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AIR FORCE INSTITUTE OF TECHNOLOGY GRADUATE SCHOOL OF ENGINEERING & MANAGEMENT

AFIT ENGINEER

The Graduate School of the U.S. Air Force

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Overcoming a Strategic Weakness

AFIT ANT Center Lowers Military Dependence on GPS

By Dr. Clark Taylor
ANT Center Director
Air Force Institute of Technology

Since becoming operational in the early 90s, the Global Positioning System (GPS) has helped enable several important military and civilian technologies, including autonomous vehicles, precise munitions, enhanced collaboration between military units, distributed, precise time synchronization, and many more. Not only does GPS enable all these applications, but the cost required to purchase a GPS receiver is extremely low (as evidenced by their inclusion in cell phones and many other consumer devices.) Therefore, GPS has been a critical enabler of many different applications, from cell phones, to civilian flight, to military missions.

Unfortunately, while GPS is immensely successful in providing position and timing information worldwide, like all radio frequency (RF) signals, GPS signals can be jammed (to prevent GPS from being used) or spoofed (to fool someone into using false signals.) Non-military examples include the truck driver who didn't want their company to track them, so they bought a small GPS jammer. Or, fans of the Pokemon Go game that started to spoof locations so they could get points in the game, without actually visiting the locations required.

While these examples may sound innocent, the effects of jamming and spoofing can be very costly. For example, the truck driver with a jammer unfortunately drove near the end of the Newark runway, causing disruptions to air traffic. In a military scenario, GPS jamming or spoofing can have even more significant consequences.

The Autonomy and Navigation Technology (ANT) Center at AFIT has spent over a decade researching and implementing techniques to help alleviate this strategic weakness. The ANT Center has three main research thrusts: (1) autonomy and cooperative systems, (2) non-global navigation satellite systems (GNSS) (GPS plus other countries navigation systems) navigation, and (3) improved GNSS navigation.

Starting with the third thrust, we are continually developing, testing, and advancing techniques to ensure that GPS can be available and trusted, even in environments where adversaries may be trying to deny, degrade, or spoof the GPS signals. The second thrust looks at how we can obtain positioning and timing when GPS is not available. This can be done using ranging radios on the ground, using cameras on-board aircraft to localize where the aircraft is, or utilizing the Earth's magnetic anomaly field to self-localize a moving object. (While there are many other techniques, both previously explored and yet to be investigated, we have limited space in this newsletter.) The first thrust, enabling autonomy, with or without GPS, is key for maintaining the U.S. competitive edge over our adversaries. One example discussed in this newsletter is enabling autonomous air-to-air refueling, even when GPS is denied.

With the high-quality students that come through AFIT, generous funding from our sponsors, and the great work of contractors and faculty in the ANT Center, we have been able to make significant strides towards lowering our overall dependence on GPS without interference. As you will see in this newsletter, we have several success stories, and there is a lot of great work still to come.

PAGES 18-25

FEATURED ANT CENTER RESEARCH

Autonomous Aircraft Flight Tests
Small Unmanned Aerial Systems
MagNav Research Collaboration
Autonomous Aerial Refueling

INSIDE THIS ISSUE

Find past issues online at:
www.AFIT.edu/EN/afitengineer

Dean Welcomes Future of New Collaborations

This is my swan song, which metaphorically conveys my last Dean's Message before my retirement. The legend has it that swans, which are mute, sing beautifully before they die. Since retirement does not equate to dying, we will focus on the metaphor of transitioning from one phase to another phase in the journey of a person's work life. Thus, this message provides me an opportunity to have some parting thoughts (not shots) in the life cycle of this newsletter, the vaunted and flaunted AFIT Engineer newsletter. What started as a simple and casual communication tool in 2018 has now become a polished quarterly publication to link AFIT's Graduate School of Engineering and Management to its internal and external constituents, shareholders, and supporters. The high repute that this quarterly newsletter enjoys now is due to the impeccable work of Ms. Stacy Burns, the editor and curator of this campuswide asset. For this, we all thank her.

As in previous issues, this December 2023 issue contains topics on AFIT's core education mission of teaching and research. Please flip the pages (digitally or physically) to see why AFIT is a special and unique place for defense-focused education. AFIT must be retained, preserved, sustained, and nurtured within the context of what the nation needs to continue to be at the forefront of national-defense goals. As defense goes, so does the entire nation. What we invest in national defense through educational programs is the ingredient for the supremacy of the nation among allies and foes.

Even as I am saying goodbye now, I am also saying welcome to a new dimension of collaboration with faculty, staff, and students. Please keep the fight for AFIT so that the institution may continue to thrive.

With our teamwork spirit beside me, I say Adieu to all.

