

AUTONOMOUS FUNCTIONS OF UNMANNED AIRCRAFT WITH ARTIFICIAL INTELLIGENCE IN LARGE SCALE COMBAT OPERATIONS

A thesis presented to the Faculty of the U.S. Army
Command and General Staff College in partial
fulfillment of the requirements for the
degree

MASTER OF MILITARY ART AND SCIENCE
Strategic Studies

by

ROBERT M. HETHERINGTON, MAJOR, USAF
M.B.A., Oklahoma State University, Stillwater, Oklahoma, 2013

Fort Leavenworth, Kansas

2021

Approved for public release; distribution is unlimited. Fair use determination or copyright permission has been obtained for the inclusion of pictures, maps, graphics, and any other works incorporated into this manuscript. A work of the United States Government is not subject to copyright, however further publication or sale of copyrighted images is not permissible.

REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.					
1. REPORT DATE (DD-MM-YYYY) 18-06-2021		2. REPORT TYPE Master's Thesis		3. DATES COVERED (From - To) SEP 2020 – JUN 2021	
4. TITLE AND SUBTITLE Autonomous Functions of Unmanned Aircraft with Artificial Intelligence in Large Scale Combat Operations				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Robert M. Hetherington, U.S. Air Force				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Command and General Staff College ATTN: ATZL-SWD-GD Fort Leavenworth, KS 66027-2301				8. PERFORMING ORG REPORT NUMBER	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION / AVAILABILITY STATEMENT Approved for Public Release; Distribution is Unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT Unmanned aircraft will continue to be critical to the defense of the United States. The National Defense Strategy prioritizes investments in artificial intelligence (AI), machine learning, and autonomous functions in order to maintain a competitive military edge. This research is based on the rigors of large-scale combat operations (LSCO), and the need to act decisively as well as ethically when developing technologies that leverage AI. The study uses qualitative research to analyze four types of autonomous unmanned aircraft that exist in technological developments and operational concepts. It uses an unclassified case study of U.S. and China military capabilities and applies several forms of analysis including professional qualitative interviews. While the analysis found utility in all four types of autonomous unmanned aircraft, it recommends prioritizing fully autonomous munitions and semi-autonomous human on the loop technologies in order to meet Joint force planning timelines centered on 2035. The findings also suggest that improvements need to be made to collecting and processing data, cloud and meshed based networks, and the security of data and network systems. The research also found that AI and autonomous functions have the potential to enhance human performance and decisions and that maintaining a mix of manned and unmanned aircraft enables the U.S. to manage combat risk and preserve the mission statement of the Department of Defense: to deter war and ensure our nation's security.					
15. SUBJECT TERMS Artificial Intelligence, Machine Learning, Unmanned Aircraft, Remotely Piloted Aircraft, Human Machine Teaming, Command and Control					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT (U)	b. ABSTRACT (U)	c. THIS PAGE (U)			19b. PHONE NUMBER (include area code)
			(U)	133	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

MASTER OF MILITARY ART AND SCIENCE

THESIS APPROVAL PAGE

Name of Candidate: Robert M. Hetherington

Thesis Title: Autonomous Functions of Unmanned Aircraft with Artificial Intelligence in
Large Scale Combat

Approved by:

_____, Thesis Committee Chair
Jacob A. Mong, M.A.

_____, Member
Kenneth E. Long, D.M.

_____, Member
Major Justin E. Estes, M.A.

Accepted this 18th day of June 2021 by:

_____, Assistant Dean of Academics for
Dale F. Spurlin, Ph.D. Degree Programs and Research

The opinions and conclusions expressed herein are those of the student author and do not necessarily represent the views of the U.S. Army Command and General Staff College or any other governmental agency. (References to this study should include the foregoing statement.)

ABSTRACT

AUTONOMOUS FUNCTIONS OF UNMANNED AIRCRAFT WITH ARTIFICIAL INTELLIGENCE IN LARGE SCALE COMBAT OPERATIONS, by Major Robert M. Hetherington, 133 pages.

Unmanned aircraft will continue to be critical to the defense of the United States. The National Defense Strategy prioritizes investments in artificial intelligence (AI), machine learning, and autonomous functions in order to maintain a competitive military edge. This research is based on the rigors of large-scale combat operations (LSCO), and the need to act decisively as well as ethically when developing technologies that leverage AI. The study uses qualitative research to analyze four types of autonomous unmanned aircraft that exist in technological developments and operational concepts. It uses an unclassified case study of U.S. and China military capabilities and applies several forms of analysis including professional qualitative interviews. While the analysis found utility in all four types of autonomous unmanned aircraft, it recommends prioritizing fully autonomous munitions and semi-autonomous human on the loop technologies in order to meet Joint force planning timelines centered on 2035. The findings also suggest that improvements need to be made to collecting and processing data, cloud and meshed based networks, and the security of data and network systems. The research also found that AI and autonomous functions have the potential to enhance human performance and decisions and that maintaining a mix of manned and unmanned aircraft enables the U.S. to manage combat risk and preserve the mission statement of the Department of Defense: to deter war and ensure our nation's security.

ACKNOWLEDGMENTS

The writing of this thesis has been my best academic learning experience. Initially, I wrestled with several topics before I was able to decide what to research, but I always maintained that I wanted my research to be meaningful to others and to produce results that the Joint force could use to solve relevant problems. Ultimately, as an Air Force aviator, I decided on this topic because of its relevance to future U.S. military force structure requirements. Also, I desired to remain informed on unmanned aircraft future applications and developments during my professional military education with the Army at Command and General Staff College. My hope was that the thesis process would help me to be a better staff officer and aspiring commander who could intelligently advocate for needs and resources. Altogether, my personal experience has been even more positive than I had hoped for and I owe that outcome to many people. First, I want to thank my wife and children for their enduring support. I would not have been able to finish this project without their personal sacrifices. I am extremely proud of my wife's academic accomplishments and I appreciate all the ways she has supported me over the years.

Second, I would like to thank my parents for teaching me to pursue new experiences, to approach things optimistically, and to be courageously self-critiquing. Undoubtedly, the personal attributes that they instilled in me helped prepare me for life's opportunities and challenges, including this one.

Last, I want to thank my committee and staff group instructors. My committee volunteered to support my research and I will not forget the time and effort they contributed to help me complete this project. I am grateful for their timely and candid feedback, and I have grown because of it. Thank you all for your outstanding support.

TABLE OF CONTENTS

	Page
ABSTRACT	iv
ACKNOWLEDGMENTS	v
TABLE OF CONTENTS	vi
ACRONYMS	viii
ILLUSTRATIONS	ix
TABLES	x
CHAPTER 1 INTRODUCTION	1
Background	1
Problem Statement	6
Pre-Research Position (R1)	7
Research Questions	9
Secondary Questions	9
Assumptions	9
Definition of Terms	10
Limitations	12
Scope and Delimitations	12
Significance of the Study	13
CHAPTER 2 LITERATURE REVIEW	14
Artificial Intelligence in Strategic Guidance	15
Different Levels of Autonomy	22
USAF Current and Future Command and Control Systems	25
Advantages and Concerns with Unmanned Autonomous Systems	29
Strategic Environment, China and Russia Artificial Intelligence Investments	39
Case Study: Chinese Airspace	45
CHAPTER 3 RESEARCH METHODOLOGY	53
Relevant Resources	53
Applied Professional Case Study Research	53
Joint Operational Design	54
Capabilities Based Assessment	55
Strengths, Weaknesses, Threats, and Opportunities (SWOT) Analysis	56
Applied Methodology	57

Ethical Assurances	58
CHAPTER 4 ANALYSIS	61
Strategic Estimate	61
Operational Approach	61
Possible Options	65
Fully Autonomous Unmanned Munition	65
Semi-autonomous Unmanned Aircraft (HITL and HOTL)	71
Fully Autonomous Unmanned Aircraft	78
Professional Recommendation (R2)	82
Stakeholder Perspectives (Interviews)	85
The Four Options Evaluated with JP 5-0 Criteria	95
Chapter Summary	98
CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS	99
Conclusion	99
Implications for Conclusions and Recommendations	101
Implementation Plan for Recommendations	103
Recommendations for Future Research	106
Personal Reflection/Final Thoughts	106
APPENDIX A AUTONOMOUS FUNCTIONS OF UNMANNED AIRCRAFT WITH ARTIFICIAL INTELLIGENCE IN LARGE-SCALE COMBAT OPERATIONS	110
Consent to Participate in a Research Study	110
Purpose of the Research Study	110
Procedures	110
Risk	111
Benefits and Compensation	112
Confidentiality	112
Contacts for Additional Assistance	113
Voluntary Participation	113
Statement of Consent	113
APPENDIX B INTERVIEW QUESTIONS	115
BIBLIOGRAPHY	117

ACRONYMS

AI	Artificial Intelligence
C2	Command and Control
CAS	Close Air Support
HITL	Human in the Loop
HOTL	Human on the Loop
LSCO	Large Scale Combat Operations
ML	Machine Learning
RPA	Remotely Piloted Aircraft
SEAD	Suppression of Enemy Air Defenses

ILLUSTRATIONS

	Page
Figure 1. Requirement for 24/7 Sustained Flight Operations	31
Figure 2. SAM and Defensive Counter-Air Coverage	48
Figure 3. Targets in China.....	49
Figure 4. U.S. Fourth Generation Aircraft Versus Selected Chinese SAM Systems.....	51
Figure 5. Scorecard Summary Coding	52

TABLES

	Page
Table 1. SWOT Analysis Takeaways	81
Table 2. Four Options Evaluated with JP 5-0 Recommended Criteria.....	97
Table 3. Updated Recommendation (R3)	101

CHAPTER 1

INTRODUCTION

Background

According to the National Security Strategy and National Defense Strategy (NDS) the strategic and operational environments have changed. Specifically, the resurgence of great power competition with Russia and China is causing military strategies and planning considerations to evolve. The National Defense Strategy (NDS) states that “inter-state strategic competition, not terrorism is now the primary concern in U.S national security.” As a result of this competition, the joint services have shifted focus to readiness and future capabilities to operate in large-scale combat operations. This type of conflict is lethal, intense, and brutal,¹ and history has shown that combat operations on this scale are more chaotic, intense, and destructive.² All of this makes the operational environments of future fights more complex with multiple warfighting domains (e.g., Air, Space, Cyberspace, Land, and Maritime) affecting the battle space at any given time. This environment has led U.S. great power competitors to invest in capabilities across the domains to close gaps in U.S. military advantages.

¹ Scott A. Porter, “Large Scale Combat Operations: Risk and Adaptability at the Corps and Division Levels,” *Small Wars Journal*, last modified 13 Oct 2020, <https://smallwarsjournal.com/jrnl/art/large-scale-combat-operations-risk-and-adaptability-corps-and-division-levels>.

² Headquarters, Department of the Army (HQDA), Field Manual (FM) 3-0, *Operations* (Washington, DC: Army Publishing Directorate, 2017), 1-2, https://armypubs.army.mil/epubs/DR_pubs/DR_a/pdf/web/ARN6687_FM%203-0%20C1%20Inc%20FINAL%20WEB.pdf.

These investments have led to capability advancements which have created robust and challenging scenarios that require better situational awareness and faster human decision making. Additionally, the amount of data available in this environment is overwhelming to current systems and decision makers, and advancements in artificial intelligence (AI), machine learning (ML), and autonomous system functions show promise to keep up with the pace of operations and maintain a competitive edge.

In particular, faster data processing within the battle space to increase situational awareness and accelerate decision making at all levels will be needed to effectively utilize remaining capabilities and achieve desired effects.³ Historically, the Air Force has used the doctrinal concept of the OODA (observe, orient, decide, and act) loop to accelerate decision making in combat operations. The OODA loop is regarded as a decision-making strategy that creates an advantage in competitive and contested environments.⁴ It was originally developed by U.S. Air Force Colonel John Boyd, and is a practical concept designed to create rational thinking in chaotic and confusing situations.⁵ The focus of the Observe step is to construct a comprehensive picture of the situation with as much accuracy as possible.⁶ The Orient phase consists of two sub-

³ Bennie J. Davis, “The AI Advantage,” *Airman Magazine*, last modified June 15, 2020, <https://airman.dodlive.mil/2020/06/15/the-ai-advantage/>.

⁴ Ibid.

⁵ John Boyd, “The OODA Loop: How Fighter Pilots Make Fast and Accurate Decisions,” *Decision Making* (blog), *Farnum Street*, January 2018, <https://fs.blog/2018/01/john-boyd-ooda-loop/>.

⁶ Ibid.

phases: destruction and creation.⁷ Destruction involves analyzing the situation in smaller components or problems so it can be better understood.⁸ Decision-makers will decompose a problem until it is familiar or close to situations for which they can develop a plan.⁹ Familiarity is gained through education, training, experience, and instructions.¹⁰ The component problems and plans are then “created” into an overall plan of action.¹¹ The Decide phase is simply the logical next step and the result of gathering sufficient data to make an informed decision. Act is the execution phase of the OODA loop process.

AI has the potential accelerate OODA loops at every tactical, operational, and strategic level.¹² For example, the situational picture will be constructed of more available data creating a more accurate observation. The data of a situation is then distilled through AI and machine learning to orient decision-makers in order to better develop plans of action more quickly. AI is needed to assist with processing and analyzing the vast amounts of data that exist. This will lead to quicker and more informed decisions and actions creating serious advantages in the battle space.

⁷ Thomas Tighe, Raymond Hill, and Greg McIntyre, “A Decision for Strategic Effects: A Conceptual Approach to Effects Based Targeting,” *Air and Space Power Journal* 9, no. 1 (Spring 1995), 3, <https://www.airuniversity.af.edu/Portals/10/ASPJ/journals/Chronicles/Hill.pdf>.

⁸ Ibid.

⁹ Ibid.

¹⁰ Ibid.

¹¹ Ibid.

¹² Davis, “The AI Advantage.”

The commercial sector is also increasing the urgency of implementing these emerging technologies as U.S. great power competitors take advantage of worldwide progress. This has resulted in adversaries uncovering ways to counter U.S. military strengths by integrating the use of AI into their own military forces. For example, adversary integrated air defense systems have become more efficient with target detection and engagement by integrating more autonomous functions which use AI.

In addition to AI, Joint All-Domain Operations (JADO) is another technology and concept that joint service functions and warfighting domains are using to synchronize efforts and create synergistic effects.¹³ This concept mitigates vulnerabilities by enhancing the effectiveness of each domain.¹⁴ All-domain operations are also being advanced and employed by our adversaries resulting in challenges and opportunities for our forces. The advancement of all-domain operations creates an increasingly contested environment that will make command and control more challenging in LSCO. As a result, the DOD created Joint All Domain Command and Control (JADC2) to connect sensors from all of the services with the Air Force as the lead agency.¹⁵

¹³ U.S. Congress, Senate, *United States Air Force Posture Statement: Fiscal Year 2021*, Statement of the Honorable Barbara Barrett, Secretary of the Air Force, and General David L. Goldfein, Chief of Staff, United States Air Force, United States Air Force Presentation to the Armed Services Committee of the United States Senate, 116th Cong., 2nd sess., March 3, 2020, 3, https://www.armed-services.senate.gov/imo/media/doc/Barrett--Goldfein_03-03-20.pdf.

¹⁴ *Ibid.*, 4.

¹⁵ John R. Hoehn, “Joint All-Domain Command and Control” (Congressional Research Service, Washington, DC, updated June 4, 2021), 2, <https://fas.org/sgp/crs/natsec/IF11493.pdf>.

The USAF is also developing the Next Generation of Air Dominance (NGAD), which is a mixed capability of manned, unmanned, and optionally manned platforms.¹⁶ that is conceptualized to rely on AI, machine learning, and human machine teaming technologies with unmanned platforms. These technologies have resulted in unmanned platforms being capable of varying types of autonomy with different levels of human interaction (e.g., human in the loop, on the loop, and off the loop). One theory is that assets with lethal capability should have a “human in the loop” when executing a lethal action.¹⁷ One of the more common concerns is that contested combat conditions will create interference with satellite links from the human to the machine and in those scenarios it is unclear how an AI enabled system would behave.¹⁸ The Air Force recognizes this as an important issue to resolve and has begun researching ways to safeguard against AI malfunctions.¹⁹ Specifically, a subcomponent program is being developed for systems utilizing AI referred to as Testing Autonomy in Complex Environments (TACE), and it is investigating, testing, and advancing AI safeguards.²⁰

¹⁶ U.S. Congress, Senate, *United States Air Force Posture Statement Fiscal Year 2021*.

¹⁷ Sean Welsh, “We need to keep humans in the loop when robots fight wars,” *The Conversation*, last modified January 28, 2016, <https://theconversation.com/we-need-to-keep-humans-in-the-loop-when-robots-fight-wars-53641>.

¹⁸ Ibid.

¹⁹ Davis, “The AI Advantage.”

²⁰ Ibid.

Problem Statement

Modern warfare is increasingly all-domain²¹ and involves simultaneous engagements in order to create effects across many or all domains. In the past several decades, U.S. forces have enjoyed dominant and uncontested superiority in every warfighting domain.²² This will not be the case in future conflicts against great power competitors. Additionally, military readiness for large-scale combat operations has been affected by our nation's longest continuous stretch of armed conflict in counter insurgency centric environments.²³ This issue coupled with rapid technological change and increasing challenges in every operating domain from our adversaries has created a new strategic security environment in which the U.S. is currently not prepared to fight.²⁴ Furthermore, re-emergent great power competitors are taking advantage of rapid distributions of technologies resulting in new warfare concepts and technologies such as data analytics, AI, autonomy, and robotics.²⁵ In light of the strategic environment and rapid technological advancements, the National Defense Strategy has prioritized

²¹ U.S. Congress, Senate, *United States Air Force Posture Statement Fiscal Year 2021*.

²² Department of Defense (DOD), *Summary of the 2018 National Defense Strategy of the United States of America: Sharpening the American Military's Competitive Edge* (NDS) (Washington, DC: DOD, 2018), 1, <https://dod.defense.gov/Portals/1/Documents/pubs/2018-National-Defense-Strategy-Summary.pdf>.

²³ Ibid.

²⁴ Ibid.

²⁵ Ibid.

investments to further discover military applications for AI, ML, and autonomy.²⁶ The U.S. military's advantages will either erode or strengthen depending on the way these new technologies are integrated,²⁷ and if we implement them more effectively than our adversaries. Joint force leadership has specifically stated that it will aim to harness and wield optimal forms of AI to accomplish all mission-sets with greater speed and accuracy.²⁸ It is critical that we use AI, autonomous functions, and human machine teaming to meet this demand for greater speed, accuracy, and lethality for the more complex and faster paced LSCO environments. Considering all these factors, now is the time for the joint force to determine the types of AI-enabled autonomous functions needed in unmanned platforms to meet the needs and requirements for large-scale combat operations within the joint planning timeframe of 2035.

Pre-Research Position (R1)

The research methodology for this thesis is an Applied Professional Case Study (APCS) which utilizes personal and professional experiences to answer the research questions and form recommendations. It is therefore necessary to acknowledge my pre-research positions to ensure that I am effectively using a balanced approach to leverage professional experience supported with sufficient academic research in order to

²⁶ DOD, NDS, 7.

²⁷ Department of the Air Force, *The United States Air Force Artificial Intelligence Annex to The Department of Defense Artificial Intelligence Strategy (USAF AI Annex to DOD AI Strategy)* (Washington, DC: Department of the Air Force, 2019), <https://www.af.mil/Portals/1/documents/5/USAF-AI-Annex-to-DoD-AI-Strategy.pdf>.

²⁸ Davis, "The AI Advantage."

synthesize recommendations that are reasonable and complete. Additionally, my pre-research position records a starting point for my personal and professional knowledge on the topic, which will allow me to later reflect on what I have learned.

To begin with, I am an experienced remotely piloted or unmanned aircraft pilot. I have personally experienced and seen the effectiveness of unmanned aircraft in counter insurgency and contingency operations. The majority of these operations have occurred in uncontested air domain environments; however, I assess that unmanned aircraft are capable of operating in contested environments with certain technological improvements. These include enhanced security on command-and-control networks and the creation of redundant communication nodes that are not reliant on satellites.

Additionally, in these contested environments it is advantageous for unmanned aircraft to be capable of some autonomous functions however humans should remain in control of the decision and execution of lethal actions for most targets. For example, it would be advantageous for a system to be capable of lethal autonomous functions in large scale combat operations (LSCO) when link or input from the human operator is lost. This could be conducted by referencing a pre-programmed database of known hostile targets like the Joint Integrated Priorities Target List (JIPTL), which would allow the aircraft to determine their proximity to those targets and conduct a strike while waiting for link with human control to be re-established. There are also non-lethal actions the system could perform to include the continued collection of various forms of intelligence (e.g., signals intelligence) and data (e.g., full motion video) until link is re-established.

Research Questions

The primary question that this research seeks to answer is what types of autonomous functions should lethal unmanned aircraft utilizing artificial intelligence and human teaming technologies be capable of given command and control challenges in non-permissive large-scale combat environments?

Secondary Questions

1. Should unmanned aircraft be capable of lethal autonomous functions?
2. What key mission sets need artificial intelligence (AI) and human teaming enabled capabilities?
3. What types of manned and unmanned assets should the joint force invest?
4. What is the right mix of manned and unmanned aircraft to achieve needed future capabilities to overmatch our adversaries?
5. What are the advantages of a predominantly unmanned force in a highly lethal large-scale combat environment?
6. What types of technologies need to be further developed in order to safeguard command and control communication links?

Assumptions

1. The DOD will continue to adequately fund AI and human teaming technologies.
2. Artificial Intelligence development is critical to the U.S. maintaining a decisive advantage in the great power competition environment.

3. Artificial Intelligence is only several years away from enabling unmanned systems to operate autonomously..²⁹
4. The private sector and industry will continue to collaborate with the joint force in developing artificial intelligence..³⁰
5. The joint force desires to use AI in all mission sets but priorities still need to be established due to constrained budgets and timelines..³¹
6. The Joint Staff will continue to pursue solutions to link sensors and data from the different services through programs similar to Joint All-Domain Operations Command and Control..³²

Definition of Terms

Automatic: No dynamic adaption of inputs, rules, and outputs..³³

Automated: Predictable behavior based on inputs, rules and outputs, requires no human intervention..³⁴

²⁹ Davis, “The AI Advantage.”

³⁰ Ibid.

³¹ Ibid.

³² Morgan Dwyer, “Making the Most of the Air Force’s Investment in Joint All Domain Command and Control,” Center for Strategic and International Studies, March 6, 2020, <https://www.csis.org/analysis/making-most-air-forces-investment-joint-all-domain-command-and-control>.

³³ Ariel M. Schuetz, “Why the DOD is Losing its Asymmetric Robotics and Autonomous Systems Advantage: An Argument for the Concept of Autonomous Function with a System,” (Master’s thesis, U.S Army Command and General Staff College, Fort Leavenworth, KS, 2018), 21.

³⁴ Ibid.

