.2	4,920.5	4,700.4	4,867.1	23,883.2

Note: Ground operations and maintenance (OM) is funded with overseas contingency operations funding.

As the roadmap notes:

DoD inventories and funding of UxS are expected to continue a gradual upward trend through 2015 (see Table 1 above) and then trend downward in 2016 and beyond, although UxS experienced a full \$1.3 billion (33.4%) reduction from fiscal year (FY) 2013 to PB2014 in combined research, development, test, and evaluation (RDT&E) and procurement funding. Outside DoD, UxS sector growth is predicted to continue to rise and was described as “the most dynamic growth sector of the world aerospace industry this decade.”

Building on the roadmap's information, we project that overall, future UxS funding will focus less on platform acquisitions and more on advanced capability and payload development. Long-endurance, unmanned ISR procurements will likely wind down, as they require a permissive, low-threat environment. Instead, the focus will be on hardening UxS and ensuring that they are able to operate effectively in anti-access/area denial environments, which will increasingly characterize the future security landscape. Indeed, the *Annual Aviation Inventory and Funding Plan, FY 2014 – 2043*, reflects this shift – between FY2014 and FY2023, DoD's aviation inventory numbers are projected to remain flat, even while annual funding levels increase from

approximately \$90 billion in FY2014 to \$110 billion in FY2023.⁴ Rather than being spent on procurement, these funds will increasingly be invested in research and development.

Helping UxS Reach Their Full Potential

“The combat potential of UVs (unmanned vehicles) is virtually unlimited ... There is no question that the Fleet/Forces of the future will be heavily dependent upon UVs.”

Roles of Unmanned Vehicles

Naval Research Advisory Committee Report

March 2003

Clearly, the U.S. military is dedicated to increasing unmanned systems’ autonomy. The 2013 *Integrated Roadmap* maintains the previous 2011 *Roadmap*’s four levels of autonomy: Human Operated (Level One), Human Delegated (Level Two), Human Supervised (Level Three), and Fully Autonomous (Level Four). However, the 2011 *Roadmap* notes that in contrast to automatic systems, which simply follow a set of preprogrammed directions to achieve a predetermined goal, autonomous systems “are self-directed towards a goal in that they do not require outside control, but rather are governed by laws and strategies that direct their behavior.”

The need for increased autonomy has been emphasized by the DoD and also by each of the Services. One of the most daunting challenges for the U.S. military Services is to reduce the prohibitively burdensome manpower requirements currently necessary to operate UxS. Another is to provide unmanned aircraft systems with resiliency when operating in environments where human control is limited. A third factor is the increasing need for unmanned aircraft systems to operate in unpredictable environments and to conduct complex and changing missions.

Manning Is Increasing TOC to Unacceptably High Levels

It is beyond debate that the cost of military manpower makes up the largest part of the total ownership cost (TOC) of military systems across all the Services. Additionally, military manpower costs are the fastest growing accounts, even as the total number of military men and women decrease. For example, military personnel expenditures have risen from \$74 billion dollars in 2001 to \$159 billion dollars in 2012, an increase of almost 115 percent. Moreover, defense analysts Mackenzie Eaglen and Michael O’Hanlon have stated that between fiscal year 2001 and 2012, the compensation cost per active-duty service member increased by 56%, after being adjusted for inflation.

In the current budgetary drawdown, the need to reduce these manning costs is not only pressing, it is absolutely imperative. The 2011 Budget Control Act mandated that DoD future expenditures be reduced by approximately \$487 billion over the next decade.⁵ The DoD recognizes that savings of this magnitude will not be possible without addressing the manpower burden. Although unmanned systems are identified as one of the few key capabilities for which

⁴ Department of Defense, *Annual Aviation Inventory and Funding Plan: Fiscal Years (FY) 2014 – 2043*, May 2013.

⁵ See “Budget Control Act of 2011,” Public Law 112-25, August 2, 2011. Accessed at:

<<http://www.gpo.gov/fdsys/pkg/PLAW-112publ25/pdf/PLAW-112publ25.pdf>>

funding levels were requested to be protected – and in some areas even increased – UxS manning requirements *must* decrease in order to fully realize the value of these investments.

