Aviation Artificial Intelligence: How Will it Fare in the Multi-Domain Environment?

A Monograph

by

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Abstract

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As the Army prepares itself to fight in the Multi-Domain Battle environment, it must assume that enemies will contest every domain and units will operate in more austere conditions, both physically and informationally. Increased sensor capabilities, proliferated and dispersed air defense systems, and contested electromagnetic spectrums challenge the air domain and severely restrict the freedom of action to which the United States has become accustomed. As the Army invests in research initiatives to mitigate the threats posed by peer competitors and develop technologies that return a marked advantage for the joint forces, Artificial Intelligence and increasing autonomy offer significant possibilities. Simultaneously, however, increasing sensor capabilities threaten remotely piloted and autonomous systems and their significant electro-magnetic emissions. With aviation assets operating across multiple areas of operations within the theater, it is critical that they possess the appropriate technologies and effects to mitigate threat capabilities and increase their survivability.

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Acronyms

A2/AD	Anti-Access/Area Denial
AI	Artificial Intelligence
ARCIC	Army Capabilities Integration Center
ASE	Aircraft Survivability Equipment
DARPA	Defense Advanced Research Projects Agency
DVE	Degraded Visual Environment
EMS	Electro-Magnetic Spectrum
EW	Electronic Warfare
FM	Field Manual
HRI	Human Robot Interaction/Interface
IADS	Integrated Air Defense System
INS	Inertial Navigation System
ISR	Intelligence, Surveillance, and Reconnaissance
JOE	Joint Operating Environment
LADAR	Laser Detection and Ranging
LiDAR	Light Detection and Ranging
MUM-T	Manned-Unmanned Teaming
NATO	North Atlantic Treaty Organization
NTSB	National Transportation Safety Board
PNT	Position, Navigation, and Timing
RAS	Robotics and Autonomous Systems
RF	Radio Frequency
TRADOC	Training and Doctrine Command
UAS	Unmanned Aerial System
UAV	Unmanned Aerial Vehicle

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Introduction

Today's technological environment is one of rapid and continual advancement. Nano-technologies, biometrics, processing power and speed, and learning technologies are increasingly available and consistently improved upon. The commercial industry is relying more on automation and technology to gain efficiency, improve safety, and speed information (or delivery of their product). Amazon Prime Air is delivering packages without the aid of a human controller, Google and Tesla have ambitious self-driving automotive projects, and aerospace companies like Northrop-Grumman, Lockheed-Martin, and Boeing are developing pilotless aircraft. As commercial and recreational popularity of "drones" and other unmanned aerial vehicles continues to increase, companies are pushing the envelope in the development of autonomous vehicles.[1]

To be any more efficient than a normal vehicle, autonomous vehicles must possess a certain degree of Artificial Intelligence (AI). Having vehicles that perform their intended functions with little or no guidance from a human controller is highly desirable for any battlefield commander. A system that can execute a set of pre-determined tasks by itself frees a human from the need to control it, and potentially removes that human from significant risk. The potential benefits of Artificial Intelligence extend beyond autonomous operations, including rapid calculations and decision aiding, and management of large amounts of information.

The inclusion of Artificial Intelligence and autonomy into the aviation field is arguably not new but has a profound impact, nonetheless. Aircraft avionics and flight control systems have long included various forms of autopilot or flight control coupling that allows the flight computer

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[1] Marcus Chavers, "Consumer Drones by the Numbers in 2017 and Beyond," Newsledge.com, May 29, 2017, accessed October 24, 2017, https://www.newsledge.com/consumer-drones-2017-numbers/; Nivedit Majumdar, "The Consumer Drone Market: Trend Analysis," Emberify Blog, January 5, 2016, accessed October 24, 2017, http://emberify.com/blog/drone-market-analysis/; Don Reisinger, "Watch Amazon's Prime Air Complete Its First Drone Delivery," Fortune.com, December 14, 2016, accessed October 24, 2017, http://fortune.com/2016/12/14/amazon-prime-air-delivery/; Lockheed Martin, "Sikorsky Successfully Completes DARPA ALIAS Phase 1 Competition with Autonomous Flight," LockheedMartin.com, May 24, 2016, accessed October 24, 2017, http://www.lockheedmartin.com/us/news/press-releases/2016/may/160524-mst-sikorsky-successfully-completes-darpa-alias-phase-one.html.

to manipulate the control surfaces and thereby control the aircraft. Likewise, onboard flight management systems assist pilots in making calculations to determine appropriate flight times, speeds, and distances. Emerging technologies, however, are introducing capabilities that require significantly smaller amounts of pilot or controller input. Department of Defense (DoD) initiatives in multiple services are testing autonomous aircraft for resupply and sustainment missions. The Lockheed-Martin corporation, working with the US Marine Corps, conducted extended field-testing of a semi-autonomous Kaman K-MAX utility helicopter in Afghanistan, opening the door to many other potential applications for unmanned rotary-wing aircraft.[2]

However, when placing these systems in a contested environment, how will they fare? The US military has enjoyed air domain superiority for the last several decades. This benefit has become an expectation of senior commanders and operational planners. Arguably, this assumption and reliance on uncontested airspace has directly impacted the development of current unmanned Intelligence, Surveillance, and Reconnaissance (ISR) systems and processes for information collection. The current generation of Unmanned Aerial Systems (UAS) requires a digital data link between the flying vehicle and the Ground Control Station (GCS). This data link is susceptible to attack or jamming from adversary Electronic Warfare (EW) or offensive cyber effects anticipated in the future battlefield and defined in the Army's "Multi-Domain Battle" concept. With the introduction of more advanced, autonomous, and integrated Air Defense systems into the operating environment, many of the Army's current unmanned aerial platforms will be unable to survive.

As the Army prepares itself to fight in the Multi-Domain Battle environment, it must assume that enemies will contest every domain and units will operate in more austere conditions,

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[2] Alex Davies, "The Marines' Self-Flying Chopper Survives a Three-Year Tour," Wired.com, July 30, 2014, accessed September 12, 2017, https://www.wired.com/2014/07/kmax-autonomous-helicopter/.

both physically and informationally.[3] Increased sensor capabilities, proliferated and dispersed air defense systems, and contested electromagnetic spectrums challenge the air domain and severely restrict the freedom of action to which the United States has become accustomed. As the Army invests in research initiatives to mitigate the threats posed by peer competitors and develop technologies that return a marked advantage for the joint forces, Artificial Intelligence and increasing autonomy possess significant possibilities. Simultaneously, however, increasing sensor capabilities threaten remotely piloted and autonomous systems and their significant electro-magnetic emissions. With aviation assets operating across multiple areas of operations within the theater, it is critical that they possess the appropriate technologies and effects to mitigate threat capabilities and increase their survivability.

Literature Review: Why Autonomy and Artificial Intelligence?

The US Military strives to remain on the cutting edge of technology as it seeks to maintain an advantage over potential peer or near-peer adversaries. Commensurate with this effort, the DoD conceptualized the “Third Offset Strategy,” continuing the intellectual framework that drives peacetime competition to maintain a strategic advantage.[4] As the name implies, two “Offsets” precede this initiative. The first took place in the 1950s, centering on the miniaturization of nuclear weapons that counterbalanced the Soviet Union’s numerical superiority in conventional ground forces. The second was the technological leap in the 1970s and 1980s that enabled precision-guided munitions and network integration on the battlefield.[5] In both instances,

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[3] US Department of the Army, Training and Doctrine Command (TRADOC) White Paper, “Multi-Domain Battle: Combined Arms for the 21st Century” (Washington, DC: Government Printing Office, 2017), 2.

[4] Katie Lange, “3rd Offset Strategy 101: What It Is, What the Tech Focuses Are,” DoDLive.mil, March 30, 2016, accessed September 12, 2017, http://www.dodlive.mil/2016/03/30/3rd-offset-strategy-101-what-it-is-what-the-tech-focuses-are/.

[5] Ibid.

American superiority waned as the Soviet Union and other potential adversaries developed similar technologies or countermeasures that achieved parity.

The heavy implementation of new and emerging technologies characterizes today's Third Offset Strategy to enable greater effects. As computerized capabilities continue improving and increasingly available throughout the world, the United States cannot expect to exercise the same domain superiority that it has enjoyed in the past. The United States, therefore, must incorporate technologies that offer exponential returns by leveraging effects across domains, enabling rapid exploitation, and reducing human exposure to increasingly lethal battlefield environments. In March 2017, the US Army Training and Doctrine Command (TRADOC) and the Georgia Tech Research Institute cosponsored the "Mad Scientist Conference," aptly titled *Robotics, Artificial Intelligence & Autonomy: Visioning Multi-Domain Warfare 2030-2050*. The focus areas of this conference clearly articulated the importance that these technologies (robotics, Artificial Intelligence, and autonomy) will have in future military operations, listing them as critical components of the Third Offset Strategy.[6]

Some of these terms have numerous definitions, due in part to the various applications of these systems in society, so it is appropriate to address how this study defines these terms. *Artificial Intelligence (AI)* is the capability of computer systems to perform tasks that normally require human intelligence such as perception, conversation, and decision-making.[7] *Autonomy* is the level of independence that humans grant a system to execute a given task. It is the condition or quality of being self-governing to achieve an assigned task based on the system's own situational awareness (integrated sensing, perceiving, analyzing), planning and decision-making.[8]

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[6] Mad Scientist Conference, "Robotics, Artificial Intelligence & Autonomy: Visioning Multi-Domain Warfare in 2030-2050." Technical Report (Washington DC: Government Printing Office, 2017), 3.

[7] US Department of the Army, Training and Doctrine Command (TRADOC) Maneuver, Aviation, and Soldier Division Army Capabilities Integration Center, *The US Army Robotic and Autonomous System Strategy* (Washington, DC: Government Printing Office, 2017), 23.

To be autonomous, the vehicle or system must learn from its experience, thereby acting as an ideal rational agent, defined by Russell and Norvig as the ability to "do whatever action is expected to maximize its performance measure, on the basis of the evidence provided by the precept sequence and whatever built-in knowledge the agent has."[9] Put another way, the ability to recognize actions and most probable outcomes based on experience and base knowledge. Another definition for it is *Reinforcement learning*: that is, learning what to do---how to map situations to actions---so as to maximize a numerical reward signal. The learner receives no command regarding which actions to take, as in most forms of machine learning, but instead must discover which actions yield the most reward by trying them.[10] According to the Defense Science Board's 2014 "Summer Study on Autonomy," AI serves as the primary intellectual foundation for autonomy, and clarifies that *Autonomy* is largely a term to reference system-level capabilities, rather than at the component-level. It is AI that enables the increasing levels of autonomy.[11]

The military applications for AI are many, but generally provide two possible opportunities: first, to make existing tasks simpler, more reliable, or more efficient; second, to introduce wholly new capabilities.[12] AI's potential for aviation also fits this framework. Within the category of the former, AI promises pilot workload reduction and decision aiding, increased interface in Manned-Unmanned Teaming (MUM-T), and increased aircraft lethality and survivability. Further, access to large databases of Air Defense threat information and rapid

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[8] Mad Scientist Conference, "Robotics, Artificial Intelligence & Autonomy: Visioning Multi-Domain Warfare in 2030-2050," 15.

[9] Stuart J. Russell, *Artificial Intelligence: A Modern Approach*, Prentice Hall Series in Artificial Intelligence (Englewood Cliffs, N.J.: Prentice Hall, 1995), 33.

[10] Richard Sutton and Andrew Barto, *Reinforcement Learning: An Introduction* (Cambridge, MA: MIT Press, 1998), 127.

[11] Defense Science Board, "Summer Study on Autonomy" (Washington, DC: Government Printing Office, 2016), 5.

[12] Richard Potember, "Perspectives on Research in Artificial Intelligence and Artificial General Intelligence Relevant to DoD," The MITRE Corporation (McLean, VA: OSD ASDR&E, 2017), 53.

calculations or decision-making would allow AI-controlled Aircraft Survivability Equipment (ASE) to defeat surface-to-air threats. Concerning the latter category, fully autonomous aircraft may provide great flexibility to commanders and reduce the demand to provide pilots for mundane or high-risk missions. As the Army leads the Future of Vertical Lift program, it is pursuing an "Optionally-Piloted" capability, recognizing the importance of retaining the option of keeping a human in the loop due to the ethics of carrying passengers and the increase of cyber targeting and Electro-Magnetic Spectrum (EMS) sensors that threaten remotely operated aircraft.[13]

Various publications from across the Department of Defense and its commitment to pursuing autonomous capabilities further evidence the growth and momentum of this research.[14] The "US Army Robotic and Autonomous Systems (RAS) Strategy," released in March 2017, and the "US Army Roadmap for Unmanned Aircraft Systems 2010-2035," released in 2010, both advocate for the growing utilization of autonomous systems. Perhaps the most foundational example of autonomy's acceptance in the military is the release of the November 2012 DoD directive 3000.09 entitled "Autonomy in Weapons Systems." TRADOC's Army Capabilities Integration Center (ARCIC) and the Defense Advanced Research Projects Agency (DARPA) also have multiple initiatives to research, develop, and field AI systems.