Semi-autonomous: Tasks may be performed using a variety of behaviors including reasoning and problem solving, adaption, self-direction, and learning.³⁵

Autonomous: Machine completes a task without human intervention using behaviors resulting from the action of computer programming with the external environment.³⁶

Human in the loop:³⁷ semi-autonomous, or only engage individual targets or specific target groups that have been selected by a human operator.³⁸

Human on the loop:³⁹ “supervised” autonomous weapon systems, in which operators have the ability to monitor and halt a weapon’s target engagement.⁴⁰

Human out of the loop:⁴¹ weapon system[s] that, once activated, can select and engage targets without further intervention by a human operator.⁴²

³⁵ Schuetz, “Why the DOD is Losing its Asymmetric Robotics and Autonomous Systems Advantage,” 21.

³⁶ Ibid.

³⁷ Kelly M. Slayer, “Defense Primer: U.S. Policy on Lethal Autonomous Weapon Systems,” (Congressional Research Service, Washington, DC, updated December 1, 2020), 1, <https://crsreports.congress.gov/product/pdf/IF/IF11150>.

³⁸ Department of Defense (DOD), DOD Directive 3000.09, *Autonomy in Weapons Systems* (Washington, DC: DOD, November 21, 2012, incorporating Change 1, May 8, 2017), 14, https://fas.org/irp/doddir/dod/d3000_09.pdf.

³⁹ Slayer, “Defense Primer,” 1.

⁴⁰ DOD, DOD Directive 3000.09, 14.

⁴¹ Slayer, “Defense Primer,” 1.

⁴² DOD, DOD Directive 3000.09, 14.

Artificial Intelligence: the ability of machines to perform tasks that normally require human intelligence..⁴³

Machine Learning: subfield of AI that is closely related to statistics and based around the idea to allow machines to learn from data..⁴⁴

Limitations

All information is based on published data and may not include the most up to date information due to limited access. Research data, analysis, and recommendations are all Unclassified; no Controlled Unclassified Information (CUI) or classified information was considered in the research or writing of this document.

Scope and Delimitations

This research seeks to determine the different types of autonomy needed to meet capability requirements of current and future mission sets in large-scale combat operations. Additionally, this research is primarily focused on the air domain and recommendations for the types of functions within that warfighting domain specifically. The research does not explicitly cover land, maritime, and space domains. Furthermore, the research is primarily limited to the joint functions of command and control, fires, information, and intelligence. Ethical concerns regarding autonomous capability will be addressed in this study; however it is not the primary focus.

⁴³ Greg Allen, “Understanding AI Technology,” Joint Artificial Intelligence Center, April 2020, 3, <https://www.ai.mil/docs/Understanding%20AI%20Technology.pdf>.

⁴⁴ Ibid.

Significance of the Study

The world around us is changing at a pace faster than ever before. New technologies are emerging that are fundamentally altering how we think about, plan and prepare for war. Whichever nation harnesses AI first will have a decisive advantage on the battlefield for many, many years. We have to get there first.

—Secretary of Defense, Dr. Mark T. Esper, quoted in Bernie Davis, “The AI Advantage”

The joint force has made significant strides in the research and development of artificial intelligence, machine learning, and human teaming technologies. The application of these technologies in future large-scale combat operations has also been explored with significant and meaningful relevance to future operating environments. Additionally, joint force operating concepts such as Air Force Vision 2035 reveal mission scenarios where blended capabilities of manned and unmanned aircraft utilize AI and semi-autonomous weapons; however, the mission sets, and levels of autonomy required for future capabilities need to be further explored and decided. Determining this will help the joint force invest effectively in future capabilities utilizing AI and autonomous functions. Last, the challenges of command and control in large scale combat operations will also be faced by our competitors. As such, it is an opportunity for the U.S. to better implement and develop emerging technologies to maintain a decisive advantage. AI leading to battlefield system autonomous functions will fill capability gaps needed for these non-permissive environments while mitigating risk associated with command-and-control interference. Ultimately, this will help the U.S. to maintain a competitive and decisive advantage in the digital age.

CHAPTER 2

LITERATURE REVIEW

AI refers to the ability of machines to perform tasks that normally require human intelligence—for example, recognizing patterns, learning from experience, drawing conclusions, making predictions, or taking action whether digitally or as the smart software behind autonomous physical systems.

—Department of Defense, *Summary of the 2019 Department of Defense Artificial Intelligence Strategy*

The 2017 National Security Strategy (NSS) established that the U.S. will prioritize emerging technologies related to advance computing and artificial intelligence. Furthermore, AI is progressing rapidly and includes applications ranging from self-driving cars to autonomous weapons.⁴⁵ The application of AI emphasized in the NSS coupled with the 2018 National Defense Strategy have sparked a rapid increase in literature related to artificial intelligence, autonomy, future warfare concepts and large-scale combat operations. As such, this literature review section is presented in five categories. First, DOD and Air Force published strategic and operational guidance related to implementing AI and autonomy. Second, explanations and interpretations of the different levels of autonomy and associated risk. Third, assessments of U.S. Air Force current and future command and control for the air domain. Fourth, broad considerations for military and civilian identified advantages and concerns associated with autonomous

⁴⁵ U.S. President, *National Security Strategy of the United States of America* (NSS) (Washington, DC: The White House, December 2017), 20, <https://www.whitehouse.gov/wp-content/uploads/2017/12/NSS-Final-12-18-2017-0905.pdf>.

weapon systems. Fifth, a case study that evaluated the military capabilities of the U.S. and China.

Artificial Intelligence in Strategic Guidance

The 2014 Air Force Strategic Master Plan entitled “America’s Air Force a Call to the Future” operationalizes the Air Force strategy and provides direction to planning and prioritizing authorities on a 20-year timeline.⁴⁶ The master plan is informed by the 2014 Air Force Strategic Environment Assessment which identified four distinct areas where threats are driving change including “speed of technological change.”⁴⁷ The plan also includes a Science and Technology Annex (STA) that looks at technology evolutions to address existing capability gaps and revolutionary technological changes that have the potential to be game changing.⁴⁸ It identifies five priority areas for investment, institutional change, and operational concepts: provide effective 21st century deterrence, maintain a robust and flexible global ISR capability, ensure a full spectrum capable and high end focused force, pursue a multi-domain approach to our five core missions, and continue the pursuit of game-changing technologies. Examples of artificial intelligence, machine learning, human teaming, and autonomy are included in each of these five

⁴⁶ Department of the Air Force, *USAF Strategic Master Plan* (Washington, DC: Department of the Air Force, May 2015), 7, https://www.af.mil/Portals/1/documents/Force%20Management/Strategic_Master_Plan.pdf.

⁴⁷ Ibid.

⁴⁸ Ibid., 8.

strategic vectors.⁴⁹ Specifically, the strategy calls for multi-domain ISR which requires capabilities that can operate in different environments with varying levels of risk and uncertainty. These environments drive a need for ISR to be more directive and more responsive to include lethal and non-lethal effects.⁵⁰ This requires ISR to be more technologically elastic through analysis architectures that better automate, integrate, and collaborate through human-machine teaming. These integrated and automated systems will empower intelligence and knowledge into actionable data varying from national level authorities to tactical warfighters.⁵¹

The Air Force Science and Technology Strategy published in April 2019 states that we must identify where our adversaries cannot easily go and then get their first rather than simply analyzing where they are going. It presents three objectives in order to meet this new vision:⁵² Develop and deliver transformational strategic capabilities, reform the way science and technology are led and managed, deepen and expand the science and technical enterprise.

Additionally, Objective 1 is sectioned into five Strategic Capabilities:

1. Global Persistent Awareness
2. Resilient information sharing

⁴⁹ Department of the Air Force, *USAF Strategic Master Plan*, 3.

⁵⁰ *Ibid.*, 41.

⁵¹ *Ibid.*, 42.

⁵² United States Air Force (USAF), *Science and Technology Strategy: Strengthening USAF Science and Technology for 2030 and Beyond* (Washington, DC: USAF), iii-iv, <https://www.af.mil/Portals/1/documents/2019%20SAF%20story%20attachments/Air%20Force%20Science%20and%20Technology%20Strategy.pdf>.

3. Rapid effective decision making
4. Complexity, unpredictability, and mass
5. Speed and reach of disruption and lethality

The five strategic capabilities cover a great deal of topics but much of it is information related to AI. To begin with, it emphasizes that the Air Force must collect decision quality data and intelligence and act upon it quicker than the enemy. The document describes AI as essential to rapid, effective decision making as increasing complexity and speed of the battlespace is outpacing human cognitive functions.⁵³ The Air Force has also developed powerful and capable sensors in space and unmanned aircraft, but these capabilities are vulnerable against increasingly capable adversaries and are expensive.⁵⁴ As such, future sensors need to be lower cost and integrated on distributed platforms which will create resiliency and complement the more expensive and exquisite sensors across domains.⁵⁵

Furthermore, the data and information must be passed through more resilient networks described as battle network technology that moves away from hub and spoke and towards meshed networks where data is shared autonomously across multiple classification levels to Joint and Allied forces.⁵⁶ The current force structure has an overreliance on very valuable assets which creates vulnerabilities and limits options for

⁵³ USAF, *Science and Technology Strategy*, 7.

⁵⁴ Ibid., 13.

⁵⁵ Ibid.

⁵⁶ Ibid.

these complex battlespaces.⁵⁷ This issue could be mitigated by augmenting high end platforms with low cost autonomous air and space systems which can absorb losses and are easier to adapt and upgrade than traditional manned systems.⁵⁸

Also, the document highlights that adversaries are using emerging technologies similar to AI to develop new integrated air defenses, mobile missile systems, long range weapons, anti-satellite systems, and conceal and deception means.⁵⁹ This is exacerbated by how AI has proliferated into the commercial sector and cannot be controlled. As a result, our adversaries are rushing to embrace these technologies in order to exploit our perceived weaknesses. Additionally, the Air Force mission sets rely on data and information insights from multiple domains (Air, Space, and Cyberspace) potentially creating additional vulnerabilities.⁶⁰ AI underpins our ability to execute these diverse missions and executing in multi-domain operations. As such, the Air Force has developed specific AI strategy documents such as The United States Air Force Artificial Intelligence Annex to the Department of Defense Artificial Intelligence Strategy, which serve as catalyst to ensure AI remains a priority in budget proposals and planning.⁶¹

⁵⁷ USAF, *Science and Technology Strategy*, 15.

⁵⁸ *Ibid.*, 8.

⁵⁹ *Ibid.*, 1.

⁶⁰ Department of the Air Force, *USAF AI Annex to DOD AI Strategy*, 2.

⁶¹ *Ibid.*, 3.

Furthermore, the DOD established the Joint Artificial Intelligence Center (JAIC) in September of 2018 to enable AI's strategic and purposeful development.⁶² The Air Force's AI strategy details the fundamental principles, enabling functions, and objectives necessary to effectively manage, maneuver, and lead in the digital age, and stresses a need to operationalize AI for support and warfighting operations.⁶³ AI enables outcomes with greater speed and accuracy, while optimizing the capabilities of each and every Airmen, which emphasizes the human teaming aspects of AI.⁶⁴ Overall, the AF believes that AI is extremely important and "akin to the development of stealth aircraft and precision guided munitions."⁶⁵

Air Force Vision 2035 is a future operating concept that is part of a series of strategic documents designed to guide the force in organizing, training, and equipping over the next few decades.⁶⁶ It serves as a companion document to "America's Air Force: A Call to the Future and the "USAF Strategic Master Plan."⁶⁷ The operating concept discusses the implication for the Air Force's five distinct core missions:

⁶² Department of the Air Force, *USAF AI Annex to DOD AI Strategy*, 3.

⁶³ *Ibid.*, 2.

⁶⁴ *Ibid.*

⁶⁵ *Ibid.*, 6.

⁶⁶ Washington (AFNS) Secretary of the Air Force Public Affairs Command Information, "Air Force Releases Future Operating Concept," U.S. Air Force, September 15, 2015, <https://www.af.mil/News/Article-Display/Article/617301/af-releases-future-operating-concept/>.

⁶⁷ *Ibid.*

1. Multi-Domain Command and Control
2. Adaptive Domain Control
3. Global Integrated Intelligence, Surveillance, and Reconnaissance
4. Rapid Global Mobility
5. Global Precision Strike⁶⁸

While all of the cores missions have aspects that will be enhanced by AI, Adaptive Domain Control (ADC) is more closely related to this research and the more recent concept of JADC2. ADC is described as using collaborative efforts with joint and coalition partners enabling Air Force forces to perform sensor and shooter functions that are able to see first, act first and neutralize or kill an adversary..⁶⁹ Through combinations of air, space, and cyberspace operations assets can operate in highly contested environments with flexible resilience amid the uncertainty of war..⁷⁰ ADC will utilize manned and unmanned aircraft teams of air, space, and cyberspace assets, operating with mission command and appropriate authorities to accomplish mission needs. These teams will leverage different strengths and be modular in nature presenting complicated targeting problems for adversaries..⁷¹ Additionally, teams create multiple dilemmas through components of offensive and defensive capabilities; they are capable of multi-

⁶⁸ Department of the Air Force, *Air Force Future Operating Concept: A View of the Air Force in 2035*, (Washington, DC: Department of the Air Force 2015), <https://www.ang.af.mil/Portals/77/documents/AFD-151207-019.pdf>.

⁶⁹ Ibid., 18.

⁷⁰ Ibid.

⁷¹ Ibid.

spectral sensors, exploiting the electromagnetic spectrum, and delivering lethal and non-lethal effects.⁷²

Teams can aggregate mass or be distinct, disparate assets depending on requirements and desired effects.⁷³ The vision further describes Air Force assets operating with a balanced capability of manned, remotely operated (unmanned), semi-autonomous, and autonomous air, space, and cyber space assets. Some of these assets have long range and high endurance capabilities to ensure global reach and persistence. Low observable aircraft shrink adversary warning times, while other platforms are purposely detectable and small to serve as inexpensive decoys.⁷⁴ Small air platforms may be delivered from a variety of airborne assets, including air mobility aircraft.⁷⁵ Mission needs dictate that unmanned aircraft conduct increasingly autonomous operations under appropriate degree of human supervision.⁷⁶ Human roles will shift more to battle managers in control of large numbers of self-coordinating platforms or programs. This human-teaming integration relies on advanced automation to reduce human task workloads leading to Airman focusing on critical activities like situational awareness, targeting, and mission-objective selection.⁷⁷

⁷² Department of the Air Force, *Air Force Future Operating Concept*, 18.

⁷³ Ibid.

⁷⁴ Ibid., 21.

⁷⁵ Ibid.

⁷⁶ Ibid.

⁷⁷ Ibid.

AF Vision 2035 has a vignette which describes the blended capability of manned and unmanned aircraft operating with several different levels of autonomy. It also provides some insight into command-and-control technology initiatives which might be more resilient than satellite-based communication infrastructures in a LSCO environment. The vignette describes a strike package composed of two F-35D and a formation of multi-mission long range (MMLR) aircraft. The scenario has the F-35s fusing data with multiple airborne and surface sensors, space assets, and real-time intelligence inputs in an electromagnetic saturated environment. The MMLRs are controlled from a disparate ground control station. They affect the battle space and enemy aircraft with a salvo of air-to-air missiles. At one-point the enemy causes the MMLR formation to lose satellite link. The F-35 takes control of the MMLR formation through laser datalink. Additionally, the MMLRs are reprogrammed to a semi-autonomous function and tasked to destroy the remaining enemy bombers. To mitigate lost laser datalink, the MMLRs are given a fully autonomous tasking of cruise missile defense. Fortunately, the MMLRs link is restored by the cyber operations team shortly after being reprogrammed and the mission is continued.⁷⁸

Different Levels of Autonomy

Lethal Autonomous Weapon Systems (LAWS) are weapons systems that independently identify a target and employ a weapon to engage and destroy the target

⁷⁸ Department of the Air Force, *Air Force Future Operating Concept*, 22.

without manual human control of the system.⁷⁹ There are differing views on if degraded communications environments present an opportunity or challenge for autonomous systems.⁸⁰ The differences in views or perspectives are centered on the level of human involvement required to execute a lethal action.

Some believe that LAWS enable military operations in non-permissive and communications degraded environments. Others believe that autonomous systems are still too unpredictable, and a human should remain in the loop for decisions. Currently, U.S. policy does not prohibit the development or employment of LAWS.⁸¹ Although the U.S. does not have any LAWS in its inventory, defense leaders have stated that the U.S. may be compelled to develop them if potential adversaries choose to do so.⁸² Department of Defense Directive 3000.09 establishes U.S. policy on autonomous systems and provides definitions for the different categories. The policy does not focus on the technological sophistication of the weapon in these definitions but rather the role of the human operator with regard to selection and engagement of targets.⁸³ LAWS is officially, defined as a weapon system that once activated, “can select and engage targets without further intervention by a human operator”⁸⁴ (i.e., human out of the loop, or full

⁷⁹ Slayer, “Defense Primer,” 1.

⁸⁰ Ibid.

⁸¹ Ibid.

⁸² Ibid.

⁸³ Ibid.

⁸⁴ DOD, DOD Directive 3000.09, 13.

autonomy). Human on the loop describes when operators have the ability to monitor and halt an autonomous weapon's engagement.⁸⁵ Human in the loop is for semi-autonomous weapons that "only engage individual targets or specific target groups that have been selected by a human operator."⁸⁶ Semi-autonomous weapons also include certain types of guided missiles that deliver effects to a target through automated functions after targets have been identified by humans.⁸⁷ Department of Defense directives require that all systems be designed to "allow commanders and operators to exercise appropriate levels of human judgement over the use of force."⁸⁸ This should be thought of as broad human involvement or decisions about how, when, where, and why the weapon will be employed versus direct involvement.⁸⁹ This includes human determination that the weapons will be used "with appropriate care and in accordance with the law of war, applicable treaties, weapon system safety rules, and applicable rules of engagement."⁹⁰

The directive also emphasizes training tactics, techniques and procedures be in place so commanders can effectively evaluate autonomy in realistic conditions.⁹¹ U.S. policy also requires that the software and hardware of all systems including lethal

⁸⁵ Slayer, "Defense Primer."

⁸⁶ DOD, DOD Directive 3000.09, 14.

⁸⁷ Slayer, "Defense Primer."

⁸⁸ DOD, DOD Directive 3000.09, 2.

⁸⁹ Slayer, "Defense Primer."

⁹⁰ DOD, DOD Directive 3000.09, 3.

⁹¹ Ibid., 8.

autonomous weapons, be tested and evaluated to ensure in realistic operational environments they function as anticipated against adaptive adversaries, and complete engagements in a timeframe consistent with the intent of the operator. The systems should also be capable of terminating engagements or know when to seek additional human operator input before continuing the engagement. Autonomous systems should be sufficiently robust to minimize failures that could lead to loss of control of the system to unauthorized or unintended engagements.⁹²

USAF Current and Future Command and Control Systems

The Air Force fundamental principle of airpower is to operate under centralized control and decentralized execution. While other joint services have command and control (C2) systems, this section focuses on current and future USAF C2, since it is the most likely service to serve as JFACC during LSCO. The Air Operations Center (AOC) coordinates with higher headquarters, joint force centers and organizations, and subordinate units to plan and execute the Air Tasking Order (ATO) using the Joint Air Tasking Cycle.⁹³ The ATO is executed on a 72-hour planning cycle and works well with strategic bombing campaigns, strikes against static forces, and planning Intelligence, Surveillance, and Reconnaissance (ISR) against insurgency.⁹⁴

⁹² DOD, DOD Directive 3000.09, 2.

⁹³ Sherrill Lengel, Jeff Hagen, Eric Hastings, Mary Lee, Matthew Sargent, Matthew Walsh, Li Ang Zhang, and David Blancett, *Joint All-Domain Command and Control for Modern Warfare* (Santa Monica, CA: RAND, 2020), https://www.rand.org/pubs/research_reports/RR4408z1.html.

⁹⁴ Ibid., 4.

Today, the U.S. Air Force uses the AOC as its command-and-control node at the operational level.⁹⁵ It has been effective historically but recently challenged for several reasons. First, systems and personnel are forward-deployed in a centralized facility making them vulnerable.⁹⁶ Second, information systems date back to the early 2000s, and critical hardware and software upgrades have been delayed.⁹⁷ Third, new functional and technical demands have been placed on the AOC to integrate cyber and space.⁹⁸ Several of the challenges and concerns with current AOC operations in LSCO with great power competitors are the survivability of the AOC facility and personnel, and the robustness of systems to cyber and communications attacks.⁹⁹ In order to modernize the AOC the Air Force has implemented a program called the AOC Pathfinder or Kessel Run (KR).¹⁰⁰ KR is utilizing agile software development to evolve command and control and all domain capabilities for the AOC.¹⁰¹ KR is just one example of efforts to achieve JADC2 with numerous stakeholders being a part of associated efforts.¹⁰² Furthermore, AI and machine learning technologies have the ability to enable and achieve JADC2.

⁹⁵ Lengel et al., *Joint All-Domain Command and Control for Modern Warfare*, iii.

⁹⁶ Ibid.

⁹⁷ Ibid.

⁹⁸ Ibid.

⁹⁹ Ibid., 6.

¹⁰⁰ Ibid., 12.

¹⁰¹ Ibid.

¹⁰² Ibid., 14.

Specifically, they can help enable a shift to distributed control by providing predictive tools, dynamic courses of action at distributed nodes, and decision tools for commanders and operators.

As of March 6, 2020, the Air Force has requested \$435 million for the Advanced Battle Management System (ABMS) which is the leading solution for Joint All-Domain Command and Control (JADC2).¹⁰³ JADC2 links sensors and shooters in all domains in order to rapidly target adversary forces.¹⁰⁴ Moreover, JADC2 seeks to integrate the planning tasking, and assessment of all-domains operations. The Air Force is currently developing ABMS using DevOps strategy with new capability demos every 4 months.¹⁰⁵ The first demo tested a data sharing architecture between an aircraft, ship destroyer, and a new cloud-based repository.¹⁰⁶ The Air Force is currently focused on the technical aspects of ABMS and plans for the other military services to accept ABMS as the starting point for JADC2 in order to develop and field additional capability.¹⁰⁷

AI can be applied to solve real-time decision problems with imperfect information scenarios which will be encountered in all-domain command and control. In order to do this AI is grouped into six categories.¹⁰⁸

¹⁰³ Dwyer, “Making the Most of the Air Force’s Investment in Joint All Domain Command and Control.”

¹⁰⁴ Ibid.

¹⁰⁵ Ibid.

¹⁰⁶ Ibid.

¹⁰⁷ Ibid.

¹⁰⁸ Lengel et al., “Joint All-Domain Command and Control for Modern Warfare.”

1. Computer Vision for detecting and classifying information in the visual world.
2. Natural Language Processing for speech, text recognition, and translation which is currently in millions of homes with smart devices.
3. Expert Systems use large amounts of data to create rules-based systems.
4. Planners enhance scheduling and resource allocation systems.
5. Machine Learning is acquired knowledge from repeated examples in real of simulated environments.
6. Robotics use a combination of AI/ML capabilities for sensing, planning, and actions to allow embodied systems interaction with the environment.

