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THESIS

**AUTONOMOUS MANEUVERING:
A DEFENSE ADVANTAGE FOR AFSOC AIRCRAFT**

by

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June 2022

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**AUTONOMOUS MANEUVERING:
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ABSTRACT

The U.S. military continues to operate in increasingly complex security environments and can no longer expect uncontested or dominant superiority in every domain. Aircraft operated by special operations forces (SOF) need improved defensive capabilities to support missions in non-permissive environments. Integrating automation and human-machine teaming into existing defensive capabilities may reduce threat reaction time and increase the effectiveness of defensive maneuvers in manned and unmanned aircraft configurations. This thesis examines the value of aircraft maneuvering as part of a threat reaction to identify situations where human intervention negatively affects timing and accuracy. It also considers opportunities to replicate Merlin Labs' approach to flight automation and incorporate a machine-trained system capable of performing defensive maneuvers into existing aircraft. The analysis indicates aircraft maneuvering is critical to an effective threat reaction, and automating select operator actions can increase survivability against certain surface-to-air threats. This thesis recommends a renewed focus on defensive capabilities for SOF aircraft and endorses integrating onboard autonomous systems into traditionally manned platforms to improve defensive threat reactions. It also advocates for continued research into the use of optionally manned aircraft in SOF missions to refine their operational utility and expand capabilities across a variety of mission platforms.

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LIST OF ACRONYMS AND ABBREVIATIONS

AAA	anti-aircraft artillery
AFRL	Air Force Research Laboratory
AFSOC	Air Force Special Operations Command
AI	artificial intelligence
BLOS	beyond line of sight
CSO	Combat Systems Officer
HMT	human machine teaming
HRT	human reaction time
IR	infrared
ISR	intelligence surveillance and reconnaissance
JAIC	Joint Artificial Intelligence Center
LOS	line of sight
MANPADS	man-portable air-defense systems
ML	machine learning
MSIC	Missile and Space Intelligence Center
RF	radio frequency
SAM	surface-to-air missile
SOCOM	Special Operations Command
SOF	special operations forces
USASOC	United States Army Special Operations Command
WEPTAC	weapons and tactics conference

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EXECUTIVE SUMMARY

The U.S. military continues to operate in increasingly complex security environments and can no longer expect uncontested or dominant superiority in every domain. Since surface-to-air threats have proliferated to hostile actors operating across the world, future operating environments will feature areas of contested airspace that will challenge the operation of manned and unmanned aircraft. Aircraft operated by special operations forces (SOF) need improved defensive capabilities to maneuver in these disputed areas while supporting traditional SOF missions. This thesis examines the advancements in commercial capabilities to reduce threat reaction time and increase the effectiveness of defensive maneuvers in manned and unmanned aircraft configurations.

Working in collaboration with the Boston-based, flight automation startup Merlin Labs, this analysis explored the potential automation of defensive maneuvers. Aircraft maneuvering is a critical aspect of an effective threat reaction and automating select operator actions can increase survivability against certain surface-to-air threats. By identifying the steps in an AC-130J threat reaction where human intervention affects the timing and accuracy of aircraft maneuvering, this analysis revealed opportunities to replicate Merlin Labs' approach to flight automation and incorporate a machine-trained system capable of performing defensive maneuvers into existing aircraft.

The critical steps identified in the threat reaction process include threat indication, threat combat identification, and threat reaction pairing. Currently, aircrew manually perform these steps to complete defensive threat maneuvers. However, each of these steps could benefit from automation and human machine teaming by improving overall performance in three notable ways. First, generating streamlined visual and audible threat indications ensures timely notification of the presence of a threat. Next, automating the identification process to accurately recognize the threat variant reduces the response time and the potential for human identification errors. Finally, synchronized pairing of threat identification to the appropriate aircraft response reduces unnecessary delays and increases the accuracy of threat maneuvering.

This thesis recommends a *renewed focus on defensive capabilities for SOF aircraft and endorses integrating onboard autonomous systems into traditionally manned platforms to improve defensive threat reactions*. Incorporating human machine teaming and autonomous capabilities into aircraft defensive systems enables defensive maneuvers to outperform legacy systems and permit operations into a wider range of environments. In addition to improving defensive maneuvers, Merlin Labs' automated flight deck offers potential uses across a variety of different aircraft and missions. *Continued research should investigate the use of optionally manned aircraft in SOF missions to refine their operational utility and expand capabilities across a variety of mission platforms*. Finally, the adoption of a Merlin System across SOF will upend established operational practices and require individual and organizational behavior change. To ease the transition and increase the adoption rate, AFSOC should implement steps that *minimize the behavior change of stakeholders while maximizing the operational benefits of the system*. Developing an understanding of artificial intelligence, machine learning, and automation will better prepare these actors for the rapid changes in military technology and the changing character of war.

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I. INTRODUCTION

Technological innovations influence the nature of warfare and shape how battles are won and lost. Throughout the past twenty years, U.S. military commitments in sustained conflicts across the Middle East have led to a focus on developing offensive capabilities to combat terrorist activities in areas consisting of relatively few threats to air operations. Special operations forces (SOF) aircraft have grown accustomed to operating freely against violent extremist organizations and have focused enhancements on improving methods for tracking and targeting terrorist networks. However, as threat environments evolve, SOF aircraft will need the capability to operate in areas consisting of increasingly sophisticated threats aimed to contest SOF's ability to access and maneuver.¹

The 2018 National Defense Strategy signaled a shift in the Department of Defense (DOD) priorities, highlighting the rise of strategic competitors to national security. It stresses the reality that the U.S. military must operate in complex security environments and can no longer expect uncontested or dominant superiority in every domain.² Because surface-to-air threats have proliferated to hostile actors operating in grey-zones, future SOF operating environments will feature areas of contested airspace that will challenge the operation of manned and unmanned aircraft. For example, various types of surface-to-air missiles (SAMs), man-portable air-defense systems (MANPADS), and radar guided anti-aircraft artillery (AAA) have turned up in armed conflicts and weak states throughout the

¹ Chris Dougherty, "Moving Beyond A2/AD," Center for a New American Security, December 3, 2020, <https://www.cnas.org/publications/commentary/moving-beyond-a2-ad>.

² Department of Defense, *Summary of the 2018 National Defense Strategy* (Washington, DC: Department of Defense, 2018), 3, <https://dod.defense.gov/Portals/1/Documents/pubs/2018-National-Defense-Strategy-Summary.pdf>.

world.³ Unfortunately, many SOF aircraft are unprepared to operate in environments denied or contested by surface-to-air threats. Equipped with limited defense systems, SOF aircrew primarily rely on avoiding threat areas to minimize their exposure to surface-to-air threats, sometimes to the detriment of the mission. To fill this critical gap, this thesis investigates potential solutions that strengthen the ability of manned and unmanned aircraft to operate in a wide variety of environments, against any adversary.

A. RESEARCH QUESTION

Can the use of artificial intelligence in AFSOC aircraft reduce threat reaction time and increase the effectiveness of defensive maneuvers? If so, how can this technology be incorporated into current manned and unmanned aircraft configurations?

B. LITERATURE REVIEW

1. Artificial Intelligence and the DOD

Advancements in the application of artificial intelligence (AI) have led to growth in automation, robotics, image recognition and many other areas.⁴ To keep pace with the accelerating field of AI, the defense sector has largely drawn from commercial technologies when adopting AI and has sought out dual-use solutions to manage the challenge of analyzing large amounts of data.⁵ Meanwhile, the U.S. military is attempting to reimagine the future of conflict with the pervasiveness of AI. However, the military's focus on developing stand-off weapons and incorporating AI into offensive systems has

³ Nelson Alusala, "Manpads: The Problem of Proliferation in Sub-Saharan Africa," *Arms Control: Africa* 1, no. 3 (July 2008): 2, Sabinet Online Ltd.; Illicit MANPADS have been proliferated in many countries but the largest number of missiles outside of government control are first- and second- generation shoulder-fired, heat or infrared-seeking missiles. Although some third- and fourth- generation missiles have been acquired and used, they are rare in comparison. Modern aircraft equipped with basic countermeasures can successfully defeat early generation MANPADS in most situations. For more on MANPADS threats see Matt Schroeder, *The MANPADS Threat and International Efforts to Address It: Ten Years after Mombasa* (Washington, DC: Federation of American Scientists, 2013), https://uploads.fas.org/2013/10/The_MANPADS_Threat.pdf.

⁴ James Johnson, "Artificial Intelligence & Future Warfare: Implications for International Security," *Defense & Security Analysis* 35, no. 2 (April 2019): 6, <https://doi.org/10.1080/14751798.2019.1600800>.

⁵ Eric Schmidt et al., *Final Report: National Security Commission on Artificial Intelligence* (Washington, DC: National Security Commission on Artificial Intelligence, 2021), 24, <https://www.nscai.gov/2021-final-report/>.

diminished the inevitable reality that in future operations SOF aircraft will need to operate in contested areas. This analysis identifies a clear focus by the DOD to adopt AI technologies across a wide spectrum of mission areas including the targeting process, intelligence analysis, and command and control, but the research currently lacks depth in applying AI principles to systems that aid in the real-time defense of aircraft.

In recent years, the DOD has focused on incorporating AI into developing capabilities, including drafting an official AI strategy and establishing the Joint Artificial Intelligence Center (JAIC): an organization to direct AI transformation for the DOD. DOD's AI Strategy defines AI as "the ability of machines to perform tasks that normally require human intelligence."⁶ Although experts agree that computers are far from achieving scalable, human level intelligence, AI currently is a "power force multiplier and enabler for several high-tech domains."⁷ Machine learning (ML) systems trained with large datasets form the basis of AI models and have greatly improved in performance and practicality in recent years.⁸ Recognizing the significance of AI, the JAIC aims to accelerate the "DOD's adoption and integration of AI to achieve mission impact at scale."⁹

With the expanding use of AI throughout the DOD, several projects stand out as leading efforts to increase warfighting capabilities, particularly by leveraging Intelligence, Surveillance, and Reconnaissance (ISR). One of the early programs to adopt AI and ML principles was Project Maven. The program utilizes algorithms to "automatically process, exploit, and disseminate full-motion video feeds from various unmanned aerial systems" and has been successfully deployed in operations in the Middle East.¹⁰ Expanding on this

⁶ Department of Defense, *Summary of the 2018 Department of Defense Artificial Intelligence Strategy* (Washington, DC: Department of Defense, 2018), 5, <https://media.defense.gov/2019/Feb/12/2002088963/-1/-1/1/SUMMARY-OF-DOD-AI-STRATEGY.PDF>.

⁷ Melanie Mitchell, *Artificial Intelligence: A Guide for Thinking Humans* (New York: Farrar, Straus, and Giroux, 2019); Johnson, "Artificial Intelligence & Future Warfare," 2.

⁸ Greg Allen, *Understanding AI Technology* (Washington, DC: Joint Artificial Intelligence Center, 2020), 3, <https://www.ai.mil/docs/Understanding%20AI%20Technology.pdf>.

⁹ "About the JAIC: The JAIC Story," Joint Artificial Intelligence Center, accessed August 16, 2021, <https://www.ai.mil/about.html>.

¹⁰ Justin Doubleday, "Project Maven Aims to Introduce AI Tools into Services' Intel Systems," *Inside the Navy* 31, no. 1 (January 2018), <https://www.jstor.org/stable/26415262>.

work, the Biometric Recognition and Identification at Altitude and Range (BRIAR) program and Next-Generation ISR plan look to further increase data collection and train algorithms to develop intelligence solutions.¹¹ Meanwhile, USSOCOM has pursued the concept of the Hyper-Enabled Operator to manage and fuse sensor data to increase the speed of decision making and achieve cognitive superiority against adversaries.¹²

Beyond intelligence gathering, autonomous swarms like in the OFFensive Swarm-Enabled Tactics (OFFSET) program feature hundreds of unmanned aircraft and ground systems collaborating to accomplish diverse missions.¹³ In addition to enhancing offensive capabilities, the DOD has sought out Small Business Innovation Research (SBIR) programs to develop AI-based algorithms to perform various functions in the Integrated Air & Missile Defense (IAMD) system to detect and defeat missile threats.¹⁴ Finally, networked systems like the Advanced Battle Management System (ABMS) use AI to fuse and process data to implement across the DOD's Joint All-Domain Command and Control (JADC2) network.¹⁵

The above programs comprise a small sample of the numerous ongoing efforts across the DOD to adopt AI technologies. They are, however, representative of the vision put forward by the DOD's AI Strategy and they represent priority areas for the DOD. The ongoing projects use AI systems for autonomy and data fusion while largely focusing on efforts that will increase the efficiency of military operators.

¹¹ Jon Harper, "Shadow Warriors Pursuing Next-Gen Surveillance Tech," National Defense, last modified May 7, 2021, <https://www.nationaldefensemagazine.org/articles/2021/5/7/shadow-warriors-pursuing-next-gen-surveillance-tech>; Nishawn Smagh, *Intelligence, Surveillance, and Reconnaissance Design for Great Power Competition*, CRS Report No. R46389 (Washington, DC: Congressional Research Service, 2020), 15, <https://crsreports.congress.gov/product/pdf/R/R46389>.

¹² Alex MacCalman et al., "The Hyper-Enabled Operator," *Small Wars Journal*, June 2019, <https://smallwarsjournal.com/jrnl/art/hyper-enabled-operator>.

¹³ Timothy Chung, "OFFensive Swarm-Enabled Tactics," Defense Advanced Research Projects Agency, accessed August 19, 2021, <https://www.darpa.mil/program/offensive-swarm-enabled-tactics>.

¹⁴ "Artificial Intelligence Application for Air and Missile Defense Combat Identification, Planning and Weapon Assignment," Small Business Innovation Research, December 10, 2019, <https://www.sbir.gov/node/1654459>.

¹⁵ Nishawn Smagh, *Joint All-Domain Command and Control (JADC2)*, CRS Report No. IF11493 (Washington, DC: Congressional Research Service, 2021), 1, <https://crsreports.congress.gov/product/pdf/IF/IF11493/13>.

This trend of research leaves space for incorporating the same AI principles into aircraft defensive systems. Incorporating existing AI technology into aircraft defensive systems will offer a solution for countering these surface-to-air threats. This problem would benefit from further research and operator collaboration to determine what type of systems would most benefit from the application of AI and what type of threats an AI-improved system would be most likely to defeat.

