NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

DEFENSE ANALYSIS CAPSTONE REPORT

ARTIFICIAL INTELLIGENCE-ENHANCED NAVIGATION FOR THE AC-130J

by

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June 2023

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REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington, DC, 20503.			
1. AGENCY USE ONLY ***(Leave blank)***	**2. REPORT DATE** June 2023	**3. REPORT TYPE AND DATES COVERED** Defense Analysis Capstone Report	
4. TITLE AND SUBTITLE ARTIFICIAL INTELLIGENCE-ENHANCED NAVIGATION FOR THE AC-130J			**5. FUNDING NUMBERS**
6. AUTHOR(S) William R. Borges, Daniel S. Christenson, and Aaron P. Drain			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A			**10. SPONSORING / MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release. Distribution is unlimited.			**12b. DISTRIBUTION CODE** A

13. ABSTRACT (maximum 200 words)

The Department of Defense's (DOD) reliance on the Global Positioning System (GPS), a satellite-based radio navigation system owned and operated by the United States government, creates a critical vulnerability within the DOD. Air Force Special Operations Command (AFSOC) must be able to operate in areas that are GPS denied and degraded. This capstone project seeks to leverage AFSOC's Rapid Capability Development Branch in conjunction with the Department of the Air Force's Massachusetts Institute of Technology Artificial Intelligence Accelerator (DAF-MIT AIA) Robust Neural Differential Models for Navigation and Beyond (MagNav) project to supplement GPS navigation. MagNav research and flight tests have shown it can supplement GPS navigation data, which would allow AFSOC aircraft to operate in GPS-denied and -degraded areas. This capstone leveraged personal relationships and institutional mechanisms to test MagNav in flight on United States Air Force aircraft. The AC-130J is scheduled for initial MagNav testing in the near future. MagNav will ensure AFSOC remains relevant and lethal for strategic competition.

14. SUBJECT TERMS autonomous systems, artificial intelligence, AC-130J, navigation, Global Positioning System, GPS, Robust Neural Differential Models for Navigation and Beyond, MagNav			**15. NUMBER OF PAGES** 65
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UU

NSN 7540-01-280-5500 Standard Form 298 (Rev. 2-89) Prescribed by ANSI Std. 239-18

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ARTIFICIAL INTELLIGENCE-ENHANCED NAVIGATION FOR THE AC-130J

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MASTER OF SCIENCE IN DEFENSE ANALYSIS
(IRREGULAR WARFARE)

and

MASTER OF SCIENCE IN APPLIED DESIGN FOR INNOVATION

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ABSTRACT

The Department of Defense's (DOD) reliance on the Global Positioning System (GPS), a satellite-based radio navigation system owned and operated by the United States government, creates a critical vulnerability within the DOD. Air Force Special Operations Command (AFSOC) must be able to operate in areas that are GPS denied and degraded. This capstone project seeks to leverage AFSOC's Rapid Capability Development Branch in conjunction with the Department of the Air Force's Massachusetts Institute of Technology Artificial Intelligence Accelerator (DAF-MIT AIA) Robust Neural Differential Models for Navigation and Beyond (MagNav) project to supplement GPS navigation. MagNav research and flight tests have shown it can supplement GPS navigation data, which would allow AFSOC aircraft to operate in GPS-denied and -degraded areas. This capstone leveraged personal relationships and institutional mechanisms to test MagNav in flight on United States Air Force aircraft. The AC-130J is scheduled for initial MagNav testing in the near future. MagNav will ensure AFSOC remains relevant and lethal for strategic competition.

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LIST OF ACRONYMS AND ABBREVIATIONS

5G	Fifth Generation
ACC	Air Force Combat Command
AFGSC	Air Force Global Strike Command
AFSOC	Air Force Special Operations Command
AFSOC/A3FR	Air Force Special Operations Command Rapid Capability Development Branch
Alt-PNT	Alternate Position Navigation and Timing
AMC	Air Force Mobility Command
CSAF	Chief of Staff of the Air Force
DAF-MIT AIA	Department of the Air Force's Massachusetts Institute of Technology Artificial Intelligence Accelerator
DO	Director of Operations
DOD	Department of Defense
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
IED	Improvised Explosive Device
INS	Internal Navigation System
MagNav	Robust Neural Differential Models for Navigation and Beyond
MIAB	Magnet in a Box
MIT	Massachusetts Institute of Technology
SST&I	Science, Systems, Technology & Innovation
USAF	United States Air Force
USSOCOM	United States Special Operations Command
USSOCOM Det 1	United States Special Operations Command Detachment 1

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EXECUTIVE SUMMARY

The Department of Defense's (DOD) overreliance on the Global Positioning System (GPS) creates a critical vulnerability within the aviation community. The DOD is pivoting away from the conflicts of the past twenty years with violent extremist organizations. These conflicts have taken place in a permissive threat environment. Air space will likely be contested as the DOD shifts its focus towards strategic competition.

To address this critical vulnerability gap, this report proposes the implementation of an alternate position, navigation, and timing solution. The capstone team recommends using the Robust Neural Differential Models for Navigation and Beyond (MagNav) on Air Force Special Operations Command (AFSOC) aircraft, specifically the AC-130J. MagNav, developed by Department of the Air Force's Massachusetts Institute of Technology Artificial Intelligence Accelerator (DAF AIA-MIT), is a blended navigation solution beginning at a known point, in conjunction with an internal navigation system (INS), a magnetometer comparison with the known magnetic map, and a machine-learning algorithm eliminating aircraft magnetic noise. MagNav is usable on every point on earth, resistant to jamming, and is all-weather capable. MagNav provides AFSOC with the edge needed in strategic competition.

According to open-source reports, near-peer adversaries such as Russia and China have shown GPS-denial capabilities. As early as 2016, the Russian government has shown deliberate and systematic interference with GPS.[1] China has also demonstrated GPS-denial capability on the Mainland, the South China Sea, and international waters.[2,3] Navigation and targeting in these environments would be substantially degraded with the current

[1] Dana Goward, "Ukraine Attacks Changed Russian GPS Jamming," GPS World, December 20, 2022, https://www.gpsworld.com/ukraine-attacks-changed-russian-gps-jamming/.

[2] Michael R. Gordon and Jeremy Page, "China Installed Military Jamming Equipment on Spratly Islands, U.S. Says," *Wall Street Journal*, April 9, 2018, sec. World, https://www.wsj.com/articles/china-installed-military-jamming-equipment-on-spratly-islands-u-s-says-1523266320.

[3] Nicola Smith, "Airline Pilots Warned about Radio Interference by Chinese Military in South China Sea," *The Telegraph*, March 20, 2023, https://www.telegraph.co.uk/world-news/2023/03/20/airline-pilots-warned-radio-interference-chinese-military-south/.

capabilities of AFSOC's fleet. This vulnerability gap was identified against peer and near-peer adversaries after the capstone team visited multiple sites exploring artificial intelligence capabilities in academia, private industry, and DOD. For this capstone project, we visited Merlin Labs, AFSOC, Anduril, Qualcomm, and DAF-MIT AIA. After we visited the DAF-MIT AIA, it became apparent that MagNav addressed DOD's overreliance on GPS.

We followed two avenues to further MagNav implementation by AFSOC: an institutional and an unconventional approach. Following the institutional approach, we submitted a MagNav proposal through the AFSOC Rapid Capability Development (AFSOC/A3FR) process. This process started with an idea submission on the AFSOC/A3FR SharePoint page. AFSOC/A3FR reviewed the proposal and subsequently turned the project over to AFSOC's Science, Systems, Technology, and Innovation (SST&I) division. The formalization of MagNav as a program of record is still an ongoing process with SST&I as we complete this report. Our capstone team followed an unconventional path through personal connections from previous operational experience in the United States Special Operations Command (USSOCOM). Our relationships allowed for direct point-to-point aircraft availability, scheduling, and flights. Together, our two parallel approaches accelerated the project timeline.

We were able to coordinate and execute a proof-of-concept test flight on a C-17 Globemaster III with the 21st Airlift Squadron at Travis AFB, in Solano County. We used two Magnet in a Box (MIAB) for testing optimization. One MIAB was placed in the front section of the cargo compartment and the other placed near the tail to ascertain which location experienced the least electromagnetic interreference. This was the first time MagNav developers utilized new software during flight that provides real time feedback on accuracy. After three days of testing preliminary results showed the system accuracy to be less than or equal to 200 meters. Future flights will be scheduled on an AC-130J utilizing similar procedures.

This report recommends that AFSOC continues MagNav formalization through the SST&I division. Project champions should pay attention to the barriers and resistance inherent in large bureaucratic organizations during all steps and implementation. The capstone team identified three practical barriers to this project: short time-horizon barriers, inappropriate incentives, and excessive bureaucracy. In order to overcome these barriers, we suggest finding long-term stakeholders, providing leaders with quantifiable milestones, and understanding how to navigate a bureaucratic organization. The following steps include ground testing, flight testing, evaluation, and eventual implementation on the AC-130J. After successful initial implementation, AFSOC should utilize this model for fleet-wide integration.

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ACKNOWLEDGMENTS

The capstone team is humbled and incredibly thankful for the opportunity to learn and grow at the Naval Postgraduate School. Working and studying alongside our sister services and international partners has been an honor. The significance of attending the Naval Postgraduate School during the ongoing conflict in Ukraine led to unique perspectives from international students and friends alike. These varied perspectives enriched our daily life as we walked the grounds and learned from others in our cohort. The team will be forever grateful for this time in our careers when we were allowed to reflect, strengthen familial relationships, and develop new meaningful friendships, even over a short period.