The Joint Force has three Air Force Vanguard programs related to enhancing faster, cheaper and more efficient capabilities that would benefit from the capabilities of ABMS.¹⁰⁹ These programs are founded in the concepts related to AI, autonomous weapons, and nano technology.¹¹⁰ Specifically, these programs are Skyborg, Golden Horde, and Navigation, Technology, Satellite-3 (NTS-3). Furthermore, the programs are designed to integrate technology and deliver new capabilities across multiple domains, simultaneously, to create complex multi-disciplinary solutions.¹¹¹

¹⁰⁹ Barbara M. Barrett, “On the Future of Air and Space Power,” interview by Strategic Studies Quarterly, September 28, 2020, *Strategic Studies Quarterly* (Winter 2020): 3-5, https://www.airuniversity.af.edu/Portals/10/SSQ/documents/Volume-14_Issue-4/SECAF.pdf.

¹¹⁰ Ibid.

¹¹¹ “Skyborg,” Air Force Research Lab, accessed November 15, 2020, <https://afresearchlab.com/technology/vanguards/successstories/skyborg>.

Skyborg is a capability of manned and unmanned aircraft teams that are autonomy focused and will enable the Air Force to operate with “quick, decisive actions in contested environments.”¹¹² The concept of Skyborg is that unmanned aircraft share data and create transferable autonomy that will enable airborne combat mass.¹¹³ One potential enabler of Skyborg is Attritable/Reusable (A/R) Unmanned Aerial Vehicles (UAVs). A/R UAVs will be capable of flying a limited number of sorties and are cheap enough to be used in highly contested environments where the risk of attrition is unacceptable for manned aircraft.¹¹⁴ These A/R UAVs will utilize AI enabled autonomy to team with other aircraft in the execution of multiple mission sets (i.e. Air interdiction, Suppression of Enemy Air Defenses, etc.).¹¹⁵ The idea is that these low costs assets are procured in addition to high-end and costly aircraft to expand future combat capacity while balancing budget and requirements.¹¹⁶

Advantages and Concerns with Unmanned Autonomous Systems

From a military perspective, autonomous systems offer many advantages. Specifically, the systems are predicted to be faster, better, and cheaper. The cost of an

¹¹² “Skyborg.”

¹¹³ Ibid.

¹¹⁴ Mark Gunzinger and Lukas Autenried, “Understanding the Promise of Skyborg and Low-Cost Attritable Unmanned Aerial Vehicles,” *Air Force Magazine*, November 1, 2020, <https://www.airforcemag.com/article/the-promise-of-skyborg/>.

¹¹⁵ Ibid.

¹¹⁶ Ibid.

unmanned system is typically one-third the cost of manned systems and are not constrained by the integration of life support systems.¹¹⁷ This consideration frees up critical space and weight and enables smaller and stealthier systems.¹¹⁸ The absence of a human in the system presents commanders with additional options in high threat environments including nuclear, chemically, or biologically contaminated environments.¹¹⁹

In regard to cost, the deployment and employment financial cost of an unmanned or remotely piloted aircraft are substantial, which is partially a result of the deployed footprint being decreased by nearly 94 percent when compared to a conventional strike aircraft.¹²⁰ Figure 1 data reflects the resources needed to fulfill and sustain (beyond 30 days) a 24/7 kinetic strike capability with either a MQ-9 (unmanned aircraft) or F-16 (manned fighter aircraft).¹²¹ Some of the key takeaways are in the cost per hour difference to operate an MQ-9 versus a F-16: \$17,000 and nearly 6,000 pounds of fuel.¹²²

¹¹⁷ Ajey Lele, "Debating Lethal Autonomous Weapon Systems," *Journal of Defence Studies* 13, no. 1 (January-March 2019): 57, https://www.researchgate.net/publication/330534643_Debating_Lethal_Autonomous_Weapon_Systems.

¹¹⁸ Ibid.

¹¹⁹ Ibid.

¹²⁰ Roderic K. Butz, "Beneath the Crosshairs: Remotely Piloted Airstrikes as a Foreign Policy Tool," *Joint Force Quarterly* 100 (1st Quarter 2021): 41.

¹²¹ Ibid.

¹²² Ibid.



Figure 1. Requirement for 24/7 Sustained Flight Operations

Source: Roderic K. Butz, “Beneath the Crosshairs: Remotely Piloted Airstrikes as a Foreign Policy Tool,” *Joint Force Quarterly* 100 (1st Quarter 2021): 41.

The Human Rights Watch Organization expresses concerns on autonomous weapons systems. An August 2020 report states weapons systems that select and engage targets without human control need to be prevented and are unacceptable.¹²³ Furthermore, retaining meaningful human control during lethal engagements is an ethical imperative, a legal necessity, and a moral obligation.¹²⁴ The organization equates the challenge of “killer robots,” to climate change, and as a threat to humanity that needs urgent international action.¹²⁵

There are several key findings from the report with most concerns being centered on the potential of removing human control from the use of force. To begin with, since 2013, 97 countries have expressed views on fully autonomous weapons in a multilateral forum.¹²⁶ The active engagement by states in the United Nations Convention on Conventional Weapons (CCW) discussions regarding “killer robots” demonstrates a growing concern about removing human control from the use of force.¹²⁷ There is also widespread international acknowledgment that technological developments are enabling military weapons systems to incorporate autonomy. The vast majority of states regard

¹²³ Brian Stauffer, “Stopping Killer Robots: Country Positions on Banning Fully Autonomous Weapons and Retaining Human Control,” Human Rights Watch, last modified August 10, 2020, https://www.hrw.org/report/2020/08/10/stopping-killer-robots/country-positions-banning-fully-autonomous-weapons-and#_ftn12.

¹²⁴ Ibid.

¹²⁵ Ibid.

¹²⁶ Ibid.

¹²⁷ Ibid.

human decision-making, control, or judgment as critical to weapons system acceptability and legality leading to a widespread agreement that humans need to retain control over the use of force.¹²⁸

Since 2013, 30 countries have called for a ban on fully autonomous weapons.¹²⁹ All CCW meetings in 2014-2019 had strong considerations or convergence on the importance of retaining human control over the use of force in weapons systems.¹³⁰ At the end of 2019, CCW participating states agreed to hold four weeks of meetings in 2020-2021 to discuss developing “a normative and operational framework” for lethal autonomous weapons systems.¹³¹ The pre-conference recommendations of the Human Rights Watch is to collaborate with international states to develop law and policy to retain meaningful human control over the use of force in fully autonomous weapons.¹³²

P. W. Singer, former director of the 21st Century Defense Initiative at the Brookings Institution, also discusses several concerns with the trends of military robots and the future of war. Specifically, he raises concerns with this revolution given the state of U.S. manufacturing when it means we go to war increasingly with soldiers whose

¹²⁸ Stauffer, “Stopping Killer Robots.”

¹²⁹ Ibid.

¹³⁰ Ibid.

¹³¹ Ibid.

¹³² Ibid.

hardware is made in China and software is written in India.¹³³ Additionally, he points out that not only has software become open-source, but also warfare.¹³⁴ For example, to build effective robotics you do not need a massive manufacturing system, which is contrary to an aircraft carrier or atomic bomb.¹³⁵ Moreover, a lot of it is do it yourself or available off the shelf. It is estimated for about a thousand U.S. dollars you could build a drone similar to the U.S. Army's handheld Raven drone.¹³⁶ He proposes that out of this environment we are going to see two trends. First, it is going to reinforce the power of individuals against governments, and second there will be an expansion in the realm of terrorism.¹³⁷

Furthermore, there is concern of the second and third order effects when using robotics and autonomous weapons systems and how they will influence our politics and decisions to go to war.¹³⁸ He quotes a former Assistant Secretary of Defense for Ronald Reagan with this statement: "I like these systems because they save American lives, but I worry about more marketization of wars, more shock-and-awe talk, to defray discussion of the costs. People are more likely to support the use of force if they view it as

¹³³ P. W. Singer, "Military Robots and the Future of War," (lecture, TED Conferences LLC, February 2009), https://www.ted.com/talks/p_w_singer_military_robots_and_the_future_of_war/transcript?language=en.

¹³⁴ Ibid.

¹³⁵ Ibid.

¹³⁶ Ibid.

¹³⁷ Ibid.

¹³⁸ Ibid.

costless.”¹³⁹ Singer reinforces this idea by arguing that the threshold to go to war is increasingly lowered as we convert more American soldiers that would be sent into harm’s way to machines.¹⁴⁰ He proposes that the future of war is already here with all of the advancements that have been made in this field in the last two decades. He states that now is the time to face the reality of 21st century war in order to not make the same mistake that a past generation did with atomic weaponry, and deal with the issues that currently surround it.¹⁴¹

In order to work through these issues and remain competitive in the AI race, the DOD created the Joint Intelligence Center (JAIC).¹⁴² As noted, AI is improving rapidly, and visions exist of it enabling autonomous systems to conduct missions, achieve sensor fusion, automate task, and make quicker decisions.¹⁴³ However, some believe that in the near term AI’s impact will only be mundane and used to perform monotonous task in uncontested environments.¹⁴⁴ It is currently effective at image recognition, recommendation systems, and language translation but in other areas AI has been less effective or short of human level achievement such as understanding the context of texts,

¹³⁹ Singer, “Military Robots and the Future of War.”

¹⁴⁰ Ibid.

¹⁴¹ Ibid.

¹⁴² Paul Maxwell, “Artificial Intelligence is the Future of Warfare (just not in the way you think),” Modern War Institute, last modified April 20, 2020, <https://mwi.usma.edu/artificial-intelligence-future-warfare-just-not-way-think/>

¹⁴³ Ibid.

¹⁴⁴ Ibid.

and multitasking (i.e. being able to solve multi type problems).¹⁴⁵ Overall, AI systems are trained for specific tasks with some examples including identifying weapons systems imagery, locating high-value targets in a crowd using facial recognition, translating text, and text generation.¹⁴⁶ AI has also been useful in areas where there are large quantities of data. One of the challenges associated with AI is that the developers need access to data which in many cases government organizations prefer to classify and restrict access.¹⁴⁷ Data sets for AI systems are also vulnerable to becoming very large (and thus slow) resulting in susceptibility to “dimensionality issues.”¹⁴⁸ For example, training systems designed to recognize weapons systems in some cases can require an exhaustive number of images in order to be completely accurate.¹⁴⁹

There is also concern that in contested domains AI systems can be easily fooled by adversarial attacks or manipulation.¹⁵⁰ Adversarial attacks can be separated into four categories: evasion, inference, poisoning, and extraction.¹⁵¹ Evasion attacks attempt to trick an AI engine to avoid detection (e.g., convincing a sensor that a tank is a school

¹⁴⁵ Maxwell, “Artificial Intelligence is the Future of Warfare.”

¹⁴⁶ Ibid.

¹⁴⁷ Ibid.

¹⁴⁸ Ibid.

¹⁴⁹ Ibid.

¹⁵⁰ Ibid.

¹⁵¹ Ibid.

bus).¹⁵² Inference attacks gain information about an AI system to enable invasion attacks. Poisoning attacks occur during training such as enemy access to the data sets used to train tools.¹⁵³ Extraction attacks attempt to create a parallel model of the system by exporting access to an AI interface.¹⁵⁴ If unauthorized access occurred one could predict decisions made by our systems, and could be used to predict how an AI controlled unmanned system will respond and thus manipulate his route and behavior with certain visual and electromagnetic stimuli.¹⁵⁵ For example, Chinese researchers have tested and claimed success in fooling the AI algorithms on Tesla's cars by subtly altering data fed to the car's sensors.¹⁵⁶ Specifically, this was accomplished by modifying the lane markings on the road, which confused the driving system and drove the car into oncoming traffic.¹⁵⁷ This hack shows that winning the AI battle might rest in mastering the uncertain vulnerabilities of the software versus employing the most impressive weapons.¹⁵⁸

¹⁵² Maxwell, "Artificial Intelligence is the Future of Warfare."

¹⁵³ Ibid.

¹⁵⁴ Ibid.

¹⁵⁵ Ibid.

¹⁵⁶ Will Knight, "Military artificial intelligence can be easily and dangerously fooled," *Technology Review*, last modified October 21, 2019, <https://www.technologyreview.com/2019/10/21/132277/military-artificial-intelligence-can-be-easily-and-dangerously-fooled/>

¹⁵⁷ Ibid.

¹⁵⁸ Ibid.

Additionally, some have concerns that “deep learning” algorithms, which function different from human perception and are used in attack unmanned aircraft or software to analyze satellite images, could be fooled with similar techniques.¹⁵⁹ Deep learning involves inputting data, such as the pixels of an image, to continuously alter connections to the network using mathematical techniques so that the output gets closer to a particular outcome.¹⁶⁰ Despite implementation of these techniques in uncontested environments, AI systems can struggle to process images that are different from its training sets such as poor lighting conditions, an obtuse angle, or partially obscured.¹⁶¹

AI systems are also currently unable to multitask; whereas a human can identify an enemy vehicle, decide on a weapon, predict the targets path, and then engage the target, this is currently impossible for an AI system and would require transfer learning which is years away from implementation.¹⁶² For example, a system trained to identify a T-90 tank would be unable to identify a Chinese Type 99 tank even though both are tanks.¹⁶³ Furthermore, many of the decisions AI enabled systems make are difficult to trace or understand. This is concerning for systems which make critical or high-risk

¹⁵⁹ Knight, “Military artificial intelligence can be easily and dangerously fooled.”

¹⁶⁰ Ibid.

¹⁶¹ Maxwell, “Artificial Intelligence is the Future of Warfare.”

¹⁶² Ibid.

¹⁶³ Ibid.

decisions involving target engagements, and an ability to audit is important for legal and moral considerations.¹⁶⁴

Strategic Environment, China and Russia Artificial Intelligence Investments

It is important during systems development to ensure that systems are aligned with strategic and operating environment conditions or end states. In VUCA (volatility, uncertainty, complexity, and ambiguity) environments, which are characterized by rapidly changing variables, there are requirements for different systems to meet evolving conditions.¹⁶⁵ This could occur in LSCO environments as the conflict progresses through the different phases of combat operations. It could also occur as operational requirements change to meet the full range of military operations across the spectrum of conflict. It is also important to realize that in an environment of great power competition it is necessary to develop systems before you need them so that you are able to respond quickly.¹⁶⁶ Also, systems need to be developed in ways that they are adaptable to the changing variables the operational environment. Overall, in an environment of great power competition the variables of VUCA change frequently. It is therefore important to have a solid understanding of the advancements our great power competitors are making in order to fully comprehend the strategic environment.

¹⁶⁴ Maxwell, “Artificial Intelligence is the Future of Warfare.”

¹⁶⁵ Kenneth E. Long, “VUCA Environment,” (lecture notes, U.S. Army Command and General Staff College, Fort Leavenworth, KS, January 2021).

¹⁶⁶ Ibid.

Both Chinese and Russian leaders have commented on the importance of these technologies to national level strategy. In July 2017, China announced its AI strategy declaring that “the world’s major developed countries are taking the development of AI as a strategy to enhance national competitiveness and protect national security.”¹⁶⁷ Vladimir Putin of Russia declared “whoever becomes the leader in [the AI] sphere will become ruler of the world.”¹⁶⁸

China’s strategy to develop AI has been described as non-linear with many different entities contributing such as the central government, domestic companies, and international trade.¹⁶⁹ In 2017, China released the “New Generation Artificial Intelligence Development Plan (AIDP).”¹⁷⁰ It is believed that China’s local and national investment in AI is in the tens of billions of dollars with the Shanghai municipal government investing \$14.6 billion in 2018.¹⁷¹

Chinese officials and government reports have begun to express similar concerns that AI “will lower the threshold of military action,” since states may be more willing to

¹⁶⁷ Knight, “Military artificial intelligence can be easily and dangerously fooled.”

¹⁶⁸ Ibid.

¹⁶⁹ Millicent Abadicio, “Artificial Intelligence in the Chinese Military-Current Initiatives,” Emerj, last modified November 21, 2019, <https://emerj.com/ai-sector-overviews/artificial-intelligence-china-military/>

¹⁷⁰ Gregory C. Allen, “Understanding China’s AI Strategy,” Center for a New American Society, February 6, 2019, <https://www.cnas.org/publications/reports/understanding-chinas-ai-strategy>.

¹⁷¹ Ibid.

take military action due to decreased risk to life.¹⁷² China's private sector has also expressed concern that global competition over AI could lead to an arms race and/or war.¹⁷³ Despite these concerns, the majority of China's leadership supports military usage of AI and are aggressively pursuing it.¹⁷⁴ Specifically, China's military seeks to "narrow the gap between the Chinese military and global advance powers" and taking advantage of the "ongoing military revolution . . . centered on information technology and intelligent technology."¹⁷⁵ An executive from China's third largest defense company Zeng Yi, described the future of AI implementation as a future battleground where no people are fighting. Zeng also predicts that by 2025 lethal autonomous weapons will be commonplace.¹⁷⁶

Additionally, China is currently the largest exporter of unmanned aircraft. The Stockholm International Peace Research Institute reported that from 2009-2013 China exported 10 unmanned aircraft to two countries. From, 2014-2018 it exported 153 to 13 countries, 5 of which were in the Middle East (Egypt, Iraq, Jordan, Saudi Arabia, and the

¹⁷² Allen, "Understanding China's AI Strategy."

¹⁷³ Ibid.

¹⁷⁴ Ibid.

¹⁷⁵ Ibid.

¹⁷⁶ Ibid.

UAE).¹⁷⁷ As a result, many have an increasing concern on the impact to peace and security due to the proliferation of unmanned aircraft.¹⁷⁸

China's national strategy also mentions that AI is a "major strategic opportunity" and proposed to "build China's first mover advantage" and lead the world in AI technology.¹⁷⁹ AI and autonomous functions have the ability to affect the character of war in several macro ways. For example, autonomous systems utilizing AI have the ability to increase the speed with which countries fight, despite whether or not humans are making the final decisions about the use of lethal force.¹⁸⁰

Many of China's drones are currently remotely piloted, however Chinese officials expect unmanned aircraft and military robotics to feature more elaborate AI and autonomous capabilities in the future.¹⁸¹ The Chinese government also intends to export its next generation stealth unmanned aircraft when available. Unmanned aircraft with autonomous capabilities are already being sold to other countries. For example, the Blowfish A2 model was sold to the UAE which has claimed capabilities to

¹⁷⁷ Abadicio, "Artificial Intelligence in the Chinese Military-Current Initiatives."

¹⁷⁸ Ibid.

¹⁷⁹ Michael C. Horowitz, "Artificial Intelligence, International Competition, and the Balance of Power," *Texas National Security Review* 1, no. 3 (May 2018): 37-57, <https://doi.org/10.15781/T2639KP49>.

¹⁸⁰ Ibid.

¹⁸¹ Allen, "Understanding China's AI Strategy."

“autonomously perform more complex combat missions, including fixed point timing detection, fixed range reconnaissance, and targeted precision strikes.”¹⁸²

Russia is also investing heavily in AI, primarily for military applications.¹⁸³ Reports suggest that the Russian military is designing autonomous submarines that could carry nuclear weapons as well as autonomous vehicles to guard against ballistic missile bases.¹⁸⁴ In October 2019, the Russian government released a national AI strategy¹⁸⁵ that is poised to better organize their AI efforts in an order to manage shortfalls in breakthroughs and funding when compared to other global competitors.¹⁸⁶ For example, the Russian Ministry of Defense in coordination with the Ministry of Education and Science has developed a 10-point plan to focus Russia’s academic, scientific, and commercial communities to collectively advance and compete in AI technologies.¹⁸⁷

¹⁸² “Blowfish A2 Product Overview,” Ziyen, January 2019, <http://ziyanuav.com/blowfish2.html>.

¹⁸³ Horowitz, “Artificial Intelligence, International Competition, and the Balance of Power.”

¹⁸⁴ Ibid.

¹⁸⁵ Margarita Konaev, “Thoughts on Russia’s AI Strategy,” Center for Security and Emerging Technology, October 30, 2019, <https://cset.georgetown.edu/article/thoughts-on-russias-ai-strategy/>.

¹⁸⁶ Samuel Bendett, “Here’s How the Russian Military is Organizing to Develop AI,” *Defense One*, last modified July 20, 2018, <https://www.defenseone.com/ideas/2018/07/russian-militarys-ai-development-roadmap/149900/>.

¹⁸⁷ Ibid.

Russian leadership believes that AI technologies are critical to remain competitive with the other world great powers, U.S. and China.¹⁸⁸

Currently, Russia lags behind in research and development which is most likely attributed to its smaller economy leading to less available funding and resources. For example, Russia's gross domestic product (GDP) is two percent of global GDP compared to 24 percent for the U.S and 15 percent for China.¹⁸⁹ Reports estimate that Russia's investment in AI is approximately \$12.5 million/year.¹⁹⁰ Comparatively, China plans to invest \$150 billion through 2030, and the U.S. spends \$7.4 billion annually on unclassified AI and related fields.¹⁹¹

Despite funding limitations, the Russian ministry of Defense has developed and funded various AI projects.¹⁹² One particular project led by the military-related United Instrument Making Corporation involves the Russian Academy of Sciences, various universities, and more than 30 private companies.¹⁹³ Additionally, Russia's Foundation for Advanced Studies, similar to the U.S. Defense Advanced Research Projects Agency,

¹⁸⁸ Alina Polyakova, "Weapons of the weak: Russia and AI-driven asymmetric warfare," The Brookings Institution, November 15, 2018, <https://www.brookings.edu/research/weapons-of-the-weak-russia-and-ai-driven-asymmetric-warfare/>

¹⁸⁹ Ibid.

¹⁹⁰ Ibid.

¹⁹¹ Ibid.

¹⁹² Samuel Bendett, "In AI, Russia is Hustling to Catch Up," *Defense One*, April 4, 2018, <https://www.defenseone.com/ideas/2018/04/russia-races-forward-ai-development/147178/>.

¹⁹³ Ibid.

announced its efforts to standardize AI development with four lines of effort: image recognition, speech recognition, control of autonomous military systems, and information support for weapon's life cycle.¹⁹⁴

There are several Russian practical military usages which will impact the air domain. One example is Russia anticipates using AI to analyze and automate satellite imagery and radar data, by quickly identifying targets in enemy air or ground forces.¹⁹⁵ The fastest breakthroughs in AI will occur with machine learning and are being accelerated in the realm of electronic warfare due to increased collection opportunities in recent years.¹⁹⁶ Specifically, Russian electronic warfare units have deployed to Syria, eastern Ukraine, and Crimea where they are able to mass data on performance, electronic signals, and signatures of American and other western assets.¹⁹⁷ This has provided Russia with an opportunity to collect on and test their systems in actual wartime environments.

Case Study: Chinese Airspace

Modern military history has shown that combined arms and synergistic effects from multiple domains that create compounding dilemmas for the enemy are the key components to winning in LSCO. U.S. airpower in particular has been critical to our nation's previous successes.

¹⁹⁴ Bendett, "In AI, Russia is Hustling to Catch Up."

¹⁹⁵ Ibid.

¹⁹⁶ Ibid.

¹⁹⁷ Ibid.