Lessons learned throughout the development process of most unmanned systems show that they can actually *increase* manning requirements. Indeed, the Air Force has estimated that the MQ-1 Predator requires a crew of about 168 personnel, while the MQ-9 Reaper requires a crew of 180 and the RQ-4 Global Hawk relies on 300 people to operate it. As General Philip Breedlove, Vice Chief of Staff of the Air Force, has emphasized, “The number one manning problem in our Air Force is manning our unmanned platforms.”⁶

From the U.S. Navy’s perspective, the full potential to have unmanned aircraft systems *reduce* overall TOC for Navy ships will not be realized without the concurrent development of the C4ISR technology that enable these systems to communicate with, and be tasked by, their operators as well as communicate and self-synchronize with each other. The Department of Defense *FY2011 – FY2036 Unmanned Systems Integrated Roadmap* notes DoD’s goal of fielding transformational capabilities will require that the department increase the autonomy of “unmanned” systems in order to decrease their associated manpower costs.

The Ever-Expanding Data Overload Challenge

Compounding the Total Ownership Cost issue, the data overload challenge generated by the proliferation of unmanned aircraft and their sensors has created its own set of manning challenges. In fact, the situation has escalated so quickly that many doubt that hiring additional analysts will help to ease the burden of sifting through thousands of hours of video.⁷ General James E. Cartwright, former Vice Chairman of the Joint Chiefs of Staff, complained that a single Air Force Predator can collect enough video in one day to occupy 19 analysts.⁸ He stated, “Today an analyst sits there and stares at Death TV for hours on end, trying to find the single target or see something move. It’s just a waste of manpower.”⁹

The data overload challenge is so serious that it’s widely estimated that the Navy will face a “tipping point” in the 2016 timeframe, after which the Navy will no longer be able to process the amount of data that it’s compiling.¹⁰ In order to combat this problem, the Navy’s Information Dominance Directorate has established a Tasking, Collection, Processing, Exploitation and Dissemination (TCPED) Working Group. This group is “actively studying Navy TCPED operations to discover a process for separating the wheat from the chaff, which

⁶ Qtd. In Lolita Baldor, “Military Wants to Fly More Sophisticated Drones,” *Associated Press*, November 04, 2010.

⁷ For example, see Kate Brannen, “U.S. Intel Chiefs Need Better Data Tools,” *Defense News*, October 18, 2010.

⁸ William Matthews, “Keeping Pace,” *Seapower Magazine*, December 2011.

⁹ Ellen Nakashima and Craig Whitlock, “Air Force’s New Tool: ‘We Can See Everything,’” *Washington Post*, January 2, 2011.

¹⁰ The ISR “tipping point” has been noted in a TCPED study from the Office of the Chief of Naval Operations and PMW 120 (Battlespace Awareness and Information Operations), an independent Navy Cyber Forces study, and the NRAC study from summer 2010. See Admiral David Dorsett, “Information Dominance Industry Day Questions and Answers,” April 2011. Accessed at:

<<https://www.afcea.org/mission/intel/documents/MasterAnswerDocument05APR11.pdf>>. See also CHIPS, “Interview With J. Terry Simpson, PEO C4I Principal Deputy for Intelligence,” April – June 2011. Accessed at: <<http://www.doncio.navy.mil/uploads/0623ATL15115.pdf>>.

should keep data transfer to a realistic level.”¹¹ However, the ultimate success of the TCPED mission will be heavily dependent on the development of supporting C4ISR capabilities.

A newsletter posted by the DON Chief Information Officer proposes a possible way ahead, arguing that “some type of autonomous analysis needs to take place on the vehicle if we hope to sever the constant link between platform and operator.”¹² Rear Admiral William Leigher, the Navy’s Director of Program Integration for Information Dominance, goes a step further, noting that the future of intelligence is “automated systems that can analyze and fuse enough intelligence information from multiple sources to begin to predict events.”¹³ Indeed, increasing unmanned systems’ capability to conduct autonomous analysis may be the only sustainable way forward, as demands for real-time ISR in three dimensions continue to increase exponentially.