The Naval Postgraduate School academic experience has enlightened us and provided an invaluable perspective. The team could not have completed this capstone project without numerous individuals and institutions' help, guidance, and generosity. The team especially appreciates the DAF-MIT AIA MagNav project lead, Major Kyle McAlpin. Additionally, Aaron Nielson's expertise, material, and willingness to help have helped shape our capstone and see it to completion. The trip leads for each site visit allowed us to engage with DOD industry and eventually helped us home in on what we thought would be the most advantageous project for AFSOC. Lastly, we owe a debt of gratitude to our advisor Dr. Matthew Zefferman, who helped our team stay on track and shift our focus when we didn't see the right path forward.

Finally, and most importantly, we would like to thank the amazing family members in our lives. Our wonderful children are an inspiration to us every day. Our spouses, Dez Goetting and Taylor Christenson, gave support, love, and encouragement throughout our studies and capstone and helped us reach the finish line.

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I. CAPSTONE INTENT

This capstone intends to identify the most immediate and effective use of AI implementation for AFSOC. The capstone team explored multiple AI use cases for quick implementation throughout capstone completion. This rapid implementation effort aligns with the intent of the AFSOC commander and the Chief of Staff of the Air Force's (CSAF) vision to innovate for strategic competition. "Humans are more important than hardware" is the United States Special Operations Command's (USSOCOM) first Special Operations Forces truth or guiding principle.[4] The then Commander of AFSOC, Lieutenant General James Slife, reiterated this concept in his testimony to the Senate Armed Services Committee on 28 April 2021. General Slife stated, "AFSOC's guiding principle is that our human capital, our airmen, are our competitive advantage."[5] Strategic competition will not change this guiding principle within the Special Operations community.

General Slife testified that "our airmen, disciplined professionals capable of complex problem solving," are AFSOC's strategic advantage.[6] Pointing to a strategic advantage within the ranks of AFSOC, General Slife said that "transformational innovation" must occur by equipping Airmen with the right tools.[7] Safeguarding Airmen while innovating for future conflict is the key to maintaining the Department of Defense's (DOD) strategic advantage. Integrating AI with AFSOC's diverse fleet would not only safeguard more of AFSOC's human capital but also place the right tools in the hands of Airmen and equip them for strategic competition and future conflict. The CSAF, General C.Q. Brown, Jr., also share this vision to innovate. He has instituted action orders to the force, charging Airmen to "accelerate change or lose."[8] One of the four action orders the

[4] John Friberg, "SOF Truths - Guidance for Special Operations Forces," *SOF News* (blog), October 28, 2017, https://sof.news/sof/sof-truths/.

[5] *Senate Armed Services Committee Emerging Threats and Capabilities Subcommittee Hearing*, 117th Cong. (2020) (statement of General James C. Slife Air Force Special Operations commander).

[6] Senate Armed Services Committee Hearing.

[7] Senate Armed Services Committee Hearing.

[8] Charles Q. Brown, Jr., "CSAF Action Orders to Accelerate Change Across the Air Force," 2022, https://www.af.mil/Portals/1/documents/2022SAF/FINAL_Modified_Action_Orders.pdf.

CSAF identified is Action Order Charlie: Competition, specifically regarding Russia and China. China has overtaken the United States in AI research by multiple measures.[9] China has more AI patents, research publications, and journal citations than any other country.[10] AI adoption and integration must be a priority for DOD to compete with Russia and China and even have a seat at the table. AFSOC can lead the USAF in AI and find its role in strategic competition with AI fleet integration. AI can enhance multiple missions within AFSOC.

[9] Brown, Jr.

[10] Kai-Fu Lee, "How China Is Using AI to Fuel the Next Industrial Revolution," *Time*, August 11, 2021, https://time.com/6084158/china-ai-factory-future/.

II. HISTORICAL EXEMPLAR

Innovation can influence how the United States adapts to problems faced in warfare. A historical example of this occurred during the wars in Iraq and Afghanistan. A significant dilemma the U.S. and its allies faced in the wars in Iraq and Afghanistan was the improvised explosive devices (IED). IEDs were a tool the insurgents were able to utilize with great success. This was a genuine problem for the U.S. military and its allies. The insurgents had a decisive advantage with IEDs because they could conceal them and leave the area. When the culprits detonate the IED, the damage is done, and they are nowhere to be found. One could argue that IEDs transformed the battlefield. According to Shell, IEDs accounted for sixty percent of American fatalities in Iraq, half of all fatalities in Afghanistan, and 3,500 in total. IEDs accounted for over 30,000 American service members being wounded in action.[11] IEDs were a considerable problem for the U.S. military. This caused a need for the military to innovate and adapt to overcome this significant crisis.

The threat of IEDs to service members and that a cheap explosive device could disable a vehicle worth hundreds of thousands of dollars is a significant problem the U.S. military needed to address, as shown in Figure 1. One of the ways the U.S. handled this issue was by turning to technology and employing Minehound and Gizmo detectors. These are essentially metal detectors on steroids. They are dual-sensor detectors that use ground-penetrating radar and sensors that can find metallic and non-metallic threats.[12] These detectors proved successful at detecting IEDs ahead of convoys and troop movements. They are an example of the U.S. military using innovation to adapt to the ever-changing battlefield and reduce the insurgent's advantage.

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[11] Jason Shell, "How the IED Won: Dispelling the Myth of Tactical Success and Innovation," *War on the Rocks*, May 1, 2017, https://warontherocks.com/2017/05/how-the-ied-won-dispelling-the-myth-of-tactical-success-and-innovation/.

[12] Christopher McCullough, "Minhunter and Gizmo Help Warfighters Finding IEDs with Mine Detectors," Defense Update, July 20, 2012, https://defense-update.com/20120720_finding-ieds-with-metal-detectors-on-steroids.html, https://defense-update.com/20120720_finding-ieds-with-metal-detectors-on-steroids.html.

Figure 1. Military Searching for IEDs[13]

[13] Source: McCullough.

III. CASE STUDIES AND PROBLEM SPACE

AI coupled with Robust Neural Differential Models for Navigation and Beyond (MagNav) can provide the U.S. with an innovative solution to the alternate position navigation and timing (Alt-PNT) dilemma, just as Minehound and Gizmo detectors solved the IED crisis. A case study will help frame the problem of Global Positioning System (GPS) jamming, denial, and spoofing. GPS jamming is the act of using a frequency-transmitting device to block or interfere with communications such as Wi-Fi networks, GPS systems, and phone calls.[14] GPS spoofing interjects a false counterfeit GPS signal to confuse the operator with erroneous information to induce navigation error.[15] GPS-denied environments encompass all reasons a GPS may not work, including simple constellation failure, adversary jamming, and spoofing attacks.[16] The war in Ukraine has now gone on for well over a year. The Ukrainian-Russian conflict has demonstrated Russia's ability to exploit GPS reliance. The highest levels of GPS jamming globally are occurring in Russia, depicted in Figure 2.

[14] TechTarget, "What Is GPS Jamming? Definition from WhatIs.Com," accessed May 3, 2023, https://www.techtarget.com/searchsecurity/definition/GPS-jamming.

[15] McAfee, "What Is GPS Spoofing?," McAfee, December 7, 2022, https://www.mcafee.com/learn/what-is-gps-spoofing/.

[16] NovAtel, "GNSS Denied?," Hexagon, 2014, https://novatel.com/tech-talk/velocity-magazine/velocity-2014/gnss-denied.

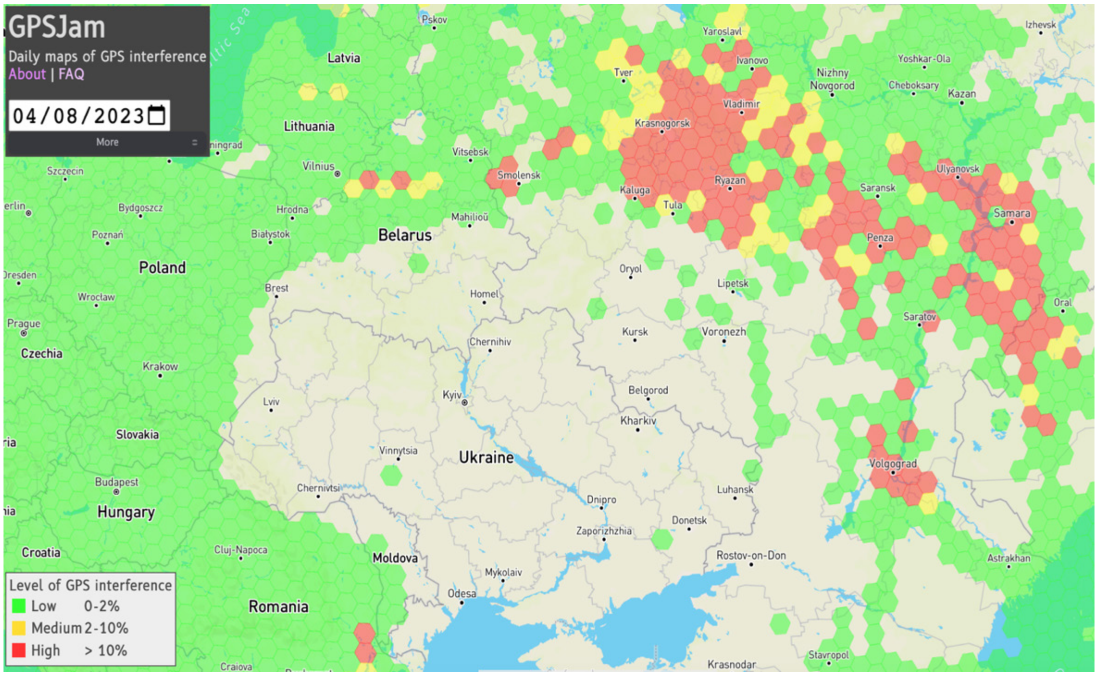

Figure 2. Russia GPS Jamming[17]

According to GPS World, the top Global Navigation Satellite System (GNSS) industry publication, "the Russian government has been deliberately and systematically interfering with GPS signals" since at least 2016.[18] GPS jamming trucks have been deployed in the current Ukrainian-Russian conflict, accompanying troops to ensure protection from GPS-guided munitions.[19] Russia has also assigned GPS spoofing equipment to move with high-value Russian targets.[20] While Russia is trying to protect its forces at the tactical level, they have also been "jamming airline satellite navigation near the Black Sea, eastern Finland, and Kaliningrad" in a more general approach.[21] According to the European Union Aviation Safety Agency, the jamming and spoofing have been so severe that it has caused rerouting, destination changes, and in some cases, the inability to

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[17] Source: Mapbox, "Daily Maps of GPS Interface (Real Time)," accessed April 11, 2023, https://gpsjam.org/.