As cutting-edge technologies continue to emerge, the public perception will likely continue to grow more favorable. AI-supported software, smart phone technologies, and other forms of semi-autonomy are present in everyday life, and largely welcomed by the public. However, many remain hesitant to rely on autonomous vehicles when it comes to air travel. A

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[13] Sydney Freedberg, "'Optionally Piloted' Aircraft Studied for Future Vertical Lift," BreakingDefense.com, September 23, 2016, accessed September 12, 2017, http://breakingdefense.com/2016/09/optionally-piloted-aircraft-studied-for-future-vertical-lift/.

[14] Defense Science Board, "Summer Study on Autonomy," ii; Scott Nicholas, "DARPA Program Aims to Increase Autonomous System Predictability, Safety," ExecutiveGov.com, August 17, 2017, accessed October 3, 2017, http://www.executivegov.com/2017/08/darpa-program-aims-to-increase-autonomous-system-predictability-safety/.

2014 study by Embry-Riddle Aeronautical University indicated that more Americans preferred a piloted aircraft to an autonomous or remotely piloted one. Even surveys among aeronautical industry stakeholders debating the future need for pilots remain divided.[15] To many Americans, trusting their lives to a computer is more palatable in a car, elevator, or subway train than in the sky.

Despite the relatively slow acceptance among the public, the investment in autonomy and AI remains a high priority for the United States Army. The sheer volume of initiatives, programs, and industry breakthroughs are indicative of the emphasis and vision of AI's role in aviation. When viewing these capabilities through the lens of Multi-Domain Battle, the battlefield survivability of these systems, that is, how well they endure the lethal and non-lethal fires of combat remains unproven. Can these systems operate in an environment that includes contested electronic and electromagnetic spectrums? The breadth of literature covering technological breakthroughs in autonomous aircraft stands juxtaposed to literature ominously warning of the targeting capabilities and Anti-Access/Area Denial (A2/AD) effectiveness of potential adversaries. Based on the growth of autonomous aviation initiatives, this research poses this question: What applications exist for autonomous and Artificial Intelligence technologies to enhance Army aviation's contribution to Multi-Domain Battle? This study will demonstrate that, because of the connectivity challenges and contested nature of the future battlefield, Artificial Intelligence to enhance human decision-making and increase the effects of human-controlled

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[15] Stephen Rice, Keegan Kraemer, Scott Winter, Rian Mehta, Victoria Dunbar, Timothy Rosser, and Julie Moore, "Passengers from India and the United States Have Differential Opinions about Autonomous AutoPilots for Commercial Flights," *International Journal of Aviation, Aeronautics, and Aerospace* 1, no. 1 (2014): 6; Katia Moskvitch, "Would You Fly in a Pilotless Airliner?" BBC.com, September 13, 2016, accessed October 31, 2017, http://www.bbc.com/future/story/20160912-would-you-fly-in-a-pilotless-airliner; David Reid, "Would you get on a pilotless plane? These people would," CNBC.com, August 30, 2017, accessed October 31, 2017, https://www.cnbc.com/2017/08/30/pilotless-airplanes-are-more-attractive-to-some-types-of-flyers-.html.

systems will be its best application. Artificial Intelligence will be more effective if paired with a human operator or supervisor than as a fully autonomous entity on the battlefield.[16]

Defining the Future Environment

The Joint Operating Environment (JOE) poses significant challenges to military operations, and its complexity will increase over the next several decades. The Multi-Domain Battle framework outlined by Army TRADOC explicates the effects and challenges that military operations can expect to encounter, and provides a clear lens through which this study approaches aviation's use of AI in this environment. The Army will continue to contribute to the Joint Force as it conducts operations throughout the world to deter aggression, protect national interests, and conduct both armed conflict and operations short of armed conflict. Many studies continue to define this future operating environment as one of contested and challenged norms, which the Joint Force will experience in all domains.[17] Current doctrine updates from across the Joint Force are incorporating changes that aid the planner and operational artist in understanding the characteristics of the new JOE. The United States Army and Marine Corps, as the primary land component operators, collectively released the "Multi-Domain Battle: Evolution of Combined Arms for the 21st Century" in September 2017 to describe the JOE's framework. Similarly, the "Joint Operating Environment 2035," released by the Joint Staff in July 2016, and the United States Air Force's "Air Superiority 2030 Flight Plan" released in May 2016, continue to shape the shared understanding of the future environment. The opening chapter of Army Field Manual (FM) 3-0 *Operations* emphasizes the understanding of the danger and intensity of the complex environment that defines future operations:

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[16] Alonso Vera, "The Challenges of Human-Autonomy Teaming" (lecture, SAE/NASA Autonomy and Next Generation, Moffett Field, CA, April 18-19, 2017), accessed October 3, 2017, https://nari.arc.nasa.gov/sites/default/files/attachments/11%29%20ALONSO%20VERA%20FINAL%20-%20SAE%20NASA%20Autonomy%20Symp%2019APR2017.pdf.

[17] US Army Capabilities Integration Center (ARCIC), US Army and Marine Corps Concept, "Multi-Domain Battle: Evolution of Combined Arms for the 21st Century, 2025-2040" (Fort Eustis, VA: Government Printing Office, 2017), 4.

> Proliferating technologies will continue to present challenges for the joint force. Unmanned systems are becoming more capable and common. Relatively inexpensive and pervasive anti-tank guided missiles and advanced rocket propelled grenades can defeat modern armored vehicles. Sensors and sensing technology are becoming commonplace. Adversaries have long-range precision strike capabilities that outrange and outnumber US systems. Advanced integrated air-defense systems can neutralize friendly air power, or they can make air operations too costly to conduct. Anti-ship missiles working in concert with an IADS can disrupt access to the coastlines and ports necessary for Army forces to enter an AO. Adversary cyberspace and space control capabilities can disrupt friendly information systems and degrade C2 across the joint force. Use of WMD and the constant pursuit of the materials, expertise, and technology to employ WMD will increase in the future. Both state and non-state actors continue to develop WMD programs to gain advantage against the United States and its allies. These trends mean that adversaries can contest US dominance in the air, land, maritime, space, and cyberspace domains.[18]

As outlined in these documents and multiple other reports, peer and near-peer competitors continue to acquire and invest in technologies and capabilities that inhibit the Joint Force with both lethal and non-lethal effects. Ease of access and increased cyber capabilities, sensing technology, and unmanned systems contribute to a more dangerous operating environment for joint forces. Competent adversaries possess capable long range and precision fires that the United States and its allies have not contended with in the operations conducted over the last several decades. The increased targeting abilities of potential adversaries requires land forces to remain mobile, protected, and in many cases, out of network or communications contact with Command and Control elements. Strategic Lines of Communication become critical vulnerabilities as adversaries seek to prevent or contest entry into the theater, seeking to strike the Joint Force before it can consolidate in the Close Area.[19] The extension of the battlefield framework in FM 3-0 from "Strategic Support Area" through the "Deep Maneuver" and "Deep

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[18] US Department of the Army, Field Manual (FM) 3-0, *Operations* (Washington DC: Government Printing Office, 2017), 1-5 – 1-6.

[19] ARCIC, US Army and Marine Corps Concept, "Multi-Domain Battle: Evolution of Combined Arms for the 21st Century, 2025-2040," 19.

Fires" areas demands that land forces possess the ability to utilize cross-domain or converging domain fires and effects great distances from their bases of support.[20]

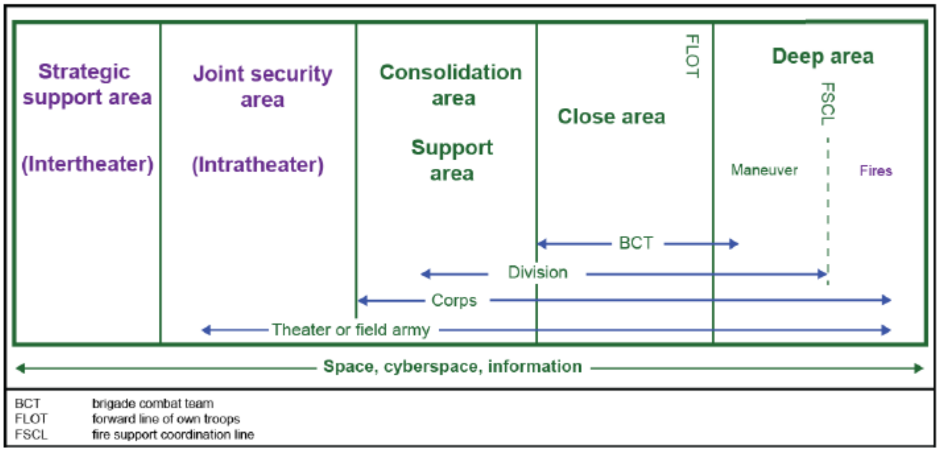

Figure 1. Corps area of operations within a theater of operations. Field Manual (FM) 3-0, *Operations,* 2017, 1-30.

The Army, as part of the Joint Force, must operate in an increasingly lethal environment across all domains as A2/AD network improvements and proliferation continues. Cyber threats challenge current communications and connectivity infrastructures, often from outside the theater of war, adding to the challenge effective Mission Command. Increasingly capable EW systems pose risks to communications and data links required of current unmanned systems, potentially severing the connection or corrupting computers altogether. This increasing effectiveness of A2/AD limits or prevents the air dominance that allied forces have long enjoyed.[21] Rather than

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[20] US Army, FM 3-0, (2017), 1-26 – 1-30.

[21] Sergey Sukhankin, "Russian Capabilities in Electronic Warfare: Plans, Achievements and Expectations," RealClearDefense.com, July 20, 2017, accessed October 26, 2017, https://www.realcleardefense.com/articles/2017/07/20/russian_capabilities_in_electronic_warfare_111852.html.; "Russian Electronic Warfare in Ukraine: Between Real and Imaginable," RealClearDefense.com, May 26, 2017, accessed October 26, 2017, https://www.realcleardefense.com/articles/2017/05/26/russian_electronic_warfare_in_ukraine_111460.html.

operating relatively unmolested, the Joint Force will seek out and create windows of advantage that will enable maneuver, leveraging multi-service and cross-domain effects.[22]

Army aviation continues to exercise its core competencies and enable maneuver forces in this operating environment, but with new challenges and limitations. Despite the threat of A2/AD networks, the aviation roles of Reconnaissance and Security, Attack, Utility, Cargo, Command and Control, and Aeromedical Evacuation will remain critical requirements of the operational commander in the land domain. Pursuant to Multi-Domain Battle's framework, aviation operations throughout the extended areas of operation will not only rely on protection from other domains (Air, Sea, Space, and Cyber), but could also enable them through sensor suites, precision fires, and Air Assault capabilities.

Methodology

This research uses a speculative future scenario development methodology to conceptualize the abilities of AI and autonomy as they apply to Army aviation, including emerging and currently fielded technologies that incorporate autonomy and workload sharing in army aircraft. The study examines the capabilities and limitations of the dynamics between humans and computers regarding decision-making and execution of tactical aviation missions. These dynamics include pilots making decisions for computers as demonstrated in current unmanned systems, computers making decisions for pilots as demonstrated in decision-aiding AI, and computers making decisions for computers as demonstrated in fully autonomous systems. These varying degrees of aircraft autonomy possess unique possibilities to expand the capabilities of Army aviation concerning risk, tactical employment, and survivability.

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[22] ARCIC, US Army and Marine Corps Concept, "Multi-Domain Battle: Evolution of Combined Arms for the 21st Century, 2025-2040," 21.

The study then projects these technologies onto the future battlefield as described by the Army's Multi-Domain Battle concept, defined in Army and joint doctrine, strategic vision statements, and published Multi-Domain Battle white papers. A major driving assumption for this research is that America's future war will be against a peer competitor who contests network connectivity, the electromagnetic spectrum, and air superiority, creating an austere environment for the Joint Force. The study analyzes the implementation of these emerging autonomous and AI-driven aircraft technologies and provides recommendations relating to the benefits and vulnerabilities of these systems in this future environment. The study focuses on a so-called "worst case scenario" as it will take as an assumption that the US Joint Force will be facing advanced adversarial denial capabilities in all domains.