Operating UxS in Non-permissive Environments

According to the DoD’s highest-level strategic guidance documents – including the *Joint Operational Access Concept* (JOAC) and *Air-Sea Battle: Service Collaboration to Address Anti-Access and Area Denial Challenges* – military operations in the future are much more likely to be conducted in operational environments characterized by the difficulty of “blue forces” entering the area (anti-access) and/or operating effectively once there (area denial).¹⁴ These difficulties may be caused by harsh environments (such as in caves or under water) or, increasingly, by adversary actions (such as jamming communications). Indeed, a recent Air Force Scientific Advisory Board report has claimed that communications links are a “primary target of the adversary” in robotic aircraft operations.¹⁵ In such environments, the external control of unmanned systems is jeopardized, and it becomes imperative that they are able to operate independently.

As one example, a serious vulnerability of unmanned systems’ is their current level of dependence on satellites for communications and command and control (C2). Satellites are increasingly vulnerable to interference from adversaries, and the DoD is working to bolster its ability to operate in a denied environment. This challenge is particularly acute for the Navy, which must maintain the capability to operate forward in anti-access/area denied (A2/AD) regions. In the case of remotely-piloted UAV such as the MQ-1 Predator and MQ-9 Reaper, if the satellite link is broken the pilot would lose direct control of the aircraft, leaving it to rely on pre-loaded software and GPS guidance. While that might be acceptable for routine missions, it presents a significant vulnerability for those missions requiring constant oversight. Overcoming this challenge will be vital to the success of the AirSea Battle Concept, and more generally, of the Joint Operational Access Concept.

¹¹ Admiral David Dorsett, “Information Dominance Industry Day Questions and Answers,” April 2011. Accessed at: <<https://www.afcea.org/mission/intel/documents/MasterAnswerDocument05APR11.pdf>>.

¹² Tom Kidd, Mikel Ryan, and Antonio Siordia, “Unmanning Unmanned Systems,” *Department of the Navy Chief Information Officer News*, May 19, 2010, accessed at: <<http://www.doncio.navy.mil/ContentView.aspx?ID=1756>>

¹³ William Matthews, “Keeping Pace,” *Seapower Magazine*, December 2011.

¹⁴ See Department of Defense, “Joint Operational Access Concept,” January 17, 2012. The JOAC defines “anti-access” as “those capabilities, usually long-range, designed to prevent an advancing enemy from entering an operational area.” It defines “area-denial” as “those capabilities, usually of shorter range, designed not to keep the enemy out but to limit his freedom of action within the operational area.” See also Robert Haffa and Anand Datla, “6 Ways to Improve UAVs,” *C4ISR Journal*, March 2012.

¹⁵ Associated Press, “Official: US Limits Intel Value of Drones,” *New York Times*, December 18, 2011.

Even if the data-links were sufficiently robust and reliable, the current level of bandwidth demanded by UxV – especially the remotely-piloted Predator and Reaper – is quickly outpacing the DoD’s supply. The shortfall is often made up through reliance on commercial satellite communications, which makes up nearly 80 percent of the U.S. government’s satellite communications capacity.¹⁶ However, commercial satellite communications are often not as secure as their government counterparts, and they are also extraordinarily expensive. This problem is expected to grow more severe as UxV demand for bandwidth continues to exceed the DoD’s ability to field its own satellite systems.

Given the persistent vulnerabilities of satellite communications and the projected imbalance between supply and demand, the only sustainable way forward is to have the ability to cut the satellite “tether” that UxV currently rely on. If these systems’ autonomy and interoperability were enhanced so that they were tasked with a mission but could “decide” themselves how best to accomplish it, operators could rely on the UxV onboard systems carrying out the mission rather than having to maintain direct control of the craft. Moreover, beyond ensuring their own effectiveness in the absence of satellite communications, UxV could also act as communications relays for other platforms if necessary.¹⁷

The Potential “Dark Side” of Autonomy

Astronauts David Bowman and Frank Poole consider disconnecting HAL's (**H**euristically programmed **A**lgorithmic computer) cognitive circuits when he appears to be mistaken in reporting the presence of a fault in the spacecraft's communications antenna. They attempt to conceal what they are saying, but are unaware that HAL can read their lips. Faced with the prospect of disconnection, HAL decides to kill the astronauts in order to protect and continue its programmed directives.