[18] Goward, "Ukraine Attacks Changed Russian GPS Jamming."

[19] Kimberly Johnson, "Airlines Report Russian GPS Jamming in Four Regions," *Flying Magazine*, April 1, 2022, https://www.flyingmag.com/airlines-report-russian-gps-jamming-in-four-regions/.

[20] Goward, "Ukraine Attacks Changed Russian GPS Jamming."

[21] Johnson, "Airlines Report Russian GPS Jamming in Four Regions."

perform a safe landing procedure.[22] Initially, when the conflict began in February of 2022, GPS jamming was mainly confined to Moscow and Minsk, as depicted in Figure 3.

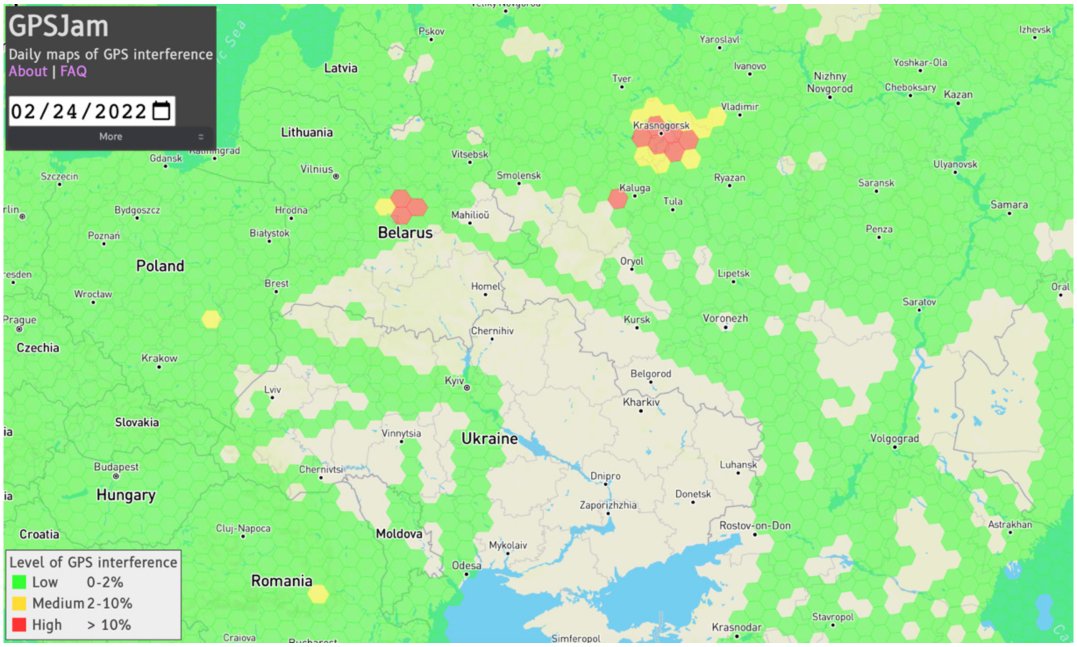

Figure 3. GPS Jamming at the Beginning of the Ukraine Conflict[23]

The GPS jamming centered in Minsk, Belarus, should be no surprise. Russia conducted a joint exercise Zapad in 2017 with Belarus. This exercise emphasized electronic warfare, specifically communication jamming in a compromised environment.[24] Norway experienced GPS jamming and signal loss as far as 600 kilometers from the jamming site.[25] Russia and Belarus trained 100,000 troops, according to North Atlantic Treaty Organization. Several regions surrounding Murmansk Oblast on Russia's northeastern border experienced GPS signal loss.[26] This joint exercise solidified and strengthened

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22 Johnson.

23 Source: Mapbox, "Daily Maps of GPS Interface (Real Time)."

24 Alexandra Coultrup, "Arctic Circle GPS Jamming," Aerospace Security, September 1, 2022, https://aerospace.csis.org/data/gps-jamming-in-the-arctic-circle/.

25 Coultrup.

26 Coultrup.

Russia's GPS jamming capabilities. Russia used this experience to its advantage in the current conflict with Ukraine. As the war in Ukraine has raged on, Russia has ramped up and deployed more GPS jamming capability. Russia's GPS denial tactics indicate they can negatively impact navigation and targeting with precision-guided munitions.

GPS jamming, denial, and spoofing are not limited to Russia. It is also common practice for China, another strategic competitor. Unfortunately, China has shown far greater capabilities than Russia. China is capable of spoofing, jamming, and complete denial of GPS. Perhaps the most concerning is the investment and development of a ground-based laser that can destroy orbiting satellites orbiting in space.[27] The ability to completely deny the use of GPS by eliminating any of the DOD's thirty-one operational GPS satellites could severely hamper the DOD's ability to wage war effectively.

Figure 4 illustrates how multiple GPS satellites make up the GNSS constellation to ensure they all work together to provide the most accurate coverage. The accuracy of GPS position depends on the number of GPS satellites a receiver can receive. As GPS satellites are removed or destroyed from the GNSS constellation, coverage in that area will degrade GPS position accuracy. With a full complement of GPS satellite coverage in a given area, GPS accuracy is within 0.643 meters or 2.1 feet ninety-five percent of the time.[28] For example, if a GPS receiver is only receiving a signal from three satellites, the best possible GPS fix will only be two-dimensional. If you are not exactly at sea level, the fix could be off by hundreds of meters. This accuracy changes dramatically if the GPS receiver can get a signal from four GPS satellites. Four satellite signals provide a three-dimensional fix, meaning the accuracy is still within the average user range error of .643 meters at any altitude. The implications of losing even one or two satellites in a coverage area would be disastrous. Most aircraft, while operating, are never at sea level, meaning the position would be entirely degraded and unusable for navigation and targeting purposes.

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[27] Bill Gertz, "Air Force Gen. John W. Raymond: Chinese Lasers, Jammers Threaten GPS Satellites," *Washington Times*, May 10, 2021, https://www.washingtontimes.com/news/2021/may/10/air-force-gen-john-w-raymond-chinese-lasers-jammer/.

[28] United States Government, "GPS Accuracy," March 3, 2022, https://www.gps.gov/systems/gps/performance/accuracy/.

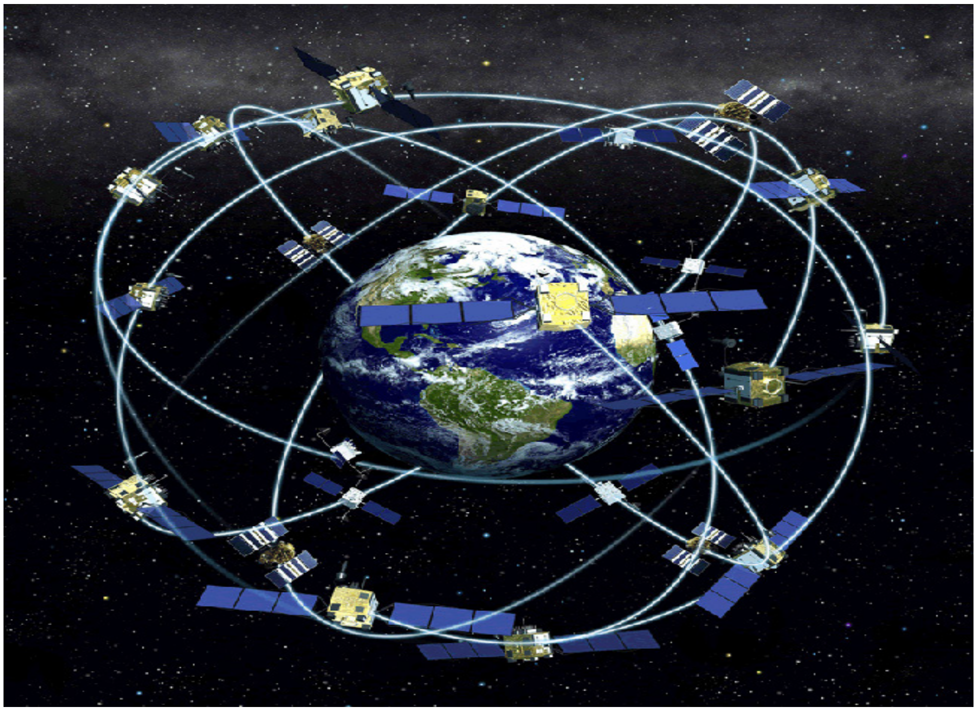

Figure 4. How GPS Works[29]

China placing GPS jamming systems on Mischief Reef in the South China Sea is another indication of the investments China is pursuing to degrade U.S. military effectiveness.[30] China's GPS jamming capability is not confined to Mainland China and the South China Sea. Chinese warships are suspected of GPS jamming on Australia's northwest shelf as recently as March 2023.[31] Multiple Qantas commercial airliners reported very high frequency and GPS interference.[32] China is also investing in GPS spoofing. China's suspected GPS spoofing seen in the seaport of Shanghai is astonishing due to the sheer number of spoofing events and targets created simultaneously.[33] In July

[29] NASA Science, "How Does GPS Work?," NASA Space Place, June 27, 2019, https://spaceplace.nasa.gov/gps/en/.