Historically, the DOD has executed a Suppression of Enemy Air Defense (SEAD) concept that involved communication jamming using the EC-130H (Air Force) and EA-6B (Navy), radar jamming by EA-6Bs (Navy) and EF-111s (Air Force), and physical destruction of enemy radars with AGM-88 HARMs fired from tactical fighters.¹⁹⁸ U.S. SEAD missions have become more dangerous however as long-range SAM batteries have begun to outrange HARMs.¹⁹⁹

As a result, China's People's Liberation Army (PLA) planners have recognized the importance of contesting U.S access to airspace in preparation for conflict.²⁰⁰ China has invested in two paths to challenge U.S airpower. First, it has deployed and developed capabilities that threaten U.S air bases and aircraft carriers.²⁰¹ These include ISR capabilities, ballistic missile and cruise missiles, submarines, and strike aircraft. Second, is the improvement of China's integrated air defense systems.²⁰² The improvements to China's air defense capabilities have occurred in exponential increments over the last 20 years. They were initially accomplished through defense modernization efforts which relied heavily on foreign military imports; however, China has also improved its

¹⁹⁸ Eric Heginbotham, Michael Nixon, Forrest E. Morgan, Jacob L. Heim, Jeff Hagen, Sheng Li, Jeffrey Engstrom, Martin C. Libicki, Paul DeLuca, David A. Shlapak, David R. Frelinger, Burgess Laird, Kyle Brady, and Lyle J. Morris, *The U.S-China Military Scorecard* (Santa Monica, CA: RAND, 2017), 97, https://www.rand.org/pubs/research_reports/RR392.html.

¹⁹⁹ Ibid.

²⁰⁰ Ibid., 103.

²⁰¹ Ibid., 97.

²⁰² Ibid.

industrial capacity to produce advanced systems internally. For example, Russia has delivered 160 S-300 PMU (SA-10C) and S-300 PMU-1 and -2 (SA-20A and B).²⁰³ Additionally, the People's Liberation Army Rocket Force is anticipating two S-400 regiments estimated at \$3 billion total acquisition costs.²⁰⁴ The S-400 is regarded as an advanced SAM system with improved radar and updated software when compared to its predecessor the S-300, and it has an alleged range of 250 kilometers.²⁰⁵

Conducted with unclassified scenarios, the RAND corporation case study provides useful simulation and analysis of U.S. capability to penetrate Chinese air defenses. Overall, the scenarios and models calculate the risk to attacking aircraft when attempting to reach aircraft weapon's range for a notional target set of 2,000+ targets. The scenarios incorporate a complete spectrum of Chinese integrated air defenses including surface to air missile sites, defensive counter air (DCA) missions, and early-warning or SAM radar detection. Figure 2, below, highlights the locations of SAM systems and DCA orbits with estimated coverage areas for 2010 and 2017.

²⁰³ Heginbotham et al., *The U.S-China Military Scorecard*, 98.

²⁰⁴ Franz-Stefan Gady, "Russia to Begin Delivery of China's Second S-400 Air Defense System Regiment in July," *The Diplomat*, April 3, 2019, <https://thediplomat.com/2019/04/russia-to-begin-delivery-of-chinas-second-s-400-air-defense-system-regiment-in-july/>.

²⁰⁵ Ibid.

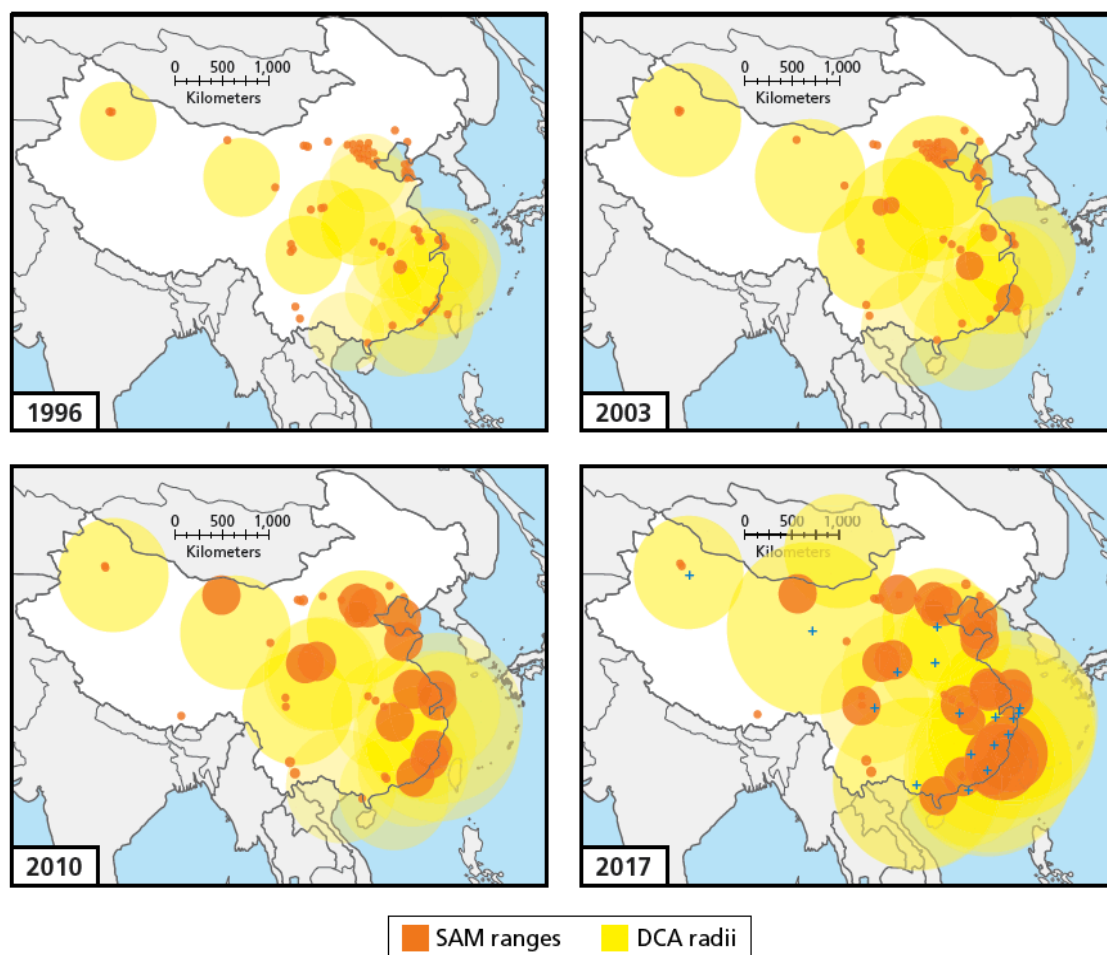


Figure 2. SAM and Defensive Counter-Air Coverage

Source: Eric Heginbotham, Michael Nixon, Forrest E. Morgan, Jacob L. Heim, Jeff Hagen, Sheng Li, Jeffrey Engstrom, Martin C. Libicki, Paul DeLuca, David A. Shlapak, David R. Frelinger, Burgess Laird, Kyle Brady, and Lyle J. Morris, *The U.S.-China Military Scorecard* (Santa Monica, CA: RAND, 2017), 109, https://www.rand.org/pubs/research_reports/RR392.html.

Figure 3 plots the locations (i.e., notional targets) used in the analysis. For the Taiwan scenario it focused on the ability of U.S. aircraft to safely attack a subset of 823

targets (highlighted in red in Figure 3) which are located within 1,000 km of Taipei.²⁰⁶

The analysis of the Spratly Islands scenario focused on 100 targets within 1,300 km of Thitu Island (green in Figure 3).²⁰⁷

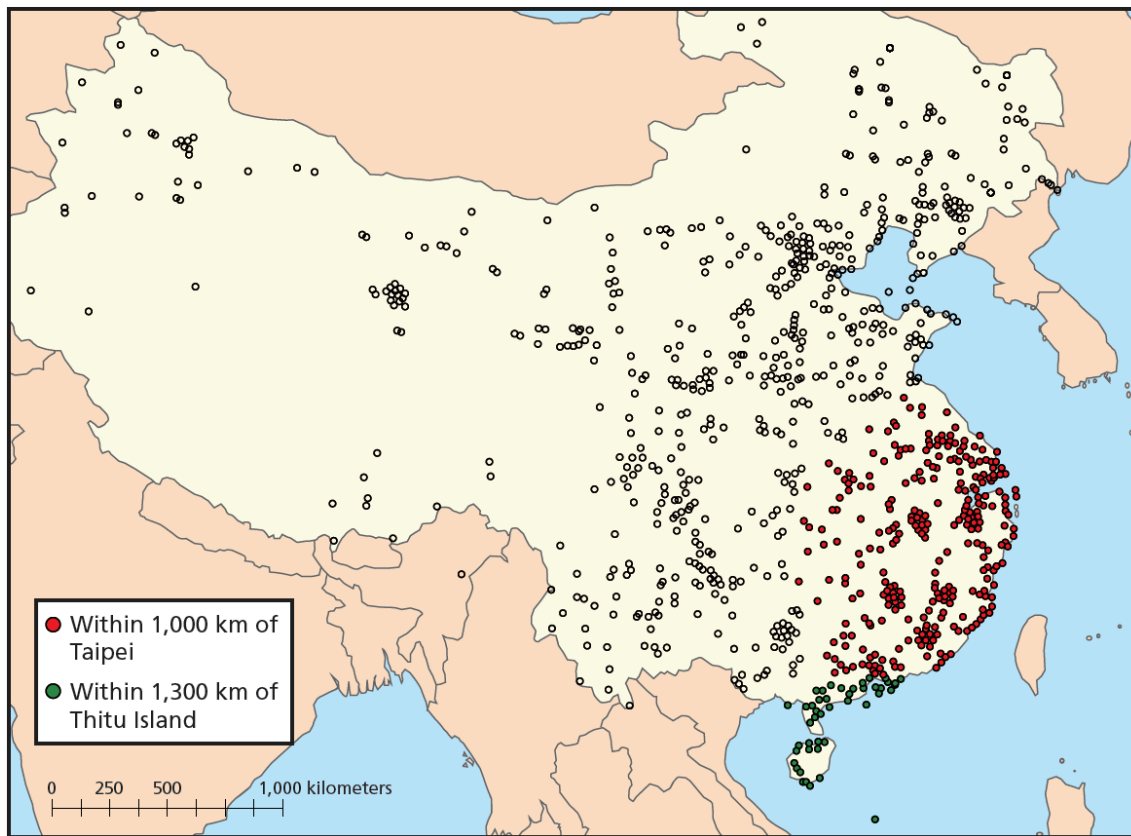


Figure 3. Targets in China

Source: Eric Heginbotham, Michael Nixon, Forrest E. Morgan, Jacob L. Heim, Jeff Hagen, Sheng Li, Jeffrey Engstrom, Martin C. Libicki, Paul DeLuca, David A. Shlapak, David R. Frelinger, Burgess Laird, Kyle Brady, and Lyle J. Morris, *The U.S-China Military Scorecard* (Santa Monica, CA: RAND, 2017), 110, https://www.rand.org/pubs/research_reports/RR392.html.

²⁰⁶ Heginbotham et al., *The U.S-China Military Scorecard*, 109.

²⁰⁷ Ibid.

The simulation models were completed with similar criteria in two geographical scenarios located near Taiwan and the Spratly Islands. The simulation and modeling specifics for the scenario settings is very detailed in the report and represents abundant technical rigor. As such, it is only necessary to capture some of the key findings which are related to this research.

Figure 4 shows outcomes for U.S. fourth generation aircraft. Specifically, it shows aircraft armed with HARMs and flying at high altitude and attacking different SAM systems without the protection of electronic warfare support.²⁰⁸ The blue dot represents an attacking 4th-generation aircraft with SEAD weapons.²⁰⁹ The radar cross section of the attacking SEAD aircraft rests on the horizontal axis, while the range of the SEAD weapon is on the vertical axis.²¹⁰

²⁰⁸ Heginbotham et al., *The U.S-China Military Scorecard*, 123.

²⁰⁹ Ibid.

²¹⁰ Ibid.

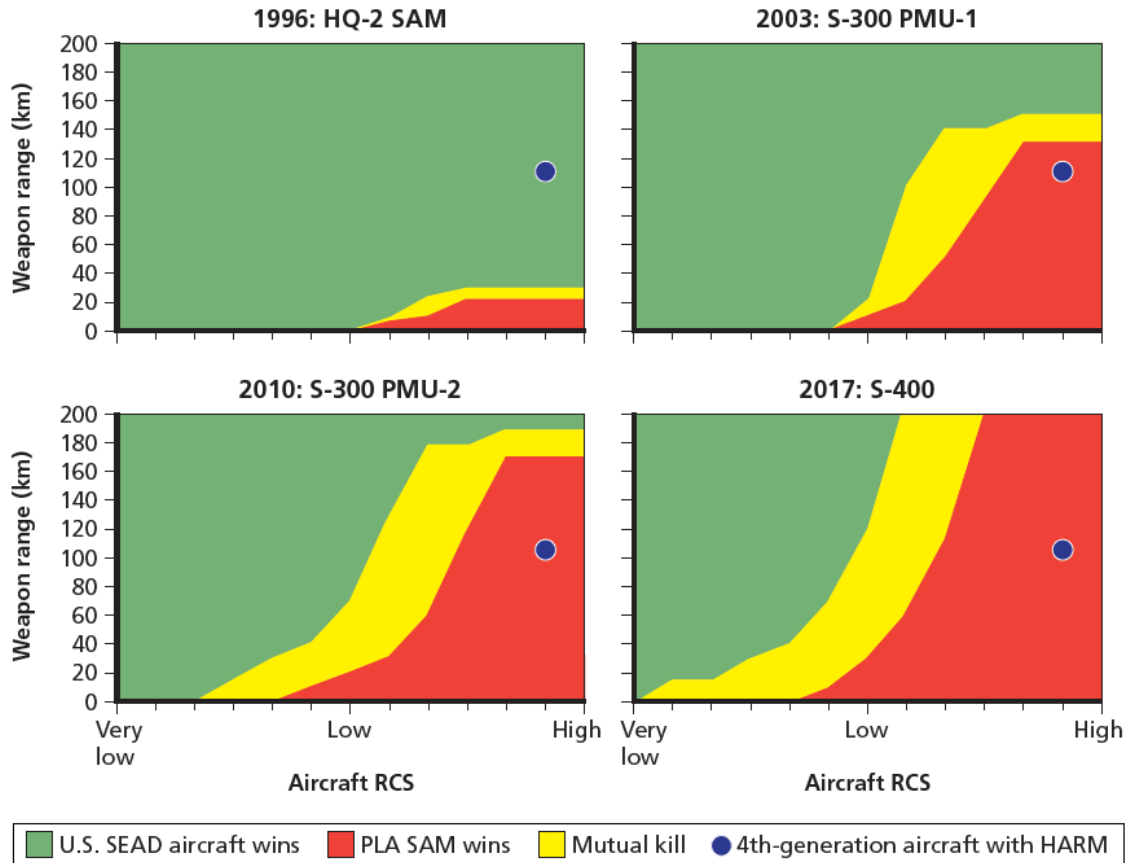


Figure 4. U.S. Fourth Generation Aircraft Versus Selected Chinese SAM Systems

Source: Eric Heginbotham, Michael Nixon, Forrest E. Morgan, Jacob L. Heim, Jeff Hagen, Sheng Li, Jeffrey Engstrom, Martin C. Libicki, Paul DeLuca, David A. Shlapak, David R. Frelinger, Burgess Laird, Kyle Brady, and Lyle J. Morris, *The U.S-China Military Scorecard* (Santa Monica, CA: RAND, 2017), 123, https://www.rand.org/pubs/research_reports/RR392.html.

Overall, the RAND report assesses that the U.S. militaries' plan to use a combination of stealth, jamming, and standoff weapons appears to be marginally successful in meeting the challenges identified against the Chinese IADs.²¹¹ However, the advantage is greater in the Spratly Islands scenario which is in the peripherals of the

²¹¹ Heginbotham et al., *The U.S-China Military Scorecard*, 130.

Chinese mainland and where integrated air defense systems are not as concentrated. Moreover, the U.S. is faced with a problem of scale given the cost of high-end systems that would be necessary for a conflict with China.²¹² Furthermore, the advancements of the modern Chinese air defenses pose a severe threat to legacy aircraft which makes it more difficult for U.S. forces to deliver ordinance in the volume that has been possible in previous conflicts without substantial risk to U.S. aircraft. Figure 5 summarizes the results from the narrative above.

Scorecard	Taiwan Conflict				Spratly Islands Conflict			
	1996	2003	2010	2017	1996	2003	2010	2017
1. Chinese attacks on air bases								
2. U.S. vs. Chinese air superiority								
3. U.S. airspace penetration								
4. U.S. attacks on air bases								
5. Chinese anti-surface warfare								
6. U.S. anti-surface warfare								
7. U.S. counterspace								
8. Chinese counterspace								
9. U.S. vs. China cyberwar								
10. Nuclear stability								

Key for Scorecards 1–9		
U.S. Capabilities		Chinese Capabilities
Major advantage		Major disadvantage
Advantage		Disadvantage
Approximate parity		Approximate parity
Disadvantage		Advantage
Major disadvantage		Major advantage

Figure 5. Scorecard Summary Coding

Source: Eric Heginbotham, Michael Nixon, Forrest E. Morgan, Jacob L. Heim, Jeff Hagen, Sheng Li, Jeffrey Engstrom, Martin C. Libicki, Paul DeLuca, David A. Shlapak, David R. Frelinger, Burgess Laird, Kyle Brady, and Lyle J. Morris, *The U.S-China Military Scorecard* (Santa Monica, CA: RAND, 2017), 131, https://www.rand.org/pubs/research_reports/RR392.html.

²¹² Heginbotham et al., *The U.S-China Military Scorecard*, 130.

CHAPTER 3

RESEARCH METHODOLOGY

The implementation of lethal unmanned aircraft utilizing artificial intelligence and human teaming technologies is a complex issue which requires multiple research methods. As such, this chapter considers methods utilized by both the U.S. military and civilian professionals. The result is a unified framework which combines useful elements from multiple models that will guide the analysis of the issue.

Relevant Resources

Applied Professional Case Study Research

The Applied Professional Case Study (APCSR) method applies the best practices of the Army Professional Body of Knowledge to provide recommendations for DOD warfighting capabilities. The method recognizes that professional experience is efficient for solving simple problems and generating efficient decisions, but is challenged to solve complicated, complex, and chaotic issues, which require a research-oriented approach. As such, APCSR applies a research-oriented approach that is multi-perspective, critical, and systematic.²¹³ The method applies a R1, R2, and R3 construct to demonstrate critical thinking backed by a sufficient research process.²¹⁴

²¹³ Seck Tai David Kwek, “Future of Singapore’s Conscript Army,” (Master’s thesis, U.S Army Command and General Staff College, Fort Leavenworth, KS, 2019).

²¹⁴ Kenneth E. Long, “Emerging Best Practices from Professional Applied Case Study Research,” (lecture notes, U.S. Army Command and General Staff College, Fort Leavenworth, KS, September 15, 2016).

R1 is the pre-research individual position or what the officer would recommend prior to conducting research, which allows assumptions and biases to be drafted in the research transparently. R2 occurs after a literature review and the first round of analysis leading to an updated personal position, which is evolved from R1 as a result of reading, analysis, and dialogue with the research committee. In order to update this position into a vetted recommendation, it is refined further through Stakeholder Lens Analysis, to reflect a systematic critical thinking approach. R3 is the updated set of recommendations that demonstrate improvements and adaptations to the R2 position as a result of various stakeholders evaluating the recommendations with suitable, feasible, and acceptable criteria.²¹⁵ For this thesis, the APCSR will be the primary framework and secondary methodologies will be used where appropriate.

Joint Operational Design

The Joint Planning Process (JPP), specifically Joint Operational Design, is methodology used by commanders and staff to organize and understand the operational environment. There are four elements in operations design: strategic guidance, concept development, plan development, and plan assessment. These elements have characteristics that are distinct from one another and are not necessarily sequential. The

²¹⁵ Kenneth E. Long, "The Applied Professional Case Study Methodology and Design," (Course Curriculum, U.S. Army Command and General Staff College, Fort Leavenworth, KS), accessed 26 November 2020, https://cgsc.blackboard.com/webapps/blackboard/content/listContent.jsp?course_id=_8676_1&content_id=_688072_1&mode=reset.

design is used to develop an understanding of the operational environment and problem prior to developing operational approaches. The general methodology design is:²¹⁶

1. Understand the strategic direction and guidance
2. Understand the strategic environment
3. Understand the operational environment
4. Define the problem
5. Identify assumptions needed to continue planning (strategic and operational assumptions)
6. Develop options
7. Identify decisions and decision points
8. Refine the operational approach
9. Develop planning guidance

This process will be used to frame the issue given the complex strategic and operational considerations. As such, joint operational design will be used as a starting point to enter the APCSR framework and provide structure to the research.

Capabilities Based Assessment

The Capabilities Based Assessment (CBA) identifies capability requirements and associated capability gaps by providing an analytic basis prior to development and

²¹⁶ Joint Chiefs of Staff (JCS), Joint Publication (JP) 5, *Doctrine for the Armed Forces of the United States* (Washington, DC: JCS, 2017), https://www.jcs.mil/Portals/36/Documents/Doctrine/pubs/jp5_0.pdf?ver=us_fQ_pGS_u65ateysmAng%3d%3d.

submission of capability requirements documents for validation.²¹⁷ The assessment begins with an analysis of the future operating environment. The CBA converts planning guidance into required capabilities and solutions through a three-phase process of Functional Area Analysis (FAA), Functional Needs Analysis (FNA), and Functional Solutions Analysis (FSA).²¹⁸ This thesis will conduct a modified CBA through the literature review and to determine the required capabilities needed to meet the future requirements identified in strategic guidance and operational concepts. These will be grouped in the domains of doctrine, organization, training, materiel, leadership, personnel, facilities, and policy (DOTMLPF-P).

Strengths, Weaknesses, Threats, and Opportunities (SWOT) Analysis

Traditional SWOT analysis is a business analysis tool that conducts an internal examination of an organization's strengths and weaknesses, and then examines the environment to identify external opportunities and threats.²¹⁹ These factors are then all synthesized into a strategic plan. A reformed SWOT analysis framework recognizes that threats and opportunities can be both internal and external, and that they can be shaped by

²¹⁷ Chairman of the Joint Chiefs of Staff (CJCS), CJCS Instruction 5123.01H, *Charter of the Joint Requirements Oversight Council (JROC) and Implementation of the Joint Capabilities Integration and Development System (JCIDS)* (Washington, DC: Joint Staff, August 31, 2018), C-B-3.

²¹⁸ U.S. Army War College, *How the Army Runs: A Senior Leader Reference Handbook, 2013-2014* (Carlisle, PA: US Army War College, 2013), 3-14, <https://apps.dtic.mil/dtic/tr/fulltext/u2/a590723.pdf>.