From Stanley Kubrick’s *2001: A Space Odyssey*

The issues involved with fielding increasingly-autonomous unmanned systems are complex, challenging and increasingly contentious. While advancing other aspects of UxS improvements in areas such as propulsion, payload, stealth, speed, endurance and other attributes are – and will remain – important, coming to grips with how much autonomy is enough and how much may be too much, is arguably *the* most important issue we need to address with unmanned systems over the next decade.

A large part of this autonomy for unmanned systems resides in their ability to “sense and adapt.” This will enable unmanned systems to achieve much greater speed in decision making than is currently possible, and allow “blue forces” to act within an adversary’s OODA (Observe, Orient, Decide, and Act) loop. Thus, as the environment and/or mission changes in

¹⁶ Grace V. Jean, “Remotely Piloted Aircraft Fuel Demand for Satellite Bandwidth, *National Defense Magazine*, July 2011.

¹⁷ Northrop Grumman has already developed this capability for use on Global Hawks. The Battlefield Airborne Communications Node (BACN), deployed aboard Global Hawks, “bridges the gaps between ... diverse weapons systems and operating units ... enabling essential situation awareness from small ground units in contact up to the highest command levels.” See Northrop Grumman, “Battlefield Airborne Communications Node and Global Hawk,” accessed at: < <http://www.is.northropgrumman.com/products/bacn/assets/BACN.pdf>>.

unpredictable ways, the ability to sense and adapt will allow unmanned systems to find the optimal solution for achieving their mission, without the need to rely on constant human operator oversight, input and *decision-making*. But are we ready for unmanned systems to operate without our decision-making, to operate inside *our* OODA loops?

In an article entitled, “Morals and the Machine,” *The Economist* addressed the issue of autonomy and humans-in-the-loop this way:

As they become smarter and more widespread, autonomous machines are bound to end up making life-or-death decisions in unpredictable situations, thus assuming—or at least appearing to assume—moral agency. Weapons systems currently have human operators “in the loop,” but as they grow more sophisticated, it will be possible to shift to “on the loop” operation, with machines carrying out orders autonomously. As that happens, they will be presented with ethical dilemmas...More collaboration is required between engineers, ethicists, lawyers and policymakers, all of whom would draw up very different types of rules if they were left to their own devices.¹⁸

These issues of trust and ethics in the face of autonomy have been exacerbated as drones’ missions increasingly include antiterrorism strike operations. Debate rages on the strategic efficacy of unmanned vehicles in the fight against terrorism, even in today’s environment of remotely-piloted vehicles. It’s reasonable to expect that these concerns would be magnified exponentially in the case of autonomous vehicles. Bill Keller put the issue of autonomy for unmanned systems this way in his Op-ed, “Smart Drones,” in the *New York Times* in March 2013:

If you find the use of remotely piloted warrior drones troubling, imagine that the decision to kill a suspected enemy is not made by an operator in a distant control room, but by the machine itself. Imagine that an aerial robot studies the landscape below, recognizes hostile activity, calculates that there is minimal risk of collateral damage, and then, with no human in the loop, pulls the trigger. Welcome to the future of warfare. While Americans are debating the president's power to order assassination by drone, powerful momentum – scientific, military and commercial – is propelling us toward the day when we cede the same lethal authority to software.¹⁹

The Department of Defense is taking the issue of human control of unmanned systems seriously and *is* beginning to issue policy to ensure that humans *do* remain in the OODA loop. A November 2012 directive by Deputy Secretary of Defense Ashton Carter issued the following guidance:

Human input and ongoing verification are required for autonomous and semi-autonomous weapon systems to help prevent unintended engagements. These systems shall be designed to allow commanders and operators to exercise appropriate levels of human judgment over the use of force. Humans who

¹⁸ See “Robot Ethics: Morals and the Machine,” *The Economist*, May 31, 2012.

¹⁹ See Bill Keller, “Smart Drones,” *New York Times*, March 16, 2013.

authorize the use of, or operate these systems, must do so with appropriate care and in accordance with the law of war, applicable treaties, weapon system safety rules and applicable rules of engagement. An autonomous system is defined as a weapon system that, once activated, can select and engage targets without further intervention by a human operator.²⁰

These are the kinds of directives *and* discussions that are – and should be – part of the dialogue between and among policy makers, military leaders, industry, academia and the science and technology community as the design and operation of tomorrow’s UxS are thoughtfully considered. This is not a trivial pursuit and – in Albert Einstein’s words – will require a new way of “figuring out how to think about the problem.” And importantly, most informed discussion begins with the premise that adversaries who intend to use UxS against our interests will *not* be inhibited by the kinds of legal, ethical and moral strictures the United States currently adheres to.