[30] Gordon and Page, "China Installed Military Jamming Equipment on Spratly Islands, U.S. Says."

[31] Smith, "Airline Pilots Warned about Radio Interference by Chinese Military in South China Sea."

[32] Smith.

[33] Mark Harris, "Ghost Ships, Crop Circles, and Soft Gold: A GPS Mystery in Shanghai," *MIT Technology Review*, November 15, 2019, https://www.technologyreview.com/2019/11/15/131940/ghost-ships-crop-circles-and-soft-gold-a-gps-mystery-in-shanghai/.

2019, three hundred vessels were simultaneously spoofed.[34] Commercial ships operating in the port of Shanghai weren't spoofed to a single location like previous spoofing seen from Russia and China, but the vessels were jumping to different locations.

This spoofing has caused cargo ships in the Shanghai seaport to crash into each other, run aground, and veer dangerously off course.[35] It's unclear from the reporting of spoofing events at the Shanghai seaport whether this is a testing ground for future attacks or testing went wrong. In either case, the implications of this level of GPS spoofing on military vessels, aircraft, and maneuvering land elements could have grave consequences. Chinese and Russian investment in GPS jamming, denial, and spoofing must be countered with alternate navigation sources to conduct safe and secure navigation and targeting.

34 Harris.

35 Harris.

IV. CAPSTONE PROJECT TRIP REPORT

This trip report provides a summary of the trips made by William, Daniel, and Aaron as part of their capstone project on artificial intelligence integration into the AFSOC fleet, which led us to focus on the problem of GPS-denied environments and culminated with us establishing a flight test with aircraft with a system developed by the Department of the Air Force's Massachusetts Institute of Technology Artificial Intelligence Accelerator (DAF-MIT AIA). The report highlights the key activities, experiences, personnel, and insights gained during the trips to Irvine, CA, Palmdale, CA, San Diego, CA, Hurlburt Field, FL, and Boston, MA.

A. MERLIN LABS FLIGHT DEMO

Merlin Labs is a company based out of Boston, Massachusetts, founded by Matt George in 2018. The company has been creating infrastructure for autonomous flight to carry goods and, eventually, people without having pilots on board the aircraft.[36] Merlin Labs seeks to allow aircraft to fly autonomously and receive directions from ATC while using a remote pilot for monitoring instead of remotely flying the aircraft.[37] The team visited Palmdale, CA, from May 12 to May 13, 2022, to attend the Merlin Labs flight demo at Palmdale Regional Airport. During the visit, the team observed how AI was used for automated flight, with the intent for future implementation on AFSOC aircraft. The team witnessed a demonstration of a DHC-6 Twin Otter using the Merlin pilot to takeoff, receive and perform air traffic control commands, navigate, and land. Following the visit, the team was tasked with researching other aircraft that could potentially benefit from the Merlin pilot and how AI could be used further in the AFSOC fleet. The team identified the C-145 Combat Coyote and C-146 Wolfhound, due to similar flight characteristics of the DHC-6 Twin Otter, as excellent candidates for Merlin Labs remote pilot implementation.

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[36] Crunchbase, "Merlin Labs - Crunchbase Company Profile & Funding," Crunchbase, accessed May 2, 2023, https://www.crunchbase.com/organization/merlin-labs.

[37] Virginia Department of Aviation, "Merlin Labs Partner with Dynamic Aviation to Bring Autonomy to Fleet," Virginia Department of Aviation, June 2021, https://doav.virginia.gov/calendar-and-news/news/2021-june/merlin-labs-partner-with-dynamic-aviation-to-bring-autonomy-to-fleet/.

B. AFSOC HEADQUARTERS VISIT

The team visited Hurlburt Field, FL, from July 20 to July 23, 2022, to meet with AFSOC Strategic Plans and Programs on current and future projects. The team was also allowed to tour an AC-130J static display. Following the visit, the team was tasked with updating AFSOC headquarters on the team's capstone project status.

C. ANDURIL SITE VISIT

The team visited Anduril in Irvine, CA, from August 29 to August 31, 2022. Anduril is a private defense technology company that builds advanced technologies to solve significant national security challenges.[38] The team learned about Lattice AI, a proprietary software used by Anduril as well as the possible use cases in AFSOC. The team also learned about sensor diffusion, computer vision, and adaptive data processing and dissemination. Following the visit, the team coordinated further and consulted with Anduril Air Force representative Matt Bebb. Additional use cases were discussed, including base defense with Anduril's mobile tower sentry, Anduril's Ghost 4 vertical takeoff and landing drone, and other potential AI-enhanced equipment on AFSOC aircraft.

D. QUALCOMM CORPORATE HEADQUARTERS VISIT

The team visited Qualcomm corporate headquarters in San Diego, CA, from October 26 to October 28, 2022. The team explored the possibilities of fifth-generation (5G) mobile networks for DOD and AI computing at the edge. Secure airborne 5G networks for communications in the joint environment were also explored. The Senior Vice President and General Manager of Qualcomm Government, Kimberly Koro, also invited our team to share use cases that might be specific to aviation and AFSOC aircraft.

E. DAF-MIT AIA VISIT

The team visited the Massachusetts Institute of Technology (MIT) campus in Boston, MA, from March 1 to March 3, 2023. The team learned about the DAF-MIT AIA

[38] Anduril, "About Anduril Blog," *About Anduril* (blog), accessed May 2, 2023, https://blog.anduril.com/about.

and DAF-MIT AIA's partnership with DOD. DAF-MIT AIA gave an overview of its mission, history, and their AI portfolio. During the visit, the team recognized that MagNav could potentially solve AFSOC's overreliance on GPS-based navigation systems. Following the visit, the team coordinated with the DAF-MIT AIA MagNav team lead for integration on AFSOC aircraft.

F. TRAVIS AFB C-17 MAGNAV TEST

The team visited Travis AFB in Solano County, California, from May 10 to May 15, 2023. The team met with representatives from AFRL, AFIT, MIT AIA, Lincoln Lab, and the 21st Airlift Squadron. During the visit, the team participated in mission planning for the flight test of the Magnet in a Box (MIAB). The team then observed a flight test of MIAB on a C-17 Globemaster III. This flight was the first time the MIAB navigated in real-time on a C-17.

G. CONCLUSION

In conclusion, these trips provided valuable insights and experiences for the team working on the capstone project for AFSOC. The team gained knowledge of artificial intelligence, automated flight, 5G technology, and MagNav, among other topics, that could benefit AFSOC in the future. The capstone's desired end state is MagNav implementation for AC-130J aircraft.

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V. MAGNAV

What are Robust Neural Differential Models for Navigation and Beyond or MagNav? MagNav combines Earth's magnetic crustal field for navigation with AI enhancement. Walter Tolles patented the concept of using the Earth's crustal magnetic field for navigation in the 1950s.[39] Figure 5 shows the Earth's magnetic crustal field is mapped well enough for magnetic navigation.

During the DAF-MIT AIA trip, we received a briefing on their full AI portfolio. Part of this portfolio included MagNav. After the team returned from the DAF-MIT AIA trip, a meeting took place with the capstone advisor. MagNav was selected as the AI instrument that could have the most comprehensive and impactful effect on AFSOC at this meeting. A plan of action was created to test the feasibility of MagNav as quickly as possible. This effort is discussed in the capstone approach section.

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[39] Albert R. Gnadt et al., "Signal Enhancement for Magnetic Navigation Challenge Problem," arXiv (January 6, 2023), http://arxiv.org/abs/2007.12158.

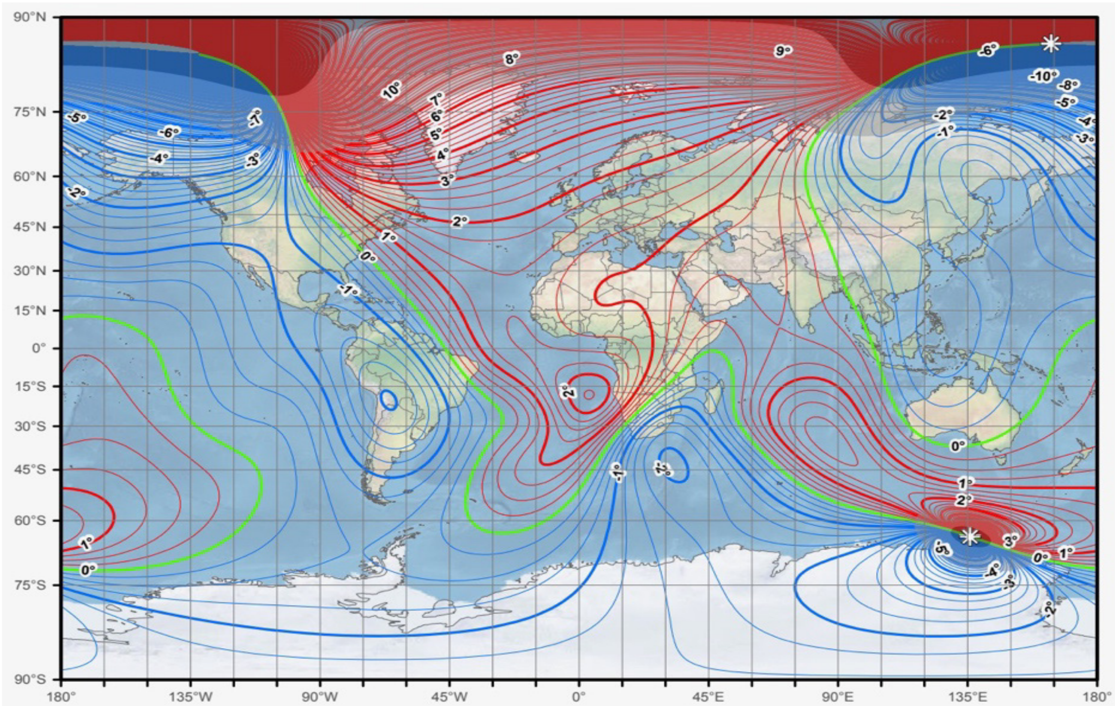

Figure 5. World Magnetic Model[40]

Using the earth's magnetic resonance for navigation provides many advantages. MagNav requires no external communication with any man-made outside cyber support, is available in all weather conditions, is usable on every point on earth, including underwater, is extremely hard to jam, and provides cost-free signal generation. In the past, there were challenges to navigating in an aircraft using resonance from the earth's crustal magnetic field. Poor magnetometers (crustal field sensors) and the inability to parse the earth's magnetic field from the vehicle on which the magnetometer is mounted hampered accurate navigation in aircraft.[41]

DAF-MIT AIA has overcome both challenges to navigating using the earth's crustal field in an aircraft. MagNav is the blended navigation solution beginning at a known point, in conjunction with an internal navigation system (INS), a magnetometer comparison

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40 Source: National Oceanic and Atmospheric Administration, "World Magnetic Model," National Centers for Environmental Information, January 10, 2023, https://www.ngdc.noaa.gov/geomag/WMM/.