²¹⁹ Adam Bradenburg, "Are Your Company's Strengths Really Weaknesses?," *Harvard Business Review*, August 22, 2019, <https://hbr.org/2019/08/are-your-companys-strengths-really-weaknesses>.

the strengths and weakness of internal and external players (i.e. the capabilities and deficiencies of other players matter, not just your own).²²⁰ Since current strategic guidance focuses on great power competition to shape our future operational concepts, this thesis will use the form of SWOT analysis which factors the strengths and weaknesses of internal and external players in order to develop a more complete analysis of military opportunities and threats.

Applied Methodology

Using the Applied Professional Case Study Research method²²¹ as the primary framework, this thesis will be structured in three phases. The first phase will focus on framing the issue and obtaining a strategic estimate and includes the pre-research position (R1) and literature review of Chapter 2. This is then inserted into the Joint Operational Design framework to identify an operational approach to achieve the desired end state of a joint force capable of quicker decisions and greater lethality through the applications of AI and human teaming. The second phase will focus on the development and analysis of possible solutions and will use suitable, feasible, and acceptable criteria and stakeholder analysis to ensure solutions are viable. Suitability criteria will focus on whether the solutions accomplish the strategic intent. For feasibility, the author and stakeholders will apply their professional evaluations based on experience and relevant criteria from the literature review. Feasibility will also consider if the solutions are achievable under current resource constraints. The output of this second phase will be the author's

²²⁰ Bradenburg, "Are Your Company's Strengths Really Weaknesses?."

²²¹ Kwek, "Future of Singapore's Conscript Army."

professional recommendation (R2). For acceptability, the author will further analyze the proposed solutions and consider the perspectives of the Chief Decision Makers by conducting stakeholders interviews to produce the final recommendation (R3). The interviews will be used to better inform the analysis section and cover any gaps in knowledge. The primary focus of the interviews will be to gather data and information that is based on the participants professional experiences related to the research topic. The third and final phase will be codified in Chapter 5 and will consider how the recommendations should be implemented with considerations to the Kotter Change Model.

Ethical Assurances

The author has networked with the Headquarters Air Force (HAF) Artificial Intelligence Cross Functional Team (AICFT) in order to discuss the research topic and learn more about the current efforts of the Air Force and Joint Force. This relationship was leveraged in order to establish additional points of contact within HAF and the Joint Staff, who have subject matter expertise related to the research topic. Experts outside of the AICFT were asked to voluntarily participate and contribute to the research through an interview. One of the staff officers is a communications officer currently working requirements for future systems on a MAJCOM staff located in the Indo Pacific region. Another is on the joint staff and a weapons school graduate with extensive remotely piloted aircraft operational experience and is currently working AI development initiatives. The other two interviewees are both graduated squadron commanders of manned and unmanned aircraft units with degrees from DOD endorsed Advanced

Academic institutions who are currently advising Joint and Air Force senior leaders on strategies to implement future airpower systems.

Participants were provided a copy of the most current research prospectus in order to ensure a clear understanding of the research, and that participants volunteer with informed consent. Additionally, participants were provided a detailed informed consent form which includes the procedures that will be followed to address human subject's protection requirements (Appendix A). The interview questions can be referenced in Appendix B. Interviews were conducted via Microsoft Teams with government accounts for enhanced security measures. It should be acknowledged that there is a small risk of hacking in MS Teams, possibly enabling third parties to digitally link that participant's identity with the recorded data. The researcher will mitigate this risk through the use of a virtual private network (VPN) to enhance the security of recorded interviews.

Furthermore, interviews were conducted on a personal computer that is password protected to prevent anyone else from access. The interviews were conducted in a private room to prevent others from observing, and they will initially be recorded using the platform's recording function and then transcribed into a digital print format. Any physical documents created and analyzed were de-identified and stored in a locked desk when not in use. After transcription was complete, the video was deleted to reduce any risk of spillage. The transcript was then be emailed to the participant for review prior to use within the research paper.

In order to comply with DoDI 3216.02, the data will be secured for three years after completion of the MMAS degree with the exception of the video files which will be deleted once the interview is transcribed into a digital print format. The researcher (i.e.,

principal investigator) will store data collected in an encrypted file on a password protected laptop and not within a shared file or cloud-based platform.

CHAPTER 4

ANALYSIS

This chapter will use the knowledge gained from the Chapter 2 literature review combined with the methodologies identified in Chapter 3 to answer the primary research question: What types of autonomous functions should lethal unmanned aircraft utilizing artificial intelligence and human teaming technologies be capable of given command and control challenges in non-permissive large-scale combat environments? This will be accomplished in two sections. First, a strategic estimate based on literature reviewed in Chapter 2 to provide the context for which the analysis is being conducted. Second, the author will present four types of lethal autonomous unmanned aircraft which were identified in the literature review as capabilities currently being developed and that the joint force could integrate. These four types will be analyzed with a strengths, weaknesses, opportunities, and threats methodology as they are presented which will also help to determine if they are suitable, feasible, and acceptable. Third, this chapter will conclude with an updated professional recommendation (R2) followed by insights from stakeholder interviews (R3) which will be used to inform and improve the final recommendations and conclusions of Chapter 5.

Strategic Estimate

Operational Approach

The Chapter 2 literature review revealed that artificial intelligence, autonomous functions, and human teaming technological advancements are capabilities that are increasingly being pursued by the U.S. and its strategic competitors. Since AI has many

potential purposes,²²² innovation is continuously fueled, and closely related algorithms of military and civilian applications cause advances in AI to disseminate around the world more rapidly.²²³ This in turn has increased competition with China and Russia and creates an evolving strategic environment centered on technological advancements. This makes the DOD's mission statement "to provide the military forces needed to deter war and ensure our nation's security" even more globally challenging. Therefore, it is critical that the U.S. identify and develop the capabilities necessary to "develop the joint force of the future" and "improve joint war fighting readiness" in order to ensure the DOD's mission.²²⁴ The future challenges that might inhibit the DOD's mission can be distilled from the literature review, and the identification of these challenges help to recognize obstacles that exist in the strategic and operational environments. The analysis that follows will be used to form recommendations which answer the research questions and to assure the DOD's mission. Specifically, the four types of lethal autonomous aircraft will be assessed with the methodologies previously identified in order to determine which solutions have the greatest potential to overcome future challenges while enhancing quicker decision making and lethality.

While it is assessed that the U.S. currently maintains an advantage in AI and autonomous capabilities, China and Russia continue to close the gap in these

²²² Horowitz, "Artificial Intelligence, International Competition, and the Balance of Power."

²²³ Ibid.

²²⁴ Chairman of the Joint Chiefs of Staff (CJCS), "Message to the Joint Force," (letter, Washington, DC, October 1, 2019), https://media.defense.gov/2019/Oct/02/2002189545/-1/-1/1/CJCS_GEN_MILLEY_LETTER_TO_THE_FORCE.pdf.

technological advantages. In order to provide focus for answering the research questions most of the analysis will be conducted for an operational environment in China's geographic area of influence. Most of the assessments will be based on a timeframe of 2035 in order to remain aligned with the preponderance of joint force strategic guidance and plans. These criteria will be created by referencing some of the key takeaways from the "U.S.-China Military Scorecard" case study which studied the U.S.'s ability to penetrate China's integrated air defenses. Since the case study provides insights on the current air defense capabilities of China, the assumption will be made that these capabilities will continue to improve and incorporate the technological investments identified in Chapter 2.

Overall, the study revealed that China has made significant improvements to anti-access/area denial capabilities, particularly in close proximity to the mainland. So far, the U.S. strategy to counter these improvements has been primarily in costly high-end fighter and stealth aircraft. Using the case study's modeling and simulation, the U.S. has maintained a slight advantage with this strategy for a large-combat scenario in the China geographic area. However, this advantage is greatest away from the mainland in areas where integrated air defenses are less dense. Additionally, the U.S. plans to use jamming and standoff weapons to suppress and defeat Chinese air defenses which will be critical to reducing risk to aircraft. These standoff weapons also decrease the number of required manned aircraft needed to prosecute targets within the engagement zones of the air defenses. This advantage is dependent on a complex C2 architecture that is vulnerable to interference and attack. This vulnerability can either occur through cyber means or by degrading and destroying critical nodes within the infrastructure. Considering these

factors, this research proposes that the three greatest air domain challenges for the joint force in a Chinese airspace operational environment are: (1) modern and dense integrated air defenses, (2) insufficient numbers of air assets to penetrate and defeat these defenses, (3) and a joint force structure that is reliant on high-end systems that creates a strategic vulnerability. This negatively effects how the U.S. calculates risk because it is not able to endure the high attrition rates predicted in large-scale combat with a great power competitor.

Thus, it is critically important for the DOD to decide on the types of autonomous functions needed in order to leverage the advantages of unmanned aircraft in LSCO while hardening C2 capabilities for highly contested environments. Given the mission statement of the DOD, determining this will be key in maintaining asymmetric capability advantages in order to deter war and provide security to our nation and its allies.

As specified in JP 5-0, Joint Planning, operational art is a part of operational design and is used by commanders and staffs to develop strategies, campaigns, and operations to organize and employ military forces by integrating ends, ways, and means.²²⁵ Considering this, the recommended operational approach will be developed using the strategic framework of Ends-Ways-Means. The *Ends* is to develop “the joint force of the future” in order to deter war and if necessary, win in conflict.²²⁶ The *Ways*, specifically for this research, are the types of autonomous functions needed for lethal unmanned aircraft to enable the accomplishment of the Ends. Last, the *Means* are the

²²⁵ JCS, JP 5.

²²⁶ CJCS, “Message to the Joint Force.”

types of technologies that are being developed which will be required to execute the Ways. This strategic framework coupled with the future challenges will be the basis for determining which solutions achieve the Ends while remaining suitable, feasible, and acceptable.

Possible Options

Based on the literature review, there are four possible options for operational consideration: (1) fully autonomous unmanned munition, (2) semi-autonomous unmanned (human in the loop) aircraft, (3) semi-autonomous unmanned (human on the loop) aircraft, and (4) fully autonomous unmanned aircraft.²²⁷ These options will be analyzed against the challenges that the U.S. would face in a large-scale combat scenario with China. The key capabilities of each option will be analyzed with an assessment of the strengths, weaknesses, opportunities, and threats (SWOT).

Fully Autonomous Unmanned Munition

The fully autonomous unmanned munition (wide area loitering munition) is a loitering anti radar weapon that searches over a wide area for radars and self-destructs into the target once they are found.²²⁸ These precision guided munitions use multiple

²²⁷ Paul Scharre, “Autonomous Weapons and Operational Risk,” Center for New American Strategy, February 2016, 20, https://s3.us-east-1.amazonaws.com/files.cnas.org/documents/CNAS_Autonomous-weapons-operational-risk.pdf?mtime=20160906080515&focal=none.

²²⁸ Ibid.

onboard sensors to detect and guide the self-destructing munition towards a target.²²⁹ For example, the Raytheon Storm Breaker provides operational flexibility by using millimeter wave radar to detect and track targets in weather, infrared imaging to locate targets day or night, and semi-active laser to track laser designators from other aircraft.²³⁰ It is also fitted with a global positioning system, and inertial guidance, in order to track targets and guide the bomb to a target.²³¹ Furthermore, these weapons are increasingly equipped with home-on-GPS jam (HOG-J) systems, which identify GPS jammers and use the source of that signal to guide the munition to the target.²³²

There are distinct differences between loitering munitions and precision guided munitions (i.e., HARM or high-speed anti-radiation missile). HARMs are often described as fire-and-forget weapons which home on enemy radars in order to destroy them and need to be launched at known or likely targets in order to be effective. They are autonomous in that once launched they do not require any further human interaction;

²²⁹ Matthew F. Noyes, “Autonomous Weapons: The Future Behind Us,” (Master’s thesis, U.S Army Command and General Staff College, Fort Leavenworth, KS, 2019), 50.

²³⁰ “StormBreaker Smart Weapons,” Raytheon, accessed 24 March 2019, <https://www.raytheon.com/capabilities/products/stormbreaker>.

²³¹ Ibid.

²³² Joe Gould, “Guided-Bomb Makers Anticipate GPS Jammers,” *Defense News*, May 31, 2015, <https://www.defensenews.com/air/2015/05/31/guided-bomb-makers-anticipate-gps-jammers/>

however, they are limited in their ability to search for targets and they only engage what the operator has designated.²³³

Loitering munitions on the other hand are designed to search for an extended period of time over a designated area in order to find and engage targets. These munitions contain components which make them close to fully autonomous systems such as the ability to process signals and take action on them.²³⁴ Another example of these munitions is the Harpy Next Generation (Harpy NG), produced by Israel Aerospace Industries. The Harpy NG is capable of loitering for nine hours and can be remotely piloted or fully autonomous.²³⁵ The Harop is a newer version of the Harpy with both systems having several notable benefits. For instance, the operator can use its camera system to track and engage moving targets or its radiation-seeker can target frequencies and attack radar sites on its own.²³⁶ It is even possible for it to utilize both functions in the same mission, so that if a radar site were to go inactive after being detected, it is possible to use electro-optical targeting to continue to track and destroy the target.²³⁷ The Harop has a range of

²³³ Scharre, “Autonomous Weapons and Operational Risk,” 20.

²³⁴ Noyes, “Autonomous Weapons: The Future Behind Us,” 51.

²³⁵ Vincent Boulanin and Maaïke Verbruggen, *Mapping the Development of Autonomy in Weapons Systems*, Stockholm International Peace Research Institute, November 2017, 54, https://www.sipri.org/sites/default/files/2017-11/siprireport_mapping_the_development_of_autonomy_in_weapon_systems_1117_1.pdf.

²³⁶ Tyler Rogoway, “Meet Israel’s ‘Suicide Squad’ of Self-Sacrificing Drones,” *The Drive*, last modified August 8, 2016, <https://www.thedrive.com/the-war-zone/4760/meet-israels-suicide-squad-of-self-sacrificing-drones>

²³⁷ *Ibid.*

600 miles and is equipped with autonomous return home and land once it is low on fuel.²³⁸

The primary strength of a wide area munition is its persistence to loiter in hostile airspace which allows it to discover unknown threats or perhaps conjectural threats in an area without a precise location. Additionally, the Harpy NG and Harop are advertised as low-cost fully autonomous weapons, however, Israel does not disclose via open source the actual per unit cost. It is known that in some cases loitering munitions are cheaper than guided munitions. For example, the AeroVironment Switchblade (US development) is estimated at \$70,000, roughly two-thirds the cost²³⁹ of the AGM 88 HARM at \$283,985 per unit.²⁴⁰ As such, loitering munitions are advantageous solely from an aspect of cost given that the munition is capable of destroying targets with less risk to more costly aircraft platforms that would employ like munitions. As an example, the F-16 C/D model, although more capable in mission type roles, is estimated at \$18.8 million per unit.²⁴¹

Loitering munitions are also capable of being low observable making them difficult to detect by the radars they are targeting to destroy. The IAI advertises the Harop

²³⁸ Rogoway, “Meet Israel’s ‘Suicide Squad’ of Self-Sacrificing Drones.”

²³⁹ Center for the Study of the Drone, “Loitering Munitions,” Bard College, accessed 17 February 2021, <https://dronecenter.bard.edu/files/2017/02/CSD-Loitering-Munitions.pdf>.

²⁴⁰ “AGM 88 HARM,” Federation of American Scientists, accessed 21 April 2021, <https://fas.org/man/dod-101/sys/smart/agm-88.htm>.

²⁴¹ “F-16 Fighting Falcon,” U.S. Air Force, September 23, 2015, <https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104505/f-16-fighting-falcon/>.

as having a radar cross section of $<.5\text{m}^2$,²⁴² which is about the size of a small bird.²⁴³

Since low observable loitering munitions are difficult to target, air defense systems either have to remain turned on for extended periods of time, making them more vulnerable to being detected and destroyed, or they must be selective about when they are searching for targets. In either case, there is greater potential for other friendly assets to have greater freedom of movement due to the target being destroyed or unable to fully operate.

There are several weaknesses to loitering munitions. To begin with, despite having impressive range, 600 miles in some cases, loitering munitions' top speeds are significantly slower than traditional fighter aircraft (F-16: 1,500 mph).²⁴⁴ The Harpy and Harop's top speeds are 258 mph.²⁴⁵ With these differences in speeds, it is more challenging and time-consuming for loitering munitions to transit to more optimal or target rich areas during active operations. The identification and need for a shift to a different target area could occur if the munitions and/or other unmanned assets were networked to swarm and share data on adversarial air defenses in a large geographic area. However, the issue created by transit times could be mitigated by having loitering munition densities great enough to limit or eliminate the need for transit.

There are several opportunities with the loitering munition. First, they do not require an airfield in order to be deployed, which is similar to the Tomahawk Land

²⁴² "Harop Loitering Munition System," Israel Aerospace Industries, accessed February 17, 2021, <https://www.iai.co.il/p/harop>.

²⁴³ Rogoway, "Meet Israel's 'Suicide Squad' of Self-Sacrificing Drones."

²⁴⁴ "F-16 Fighting Falcon."

²⁴⁵ "Harop Loitering Munition."

Attack Missile (TLAM). This is noteworthy as there is growing concern associated with China's capabilities to target U.S. and allied airfields within Indo-Pacific region. As such, in a counteroffensive scenario where airfield availability and capacity has been reduced, loitering munitions would provide the U.S. with greater options to suppress enemy air defenses while long-range air assets are launched from more distant airfields. Another opportunity, is that with the relatively low-cost of the systems our allies in the region will be able to afford them in higher quantities, increasing capacity and capability during conflict for multi-national operations.

In regard to threats, adversaries may be able to threaten these systems by spoofing the signals autonomy with relatively low-cost technology. For instance, GPS jammers that are capable of enveloping several city blocks are available for only a couple hundred dollars.²⁴⁶ Furthermore, if the enemy were able to deploy decoys which replicate the signal of the radar system that the loitering munition is seeking or if visual-only decoys were geographically close enough to the actual emitting system, then the munition may engage the incorrect piece of equipment and self-destruct unnecessarily.

Overall, loitering munition systems like the Harpy and Harop add operational flexibility to a SEAD strike package. Additionally, by eliminating air defense threats or overwhelming them with targets to track and engage, there is the potential to decrease risk to more costly manned and unmanned aircraft.

²⁴⁶ Gould, "Guided-Bomb Makers Anticipate GPS Jammers."

Semi-autonomous Unmanned Aircraft (HITL and HOTL)

There are two variations of the semi-autonomous unmanned aircraft. The first variation is “human in the loop” (HITL) in which platforms only engage individual targets or specific target groups that have been selected by a human operator.²⁴⁷ This is the more conservative variant of semi-autonomous system as the aircraft only searches for targets autonomously in an area and then seeks further guidance from the human operator before potentially completing the targeting process. Despite being sometimes construed as a new concept this is relatively close to much of the automation that is used currently to assist in target identification for manned and unmanned aircraft. Therefore, it is something operators would be more familiar with and comfortable executing.

The primary difference based on future operational concepts of HITL and how it would be employed is that pilots would have more than one target identification system and aircraft to select targets with and to monitor. Under concepts of Joint All-Domain Command and Control (JADC2) and Advanced Battle Management System (ABMS) human operators will not only have more than one targeting system or aircraft they will also have more complex and integrated sources of data to process which is one of the primary arguments using AI and algorithms in order to automate data processing.

All of this might sound like an overwhelming task for human operators, however when one reviews the targeting process for close air support (CAS), which has been used extensively for the last two decades, it is comparable to the task management load of a Joint Terminal Air Controller (JTAC), who is responsible for air-to-ground integration

²⁴⁷ DOD, DOD Directive 3000.09, 14.

and deconfliction of fires in close proximity to friendlies. This role requires JTACs to be trained in controlling airspace and the engagement of ground targets for multiple aircraft within the same area. This includes providing inputs to the aircraft for the search and selection of targets, which would be similar to human operators passing guidance to HITL unmanned aircraft systems the types of targets to search for with in an area of interest. The JTAC also has the authority to give final clearances for attacking aircraft to release weapons (“cleared hot”), which is comparable to the expected role of human operators controlling HITL systems. Altogether, it is reasonable to believe that human operators would have the capacity to manage multiple HITL aircraft much like a JTAC while ensuring safe integration and deconfliction of fires.

The other form of semi-autonomous operations is “human on the loop” (HOTL) and is described as supervisory since human operators have the ability to monitor and halt a weapon’s target engagement. This ability to intervene or halt a weapon is comparable to a JTAC’s authority to abort an engagement even after passing a clearance to release weapons. HOTL is considered just short of full autonomy since the weapon system is capable of completing the targeting process on its own without seeking further approval from the operator prior to engagement. This in turn leads to quicker actions and in some cases greater lethality by eliminating human operator inputs from the kill-chain. However, it also increases risk by removing the requirement for a human to validate the target. The human remains as a fail-safe to intervene in the case of a weapon system malfunction or if the validity of a target is uncertain. Strike Coordination and Reconnaissance (SCAR) is a mission that could be conducted with human operators on

the loop by directing semi-autonomous systems to complete tasks.²⁴⁸ According to JP 3-03, SCAR is used for detecting targets and coordinating or performing attack or reconnaissance on those targets.²⁴⁹ These missions are flown in specified geographic areas and are part of the C2 process that is used to coordinate multiple flights of aircraft, detect and attack targets, neutralize enemy air defenses, and provide battle damage assessments.²⁵⁰ The target areas are defined by a box or grid and exist where potential targets are known or suspected, or where mobile enemy ground units have relocated.²⁵¹ The SCAR tasks are managed by the SCAR-C (coordinator) and include cycling multiple attacking aircraft through the target area and providing prioritized targeting guidance and enemy air defense updates to maximize the effect of each sortie.²⁵²

Since semi-autonomous systems have different strengths and weaknesses associated with HITL or HOTL, opportunities are created if platforms are capable of being rapidly altered. This would allow platforms to be tailored to the operational environment with considerations to the spectrum of armed conflict, specifically for the mission scenario in which they are being deployed. This could be accomplished by creating platforms which have modular capabilities for user command interfaces,

²⁴⁸ Joint Chiefs of Staff (JCS), Joint Publication (JP) 3-03, *Joint Interdiction* (Washington, DC: JCS, 2016), II-11, https://www.jcs.mil/Portals/36/Documents/Doctrine/pubs/jp3_03.pdf.

²⁴⁹ Ibid.

²⁵⁰ Ibid.

²⁵¹ Ibid.

²⁵² Ibid.

datalinks, and software.²⁵³ The Boeing Airpower Teaming System (ATS) provides an example of a platform that is striving to achieve these results. It is described as having a nose section that can be swapped between missions, which gives it different capabilities depending on the mission set it is being tasked to conduct.²⁵⁴ One added benefit is that the core airframe remains the same.²⁵⁵

There are tremendous benefits to an airframe built on this design. First, the aircraft is easier to scale to meet current or projected operational needs as they evolve. With the airframe remaining the same and the ability to change mission capabilities modularly in the nose of the aircraft, the airframe can be produced in quantity with decreased risk that the mission capabilities will become irrelevant. In regard to cost, the program has a goal to make an attritable aircraft that is survivable but cost around \$2 million, which is not much more than the price of a Tomahawk missile. These attributes have remarkable implications for an operational environment which is rapidly changing due to consistently changing technological advancements, especially when those emerging technologies are being harnessed by our competitors to counter or match our military capabilities.