2. Technology Acquisition

The Special Operations Forces Acquisition, Technology, and Logistics (SOF AT&L) Center is “responsible for all USSOCOM research, development, acquisition, procurement, and logistics.”¹⁶ This center has grown into a network of organizations that set priorities for special operations forces and Air Force Special Operations Command (AFSOC) aircraft. Within their aviation systems section are nineteen desired abilities and enhancements.¹⁷ This research will specifically contribute to three of them: Aircraft Self Defense Systems, Radio Frequency Countermeasures, and Reduced Operator Workload. To complement this organization, AFSOC Headquarters has assigned A5RE to lead the aircraft Radio Frequency Countermeasures effort. This group, along with the rest of the A5 directorate of AFSOC headquarters, are responsible for setting and meeting requirements through the required capabilities list (RCL) and the prioritized gap list (PGL). The two documents address the proactive and reactive motivations for technology and capability development. AFSOC A5RE are pursuing solutions focused on maximizing the standoff capability to avoid the threat altogether or exquisite system design to defeat the threat system.¹⁸ While these solutions provide two possible paths to defeat a threat in a non-

¹⁶ “SOF AT&L,” United States Special Operations Command, accessed August 18, 2021, <https://www.socom.mil/SOF-ATL>.

¹⁷ “Aviation Systems SOF AT&L,” United States Special Operations Command, accessed August 18, 2021, <https://www.socom.mil/SOF-ATL/Pages/Capabilities.aspx>.

¹⁸ Air Force Special Operations Command, *Contractor Visits, Technology Review, and Presentations*, AFSOCHI 64-103 (Hurlburt Field, Florida: Air Force Special Operations Command, 2020), 3.

permissive environment, they do not exploit the threat through the maneuver, which is a key aspect that this research focuses on.¹⁹

3. Threat Characterization

Identifying the threat to special operations aircraft in the next fight is the subject of much research. Threats are grouped as air defense artillery, infrared missile systems, radar missile systems, and electromagnetic spectrum denial systems. Each threat system is unique in its origin, development, and employment, but fundamental principles guide each group. These principles have dictated the tactics used to defeat these systems, and when tactics have failed, technology has helped bridge the gap. An early example is the Freya radar system used by the Germans in WWII, which was later countered with the creation of chaff.²⁰ The grandchildren of this radar system now boast ranges in the thousands of miles. They may even be accompanied by directed energy weapons or lasers capable of destroying parts of an aircraft in flight.²¹ This research will frame the objectives of the algorithm to shape development, but it will be developed with the principal requirement that it can be translated to any type of threat system. Specifically, the algorithm may only be tested against one type of radar shooting one kind of weapon. Nevertheless, the ability to accurately match sensor data inputs to maneuver action outputs must be transferrable.

4. Gap in Research (Defense of Aircraft)

Operational requirements from counter-terrorism efforts have dictated resource allocation and technology development for the last twenty years. While the mission of AFSOC has not changed, the environment in which it will conduct operations is changing. Defense through offense has proven to be a profitable strategy, but this does not mean that defense should be an afterthought. The preponderance of resources outlined in the most recent draft National Defense Authorization Act indicates that leaders want new solutions

¹⁹ AFSOC/A5KG, “Small Cruise Missile (SCM) Pathfinding Effort” (presentation, Air Force Special Operations Command WEPTAC, Hurlburt Field, Florida, June 24, 2021).

²⁰ Michael Svejgaard, “Who’ll Stop the Rain?,” *Journal of Electronic Defense* 26, no. 10 (October 2003): 62, ProQuest.

²¹ Dave Majumdar, “Can America Crush Russia’s A2/AD ‘Bubbles’?,” *The National Interest* (blog), June 29, 2016, <https://nationalinterest.org/blog/the-buzz/can-america-crush-russias-a2-ad-bubbles-16791>.

to the same problems. Artificial intelligence and, more specifically, algorithmic processing of sensor data trained to optimize specific tasks can help eliminate human induced delays and errors from the defense equation.

C. MERLIN LABS

In 2020, SOCOM and AFSOC authored a Concept of Employment (CONEMP) for a remotely piloted AC-130J and selected Merlin Labs to develop a solution for basic flight operations. As a small technology company based in Boston, Merlin Labs specializes in developing autonomous systems that fly airplanes. Focused on creating software and hardware that function in place of a human pilot, their efforts are concentrated on reaching the final goal of on-board autonomy.²² Merlin Labs aims to outfit general aviation aircraft with add-on components to give a traditionally manned aircraft the capability to operate flight profiles autonomously.

1. The Merlin System

A Merlin equipped aircraft consists of a set of independent servos, sensors, and computers that interface with the existing platform to replace the control functions typically performed by a human pilot. The Merlin software that controls the aircraft incorporates situational awareness inputs from GPS, ADS-B receivers, and radar altimeters to develop an understanding of the airspace and ground environment. Given these inputs, the Merlin software, either autonomously or remotely controlled depending on the installed configuration, actuates flight controls to mimic learned flight maneuvers to accomplish a given flight profile from takeoff through landing.

The Merlin flight models are trained to mimic flight maneuvers through a series of flight simulations and survey flights conducted on surrogate aircraft. During the survey flights, Merlin engineers adjust control parameters to optimize control of a surrogate aircraft and fine tune the autonomous flight software. Once the flight software is tuned to

²² “Merlin Labs: About Us,” Merlin Labs, accessed December 16, 2021, <https://www.merlinlabs.com/about/>.

operate the surrogate aircraft, a series of transfer functions is accomplished to mimic the flight and control characteristics of a desired aircraft.

The use of transfer functions in the Merlin software allows further testing and tuning of a desired aircraft by using a Merlin designated surrogate aircraft. This provides Merlin engineers ample opportunity to optimize the flight software without requiring excessive flight tests on the desired aircraft. For example, once the transfer functions are developed for the C-130J, Merlin Labs can perform most of the test flights to optimize the flight software on a less expensive surrogate aircraft. Notably, the rapid development and experimentation of Merlin automation capabilities could allow the company to quickly scale autonomous systems across a variety of aircraft.

The Merlin System is designed to operate autonomously using a pre-programmed flight profile designed specifically for each mission. Similar to creating a pre-mission flight plan, mission planners can utilize the Merlin software to assign GPS waypoints for navigation, load a mission profile with planned maneuvers, and designate takeoff and landing sites for the aircraft to operate. The system can also receive real-time updates for mission taskings to include remotely controlled flight maneuvers.

Although Merlin Labs is striving for a fully autonomous system, its current configuration requires remote intervention by operators to augment its automated capabilities. To communicate with the Merlin System, an operator can remotely send commands through a graphical user interface (GUI) or through a voice command module. The following are human and machine interactions or commands:

1. Increase, decrease, and maintain heading
2. Increase, decrease, and maintain altitude
3. Increase, decrease, and maintain airspeed
4. Takeoff from a user specified point on the runway
5. Land on a user specified runway

This research focuses on an alliance between Merlin Labs, Naval Surface Warfare Division – Dahlgren, USSOCOM PEO-FW Gunships Division, AFSOC A5, and the NPS

research team. Their solution is still in progress but has shown promise regarding defensive threat reaction functionality. The research team will bring aircraft technical information and AFSOC mission execution data to the team to refine the Merlin Pilots capabilities and requirements. Merlin Labs' stages of develop are expected to occur in the following order:

- Stage 1 (July to December 2021): C-130J and Merlin Pilot planning phase.
- Stage 2 (January 2021 to July 2022): Initial Concept Design.
 - Planned for 1 August 2022
- Stage 3 (August to October 2022): C-130J and Merlin Pilot integration.
 - Aircraft in the Loop Test planned for 15 October 2022
- Stage 4 (October to December 2022): C-130J Flight Test
 - Aircraft demonstration planned for 15 December 2022

2. Stakeholders

This effort will be influenced by collaborative experts across DOD and industry. The current configuration of experts is grouped as follows:

- Potential operational customers:
 1. Air Force Special Operations Command Headquarters (AFSOC) A5RE
 2. AFSOC A5K
 3. AFSOC A8I
 4. United States Special Operations Command (USSOCOM) PEO-FW
 5. Air Force Headquarters (HAF) Futures
 6. Air Force Mobility Command (AMC)
- Potential research stakeholders:
 1. Joint Interagency Field Experimentation Program (JIFX), NPS

2. Center for Survivability and Lethality, NPS
3. Joint Artificial Intelligence Center (JAIC)
4. Air Force Research Laboratory (AFRL) RY, Sensor Fusion
5. Defense Systems Information Analysis Center (DSIAC)
6. National Defense Industrial Association (NDIA)
7. Naval Surface Warfare Division – Dahlgren, Virginia
8. Merlin Labs, Inc

This research expands upon the concepts and capabilities being developed by Merlin Labs using a Cooperative Research and Development Agreement (CRADA) through Naval Postgraduate School (NPS). Working with AFSOC A5 as the primary operational customer, this research aims to produce the following deliverables:

- Concept of Operations (CONOP) that articulates potential actions, missions, and use case scenarios for Merlin Labs technologies
- Final Outbrief Presentation delivered to AFSOC stakeholders culminating research efforts and offering recommendations aimed at adopting and implementing optionally manned capabilities
- Research Meeting Notes that capture key processes in the research journey and preserve operational customers and stakeholder contacts for continuity

II. DEFENSIVE ADVANTAGE

A. PROBLEM AND SOLUTION SPACE

1. Framework

The research question and problem described in Chapter 1 must be scoped to permit incremental progress and shape this research team’s efforts. The team considered multiple points of view from the tactical to the strategic and from the individual to the organization. Ultimately, the research was narrowed down to address the problem from the single AC-130J aircrew and single aircraft perspective. From that perspective, the research team followed a portion of the Design Council’s “Framework for Innovation” to identify factors that contribute or directly lead to an AFSOC aircraft being shot down. Figure 1 graphically depicts the framework.

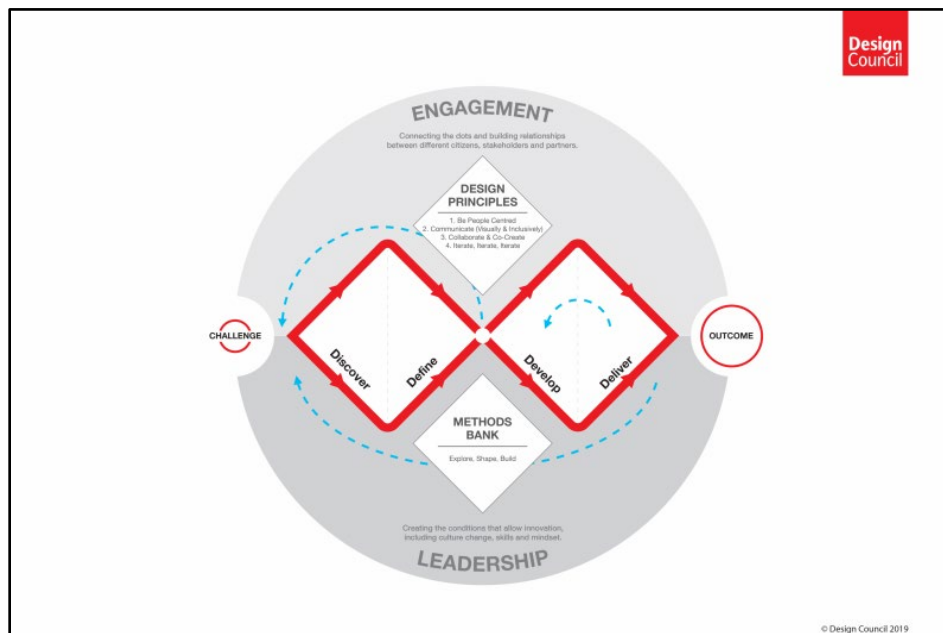


Figure 1. Design Council’s Framework for Innovation.²³

²³ Source: “What Is the Framework for Innovation? Design Council’s Evolved Double Diamond,” Design Council, March 17, 2015, <https://www.designcouncil.org.uk/news-opinion/what-framework-innovation-design-councils-evolved-double-diamond>.

The research team was able to identify four critical factors and the major organizations responsible for investigating and developing solutions to those factors. This led the team to select the aircrew specific factors which are part of training and execution of everyday flight activity while in combat. During the development stage, stakeholders were identified and comprise the three groups listed in Figure 2.

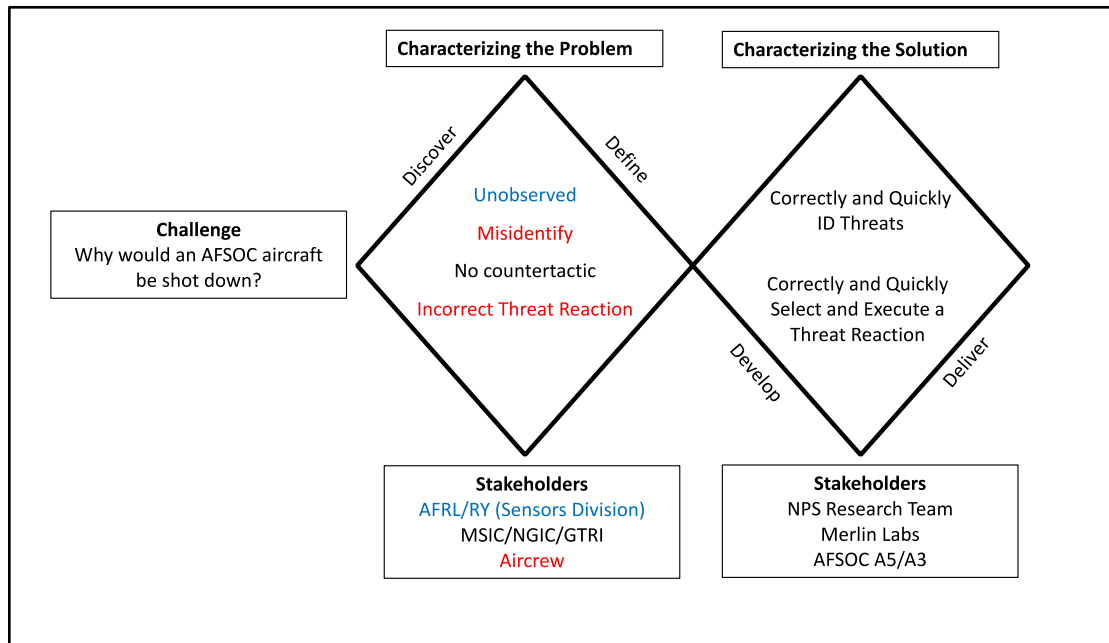


Figure 2. Research Team's Problem Analysis.