41 Gnadt et al., "Signal Enhancement for Magnetic Navigation Challenge Problem."

with the available magnetic map shown in Figure 6, and a machine learning algorithm eliminating aircraft noise (magnetic field generated by the vehicle).

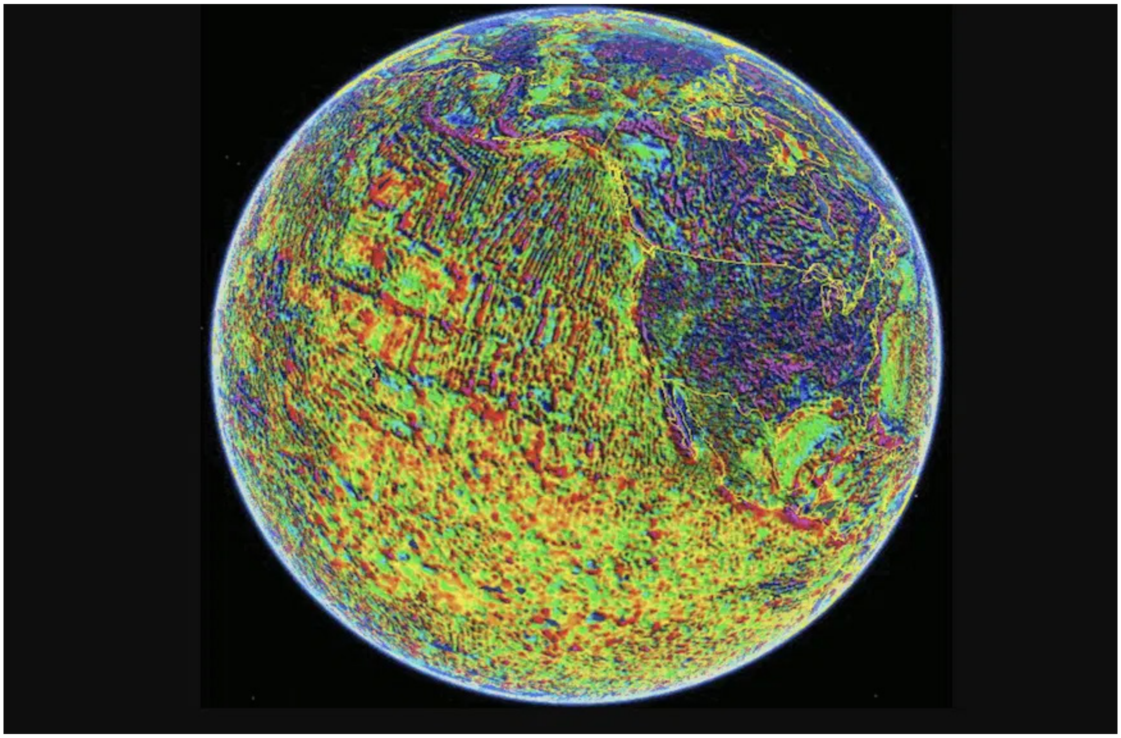

Figure 6. Earth's Magnetic Map[42]

Every aircraft in AFSOC's fleet already utilizes an INS. The addition of MagNav would make every aircraft in AFSOC resilient in a GPS-denied, jammed, or spoofed environment.

DAF-MIT AIA has already seen successful results with several aircraft. The civilian geo-survey aircraft tested had navigational accuracy of 19–32 meters. The F-16 Fighting Falcon of Air Combat Command (ACC)aircraft tested had navigational accuracy of 59 meters. The C-17 Globemaster of Air Mobility Command (AMC) initial aircraft test has had similar results to the F-16 accuracy but is just in the initial stages of feasibility tests. The following aircraft scheduled for MagNav testing is the B-52 Stratofortress of Air

[42] Source: Stefan Maus, "Earth Magnetic Anomaly Grid," Geomagnetism, July 6, 2015, https://www.geomag.us/models/emag2.html.

Force Global Strike Command (AFGSC). AFSOC must join ACC, AFGSC, and AMC to stay relevant for strategic competition.

VI. CAPSTONE APPROACH

The Capstone team identified MagNav as the AI innovation that could make the most widespread impact on AFSOC; we contacted multiple stakeholders across AFSOC and USSOCOM. The capstone team opened a direct line of communication with the DAF-MIT AIA MagNav team, USSOCOM Detachment 1 (SOCOM Det 1), AFSOC/Weapons and Tactics, AFSOC/Gunship Requirements, the 14th Weapons Squadron, the 18th Special Operations Test and Evaluation Squadron, and the 492nd Special Operations Training Support Squadron. Two paths for institutional adoption were identified after contacting all stakeholders within AFSOC and USSOCOM. The first path is through the institutional process AFSOC/A3FW, which has proven to be more time-consuming and full of bureaucratic red tape. The second unconventional path at SOCOM Det 1 is working through an already-established personal relationship. This path has seen rapid progress in setting up an initial MagNav feasibility test. Unfortunately, the unconventional approach has no mechanism for continued effort once the individuals move on to different positions, commands, or projects.

The institutional approach for MagNav adoption by AFSOC is through an AFSOC process called Rapid Capability Development. This process entails accessing the AFSOC Rapid Capability Development Branch (AFSOC/A3FR) SharePoint Idea Submission page at the following URL https://usaf.dps.mil/sites/AFSOC-A3/AFSOC-A3F/A3FR/SitePages/Idea.aspx. The "Idea Submission" page has a form that details who is submitting the idea, a contact number for the idea submitter, a brief description of the idea, the aim of the idea, and the operating environment for the idea, as seen in Figure 7. This avenue must be reviewed at multiple levels within AFSOC before action can be taken to test the new capability. The initial idea was submitted on 22 March 2022. The idea submission initial review has still not taken place as of mid-April. This avenue for adoption is still being pursued in a parallel effort to help with eventual institutional adoption. The capstone team is conducting weekly progress checks to monitor the progress of the idea submission through the AFSOC/A3FR process. Another NPS student, Maj Thomas Repsha, will also take over the MagNav effort and continue working with the DAF-MIT

AIA team. The capstone team will continue to work with AFSOC/A3FR throughout the idea submission process.

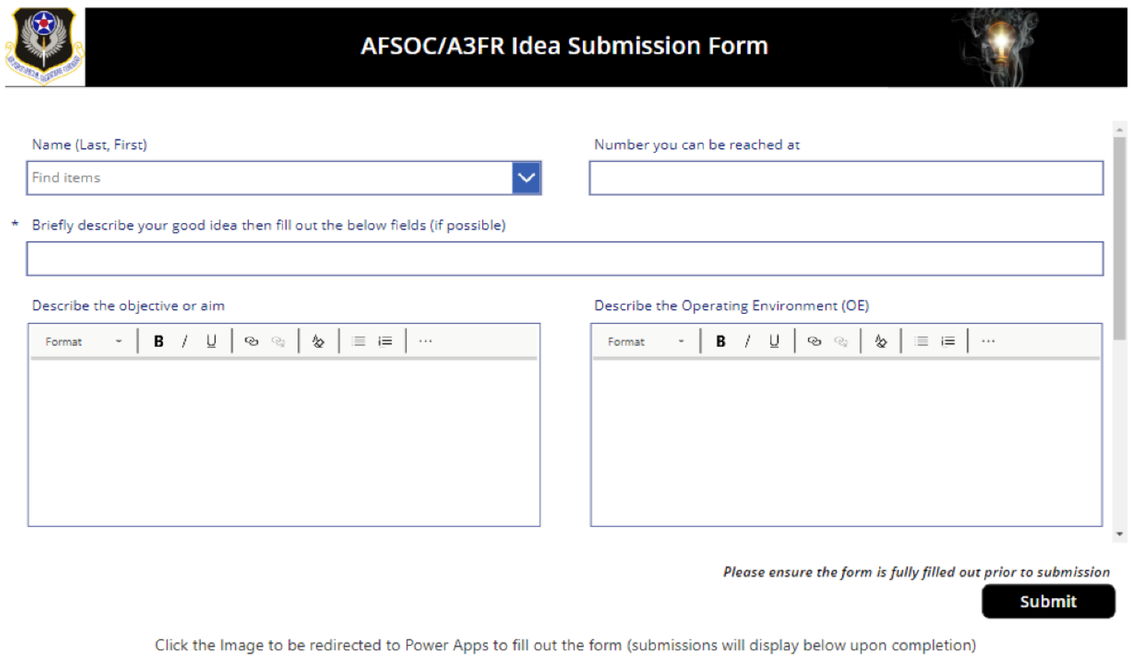

Figure 7. AFSOC Idea Submission Form

The unconventional path was through contact with the Director of Operations (DO) of SOCOM Det 1, who had a personal connection with the capstone team. Once the SOCOM Det 1/DO confirmed that aircraft availability and the concept would not interfere with any current SOCOM Det 1 priorities, additional concerns, and factors were discussed. The SOCOM Det 1/DO directed the capstone team to request aircraft support through AFSOC/A5KG to ensure proper channels were utilized. The capstone team also had a previous personal relationship with the Chief AFSOC/A5KG. This personal connection facilitated a rapid response between SOCOM Det 1 and AFSOC/A5KG. Further coordination was required with the DAF-MIT AIA MagNav team lead for the availability of magnet-in-a-box equipment. Initial feasibility testing for MagNav on the AC-130J is scheduled for mid-May.