Furthermore, since one of the operational concepts of the ATS and other “loyal wingman” programs is semi-autonomous aircraft into formations of other manned

²⁵³ Tyler Rogoway, “Everything We Learned from Boeing About Its Potentially Game-Changing Loyal Wingman Drone,” *The Drive*, May 4, 2020, <https://www.thedrive.com/the-war-zone/33271/everything-we-learned-from-boeing-about-its-potentially-game-changing-loyal-wingman-drone>

²⁵⁴ Ibid.

²⁵⁵ Ibid.

aircraft, there are opportunities for communications between the manned and unmanned platforms in the formation to use other forms of high-powered communication datalinks between aircraft. This would also mitigate some of the risk and growing concerns with satellite communications where bandwidth and capacity have become limited and overwhelmed. As previously discussed, satellite communications are also believed to be vulnerable in non-permissive large-scale combat environments. One potential alternative form of technology is laser data communications, which are being explored by several researchers to include Airbus and the University of Oxford who collaborated on the Hyperion Project, which is a project seeking to use Free Space Optical (FSO) systems that use directed or invisible light from a laser for data link.²⁵⁶ FSO systems are less susceptible to jamming and interception than radio signals and are potentially capable of data transfer rates of up to one gigabyte per second.²⁵⁷ In this program, researchers have successfully flight-tested this technology with a range of about one kilometer.²⁵⁸

Overall, semi-autonomous aircraft seem to have tremendous potential in numerous mission sets. There is also decreased risk of operational mistakes by keeping a human involved in the decision-making process. Semi-autonomous unmanned aircraft could be used for DCA or other mission sets, which are typically of higher risk to the aircrew of manned aircraft. This would allow the Air Component Commander to better

²⁵⁶ Eric Tegler, “Why Talk to Drones Over Radio When You Can Use Lasers,” *Popular Mechanics*, March 18, 2016, <https://www.popularmechanics.com/flight/drones/a19999/laser-communication-drones/>.

²⁵⁷ Ibid.

²⁵⁸ Ibid.

manage the availability and use of manned aircraft for the mission sets needed in the operational environment while managing risk to aircrew with unmanned autonomous aircraft to include mixed formations with “loyal wingmen.”²⁵⁹ For example, semi-autonomous unmanned aircraft could be used to protect high-value aircraft types, e.g., air-refueling tankers and tactical airborne C2 capabilities (AWACS/JSTARS). These high-value assets are often targeted by the enemy knowing that if they are able to decrease availability of their capabilities then combat power is reduced. As such, high value assets are often displaced safe distances from enemy air defenses and are protected by defensive counter air (DCA) fighter aircraft orbits. The fighter aircraft capable of DCA are also able to perform other mission sets to include offensive counter air (OCA), air interdiction, CAS, SEAD/Destruction of Enemy Air Defenses (DEAD), and fighter escort. As a result, the assets that are used for DCA limit what is available for other air-to-air and air to ground missions.

There are also weaknesses or threats with autonomous aircraft executing these other mission sets. One example is using autonomous aircraft to protect high-value assets in DCA orbits which are often conducted in friendly controlled airspace which could increase the potential of fratricide by misidentifying friendly aircraft as enemy. This is because friendly fighter aircraft returning for air-refueling near the DCA orbits, and enemy aircraft will most likely be approaching the tanker formation from the same direction. While there are measures to mitigate risk in this situation such as encrypted identification of friend or foe (IFF) emissions, these are often turned off during air-

²⁵⁹ Rogoway, “Everything We Learned from Boeing about Its Potentially Game-Changing Loyal Wingman Drone.”

refueling operations and many coalition or multi-national partners do not have IFF or their systems are incompatible with U.S. systems. Considering these factors, it is best to keep a human in or on the loop to better discern friend from foe.

The interactions between the human and autonomous system could also be regulated by using weapons control status procedures which are part of current doctrine and are outlined in JP 3-01, *Countering Air and Missile Threats*. There are three levels of weapons control status which set conditions, based on the rules of engagement under which friendly assets are permitted to engage threats.²⁶⁰ Weapons hold is the most restrictive and allows units are to only fire in self-defense or when ordered by proper higher authority.²⁶¹ Weapons tight is considered the normal status and units may only engage on targets positively identified as hostile according to the current rules of engagement.²⁶² Weapons free is the least restrictive in which units may engage targets not positively identified as friendly.²⁶³ This type of guidance could be used with an autonomous system and would provide criteria that would regulate the level of decisions the systems would be responsible for making based on the conditions of the operating environment.

²⁶⁰ Joint Chiefs of Staff (JCS), Joint Publication (JP) 3-01, *Air and Missile Threats* (Washington, DC: JCS, 2017), https://www.jcs.mil/Portals/36/Documents/Doctrine/pubs/jp3_01_pa.pdf.

²⁶¹ Ibid.

²⁶² Ibid.

²⁶³ Ibid.

Additionally, since it is possible for a human to monitor more than one autonomous weapons system simultaneously, there is the potential to create faster human decisions by leveraging HITL or HOTL system autonomy. This could lead to greater force lethality through shortened kill chain timelines with only a couple of potential downsides. First, depending on how many systems the human is required to monitor there is potential for that person to become overwhelmed and task saturated leading to mistakes. There is also increased risk for this to occur with systems that operate under HOTL with the human in a supervisory role. The faster the pace of operations and how quickly the semi-autonomous systems are discovering targets to destroy, the more difficult it becomes for the human to intervene or recognize when things have gone awry. The potential for the human to become task saturated with HITL systems still exists but the possibility of it spiraling out of control is mitigated by the fact that the systems would be seeking human input before taking lethal actions. This serves as a safety measure to ensure the pace of operations does not exceed the piece of task management that is required from the human operator when executing an engagement.

Fully Autonomous Unmanned Aircraft

The final potential type of autonomous platform is the fully autonomous unmanned aircraft. This is commonly referred to as human out of the loop since the weapon system can select and engage targets without further coordination with a human operator.²⁶⁴ This type of system is mostly likely preferred in highly contested

²⁶⁴ Slayer, “Defense Primer.”

environments where communications between the aircraft and operator are degraded or non-existent.²⁶⁵ The strengths of a fully autonomous aircraft are similar to the fully autonomous munition, however there are some noteworthy differences. For instance, the autonomous aircraft is capable of carrying multiple munitions making it possible for it to strike multiple targets instead of only one. Also, assuming the aircraft survives the combat environment, it is recoverable and therefore available for future missions.

There are also some weaknesses associated with the fully autonomous aircraft. For example, it would be more difficult to change the mission tasking of a fully autonomous system. Receive a new tasking during a mission is a common occurrence for aircraft as operational adjustments are made in order to adapt to the changing combat environment. The inability to do this would make it difficult to shift these assets to where they are needed most on the battlefield. This could be mitigated with opportunities like “swarm” technology where data is shared between autonomous platforms in different geographical regions, and adjustments are then made to aircraft taskings based on the collective assessments of the swarm. This concept however is most likely unfeasible by 2035, given the current levels of the technologies that would be required to execute it as well as the collective unease for this level of autonomy in the international community. Also, data would need to be shared between the platforms in large amounts where communications may be contested and could be the very reason a fully autonomous system was chosen for the mission in the first place.

²⁶⁵ Scharre, “Autonomous Weapons and Operational Risk.”

Another opportunity with fully autonomous systems might actually stem from it being closed off from further human input after it is launched to perform its mission. This is an opportunity because it provides a means to mitigate some of the concerns with adversaries interfering or assuming control of unmanned autonomous systems. This could be used against known fixed targets with permissive rules of engagement and under increased assumptions of risk, which would be more likely in a LSCO scenario. The benefit of this is that it would narrow the parameters assigned to the unmanned system which would reduce the risk of them being executed autonomously by a machine.

Overall, fully autonomous systems are best suited for contested environments where communications are predicted to be denied. They provide a means to degrade adversary enemy defenses during the early phases of large-scale combat operations. Additionally, they reduce the risk to manned aircraft performing a variety of mission sets in operational environments when adversary air defenses would be at full strength.

The SWOT analysis narrative above discovered that each of the four options are useful depending on factors like the phase of a conflict and the operating environment conditions. The different types of autonomy also create options for commanders to manage risk based on how the systems operate and the ways that they can be employed. The results of the SWOT methodology are summarized in below (see Table 1).

Table 1. SWOT Analysis Takeaways

	Fully autonomous unmanned munition	Semi-autonomous unmanned (HITL)	Semi-autonomous unmanned (HOTL)	Fully autonomous unmanned aircraft
Strengths	-Persistent loiter time (9+ hours) -Deployable in hostile airspace -ISR and strike capabilities -Recoverable if not destroyed -Low radar cross section -Low cost and fully autonomous (roughly cost of common air to ground munitions)	-Systems discover targets on their own which increases targeting capacity -Systems can be low cost with some equivalent to other standoff munitions	-Systems discover targets on their own which increases targeting capacity -Systems can be low cost with some equivalent to other standoff munitions	-Minimize threats to adversary manipulation in contested environments by having closed systems -Systems are capable of carrying multiple munitions -Systems are recoverable -Acceptable to employ in high-risk environments
Weaknesses	-Slow speeds limit reaction time and flexibility to emerging opportunities	-Lethal targeting scenarios are limited to the speed that the human operator can process the information and make a decision	-Increased risk due to systems being able to complete targeting engagements autonomously	-Increased risk since system complete engagements autonomously -Operators are unable to intervene if system malfunctions or misidentifies a target -Difficult to change tasking after launch
Opportunities	-High loitering munition densities mitigate slower speeds -Airfield not required to be deployed, useful in counteroffensive scenarios -Low cost makes them affordable to allies increasing multi-national opportunities -Decreases risk to other more costly aircraft	-Greater possibilities for modularity between semi-autonomous capabilities -Modular capabilities make it possible for systems to be updated -Manned and unmanned platform teams (loyal wingmen program) -Mitigate hostile environment C2 risk with alternative forms of C2 links (directional datalinks)	-Greater possibilities for modularity between semi-autonomous capabilities -Modular capabilities make it possible for systems to be updated -Manned and unmanned platform teams (loyal wingmen program) -Mitigate hostile environment C2 risk with alternative forms of C2 links (directional datalinks)	-Artificial intelligence swarms could share emerging opportunities with other systems and increase targeting effectiveness -Mitigate risk with weapons control status (e.g., weapons hold: “engage only if engaged or ordered to engage”)
Threats	-Signals spoofing and enemy system decoys could affect autonomy -GPS jammers	-Increased risk for adversary interference and manipulation due to C2 network reliance	-Increased risk for adversary interference and manipulation due to C2 network reliance	-Increased risk for engagements on misidentified targets -Increased risk of fratricide

Source: Created by the author.

Professional Recommendation (R2)

This updated recommendation considers the literature review and the results of the SWOT analysis on the four different types of autonomous unmanned aircraft and applies them to an early phase of LSCO conflict (e.g., the penetration of advanced IADS airspace). It also factors in the predicted range of military operations that would occur in a conflict of that magnitude. To begin, the analysis discovered that there are distinct attributes associated with each type of autonomy which makes it most advantageous to have a mix of the four types of autonomous unmanned aircraft. Moreover, having a mix will create more adaptability and options during LSCO which is characterized by the variables of a VUCA (volatile, uncertain, complex, and ambiguous) environment (described in Chapter 2). The specific mix of the needed aircraft types will change based on evolving operational conditions and it is possible to manage this mix in a cost-effective manner by investing in modular systems which would allow aircraft to alter capabilities and switch between the different types of autonomy.

Fully autonomous munitions and semi-autonomous aircraft (HOTL) provide the best balance between quicker decision making with increased lethality while mitigating risk associated with autonomy and faster paced operations. These systems are more familiar to the chief decision makers and the human operators which make them the most reasonable option for the U.S. to achieve by 2035. The use of fully autonomous munitions is most advantageous when the operational environment is rich with military targets and the risk with using other assets is deemed to be too high. The munitions are also difficult to detect due to size and a low radar cross section. They are low cost and, in some cases, cost as much as the munitions that would be employed against like targets by

an aircraft. The difference is that the fully autonomous munition is able to search over a wide area on its own and in turn increases the air to ground targeting capacity. These munitions are best optimized for scenarios where enemy IADS are near full strength. This makes it easier for the autonomous munitions to identify valid military targets and it decreases risk to the manned aircraft that would be employed for similar missions. There is a risk of the munition mis-identifying an invalid target as valid but the collateral damage that a single munition would impose is small and should be considered acceptable in the context of LSCO.

The use of semi-autonomous systems is most advantageous during the phases of large-scale combat when it becomes more difficult to discern between valid and invalid targets. Also, semi-autonomous HITL and HOTL systems decrease risk associated with more complex target sets that require multiple variables for identification. The automated target identification and database deconfliction of the system make it possible to discover targets at a quicker pace without removing the critical cognitive functions of the human from decisions involving lethality. Additionally, the projected cost of these systems makes it possible to produce them on a large scale. There is also increased operational flexibility, if modular capabilities are incorporated in order to allow the systems to be adjusted to evolving mission requirements. This creates an opportunity for aircraft systems to switch between the different types of autonomy in between missions in order to meet evolving operational needs.

Considering all these factors, it is recommended to package the four different types to create synergistic capabilities and effects. First, fully autonomous unmanned aircraft should be used against known fixed targets. These assets would carry multiple

munitions which would be needed for some of the more robust fixed target sets. Often, these targets are comprised of several components that are integrated with other air defense systems for enhanced targeting and engagement range. The fully autonomous aircraft would be capable of targeting these different components. Even at high attrition rates, if the aircraft were networked then targets that were identified could continue to be prosecuted by the aircraft that remain. This would force the enemy to take calculated risk when turning on surface to air systems and risking their exposure. As enemy air defenses are identified the database of known fixed targets is increased and the ability to use other standoff weapons becomes more available. The fully autonomous munitions could also be used to reduce the number of surface-to-air threats. These systems are difficult to detect, provide persistence over a target area, and are low-cost attritable. They increase the overall air-to-ground targeting capacity and effectiveness.

Next, the semi-autonomous unmanned aircraft should be integrated in order to target the more complex ground target sets which are more difficult to find or validate. These target sets require the more advanced cognitive decision making of human operators to ensure strikes are conducted on valid targets remaining in the operational environment. Additionally, semi-autonomous aircraft could be used to conduct offensive counter air (OCA), air interdiction, CAS, SEAD/Destruction of Enemy Air Defenses (DEAD), and fighter escort missions using the concept of loyal wingmen. This increases the mission capacity for all of these mission sets and decreases risk to the manned aircraft who are part of the flight formation. Semi-autonomous aircraft should also be used to conduct defensive missions to protect high-value assets (e.g., air-refueling tankers, tactical airborne C2).

Stakeholder Perspectives (Interviews)

This section considers the perspectives of four DOD staff officers who are current stakeholders in the development of artificial intelligence, lethal autonomous functions, and command and control. The analysis is a synthesis of knowledge gained from the interviews with these subject matter experts. Due to the qualitative data being collected via interviews, the technique of coding was used to discover several themes which will be used to better inform the final conclusions and recommendations to the primary and secondary research questions. Overall, the majority of participant responses centered on five themes: collecting and processing data, creating meshed based networks, enhancing security of data and network systems, using AI and ML to enhance human performance and decisions, and utilizing a mix of manned and unmanned aircraft to manage mission risk. Ultimately, these different initiatives enable and create opportunities for the different types of autonomous functions to be realized within the future joint force.

To begin with, one of the primary benefits of AI is that it can be used to process large amounts of data. Given the number of sensors that exist in the joint force there are situations where too much data exists for humans to feasibly process it into useful information.²⁶⁶ Since AI relies on having data available to process, efficient means to collect and manage that data is critical. In order to do this, means need to be created to centrally store data so AI and autonomous systems can quickly access and process it. The DOD is developing a platform referred to as the Joint Common Foundation (JCF) to

²⁶⁶ Pentagon staff member, Microsoft Teams interview by author, March 17, 2021.

realize the necessary collection of data needed for AI. The intent of JCF is to develop a cloud-enabled platform that will accelerate the development, testing, and fielding of new AI capabilities.²⁶⁷

The creation and use of a common AI platform with shared infrastructure resources sets conditions for progress with AI initiatives building momentum across the entire DOD enterprise.²⁶⁸ Establishing a shared infrastructure will be as critical as the capability to store data in order to connect different weapons systems to the data and create a means to share data between users. As part of this initiative, the Air Force has begun to disaggregate networks in terms of hardware and is rapidly moving towards cloud-based networks.²⁶⁹ This is because the server is no longer the most important piece of the network.²⁷⁰ Instead, it is more important to allow users access to that information wherever they exist organically.²⁷¹ In general, cloud-based systems allow information to be more effectively manipulated or distributed to weapon systems.²⁷² The end goal needs to be to create systems that co-locate data that is accessible and provides meaningful information efficiently to warfighters who are making mission related decisions.

²⁶⁷ “Transforming the Department of Defense through AI: The Joint Artificial Intelligence Center,” The Joint Artificial Intelligence Center, accessed April 11, 2021, <https://www.ai.mil>.

²⁶⁸ Ibid.

²⁶⁹ Air Force staff member, telephone interview by author, March 15, 2021.

²⁷⁰ Ibid.

²⁷¹ Ibid.

²⁷² Ibid.

Since there are limitations on how much data and information a human can process, the next critical step after data accessibility is to create resources that help process data for accelerated human decisions. There are also several ways that AI can enable faster decisions and enhance the performance of human operators. For instance, data collection sensors need to be developed to feed AI-enabled algorithms.²⁷³ The problem with current sensors is that they are designed to feed data and information to the human eye which takes too much time to process when compared to sensors that are designed to feed algorithms which look at data faster and with greater range.²⁷⁴

Another benefit of algorithmic sensors is their potential to more efficiently distribute data. For example, algorithms could exist within components of weapons systems and process data as it is being discovered by on-board sensors. This would be the most efficient way for remote or on-board operators to be sent information. It would also help to ensure that time critical decisions are made with the most current and relevant information to the operating environment. These on-board algorithms could also be used to feed information to other users who are connected to the same network. This sharing of information could occur within the operating area from platform to platform or by the data being sent to a central storage location and accessed later. By storing it within a central location in which all users are connected and able to access, it is possible for the C2 network to determine what systems might need that information and distribute it, or for a system to access the data and filter it to what is useful.

²⁷³ Joint staff member, telephone interview by author, March 13, 2021.

²⁷⁴ Ibid.

In order for networks to function in this manner they must be built on concepts that accelerate and distribute the functions of information sharing. For example, the joint force is currently trying to identify areas where the human is not adding much value and automate those steps.²⁷⁵ This will eliminate instances where humans are simply transferring data from one system to another and uncover where the machine-to-machine interfaces can be created.²⁷⁶ This is one of the primary foci in building the data centric command and control networks of the future.²⁷⁷

With data centrality being critical to future operations, it is necessary to create networks that are meshed and able to share data even in contested environments. The concept of meshed networks creates diversity within the overarching C2 network and is different from past efforts to improve C2, which were primarily focused on developing redundancy.²⁷⁸ It is possible to create meshed networks through multiple means of connectivity including space-based, line-of-sight, or directional datalinks. By creating diversity in the ways to connect, the overall resiliencies of C2 networks are enhanced. This makes it more challenging for the enemy to target single points of failure or critical C2 nodes that would degrade, disrupt, interfere, or limit (DDIL) communication

²⁷⁵ Pentagon staff member interview.

²⁷⁶ Ibid.

²⁷⁷ Ibid.

²⁷⁸ Ibid.

operations..²⁷⁹ DDIL is one of the terms which the joint force uses to describe the contested communication environments of high-end fights with peer adversaries..²⁸⁰

Furthermore, the resiliency of C2 networks is enhanced by creating diversity from the systems that provide C2 capabilities. This could be accomplished by using existent unmanned aircraft and converting them into C2 capable nodes and relays. The MQ-9, for example provides a persistent loiter time (approximately 22 hours) and could be placed on the edge of contested airspace to distribute data and coordinate mission tasks..²⁸¹ One benefit to using unmanned platforms for C2 nodes is that they are relatively low cost and easy to produce making them attritable. This also creates opportunities to produce them in large scale numbers and increase the overall C2 network density. It is necessary to have C2 assets that are dense and attritable since adversaries will target nodes and relays..²⁸² It is also relatively easy for adversaries to target C2 nodes due to the high levels of signals the platforms emit..²⁸³

Directional datalinks are an additional way to create resiliency within networks and control unmanned systems. One of the challenges with remote datalinks occurs when ground control stations are not in the “bubble of connectivity” and the operator is unable

²⁷⁹ Pentagon staff member interview.

²⁸⁰ Ibid.

²⁸¹ Joint staff member interview.

²⁸² Ibid.

²⁸³ Ibid.

to control the platform.²⁸⁴ In order to overcome this, ways need to be discovered to include human control from alternative forms of connectivity that happen to be near the platform.²⁸⁵ This would also address one of the problems with systems that are fully autonomous which is how to exfiltrate real time data.²⁸⁶ One of the ways to resolve this is to have an autonomous system that is able to be controlled when it moves inside of the “bubble of connectivity” of a manned system.²⁸⁷

Since a great deal of our position, navigation, and communication is reliant on satellite technologies there is a need to be more responsive in space. Specifically, there is a need to replace space systems quickly.²⁸⁸ and to be able to shift space capabilities between assets. The resiliency of satellites could be increased by placing them at higher altitudes.²⁸⁹ Also, the resiliency of battlespace meshed networks could be enhanced by increasing the density of available satellites and placing them in different ranged orbits so that they are traversing the earth at faster speeds, which would make them more difficult to target.²⁹⁰

²⁸⁴ Special operations staff member, telephone interview by author, March 19, 2021.

²⁸⁵ Ibid.

²⁸⁶ Ibid.

²⁸⁷ Ibid.

²⁸⁸ Joint staff member interview.

²⁸⁹ Ibid.

²⁹⁰ Special operations staff member interview.

By creating meshed based networks, it is possible for aircraft and weapons to function collectively and autonomously against targets, however, in order to do this, the joint force needs to have an airborne joint connection node. This universal node would enable all of the different waveforms, datalinks, and radios within the DOD to communicate, and would be more feasible to develop than converting every existing waveform and datalink across the services to a standard.²⁹¹ Realistically, it would not be feasible to develop a joint waveform or datalink because the different services have assets that are reliant on those specific signals, and a universal node would allow current and future systems more flexibility when using signals and connecting to a meshed network.²⁹²

With great numbers of users connecting to networks it is important to ensure that increased access is supported by enhanced security measures. Specifically, the DOD is making investments in artificial intelligence and zero trust network security.²⁹³ These network improvements ensure that certain information is only available to certain users at a specific time, and that roles are managed to mitigate outside influence within the cyber domain.²⁹⁴ Quantum computing and block chain technologies are other must haves in order to secure the transmission of data but those still need to be developed.²⁹⁵

²⁹¹ Joint staff member interview.