On January 31, 1991, an Air Force AC-130H, callsign Spirit 03, was shot down by a surface-to-air missile which spurred an investigation into the aircraft's defensive capabilities and the aircrew's defensive actions. In doing so, leadership identified the same problem and solution characterization depicted in Figure 2. In an interview with now retired Major General Mark Hicks, he stated, "the crash of Spirit 03 motivated widespread implementation of these [automated missile warning systems] technologies...but they would not have made much of a difference without developing better tactics, too."²⁴ This

²⁴ David Roza, "No Enemy Has Downed an Air Force AC-130 Gunship in 30 Years. Here's Why," *Task & Purpose* (blog), February 5, 2021, <https://taskandpurpose.com/news/air-force-ac-130-gunship-crash-desert-storm-spirit-03/>.

remark accurately reflects the inherent bond between human and machine and the need for effective integration for success. Major General Hicks went on to say, “the fundamental lesson learned is to always expect to be fired upon when firing.”²⁵ This message should resonate across all AC-130 missions and should be an ongoing assumption for SOF aircrews operating in future conflict environments.

2. Assumptions and Purpose

The research team used the following assumptions surrounding the identified problem and future operating environment to bound research efforts:

1. AFSOC aircraft will either knowingly or unintentionally trespass into a surface-to-air threat’s weapon engagement zone.
2. The aircrew can only rely on onboard systems for threat notification and aircraft defense
3. A threat reaction is any combination of maneuver, expendables, and/or non-kinetic effects required to counter a surface-to-air threat.
4. The Merlin System will be permanently installed on AC-130J aircraft to permit optionally piloted operations.

The purpose of this endeavor is to expose the gap in optionally piloted AC-130J defenses, explain the potential of Merlin Labs technology, and provide a solution to enable future AC-130J operations in non-permissible environments.

B. OPTIONALLY MANNED AIRCRAFT DEFENSE ROADMAP

1. Dissecting AC-130J Threat Reactions

AC-130J aircrew continuously train and evaluate pilots and combat systems officers to perform defensive threat reactions. These threat reactions are in response to surface-to-air missiles and air defense artillery fired using one or a combination of four guidance systems: radar, infrared, laser, and optical. The research team focused their efforts

²⁵ Roza.

on radar guided surface-to-air missiles (RF SAM) and infrared surface-to-air missiles (IR SAM), the latter of which encompasses manned portable air defense systems (MANPADS). These two systems represent the most proliferated and deadly threat to AFSOC aircraft described in the strategic environment in Chapter 1 and thus warranted the focus. AC-130 aircrew also focus their training efforts by periodically flying against replicants of these threats which are positioned on military training ranges throughout the United States.²⁶

When AFSOC aircrew fly against threat emulators they grade their performance by measuring the speed and annotating the accuracy of the threat reaction. Instructors overseeing training missions record and save performance data to pair with a recording of the sequence of events for post mission review. The data recording allows aircrew an opportunity to review the objective evidence chronicled during a simulated threat engagement to determine whether the crew would have successfully defeated a surface-to-air missile system. Instructors aim to develop competent, proficient, and highly capable aircrew to defend by pushing their training to develop speed and accuracy. However, an operator's speed and accuracy are influenced by their level of fear, fatigue, and other emotions. Eliminating or reducing the influence of those emotions through the use of automation and human machine teaming can improve the speed and accuracy of threat reactions.²⁷

The first contributing factor to successful threat reactions is speed. The quality of the threat reaction is meaningless if it is performed so late that the missile has already reached its target. Human reaction time (HRT) is used to evaluate the speed of a person's response. In 1953, Dr. Leonard Carmichael, a psychologist and secretary of the Smithsonian Institution in Washington said, "when the pilot of a jet plane sights an enemy jet approaching, it takes at least one-fifth of a second for his eye-nerve muscle system to

²⁶ Charles V. Rivezzo, "Advancing Airpower," *Airman (Online)*, (October 2011), ProQuest.

²⁷ Paul Scharre and Michael Horowitz, *Artificial Intelligence, Center for a New American Security Reports* (Washington, DC: Center for a New American Security, 2018), 10, ProQuest.

go into appropriate action.”²⁸ While his interpretation of this data might later be considered misguided, the identification of physical and cognitive limitations for human reactions is important.

The second contributing factor is choice accuracy. The pilot and combat systems officer are expected to attain and then maintain a certain level of accuracy during multiple stages of a threat reaction. First, the combat systems officer (CSO) must accurately interpret the symbology displayed by the defensive system to identify the threat. Second, the CSO must accurately select the right defensive maneuver from a memorized list. Third, the CSO must accurately recite a threat call which is the directive communication to the pilot to initiate a threat reaction. The CSO’s accuracy in accomplishing these tasks is imperative to the survival of the crew. It is also important to note that each of these three decision points impacts the follow-on decision. Each event has the potential to cause an error in the following dependent events.

Measuring human reaction time requires first identifying the two types of human reactions. Captain Demirarslan outlined the two levels of human reaction time as simple reaction time and complex reaction time.²⁹ Simple reaction time is defined as the “shortest time between the moment a sensory receptor is stimulated and the time a body element reacts.”³⁰ This means someone responds to a sensory input with a physical reaction. No decisions are necessary in a simple reaction. Complex reaction time is when the “scientist attempts to include human information processing time.”³¹ This means decisions or choices must be made based on the interpretation of the information input. Both reactions are initiated by external stimulus such as a traffic light represented in Figure 3. Captain Demirarslan went on to compare the decision processing time of his experiment with that of fighter pilots in flight.

²⁸ Leonard Carmichael, “Jet Pilot Reaction Time,” *The Science News-Letter* 64, no. 22 (1953): 339, <https://www.jstor.org/stable/3932712>.

²⁹ Hasan H. Demirarslan, *Visual Information Processing and Response Time in Traffic-Signal Cognition*, AFIT/GOR/ENS/92M-8 (Wright-Patterson AFB, Ohio: Air Force Institute of Technology, 1992), 26, <https://apps.dtic.mil/sti/citations/ADA248165>.

³⁰ Demirarslan, 26.

³¹ Demirarslan, 26.

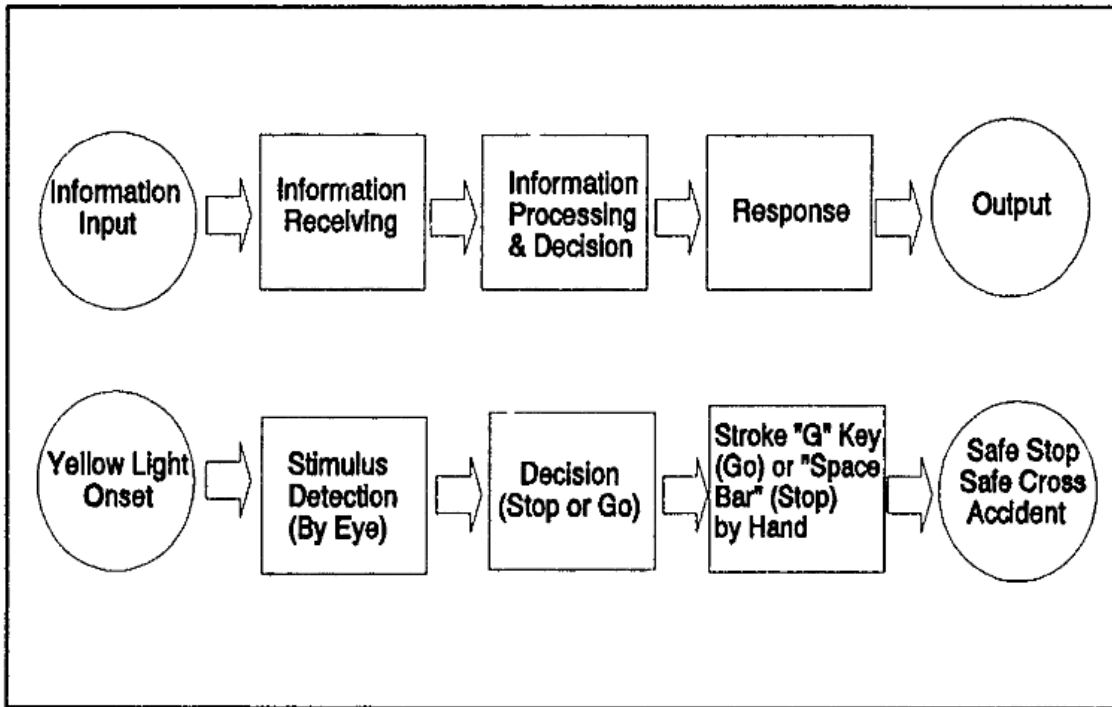


Figure 3. Representation of Basic Functions Performed by Human in Man-Machine System.³²

He found that, “a fighter pilot often needs to make quick decisions. Most of the decision can be explained with complex reaction time distribution...This refers to the reduction in the total reaction time. Still, at that point, the biggest contributor will be decision process time.”³³ The findings from this experiment provided in Table 1 demonstrate the temporal effect of decision making. Aircrew and Merlin Pilot integration offers an opportunity to decrease complex reaction time.

³² Source: Demirarslan, 20.

³³ Demirarslan, 69.

Table 1. Decision Process Time Statistics.³⁴

	MEAN	VARIANCE
CHOICE REACTION TIME	0.49 sc	0.026 sc
SIMPLE REACTION TIME	0.35 sc	0.005 sc
DECISION PROCESS TIME	0.14 sc	0.021 sc

Incorporating the Merlin Pilot into the AC-130J aircraft can improve the speed and accuracy of threat maneuvers and increase the overall safety of the aircraft. This claim requires analysis of the workflow involved with AC-130J threat reactions to determine the various system inputs, decision criteria, and desired outputs for the current manned configuration. This information exposed the opportunity space for machine intervention. Finally, the research team, in collaboration with Merlin Labs, investigated a proposed solution replicating Merlin Labs' flight automation efforts.

Figure 4 illustrates the current process aircrew onboard an AC-130J follow to accomplish a threat reaction in response to a radar guided surface-to-air missile system.

³⁴ Source: Demirarslan, 47.

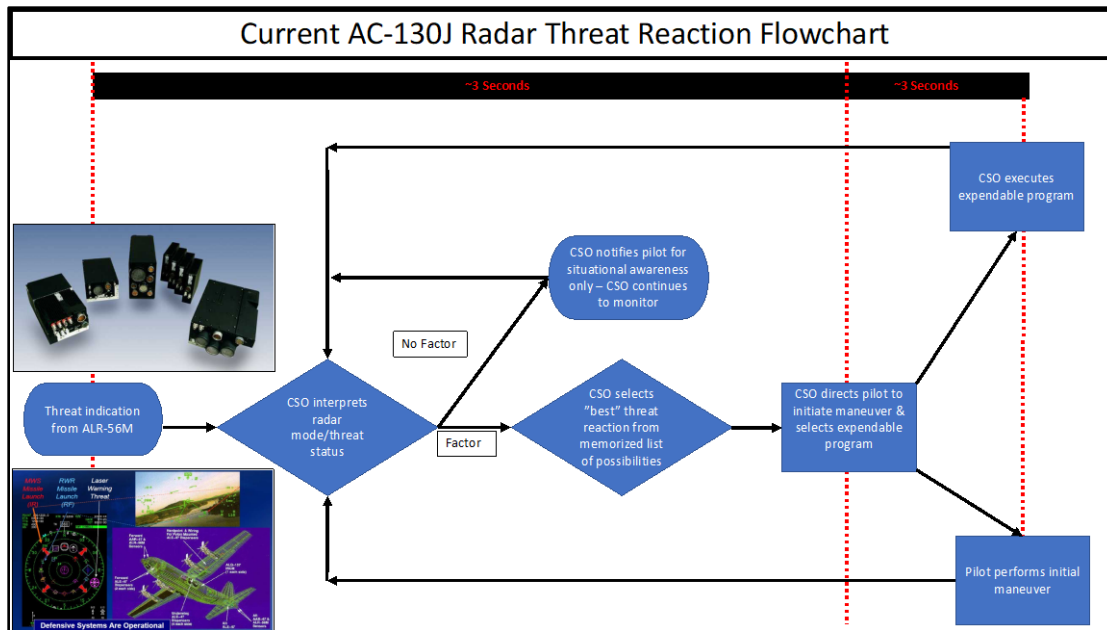


Figure 4. Current AC-130J Radar Threat Reaction Flowchart.

Like Captain Demirarslan’s traffic light workflow model, it begins with an information input which must be received by a crewmember. This responsibility is primarily tasked to the CSO monitoring the defensive systems displays. There are two complex or choice reactions identified on the flowchart and listed in Table 2. How each reaction is accomplished and what equipment and information is necessary must be noted.

Table 2. AC-130J RF SAM Reaction List.

AC-130J RF SAM Reaction List		
Complex Reaction	CSO directs pilot to initiate maneuver & selects expendable program	0-3 sec.
Complex Reaction	Pilot initiates maneuver and CSO selects expendable program	3-6 sec.

First, the initial input from the ALR-56M Radar Warning Receiver threat signal indication is primarily monitored by the CSO with the pilot and copilot also able to continuously monitor as secondary responsibilities. Therefore, three crew members with visual and audible monitoring capability can react to the presence of a RF SAM. Simulator

and flight training ensures that all three of these crewmembers habitually monitor and respond to the audible tone and symbology displayed by the ALR-56M. Technology modernization efforts such as heads up display (HUD) and helmet mounted display (HMD) integration of threat symbology also facilitate faster reaction times by pilots.³⁵ While these systems provide quick notification that a threat exists, they rely on the CSO or pilot to perform the bulk of the work.

The first complex reaction begins with the initial threat indication as previously discussed and terminates with the CSO providing a standardized threat call which directs the pilot to initiate a maneuver. Immediately following notification of the RF SAM, the CSO must determine the variant and the mode of the system. For example, in the SA-2 SAM system, the “used both a search-acquisition beam and a lock-on, or attack, mode.”³⁶ The SAM system variant the category of the radar’s mode influence the appropriate threat maneuver response. After identifying the threat guidance system (RF), the variant (Fan Song), and the mode (Search/Acquisition) the CSO selects the best reaction. This linear process delineates a corresponding threat reaction based on testing and modeling scenarios. In training, an instructor will often quiz a student or entire crew on the correct response to a given threat in preparation for flights against threat emitter systems at sites such as the Snyder Electronic Scoring Site.³⁷ While the defensive system provides the threat information to the CSO, the pilot must also consider the current aircraft configuration and other factors to determine the appropriate threat maneuver. Figure 5 illustrates these additional inputs.

³⁵ “AN/ALR-56 Radar Warning Receivers,” BAE Systems, accessed March 31, 2022, <https://www.baesystems.com/en-us/product/an-alr-56-radar-warning-receivers>.