For these reasons, further discussions and debate on UxS issues are crucial if we envision unmanned systems as warfighting tools – and indeed as warfighter’s partners – in the increasingly challenging future security environment. Industry *must* be part of these discussions. As Lieutenant General David Deptula suggested, “The challenge before us is to transform *today* to dominate an operational environment that *has yet to evolve*, and to counter adversaries who *have yet to materialize*.” UxS will be central to confronting this challenge.

Designing Autonomous Systems with the *Right Degree of Autonomy*

Goldilocks went for a walk in the forest. Pretty soon, she came upon a house. She knocked and, when no one answered, she walked right in. At the table in the kitchen, there were three bowls of porridge. Goldilocks was hungry. She tasted the porridge from the first bowl. "This porridge is too hot!" she exclaimed. So, she tasted the porridge from the second bowl. "This porridge is too cold," she said. So, she tasted the last bowl of porridge. "Ahhh, this porridge is just right," she said happily and she ate it all up.

From *Goldilocks and the Three Bears*
By Robert Southey

While most readers may find it surprising to find a quote from a children’s fairy tale in a professional paper, for the issue of unmanned systems and autonomy, this passage *does* capture the challenge. As the Services look to achieve the right balance of autonomy and human interaction – to balance these two often-opposing forces and get them “just right” – in their efforts to push UxS capabilities to the cutting-edge, they must turn to industry for innovative solutions.

The capabilities required to find this “just right” balance must leverage many technologies that are still emerging. But few companies have the discretionary R&D funds to keep running down blind alleys in their pursuit of capabilities that the Services know they need – but as of yet only dimly perceive. Without putting too fine a point on it, the military knows what it *wants* to

²⁰ Deputy Secretary of Defense Ashton Carter, “Autonomy in Weapon Systems,” Memorandum, November 21, 2012. See also “Carter: Human Input Required for Autonomous Weapon Systems,” *Inside the Pentagon*, November 29, 2012.

achieve, but not what technologies or even capabilities it *needs* to field UxS with the right balance of autonomy and human interaction. The Defense Science Board report, *The Role of Autonomy in DoD Systems*, put it this way:

Instead of viewing autonomy as an intrinsic property of unmanned systems in isolation, the design and operation of unmanned systems needs to be considered in terms of human-systems collaboration...A key challenge for operators is maintaining the human-machine collaboration needed to execute their mission, which is frequently handicapped by poor design...A key challenge facing unmanned systems developers is the move from a hardware-oriented, vehicle-centric development and acquisition process to one that emphasizes the primacy of software in creating autonomy.

It is important for industry – and all of industry, not just UxS vehicle manufacturers – to focus on reports like this one, for the issue of “the primacy of software” is one that deserves special consideration. The manned F-35 Lightning has **ten billion** lines of computer code – and counting – and there is human supervision by the pilot! How many lines of code will need to be built into an unmanned system to get the balance of autonomy and human interaction “just right?”

While there is no point-solution or easy answer to this challenge, there are some trend lines we can leverage to invest R&D dollars so they can ultimately produce UxS the Services will embrace – and indeed –be unable to live without. The focus in the next decade-plus should be to:

- Make the C4 architecture a priority in unmanned systems development
- Build in a “sense and adapt” capability in all unmanned systems
- Concurrently develop CONOPS and tactics, techniques and procedures for each UxS
- Leverage queuing theory to enable UxS to balk or renege on a mission
- Develop target recognition algorithms that are on a par with those of manned systems
- Develop anticipatory intelligence and decision support software into unmanned systems

The last point regarding decision support software is one where the “unmanned community” has yet to leverage the cutting-edge technology that already populates military command centers. For the relatively small numbers of UxS that will engage and enemy with a weapon, this is crucial. Prior to firing a weapon, the unmanned platform need only provide the operator – and there must be an operator in the loop – with a “pros and cons” decision matrix regarding what that firing might entail. When we build that capability into unmanned systems we will, indeed, have gotten it “just right.”