²⁹² Ibid.

²⁹³ Air force staff member, telephone interview by author, March 15, 2021.

²⁹⁴ Ibid.

²⁹⁵ Pentagon staff member interview.

The primary strength of AI and machine learning is that they create opportunities to enhance human decisions and performance. As evidenced, the enhancement of human decision making is predicated on the improvement of data processing and distribution. If we are able to accomplish faster data processing with algorithmic tasks and fuse the data from multiple sensors, then we will have laid the foundation for AI to help humans through data recall and analytics. In order for these types of technologies to succeed the relationship between training and combat will need to change dramatically.²⁹⁶ Previously, training was developed for certain skill sets so that they could be executed in combat.²⁹⁷ If artificial intelligence curation were to occur, then it would be possible to build “playbook activities” during training so that more options are available during combat.²⁹⁸ To expand on this, if it is possible to put a camera in a phone, then why not put a camera in every munition available.²⁹⁹ If that same concept is applied to AI, then it is possible to place some form of basic AI/ML or machine vision in any system.³⁰⁰ The benefit of machine vision is that it is able to make decisions that have previously been made by humans.³⁰¹ This technology enables an AI system to recognize former tactical

²⁹⁶ Special operations staff member interview.

²⁹⁷ Ibid.

²⁹⁸ Ibid.

²⁹⁹ Ibid.

³⁰⁰ Ibid.

³⁰¹ Ibid.

situations and develop recommendations for human operators..³⁰² These might include weapons configurations or mode selects based on the inputs the system received from the human during training, and the system is able to do custodial functions and determine presets or recommended courses of actions for the human to approve or use..³⁰³ Where AI works best is when it is informing courses of actions for the human to decide on and add elements of operational art..³⁰⁴ In essence, the AI sifts through the data and presents the human operators with options, and then the human decides based on operational art and current mission parameters what the best decision is to execute the mission..³⁰⁵

In order to manage mission risk, it is most effective to utilize a mix of manned and unmanned aircraft. It is also useful to match different types of autonomy to risk in the operational environment. Additionally, risk calculations should factor the risk of different types of autonomy making mistakes which should involve considerations to the current phase of the conflict and mission objectives. One of the ways to mitigate risk exposure to manned assets is to pair them with unmanned assets in order to augment capabilities..³⁰⁶ For example, the manned 5th and 6th generation aircraft could have welded wingmen that are able to execute autonomous functions but are able to only do so at the behest of the

³⁰² Special operations staff member interview.

³⁰³ Ibid.

³⁰⁴ Air force staff member interview.

³⁰⁵ Ibid.

³⁰⁶ Pentagon staff member interview.

manned “flight lead.”³⁰⁷ This not only mitigates risk to the manned aircraft, but it helps ensure that autonomous aircraft operate within the rules of war by keeping a human involved in the process.

Considering the possibilities associated with humans commanding multiple unmanned aircraft starts to change the way commanding airpower is conceptualized. If AI reaches its full potential, then air warfare is going to get to a point where multi-element swarms are fighting other multi-element swarms, and then forces will have to start thinking about controlling elements with the concept of mission command.³⁰⁸ This is when commanding the air becomes more about imposing a commander’s will on the battlefield by giving guidance and intent to the autonomous system rather than humans.³⁰⁹

The other benefit of using swarms or low-cost unmanned aircraft is that they create dilemmas for the enemy while mitigating risk for other friendly forces including more exquisite manned and unmanned assets. One of the ways to acquire the unmanned aircraft needed to create this dilemma is by upgrading systems that currently exist in the DOD inventory. Specifically, upgrading unmanned aircraft that are used for slow and persistent missions would be useful in establishing a skirmishing line in the LSCO environment. For example, air-to-air missiles could be placed on MQ-9s and essentially

³⁰⁷ Pentagon staff member interview.

³⁰⁸ Special operations staff member interview.

³⁰⁹ Ibid.

make them flying SAM sites to help defend the air..³¹⁰ If you do this then you force the enemy to engage and it is possible to develop friendly tactics that aren't predicated on survival of the platform..³¹¹ This situation places adversaries in tougher positions of strategy. The enemy will most likely be able to get through the skirmish line, but they are going to suffer losses, and they are wasting time and energy to develop a plan to breach it..³¹² This enables more exquisite friendly force aircraft to fight an enemy force that has been degraded by low cost attritable platforms which helps us to regain the initiative..³¹³ The joint force needs to use the persistent pieces as sacrificial lambs, which potentially forces the enemy to place something at risk that they do not want to lose..³¹⁴ Also, the enemy has to decide between risking exposure of one of his exquisite pieces of equipment in order to destroy an attritable system that may or may not be threatening..³¹⁵

The Four Options Evaluated with JP 5-0 Criteria

The stakeholder interviews provided valuable information and insights that will be used to improve the recommendations and conclusions in Chapter 5. With this additional information it is also possible to grade the four autonomous unmanned aircraft options using a Joint Planning Process procedure, which is the parent of Joint Operational

³¹⁰ Special operations staff member interview.

³¹¹ Ibid.

³¹² Ibid.

³¹³ Ibid.

³¹⁴ Ibid.

³¹⁵ Ibid.

Design methodology as defined in Chapter 3, referred to as course of action evaluation. This will provide a preferred order of the systems for the joint force to invest. The criteria used were determined based on a LSCO scenario with China as outlined in the RAND Case study that was referenced in the Chapter 2 literature review.

To begin with, flexibility was chosen because of how quickly the operational environment can change which drives a need for capabilities to be adaptable. The year 2035 was used since it the timeframe chosen by the joint force to support future strategy and planning activities.³¹⁶ Since the air domain is historically used in the early phases of conflict to prepare or shape the battlefield for follow on operations, the evaluation criteria graded each of the four capabilities against the early phases of LSCO. Multinational opportunity was used as grading criteria since the U.S. has strategic partnerships and alliances within the Indo-Pacific theater that would most likely be involved during a conflict of this magnitude. Furthermore, the Indo-Pacific theater of operations is a large geographic region with vast spaces of ocean which make sustainment and support logistics challenging. This drives a need to select capabilities that have low requirements in those categories. Additionally, the risk of friendly and civilian casualties was chosen as that has historically been strongly considered by senior leaders during pre-war planning considerations. The last piece of criteria is surprise which was chosen since China has

³¹⁶ Joint Chiefs of Staff (JCS), *Joint Operating Environment (JOE 2035): The Joint Force in a Contested and Disordered World* (Washington, DC: JCS, July 2016); Joint Chiefs of Staff (JCS), *National Military Strategy of the United States of America, 2015: The United States Military's Contribution to National Security* (NMS) (Washington, DC: JCS, June 2015), https://www.jcs.mil/Portals/36/Documents/Publications/National_Military_Strategy_2015.pdf.

significant anti-access and area denial capabilities that would be highly effective defense against an offensive operation.

In order to simplify the grading scheme, it was decided to evaluate each criterion on an even scale and rank the options against one another. Therefore, the option which has the lowest overall score was deemed the preferred option for the context of the scenario identified in this chapter's introductory strategic estimate. See Table 2.

Table 2. Four Options Evaluated with JP 5-0 Recommended Criteria

	Fully autonomous unmanned munition	Semi-autonomous unmanned (HITL)	Semi-autonomous unmanned (HOTL)	Fully autonomous unmanned aircraft
Flexibility	4 (capabilities limited to air to ground missions)	2 (requires human input)	1 (operates autonomously but can still take input)	3 (provides commanders options for high-risk scenarios)
Time: 2035	-1 (technology exists with allied countries)	-2 (easiest/quickest transition with existing force structure)	-3 (fully autonomous aspects create policy obstacles)	-4 (AI/machine learning maturation and policy limitations)
Shape the early phases of the LSCO operational environments	-1 (high risk munitions that are attritable and can be employed in high density due to cost)	-4 (better for lower risk environments paired with manned loyal wingmen)	-3 (high risk multi munition systems that are best for targets areas mixed with civilian considerations)	-2 (high risk multi munition systems that are good for early phases of LSCO)
Multinational opportunities	-1 (low cost, low personnel requirements)	3 (personnel requirements are higher, interoperability challenges)	-2 (personnel requirements are lower, interoperability challenges)	-4 (growing international unease with multi-munition autonomous systems)
Low sustainment/support requirement	-1 (low infrastructure support requirements e.g., airfields not required)	-4 (requires robust C2 networks, higher cyber support demands, most prototypes require airfields)	-3 (requires robust C2 networks, higher cyber support demands, most prototypes require airfield, still able to complete kill chain autonomously)	-2 low infrastructure support requirements
Risk of casualties (Friendly/Civilian)	-3	-1(lowest)	-2	-4 (highest)
Surprise	-1 (launch from anywhere, smaller systems with low radar cross sections)	-4 (highest ELINT signatures)	-3 (higher ELINT signatures)	-2 (closed systems with low signatures)
Total	12 (1st)	20 (3rd)	17 (2nd)	21 (4th)

Source: Created by the author.

Chapter Summary

This chapter presented information and analysis for four different types of autonomous aircraft and functions that lethal unmanned aircraft could be capable of in non-permissive large scale combat operations. It used several types of analysis to present each option and included how that capability might be used in the DOD. The stakeholder interviews revealed that considerations exist for additional types of autonomous functions that will enable the effective employment of lethal autonomous unmanned aircraft. Specifically, in order for lethal autonomous unmanned aircraft to reach their full potential, other capabilities that support them need to improve. These improvements include developing data management and processing, creating meshed based networks, enhancing security of data and network systems, using AI and ML to enhance human performance and decisions, and utilizing a mix of manned and unmanned aircraft to manage mission risk. The next chapter will summarize the conclusions and recommendations of this research.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

Conclusion

This thesis examined the primary research question: What types of autonomous functions should lethal unmanned aircraft utilizing artificial intelligence and human teaming technologies be capable of given command and control challenges in non-permissive large-scale combat environments? Considering the different parts of that question, the DOD should have a mix of the different types of autonomous functions that were identified in the four options presented in the Chapter 4. Based on the course of action evaluation criteria from Chapter 4 the fully autonomous munition and the semi-autonomous HOTL aircraft are the two preferred options for integration into the DOD force structure for LSCO by 2035. However, the research analysis found that there is utility in each type of autonomous system depending on the phase of conflict with every type having potential to enhance joint force lethality and accelerate human decision making and performance.

Additionally, future autonomous systems require improvements to other capabilities starting with the management and processing of data, which is predicated on having a way to centrally store that data, so it is easily accessed by the user or warfighter. It is then critical to process data in ways that harnesses the strengths of autonomy which include math and risk.³¹⁷ These data processing capabilities are advanced by artificial intelligence through algorithms which have the potential to create technological growth

³¹⁷ Special operations staff member interview.

in machine learning and vision which result in autonomous systems providing better courses of actions and recommendations to human operators. This outcome sets the conditions for improved trust between human operators and autonomous systems as the utilized artificial intelligence more routinely makes valid recommendations resulting in future entities functioning more and more as human-machine teams.

In order to utilize the advanced data processing that occurs with algorithmic functions, enhancements in the sharing of data and information between systems is necessary which requires improvements in C2 networks. The types of C2 networks that need to be created are cloud based and meshed. This not only increases the accessibility and speed in which information can be shared but it also mitigates risk to C2 functions within contested environments by increasing diversity in connectivity options. Besides meshed networks, connectivity in C2 networks could be enhanced with more resilient and dense space assets, directional datalinks, and laser datalinks. It is also key for the density of C2 nodes and relays to be increased in order to ensure connectivity in an environment where the enemy will be targeting and destroying these assets.

The table below summarizes the research conclusions and provides the updated recommendations (R3) for the primary and secondary research questions (see Table 3). It is a synthesis of the data and perspectives from the literature review, professional analysis, and stakeholder analysis.

Table 3. Updated Recommendation (R3)

Research Questions	Conclusions/Recommendations
What types of autonomous functions should lethal unmanned aircraft utilizing artificial intelligence and human teaming technologies be capable of given command and control challenges in non-permissive large-scale combat environments?	-The fully autonomous munition is the preferred option for a LSCO environment within a contested C2 environment. It has the greatest potential to be realized in the DOD by 2035 and is a capability currently possessed by U.S allies. -It does not require an airfield, and it is similar in cost to like munitions except it has greater target area persistence and it does not require an aircraft for employment. -Semi-autonomous (HOTL) systems are the next best option due to having fully autonomous functions, but humans retain the ability to intervene if necessary. This type of system is able to realize most of the benefits with fully autonomous systems while mitigating risk associated of machine errors by retaining the human as a fail-safe. -Despite the two preferred option above, the DOD should develop and create a diverse mix of the four options for autonomous unmanned aircraft since utility is found when employing them across the spectrum of armed conflict.
Should unmanned aircraft be capable of lethal autonomous functions?	Yes. Specifically, in the early phases of a LSCO environment when military targets are dense and the threat to friendly casualties are the greatest.
What key mission sets need artificial intelligence (AI) and human teaming enabled capabilities?	All DOD mission sets could benefit from artificial intelligence and human teaming. Mission sets for phases of conflict when it is easier to distinguish friend from foe are most advantageous for full autonomy (e.g., supersonic aircraft from direction of enemy forces without IFF code). The loyal wingman concept should be used to expand human agency and performance (e.g., find, fix, target, and track functions and develop COAs for human decisions and/or actions). Loyal wingman aircraft should also be developed with performance parameters that are not restricted by human physical limitations.
What types of manned and unmanned assets should the joint force invest?	-Persistent, exquisite, and legacy platforms to present commanders with options based on risk assessments and better develop strategies to counter enemy plans -Modifications/upgrades to current unmanned aircraft to cut cost and generate quick capabilities towards future requirements
What is the right mix of manned and unmanned aircraft to achieve needed future capabilities to overmatch our adversaries?	-The mix should be determined by establishing ways for unmanned aircraft to support missions that require manned aircraft. -Unmanned aircraft should be used to manage risk and create capabilities where gaps exist due to physical limitations of human beings
What are the advantages of a predominantly unmanned force in a highly lethal large-scale combat environment?	-Commanders are able to accept higher levels of risk -Planners and Commanders are able to develop strategies that are not predicated on aircraft survival
What types of technologies need to be further developed in order to safeguard command and control communication links?	-Cloud based or central data storage -AI-enabled algorithmic processing -Joint Universal C2 node (air, space, or terrestrial based) -Meshed networks -Zero trust networks

Source: Created by the author.

Implications for Conclusions and Recommendations

This research validated that there is utility in integrating artificial intelligence and autonomous functions in unmanned aircraft within the joint force structure. In particular, lethal unmanned aircraft with different types of autonomous functions present

commanders with greater options when trying to meet the challenges associated with large scale combat operations. Also, there are advantages in having both semi-autonomous and fully autonomous systems in order to meet mission requirements across the fully range of military operations and spectrum of conflict.

These force structure requirements of the future should be integrated with not only new program acquisitions but also modifications and upgrades to current weapons systems. For example, the MQ-9 has been one of the joint force's most useful platforms in counter insurgency operations which is primarily because of its capabilities that enable it to be a persistent attack and reconnaissance platform. It is also an affordable platform when compared to other major weapons systems that possess technologies that are considered more exquisite (e.g., stealth). The joint force of the future needs persistent, affordable, and attritable aircraft in order create the mass in airpower needed for LSCO with great power competitors. Additionally, there needs to be a mix of persistent, exquisite, and legacy platforms.³¹⁸ meaning the air assets cannot be designed entirely on exquisite and costly platforms. If it is, then it will be challenging for commanders to manage risk in scenarios since they will be hesitant to accept any risk.

It will also be challenging to create dilemmas for the enemy which are predicated on trading losses since the force structure will not have any pawns to use in operational strategies. The low-cost assets that exist in the current inventory could be used to create the pawns that are needed by modifying platforms for future requirements. Furthermore,

³¹⁸ Special operations staff member interview.

current unmanned platforms could be modified to fill missions in joint C2, air-to-air offensive and defensive operations, and wide area airborne ground surveillance.

These missions are currently flown by manned high value assets that are deficient in numbers for a LSCO environment resulting in commanders taking measures to protect them by displacing them from the high-risk regions of the area of operations. In turn, this makes them less effective because they are not placed close enough to the fight to be efficiently utilized by the assets they support, or they are unable to employ their full complement of capabilities. Overall, autonomous unmanned aircraft provide benefits in cost, availability, persistence, and risk all of which help the joint force to meet challenges within the air domain. These challenges were identified in the strategic estimate of Chapter 4 and include (1) modern and dense enemy integrated air defenses, (2) insufficient numbers of air assets to penetrate and defeat these defenses, (3) and a joint force structure that is reliant on high-end systems.

Implementation Plan for Recommendations

This section proposes ways for the DOD to implement the recommendations presented in this thesis. The implementation plan will be informed by the Kotter change model, which uses 8 steps to lead change within an organization. It is a useful process for organizations to use when they are trying to transform an organization in order to execute strategies.³¹⁹ In the case of the U.S. military, organizations within the DOD seek to develop capabilities and justify resources by remaining aligned with national level

³¹⁹ “The 8-Step Process for Leading Change,” Kotter, accessed May 9, 2021, <https://www.kotterinc.com/8-steps-process-for-leading-change/>.

strategic end states and objectives. This section will only focus on the first four steps of Kotter's model which concentrate on overcoming the existing status quo and setting the conditions for change.³²⁰

The DOD currently has several initiatives which support these steps but there are still ways to improve. First, the NDS and NMS "establish a sense of urgency"³²¹ or desire to create change by asserting that great power competitors are threatening the nation's security by challenging the U.S. military's competitive advantage. Specifically, the NDS emphasizes that emerging technologies to include artificial intelligence and autonomous system capabilities are being developed by competitors and that it is critical for the U.S. to be the first nation to develop and integrate these technologies. This overarching national strategy guidance has spurred the creation of additional DOD strategy documents to include the "DOD Artificial Intelligence Strategy" and the "USAF AI Annex to DOD AI Strategy." These documents establish goals and objectives for AI within the DOD and set a timeline to accomplish them, all of which set conditions for change.

The next step is to "create a guiding coalition,"³²² which DOD leadership has done by establishing organizations like the Joint Artificial Intelligence Center and the Air

³²⁰ Billy Miller and Ken Turner, "L105RB: Leading Organizational Changes: A Leader's Role," in *L100: Developing Organizations and Leaders* (Advance Sheet, Department of Command Leadership, US Army Command and General Staff College, June 2020).

³²¹ Ibid.

³²² Ibid.

Force AI Cross Functional Team. These organizations are key to “developing a vision and strategy”³²³ which helps the organizational members to conceptualize an operational approach that is supported by plans in order to achieve a future state (e.g., Air Force Vision 2035).

“Communicating the change vision,”³²⁴ which is the responsibility of organizational leadership, is the fourth step and is one of the steps within the Kotter Change process that the DOD needs to improve. Currently, it appears that national level leadership is undecided on the types of autonomous functions that the DOD will develop and integrate into the joint force. While DOD leadership has been consistent with clearly messaging that U.S. military forces will use AI with high ethical principles based on transparency, reliability, governability, and core values,³²⁵ it is still unclear what specific types of autonomy will be supported and integrated by the joint force timeline of 2035. This makes the realization of these autonomous functions difficult since industry partners and DOD research labs lack clear guidance on the specific capabilities that need to be developed. Also, by not providing clear guidance on the types of autonomous functions that need to be created, there is an implied lack of confidence in current technological developments, specifically for fully autonomous systems. If it was clearly stated that the use of lethal autonomous weapon systems is aligned with future mission requirements,

³²³ Miller and Turner, “L105RB.”

³²⁴ Ibid.

³²⁵ Jim Garamone, “Esper Says Artificial Intelligence Will Change the Battlefield,” *DOD News*, September 9, 2020, <https://www.defense.gov/Explore/News/Article/Article/2340972/esper-says-artificial-intelligence-will-change-the-battlefield/>.

then the development and integration of these systems would be assured by synchronizing the plans, programs, requirements, and budgets that are needed for their development.

Recommendations for Future Research

This thesis researched several questions related to lethal autonomous unmanned aircraft and artificial intelligence in future warfare. Through the research process, several other topics related to this field were discovered which need to be further explored and are included in the proposed research questions below.

Do autonomous capabilities deter war by increasing military strength or do they increase war's likelihood by decreasing risk to human life making the decision to engage in military conflict easier?

Does artificial intelligence increase the speed and accuracy of human decisions by accelerating data processing and presenting human operators with executable options or does it increase the likelihood for operators to become task saturated and increase the risk of poor and hasty decisions?

What are the differences between command and control and how should the relationship between the two be used in the future to ensure that meaningful human involvement remains a part of the employment in lethal autonomous weapon systems?

Personal Reflection/Final Thoughts

The entirety of my Army Command and General Staff College experience has been a tremendous learning and growth experience. This marks the completion of my first academic research project, which has inspired me to conduct additional research in

the future to not only contribute to the professional body of knowledge but for continued personal growth. I chose this research topic because unmanned aircraft operations are related to my previous professional experiences and my future military career will most likely continue to involve remotely piloted aircraft operations. Therefore, I wanted to be informed on future unmanned applications and technologies in order to be a better staff officer and aspiring commander who can intelligently advocate for resources in the remotely piloted aircraft community.

The writing of this thesis has taken me approximately nine months and it has required persistent focus with at least an hour of everyday dedicated to completing it. One of the reasons this level of focus was required is because the topic of unmanned aircraft and future artificial intelligence applications has been heavily researched and debated by others making academic sources of information plentiful. In a way, this made the literature review more challenging since more effort was required to ensure the sources I referenced would remain within the scope of my research as outlined in Chapter 1. Ultimately, I believe the experiences and challenges associated with this process have improved my ability to solve complex problems in the future where vast amounts of information are available and problems overlap. In these instances, it is important to have a clearly defined problem statement in order to remain focused on one specific issue or the conditions that needs to be improved. If there are multiple gaps that need to be improved between the current state and the desired end state, then having a clear problem statement helps to focus efforts on a single gap. Through my entire CGSC experience, I have practiced defining problems and using personal and professional experiences supported by academic research to form recommendations. This experience will help me

in the future as a field grade officer to better lead staffs, teams, and individuals to meet organizational goals.

I have also learned that there is tremendous value in having multiple perspectives to help develop critical, creative, and informed solutions. The seminars within CGSC are composed of officers from 15 different career fields with a diverse mix of racial and gender backgrounds. By creating diverse seminars, students are exposed to a variety of perspectives resulting in field grade officers who are able to think more critically and creatively and lead more effectively. Similarly, my intent behind conducting qualitative interviews was to ensure that I considered multiple perspectives from officers of different backgrounds in order to form more complete conclusions and recommendations.

When I first started my research, my initial thought was that my recommendations needed to be groundbreaking in order for them to be meaningful to others. Through this process I have come to the realization that while new recommendations are beneficial, it is equally important for academic research to validate or expand on the current body of knowledge. By doing this there is an increased probability that comparable recommendations will come to fruition and create the change that is needed, which is ultimately what is most important and meaningful.