VII. BARRIERS AND RECOMMENDATIONS

As with any change, there will be barriers. One of the biggest challenges will be working through the resistance to innovate or adapt a new way of doing things. AFSOC, much like any military Major Command, is a large bureaucratic organization. Mintzberg, Quinn, and Ghoshal all point out seven barriers that could affect innovation in large organizations; short time-horizons, inappropriate incentives, excessive bureaucracy, accounting practices, excessive rationalism, top management isolation, and intolerance of fanatics.[43] As the MAGNAV concept continues testing and feasibility, future teams should be aware of these barriers and consider our teams' suggestions on how to work through them. Our team has identified three barriers that have affected our capstone project, and vigilance should be used for future teams.

People may be tempted to favor short-term wins instead of the long-term work required for successful innovation in short time-horizons.[44] This could put this project at risk of being fully operational because it will need much more time to be fully implemented. When working with active-duty military, there is a lot of turnover and incentives for the quick win. This may come up as officers and enlisted leaders are looking for information to put on quarterly awards or even performance evaluations. Our team suggests continued articulation on how these fit into the long-term strategic goals so that leaders and subordinates will not cripple themselves on the quick victory. A specific example of this occurred when we were working with an industry partner. The partner lost funding for the short-term and ceased communication once that incentive was removed. As mentioned earlier, short time-horizons may feed into the quick win for teams and leaders, which can be attributed to inappropriate incentives.

Inappropriate incentives mean that the current incentive program does not correctly reward innovation.[45] True innovation will involve failure and surprises. AFSOC and the

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[43] Henry Mintzberg, James Quinn, and Sumantra Ghoshal, *The Strategy Process: Revised European Edition* (Prentice Hall, 1995), 727–28.

[44] Mintzberg, Quinn, and Ghoshal, *The Strategy Process: Revised European Edition*.

[45] Mintzberg, Quinn, and Ghoshal.

Air Force at large incentivize quantifiable data within a limited timeframe. This incentivized short term projects that can be encapsulated in a performance report used for promotion and professional success. Due to this, and the short time-horizon issue, decision-makers may go for what is already known and successful to ensure their professional careers progress. An example of this is the repeated reliance on GPS and GPS hardening systems that are myopic fixes, instead of long-term new Alt-PNT research and development. This culture-embedded problem is much larger than our team and future teams' ability to change. Changing the current incentive system within the USAF requires additional research and testing outside this project's scope. Our team suggests monitoring this problem and finding ways to articulate short-term wins that fit within the current system while testing MAGNAV and looking to incentivize non-malicious failure.

Excessive bureaucracy, commonly found in large organizations, is the third stressed barrier the team has encountered. Large organizations use bureaucracy for many good things, which can create more friction regarding innovation or rapid change. Excessive bureaucracy is where there are so many approvals that a vital time window can be missed.[46] This can also increase risk and costs for the organization when simple, quick tests get skipped because there are too many layers. We experienced this with aircraft availability for MagNav testing. The approval authority was too lengthy and convoluted, which forced us to pivot the proof-of-concept test to an available and approved C-17. We suggest that future teams maintain strong communication throughout the whole process to ensure decision-makers are timely. Additionally, future teams should guard against allowing unnecessary people in the decision-making process.

46 Mintzberg, Quinn, and Ghoshal.

VIII. WAY FORWARD SCHEDULE

AFSOC's acquisition and requirements process has hampered the quick implementation of MagNav. The capstone team is pursuing multiple avenues for testing, implementation, and eventual operational use. The capstone team's next steps include proof-of-concept flights and continued institutional interface with AFSOC's Science, Systems, Technology & Innovation (SST&I) division. SST&I has taken over the MagNav idea submission from A3FR and formalized it for further review. The following schedule details several benchmarks.

1. Formal submission to AFSOC/AF3R – 9 April 2023
2. AF3R turns MagNav over to SST&I – 19 April 2023
3. SST&I/Capstone teleconference – 21 April 2023
4. SST&I Initiative Nomination submitted – 3 May 2023
5. C-17 proof of concept flights – 10–15 May 2023
6. AC-130J initial MIAB testing – 22 May 2023
7. AC-130J testing scheduled – June-July 2023

As part of the capstone project handoff, Maj Thomas Repsha will conduct the initial MIAB and AC-130J testing from June to July 2023. This will ensure the continuity of the effort and keep an ongoing interface with stakeholders throughout DOD.

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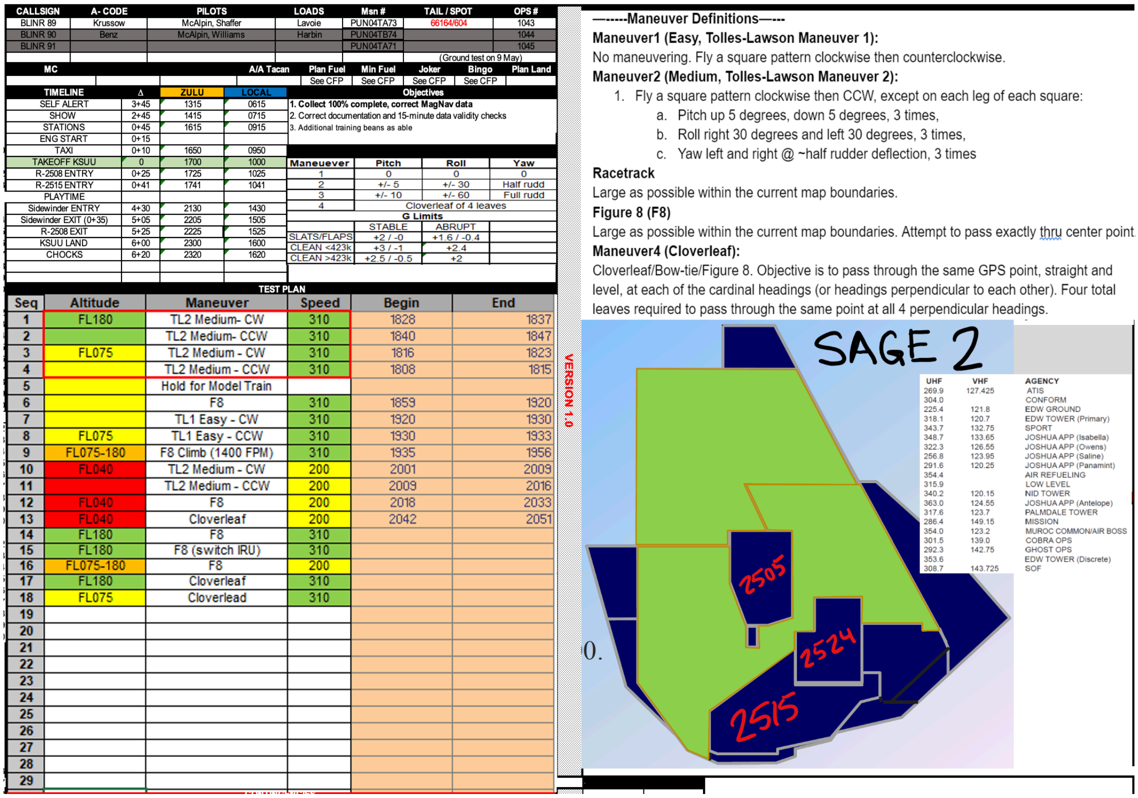
IX. MAGNAV PROOF OF CONCEPT TEST

The capstone MagNav proof of concept test intends to demonstrate MagNav and associated capabilities for eventual AFSOC testing. The capstone team traveled to Travis Air Force Base for the initial MagNav proof of concept capstone test on 10–15 May 2023. On day one, May 10, 2023, the capstone team was introduced to MagNav program leads, received a MIAB component walkthrough, and mission planned for Day two flight profile. The MagNav program leads included AFIT, AFRL, DAF-AIA MIT, and Lincoln Laboratory personnel. Johnathan Taylor from AFIT, who built the MIAB gave a detailed walkthrough that covered MIAB's components. Mr. Taylor also explained the data generated by the MIAB and why that data was needed to determine platform magnetic interference. Lastly, on day one, the MagNav team mission planned the test profile for the following day's flight and ensured the scheduled six-hour sortie contained all the necessary test components required for a successful mission. Kneeboard with trip planned events in Figure 8.