This study utilizes the Schwartz Model for scenario development.[23] Recognizing the dynamic and unpredictable nature of the future, a scale consisting of four quadrants depicts the potential environments challenging future operations. These quadrants, characterized by variable relationships of "Low and High Intensity" and "Low and High Enemy Capability" frame the potential scenarios. Nesting with the United States Army's focus on Large-Scale Ground Combat in a Multi-Domain environment, the scenario resides in the fourth quadrant (see figure 2) where the Joint Force faces a highly capable enemy in high intensity combat.[24]

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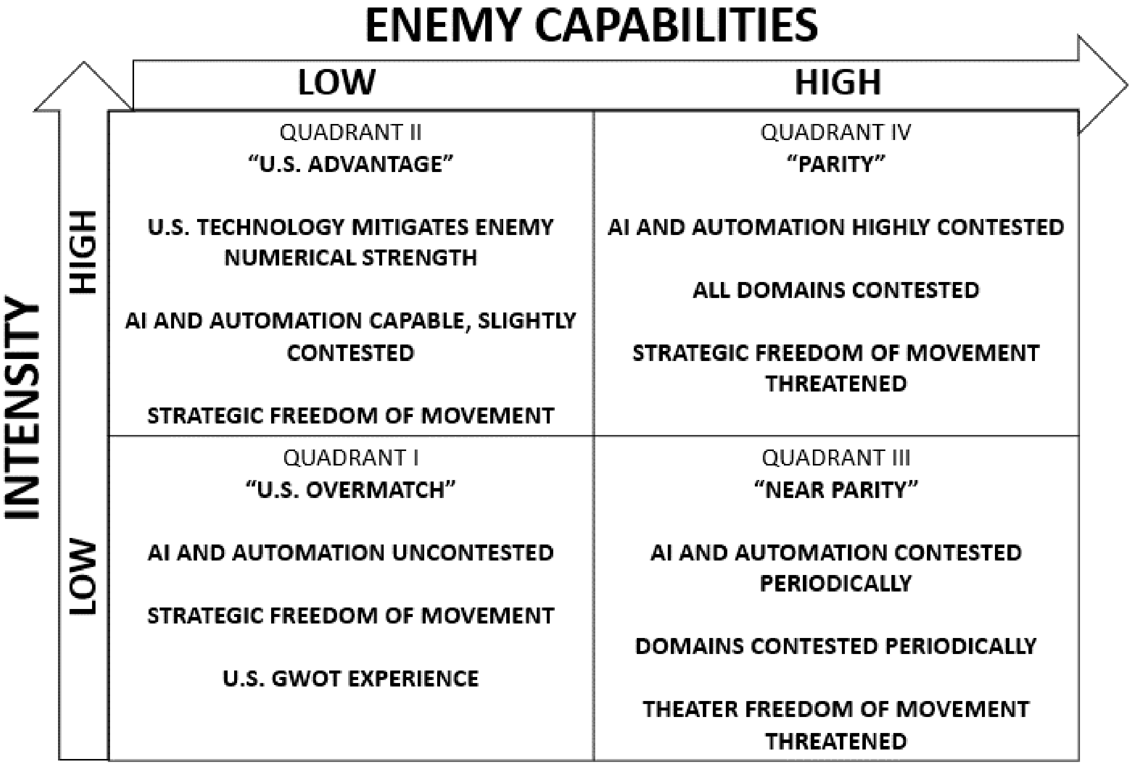
[23] Peter Schwartz, *The Art of the Long View: Paths to Strategic Insight for Yourself and Your Company*, currency pbk. ed. (New York: Currency Doubleday, 1996), 241-48.

[24] Joe Lacdan, "Revised doctrine prepares Soldiers for changing global threats," Army.mil, October 6, 2017, accessed January 25, 2018, https://www.army.mil/article/195034/revised_doctrine_prepares_soldiers_for_changing_global_threats.



	LOW	HIGH
HIGH	QUADRANT II **"U.S. ADVANTAGE"** **U.S. TECHNOLOGY MITIGATES ENEMY NUMERICAL STRENGTH** **AI AND AUTOMATION CAPABLE, SLIGHTLY CONTESTED** **STRATEGIC FREEDOM OF MOVEMENT**	QUADRANT IV **"PARITY"** **AI AND AUTOMATION HIGHLY CONTESTED** **ALL DOMAINS CONTESTED** **STRATEGIC FREEDOM OF MOVEMENT THREATENED**
LOW	QUADRANT I **"U.S. OVERMATCH"** **AI AND AUTOMATION UNCONTESTED** **STRATEGIC FREEDOM OF MOVEMENT** **U.S. GWOT EXPERIENCE**	QUADRANT III **"NEAR PARITY"** **AI AND AUTOMATION CONTESTED PERIODICALLY** **DOMAINS CONTESTED PERIODICALLY** **THEATER FREEDOM OF MOVEMENT THREATENED**

Figure 2. Methodology framework for scenario development. Figure created by author.

Whereas many of these technologies are in their infancy and therefore largely conceptual in terms of their battlefield effectiveness, the analysis presented will remain as objective as possible, acknowledging the potential benefits and drawbacks alike. This study views emerging technologies in terms of technical capability to both operational commanders and aircrew members in a combat environment. It is this study's intention to consolidate analysis on the operational effectiveness of autonomy and AI in aviation, and therefore will consider algorithmic, computer programming and coding, and otherwise technically specific topics as outside the scope of the paper.

Current Unmanned Aerial Vehicles Vulnerabilities

Numerous agencies and industry leaders have a vested interest in the growth and applicability of autonomous systems, and it is therefore critical to recognize a common framework for identifying levels of autonomy. The National Institute for Standards and Technology (NIST) clarified the definitions of autonomy levels for various industries and this study relies upon them as well. These levels begin with full autonomy and incrementally descend from semi-autonomous to teleoperation and ultimately to remote control. At the highest fully autonomous level, the unmanned system can accomplish its mission within a defined scope, without human intervention. One-step below is the semi-autonomous system wherein the unmanned system plans and executes its mission tasks, but requires various levels of interaction with a human controller. Teleoperation, the next lower level, requires the human operator, using sensory or video feedback, either directly controls the aircraft or assigns incremental goals or waypoints on a continuous basis, from off the vehicle and via a tethered or radio linked control device. The lowest and most analog level is remote control. This level requires constant control from a human controller via constant tether or radio link via visual line-of-sight.[25]

Many of the unmanned aerial vehicles in use by the current Joint Force reside in the teleoperation category, requiring sporadic human control input for flight direction, telemetry control, or payload and sensor operation. While these systems provide great enabling benefits to operational commanders, electronic tethers or communications links necessarily constrain them for mission execution and sensor-gathered information sharing. These links, usually connecting the Ground Control Station to the aircraft by satellite link, are the arteries by which the UAV

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[25] Hui-Min Huang, *NIST Special Publication 1011: Autonomy Levels for Unmanned Systems (ALFUS) Framework: Volume I: Terminology* (Gaithersburg, MD: National Institute of Standards and Technology, 2004), 14; Phillip J. Durst and Wendell Gray, *Levels of Autonomy and Autonomous System Performance Assessment for Intelligent Unmanned Systems* (Vicksburg, MS: The US Army Engineer Research and Development Center (ERDC), 2014), 12-13.

must operate, and are susceptible to interference from adversarial Electronic Warfare attacks.[26] This digital architecture is the focal point of much debate and concern regarding a significant vulnerability of unmanned systems.

A central concern to critics of UAVs is the vulnerability of the vehicle's communications link to both "GPS spoofing" and cyber-attack or "hacking." The 2011 loss of a Central Intelligence Agency RQ-170 Sentinel UAV over Iran prompted much debate and speculation regarding the circumstances and potential vulnerabilities. Iran claimed it had successfully hacked the aircraft and wrested its controls from the owner, causing it to land intact inside Iran.[27] While the real conditions that were present in this instance remain elusive, hacking electronic data links and GPS spoofing of other UAVs exist as vulnerabilities that have been experienced and demonstrated.[28] UAVs possess the capability to default to pre-programmed routes and holding locations as part of their lost datalink procedures, but this communications link must remain intact for GCS-to-aircraft commands and direction to the sensors, as well as for the sensor and telemetry information sharing from aircraft-to-GCS.

Similarly, UAVs remain vulnerable to detection and targeting of the Radio Frequency (RF) signatures they emit. Like any electromagnetic device or system, every UAV emits a signature from its wireless communications and from its onboard flight control software. In addition to traditional Air Defense radar systems that detect aircraft from radar cross-sections,

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[26] Todd Humphreys, *Statement on the Vulnerability of Civil Unmanned Aerial Vehicles and Other Systems to Civil GPS Spoofing* (Austin: The University of Texas, 2012), 3-4.

[27] Justin King, "The Story You Aren't Being Told About Iran Capturing Two American Vessels," MintPressNews.com, January 20, 2016, accessed October 30, 2017, http://www.mintpressnews.com/the-story-you-arent-being-told-about-iran-capturing-two-american-vessels/212937/; David Axe, "Nah, Iran Probably Didn't Hack CIA's Stealth Drone," Wired.Com, April 24, 2012, accessed October 30, 2017, https://www.wired.com/2012/04/iran-drone-hack/.

[28] John Roberts, "Drones Vulnerable to Terrorist Hijacking, Researchers Say," FoxNews.com, June 25, 2012, accessed October 30, 2017, http://www.foxnews.com/tech/2012/06/25/drones-vulnerable-to-terrorist-hijacking-researchers-say.html; Aliya Sternstein, "How to Hack a Military Drone," DefenseOne.com, April 29, 2015, accessed October 30, 2017, http://www.defenseone.com/technology/2015/04/how-hack-military-drone/111391/.

purpose-built scanners detect these emissions on the electromagnetic spectrum and differentiate between vehicle types.[29] The need for a near-constant communications link to control a teleoperated system becomes a threat to the battlefield survivability of today's unmanned systems.

Autonomous Aircraft Untethered

A major operational benefit of autonomous systems over teleoperated or remotely controlled aircraft is their independence from a continuous electronic tether. If an autonomous aircraft can embark on a mission with preprogrammed instructions or a set of known criteria, it could avoid GPS spoofing by use of onboard Position, Navigation, and Timing (PNT) systems. Inertial Navigation System (INS) are un-reliant on external aids to navigate, as radio navigation or GPS are, and are commonly used in aircraft for navigational and flight management systems. A traditional INS-based system uses the known start point of the vehicle and maintains awareness of its position by tracking the inertial (latitudinal and longitudinal) changes and velocity. This method does not require external reference for its operation, but often contains small degrees of motion-induced error. GPS often augments INS to compensate for this variance. Industry leaders are now incorporating into autonomous aircraft the collaboration of multiple sensors such as INS, Doppler Velocity Radars, and Light or Laser Detection and Ranging (LiDAR/LADAR) to minimize inherent errors and to protect against sensor corruption by building system redundancy.[30] Likewise, DARPA is managing several programs to improve micro-PNT systems with higher accuracy that would be very beneficial to an autonomous aircraft in a GPS-contested environment.[31]

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[29] Phuc Nguyen, Hoang Truong, Mahesh Ravindranathan, Anh Nguyen, Richard Han, Tam Vu, *Drone Presence Detection by Identifying Physical Signatures in the Drone's RF Communication* (Boulder: University of Colorado, 2017), 212.

[30] Pam Cleveland, "Spoofs, Lies, and GPS," KVHMobileWorld.com, August 31, 2017, accessed October 30, 2017, http://www.kvhmobileworld.kvh.com/spoofs-lies-and-gps/.

These improvements in internal or inertial navigational systems minimize the propensity of aircraft navigation to be "spoofed" or jammed. When combined with the emergent "sense-and-avoid" or dynamic 3-D mapping technologies, navigational reliability in autonomous aircraft is quite robust. Similar to existing pre-mission planning steps of manned aviation, the mission planners at the GCS would simply load the local map data with pertinent waypoints, target areas, or destinations in the autonomous aircraft database or flight management system. The aircraft uses this map data as a reference to fly either a predetermined route, reinforced by terrain sensing similar to a Tomahawk Land Attack Missile (TLAM), or a new route dictated by the local threat.