Adedeji B. Badiru, Ph.D., PE
Dean, Graduate School of Engineering and Management

U.S. Air Force photo by Katie Scott

Dr. Badiru poses with the Bent of Tau Beta Pi, the oldest engineering honor society, in 2021. The statue was dedicated to the Graduate School in recognition of outstanding contributions to education in science and engineering by the Ohio ETA Chapter established in February 1959.

READ MORE ON PAGES 16-17

Read about Dr. Badiru's many accomplishments during his time as Dean of the Graduate School of Engineering and Management.

TEACHING WHAT WE RESEARCH. RESEARCHING WHAT WE TEACH.

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Record Number of Doctoral Degrees Granted to Female Students at Fall Commencement

The Air Force Institute of Technology's Graduate School of Engineering and Management held the 2023 fall commencement ceremony Sept. 14 at the Dayton Masonic Center to celebrate 77 new graduates. The Graduate School conferred 54 master's degrees and 23 doctorate degrees in science, technology, engineering and math fields. Additionally, three master's students and two doctoral alumni who graduated earlier in the academic year returned to participate in the ceremony.

The graduating class included 65 Air and Space Force officers and 11 civilians. One international student from Saudi Arabia received a master's degree. Of particular note, were the seven females in the class who earned doctoral degrees – the most in one quarter at AFIT.

The keynote speaker was Lt. Gen. Donna Shipton, military deputy, Office of the Assistant Secretary of the Air Force for Acquisition, Technology, and Logistics. She is responsible for research and development, test, production, product support and modernization of Air Force programs worth more than $60 billion annually. Shipton is an AFIT alum having earned a Master of Space Systems degree in 2005.

"I know a little bit about what you, the graduates, have experienced to get here tonight," Shipton said. "You should be extremely proud of your accomplishments."

U.S. Air Force photo by Richard Oriez

The Air Force Institute of Technology's Graduate School of Engineering and Management conferred seven doctorate degrees to females during the September 2023 graduation ceremony. This marks the highest number of females to earn doctorate degrees in one quarter at AFIT.

Following her graduation from AFIT, Shipton's follow-on assignment was as a program manager for a classified, cutting edge, counterspace technology demonstrator at Los Angeles Air Force Base. "It was the education that I gained at AFIT that prepared me for the challenges that I encountered on that program," Shipton said. "For more than 100 years, it's been the legacy of this fine Institution to take some of the greatest minds of our Department, and steep them in the latest research and learning so they can extend that excellence into our Force."

Shipton emphasized to the graduates that the Department of Defense now confronts its most technologically capable and well-resourced foreign competitors in history. "In this time of strategic competition, we need leaders at all levels who have a deep expertise in emerging technologies and their application to military operations," Shipton said. "As you move on to your next assignments, you will play a major role in carrying out the Secretary of the Air Force's imperatives as you implement the potential of our technology and our ideas."

LIST OF GRADUATES ONLINE:

The list of Sept 2023 graduates can be found at: https://e.AFIT.edu/HtDT5

U.S. Air Force photo by Richard Oriez

Lt. Gen. Donna Shipton, military deputy, Office of the Assistant Secretary of the Air Force for Acquisition, Technology, and Logistics served as the commencement guest speaker.

U.S. Air Force photo by Katie Scott

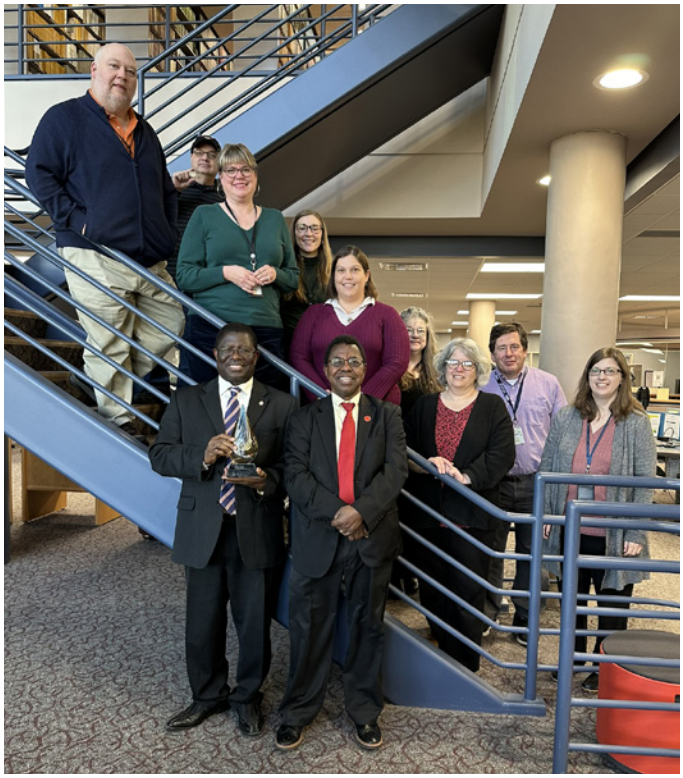
AFIT's graduating class in September 2023 was comprised of 54 master's degree and 23 doctorate degree graduates.