³⁶ Albert F. Becker, “ELINT, or Electronic Intelligence, Helped Win the ‘Battle of the Beams’ against the Radar of the Deadly SA-2 SAM,” *Vietnam*, December 2001, 64, ProQuest.

³⁷ Rivezzo, “Advancing Airpower.”

AC-130J CSO Selects "Best" Reaction Process		
Current Process		
SYSTEM	INPUTS	REQUIRED INFORMATION TO SELECT BEST REACTION
ALR-56M	Symbol ID Symbol Border Symbol Bearing Frequency/Sound	What type of threat is it? Air to Air/Surface to Air Missile/ADA What is the priority threat? What is the relative bearing of the priority threat? What radar is it and what mode is it in?
1553 Data Bus	Heading AGL Altitude Airspeed	What part of the flight envelop is the aircraft in? (i.e., close to stall?)
Radar Radar Altimeter Moving Map	Terrain	Where is the aircraft in relation to the ground?
Human Factors of Situational Awareness & Risk Level	Current Mission Responsibilities	What is the aircraft currently tasked to do and what is the acceptable level of risk for the mission and the force?

Figure 5. AC-130J Aircraft RF SAM Inputs.

The aircraft’s heading, altitude, and airspeed are critical for all phases of flight and for performing threat reactions. The pilot must maneuver the aircraft within the flight envelop to ensure survivability. This information is provided on numerous displays available to the crew but is consolidated from several sensors into the 1553 data bus. Just as important as keeping the aircraft inside the flight envelop is its proximity to terrain. Three systems provide situational awareness to monitor the ground and the aircraft’s proximity to it. The radar, radar altimeter, and a moving map or chart display this data in real time.

Unique to military aircraft is the need to balance current mission responsibilities against risk levels. Situations exist where military aircraft will not react or will delay reacting because the accomplishment of their mission duties outweigh their survival. The human crew is needed to ensure these inputs are interpreted correctly before and during a mission to enable mission success while safeguarding the aircraft during the threat situation.

After consideration of the inputs, the CSO and pilot implement the best choice for the threat, aircraft, environment, and their mission responsibilities as depicted in Figure 6.

This output is an audible threat call unique to the AC-130J but standardized with the crews that fly them. The number of inputs and discriminators dictate maintaining intense initial and currency training of CSOs and pilots. Following the standardized threat call, the crew maneuvers the aircraft in coordination with the applicable expendable plan. While manned AC-130J aircraft are well trained to accomplish this task, the current Merlin Pilot integration plan lacks a method to accomplish these survival requirements.

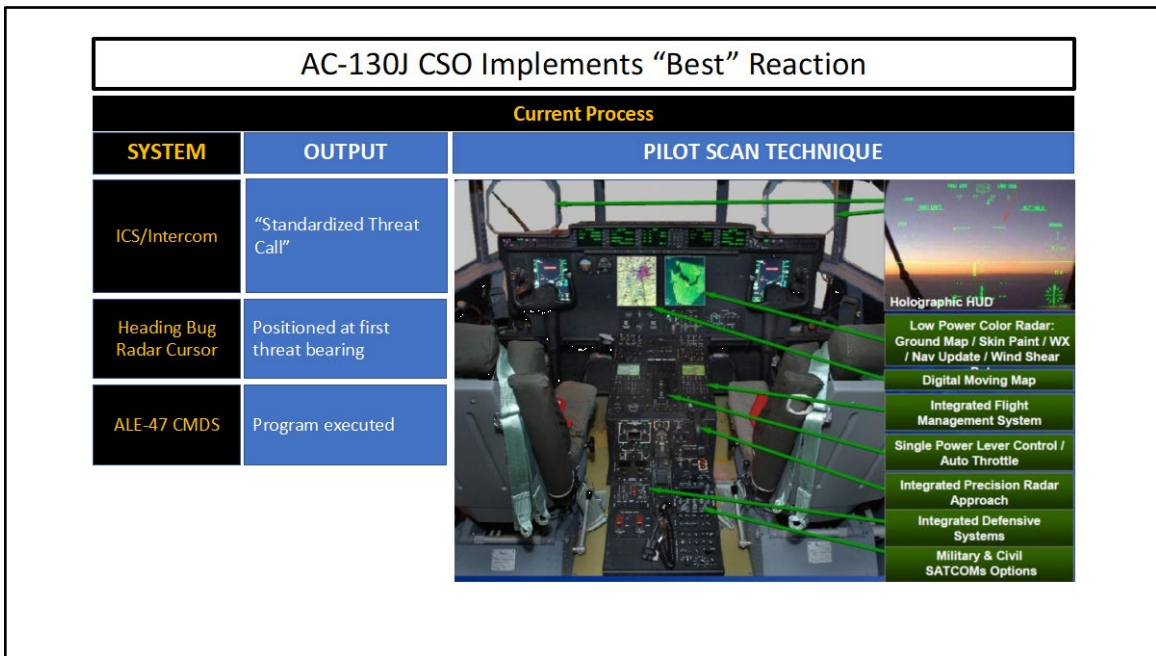


Figure 6. AC-130J Threat Reaction Outputs.

2. Automation Opportunities

The necessary tasks for survival captured in the Figure 4 flowchart vectored the optionally piloted solution toward increased integration between the Merlin Pilot and the human crews which fly AC-130J. The human machine teaming (HMT) integration can capitalize on three areas: (1) threat indication, (2) threat combat identification, and (3) threat and reaction pairing. These three factors are the opportunity space for automation and HMT to strengthen AC-130J manned operations and to fill the gap in unmanned AC-130J design.

Analyzing the AC-130J threat reaction process in an architectural framework of human machine teaming reveals opportunities for increased efficiency. Azad and Carla Madni describe such a framework in their article for exploring adapting human machine teaming options.”³⁸ The Madni team investigated the background of aircraft and automation from autopilot and artificial intelligence integration to current programs such as “autonomous wingman.”³⁹ From this perspective, they determined that, “in the foreseeable future, it is imperative that advances are made in effective human teaming with semi-autonomous systems.”⁴⁰ People should not consider full autonomy as a realized truth but also should regard the machine as a “teammate not a henchman.”⁴¹ Step one to investigate the HMT potential is to apply the HMT ontology to the AC-130J threat reaction process.

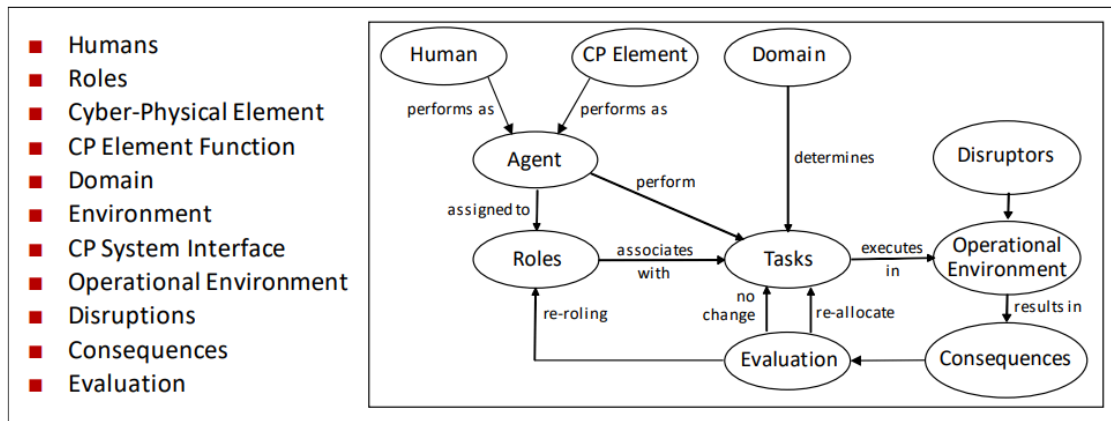


Figure 7. HMT Ontology⁴²

³⁸ Azad M. Madni and Carla C. Madni, “Architectural Framework for Exploring Adaptive Human-Machine Teaming Options in Simulated Dynamic Environments,” *Systems* 6, no. 4 (2018): 1, <https://doi.org/10.3390/systems6040044>.

³⁹ Madni and Madni, 4.

⁴⁰ Madni and Madni, 3.

⁴¹ Madni and Madni, 2.

⁴² Source: Madni and Madni, 8.

The HMT ontology depicted in Figure 7 reveals the following elements of the AC-130J threat reaction. These elements offer a wholistic look at the AC-130J threat reaction process. With these elements and the three integration opportunities identified earlier, the decision to shift HMT taskings considered the dynamic task allocation criteria that Azad and Carla Madni explained.

- Humans involved in the process are the pilot(s) and the CSO.
- The role is defender of the aircraft. These two groups of aircrew members have the requisite training, knowledge, responsibility, and authority necessary to perform a threat reaction.
- The only agent to perform a threat reaction now is a human.
- The tasks performed by the agent are threat indication, combat identification, threat locating, threat and reaction pairing, threat call declaration, and physical threat reaction execution.
- The machine elements of the threat reaction consist of sensors, processors, aircraft data bus, heads up displays, helmet mounted displays, and expendable systems.
- The AC-130J threat reaction domain is the air during all phases of flight.
- Disruptor elements that influence the HMT relationship and development are weather, terrain, and secondary crew taskings.
- The AC-130J does not require an adaptation or modification to the existing structure of the aircraft beyond the current Merlin Pilot integration plan. This modification currently permits the Merlin Pilot to maneuver the aircraft based on task selection by a human operator at a ground or airborne control station. Software adaptation does require a change.

Table 3. Dynamic Task Allocation Criteria.⁴³

Table 1. Dynamic Task Allocation Criteria.	
<ul style="list-style-type: none"> • Human strengths and limitations <ul style="list-style-type: none"> - strengths: creativity, ability to improvise, generate novel options - limitations: cognitive, attentional, memory, fatigue, emotional state • CP elements (machine) strengths and limitations <ul style="list-style-type: none"> - strengths: repeatability, consistency, computational speed, memory - limitations: coping with novel situations, deep contextual awareness • Contextual factors that favor one over the other; for example: <ul style="list-style-type: none"> - respective availability - observability - existence of physical hazards - accessibility - cognitive load imposed by task on human/human's space mental capacity • Heuristics that take the above into account 	

Although the three opportunity areas identified (1) threat indication, (2) threat combat identification, and (3) threat and reaction pairing are completely human performed a machine teammate can improve performance. Human strengths are necessary for the complex missions that AFSOC aircrews are frequently tasked to support. The complexities of orchestrating the crew and taskings of an entire AC-130J are demanding for aircraft commanders who are often also in physical control and are hand flying the aircraft at the same time. The human limitations in Table 3 are amplified by combat. Complex, long duration, physically and emotionally demanding missions test the character of AFSOC aircrew every day. Alternatively, the machine, with no regard for emotion, fatigue, or fear offer a consistent, repeatable, and rapid solution. The machine's limitations demand the creative and original problem-solving ability of a human crew member. No formula exists to accomplish an entire AFSOC mission from start to finish however the ability to automate small portions of a mission's tasks such as defensive threat reactions offer human aircrew an enduring advantage.

⁴³ Source: Madni and Madni, 7.

3. A Faster and More Accurate Solution

During unmanned remotely piloted operations the AC-130J requires a swift threat indication method. The solution presumes that there will be a remote pilot control station composed of two pilots as well as a remote CSO control station consisting of two CSOs. This configuration mimics the current AC-130J crew dynamic which would allow for easier transition from remotely piloted to manned operations within deployed crews. Within this four-person crew, the aircraft commander is the primary person responsible for notifying the crew of an impending surface-to-air threat. Due to flight control access and authority requirements, the aircraft commander must receive immediate threat indications followed by the other three remote crew members. Alternative remote crew configurations are discussed later in this section.

Framing a solution in the RF SAM threat environment, a visual and audible indication provides the manned crew with adequate warning and is necessary for flight operations.⁴⁴ The traditional method delivers a distinctive notification tone followed by a unique visual warning. Since there is an opportunity to design a remote pilot control station, a new method to integrate these traditional methods is desired. Flight control software must include an integrated representation of this visual indication, and the station's audio control system must incorporate the tones associated with each defensive system. To take advantage of the automation opportunities, the common operating picture software must assign the visual indication and the tone the appropriate priority level to the pilot. This ensures timely notification of the presence of a threat. Limitations with remotely piloted AC-130J operations will include latency issues associated with the line of communication from the aircraft to the station. Varying methods including beyond line of sight (BLOS) and line of sight (LOS) present contrasting issues with signal latency. In 2016 Alan Hobbs and Beth Lyall published an article outlining guidelines for a pilot control station which address factors such as signal latency.⁴⁵ They discussed how current guidelines direct the type of information that must be provided to the aircrew but neglect the human factors that

⁴⁴ BAE Systems, "AN/ALR-56 Radar Warning Receivers."

⁴⁵ Alan Hobbs and Beth Lyall, "Human Factors Guidelines for Unmanned Aircraft Systems," *Ergonomics in Design* 24, no. 3 (July 1, 2016): 24, <https://doi.org/10.1177/1064804616640632>.

will impact the ability to digest and act upon that information.⁴⁶ This recommendation contributes to their point but addresses the current lack of defensive system integration into the Merlin Pilot to operate in environments such as RF SAM areas.

The second opportunity space, threat combat identification, can address how the visual and audible threat indications are depicted in the pilot control station. If the Merlin Pilot is integrated into the AC-130J's onboard systems or a defensive systems data computer, the identification process can be automated for display to the aircrew rather than requiring a human to decode the information prior to decision making. At this point it is critical to clarify that although one threat example, RF SAM, has been used so far, there are multiple systems for different types of threats that must be presented together. Companies such as Nextiva Analytics developed integrated threat management systems with success for ground defenses at the Port of Los Angeles as discussed in an article from *Security Technology Executive*.⁴⁷ Onboard flight displays currently present a portion of this integrated threat management system but still lack some data such as countermeasures systems. In lieu of a synthesized onboard system to offboard a common operating picture, the pilot control station must blend the data from individual onboard systems for faster and accurate threat reactions.

This blended, defense focused common operating picture requires a catalog. This catalog is all the surface-to-air systems and associated data from organizations such as the Missile and Space Intelligence Center (MSIC). MSIC openly states that it, “provides our customers – warfighters, weapons developers, policymakers, and homeland security – intelligence assessments on foreign weapons systems.”⁴⁸ The integration of data from organizations like MSIC would supplement training and memorization times. The data also provides the amplifying information which separates simply identify the presence of a threat from characterizing the threat for decision making. This claim offers more

⁴⁶ Hobbs and Lyall, 25.