Current UxS Research and Development Initiatives

Unmanned systems have the potential to create strategic, operational, and tactical possibilities that did not exist a decade ago – but this promise will not be realized without substantial improvements in the C4ISR systems that will allow them to achieve true autonomy. The Navy laboratory community is embarked on leading-edge research to address this challenge. Near-term work aimed at reducing the manpower burden that unmanned systems currently require includes:

- *Distributed Control of Unmanned Systems Using Widgets*: This SSC Pacific project is developing technology that will demonstrate the ability to tactically control unmanned systems within a distributed system by breaking the missions into tasks to be displayed by widgets within the Ozone Widget Framework (OWF). The large amounts of data originating from unmanned systems will be stored within the cloud to be retrieved, appended, visualized and stored by other local and remote operators.
- *ICOP*: ICOP (Intelligence Carry on Program) leverages the Distributed Common Ground System – Navy (DCGS-N) in providing workstations onboard U.S. Navy surface combatants to exploit data and video from multiple UxS simultaneously. This system been fielded in exercises such as Trident Warrior 2011 to enable one operator to view and exploit video from several UAVs such as Scan Eagle and Predator, freeing the UAV launching platform from the one operator, one joystick, one UAV paradigm.
- *MOCU*: The Multi-Robot Operator Control Unit (MOCU) is an unmanned systems project that allows one operator to control multiple systems in order to reduce manning costs. MOCU is a graphical operator-control software package that allows simultaneous control of multiple unmanned systems from a single console. Given the severely proscribed manning profile for Navy ships like the DDG-1000 and the LCS, MOCU is envisioned to be a strong enabler aboard these – as well as future – Navy surface combatants.

Longer-term cutting-edge work being spearheaded by the U.S. Navy laboratory community that is designed to increase unmanned systems' level of autonomy includes:

- *UV-Sentry*: The “UV-Sentry” project enables cooperative autonomy and autonomous command and control of UxS. This, in turn, allows for automated data fusion into a common operational picture. Thus, a constellation of unmanned systems with increased intelligence and the ability to adaptively collect and process sensor data into actionable information operate in a self-synchronized manner without having many operators provide constant input and direction.
- *JUDIE*: The Joint Unmanned Aircraft Systems Digital Information Exchange (JUDIE) is a project designed to enable UxS information-exchange as an initial step in enabling UxS to self-synchronize and ultimately work as swarms. It is an inter-Service project involving all the military Services and is using the MQ-1 Predator and RQ-7 Shadow UxS as test platforms.

- *X-47B Unmanned Combat Air System Demonstrator (UCAS)*: The X-47B is the Navy's carrier-launched Unmanned Combat Air System, currently in its demonstration phase. A breakthrough capability, the X-47B is the Navy's first autonomous aircraft. It has performed impressively in recent tests, successfully completing both catapult take-offs and arrested landings from an aircraft carrier, both during the day and at night. These successes were rewarded in April 2014, when the X-47 was awarded the prestigious Collier Trophy, which recognizes outstanding aeronautics achievement.

The work the Navy is doing with the Multi-Robot Operator Control Unit (MOCU) is representative of some of the groundbreaking efforts that the DoD must accelerate to help UxS reach their full potential. MOCU is a flexible software framework that has been used to control many different unmanned systems across most all domains: land, sea, undersea, and air. It is modular and is open-architecture, making it easily adaptable for the Navy's current SOA and cloud computing initiatives. And importantly, MOCU is government developed and owned.

MOCU is the common controller for both USV mission modules on the Littoral Combat Ship, and it is planned for use as the common controller for the next generation of EOD robots. In fact, it has been used to control dozens of unmanned ground, air, and maritime systems in R&D labs and Government organizations. MOCU was designed from the ground-up to control multiple heterogeneous vehicles – without being tied to any specific vehicle, vehicle type, or protocol. Additionally, MOCU's modularity, scalability and flexible display enable control of a wide range of vehicles.

MOCU is currently undergoing testing in Small Unmanned Air Systems (SUAS) such as the Raven UAS. This is important, as SUAS provide organic, portable and nearly instant aerial surveillance to dismounted warfighters such as Special Operations forces. Given the increasing use of SUAS by special operators, MOCU is having an immediate influence in the field **today** where it is being beta-tested by Naval Special Operations forces. While a full description of the benefits MOCU brings to the warfighter is beyond the scope of this paper, among its manifest attributes are the fact that it uses existing tactical, wearable computers thus improving portability, and that it uses a common software framework, thus creating commonality for more streamlined logistics.