CALLSIGN	A- CODE	PILOTS	LOADS	Msn #	TAIL / SPOT	OPS #
BLINR 89	Krussow	McAlpin, Shaffer	Lavoie	PUN04TA73	66164/604	1043
BLINR 90	Benz	McAlpin, Williams	Harbin	PUN04TB74		1044
BLINR 91				PUN04TA71		1045
					(Ground test on 9 May)	

MC			A/A Tacan	Plan Fuel	Min Fuel	Joker	Bingo	Plan Land
				See CFP	See CFP	See CFP	See CFP	

TIMELINE	Δ	ZULU	LOCAL
SELF ALERT	3+45	1315	0615
SHOW	2+45	1415	0715
STATIONS	0+45	1615	0915
ENG START	0+15		
TAXI	0+10	1650	0950
TAKEOFF KSUU	0	1700	1000
R-2508 ENTRY	0+25	1725	1025
R-2515 ENTRY	0+41	1741	1041
PLAYTIME			
Sidewinder ENTRY	4+30	2130	1430
Sidewinder EXIT (0+35)	5+05	2205	1505
R-2508 EXIT	5+25	2225	1525
KSUU LAND	6+00	2300	1600
CHOCKS	6+20	2320	1620

Objectives

1. Collect 100% complete, correct MagNav data
2. Correct documentation and 15-minute data validity checks
3. Additional training beans as able

Maneuever	Pitch	Roll	Yaw
1	0	0	0
2	+/- 5	+/- 30	Half rudd
3	+/- 10	+/- 60	Full rudd
4	Cloverleaf of 4 leaves		

G Limits	STABLE	ABRUPT	
SLATS/FLAPS	+2 / -0	+1.6 / -0.4	
CLEAN <423k	+3 / -1	+2.4	
CLEAN >423k	+2.5 / -0.5	+2	

TEST PLAN

Seq	Altitude	Maneuver	Speed	Begin	End
1	FL180	TL2 Medium- CW	310	1828	1837
2		TL2 Medium- CCW	310	1840	1847
3	FL075	TL2 Medium - CW	310	1816	1823
4		TL2 Medium - CCW	310	1808	1815
5		Hold for Model Train			
6		F8	310	1859	1920
7		TL1 Easy - CW	310	1920	1930
8	FL075	TL1 Easy - CCW	310	1930	1933
9	FL075-180	F8 Climb (1400 FPM)	310	1935	1956
10	FL040	TL2 Medium - CW	200	2001	2009
11		TL2 Medium - CCW	200	2009	2016
12	FL040	F8	200	2018	2033
13	FL040	Cloverleaf	200	2042	2051
14	FL180	F8	310		
15	FL180	F8 (switch IRU)	310		
16	FL075-180	F8	200		
17	FL180	Cloverleaf	310		
18	FL075	Cloverlead	310		
19					
20					
21					
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24					
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27					
28					
29					

VERSION 1.0

—-----Maneuver Definitions—---

Maneuver1 (Easy, Tolles-Lawson Maneuver 1):

No maneuvering. Fly a square pattern clockwise then counterclockwise.

Maneuver2 (Medium, Tolles-Lawson Maneuver 2):

1. Fly a square pattern clockwise then CCW, except on each leg of each square:
   a. Pitch up 5 degrees, down 5 degrees, 3 times,
   b. Roll right 30 degrees and left 30 degrees, 3 times,
   c. Yaw left and right @ ~half rudder deflection, 3 times

Racetrack

Large as possible within the current map boundaries.

Figure 8 (F8)

Large as possible within the current map boundaries. Attempt to pass exactly thru center point.

Maneuver4 (Cloverleaf):

Cloverleaf/Bow-tie/Figure 8. Objective is to pass through the same GPS point, straight and level, at each of the cardinal headings (or headings perpendicular to each other). Four total leaves required to pass through the same point at all 4 perpendicular headings.

UHF	VHF	AGENCY
269.9	127.425	ATIS
304.0		CONFORM
225.4	121.8	EDW GROUND
318.1	120.7	EDW TOWER (Primary)
343.7	132.75	SPORT
348.7	133.65	JOSHUA APP (Isabella)
322.3	126.55	JOSHUA APP (Owens)
256.8	123.95	JOSHUA APP (Saline)
291.6	120.25	JOSHUA APP (Panamint)
354.4		AIR REFUELING
315.9		LOW LEVEL
340.2	120.15	NID TOWER
363.0	124.55	JOSHUA APP (Antelope)
317.6	123.7	PALMDALE TOWER
286.4	149.15	MISSION
354.0	123.2	MUROC COMMON/AIR BOSS
301.5	139.0	COBRA OPS
292.3	142.75	GHOST OPS
353.6		EDW TOWER (Discrete)
308.7	143.725	SOF

Figure 8. MagNav Data Card

On day two, May 11, 2023, the capstone team arrived at the 21st Airlift Squadron and met with the C-17 aircrew that executed the MagNav sortie. The C-17 aircrew conducted a mission brief that covered the sortie objectives, testing profile, scheduled Tolles-Lawson maneuvers, and the flight restrictions for low-level operations (low-level flight not required for MagNav testing).

a. Sortie objectives included:

1. Collection of 100%complete and correct MagNav data.
2. Correct documentation and 15-minute data validity checks.
3. Additional training events logged for the C-17 aircrew if possible.

b. Testing profile (4 1/2 hours):

(1) Tolles-Lawson Maneuver 1 – Fly straight and level square pattern clockwise, then counterclockwise.

(2) Tolles-Lawson Maneuver 2 – Fly the square pattern clockwise, then counterclockwise, with different flight control inputs on each leg of the square pattern.

a. Pitch up 5 degrees, down 5 degrees 3 times.

b. Roll right 30 degrees and left 30 degrees 3 times

c. Yaw left and right at half rudder deflection 3 times.

(3) Tolles-Lawson Maneuver 3 – Fly the square pattern clockwise, then counterclockwise, with different flight control inputs on each leg of the square pattern.

a. Pitch up 10 degrees, down 10 degrees 3 times.

b. Roll right 60 degrees and left 60 degrees 3 times

c. Yaw left and right at full rudder deflection 3 times.

(4) Tolles-Lawson Maneuver 4 – Fly in a cloverleaf pattern as far as possible within the confines of the restricted maneuver airspace. As each loop is flown, attempt to fly back through the center point of the cloverleaf, shown in Figure 9.

a. Pass through the same GPS center point on each pass at each cardinal heading.

b. Ensure the aircraft is straight and level on each center point pass.

c. Stay within the confines of the restricted maneuvering airspace at all times.

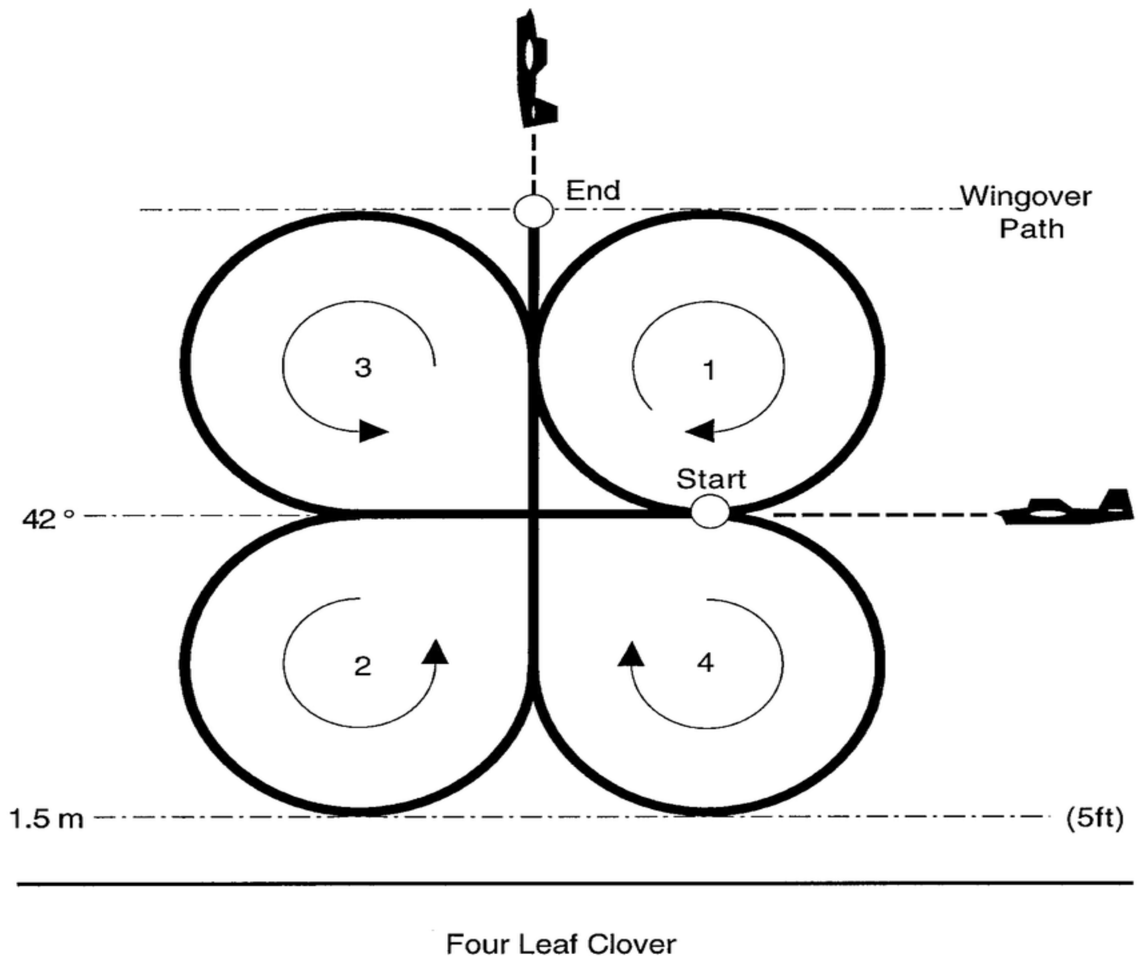

Figure 9. Four Leaf Clover[47]

Following the aircrew mission brief, the capstone team went to the C-17 and observed the set-up of two MIABs. One MIAB was placed at the forward edge of the cargo compartment at the base of the flight deck staircase, shown in Figures 9 and 10. The second MIAB was put just forward of the left paratroop door, shown in Figures 11 and 12.

[47] Source: Erick Camara and Suze Nei P. Guimaraes, "Magnetic Airborne Survey - Geophysical Flight," *Geoscienctific Instrumentation Methods and Data Systems*, June 2016, 181–92, https://doi.org/10.5194/gi-5-181-2016.