⁴⁷ “Integrated Threat Management,” *Security Technology Executive*, September 2010, 40, ProQuest.

⁴⁸ “Defense Intelligence Agency,” Missile and Space Intelligence Center, accessed April 7, 2022, <https://www.dia.mil/About/Organization/MSIC/>.

justification for what to display but the blended defense common operating picture offers argues for how to display threat data.

The third opportunity area also requires a catalog. This is a catalog of all possible threat reactions taught to AC-130J aircrew. Since the threat reaction corresponds to the specific threat in question, reaching it quickly is crucial to survivability. By automating the pairing of the identified threat to the appropriate reaction, the aircrew at the pilot control station can operate in a supervisory role as opposed to an initiator of the maneuver. In this role the pilot simplifies the threat input discussed from Figure 5 and can focus on the remaining aircraft status, terrain, and mission inputs. Figure 8 offers a quick look diagram of the three automation areas, the software, and systems associated with their automation. There are several human machine teaming and human factors that require analysis for how to incorporate the data into the pilot control station. This solution argues for the addition of threat data into the pilot control station and offers a basic layout. It also only addresses the first complex reaction depicted in Table 3. The second complex reaction aims to physically perform the threat reaction in a fast and accurate manner.

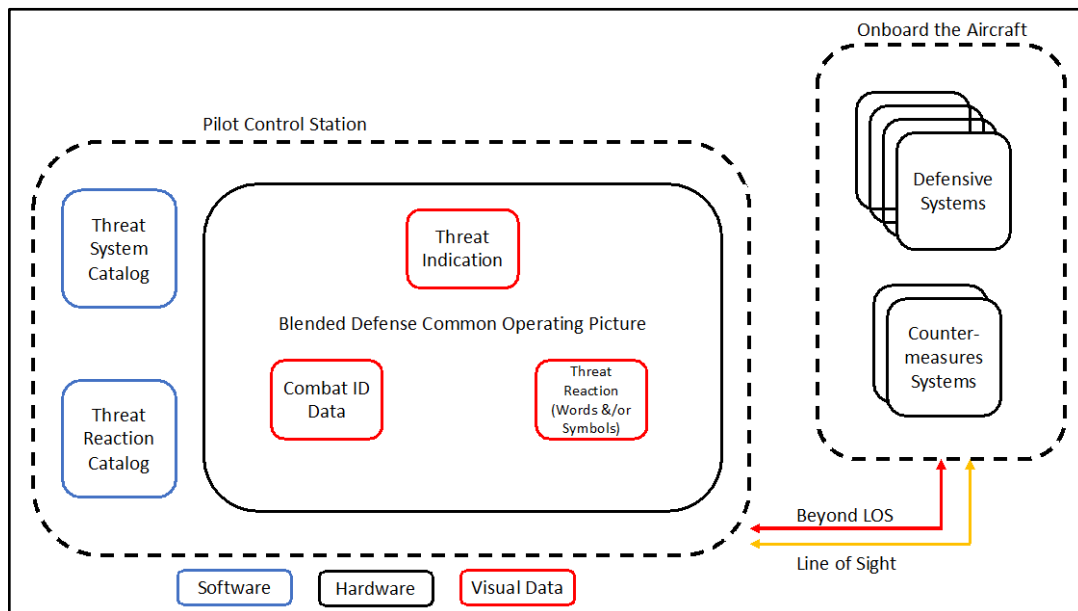


Figure 8. Threat Reaction Automation Diagram.

The Merlin Pilot effort is focused on automating basic flight fundamentals to provide an entry level capability for optionally piloted operations but may also present an opportunity for faster and more efficient threat reactions. During the development phase of the Merlin System, engineers trained the machine using human pilot inputs in actual and simulated flight situations. For example, on 18 November 2022, a Merlin Pilot installed on a civilian Beechcraft King Air successfully took off, made course and altitude changes, and then landed at the push a button from an unlicensed pilot on a tablet. These flight control inputs and maneuvers are the building blocks of a defensive threat reaction. While much remains concerning development and integration of the Merlin Pilot into the AC-130J, the defensive roadmap should not be delayed.

During unmanned remotely piloted operations the pilot at the control station can either hand fly a defensive maneuver under varying degrees of time delay, or the system can be designed to operate autonomously under certain circumstances. Mission planning and system configuration will determine the time delay that crews can expect to encounter during a mission. This delay may render the threat reaction moot because of the discussion above regarding reaction time to surface-to-air threats. Therefore, any defensive capability should also offer a semi-autonomous, man on the loop option for the aircrew. Considering the solution discussed in Figure 8, the Merlin Pilot can be taught to mimic a human pilot to perform a defensive threat reaction in response to the combat identification data. For the Merlin Pilot to learn a new behavior such as performing a defensive threat reaction, it must first learn all the skills necessary to accomplish that behavior.

Like a human pilot, the Merlin Pilot must learn a set of basic skills to defend the airplane from surface-to-air threats. This not only involves the mastery of control inputs to achieve desired movement of the airplane but also coordination with other mission aircraft. Table 4 lists the primary skills necessary to defend an AC-130J under threat from surface-to-air systems. It would be easy to hand this list of skills to a commercial company such as Merlin Labs as a list of demands but that would negate the most important factor. Integration between the human aircrew and the Merlin Pilot is the strength to exploit. Pilots and CSOs are performing these skills every day on countless aircraft on AFSOC training flights and simulators. Data recorded from timing, control inputs, and decision priorities

can be exploited if the machine and the human are able to interact with one another in a training environment.

Table 4. Automated Pilot Defense Skills

Automated Pilot Defense Skills	
1	Rapid Throttle Changes
2	Full Yoke Roll Deflection
3	Elevator Control for G-Onset and Control
4	Flap Positioning Control
5	Dispense Expendable Program
6	Aircraft Collision Avoidance
7	Ground Collision Avoidance
8	Report Threat Information

Training the Merlin Pilot to accomplish these skills will require data. Dr. Gregory C. Allen the Chief of Strategy and Communications at the DOD Joint Artificial Intelligence Center (JAIC) wrote that, “system performance is directly tied to data quantity, quality, and representativeness. Usually, the biggest challenges relate to getting sufficient high-quality training data.”⁴⁹

An article written by retired Lieutenant Colonel Henry Zeybel called “Dodging SAMs High Above Laos” is a case study which highlights these defensive skills. Zeybel recounts the heroic acts of AC-130 pilot Major Ed Holley who performed a difficult threat reaction to defeat a SA-2 surface-to-air missile while flying over Laos on March 2, 1971.⁵⁰ The sequence of events starts with the crew shooting their 40mm and 20mm guns at enemy vehicles and swiftly receiving anti-aircraft artillery in return. Although accustomed to AAA, the crew was surprised by a hidden SA-2 that unexpectedly locked onto their

⁴⁹ Allen, *Understanding AI Technology*, 4.

⁵⁰ Henry Zeybel, “Dodging SAMs High Above Laos,” *Vietnam*, April 2009, 36, ProQuest.

position and fired.⁵¹ Zeybel, who was a pilot on the aircraft as well as the author, reflects on the audio that accompanied the radar activity and how it was used for combat ID purposes. Scanning outside the aircraft, the crewmembers recognized and relayed the missiles characteristics to the pilots which prompted Major Holley to “roll the gunship into a 135-degree bank, practically upside down, and then arc the nose earthward in a 4,000 foot-per-minute dive.”⁵²

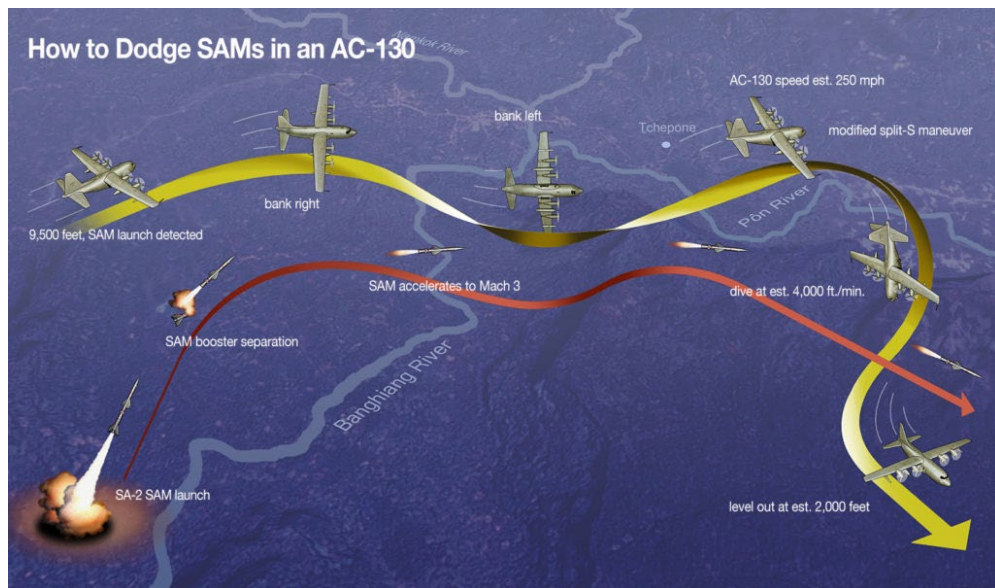


Figure 9. Diagram of AC-130 Defensive Threat Reaction.⁵³

The turn, dive, and airspeed change constituted the best AC-130 defensive threat reaction to defeat a SA-2 which Zeybel depicted in Figure 9. The crew discussed their SA-2 response plan only one time prior to the engagement “during a game of What if...?”⁵⁴ The article makes numerous references to the intensity of the moment and the distortion of time believing that “seconds passed like minutes.”⁵⁵ This first-hand account undoubtedly

⁵¹ Zeybel, 37.

⁵² Zeybel, 37.

⁵³ Source: Zeybel, 40.

⁵⁴ Zeybel, 40.

⁵⁵ Zeybel, 39.

recognizes the bravery of the Major Ed Holley but also pinpoints the necessity for improved AC-130 aircraft defensive systems even in seemingly permissive environments. The SA-2 engagement of an AC-130 in 1971 amplifies Major General Hicks' earlier remark that AC-130 crews should, "expect to be fired upon when firing."⁵⁶ The lessons from this case helped determine the inputs, outputs, and resources necessary to instill a defensive capability for remotely piloted gunships.

The solution discussed only addresses defensive threat reactions in a remotely piloted configuration but there is also potential benefit to manned operations. The solution assumes the Merlin Pilot would be permanently installed on the aircraft. Planes with this capability onboard would be able to exploit the solutions to the complex reaction times previously discussed but requires an integration plan to allow human machine teaming between onboard crewmembers and the Merlin Pilot. The first reaction involving (1) threat indication, (2) combat identification, and (3) threat and reaction pairing must be viewable to the pilot. The second reaction which is an automated maneuver in the remotely piloted mode must account for the onboard pilot's real time analysis of the aircraft status, terrain, and mission responsibilities which may be different than a pilot sitting at a control station on the ground.

C. MERLIN SYSTEM ADOPTION

The application of innovative technology into a larger military strategy influences battlefield outcomes and leads to the success or failure of operations. However, technology by itself is insufficient for victory. Tools must be adopted into integrated practices that are synthesized into an effective concept of operations.⁵⁷ Moreover, the successful diffusion and subsequent adoption of technology by operators, strategists, and other stakeholders is never guaranteed. Eric Schmidt captured this concept during his 2018 testimony to the House Armed Services Committee when he noted, "DOD does not have an innovation

⁵⁶ Roza, "No Enemy Has Downed an Air Force AC-130 Gunship in 30 Years. Here's Why."

⁵⁷ John Arquilla, "A Study in Technology Strategy: The Curious Case of Alfred von Tirpitz," *Comparative Strategy* 36, no. 2 (March 15, 2017): 148, <https://doi.org/10.1080/01495933.2017.1317540>.

problem; it has an innovation *adoption* problem.”⁵⁸ Schmidt’s statement was aimed at the limitations of the larger defense organization but his idea of inertia acting as a hinderance to innovation applies down to the operator level as well.

Adopters of innovation tend to vary across a series of categories representative of their willingness to adopt new innovations. Everette Rogers and Geoffrey Moore depict this spectrum in a bell curve using five categories of innovators as shown in Figure 10. Each category represents a decreasing propensity to adopt innovations ranging from innovators on one extreme to laggards on the other.⁵⁹ Although the categorization of adopters is useful for understanding the variance of stakeholder responsiveness, it does not account for differences between products and the perceived effect those products have on users.⁶⁰ Certain product attributes may shift the balance of the adoption categories and entice stakeholders from an initially resistant position into a more open category regarding product adoption. To understand the adoption potential of automated capabilities utilized by a Merlin System, it is necessary to analyze the effect this system has on stakeholder perceptions from the psychological and product value perspectives.

⁵⁸ *Promoting DOD’s Culture of Innovation: Testimony before the Committee on Armed Services, House of Representatives*, 115th Cong. 102 (2018) (statement of Eric Schmidt, Defense Innovation Board Chairman).

⁵⁹ John T Gourville, “Note on Innovation Diffusion: Rogers’ Five Factors,” *Harvard Business School*, April 2006, 1, Harvard Business Publishing Education.

⁶⁰ Gourville, 2.

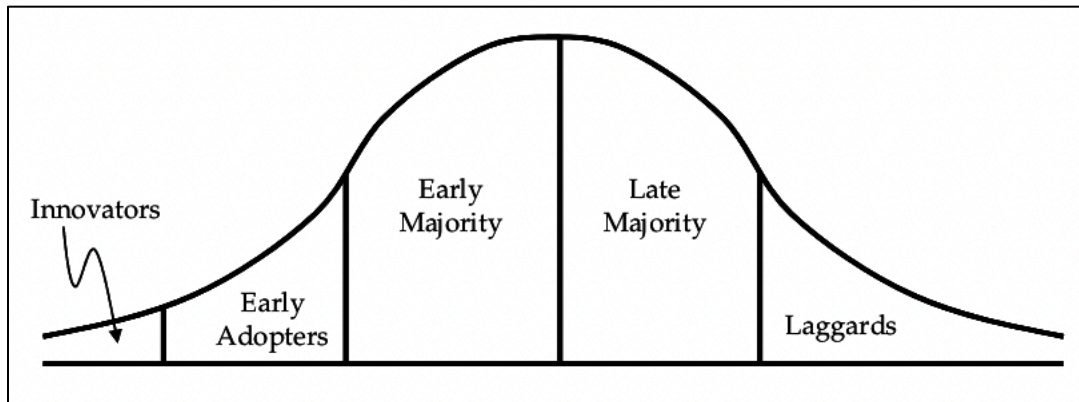


Figure 10. Categorization of Innovation Adopters⁶¹

1. Psychology of Behavior Change

Individual and organizational behavior change is essential as new innovations upend established practices. As change occurs, trade-offs are made between accepting benefits of a new innovation while giving up benefits of a legacy system.⁶² In evaluating trade-offs, Richard Thaler noted a consumer bias, termed the “endowment effect,” where people irrationally overvalue their possessions while undervaluing items they don’t have.⁶³ Viewing behavior change in the context of gains and losses, people are more likely to overvalue their current situation and see changing their behavior as a loss of some intrinsic possession. As a result, decisions, or more likely, indecision, will favor the status quo and avoid behavior change that upends what feels normal.⁶⁴

Use of a Merlin System in aircraft requires behavior change across aircrew and the larger AFSOC organization. As the system is integrated into platforms, pilots may resist the change it induces as they view the automation of flying actions as a threat to their

⁶¹ Source: Gourville, 1.