Longer term, the UCAS and follow-on UCLASS will be the Navy's first autonomous, carrier-launched UxS. As noted in the *Naval Aviation Vision*, the X-47B "is driven autonomously (self-piloted, with human input) using programmed routines and algorithms in autonomous logic that tell the system what to do, as opposed to being driven using a joystick." This helps to reduce manning costs while shortening response time on crowded carrier decks. The X-47B is the prototype for the Unmanned Carrier-Launched Airborne Surveillance and Strike (UCLASS) systems, which the Navy plans to field by 2020. UCLASS is designed for long-range ISR and strike missions, which it will perform with some degree of autonomy as well.²¹

²¹ While there has been some confusion over the planned role and missions of UCLASS, Admiral Mathias Winter, PEO Unmanned Aviation and Strike Weapons, clarified them during his speech at the Navy League's Sea-Air-

These efforts and others like them support the goals of the DoD *Unmanned Systems Roadmap* of enabling constellations of unmanned systems to provide their own C4. This is vital to reducing the extent of human operators' engagement in direct, manual control of unmanned vehicles. If this C4 breakthrough is achieved, it may well exceed improvement in UxS propulsion, payload, stealth and other attributes and unleash the revolutionary changes these unmanned systems can deliver.

International Considerations

Although the U.S. DoD continues to lead the development, ownership and operation of UxS globally, the benefits of UxS and their effectiveness in missions ranging from surveillance, to strike, to signal relay, and to cargo transportation have been recognized by many other nations as well. These governments are seeking to integrate UxS into their own suite of military capabilities, either through the acquisition of foreign systems or, as at least forty nations are currently doing, through the development of indigenous systems.²² Emerging markets for UxS include Russia, China, India and South Korea. As IHS Jane's analyst Derrick Maple noted at the August 2012 Association for Unmanned Vehicle Systems International's (AUVSI's) annual North America Unmanned Systems conference, "We are very much still at the early stages of the lifecycle of this market ... The global market over the next 10 years will grow despite budget constraints, and it is a major developing marketplace." Mr. Maple projected that about \$81.3 billion would be spent globally over the next ten years on unmanned aircraft procurement, services, and research and development.²³

Many of the U.S. coalition partners, including Great Britain and Italy, are already using UxS in the operations in Iraq and Afghanistan.²⁴ Israel has also swiftly incorporated armed drones into its military forces, and employs them for a variety of missions. Most recently, UxS played a major role in the eight days of fighting over Gaza between November 14 and November 21, 2012, with one source noting that "The type of surgical warfare fought over Gaza could not have been performed without the massive use of unmanned platforms."²⁵

Australia, a key U.S. ally in the Asia Pacific region, has a particularly pressing need to integrate UxS into its current fleet. Although the RAAF has leased a Heron UxS for use in Afghanistan

Space conference in April 2014. He noted that UCLASS will help to meet the Navy's need for continuous ISR collection, while having a "limited" capability to strike targets on the ground. He also explained that it would initially operate in uncontested airspace, but would later be modified to allow for use in contested airspace as well. See Valerie Insinna, "Confusion Surrounds Navy's Carrier-Based Drone," *National Defense Magazine*, May 2014.

²² March 23, 2011 statement by U.S. Representative John F. Tierney on the "Rise of Drones: Unmanned Systems and the Future of War." Statement available at: < <https://hsdl.org/?view&doc=120460&coll=limited>>.

²³ Marcus Weisgerber, "Analysts See Unmanned Aircraft Market Growing," *Defense News*, August 8, 2012. Accessed at: < <http://www.defensenews.com/article/20120808/DEFREG02/308080001/Analysts-See-Unmanned-Aircraft-Market-Growing>>.