Operation without constant datalink with a GCS is another improvement to autonomous aircraft survivability. Unlike the UAV, communications link mentioned above, AI controlling an aircraft would use its known parameters for flight without the need for a constant link to report telemetry or other flight characteristics. This reduced RF signature further limits the ability of sensors to identify and fix the aircraft. Traditional survivability equipment on the aircraft is still critical to defeat radar-guided and infrared homing air defense weapons, but this reduced emission is yet another means of threat mitigation in a combat zone.

This adds, however, the challenge of command and control or directives necessary for the aircraft to conduct its mission. While a communications datalink does tether the UAV, it is capable of receiving near-real time commands from the controller at a GCS or another airborne platform. This means that as events change during the course of an operation, the controller can quickly redirect or employ the UAV to be most effective. This capability is questionable when an autonomous aircraft does not employ a constant datalink. In other words, if an autonomous aircraft is operating without constant datalink connectivity, how does an operator redirect the aircraft without exposing it to advanced A2/AD sensors?

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[31] Robert Lutwak, "Micro-Technology for Positioning, Navigation and Timing (Micro-PNT)," DARPA.mil, accessed October 30, 2017, https://www.darpa.mil/program/micro-technology-for-positioning-navigation-and-timing.

Inherent Risks of Piloted Aircraft

The status quo of human-piloted aircraft as the centerpiece of Army aviation is not without its disadvantages. Army helicopters operate as two-pilot and multi-crewmember aircraft, enabling crewmember performance cross-checking, workload sharing or distribution, and greater obstacle avoidance than single-pilot aircraft. Nevertheless, these additional crewmembers do not necessarily equate to definitively safer aircraft operation. In the year from October 2014 to October 2015, the Army's Combat Readiness Center (CRC) reported 19 Class A aviation accidents resulting in the deaths of six soldiers.[32] In separate reports, the Army CRC reported 25 and 29 Class A accidents in Fiscal Year 2016 and 2017, resulting in 8 and 10 fatalities, respectively.[33] Numerous reports and studies on aviation mishaps conducted over the last several decades cite the primary cause as pilot error. Statistics vary slightly across military, private, and commercial aviation industries, but generally agree that human related factors cause 80 percent of accidents with "Loss of Control Inflight" and "Controlled Flight into Terrain" as the two leading scenarios.[34] Task saturation, fixation, or other distractions can seriously impair a pilot's ability to multi-task and prioritize actions in the cockpit.

The atmospheric or environmental conditions of the tactical environment in which Army aviation must operate also has significant bearing on aviation's effectiveness. In an era of greater sensitivity to casualty rates, elevated risk to human life automatically categorizes missions as high risk. With the complex synchronization required to execute a combined arms or air-ground

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[32] Ryan Browne, "Military aircraft accidents costing lives, billions of dollars," CNN.com, June 20, 2016, accessed October 31, 2017, http://www.cnn.com/2016/06/20/politics/military-aviation-crash/index.html: Class A accident refers to an aviation mishap that results in a fatality, destroyed or missing aircraft, or cost of damage exceeding 2 million dollars. See Army Regulation (AR) 385-10 page 27 for additional information.

[33] US Army Combat Readiness Center, "US Army Accident Information: Aviation Accident Statistics – Fiscal Year End" (Fort Rucker, AL: Government Printing Office, 2017), 2.

[34] Les Dorr, "Fact Sheet - General Aviation Safety," FAA.gov, October 24, 2017, accessed January 18, 2018, https://www.faa.gov/news/fact_sheets/news_story.cfm?newsId=21274.

mission, the rapid reports and near-constant communications can further distract an already task-saturated crew. Crewmembers hone the requisite task management skills through training and experience, but it continues to contribute to the fatigue of aircrew members. Long duration missions and flights in adverse weather or Degraded Visual Environments (DVE) increase the physical and emotional stress, fatigue, and cognitive demands on pilots and crewmembers. All of these factors, in addition to crew experience, illumination levels during periods of darkness, and potential enemy threats, increase the mission's risk.

With precious few systems in Army aviation to minimize the impact of DVE effects on aviation operations, operational commanders often have no choice but to cease operations when the visibility becomes too degraded. Poor visibility and obscurants mask obstacles, terrain, threats, and the relative motion of an aircraft from the pilot's recognition. Multiple breakthroughs such as the Army's Aviation and Missile Research and Engineering Center (AMRDEC) Degraded Visual Environment Mitigation (DVE-M) program, BAE System's Brownout Landing Aid System Technology (BLAST), and the collaborative efforts of the United States Army and United States Air Force in the Three-Dimensional Landing Zone (3D-LZ) provide risk mitigation measures for landing and operating in poor visibility. Each of these systems use LADAR or similar sensing technology to provide cueing assistance, obstacle detection, and aircraft control information to the pilot to enable safe landing with minimal visual references. Despite multiple sensor and visual display, advancements demonstrated in this technology, these systems still require human input to the aircraft flight controls and are therefore still susceptible to human errors or lapses in judgment.[35]

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[35] Mark Schauer, "Degraded visual environment researchers conduct milestone testing," Army.mil, September 26, 2016, accessed November 1, 2017, https://www.army.mil/article/175745/degraded_visual_environment_researchers_conduct_milestone_testing; Zoltan Szoboszlay, Brian Fujizawa, and Carl Ott, "3D-LZ Flight Test of 2013: Landing an EH-60L Helicopter in a Brownout Degraded Visual Environment" (presented at the AHS 70th Annual Forum, Montréal, Québec, Canada, May 20, 2014), 4-5.

Operational Benefits of Autonomous Aircraft

Computers do not experience fatigue as human operators do, and they are likewise immune to emotional factors that can inhibit or otherwise effect the judgement of a pilot or aircrew member. Aircraft controlled by AI are unencumbered with the proprioceptive feelings of flight, and thus are immune to the relative motion illusions common to adverse weather or DVE operations. However, autonomous systems must be able to execute actions that follow a logical framework demonstrated by basic human cognition. To evaluate the capabilities of autonomous systems, the Defense Science Board listed four overarching categories that were critical to the successful incorporation of autonomy into battlefield systems. The board posited that systems must successfully demonstrate the capability to *Sense, Think/Decide*, *Act*, and *Team.*[36] Improvements in the *Sense, Think/Decide,* and *Team* functionalities directly affect AI and autonomy. Based on the focus of this study and the technical nature of robotics, this section will omit further discussion of the *Act* functionality, although its development is equally critical to the advancement of autonomous systems.

Advanced sensor technology is developing in multiple fields across the Department of Defense with significant impact on aviation. The ability of Light Detection and Ranging (LiDAR) to enable three-dimensional mapping is a growing capability for UAV navigation, demonstrating the ability for vehicles to navigate in unfamiliar areas while avoiding obstacles with little or no human interaction.[37] These navigational capabilities are combined with other sensor technologies that enable detection, recognition, and avoidance or targeting of threat signatures in order to ensure aircraft survival and mission accomplishment. The ability to maneuver quickly through

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[36] Defense Science Board, “Summer Study on Autonomy” (2016), 9-11.

[37] Gail Overton, “LIDAR: LIDAR nears ubiquity as miniature systems proliferate,” LaserFocusWorld.com, October 13, 2015, accessed November 1, 2017, http://www.laserfocusworld.com/articles/print/volume-51/issue-10/features/lidar-lidar-nears-ubiquity-as-miniature-systems-proliferate.html; Ascending Technologies, “ETHZ: Drones with a Sense of Direction,” November 10, 2015, accessed November 1, 2017, http://www.asctec.de/en/ethz-drones-with-a-sense-of-direction/.

unfamiliar terrain remains when the vehicle is untethered from a constant control datalink.[38] Several commercial drones equipped with camera-based sensor technology for mapping and navigation are already available for purchase. 3DR's "Site Scan" is a ground-mapping program capable of autonomously navigating a predetermined area while providing 3-D imaging of obstacles and terrain.[39] A newly marketed drone from Nvidia is capable of navigating a forested trail without GPS, using video sensing while comparing its camera picture to a video database in its memory.[40]

Evidence of these advancements in autonomy continues in the successful demonstrations of Aurora Flight Sciences' Autonomous Aerial Cargo/Utility System (AACUS), developed in cooperation with the Office of Naval Research, which showcases the ability to provide broad mission direction to an unmanned aircraft autonomously maneuvering and landing without human interaction. AACUS is an optional addition to an existing airframe allowing it to execute fully autonomous or optionally-piloted cargo and utility missions. The aircraft receives instruction from a digital tablet-based command signal that designates the intended landing zone. The AACUS-equipped aircraft utilizes various sensor inputs to fly a self-adjusting course that avoids obstacles and arrives in the terminal area to begin its landing sequence. If the designated landing zone is untenable, it uses its onboard sensor suite and navigation aids to locate the nearest suitable landing area.[41]

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[38] Defense Advanced Research Projects Agency (DARPA), "Smart Quadcopters Find their Way without Human Help or GPS," DARPA.mil, June 28, 2017, accessed November 1, 2017, https://www.darpa.mil/news-events/2017-06-28.

[39] 3D Robotics Inc, "How to Get Started with Drones for Surveying and Mapping," 3DR.com, 2017, accessed November 2, 2017, https://3dr.com/enterprise/industries/survey-mapping/.

[40] Paul Ridden, "Nvidia's autonomous drone keeps on track without GPS," GIZMAG Limited, June 14, 2017, accessed November 2, 2017, https://newatlas.com/nvidia-camera-based-learning-navigation/50036/.

[41] Aurora Flight Sciences, *AACUS: Autonomous Aerial Cargo/Utility System* (Manassas, VA: Aurora Flight Sciences, 2017), 2-3.

Another Artificial Intelligence enhancement opportunity is Aircraft Survivability Equipment (ASE). ASE is the collection of sensors and countermeasures that help aircraft defeat air defense weapons that are largely reactive and often operate in an automatic setting, requiring little to no interaction from the aircrew. Although an AI-run survivability system would entail little more than rapid recall ability, it bears mentioning as a significant possibility. As mentioned, ASE currently requires little supervision or input from the aircrew during its operation. However, the specific payload of countermeasures must be determined ahead of time, when ground crews configure the types of countermeasures based on the air defense or missile systems of greatest threat or highest likelihood. AI-augmented aircraft survivability equipment drastically increases the probability of defeating enemy surface to air missiles with its access to large data sets. This would allow a standardized payload of countermeasures on the aircraft able to defeat any number of threat types, rather than one tailored to the highest assumed threat, carrying risk of being unable to defeat other threat types. With an AI ASE system able to rapidly recognize a threat signature and matching it to a vast database of most effective defeat solutions, the system could deploy tailorable countermeasures to defeat that particular threat.

Artificial Intelligence also helps overcome the challenge of a system's ability to "Think" or "Decide." This functionality is the critical binding that connects sensors with the motion, action, or reaction of the vehicle. Current computer "thinking" largely deals with managing or referencing large data sets. Further developments in AI will continue to mature its ability to demonstrate reason and logic while recognizing anomalies. Computers today can quickly, accurately scan items, inputs, or keystrokes, and compare them to known references. Examples of this include Microsoft Word's recognition of a misspelled word in a document or facial recognition technology comparing a scanned input with a sample or reference information.

Advancements continue in this field, as in 2015, when an AI system named ALPHA, created by fledgling company Psibernetix, Inc, beat an experienced Air Force fighter pilot during multiple air-to-air combat simulations. The human competitor, Colonel (Ret) Gene Lee, exclaimed how fast and accurate the system was, successfully defeating every move the veteran flight instructor made during the engagements. “I was surprised at how aware and reactive it was. It seemed to be aware of my intentions and reacted instantly to my changes in flight and my missile deployment. It knew how to defeat the shot I was taking. It moved instantly between defensive and offensive actions as needed.”[42] ALPHA uses a type of “fuzzy logic” that essentially breaks situations into smaller “if-then” scenarios. During engagements, ALPHA weighs the distances between aerial targets, threats posed based on weapons types, and probabilities of a successful shoot-down if engaged before “deciding” to engage its opponent.[43] This example clearly demonstrates the growing ability of computers to weigh decisions and follow a series of selective actions that resembles logic. Further developments in this area will only continue to strengthen AI’s applications and increase its utility in combat by rapidly working through factors to arrive at critical decision points.

Human and AI Teaming

The final critical functionality addressed by the Defense Science Board was that of *Team.* Much research has cited the collaborative pairing of human and AI capabilities as being superior to either component by themselves – “The whole is greater than the sum of its parts,” as Aristotle would say. Even the vast amount of data accessible to an AI-driven system can be useless without meaning or interpretation. Autonomous systems with advanced sensor technology could rapidly and effectively detect, target, and engage multiple targets, but could they differentiate between combatants and non-combatants or make an ethical decision to withhold an engagement? Could

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[42] M. B. Reilly, “Beyond video games: New artificial intelligence beats tactical experts in combat simulation,” UC Magazine, June 27, 2016, accessed November 2, 2017, http://magazine.uc.edu/editors_picks/recent_features/alpha.html.