⁶² John T Gourville, “Eager Sellers and Stony Buyers: Understanding the Psychology of New-Product Adoption,” *Harvard Business Review*, June 1, 2006, 102, <https://hbr.org/2006/06/eager-sellers-and-stony-buyers-understanding-the-psychology-of-new-product-adoption>.

⁶³ Daniel Kahneman, Jack L. Knetsch, and Richard H. Thaler, “Anomalies: The Endowment Effect, Loss Aversion, and Status Quo Bias,” *The Journal of Economic Perspectives* 5, no. 1 (1991): 194, <http://www.jstor.org/stable/1942711>.

⁶⁴ Gourville, “Eager Sellers and Stony Buyers: Understanding the Psychology of New-Product Adoption,” 101.

profession. The system's ability to perform critical flight functions, including defensive maneuvers, will threaten the status quo as pilots view the apparent loss of their individual utility. In accordance with the psychological biases previously identified, aircrew will fail to accurately value the potential benefits of a Merlin System while overvaluing their own worth to a mission. Operator resistance can propagate across units and limit how a new innovative system is employed.

Additionally, if AFSOC aims to adopt autonomous capabilities for traditionally manned aircraft, the new balance of manpower and the resulting change in force presentation to combatant commanders will require significant organizational behavior change. From supporting infrastructure to deployment of forces, stakeholders at all levels of AFSOC will need to adopt changes for the system to become a success. The more intermediaries that need to adopt behavior change, the greater the interdependence and integration risks will be.⁶⁵ Each stakeholder is a node in the ecosystem that contends with their own psychological gains and losses. The respective nodes generate organizational inertia that resist change and favor the status quo, thereby threatening the successful adoption of innovation.

2. The Value of Perceptions

The value of an innovation is partly determined by the benefits it delivers versus the risks it produces. However, controversy arises when making this comparison because the benefits and risks are largely dependent on how one calculates these factors. Notably, it is dependent on the opinions of the person making the comparison. The comparison draws on a multitude of external factors, shared assumptions, and individual biases. The outcome of such uncertainty generates a divergence between benefits and risks based on an individual's perceptions.⁶⁶ How an individual perceives benefits and risks directly influences the rate of innovation adoption.

⁶⁵ Ron Adner, "Match Your Innovation Strategy to Your Innovation Ecosystem," *Harvard Business Review*, April 1, 2006, <https://hbr.org/2006/04/match-your-innovation-strategy-to-your-innovation-ecosystem>.

⁶⁶ Calestous Juma, *Innovation and Its Enemies: Why People Resist New Technologies* (New York: Oxford University Press, 2016), 7.

Perceptions of product value along five key factors govern the rate of innovation adoption. First, relative advantage, or the “degree to which an innovation is perceived as being better than the idea it supersedes,” directly relates to increased adoption.⁶⁷ The benefits of a Merlin System could be objectively measured in reduced training costs, manpower reductions, and increased survivability. The benefits could also be measured subjectively based on how stakeholders believe the system is performing and whether the new capability improves overall mission effectiveness. The culmination of the objective and subjective measures of benefits yields an assessment of the relative advantage a Merlin System provides over legacy manned aircraft. Based largely on perceived benefits, this assessment changes depending on whether the benefits are viewed from the perspective of aircrew, supported forces, or leadership. The resulting rate of adoption will vary for stakeholders along those same lines.

The second factor, compatibility, pertains to how consistent an innovation is with the product it replaces regarding values, experiences, and user habits.⁶⁸ Similar to relative advantage, stakeholder’s biases and experiences influence a system’s perceived compatibility. From the perspective of aircrew, the Merlin System is largely incompatible with their personal experiences and habits because the system does not require aircrew intervention to operate. However, from a macro perspective, the system is compatible with a variety of existing aircraft. It can be utilized in similar missions to traditionally manned platforms and the concept of reducing manpower requirements aligns with strategic guidance.

The third factor, complexity, is a mostly subjective measurement of the difficulty to operate and understand the system.⁶⁹ The Merlin System is specifically designed to reduce complexity by utilizing existing aircraft as the foundation of its platform. Additionally, the complexity of the system remains relatively consistent as missions become more complex and the operating environment expands. Regardless of the mission

⁶⁷ Everett M. Rogers, *Diffusion of Innovations*, 5th ed. (New York: Free Press, 2003), 229.

⁶⁸ Rogers, 240.

⁶⁹ Rogers, 257.

a Merlin aircraft is tasked against, the system operates in a consistent manner and does not entail additional complexity.

The fourth factor, trialability, measures the “degree to which an innovation may be experimented with on a limited basis.”⁷⁰ Experimenting with the Merlin System is feasible because a system can be easily installed and removed on single aircraft at a time. Using the system in an optionally manned capacity keeps an aircraft ready for traditionally manned use while providing opportunities to experiment with the autonomous and remote capabilities of the Merlin System.

Finally, observability is the “degree to which the results of an innovation are visible to others.”⁷¹ Until the civilian applications of a Merlin System increase, the observability of the system will remain low. Observability will gradually increase if a system is installed for experimentation and training but otherwise it will largely remain shrouded in mystery for most parties.

3. Recommendations for Adoption

To increase the rate of adoption of a Merlin System across AFSOC, it is important to minimize the behavior change of stakeholders while maximizing the operational benefits of the system. While psychological factors and individual perceptions will play an oversized role the rate of adoption, certain steps can be taken to reduce the institutional inertia that slows adoption. Changing the minds of stakeholders is the first step to induce change and it must involve piquing interest in the underlying technology from the ground up.

Stakeholders must develop a better understanding of how artificial intelligence, machine learning, and automation are maturing in military technology. They need to adopt an appreciation for different ways to fight wars and experiment with new ideas that challenge traditional organizational processes. Benjamin Jensen proposes challenging traditional processes using incubators and advocacy networks to facilitate organizational

⁷⁰ Rogers, 258.

⁷¹ Rogers, 258.

understanding and diffusion of new ideas.⁷² Jensen notes that military incubators are historically institutional groups located in organizations with positional legitimation.⁷³

However, propagating solutions doesn't necessarily require official designation of research groups and the use of think tanks. The incubation of new ideas entails validating processes and testing the practical application of ideas.⁷⁴ AFSOC's greatest asset is its human capital, an adaptive force cultivated with knowledge and experience.⁷⁵ To increase the Merlin System rate of adoption AFSOC should build the operating concepts, tactics, and mission scenarios from the bottom up. Introduce talented Airmen from the squadron level, beginning with the weapons school and operational squadrons, the basics of the Merlin System's underlying technology and let the units develop methods and processes for incorporating optionally manned capabilities into their mission. Give the units "space" to experiment and test new approaches while ensuring the Airmen have enough free time (i.e. slack) to capitalize on their knowledge base.⁷⁶ Operate within safety boundaries, but encourage rapid testing of new ideas and aim for incremental gains that work towards transformational goals.⁷⁷ Learn from failure rather than punish it. With the squadrons acting as incubators for the Merlin System, trialability and observability increase, and the perceived complexity of operating autonomous systems decreases. As more stakeholders become familiar with the technology and comfortable with the necessary behavior changes, the status quo shifts away from traditional ways of operating and the rate of adoption of new processes and technology will increase.

⁷² Benjamin M. Jensen, *Forging the Sword: Doctrinal Change in the U.S. Army* (Stanford: Stanford University Press, 2016), 18.

⁷³ Jensen, 21.

⁷⁴ Charles O'Reilly and Andrew J. M. Binns, "The Three Stages of Disruptive Innovation: Idea Generation, Incubation, and Scaling," *California Management Review* 61, no. 3 (May 2019): 55, <https://doi.org/10.1177/0008125619841878>.

⁷⁵ Air Force Special Operations Command, *AFSOC Strategic Guidance* (Hurlburt Field, Florida: Air Force Special Operations Command, 2020), 3, <https://media.defense.gov/2020/May/26/2002305551/-1/-1/1/AFSOC%20STRATEGIC%20GUIDANCE.PDF>.

⁷⁶ Bharat Rao, Adam Harrison, and Bala Mulloth, *Defense Technological Innovation: Issues and Challenges in an Era of Converging Technologies* (Cheltenham, UK: Edward Elgar Publishing, 2020), 128.

⁷⁷ Christian Brose, *The Kill Chain: Defending America in the Future of High-Tech Warfare* (New York: Hachette Books, 2020), 232.

As new theories are being developed and shaped into organizational processes, advocacy networks can circulate and legitimize the new ideas.⁷⁸ In recent history, peer-to-peer networks of military professionals have increasingly utilized online forums, in addition to traditional professional journals, for the exchange of ideas and inclusion of younger groups of officers.⁷⁹ These networks and forums enable a professional discourse that quickly spreads across otherwise separate communities while encouraging the participation of a variety of viewpoints. Proponents of a Merlin System should initiate professional discourse across a variety of specific forums to seed the ideas and concepts of optionally manned capabilities to pique stakeholder interest and increase observability.

AFSOC's yearly weapons and tactics conference (WEPTAC) brings together operators and tactical experts from across special operations to address a variety of problem sets. In 2021, AFSOC's Major General Eric Hill described WEPTAC as "a forum where some of our best minds develop ways for us to stay relevant in the fight."⁸⁰ WEPTAC offers a unique forum that serves as a dual-purpose incubator and networking opportunity as ideas and recommendations that come out of the conference gain visibility across the command. Introducing the Merlin System to a WEPTAC working group will educate mid-level tactical professionals about optionally manned capabilities, resulting in direct feedback and crowd-sourced ideas for implementation into various missions. By developing ideas to optimize implementation, stakeholders can maximize the system's relative advantage over existing platforms and further increase observability in the system leading to an increased rate of adoption.

Overcoming decades of established processes and deeply engrained aviation tradition in AFSOC culture will not be an overnight change. Recognizing that perceptions are critically important to an innovation's rate of adoption is an important step in easing the transition. Significantly, AFSOC must also maximize the perceived advantages while

⁷⁸ Jensen, *Forging the Sword*, 19.

⁷⁹ Jensen, 153.

⁸⁰ Brandon Esau, "WEPTAC 2021: Staying Relevant for Future Fights," Air Force Special Operations Command, last modified July 15, 2021, <https://www.afsoc.af.mil/News/Article-Display/Article/2695269/weptac-2021-staying-relevant-for-future-fights/>.

minimizing the perceived behavioral changes. While each aviation community will need to adapt unique changes if they are to implement optionally manned capabilities, they should prioritize factors that highlight the benefits a Merlin System can bring and minimize the compatibility differences required for implementation.

Finally, successful adoption will likely occur in incremental steps and not all stakeholders will accept change at the same rate. The transition between early adopters and the early majority sometimes happens seamlessly while other times it occurs over a long, strenuous period leaving organizations stuck in an innovation purgatory.⁸¹ Utilize trusted sources to advocate the value of optionally manned capabilities across the AFSOC network and overcome this potential divide.

D. CONCLUSION

1. Future Research

The ongoing collaboration between the authors and Merlin Labs has focused on replicating known defensive maneuvers as defined by official tactical publications like the AFTTP 3-1. These maneuvers are developed through close coordination with aircraft engineers, threat experts, and operational tacticians to ensure the maneuvers are effective, safe, and reasonably simple for aircrew. Aircrew memorize the specific parameters for each maneuver and must be able to recall from memory the exact sequence of control inputs to achieve the precise flight characteristics to maximize their survival. AFSOC crewmembers train extensively against a variety of simulated threats to engrain threat maneuvers into their muscle memory. To maximize the aircrew's ability to retain information, defensive tactics are limited to a narrow set of maneuvers. The automation of defensive maneuvers, as discussed in this thesis, presents the possibility to increase the number and type of available maneuvers to maximize the survivability against a larger swath of surface-to-air threats.

Future research should assess the potential of pairing specific types of defensive maneuvers against specific threat systems while optimizing the timing of the respective

⁸¹ Gourville, "Note on Innovation Diffusion: Rogers' Five Factors," 1.

maneuvers paired with various expendables. The Merlin System could be trained to a much larger number of maneuvers than a human pilot would be able to access from memory and could accomplish variations of certain maneuvers depending on a real-time assessment of the threat environment. Future research should also examine the effect of timing between a defensive maneuver and paired expendables. The Merlin System could be programmed to optimize its maneuver based on the type of expendable a defensive system selects and the timing of its deployment.

The focus of this research was largely limited to identifying the importance of incorporating defensive capabilities into an automated flight deck and offering a potential solution using automated defensive maneuvers. However, the Merlin System has significant potential for a variety of different mission sets. Future research should examine the applicability of converting traditionally manned aircraft into optionally manned aircraft for certain missions. Potential mission sets include, intelligence collection, aerial refueling, special mobility and resupply, supplement to training scenarios, and use in chemical, biological, radiological, nuclear, and high yield explosive (CBRNE) conditions. The compatibility of the Merlin System offers great potential for expanded use wherever risk to aircrew or manpower restrictions prevent mission accomplishment.

Finally, research into the automated flight deck and integration of a Merlin System has been limited to single systems operating in isolation from other platforms. However, the importance of information sharing continues to grow, and the networked cooperation and coordination of communication systems requires an organizational redesign.⁸² Future research should examine how Merlin equipped aircraft fit into a broader networked system and what role optionally manned aircraft can play in manned-unmanned teaming. The Merlin System's unique capabilities must be integrated into a larger, cohesive network as new methods of warfare take over.