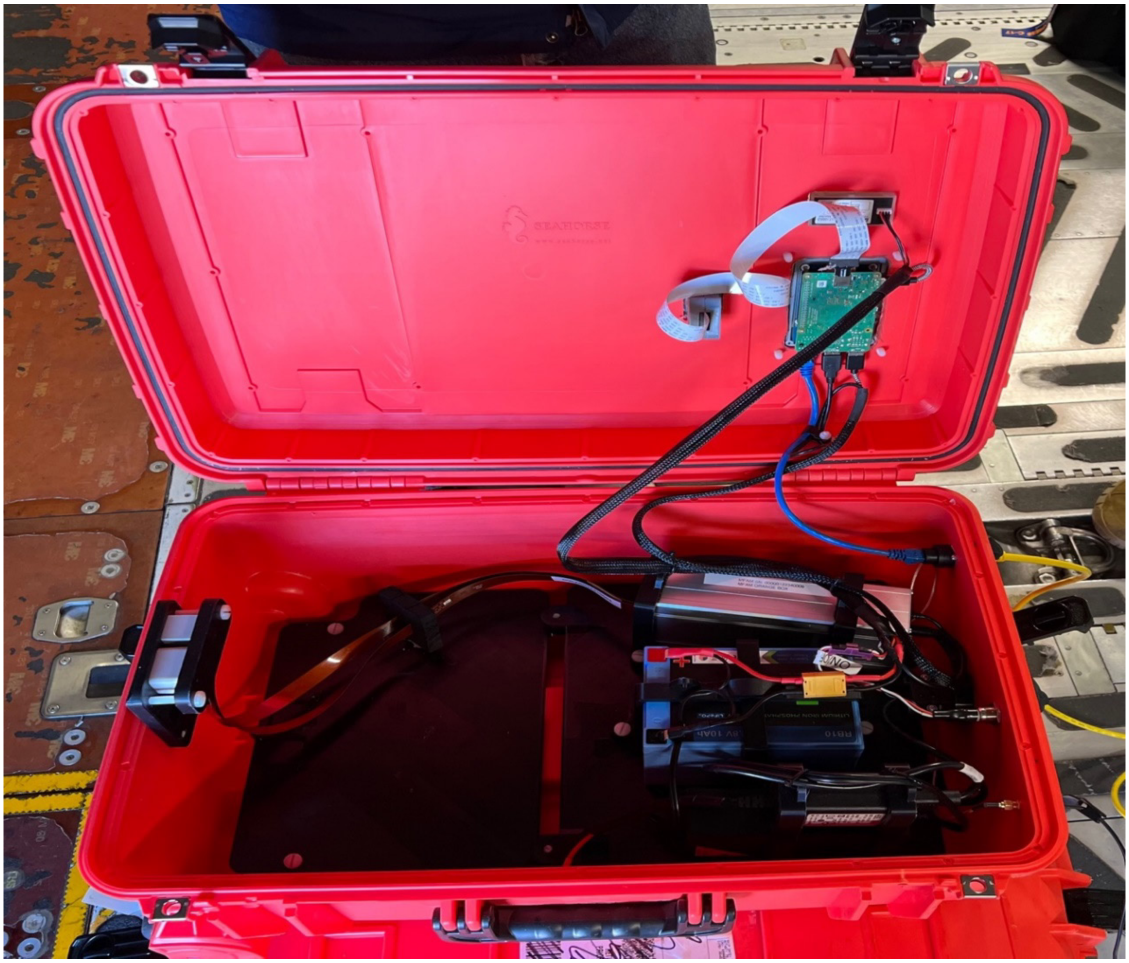

Figure 10. MIAB 1

Figure 11. MIAB 1

Figure 12. MIAB 2

Figure 13. MIAB 2

These two locations were selected by the MagNav team to compare the level of magnetic interference generated by the platform (C-17) during MagNav testing. Once the MIABs were secured in their respective locations, the MagNav team ran several ground tests over the next hour and a half. Upon completing a successful MIAB ground test and confirming that the MIABs were working correctly, the C-17 crew took off for mission completion. The C-17 crew flew the sortie, and all test parameters were flown and completed as planned.

On day three, May 12, 2023, the capstone team arrived at the base operations due to a base-wide exercise. The C-17 aircrew conducted a mission brief that covered the sortie objectives, testing profile, scheduled Tolles-Lawson maneuvers, and the check-ride profile.

a. Sortie objectives included:

1. Collection of 100% complete and correct MagNav data.
2. Correct documentation and 15-minute data validity checks.
3. C-17 aircrew member checkride.
4. Participation in the base exercise "elephant walk."

b. Testing profile (2 1/2 hours):

(1) Tolles-Lawson Maneuver 1 – Fly straight and level square pattern clockwise, then counterclockwise.

(2) Tolles-Lawson Maneuver 2 – Fly the square pattern clockwise, then counterclockwise, with different flight control inputs on each leg of the square pattern.

a. Pitch up 5 degrees, down 5 degrees 3 times.

b. Roll right 30 degrees and left 30 degrees 3 times

c. Yaw left and right at half rudder deflection 3 times.

(3) Tolles-Lawson Maneuver 3 – Fly the square pattern clockwise, then counterclockwise, with different flight control inputs on each leg of the square pattern.

a. Pitch up 10 degrees, down 10 degrees 3 times.

b. Roll right 60 degrees and left 60 degrees 3 times

c. Yaw left and right at full rudder deflection 3 times.

(4) Tolles-Lawson Maneuver 4 – Fly in a cloverleaf pattern as far as possible within the confines of the restricted maneuver airspace. As each loop is flown, attempt to fly back through the center point of the cloverleaf.

a. Pass through the same GPS center point on each pass at each cardinal heading.

b. Ensure the aircraft is straight and level on each center point pass.

c. Stay within the confines of the restricted maneuvering airspace at all times.

These two locations were selected by the MagNav team to compare the level of magnetic interference generated by the platform (C-17) during MagNav testing. Once the MIABs were secured in their respective locations, the MagNav team ran several ground tests over the next hour and a half. Upon completing a successful MIAB ground test and confirming that the MIABs were working correctly, the C-17crewtook took off for mission completion. The C-17 crew flew the sortie, and all test parameters were flown and completed as planned.

The C-17 sortie on 11 May 2023 was the first time MIAB used new software to report navigational accuracy simultaneously. Past iterations of MagNav captured data during a test flight, then post-flight, all the data would get analyzed to determine the accuracy that MagNav recorded. Simultaneous accuracy reporting is a crucial step in utilizing MagNav for real-time navigation by aircrew members. AFSOC can utilize this proof-of-concept test and parameters with very few adjustments. Updated Eglin range magnetic charts must be obtained for cross reference of MagNav accuracy. This is the only change that AFSOC needs to accomplish before flights can start on the AC-130J.

X. CONCLUSION

In conclusion, the overreliance on GPS-based navigation can become a significant problem for the U.S., especially in strategic competition. Because of this, Alt-PNT is becoming increasingly necessary. Improvised metal detectors became a solution for the U.S. military dealing with IED issues in Iraq and Afghanistan. Likewise, innovative solutions like MagNav will play a crucial role in solving the Alt-PNT dilemma. As competition continues, it is vital that the U.S. innovates and further protects its assets by adding additional navigational means. MagNav is likely the successful solution the U.S. needs to face the emerging threats caused by the denial of GPS.

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APPENDIX

A. TRIP LOG MERLIN LABS FLIGHT DEMO

WHO: Bill, Daniel, Aaron

WHAT: Merlin Labs flight demo

WHEN: 12 May -13 May 22

WHERE: Palmdale, CA

a. Topics

1. Artificial Intelligence used for automated flight
2. AFSOC aircraft use cases
3. Demonstration of Twin Otter using Merlin pilot to takeoff, navigate, and land.

b. Due Out

1. Research other aircraft that could potentially benefit from the Merlin pilot.
2. How else could AI be used in the AFSOC fleet

B. TRIP LOG AFSOC HQ VISIT

WHO: Bill, Daniel, Aaron

WHAT: AFSOC HQ visit

WHEN: 20 Jul – 23 Jul 22

WHERE: Hurlburt Field, FL

a. Topics

1. Meet with AFSOC A5/8 on current and future projects
2. AC-130J static display

b. Due Out

1. Follow up with AFSOC HQ on the project

C. TRIP LOG ANDURIL VISIT

WHO: Bill, Daniel, Aaron, and NPS students

WHAT: ANDURIL site visit

WHEN: 29 Aug – 31 Aug 22

WHERE: ANDURIL HQ, Irvine, CA

a. Topics

1. Lattice AI software
2. AFSOC use cases
3. Sensor diffusion/ Computer vision

b. Due Out

1. Follow up with Matt Bebb (Air Force rep)
2. Look at potential uses for Anduril equipment on AFSOC aircraft.

D. TRIP LOG QAULCOMM HQ VISIT

WHO: Bill, Daniel, Aaron

WHAT: Qualcomm HQ visit

WHEN: 26 Oct – 28 Oct 22

WHERE: San Diego, CA

a. Topics

1. 5G possibilities for the DOD
2. Computing at the edge

b. Due Out

1. Possible future war game with Qualcomm engineers.
2. Looking into a 5G network for all player's comms in the operating area.

E. TRIP LOG MIT

WHO: Bill, Daniel, Aaron

WHAT: DAF/AIA

WHEN: 1 Mar – 3 Mar 23

WHERE: MIT campus, Boston, MA

a. Topics

1. AI for the DOD
2. Air Force future with MIT
3. MagNav

b. Due Out

1. Follow up with the team for MagNav use on AFSOC aircraft.

F. TRIP LOG TRAVIS AIR FORCE BASE

WHO: Bill, Daniel, Aaron

WHAT: DAF/AIA

WHEN: 10 May –15 May 23

WHERE: Travis Air Force Base

a. Topics

1. MagNav
2. C-17 Globemaster III flight test of MIAB

b. Due Out

1. Follow up with the team for MagNav data

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