In that same vein, autonomous functions in lethal unmanned aircraft have been recommended by others as a capability that is needed in order to uphold the DOD's strategic plans and operational concepts of the future. It is becoming time critical to develop and integrate these capabilities if they are going to be ready by the joint force timelines of 2035. Several industry partners and DOD research labs have begun developing capabilities but a clearer understanding of the types of autonomy the DOD

endorses for the future will provide the focus necessary to realize these capabilities.

Given the utility and broad range of potential applications for autonomous systems, the fielding of these capabilities will undoubtedly help to preserve the DOD's mission to provide military forces needed to deter war and ensure the nation's security.

APPENDIX A

AUTONOMOUS FUNCTIONS OF UNMANNED AIRCRAFT WITH ARTIFICIAL INTELLIGENCE IN LARGE-SCALE COMBAT OPERATIONS

Consent to Participate in a Research Study

This is a research study conducted in support of my completion of a master's thesis at the US Army Command and General Staff College (CGSC). This form provides information to you on your rights as a voluntary research participant in the above-named study and of the responsibilities the researcher has during this study. As a voluntary participant, you can withdraw from the study at any time, do not have to offer a reason, and will not experience negative (e.g., lower grades, poor performance evaluation) or positive (e.g., promotion, good performance evaluation) consequences for doing so. The CGSC has approved this study and supports the research.

Purpose of the Research Study

This research study will explore the types of autonomous functions needed in unmanned platforms to fill capability gaps for large-scale combat operations by 2035.

Procedures

To accurately assess capability gaps and solutions, I will be interviewing subject matter experts in the areas of autonomous systems, artificial intelligence, and joint command and control systems. I will interview up to 10 individuals through a video teleconference platform like Zoom, recording the interviews for later transcription. Each interview will not take more than an hour although a follow-up interview might be

needed. I will personally transcribe your interview and email the transcript to you for review prior to using any data in my paper.

All digital files will be stored securely at my residence in a locked container and used on a password protected personal computer. Once you have approved the transcript, I will delete recordings for your interview so only the transcript remains as data for my study. If you cannot do a video teleconference, then we can do a recorded telephone conversation instead. If neither of these are acceptable, I can email my interview questions to you and ask that you respond to them in that manner.

My thesis will be an unclassified document, so I ask that you do not discuss any classified information, potential violations of law or regulations, or any information that might put your security clearance, credentials, or work access at risk. If in doubt, consult with your commander or supervisor prior to agreeing to do the interview. If I believe our discussion is going into a classified or restricted topic, I will stop the interview and ensure we remain unrestricted prior to continuing the interview.

Risk

I will be asking for your opinions and judgments in my topic area. Some of your comments might disagree with those of the Department of Defense or your supervisors, in turn affecting your current or future employment. To mitigate this risk, I will not use your real name on any files or in my final report unless you specifically ask me to do so. I

will also review transcript comments and not use any from you that might lead a reasonable person to identify you from the comments.

Benefits and Compensation

This is a research study and there is no expectation that you will receive any direct benefit from participation. I will provide a copy of the approved thesis to you if desired so you can see how your assessments and opinions compare to others. Per DoD policy, you will not be compensated for your participation.

Confidentiality

The confidentiality of your interview is important to me. I will not use your name, or the names of any individuals described in your interview in my report. This informed consent form is the only document that will directly link you to participating in my study. The only individuals with access to your data will be me, my committee chair, and human protection program officials (to ensure I am complying with my responsibilities as a researcher). It should be acknowledged however that there is a small risk of hacking in a digital platform like Zoom or Microsoft Teams, possibly enabling third parties to digitally link your participation with the recorded data. I will mitigate this risk through the use of a virtual private network (VPN) to enhance the security of recorded interviews.

All data obtained about or from you, as an individual, will be considered privileged and held in confidence; you will not be identified in any presentation of the results unless you wish so. Furthermore, any documents analyzed will be de-identified and stored in a locked desk when not in use. Complete confidentiality cannot be

promised, particularly to participants who are military personnel, because information bearing on your health might be required to be reported to appropriate officials.

All data related to this study will remain secured for a period of not less than three years from the approval date for the research study report. The researcher (i.e., principal investigator) will store data collected in an encrypted file on a password protected laptop and not within a shared file or cloud-based platform.

Contacts for Additional Assistance

If you have a concern about this study or how it is conducted, you can contact me at robert.m.hetherington.mil@mail.mil or the CGSC Human Protections Director (Dr. Dale Spurlin) at dale.f.spurlin.civ@mail.mil.

Voluntary Participation

Participation in a research study is voluntary. Anyone who is asked to be in a research study may decline. No one has to become a research participant. If you start a research study, you may stop at any time, or decline to participate in any portion of the study. You do not need to give a reason. No one can discriminate against you or treat you differently if you choose not to be in a research study or later decide to stop your participation.

Statement of Consent

I have read this form and its contents were explained. I agree to be in this research study for the purposes listed above. All of my questions were answered to my

satisfaction. I understand I will receive a signed and dated copy of this form for my records.

_____/_____/_____
Signature of Research Participant Date

Printed Name of Research Participant

_____/_____/_____
Principal Investigator Signature Date

APPENDIX B

INTERVIEW QUESTIONS

1. What are the greatest future challenges for fielding capabilities utilizing artificial intelligence and autonomous unmanned aircraft?
2. By 2035, what do you see as the most feasible, suitable, and reasonable types of autonomous functions for unmanned aircraft?
3. Do you think it is feasible for the joint force to have assets capable of multiple levels of autonomy which can then be tailored to specific levels of armed conflict and/or operating environment?
4. How is the joint force developing ways to protect command and control of unmanned systems from adversarial interference or manipulation?
5. What are the future decisions that need to be made in order to meet the future joint force timelines of 2035?
6. How are command and control networks being developed in order to enable the networks needed for aircraft and weapons to function collectively and autonomously against targets?
7. In the current RPA/unmanned aircraft community, what types of autonomous capabilities do think are most feasible to achieve by 2035 utilizing the current personnel force structure and predicted technological improvements?
8. Given the state of artificial intelligence, autonomous weapons, and nanotechnology, what do you see as the greatest opportunities?
9. What key mission sets need artificial intelligence and human teaming enabled capabilities?

10. What types of manned and unmanned assets should the joint force invest?
11. What is the right mix of manned and unmanned aircraft to achieve needed future capabilities to overmatch our adversaries?
12. What are the advantages of a predominantly unmanned force in a highly lethal large-scale combat environment?
13. What types of technologies need to be further developed in order to safeguard command and control communication links?
14. What capabilities are being pursued in order to safeguard human life from autonomous systems making critical mistakes?

BIBLIOGRAPHY

- Abadicio, Millicent. "Artificial Intelligence in the Chinese Military-Current Initiatives." *Emerj*. Last modified November 21, 2019. <https://emerj.com/ai-sector-overviews/artificial-intelligence-china-military/>.
- Air Force Research Laboratory. "Skyborg." Accessed November 15, 2020. <https://afresearchlab.com/technology/vanguards/successstories/skyborg>.
- Air Force Staff Member. Telephone interview by author. March 15, 2021.
- Allen, Greg. "Understanding AI Technology." Joint Artificial Intelligence Center, April 2020. <https://www.ai.mil/docs/Understanding%20AI%20Technology.pdf>.
- . "Understanding China's AI Strategy." Center for a New American Society, February 6, 2019. <https://www.cnas.org/publications/reports/understanding-chinas-ai-strategy>.
- Barrett, Barbara M., "On the Future of Air and Space Power." Interview by Strategic Studies Quarterly, September 28, 2020. *Strategic Studies Quarterly* (Winter 2020): 3-5. https://www.airuniversity.af.edu/Portals/10/SSQ/documents/Volume-14_Issue-4/SECAF.pdf.
- Bendett, Samuel. "Here's How the Russian Military is Organizing to Develop AI." *Defense One*. Last modified July 20, 2018. <https://www.defenseone.com/ideas/2018/07/russian-militarys-ai-development-roadmap/149900/>.
- . "In AI, Russia is Hustling to Catch Up." *Defense One*, April 4, 2018. <https://www.defenseone.com/ideas/2018/04/russia-races-forward-ai-development/147178/>.
- Boulanin, Vincent, and Maaike Verbruggen. *Mapping the Development of Autonomy in Weapons Systems*. Stockholm International Peace Research Institute, November 2017. https://www.sipri.org/sites/default/files/2017-11/siprireport_mapping_the_development_of_autonomy_in_weapon_systems_1117_1.pdf.
- Boyd, John. "The OODA Loop: How Fighter Pilots Make Fast and Accurate Decisions." *Decision Making* (blog). *Farnum Street*, January 2018. <https://fs.blog/2018/01/john-boyd-ooda-loop/>.
- Bradenburg, Adam. "Are Your Company's Strengths Really Weaknesses?" *Harvard Business Review*, August 22, 2019. <https://hbr.org/2019/08/are-your-companys-strengths-really-weaknesses>.
- Butz, Roderic K. "Beneath the Crosshairs: Remotely Piloted Airstrikes as a Foreign Policy Tool." *Joint Force Quarterly* 100 (1st Quarter 2021): 36-48.

- Center for the Study of the Drone. “Loitering Munitions.” Bard College. Accessed February 17, 2021. <https://dronecenter.bard.edu/files/2017/02/CSD-Loitering-Munitions.pdf>.
- Chairman of the Joint Chiefs of Staff (CJCS). CJCS Instruction 5123.01H, *Charter of the Joint Requirements Oversight Council (JROC) and Implementation of the Joint Capabilities Integration and Development System (JCIDS)*. Washington, DC: Joint Staff, August 31, 2018.
- . “Message to the Joint Force.” Letter, Washington, DC, October 1, 2019. https://media.defense.gov/2019/Oct/02/2002189545/-1/-1/1/CJCS_GEN_MILLEY_LETTER_TO_THE_FORCE.pdf.
- Davis, Bennie, J. “The AI Advantage.” *Airman Magazine*. Last modified June 15, 2020. <https://airman.dodlive.mil/2020/06/15/the-ai-advantage/>.
- Department of the Air Force. 2019: *The United States Air Force Artificial Intelligence Annex to The Department of Defense Artificial Intelligence Strategy*. Washington, DC: Department of the Air Force, 2019. <https://www.af.mil/Portals/1/documents/5/USAF-AI-Annex-to-DoD-AI-Strategy.pdf>.
- . *Air Force Future Operating Concept, A View of the Air Force in 2035*. Washington, DC: Department of the Air Force, 2015. <https://www.af.mil/Portals/77/documents/AFD-151207-019.pdf>.
- . *USAF Strategic Master Plan*. Washington, DC: Department of the Air Force, May 2015. https://www.af.mil/Portals/1/documents/Force%20Management/Strategic_Master_Plan.pdf.
- Department of Defense (DOD). DOD Directive 3000.09, *Autonomy in Weapons Systems*. Washington, DC: DOD, November 21, 2012. Incorporating Change 1, May 8, 2017. https://fas.org/irp/doddir/dod/d3000_09.pdf.
- . *Summary of the 2018 National Defense Strategy of the United States of America: Sharpening the American Military’s Competitive Edge*. Washington, DC: DOD, 2018. <https://dod.defense.gov/Portals/1/Documents/pubs/2018-National-Defense-Strategy-Summary.pdf>.
- Dwyer, Morgan. “Making the Most of the Air Force’s Investment in Joint All Domain Command and Control.” Center for Strategic and International Studies, March 6, 2020. <https://www.csis.org/analysis/making-most-air-forces-investment-joint-all-domain-command-and-control>.
- Federation of American Scientists. “AGM 88 HARM.” Accessed April 21, 2021. <https://fas.org/man/dod-101/sys/smart/agm-88.htm>.

- Gady, Franz-Stefan. "Russia to Begin Delivery of China's Second S-400 Air Defense System Regiment in July." *The Diplomat*, April 3, 2019. <https://thediplomat.com/2019/04/russia-to-begin-delivery-of-chinas-second-s-400-air-defense-system-regiment-in-july/>.
- Garamone, Jim. "Esper Says Artificial Intelligence Will Change the Battlefield." *DOD News*, September 9, 2020. <https://www.defense.gov/Explore/News/Article/Article/2340972/esper-says-artificial-intelligence-will-change-the-battlefield>.
- Gould, Joe. "Guided-Bomb Makers Anticipate GPS Jammers." *Defense News*, May 31, 2015. <https://www.defensenews.com/air/2015/05/31/guided-bomb-makers-anticipate-gps-jammers/>.
- Gunzinger, Mark, and Lukas Autenried. "The Promise of Skyborg." *Air Force Magazine*, November 1, 2020. <https://www.airforcemag.com/article/the-promise-of-skyborg/>.
- Headquarters, Department of the Army. Field Manual 3-0, *Operations*. Washington, DC: Army Publishing Directorate, 2017. https://armypubs.army.mil/epubs/DR_pubs/DR_a/pdf/web/ARN6687_FM%203-0%20C1%20Inc%20FINAL%20WEB.pdf.
- Heginbotham, Eric, Michael Nixon, Forrest E. Morgan, Jacob L. Heim, Jeff Hagen, Sheng Li, Jeffrey Engstrom, Martin C. Libicki, Paul DeLuca, David A. Shlapak, David R. Frelinger, Burgess Laird, Kyle Brady, and Lyle J. Morris. *The U.S.-China Military Scorecard*. Santa Monica, CA: RAND, 2017. https://www.rand.org/pubs/research_reports/RR392.html.
- Hoehn, John R. "Joint All-Domain Command and Control." Congressional Research Service, Washington, DC, updated June 4, 2021. <https://fas.org/sgp/crs/natsec/IF11493.pdf>.
- Horowitz, Michael C. "Artificial Intelligence, International Competition, and the Balance of Power." *Texas National Security Review* 1, no. 3 (May 2018): 37-57. <https://tnsr.org/2018/05/artificial-intelligence-international-competition-and-the-balance-of-power/>.
- Israel Aerospace Industries. "Harop Loitering Munition System." Accessed February 17, 2021. <https://www.iai.co.il/p/harop>.
- Joint Artificial Intelligence Center. "Transforming the Department of Defense through AI: The Joint Artificial Intelligence Center." Accessed April 11, 2021. <https://www.ai.mil>.
- Joint Chiefs of Staff (JCS). Joint Publication 3-01, *Air and Missile Threats*. Washington, DC: JCS, 2017. https://www.jcs.mil/Portals/36/Documents/Doctrine/pubs/jp3_01_pa.pdf.

- . Joint Publication 3-03, *Joint Interdiction*. Washington, DC: JCS, 2016. https://www.jcs.mil/Portals/36/Documents/Doctrine/pubs/jp3_03.pdf.
- . Joint Publication 5, *Doctrine for the Armed Forces of the United States*. Washington, DC: JCS, 2017. https://www.jcs.mil/Portals/36/Documents/Doctrine/pubs/jp5_0_20171606.pdf.
- . *Joint Operating Environment (JOE 2035): The Joint Force in a Contested and Disordered World*. Washington, DC: JCS, July 2016.
- . *National Military Strategy of the United States of America, 2015: The United States Military's Contribution to National Security*. Washington, DC: JCS, June 2015. https://www.jcs.mil/Portals/36/Documents/Publications/National_Military_Strategy_2015.pdf.
- Joint Staff Member. Telephone interview by author. March 13, 2021.
- Knight, Will. "Military artificial intelligence can be easily and dangerously fooled." *Technology Review*. Last modified October 21, 2019. <https://www.technologyreview.com/2019/10/21/132277/military-artificial-intelligence-can-be-easily-and-dangerously-fooled/>.
- Konaev, Margarita. "Thoughts on Russia's AI Strategy." Center for Security and Emerging Technology, October 30, 2019. <https://cset.georgetown.edu/article/thoughts-on-russias-ai-strategy/>.
- Kotter. "The 8-Step Process for Leading Change." Accessed May 9, 2021. <https://www.kotterinc.com/8-steps-process-for-leading-change/>.
- Kwek, Seck Tai David. "Future of Singapore's Conscript Army." Master's Thesis, U.S Army Command and General Staff College, Fort Leavenworth, KS, 2019.
- Lele, Ajey. "Debating Lethal Autonomous Weapon Systems." *Journal of Defence Studies* 13, no. 1 (January-March 2019): 51-70. https://www.researchgate.net/publication/330534643_Debating_Lethal_Autonomous_Weapon_Systems.
- Lengel, Sherrill, Jeff Hagen, Eric Hastings, Mary Lee, Matthew Sargent, Matthew Walsh, Li Ang Zhang, and David Blancett. *Joint All-Domain Command and Control for Modern Warfare*. Santa Monica, CA: RAND, 2020. https://www.rand.org/pubs/research_reports/RR4408z1.html.
- Long, Kenneth E. "The Applied Professional Case Study Methodology and Design." Course Curriculum, U.S. Army Command and General Staff College. Accessed November 26, 2020. https://cgsc.blackboard.com/webapps/blackboard/content/listContent.jsp?course_id=_8676_1&content_id=_688072_1&mode=reset.

- . “Emerging Best Practices from Professional Applied Case Study Research.” Lecture Notes, U.S. Army Command and General Staff College, Fort Leavenworth, KS, September 15, 2016.
- . “VUCA Environment.” Lecture Notes, U.S. Army Command and General Staff College, Fort Leavenworth, KS, January 2021.
- Maxwell, Paul. “Artificial Intelligence is the Future of Warfare (just not in the way you think).” Modern War Institute. Last modified April 20, 2020. <https://mwi.usma.edu/artificial-intelligence-future-warfare-just-not-way-think/>.
- Miller, Billy, and Ken Turner. “L105RB: Leading Organizational Changes: A Leader’s Role.” In *L100: Developing Organizations and Leaders*. Advance Sheet, Department of Command Leadership, US Army Command and General Staff College, June 2020.
- Noyes, Matthew F. “Autonomous Weapons: The Future behind Us.” Master’s Thesis, U.S Army Command and General Staff College, Fort Leavenworth, KS, 2019.
- Pentagon Staff Member. Microsoft Teams interview by author. March 17, 2021.
- Polyakova, Alina. “Weapons of the weak: Russia and AI-driven asymmetric warfare.” The Brookings Institution, November 15, 2018. <https://www.brookings.edu/research/weapons-of-the-weak-russia-and-ai-driven-asymmetric-warfare/>.
- Porter, Scott A. “Large Scale Combat Operations: Risk and Adaptability at the Corps and Division Levels.” *Small Wars Journal*. Last modified October 13, 2020. <https://smallwarsjournal.com/jrnl/art/large-scale-combat-operations-risk-and-adaptability-corps-and-division-levels>.
- Raytheon. “StormBreaker Smart Weapons.” Accessed March 24, 2019. <https://www.raytheon.com/capabilities/products/stormbreaker>.
- Rogoway, Tyler. “Everything We Learned from Boeing About Its Potentially Game-Changing Loyal Wingman Drone.” *The Drive*, May 4, 2020. <https://www.thedrive.com/the-war-zone/33271/everything-we-learned-from-boeing-about-its-potentially-game-changing-loyal-wingman-drone>.
- . “Meet Israel’s ‘Suicide Squad’ of Self-Sacrificing Drones.” *The Drive*. Last modified August 8, 2016. <https://www.thedrive.com/the-war-zone/4760/meet-israels-suicide-squad-of-self-sacrificing-drones>.
- Scharre, Paul. “Autonomous Weapons and Operational Risk.” Center for New American Strategy. February 2016. https://s3.us-east-1.amazonaws.com/files.cnas.org/documents/CNAS_Autonomous-weapons-operational-risk.pdf?mtime=20160906080515&focal=none.

- Schuetz, Ariel M. "Why the DOD is Losing its Asymmetric Robotics and Autonomous Systems Advantage: An Argument for the Concept of Autonomous Function with a System." Master's Thesis, U.S Army Command and General Staff College, Fort Leavenworth, KS, 2018.
- Singer, P. W. "Military Robots and the Future of War." Lecture, TED Conferences LLC, February 2009. https://www.ted.com/talks/p_w_singer_military_robots_and_the_future_of_war/transcript?language=en.
- Slayer, Kelly M. "Defense Primer: U.S. Policy on Lethal Autonomous Weapon Systems." Congressional Research Service, Washington, DC, updated December 1, 2020. <https://crsreports.congress.gov/product/pdf/IF/IF11150>.
- Special Operations Staff Member. Telephone interview by author. March 19, 2021.
- Stauffer, Brian. "Stopping Killer Robots: Country Positions on Banning Fully Autonomous Weapons and Retaining Human Control." Human Rights Watch. Last modified August 10, 2020. https://www.hrw.org/report/2020/08/10/stopping-killer-robots/country-positions-banning-fully-autonomous-weapons-and#_ftn12.
- Tegler, Eric. "Why Talk to Drones Over Radio When You Can Use Lasers?" *Popular Mechanics*, March 18, 2016. <https://www.popularmechanics.com/flight/drones/a19999/laser-communication-drones/>.
- Tighe, Thomas, Raymond Hill, and Greg McIntyre. "A Decision for Strategic Effects: A Conceptual Approach to Effects Based Targeting." *Air and Space Power Journal* 9, no. 1 (Spring 1995). <https://www.airuniversity.af.edu/Portals/10/ASPJ/journals/Chronicles/Hill.pdf>.
- U.S. Air Force. "F-16 Fighting Falcon." September 23, 2015. <https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104505/f-16-fighting-falcon/>.
- U.S. Army War College. *How the Army Runs: A Senior Leader Reference Handbook, 2013-2014*. Carlisle, PA: US Army War College, 2013.
- U.S. Congress. Senate. *United States Air Force Posture Statement: Fiscal Year 2021*. Statement of the Honorable Barbara Barrett, Secretary of the Air Force, and General David L. Goldfein, Chief of Staff, United States Air Force. United States Air Force Presentation to the Armed Services Committee of the United States Senate. 116th Cong., 2nd sess., March 3, 2020. https://www.armed-services.senate.gov/imo/media/doc/Barrett--Goldfein_03-03-20.pdf.
- U.S. President. *National Security Strategy of the United States of America*. Washington, DC: The White House, December 2017. <https://www.whitehouse.gov/wp-content/uploads/2017/12/NSS-Final-12-18-2017-0905.pdf>.

United States Air Force (USAF). *Science and Technology Strategy: Strengthening USAF Science and Technology for 2030 and Beyond*. Washington, DC: USAF, April 2019. <https://www.af.mil/Portals/1/documents/2019%20SAF%20story%20attachments/Air%20Force%20Science%20and%20Technology%20Strategy.pdf>.

Washington (AFNS) Secretary of the Air Force Public Affairs Command Information. "Air Force Releases Future Operating Concept." U.S. Air Force, September 15, 2015. <https://www.af.mil/News/Article-Display/Article/617301/af-releases-future-operating-concept/>.

Welsh, Sean. "We need to keep humans in the loop when robots fight wars." *The Conversation*. Last modified January 28, 2016. <https://theconversation.com/we-need-to-keep-humans-in-the-loop-when-robots-fight-wars-53641>.

Ziyanauv. "Blowfish A2 Product Overview." January 2019. <http://ziyanuav.com/blowfish2.html>.