[43] Nicholas Ernest, David Carroll, Corey Schumacher, Matthew Clark, Kelly Cohen, and Gene Lee, “Genetic Fuzzy based Artificial Intelligence for Unmanned Combat Aerial Vehicle Control in Simulated Air Combat Missions,” *Journal of Defense Management* 6, no. 1 (2016): 6.

an autonomous strike aircraft recognize non-combatant status? Would it automatically return fire on a friendly vehicle or aircraft mistakenly firing in a friendly fire incident?

The advantages of human-AI pairing over both fully autonomous systems and solely human systems are apparent from multiple positions. The amateur chess players Steven Cramton and Zackary Stephen achieved notoriety for their 2005 Freestyle Chess tournament win where they augmented their own strategy and decision making with the help of computers.[44] The aviation industry, like others rapidly investing in increasingly autonomous systems, contains historical examples of human actions that AI systems cannot replicate.

The 2009 crash of US Airways flight 1549 in New York City's Hudson River exemplifies the counter-intuitive and instinctive decision making of an experienced pilot. When airplane Captain Chesley Sullenberger experienced the loss of both engines due to the ingestion of birds during the Airbus A320's climb-out after take-off, he determined that the aircraft was unable to make the course reversal and landing back at the airfield without power. Any traditional body of knowledge, reference publication, or pilot handbook would advise landing on solid ground as preferable, and would only mention ditching as a consideration during overwater or trans-oceanic flights. Captain Sullenberger displayed a counter-intuitive decision that was the result of weighing options and deciding that the risk of crash landing on land, in an urban environment, was greater than the risk posed by ditching in the water. As noted in the official National Transportation Safety Board (NTSB) report on the incident, "The captain's decision to ditch on the Hudson River rather than attempting to land at an airport provided the highest probability that the accident would be survivable."[45]

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[44] Chess News, "Dark horse ZackS wins Freestyle Chess Tournament," ChessNews.com, June 19, 2005, accessed November 2, 2017, http://en.chessbase.com/post/dark-horse-zacks-wins-freestyle-che-tournament.

[45] *Accident Report NTSB/AAR-10/03: Loss of Thrust in Both Engines After Encountering a Flock of Birds and Subsequent Ditching on the Hudson River* (Washington, DC: National Transportation Safety Board, 2010), 119-20.

Similarly, the 1989 crash of United Airlines Flight 232 in Sioux City, Iowa demonstrated a team of human pilots using aircraft systems in ways never intended by design but with favorable outcomes that limited the effects of a catastrophic failure. When the McDonnell-Douglas DC-10's tail-mounted turbine engine failed and caused the drainage of all hydraulic systems, the pilots lost much of their control authority over the aircraft, especially in the lateral axis. The flight crew discovered that they could exercise a small degree of lateral control by manipulating the throttles for the engines on each wing. Throttles are not generally considered a component of maneuvering an aircraft in flight, with the exception of power required to maintain speed, steep turns, or climbs and descents. The crew used an electro-mechanical component of the airframe in a nonstandard method that resulted in relatively fewer deaths when the aircraft crashed upon the attempted landing. As noted in the NTSB report, "The Safety Board believes that under the circumstances the [United Airlines] flight crew performance was highly commendable and greatly exceeded reasonable expectations."[46]

These events compliment the disposition of many in the aviation industry that agree that AI as a means to aid a pilot's management of large amounts of data or aid in decision making are superior to complete autonomy in complex battlefield environments. Where automated AI-controlled aircraft possess significant possibilities to increase safety and effectiveness in such scenarios as poor weather, landing in DVE conditions, or complex integration of airspace, having a pilot with the ability to resume manual control of an aircraft offers greater safety redundancy.[47]

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[46] *Accident Report NTSB/AAR-90/06: United Airlines Flight 232, McDonnell Douglas DC-10-10, Sioux Gateway Airport, Sioux City, lowa, July 19,1989* (Washington, DC: National Transportation Safety Board, 1990), 82.

[47] Patrick Smith, "Why Pilots Still Matter," NewYorkTimes.com, April 10, 2015, accessed November 2, 2017, https://www.nytimes.com/2015/04/10/opinion/why-pilots-still-matter.html; Dan Reed, "Here's Why Technology, Artificial Intelligence Aren't Good Answers For The Growing Pilot Shortage," Forbes.com, August 11, 2017, accessed November 2, 2017, https://www.forbes.com/sites/danielreed/2017/08/11/heres-why-technology-artificial-intelligence-arent-good-answers-for-the-growing-pilot-shortage/#4c2796cd3527; Mike Pietrucha, "Why the Next Fighter Will Be Manned, and the One After That," WarOntheRocks.com, August 5, 2015, accessed November 2, 2017, https://warontherocks.com/2015/08/why-the-next-fighter-will-be-manned-and-the-one-after-that/.

The promise of DARPA's Aircrew Labor In-Cockpit Automation System (ALIAS) is that, similar to the Navy's AACUS, it serves as a "robotic copilot," modularly installed in an aircraft and tablet-controlled.[48] This system can fly autonomously without pilot control, or can be disengaged if the pilot senses an error or opts to control the aircraft manually.

Department of Defense policy requires the design of autonomous systems so that a human operator can exercise an appropriate level of judgement and control over the system. Likewise, the policy recognizes the potential danger of relying on full autonomy in potentially contested environments. "Semi-autonomous weapon systems that are onboard or integrated with unmanned platforms must be designed such that, in the event of degraded or lost communications, the system does not autonomously select and engage individual targets or specific target groups that have not been previously selected by an authorized human operator."[49] Experts in the field seem to corroborate this policy, as indicated by Dr. Alonso Vera, Chief of the Human Systems Integration Division at the National Air and Space Administration (NASA). He highlighted that AI technologies should not replace human involvement in systems, but "as machine intelligence advances, the need for better human interfaces increases,"[50]

Duke University Mechanical Engineering Professor Dr. Mary Cummings discusses the types of tasks best suited for each type of decision-making. She considers three broad categories of tasks: Skill-based tasks, Rules-based tasks, and Knowledge-based tasks or Expertise. Skill-based tasks or those requiring a high degree of technical accuracy and a generally low degree of uncertainty. Self-parking cars and basic aircraft flight maneuvers are examples of skill-based

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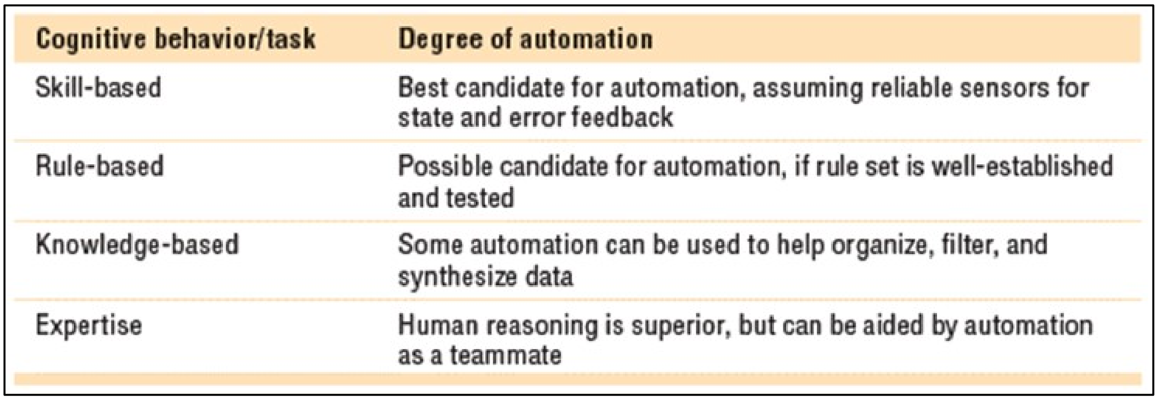
[48] Graham Drozeski, "Aircrew Labor In-Cockpit Automation System (ALIAS)," DARPA.mil, accessed September 12, 2017, https://www.darpa.mil/program/aircrew-labor-in-cockpit-automation-system.

[49] US Department of Defense, *Autonomy in Weapons Systems Directive Number 3000.09*, (Washington, DC: Government Printing Office, 2012), 2-3.

[50] Alonso Vera, "The Challenges of Human-Autonomy Teaming" (Slides presented at the 2017 SAE/NASA Autonomy and Next Generation Flight Deck Symposium, Moffet Field, CA, April 18, 2017), 6.

tasks that autonomy can usually execute more accurately than a human operator. Rules-based tasks are those simple "if-then" actions that are often automatic and, based on being highly reflexive, easily executed by automation.[51]



Cognitive behavior/task	Degree of automation
Skill-based	Best candidate for automation, assuming reliable sensors for state and error feedback
Rule-based	Possible candidate for automation, if rule set is well-established and tested
Knowledge-based	Some automation can be used to help organize, filter, and synthesize data
Expertise	Human reasoning is superior, but can be aided by automation as a teammate

Figure 3. Cognitive categorization of tasks. Mary Cummings, "Man versus Machine or Man + Machine?," *Computing Now*, 2014, 8.

Knowledge-based tasks, as well as expertise, are much more difficult to automate, as they require the highest amount of cognition and often reside in realms of high uncertainty. Complex problems, body language, and emotional cues or ethical considerations in combat are pertinent examples of scenarios where AI could aid a human by providing rules-based input or rapid data review, but lacks the ability to cognitively infer the weight of various factors. An often-referenced example of this challenge to machine learning is one computer's recognition of photographs of animals that only yields a success rate of 15.8 percent.[52] Despite the rapid sensing capabilities and advanced computing power of AI systems, the data produced still requires vetting by a human supervisor to ensure its accuracy or context.

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[51] Mary Cummings, "Man versus Machine or Man + Machine?;" *Computing Now* 29, no. 5 (September/October 2014): 5-7.

[52] Ibid.; Richard Potember, "Perspectives on Research in Artificial Intelligence and Artificial General Intelligence Relevant to DoD," The MITRE Corporation (McLean, VA: OSD ASDR&E, 2017), 30-31.

As discussed above, the future combat environment is one of complexity and contested norms. The conduct of combat will continue to trend towards urban or populated areas, resulting in the presence of large numbers of noncombatants on the battlefield. These considerations, in addition to other factors, create complicated battlefield dynamics. The blurring of lines between conventional military action and unconventional irregular warfare, along with the increased challenge of distinguishing non-combatants in this increasingly urban environment, necessitate the highest degree of prudence while employing new technologies. As with past military conflicts, there are periods of time or geographic spaces of low threat and intensity. Operating within these areas, the aviation tasks arguably reside heavily in the realms of rules-based and skills-based. In contested areas containing combat operations, however, aviation must manage the blended experience of skills, knowledge, and expertise-based tasks, lending to the criticality of maintaining human cognition in some capacity.

Framing the Future Scenario

This study now projects into the future operating environment though the scenario in which the United States may find itself in coming decades. The analysis assumes the United States' adversary is a peer competitor, utilizing high technological capability in a high intensity combat environment. Relying upon the construction of the four quadrants explained in the methodology section (see Figure 4) to depict the relative intensity of combat with the enemy technological capability, this scenario exists in the fourth quadrant. Challenging and contesting every domain in which the United States has become accustomed to controlling, the adversary is a peer competitor, defining the scenario as "Parity." Recent military history has seen the United States operate almost exclusively in "Quadrant I" and "Quadrant II", however the Army's shifting doctrinal focus on returning to large-scale land war requires the study to analyze these capabilities in the more contested environment.