D'Azzo Library Recognized at Library of Congress

The Federal Library and Information Network (FEDLINK) selected the D'Azzo Research Library for the 2019 Federal Library/ Information Centers of the Year award in the large library/information center category. The award recognizes the many innovative ways that federal libraries fulfill the information demands of the government, business, and scholarly communities.

The D'Azzo Research Library, a joint effort between the Air Force Institute of Technology's Academic Library and the Air Force Research Laboratory's (AFRL) Technical Library, was honored for increasing information access and outreach to AFIT students and faculty, AFRL engineers and scientists, and the global research community.

Federal libraries and staff throughout the United States and abroad compete for the awards every year, and FEDLINK hosts the annual award winners at a recognition ceremony in Washington, D.C. Unfortunately, this event had been postponed over the last few years, so, in an effort to honor the winners from 2019-2022 in person, a special ceremony was held this year at the Library of Congress.



Contributed photos

Front row left to right: Dr. Ellis Beteck, AFIT Library Director and Dr. Adedeji Badiru, Graduate School Dean.

Library staff left to right: Wheeler Hall, reference librarian; Charles Clausen, serials technician; Renate Lester, research librarian; Lauren Erdmann-Rued, circulation technician; April Cottrell, technical services librarian; Kathleen Siry, chief of technical services; Amy High, chief of reader services; Richard Mansfield, electronic resources librarian; Sara Craycraft, research librarian.

In July 2023, Ms. Annette Sheppard, AFRL Library Director and Dr. Ellis Beteck, AFIT Library Director travelled to Washington, D.C. to participate in FEDLINK's recognition award ceremony. Dr. Carla Hayden, 14th Librarian of Congress, was on hand to present remarks at the ceremony.

"The library is extremely honored to receive this important award—The 2019 Large Library Information Center of the Year. We are immensely grateful to be recognized by FEDLINK for the hard work, innovation and creativity of the D'Azzo Research Library. To this end, it is an honor to receive recognition for our work, and the biggest appreciation goes to the entire D'Azzo Research Library team whose efforts helped the library to achieve this significant milestone. We are thrilled and grateful to receive this prestigious award," Beteck said.

The D'Azzo Research Library was recognized for achievements in 2019 which included: collaborating to purchase more than 23 databases and journal collections, saving more than $382,000; staff of 13 responding to 5,612 reference requests and teaching 36 academic research classes to 532 participants while completing a library space reconfiguration that increased visits by eight percent. Also in fiscal year 2019, the library launched its institutional repository, AFIT Scholar, a single, central, searchable database and delivered 36,850 thesis and dissertation downloads to 2,486 institutions in 166 countries.

"We are striving to meet the needs of the faculty, students and researchers and we continue to provide information resources and create the opportunity to develop user-defined, open spaces – places where users can collaborate and work together," Beteck said.

"We believe the faculty, students and researchers will find the progress that we have made to define the role of the library in the 21st century research library within the Air Force Institute of Technology and the Air Force Research Laboratory invaluable. In addition and perhaps more remarkable, we are committed to constantly monitor and assess existing progress and anticipate future pathways to the demonstration and growth of the library collections and learning spaces," Beteck concluded.

> "We are striving to meet the needs of the faculty, students and researchers and we continue to provide information resources and create the opportunity to develop user-defined, open spaces—places where users can collaborate and work together."
>
> — Dr. Ellis Beteck, AFIT Library Director

Dr. Adedeji Badiru, left, congratulates Dr. Ellis Beteck on the 2019 FEDLINK Library of the Year award.

D'Azzo Research Library Achievements Since FEDLINK Award in 2019

>>2020

- During the COVID pandemic, the library provided curbside service for students and faculty needing actual books until the library reopened in October 2020.
- Two library staff members were recognized in 2020. Mr. Rich Mansfield, Electronic Resources Librarian, earned the SOCHE Staff Excellence Award in February 2020 for his work on AFIT Scholar (AFIT Institutional Repository), which collects, preserves and disseminates AFIT theses, dissertations, faculty publications and other intellectual output. Ms. Ruth Randall, Interlibrary Loan Technician, was honored with the AFIT Third Quarter Civilian Category 1 Award for her work with the curbside book delivery program.
- With funding from AFIT and AFRL administrations, the architectural firm, Luckett & Farley, were contracted to do a conceptual study to renovate the D'Azzo Research Library. The project was coordinated through the Wright-Patterson AFB Civil Engineering office. The architects spent time with both the AFIT and AFRL library staff. Meetings continued online after the library facility closed, and the final draft of their plan was approved in September 2020.