⁸² John Arquilla, *Bitskrieg: The New Challenge of Cyberwarfare* (Cambridge, UK: Polity Press, 2021), 79.

2. Summary

The speed of information and the growing complexity of warfare is propelling innovation. Technologies are increasingly integrating automation by using tools like artificial intelligence and machine learning as a continuum shift moves humans further from the battlefield and outside the proverbial loop. Machines and automated systems will continue to present unique challenges and opportunities as military planners seek new ways to integrate developing capabilities into sound concepts of operation. Christian Brose equates this to the challenge of “adapting to an era of human command and machine control.”⁸³

The use of automated flight decks and the Merlin System creates opportunities to expand traditionally manned aircraft into new operating environments. Adapting to higher threat areas requires a refocus into new capabilities to increase survivability and favor a defensive advantage. Speed and accuracy remain paramount to threat reactions, and the advent of a solution like the one presented in this thesis could help increase that defensive advantage.

While unmanned systems and platforms will continue to provide vast potential for use, the development of optionally manned aircraft suggests that humans will still play a role in warfare. The principal element of an optionally manned system suggests that certain missions and tasks will continue to require aircrew. Optionally manned systems provide commanders the flexibility to select the appropriate system for a specific mission. Striking the right balance of unmanned and manned systems may turn out to be the key factor in successful implementation of airpower.

⁸³ Brose, *The Kill Chain*, 122.

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APPENDIX A: RESEARCH TEAM MEETING NOTES

WHO: Jon and Randy and Air Force Futures Team

WHAT: Meeting discussing ongoing AF Futures projects and aligning with NPS research efforts

WHEN: 7 Jun 21

WHERE: STBL

TOPICS:

1. Force Design mindset. Tech problem or mindset problem?
 - a. Logistics under attack
 - b. Operate in space
 - c. MDS Divestment

2. Autonomous Collaborative Platforms
3. Agile Combat Employment (ACE)
4. AISUM
5. AF Futures model
 - a. FIT
 - b. CFT

DUE OUT:

1. Nothing specific, continue to further develop research ideas

WHO: Jon and Randy and NPS studs and Anduril Team

WHAT: ANDURIL site visit

WHEN: 11 Jun 21

WHERE: ANDURIL HQ, Irvine, CA

TOPICS:

1. Lattice AI software
2. Months not years
3. Rapid, incremental approach to innovation
 - a. Self-funded R&D is unique to ANDURIL

DUE OUT:

2. Follow up with jackson on possible research collaboration

WHO: Jon and Randy and Jackson Holahan

WHAT: Teams Meeting

WHEN: 14 Jul 21

WHERE: Remote

TOPICS:

1. Anduril is focused on projects that will generate value with their work/resources
 - a. Must meet high bar of months not years
 - b. 8+ figure returns is desired
2. Anduril needs NPS students to provide a credible narrative when pitching ideas and projects that can overcome the high bar for engineering work
3. Especially interested in work that can utilize existing capabilities in demonstrations for new CONOP
4. Seek demos that demonstrate incremental gains and show action

DUE OUT:

1. Provide visual roadmap of our research ideas. Create timeline with realistic expectations and what we expect to achieve

WHO: Jon and Randy

WHAT: Thesis Meeting

WHEN: 16 Jul 21

WHERE: Library

TOPICS:

1. Discussed AFSOC involvement in actions leading up to conflict and how their role changes in the environment during/after conflict
2. Discussed core SOCOM missions and which ones will be applicable in future threat environments
3. Offense/Defense analysis of AFSOC current state
 - a. Is status quo sufficient? What gaps/limitations exist? How to solve?
4. Desired Thesis/Capstone construct: Research a mission set/capability or key concept while linking the possible solution to a demo of a tech that is being researched
5. What is a better process: find a capability or mission set and seek an ongoing tech to link up and solve or choose an interesting tech and see where we can apply it to ongoing missions?

DUE OUT:

3. Meet with JD for direction on our ideas

WHO: Jon and Randy and JD

WHAT: Thesis Meeting

WHEN: 16 Jul 21

WHERE: Teams

TOPICS:

1. Go towards conceptual – discuss theoretical principles
2. What are operational and strategic impacts of collective maneuverability and access to survive in second island chain fight?
 - a. What info would need to be shared to survive?
 - i. Defensive threat picture analysis
3. Platform agnostic – Yes, but with a focused example (AC-130)
4. Focus on less technical and more doctrinal
5. Figure out what the actual problem is.
 - a. Attack the human brain of getting your thesis achieved.

DUE OUT:

1. Meet potential advisors

WHO: Jon and Randy and Prof Houck

WHAT: Thesis Meeting

WHEN: 29 Jul 21

WHERE: Prof Houck's office

TOPICS:

1. Research question feedback
 - a. Instead of yes/no, format the question as a “under what conditions,” or “how might”
2. What are the pros and cons of AI?
 - a. What are the differences between now and where we go?
3. How will sensor fusion w/AI allow SOF aircraft to defend itself?
4. Brian Greenshields second reader option?
5. Can we borrow a model from another sector and apply it to our problem set – stock market, cyber, finance?

DUE OUT:

1. Meet with Col Greenshields

WHO: Jon and Randy and Mr. Greenshields

WHAT: Thesis Meeting

WHEN: 18 Aug

WHERE: Teams

TOPICS:

1. Identify the environment where we will be operating
 - a. How to control escalation? Is this inherently de-escalatory?
2. Computer science department may have ongoing work that could align with this project
3. Chris Manual connection to DIU
4. Field work and test ranges are available at NPS (JIFX)
5. Provided multiple rapid tech POCs (LLNL, SCO OSD, A3, etc)

DUE OUT:

1. Write up explanatory paragraph that describes our research and explains what we believe AI can do for us?

WHO: Jon and Randy and Prof Blanken

WHAT: Thesis Meeting

WHEN: 1 Sep 21

WHERE: Teams

TOPICS:

1. Discussed RoboDojo lab integration with Kristen Solace
2. Steve Mullins and Mike Richardson connection to JIFX
3. Make partnerships but don't rely on other people
 - a. Who is the actual end user? -what is your target audience
 - b. Vector your project towards the target audience
4. Chris Manual – Emerging Technologies Center for IP rights

DUE OUT:

1. None

WHO: Jon and Randy and Prof Blanken

WHAT: Thesis Meeting

WHEN: 13 Sep 21

WHERE: Starbucks

TOPICS:

1. Thesis proposal signed
2. Find tech advisor to include on the team
3. Coordinate w/ Sean for Anduril collaboration as required

DUE OUT:

1. Contact Mr. Greenshields as a possible second reader

WHO: Jon and Randy and Dr. Terry Wilson (PI/PM, Autonomous Air Combat Operations (AACO), Dir, AI Development and Transition AFRL/ACT3)

WHAT: Research discussion

WHEN: 13 Sep 21

WHERE: Phone Call

TOPICS:

1. Need to scope down project to a simpler problem set
2. How will training AI work?
 - a. AI responds with precision faster than a human pilot
 - b. Reinforcement training using look up tables with optimal actions to take
 - c. How do you get your data?
3. Autonomy capability Team 3
 - a. Operationalize AI

DUE OUT:

1. Better scope research question

WHO: Jon and Prof Chris Adams

WHAT: Thesis Meeting

WHEN: 17 Sep 21

WHERE: NPS Office

TOPICS:

1. CAVR – Automated drone lab
 - a. Doug Horner – autonomous systems
2. Survivability class taught in Jan
 - a. SA-6 possible missile – get unclass specs
 - b. Control system theory – az, range, maneuver
3. Find an example or vignette to add to the thesis
4. Helo systems are using similar technology
 - a. CW4 mark Chamberlain – Helo survivability – when to maneuver against threats
5. Thesis needs to show probability of hit change across the whole launch process, unlikely to be a significant difference
6. Simulate the sensor fusion, simulate the control system theory
 - a. Not a ML system, simple x then y maneuvers
 - b. Heavy control system theory – must assume a lot

DUE OUT:

1. Continue to re-evaluate scope

WHO: Jon and Randy

WHAT: 1st post Thesis proposal completion meeting.

WHEN: 22 September 21, 1300-1500

WHERE: Jon's garage

TOP 3:

1. We discussed the thesis product in depth. The idea of reaching out to Mr. Kemp and AFSOC A5RE as our champion. Randy brought up the idea of chairing a portion of the next AFSOC WEPTAC with the intent of our research being the topic. For example, how can AFSOC boost aircraft defense and survivability in non-permissive environments by using artificial intelligence tools.
2. We decided to change our second reader to Col Greenshields and remove Shannon. We will use local NPS experts as resources and references instead of trying to make this research meet their current efforts and requirements.
3. We discussed the methodology more. Big ideas that deserve some developments are gathering defensive maneuver effectiveness data from NGIC/MSIC/GTRI for incorporation and justification for the importance of maneuvering and maneuvering in a "**TIMELY**" manner. The research does not require a drone to be developed for the claim to be made. We need to talk more about building an algorithm, how to test or compare the effectiveness of an algorithm against current available data. The current available data may be buried in test reports with 18th SOTES/413 FLTS/SOCOM Det 1.

DUE OUT:

1. Figure out how to change or amend a thesis proposal for 2nd reader.
2. Establish contacts at MSIC/NGIC/GTRI for sourcing of modeling and maneuver effectiveness.
3. Talk with Mr. Kemp about being the AFSOC "Champion" of our research.

WHO: Jon and Randy

WHAT: 2nd post Thesis proposal completion meeting.

WHEN: 20 October 21

WHERE: Starbucks patio

TOP 3:

1. We discussed whether ForceX is worth investigating as a partner for development of a solution.
2. Randy brought up a future meeting with Nick Villamez, a computer science student at NPS.
3. We decided to reach out to Mr. Kemp again to reiterate that he is our intended audience and see if he is interested in being our champion/consumer. Randy included the AFSOC Patch and AFSOC EWO in the list.

DUE OUT:

1. None annotated

WHO: Randy and Nick Villamez (Computer Science Department, NPS)

WHAT: Computer Science collaboration meeting

WHEN: 21 October 21

WHERE: Library Patio

TOP 3:

1. Nick recommends scoping the thesis down to a single threat, sensor, and reaction to show a “win” or a viable solution.
2. He recommended making a flow chart of how the process is now and then one for how we want it to be with the solution. Tie this into a case study and provide this information to a designer.
3. Nick said to take these products to ForceX (if allowed) or KessleRun to start the technical discussions.

DUE OUT:

1. Make a flow chart
2. Back brief Jon

WHO: Randy and Jon

WHAT: 3rd Thesis Meeting

WHEN: 26 October 21

WHERE: Library Room 253, 0900-1200

TOP 3:

1. After analyzing a first hack at the thesis outline, Jon recommended that we find a method to derive our solution. This can be from other projects, theses, or commercial research.
2. Jon came up with a great vignette that details a very realistic and somewhat surprising situation for AFSOC aircraft. Use this for the paper.
3. We spoke with Mr. Kemp on the phone and he provided comments that were resistant to full automation. He gave examples of it not being accepted by “crew ... studies.” Randy talked him off the ledge and provided inputs from an EWO perspective. He was receptive about being the product receiver and showing us to PEO FW, Mr. Bob Steward.

DUE OUT:

1. Email Bob Steward
2. Find out if we can talk to ForceX
3. Find a Model for analysis
4. Mine data in MSIC and find a contact
5. Contact Greenshields to have a second reader meeting

WHO: Randy, Jon, and Robert Steward (SOCOM PEO-Fixed Wing)

WHAT: SOCOM PEO-FW

WHEN: 2 November 21

WHERE: Cell phone conference call, 0800-0830

TOPICS:

1. Remote gunship is 2 prong attacks. Front and then MOP. The front has gotten far with remote servo and controls. Ground demo in December. We need to get our hands on the Dahlgren white paper. Any defensive efforts for AI? None, crew reduction mandate. Greg Chapman is still at ForceX, Aaron Commons is the other to check. Brandon Troyer of big safari is an expert to consult.
2. Dahlgren is doing some kill chain automation as well. Matt Johnson is a guy to talk to there.
3. What kind of AI are we talking about? Front end sensor fusion would be nice.
4. Product, present the information as quick as possible, do it audibly. Expand on the work they have already done for ATW notification. It becomes a wave file over audio for ICS.
5. The A5 shop and PEO-FW is who would own. AFSOC would have to say they want it, then it is SOCOMs job to do.
6. Northrup Grumman maker of ATW might be a good company to try and talk to. Lockheed is in the beginning stages of fielding a new IR system. Might be worth searching for.

DUE OUT:

1. Talk to the contacts that Mr. Steward provides

WHO: Randy, Jon, and Matthew Johnson (BMS PSP PM)

WHAT: Navy Dahlgren Remote Gunship Discussion (AI/ML)

WHEN: 10 November 21

WHERE: Cell phone conference call, 0730-0830

TOPICS:

1. Can the remote station operate from any aircraft?
2. Sited a concern of near-peer engagements and the survivability of the crew in the white paper.
3. ITMS-integrated tactical management systems. AFSOC wrote a CDD for it in 2017 and it did not give much guidance. Intro machines to a crew. This sat dormant for a while and covers the AC and MC. Recently the MC program office (AFSOC) has taken the lead to integrate it. The aim is to integrate these systems so that all the systems on the aircraft can benefit from them. CDD directed leveraging machines to introduce automation to reduce crew workload.
4. OMS/UCI is the new COT and is a government owned interface that on and outside of platform nodes can access. Publish/Subscribe framework that “anybody/everybody” can access and share
5. The remote gunship white paper does not seem to be going anywhere yet...Matt Johnson can be the POC for us in this.
6. Merlin Labs is tasked with demo'ing on a surrogate aircraft that automated pilot can be done. This is the parallel effort to the Dahlgren effort. They are going to do this demo in California on November 18th. There is a digital zoom link to watch it virtually.
7. Matt is going to send us a kickoff briefing from SNC which is a first look at where things are going to end up. A lot of it is the offensive side.
8. He has been working with A3T and FW to show them that they can do some things with data from simulation data. The training programs are developed from some of the VR people. SOCOM is convinced that they want to go with Dahlgren to do a 30mm VR trainer. This will also go on the EFB and is going to deliver in January. This is for gunner training. Foley sat in on this demo.
9. Maybe we should do the work with Dahlgren and then provide the command output to Merlin instead of working with Merlin or ForceX. This would cut out contractors and make the data quicker and more open to access and share.