²⁴ See U.K. Ministry of Defence, "The U.K. Approach to Unmanned Aircraft Systems," Joint Doctrine Note 2/11, March 30, 2011. Accessed at: < https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/33711/20110505JDN_211_UAS_v2U.pdf>

²⁵ Arie Egozi, "Israeli Sources Hail UAV Contribution to Gaza Operation," *Flight Global*, November 23, 2012. Accessed at: < <http://www.flightglobal.com/news/articles/israeli-sources-hail-uav-contribution-to-gaza-operation-379396/>>.

supporting coalition operations, analysts have argued that Australia's geopolitical reality necessitates the deployment of a High Altitude Long Endurance (HALE) UxS for broad area maritime surveillance.²⁶ Australia is responsible for a daunting 12 percent of the world's oceans; only a UxS such as the MQ-4C Triton, boasting endurance of about 30 hours and an operating altitude of 60,000 feet, is capable of providing the requisite levels of surveillance to monitor such an extensive area. The Triton's impressive capability could be complemented by the acquisition of Medium Altitude Long Endurance (MALE) platforms, which would offer more a more highly focused surveillance capability.

China's government also has ambitious goals to bolster its UxS technology capabilities, and its indigenous UxS development has progressed more rapidly than anticipated.²⁷ Many analysts were taken aback when China displayed its capabilities at the November 2012 Zhuhai air show. At the airshow, China showed off a model of the new Harrier III UAV and the Blue Fox target drone, which is based on the L-15 fighter jet trainer. It also displayed unmanned combat aerial vehicles (UCAVs), including the Yilong and the CH-4, both strongly influenced by the U.S.-built MQ-9 Reaper.²⁸ According to the U.S.-China Economic and Security Review Commission,²⁹ the People's Liberation Army (PLA) primarily uses UxS for intelligence, surveillance and reconnaissance (ISR) missions and for communications relay. However, these roles are expected to expand as the PLA "probably is developing and operating" UxS for electronic warfare and strike missions. A key difference between U.S. and Chinese UxS development is that American drones are largely designed for low-end operations – such as targeting suspected terrorists and guerilla fighters – that do not require access to contested or denied airspace. By contrast, Chinese drones are being designed for precisely that – they are intended for use in maritime situations, particularly in maritime territorial disputes.³⁰ Indeed, in September 2013 the Chinese navy sent a surveillance drone near the disputed Diaoyu Islands, marking the first deployment of a UxS over the East China Sea.

As these nations' indigenous UxS development programs progress, there will be increased opportunities for joint research and development of UxS between the United States and its allies and partner nations. In addition, these nations would be well served to leverage the lessons learned in the course of the United States' experience spearheading the development and operations of UxS.

The Way Ahead

The future for unmanned vehicles is virtually unlimited. Evolutionary change is good and, in many ways, easy. Revolutionary change, however, will not occur without big bets and a

²⁶ Kym Bergman, "Uninhabited Systems for the ADF – Getting the Balance Right," *Asia-Pacific Defense Reporter*, September 2013.

²⁷ China's indigenous UxS development replicates foreign designs through the use of cyberespionage, reverse engineering, study of open source material, and debriefings of American UxS experts. See Edward Wong, "Hacking U.S. Secrets, China Pushes for Drones," *New York Times*, September 20, 2013.

²⁸ Wendell Minnick, "China's Unmanned Aircraft Evolve From Figment to Reality," *Defense News*, November 26, 2012.

²⁹ Kimberly Hsu, "China's Military Unmanned Aerial Vehicle Industry," U.S.-China Economic and Security Review Commission, June 13, 2013. Accessed at: < <http://www.uscc.gov/Research/china%E2%80%99s-military-unmanned-aerial-vehicle-industry>>.

³⁰ Edward Wong, "Hacking U.S. Secrets, China Pushes for Drones," *New York Times*, September 20, 2013.

thoughtful degree of risk-taking. One way to spur this revolutionary change is to operationalize the mandate of the *FY2009 – FY2034 Unmanned Systems Roadmap* to “expedite the transition of unmanned technologies from research and development activities into the hands of the Warfighter.”

There is no more propitious time to do this. If the Navy capitalizes on this opportunity, unmanned aircraft systems will continue to change the tactics of today’s Navy, the operational concepts of tomorrow’s Navy, and will usher in a strategic shift for the Navy-after-Next. The challenge before us is to transform *today* to dominate an operational environment that *has yet to evolve*, and to counter adversaries who *have yet to materialize*.” Unmanned aircraft systems can lead the way.