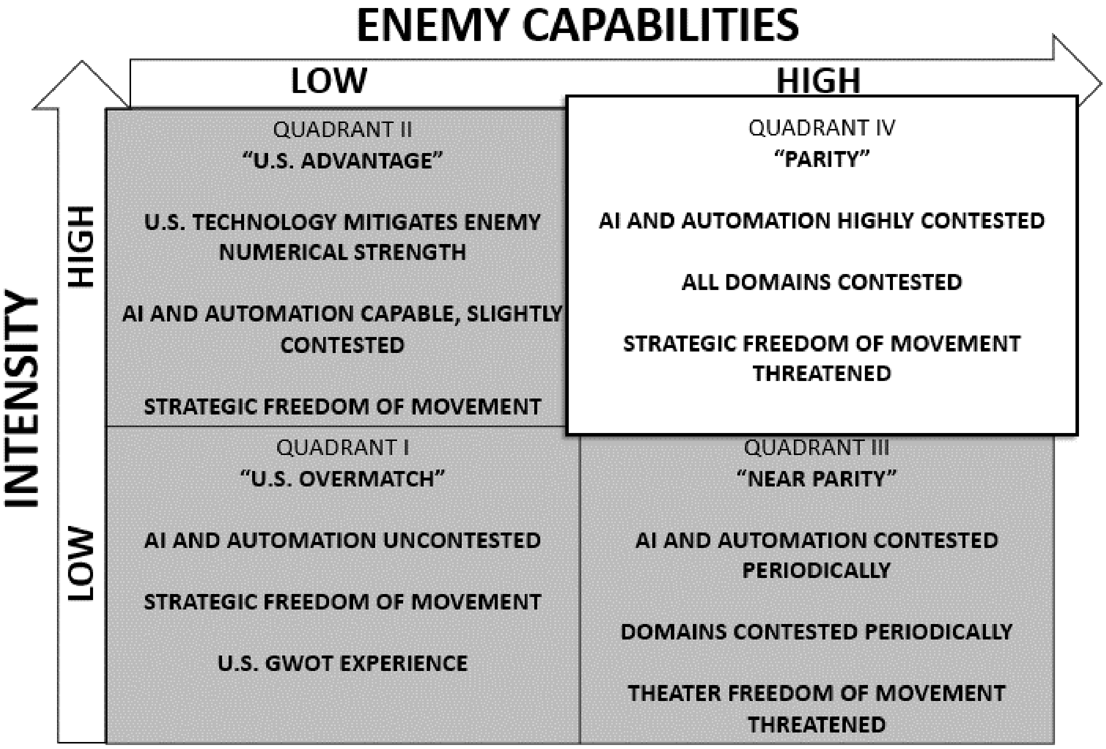

Figure 4. Scenario framework for analysis. Figure created by author.

The "Parity" scenario outlined above takes place in the year 2038, and there is little reason to think that the geopolitical complications or technological advancements of the present day will subside at this point in the future. United States doctrine continues to adapt to changing technologies and battlefield framework, further refining the Multi-Domain Battle concept and attempting to keep pace with growing complexities of hybrid threats from conventional and unconventional forces. Sensor effectiveness continues to increase and becomes more miniaturized while the proliferation of A2/AD systems lingers, growing capabilities in failing states and non-state actors. Russia and China sell advanced Air Defense systems to various nations, with some systems coming into the hands of non-state actors as states fail or extremist groups break from their former governments. Artificial Intelligence technologies advance and embed in semi-autonomous and autonomous weapons systems in Russia and China, proliferated to other regions, such as the Middle East and Southwest Asia, through collaboration with countries like Iran and Pakistan.[53]

Cyber theft and counterintelligence from foreign services and non-state actors undermine the technological hegemony once enjoyed by the United States by making accessible many technical details of low observability (stealth) and aircraft survivability systems.[54] Cyber thieves and hackers obtain sensitive information through illegal cyber activity in the late 2010s and 2020s and sell it to foreign intelligence services in Russia, China, and Iran, and elsewhere, where they increase the countermeasure effectiveness of their A2/AD and defensive systems. The US continues to develop and refine new systems and technologies, but the overmatch once enjoyed has given way to parity in many areas and potential relative inferiority against advanced EW and cyber technologies of adversarial nations.

An unnamed hostile country, seeking to exert regional dominance by closing international shipping lanes and seizing areas rich in oil refining, attacks United States diplomatic centers in the region and poses further threats to US national interests and domestic safety. The aim of this nation is to push US influence out of the immediate region and forcibly seize adjacent territory that it has often claimed rightful ownership of, becoming a near hegemonic regional power by controlling a substantial oil base and adjacent shipping lanes. In response to these threats, the United States secures a United Nations Security Council (UNSC) Resolution supporting military action against this aggressive nation. The UNSC passes Security Council Resolution 9475 and multiple countries pledge various forms of support. However, the countries

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[53] Patrick Tucker, “China Will Surpass US in AI Around 2025, Says Google’s Eric Schmidt,” DefenseOne.com, November 1, 2017, accessed November 16, 2017, http://www.defenseone.com/technology/2017/11/google-chief-china-will-surpass-us-ai-around-2025/142214/?oref=search_AI.

[54] Chris Bing, “How China’s cyber command is being built to supersede its US military counterpart,” CyberScoop.com, June 22, 2017, accessed November 8, 2017, https://www.cyberscoop.com/china-ssf-cyber-command-strategic-support-force-pla-nsa-dod/; Michael O'Hanlon, “Cyber threats and how the United States should prepare,” Brookings.edu, June 14, 2017, accessed November 8, 2017, https://www.brookings.edu/blog/order-from-chaos/2017/06/14/cyber-threats-and-how-the-united-states-should-prepare/.

bordering the aggressor abstain from support and reject passage of coalition forces through their countries for fear of reprisal from their targeted neighbor. This complicates the basing and inhibits the operational reach of the Joint Force, requiring a joint forcible entry into enemy sovereign territory. The Joint Force maintains aviation assets that span the breadth of available technology as the force is undergoing new systems fielding. The fleet of aircraft available includes legacy UAVs, optionally manned and AI-assisted aircraft, and limited numbers of newer, fully autonomous aircraft.

Multi-Domain Battle's Effect on Current UAVs

National and Strategic ISR assets initially provide near-real-time intelligence about the operating environment as the United States Joint Force begins setting conditions. As forcible entry operations begin, the enemy uses centralized cyber-warfare units and a network of de-centralized hackers to conduct cyber-attacks targeting the digital architecture of the intelligence system, limiting the situational awareness of the Joint Force Commander and planners. The degraded connectivity requires an increased reliance on operational and theater ISR. EW operators with advanced sensors easily target UAVs employed to gather intelligence about A2/AD systems and enemy defenses when they detect the UAVs' Radio-Frequency range. Enemy cyber and EW effects jam, spoof, and otherwise contest the UAV RF-range. This targeting forces many UAVs into their preprogrammed lost datalink procedures, where some return without transmitting any useful data, and others suffer corrupted data that causes their crash or forced landing. For a few UAVs, enemy cyber and EW operators intercept, hack, and manipulate the sensor feed, sending erroneous reports to operators and analysts, causing much confusion among staffs.[55]

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[55] Gannaway Web Holdings, LLC, US Patent "US 8515241 B2 – Real-time video editing" (USA, 2011).

GPS-spoofing has a similar effect on attack UAVs. Enemy EW operators use GPS jamming and spoofing to confuse UAVs trying to engage targets, resulting in missed shots and in some cases, fratricide. The poor survival rate and general unreliability of UAVs in the early stages of combat causes planners to move many of these vehicles to generally uncontested areas where they perform aerial surveillance and radio relay functions. Some UAVs are kept forward with combat units to fill ISR needs when other assets are unavailable, but many commanders require redundant source intelligence, not trusting the reliability of unsecured video feeds.

Army aviation makes marginal use of Manned-Unmanned Teaming (MUM-T) during this stage, where units exploit periods of air defense degradation. Army attack and reconnaissance aircraft using armed UAVs to engage additional targets beyond the reach of manned aircraft minimize the exposure time of the crews, but many of these data links become jammed. The cognitive demand of managing multiple UAVs, coupled with the stress of the high threat environment, add to crewmember fatigue and the inherent risk of the missions. Manned aircraft accidents and lapses in pilot judgement increase.

The benefits of legacy UAVs in this environment are only a marginal increase from the current environment and offer little marked advantage over adversaries with advanced sensor capabilities that detect RF-data links. The increased pace of large-scale conflict exacts a large toll on the pilots and crewmembers in this environment, and the risk of exhaustion or burnout of both operators and maintainers limits the opportunities to surge to exploit successes or consolidate gains.

Multi-Domain Battle’s Effect on Autonomous Aircraft

Operating from intermediate staging locations in the joint operations area, autonomous aircraft offer greater flexibility than UAVs as they conduct aerial refueling to extend their range and operating time. Additionally, the presumably larger airframes support a more robust payload of sensors and weapons. For large-scale combat, the aircraft enable more efficient planning of aviation operations, as greater numbers of pilots are available for planning and liaison work rather than flying routine missions on a daily basis. Uninhibited by crewmember fatigue or attrition, only maintenance limits the turn-around time of these aircraft, and ground crews work feverishly to provide operational aircraft to support the mission load.

Receiving preprogrammed mission instructions, autonomous aircraft move to conduct their assigned tasks. Attack and ISR aircraft, benefiting from closed-loop AI systems uninhibited by a constant datalink tether, operate with greater survivability than UAVs with easily targeted communications datalinks. INS and 3D-mapping capabilities onboard autonomous aircraft help the Joint Force maintain the operational advantage and control tempo by operating during inclement weather that prohibits manned aviation flights. During this window of opportunity created by rain, fog, and low ceilings, autonomous ISR platforms map hazards and terrain along routes into engagement areas. They relay this information back to controllers during periodic datalinks that allow the reception of updated mission instructions. The poor weather causes many air defense controllers to remain in the comfort of sheltered positions, increasing the ease of targeting air defenses.

The periodic windows of data transfer create similar vulnerabilities to the autonomous aircraft. A2/AD network sensors detect the emissions and RF signatures when activated, resulting in the alert and engagement of both air defense systems and enemy aircraft. Fast-changing battlefield dynamics generate challenges to autonomous aircraft effectiveness. Changes to mission orders cannot reach the aircraft until the windows of connectivity, risking missed changes to targeting guidance, or dynamic re-tasking to provide support to more pressing operations. Likewise, when conducting operations in and around urban areas, autonomous systems struggle to accurately distinguish between noncombatants and combatants, and how to deal with friendly fire received from coalition forces. When an air defense acquisition radar in a forward area interrogated an autonomous aircraft with a faulty transponder during poor visibility, the negative signal that returned caused the operators to mistake it for an enemy aircraft. When they engage with a surface to air missile, the onboard ASE defeats the missile and the aircraft fires in return to destroy the threatening equipment in accordance with operating procedures. The missile shot from the aircraft to destroy the vehicle kills three soldiers.

Not immune to jamming and EA attacks from enemy EW units, some autonomous aircraft fall victim to digital corruption and spoofing as advanced A2/AD capabilities cause computer errors in flight. While the INS is largely reliable and mostly fail-safe, corrupted files and EA-induced signal errors cause AI-governed autonomous aircraft to crash or misinterpret their location. On-board troubleshooting returns control to some of these aircraft as they near friendly lines, but many crash or are shot down. Without pilots or systems managers in the aircraft to overrule faulty computer systems, most doomed aircraft are unaware of the erroneous computer information.

As operations progress, joint planners begin assigning autonomous aircraft deep strike missions against known targets and resupply or recovery missions during low visibility to reduce the risk to crewmembers. Many autonomous systems operate in a constant aerial resupply “ring route” bringing supplies from ships to logistic hubs on shore. Airspace deconfliction becomes difficult with sporadically maintained datalinks in autonomous aircraft, and while sense-and-avoid technologies keep aircraft from colliding with one another, comfort and trust in clearance of fires is slow to build.

Multi-Domain Battle’s Effect on Human/AI Teaming

The generally poor survival of legacy UAVs and the reliability challenges of fully autonomous aircraft added to the mission expansion of aircraft using Human/AI Teaming, proving effective in the kinetic and challenging environment. Many of these aircraft also use MUM-T as pilots manage groups of unmanned aircraft, executing deep strikes and receiving guidance from the human controller. When EW sensors target datalinks and electronic emissions, the mixed aircraft package identifies the EW source. These missions suffer lower attrition than the legacy UAVs due to their semi-autonomy and ability share information between aircraft. Likewise, the AI systems in the piloted aircraft reduce pilot workloads, allowing for better management of multiple unmanned systems and lower crewmember fatigue than traditional UAV MUM-T missions.

AI-enabled three-dimensional mapping allows pilots to negotiate terrain and hazards during poor weather for aeromedical evacuations and other critical missions. Human pilot supervision enables better decision making for Air Assaults and Personnel Recovery missions, where landing zones and extraction points change relative to enemy positions and terrain. AI systems in the aircraft increase the safety and effectiveness of DVE operations, and its access to large datasets help identify and categorize targets, aiding the pilot in choosing engagement priorities. Additionally, AI systems aide in managing battle damage, where the use of onboard sensors communicates actual damage results to pilots, rather than vague warning lights indicating an anomaly in critical aircraft systems.