DUE OUT:

1. We still need a methodology for how we are going to solve our thesis' problem.
2. Make updates to the flow chart
3. Follow up with MSIC contact Wayne
4. Follow up with Greenshields

5. We need to get a copy of the CONEMP from AFSOC that proposed the remotely operated gunship as part of a strategy to reduce risk to forces, increase lethality, and improve affordability.
6. Request a copy of the ITMS CDD from AFSOC.

WHO: Randy, Mitre, SOCOM, and Merlin personnel

WHAT: Flight Test of autonomous operations onboard Kingair platform

WHEN: 19 November 21

WHERE: Mojave, California

TOPICS:

1. The CEO named Matt was there and met Randy in the parking lot. The agenda for the day's activities are in the resources folder.
2. The slides for the day also indicate their process for "tuning" which is very interesting. It is like fine tuning or adjusting gain for the sensitivity of controls from aircraft to aircraft. Then they verify it through many ways.
3. The flight I rode on was 0856 takeoff and 0924 land. The machine, which they are calling the "Merlin Pilot" performed takeoff, point to point flying, airspeed change, altitude change, and landing without human inputs. I provided commands to do all these functions from a seat in the back of the plane with an iPad running a User Interface (UI) developed by Merlin. The takeoff and landing felt like a normal takeoff and landing. There were very smooth inputs and adjustments which made it seem like a human was flying.
4. Limitations I saw were that the merlin pilot cannot apply brakes, cannot taxi, cannot perform checklist functions (anti-ice application). All communication onboard the airplane was done via wifi. Signal was pushed from the aircraft to the ground station (observe only ground station) via S-Band.
5. I spoke with Merlin representative Ashley Pelzek about their willingness to combine for a CRADA with NPS. They were very interested in collaborating.

DUE OUT:

1. We still need a methodology for how we are going to solve our thesis' problem.
2. Make updates to the flow chart
3. Follow up with MSIC contact Wayne
4. Follow up with Greenshields
5. Talk to Leo about CRADA with Merlin

WHO: Randy, Jon, and Leo

WHAT: Thesis Meeting

WHEN: 29 November 21

WHERE: MS Teams

TOPICS:

1. How does a CRADA become a CRADA? Agata Maslowska is the NPS writer of CRADAs. SOCOM sees a benefit in us teaming up with Merlin which is funded. Do you or NPS care? He seemed like he cares. We can talk to Ashley at Merlin about which kind to pursue and what resources or information would be included. It would be beneficial to talk about the relationships between SOCOM and Merlin Labs.
 - a. Limited CRADA: taking IP from a company and working with it and providing feedback during our research.
 - b. Full CRADA: Coproducing new technology.
 - c. We need to stay away from experimenting on human subjects because it is highly regulated and needs to be controlled.
2. Talk to Bob Steward to learn a little more about StratFi for Leo and the others at the DA department.
3. If we can get first year people interested in this organization, he is saying that it would be good to include them. Leo is interested in why AFSOC and HAF does not really seem interested in the program. This could pertain to an ecosystem type problem.

DUE OUT:

1. Talk to our champions and see if they would like a different product than a thesis paper.
2. Set a meeting between Merlin Labs and NPS for January to discuss CRADA.

WHO: Randy, Jon, and Wayne Westerhouse (IR division)

WHAT: MSIC Data Request

WHEN: 6 Dec 2021

WHERE: Unclassified Teleconference

TOPICS:

1. The effectiveness of a maneuver against modern missiles is minimal at best.
2. Their models would support a threat against a maneuver simulation. He suspects that the threat reaction is more important than the maneuver itself.
3. Define the trajectory and the maneuvers that we want to pull. Then they can run the simulation and provide us the data if we are specific. Put in a coliseum (requires an account) request and run it for a timeline of 3-6 months. The number of systems, aircraft trajectory, the timeline of the maneuver, and the aircraft type. We can say precoordinated with Wayne Westerhouse. If we want to use him as our point man, we can and bro network it out.

DUE OUT:

1. Send Wayne my SIPR to get a copy of the request
2. Put together the list of inputs for the modeling. What output we want from what inputs.

WHO: Jon, AFSOC (Doug Gosch), AMC (Lt Col Daniel Eastman), SOCOM PEO-FW (Jean-Paul)

WHAT: Monthly RG IPT Telecom

WHEN: 16 Dec 2021

WHERE: Unclassified Teleconference

TOPICS:

1. CAD-D and Merlin Labs unable to join in meeting
2. SOF S&T Funds did not prioritize RG for FY22 funding, the next phase needs \$1.5M for next year, \$500K is covered, PEO-FW will cover \$500K, the next \$500K is in question
3. Next phase will consist of take-off and land demo w/ surrogate aircraft between Mar-Jun. Once this is complete, PEO-FW may feel they have sufficient data to show success of the overall project without having to do a C-130 demo, at that point it is up to AFSOC whether they want to pursue further
4. AMC and ML had a CRADA meeting last week to discuss future C-130 and KC-135 integration, desire to re-use and share existing air force flight test data with ML to avoid having to fly as many test flights with ML equipment
5. Collaboration between AMC and AFSOC is limited at this point because the project is too early. AMC is seeking Navy POCs for possible collaboration
6. Big question on whether AFSOC is still interested in RG or not
7. Lockheed Martin is pursuing similar technology with a Dash 42?
8. Next meeting is scheduled for January 20th.

DUE OUT:

1. None

WHO: Randy, Bill Borges, Ashley Pelzek (VP Business Operations (cell) 413-348-9950)

WHAT: Merlin and NPS CRADA Interest Meeting

WHEN: 10 Jan 22 (1200-1300PST)

WHERE: Unclassified Zoom Meeting

TOPICS:

1. The meeting started with Ashley providing a 5-10 minute overview of who Merlin is and what they are doing for Bill's sake. Randy then provided 5-10 minutes of what our research team is working on regarding the defense of AFSOC aircraft. Randy referenced and used the slides to emphasize key points of collaboration and cross over potential between the two entities.
2. Ashley expressed interest and wants to be tied into what our NPS product will be and how it will be propagated. Right now, it is a written thesis which will be released and distributed to SOCOM and AFSOC headquarters personnel. This is still subject to change or to be added to.
3. Both sides discussed what we want from the relationship. NPS wants the technical expertise to act as a model to solve the problem of automated threat reactions for manned and unmanned aircraft. Merlin is interested in our expertise as AFSOC members because we can provide advocacy to our superiors on their behalf. Second, Merlin is interested in the technical data if we can receive the rights to release it. Even without the data Merlin is interested.

DUE OUT:

1. Talk to AFSOC HQ and SOCOM to find out what and how much technical data can be released to Merlin in a CRADA and even without one.
2. Determine CRADA verbiage to share with the NPS CRADA creator.
3. Coordinate a meeting with Leo and Ashley for the adults in the room to say yes.

WHO: Jon & Randy, AFSOC (Doug Gosch), AMC (Lt Col Daniel Eastman), SOCOM
PEO-FW (Jean-Paul)

WHAT: Monthly RG IPT Telecom

WHEN: 20 Jan 22 (1200PST)

WHERE: Unclassified Teleconference

TOPICS:

1. Merlin is putting together a milestone chart for flight demo.
2. SOCOM has seen a CRADA proposed by Gutwerx? Involving a few entities. It would be to create a twin otter version of the gunship. Background effort was accomplished by Fulcrum Concepts about 2 years ago. This focused on what munitions would work best for a twin otter. The PEO is interested in pursuing that. GFE versus non-GFE is a current issue?
3. Ask them about what the MIPR package looks like or is. Also ask for info on the Fulcrum Concepts twin otter project.

DUE OUT:

WHO: Jon & Randy, AFSOC (Doug Gosch), Merlin Labs (Ashley), Ray Wells (AFWERX) SOCOM PEO-FW (Jean-Paul),

WHAT: Monthly RG IPT Telecom

WHEN: 17 Feb 22(1200PST)

WHERE: Unclassified Teleconference

TOPICS:

1. Last week of May final flight demonstration. Last week of March possible flight testing – late march tuning flight is possible, early April more mission work will be conducted
2. Funding for second part of the effort may be getting allocated to a different program from SOCOM PEO-FW, it will get funded eventually but may be delayed due to a JUON for a different project.
3. Possible AMC collaboration with AFSOC is moving forward. Still need to figure out scheduling for aircraft testing on the C-130J
4. December flight test of twin otter for takeoff and land?
5. Twin otter currently under tuning, integration of the hardware to the platform comes next. C-130J tuning could occur prior to twin otter t/o land demonstrations.

DUE OUT:

WHO: Jon & Randy, Ashley Pelzek, Joe (CTO),

WHAT: Merlin CRADA Discussion

WHEN: 22 Feb 22(0800PST)

WHERE: Zoom Call

TOPICS:

1. Merlin and Joe agreed to a CRADA and are reviewing the worksheet to send back to us for routing.
2. They are very interested in the CONOP tasking as a product and Ashley would like to be the person contacted and collaborated with for that.
3. A5 is going to come out in April to take a look at a flight demo.

DUE OUT:

WHO: Jon & Randy, Ashley Pelzek, Joe (CTO),

WHAT: Merlin CRADA Discussion

WHEN: 22 Mar 22(0800PST)

WHERE: Zoom Call


TOPICS:

1. CRADA Final Draft review from Agata Maslowski. Dr. Bondaryk wanted to clarify the scope and end product for the project. The defensive capability is outside of the scope and was a question of theirs. Randy discussed the roadmap as a discussion of the capability to help a human.
2. -1, -4, and technical data documents are enroute and coming from Matt Toppin at SOCOM Det 1. Randy spoke to him this morning to confirm.
3. Jon discussed the GPS denied issues. They want access to the already integrated onboard systems. They are flying 1-3 flights a week right now and SOCOM is coming April 20th. We are welcome to come and join. The end of May they will have a twin otter flight as well.

DUE OUT:

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APPENDIX B: IRREGULAR WARFARE INITIATIVE BRIEFING




NAVAL
POSTGRADUATE
SCHOOL

A Defense Advantage for AFSOC Aircraft

Maj Randy Buckley, USAF
Maj Jonathan Pryor, USAF
24 FEB 2022

The Nation's Premier Defense Research University
Monterey, California
WWW.NPS.EDU




NAVAL
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SCHOOL


Background and Research Question

AFSOC/A8I How will special operations aircraft defend themselves to accomplish their mission in non-permissive environments?

Islamic State might have taken advanced MANPADS from Syrian airfield
Thomas Gibbons-Neff • August 25, 2014

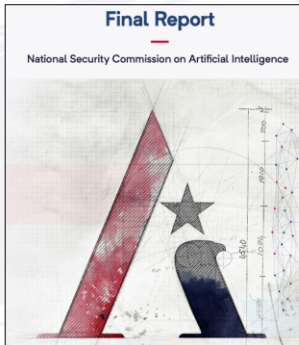


A Man Portable Air Defense System is seen in this undated file photo. (AP Photo/Small Arms Survey)



26 October 2019

Final Report
National Security Commission on Artificial Intelligence



Scoped Questions: How can the use of AI in AFSOC aircraft reduce threat reaction time and increase the effectiveness of defensive threat maneuvers?

WWW.NPS.EDU



The Problem

- Reliance on unmanned assets
 - Limited defensive capability
- Current defensive threat reactions
 - Dependent on human operator
- What tasks can be automated and optimized?
 - AI/ML dual-use technology



WWW.NPS.EDU



Proposed Solution

- Merlin Labs
 - Traditional aircraft → Optionally manned aircraft
- Apply training concepts to defensive maneuvers
 - Optimize defensive maneuvers and eliminate errors
- Incorporate into existing AFSOC aircraft
 - Increased survivability with or without aircrew onboard

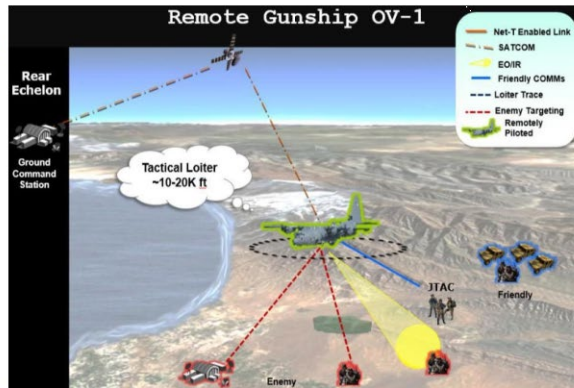


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4



- Impacts Today:
 - Capitalize on human and machine advantages
 - Crew member task unloading
 - Current fleet remains relevant (Baghdadi Raid)
- Impacts Tomorrow:
 - Merlin pilots can fly any aircraft that AFSOC owns or buys in the future
 - Organize by mission not platform



Background / Research Question	The Problem
<ul style="list-style-type: none"> ➢ The US military continues to operate in increasingly complex environments and cannot expect to fly uncontested missions. ➢ How can the use of AI in AFSOC aircraft reduce threat reaction time and increase the effectiveness of defensive threat maneuvers? 	<ul style="list-style-type: none"> ➢ Reliance on unmanned assets <ul style="list-style-type: none"> ➢ Limited defensive capability ➢ Current defensive threat reactions <ul style="list-style-type: none"> ➢ Dependent on human operator ➢ What tasks can be automated and optimized? <ul style="list-style-type: none"> ➢ AI/ML dual-use technology
Proposed Solution	Implications
<ul style="list-style-type: none"> ➢ Merlin Labs <ul style="list-style-type: none"> ➢ Traditional aircraft → Optionally manned aircraft ➢ Apply training concepts to defensive maneuvers <ul style="list-style-type: none"> ➢ Optimize defensive maneuvers and eliminate errors ➢ Incorporate into existing AFSOC aircraft <ul style="list-style-type: none"> ➢ Increased survivability with or without aircrew onboard 	<ul style="list-style-type: none"> ➢ Today: <ul style="list-style-type: none"> ➢ Take advantage of human and machine advantages ➢ Today's AFSOC fleet can be relevant in X threat level when coupled with optionally manned kits ➢ Tomorrow: <ul style="list-style-type: none"> ➢ Merlin Pilot can be taught to fly an aircraft in approximately 2 months from aircraft purchase ➢ AFSOC can organize around missions instead of platforms

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APPENDIX C: AUTOMATED FLIGHT DECK: MERLIN PILOT CONCEPT OF OPERATIONS

AFSOC/A5KG (AC-130 Requirements) and AFSOC/A3TW (Weapons and Tactics) requested the development of a concept of operations (CONOP) for the Merlin Pilot also referred to as the automated flight deck effort. The research team wrote this document and coordinated with both offices to transfer ownership to AFSOC headquarters. Contact AFSOC/A5KG or AFSOC/A3TW for access.

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