AI-enabled aircraft redundant control saves multiple lives, as during one aeromedical evacuation flight. As the aircraft began its takeoff after retrieving a medical patient, a mortar exploded just in front of the aircraft. Shrapnel from the blast kills the pilot and knocks the copilot unconscious. As the aircraft continues its climb and begins to roll inadvertently, the ALIAS "artificial autopilot," senses the unsafe attitude and regains control of the aircraft, flying to its known destination in the navigation system. This system not only saved the aircraft, patient, and the in-flight medical crew, but also saved the copilot, who received treatment at the medical facility upon landing.

Inversely, pilots flying optionally piloted aircraft in autonomous mode override AI computers when they experience faults. On multiple occasions, pilots counter the computer-controlled inputs of the aircraft autopilot. On several occasions, AI fire control systems prompt pilots to engage enemy targets, which pilots over-rule because of proximity to noncombatants or the overt gestures of surrender from enemy soldiers. When computer errors or EW affects corrupt the computer system, causing the aircraft to begin losing control or make erratic movements, the pilots take manual control of the aircraft, rebooting or isolating the affected systems.

Recommendations and Conclusion

The above scenario is a fictitious story of future developments. Generalized and anecdotal as it may be, it serves its purpose of examining the potential benefits and drawbacks of autonomy and artificial intelligence in aviation. Advances in AI continue at a rapid pace, and the demonstrations for its applicability in aircraft continue to inspire. However, when placed in the context of a dynamic, austere, contested combat environment like the one envisioned in Multi-Domain Battle, its utility becomes more focused and acute. The applications of unmanned systems that the Joint Force has become familiar with over the last two decades will not likely survive large-scale combat with a sophisticated enemy. Tactics, techniques, and procedures will continue to evolve based on lessons learned. However, much of the foundational digital architecture to employ such systems in combat will remain vulnerable to the enemy with relatively little effort.

It is doubtful that the DoD policy on autonomous weapons will remove a human from the decision cycle anytime soon. The United States must focus, for the near term, on minimizing the technology gap caused by advances in foreign nations by investing in AI capabilities. Likewise, further research and robust testing of AI limitations and vulnerabilities will help narrow the capabilities gap that will exist as countries like China emphasize autonomy. As Army doctrine returns its focus to large scale ground combat, it must remain mindful of persistent and increasingly capable A2/AD networks. Advancing technologies that enable greater battlefield flexibility must not hamstring operational planners or commanders through over reliance. When technology fails to perform, a human must be in a position to continue the mission. Studies from multiple fields and disciplines have articulated the superiority of AI when teamed with human operators, leveraging the large data and rapid computing ability of the machine with the cognition and contextual understanding of the human mind. It is in this capacity of cognitive aiding that AI can have its greatest effect.

Autonomy enabled by artificial intelligence provides notable advantages for aviation. Increasingly frequent tests are demonstrating autonomous flight with safe navigation of obstacles and hazards. Nonetheless, the technological breakthroughs of AI are still inferior to the synergy gained by teaming the human and computer. The ability to understand perspective, human agency, emotion, and intent is a solely human endeavor. When the precision, speed, and accuracy of a computer gain a human supervisor who wields the power of context and expertise, the new collective machine is superior. Optionally piloted aircraft promise the blending of the accuracy and exactness demanded of a precision weapon, with access to the full cognition, redundancy, and decision-making expected of commanders in combat. As proponents of aviation technology continue to develop systems to incorporate AI, their designs should retain the capacity for human oversight and be very judicious regarding full autonomy authority.

By many accounts, an autonomous aircraft can execute missions with greater precision and endurance than one piloted by a human. However, when a human must, by policy and ethical necessity, bear the burden of taking human life, it follows that they must be in a position to exercise the best judgement. The use of computers and the digitization of war fighting are not going to end, and none should assume these roles in aviation would subside. The practice of applying artificial intelligence should continue to be subordinate to the human demands of combat, and Army aircraft will continue to be most effective with a human retaining some form of control and decision-making authority.

Bibliography

3D Robotics, Inc. “How to Get Started with Drones for Surveying and Mapping.” 3DR.com. 2017. Accessed November 2, 2017. https://3dr.com/enterprise/industries/survey-mapping/.

Abbeel, Pieter, Adam Coates, Timothy Hunter, and Andrew Ng. “Autonomous Autorotation of an RC Helicopter.” Stanford, CA: Stanford University, 2008.

Accident Report NTSB/AAR-10/03: Loss of Thrust in Both Engines After Encountering a Flock of Birds and Subsequent Ditching on the Hudson River. Washington, DC: National Transportation Safety Board, 2010.

Accident Report NTSB/AAR-90/06: United Airlines Flight 232, McDonnell Douglas DC-10-10, Sioux Gateway Airport, Sioux City, lowa, July 19,1989. Washington, DC: National Transportation Safety Board, 1990.

Ascending Technologies. “ETHZ: Drones with a Sense of Direction.” November 10, 2015. Accessed November 1, 2017. http://www.asctec.de/en/ethz-drones-with-a-sense-of-direction/.

Aurora Flight Sciences. *AACUS: Autonomous Aerial Cargo/Utility System*. Manassas, VA: Aurora Flight Sciences, 2017.

Axe, David. “Nah, Iran Probably Didn't Hack CIA's Stealth Drone.” Wired.Com. April 24, 2012. Accessed October 30, 2017. https://www.wired.com/2012/04/iran-drone-hack/.

Ayers, Grant E. and Nicholas McDonald. “Self-Aware Unmanned Aerial Vehicle.” Salt Lake City: University of Utah, 2010.

Bing, Chris. “How China's cyber command is being built to supersede its US military counterpart.” CyberScoop.com. June 22, 2017. Accessed November 8, 2017. https://www.cyberscoop.com/china-ssf-cyber-command-strategic-support-force-pla-nsa-dod/.

Bontea, Sirius T. “America’s Achilles Heel: Defense Against High-Altitude Electromagnetic Pulse–Policy vs. Practice.” Master’s thesis, US Army Command and General Staff College, 2014.

Brock, John W. “Why the United States Must Adopt Lethal Autonomous Weapon Systems.” Master’s thesis, US Army Command and General Staff College, 2017.

Browne, Ryan. “Military aircraft accidents costing lives, billions of dollars.” CNN.com. June 20, 2016. Accessed October 31, 2017. http://www.cnn.com/2016/06/20/politics/military-aviation-crash/index.html.

Buss, Darren W. “Evolution of Army Attack Aviation: A Chaotic Coupled Pendulums Analogy.” Master’s thesis, US Army Command and General Staff College, 2013.

Chavers, Marcus. “Consumer Drones by the Numbers in 2017 and Beyond.” Newsledge.com. May 29, 2017. Accessed October 24, 2017. https://www.newsledge.com/consumer-drones-2017-numbers/.

ChessNews.com. “Dark horse ZackS wins Freestyle Chess Tournament.” June 19, 2005. Accessed November 2, 2017. http://en.chessbase.com/post/dark-horse-zacks-wins-freestyle-che-tournament.

Chivers, Luke. “The Application of Unmanned Rotary-Wing Aircraft in Tactical Logistics in Support of Joint Operations.” Master’s thesis, US Army Command and General Staff College, 2013.

Cleveland, Pam. “Spoofs, Lies, and GPS.” KVHMobileWorld.com. August 31, 2017. Accessed October 30, 2017. http://www.kvhmobileworld.kvh.com/spoofs-lies-and-gps/.

Cummings, Mary. “Autonomous Aerial Cargo/Utility System (AACUS) Concept of Operations.” Office of Naval Research. Date unknown.

________. “Man versus Machine or Man + Machine?” *Computing Now* 29, no. 5 (September/October 2014): 2-8.

DARPA.mil. “Smart Quadcopters Find their Way without Human Help or GPS.” June 28, 2017. Accessed November 1, 2017. https://www.darpa.mil/news-events/2017-06-28.

Davies, Alex. “The Marines’ Self-Flying Chopper Survives a Three-Year Tour.” Wired.com. July 30, 2014. Accessed September 12, 2017. https://www.wired.com/2014/07/kmax-autonomous-helicopter/.

Defense Science Board. “Summer Study on Autonomy.” Washington, DC: Government Printing Office. 2016

Dorr, Les. “Fact Sheet - General Aviation Safety.” FAA.gov. October 24, 2017. Accessed January 18, 2018. https://www.faa.gov/news/fact_sheets/news_story.cfm?newsId=21274.

Doumpos, Michael. *Multicriteria Decision Aid and Artificial Intelligence: Links, Theories, and Applications.* West Sussex, UK: Wiley and Sons Publications, ltd. 2013.

Drozeski, Graham. “Aircrew Labor In-Cockpit Automation System (ALIAS).” DARPA.mil. Accessed September 12, 2017. https://www.darpa.mil/program/aircrew-labor-in-cockpit-automation-system.

Durst, Phillip J., and Wendell Gray. *Levels of Autonomy and Autonomous System Performance Assessment for Intelligent Unmanned Systems*. Vicksburg, MS: The US Army Engineer Research and Development Center (ERDC), 2014.

Ernest, Nicholas, David Carroll, Corey Schumacher, Matthew Clark, Kelly Cohen, and Gene Lee. “Genetic Fuzzy based Artificial Intelligence for Unmanned Combat Aerial Vehicle Control in Simulated Air Combat Missions.” *Journal of Defense Management* 6, no. 1 (2016): 6.

Federal Aviation Administration (FAA). "Unmanned Aircraft Systems (UAS) Regulations and Policies." Department of Transportation. Accessed August 31, 2017. https://www.faa.gov/uas/resources/uas_regulations_policy/.

Flade, John W. "Teaching a New Dog Old Tricks: Replacing Man with Artificial Intelligence in Combat Aircraft." Master's thesis, US Army War College, 2000.

Freedberg, Sydney. "'Optionally Piloted' Aircraft Studied for Future Vertical Lift." BreakingDefense.com. September 23, 2016. Accessed September 12, 2017. http://breakingdefense.com/2016/09/optionally-piloted-aircraft-studied-for-future-vertical-lift/.

________. "New Army Unit to Test Tactics: Meet the Multi-Domain Task Force." BreakingDefense.com. March 21, 2017. Accessed September 25, 2017. http://breakingdefense.com/2017/03/new-army-unit-to-test-tactics-meet-the-multi-domain-task-force/.

________. "War Without Fear: Dep Sec Def Work on How AI Changes Conflict." BreakingDefense.com. May 31, 2017. Accessed September 1, 2017. http://breakingdefense.com/2017/05/killer-robots-arent-the-problem-its-unpredictable-ai/.

________. "Artificial Stupidity: Learning to Trust Artificial Intelligence (Sometimes)." BreakingDefense.com. July 5, 2017. Accessed August 20, 2017. http://breakingdefense.com/2017/07/artificial-stupidity-learning-to-trust-the-machine/.

Gannaway Web Holdings, LLC. "US 8515241 B2 – Real-Time Video Editing". USA, 2011.

Gonzales, Daniel and Sarah Harting. "Designing Unmanned Systems with Greater Autonomy." Santa Monica, CA: RAND Corporation, 2014.

Heiss, Kevin L. "A Cost Benefit Analysis of Fire Scout Vertical Takeoff and Landing Tactical Unmanned Aerial Vehicle (VTUAV) Operator Alternatives." Master's thesis, US Naval Postgraduate School, 2012.

Hirschberg, Mike. "JMR [Joint Multi-Role] Technology Demonstration Update: The Road to Future Vertical Lift." *Vertiflite Magazine* 62, no. 1 (January/February 2016): 22-27.

Huang, Hui-Min. *NIST Special Publication 1011: Autonomy Levels for Unmanned Systems (ALFUS) Framework: Volume I: Terminology*. Gaithersburg, MD: National Institute of Standards and Technology, 2004.

Humphreys, Todd. *Statement on the Vulnerability of Civil Unmanned Aerial Vehicles and Other Systems to Civil GPS Spoofing*. Austin, TX: The University of Texas, 2012.

Jackman, Ben. "Understanding the Anti-Access and Area Denial Threat: An Army Perspective." Master's thesis, US Army Command and General Staff College, 2015.

Kelly Blue Book. *Future Autonomous Vehicle Driver Study*. Irvine, CA: 2016. Accessed December 10, 2016. http://mediaroom.kbb.com/future-autonomous-vehicle-driver-study.

King, Justin. “The Story You Aren’t Being Told About Iran Capturing Two American Vessels.” MintPressNews.com. January 20, 2016. Accessed October 30, 2017. http://www.mintpressnews.com/the-story-you-arent-being-told-about-iran-capturing-two-american-vessels/212937/.

Kurzweil, Ray. “The Coming Merging of Mind and Machine | Kurzweilai.” *Kurzweilai Accelerating Intelligence*. Last modified 2001. Accessed August 27, 2017. http://www.kurzweilai.net/the-coming-merging-of-mind-and-machine.

Lacdan, Joe. “Revised doctrine prepares Soldiers for changing global threats.” Army.mil. October 6, 2017. Accessed January 25, 2018. https://www.army.mil/article/195034/revised_doctrine_prepares_soldiers_for_changing_global_threats.

Lange, Katie. “3rd Offset Strategy 101: What It Is, What the Tech Focuses Are.” DoDLive.mil. March 30, 2016. Accessed September 12, 2017. http://www.dodlive.mil/2016/03/30/3rd-offset-strategy-101-what-it-is-what-the-tech-focuses-are/.

Lin, Jeffrey and P.W. Singer. “The Military Applications of China’s CES Passenger Drone.” *Popular Science*. January 13, 2016. Accessed on November 1, 2016. http://www.popsci.com/military-applications-chinas-ces-passenger-drone.

Lindsay, Douglas T. “US Army Attack Aviation in a Decisive Action Environment: History, Doctrine, and a Need for Doctrinal Refinement.” Master’s thesis, US Army Command and General Staff College, 2015.

LockheedMartin.com. “Sikorsky MATRIX™ Technology.” Accessed September 25, 2017. http://lockheedmartin.com/us/products/matrix.html.

________. “Sikorsky Successfully Completes DARPA ALIAS Phase 1 Competition with Autonomous Flight.” May 24, 2016. Accessed October 24, 2017. http://www.lockheedmartin.com/us/news/press-releases/2016/may/160524-mst-sikorsky-successfully-completes-darpa-alias-phase-one.html.

Lutwak, Robert. “Micro-Technology for Positioning, Navigation and Timing (Micro-PNT).” DARPA.mil. Accessed October 30, 2017. https://www.darpa.mil/program/micro-technology-for-positioning-navigation-and-timing.

Mad Scientist Conference. “Robotics, Artificial Intelligence & Autonomy: Visioning Multi-Domain Warfare in 2030-2050.” Technical Report. Washington DC: Government Printing Office, 2017.

Majumdar, Nivedit. “The Consumer Drone Market: Trend Analysis.” Emberify Blog. January 5, 2016. Accessed October 24, 2017. http://emberify.com/blog/drone-market-analysis/.

McKiernan, Jeffrey A. “Focused Lens on Unmanned Aerial Systems.” Master’s thesis, US Army Command and General Staff College, 2014.

Moser, Mark A. “The Aviation Detachment in the US Army’s Unit of Action: Full Spectrum Dominance.” Master’s thesis, US Army Command and General Staff College, 2003.

Moskvitch, Katia. “Would You Fly in a Pilotless Airliner?” BBC.com. September 13, 2016. Accessed October 31, 2017. http://www.bbc.com/future/story/20160912-would-you-fly-in-a-pilotless-airliner.

Muraru, Adrian. “An Overview on the Concept of UAV Survivability.” International Conference on Scientific paper, Henri Coanda Air Force Academy, Romania, 2011.

Ng, Andrew, Jin Kim, Michael Jordan, and Shankar Sastry. “Autonomous Helicopter Flight via Reinforcement Learning.” Berkley, CA: University of California, 2003.

Nicholas, Scott. “DARPA Program Aims to Increase Autonomous System Predictability, Safety.” ExecutiveGov.com. August 17, 2017. Accessed October 3, 2017. http://www.executivegov.com/2017/08/darpa-program-aims-to-increase-autonomous-system-predictability-safety/.

Nguyen, Phuc, Hoang Truong, Mahesh Ravindranathan, Anh Nguyen, Richard Han, Tam Vu. *Drone Presence Detection by Identifying Physical Signatures in the Drone’s RF Communication.* Boulder: University of Colorado, 2017.

North Atlantic Treaty Organization (NATO). “Safe Ride Standards for Casualty Evacuation Using Unmanned Aerial Vehicles.” Technical Report, 2012.

O’Hanlon, Michael. “Cyber threats and how the United States should prepare.” Brookings.edu. June 14, 2017. Accessed November 8, 2017. https://www.brookings.edu/blog/order-from-chaos/2017/06/14/cyber-threats-and-how-the-united-states-should-prepare/.

“Open Letter on Autonomous Weapons - Future of Life Institute.” *Future of Life Institute*. Last modified 2015. Accessed March 12, 2017. http://futureoflife.org/open-letter-autonomous-weapons/.

Overton, Gail. “LIDAR: LIDAR nears ubiquity as miniature systems proliferate.” LaserFocusWorld.com. October 13, 2015. Accessed November 1, 2017. http://www.laserfocusworld.com/articles/print/volume-51/issue-10/features/lidar-lidar-nears-ubiquity-as-miniature-systems-proliferate.html.

Perkins, David G. “Multi-Domain Battle: Driving Change to Win in the Future.” *Military Review* 97, no. 4 (July/August 2017): 6-12.

Pietrucha, Mike. “Why the Next Fighter Will Be Manned, and the One After That.” WarOntheRocks.com. August 5, 2015. Accessed November 2, 2017. https://warontherocks.com/2015/08/why-the-next-fighter-will-be-manned-and-the-one-after-that/.

Potember, Richard. “Perspectives on Research in Artificial Intelligence and Artificial General Intelligence Relevant to DoD.” The MITRE Corporation. McLean, VA: OSD ASDR&E, 2017.

Raub, Jason S. “The Decline of Air Assault Operations.” Master’s thesis, US Army Command and General Staff College, 2016.

Reed, Dan. “Here’s Why Technology, Artificial Intelligence Aren’t Good Answers For The Growing Pilot Shortage.” Forbes.com. August 11, 2017. Accessed November 2, 2017. https://www.forbes.com/sites/danielreed/2017/08/11/heres-why-technology-artificial-intelligence-arent-good-answers-for-the-growing-pilot-shortage/#4c2796cd3527.

Reid, David. “Would you get on a pilotless plane? These people would.” CNBC.com. August 30, 2017. Accessed October 31, 2017. https://www.cnbc.com/2017/08/30/pilotless-airplanes-are-more-attractive-to-some-types-of-flyers-.html.

Reilly, M. B. “Beyond video games: New artificial intelligence beats tactical experts in combat simulation.” *UC Magazine*. June 27, 2016. Accessed November 2, 2017. http://magazine.uc.edu/editors_picks/recent_features/alpha.html.

Rice, Stephen, Keegan Kraemer, Scott Winter, Rian Mehta, Victoria Dunbar, Timothy Rosser, and Julie Moore. “Passengers from India and the United States Have Differential Opinions about Autonomous Auto-Pilots for Commercial Flights.” *International Journal of Aviation, Aeronautics, and Aerospace* 1, no. 1 (February 2014): 1-9.

Ridden, Paul. “Nvidia’s autonomous drone keeps on track without GPS.” GIZMAG Limited. June 14, 2017. Accessed November 2, 2017. https://newatlas.com/nvidia-camera-based-learning-navigation/50036/.

Roberts, John. “Drones Vulnerable to Terrorist Hijacking, Researchers Say.” FoxNews.com. June 25, 2012. Accessed October 30, 2017. http://www.foxnews.com/tech/2012/06/25/drones-vulnerable-to-terrorist-hijacking-researchers-say.html.

Russell, Stuart J. *Artificial Intelligence: A Modern Approach*. Prentice Hall Series in Artificial Intelligence. Englewood Cliffs, NJ: Prentice Hall, 1995.

Schauer, Mark. “Degraded visual environment researchers conduct milestone testing.” Army.mil. September 26, 2016. Accessed November 1, 2017. https://www.army.mil/article/175745/degraded_visual_environment_researchers_conduct_milestone_testing.

Schwartz, Peter. *The Art of the Long View: Paths to Strategic Insight for Yourself and Your Company*. currency pbk. ed. New York: Currency Doubleday, 1996.

Smith, Patrick. “Why Pilots Still Matter.” NewYorkTimes.com. April 10, 2015. Accessed November 2, 2017. https://www.nytimes.com/2015/04/10/opinion/why-pilots-still-matter.html?_r=0.

Sophie, John T. “China’s Anti-Access/Area-Denial Strategy and Implications for Special Operations Forces Air Mobility.” Master’s thesis, US Army Command and General Staff College, 2014.

Sternstein, Aliya. “How to Hack a Military Drone.” DefenseOne.com. April 29, 2015. Accessed October 30, 2017. http://www.defenseone.com/technology/2015/04/how-hack-military-drone/111391/.

Sukhankin, Sergey. “Russian Capabilities in Electronic Warfare: Plans, Achievements and Expectations.” RealClearDefense.com. July 20, 2017. Accessed October 26, 2017. https://www.realcleardefense.com/articles/2017/07/20/russian_capabilities_in_electronic_warfare_111852.html.

________. “Russian Electronic Warfare in Ukraine: Between Real and Imaginable.” RealClearDefense.com. May 26, 2017. Accessed October 26, 2017. https://www.realcleardefense.com/articles/2017/05/26/russian_electronic_warfare_in_ukraine_111460.html.

Sutton, Richard, and Andrew Barto. *Reinforcement Learning: An Introduction*. Cambridge, MA: MIT Press, 1998.

Szoboszlay, Zoltan, Brian Fujizawa, and Carl Ott. “3D-LZ Flight Test of 2013: Landing an EH-60L Helicopter in a Brownout Degraded Visual Environment.” Presented at the AHS 70th Annual Forum, Montréal, Québec, Canada, May 20, 2014.

Taranto, Matthew T. “A Human Factors Analysis of USAF Remotely Piloted Aircraft Mishaps.” Master’s thesis, US Naval Postgraduate School, 2013.

Trimble, David T. “USAF Role in Future Air Warfare: Manned or Unmanned?” Master’s thesis, US Army War College, 2010.

Tucker, Patrick. “China Will Surpass US in AI Around 2025, Says Google’s Eric Schmidt.” DefenseOne.com. November 1, 2017. Accessed November 16, 2017. http://www.defenseone.com/technology/2017/11/google-chief-china-will-surpass-us-ai-around-2025/142214/?oref=search_AI.

US Army Aviation Center of Excellence (USAACE) Capability Development and Integration Directorate. Accessed August 31, 2017. http://www.rucker.army.mil/usaace/directorates/cdid/.

US Army Capabilities Integration Center (ARCIC). US Army and Marine Corps Concept, “Multi-Domain Battle: Evolution of Combined Arms for the 21st Century, 2025-2040.” Fort Eustis, VA: Government Printing Office, 2017.

US Army Combat Readiness Center. “US Army Accident Information: Aviation Accident Statistics – Fiscal Year End.” Fort Rucker, AL: Government Printing Office, 2017.

US Army Unmanned Aerial Systems (UAS) Center of Excellence. *US Army Roadmap for Unmanned Aircraft Systems 2010-2035.* Fort Rucker, AL: Government Printing Office, 2009.

US Department of the Air Force. “Air Superiority 2030 Flight Plan: Enterprise Capability Collaboration Team.” Washington, DC: Government Printing Office, 2016.

US Department of the Army. Army Doctrine Publication 3-0, *Operations*. Washington, DC: Government Printing Office, 2017.

________. Field Manual 3-0, *Operations.* Washington, DC: Government Printing Office, 2017.

________. Training and Doctrine Command. White Paper, *Multi-Domain Battle: Combined Arms for the 21st Century*. Washington, DC: Government Printing Office, 2017.

________. Training and Doctrine Command, Maneuver, Aviation, and Soldier Division Army Capabilities Integration Center. *The US Army Robotic and Autonomous System Strategy*. Washington, DC: Government Printing Office, 2017.

US Department of Defense. *Autonomy in Weapons Systems Directive Number 3000.09.* Washington, DC: Government Printing Office, 2012.

________. *Joint Operating Environment 2035: The Joint Force in a Contested and Disordered World.* Washington, DC: Government Printing Office, 2016.

Vera, Alonso. “The Challenges of Human-Autonomy Teaming.” Lecture, SAE/NASA Autonomy and Next Generation, Moffett Field, CA, April 18-19, 2017. Accessed October 3, 2017. https://nari.arc.nasa.gov/sites/default/files/attachments/11%29%20ALONSO%20VERA%20FINAL%20-%20SAE%20NASA%20Autonomy%20Symp%2019APR2017.pdf.

Wegner, Robert G. “A Pilotless Army in the Megalopolis.” Master’s thesis, US Army Command and General Staff College, 2004.