>>2021

- The library team assisted students and faculty and taught online classes via Microsoft Teams.
- 1,354 items were added to AFIT Scholar and the collection size grew to 5,798 compared to 4,444 in AY20.

>>2022

- The librarians scripted and produced short, online instructional videos to help students and staff understand how to locate and use many library resources. The videos are highlighted on the library's homepage at https://afit.libguides.com/tutorials, and hosted on AFIT's YouTube channel.
- Initiated project to inventory all of the classified theses and dissertations (consolidated all theses and dissertations into a smaller storage area, sorted them by missing documentation, and developed a plan to dispose of extra copies).

>>2023

- AFIT and AFRL updated their Memorandum of Agreement (MOA) to include an even more extensive listing of shared electronic resources.
- Library visitors exceeded pre-COVID numbers jumping from 53,534 to 82,593 in 2023.

AY23 AFIT Scholar Highlights

AFIT Scholar AY23 Statistics

- 235,000 downloads from 8,123 institutions and visitors from 207 countries
- Over 6,000 theses and dissertations from AFIT graduates (from 1996 to 2022)
- Over 1,000 faculty publications
- New collection areas on the repository were built to feature ANT, AFCEC, and climate resiliency research

Special Community Areas	Downloads During AY23	Associated Works
ANT Center	12522	431
AFCEC-sponsored research	3961	50
AF CSE Case Studies (2003-2012)	4553	13
Climate Resiliency [topic]	1021	22

AFIT Scholar Increasing Impact

- Collection readership in AY18 was 9,453 and in AY23, it was 235,634 – an increase of 226,181 or 2,393%.
- Collection size in AY18 was 1,614 and in AY23 it was 7,440; 5,826 or 361% increase.

AFIT Scholar AY23 Usage Map

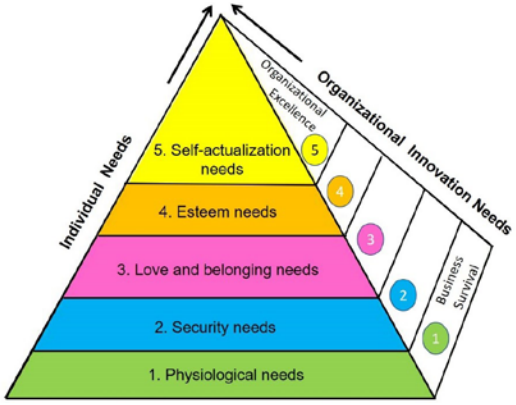
Map data ©2023 Google, INEGI

10,000+ views | 1,000-9,999 views | 100-999 views | 0-99 views

AFIT Graduate School Dean Delivers Presentation at NATO STO Conference

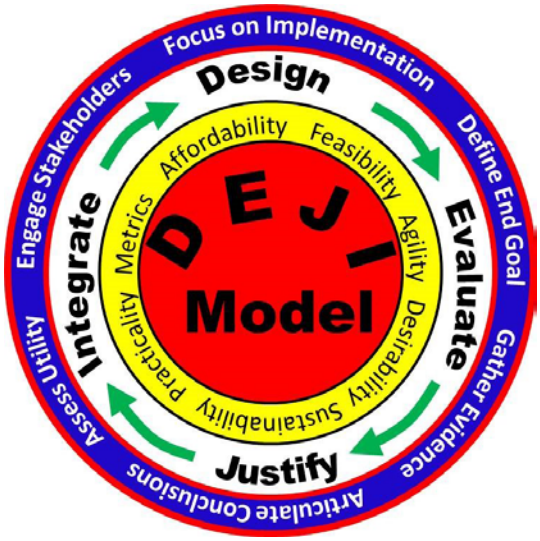
Dr. Adedeji Badiru, AFIT Graduate School of Engineering and Management Dean and Professor of Systems Engineering, recently presented his work titled "Analytic Integration Model for Systems Optimization" at the NATO Science and Technology Organization (STO) Operations Research and Analysis Conference at the Johns Hopkins University Applied Physics Laboratory in Laurel, Maryland. Badiru is the developer of the trademarked DEJI (Design, Evaluation, Justification, and Integration) Systems Model and is an expert in the areas of mathematical modeling, project modeling and analysis, economic analysis, systems engineering models, and efficiency/productivity analysis and improvement.

The premise of Badiru's presentation was that the mathematical rigor in modeling and analysis should be tempered by human-factor considerations. Of particular interest in this regard is the application of Maslow's Hierarchy of Human Needs in decisions involving multi-national interests. Ultimately, humans will be in the loop of implementing decisions that are arrived at via complex mathematical modeling. It behooves the analysts and decision makers to incorporate human factors and the diverse needs of humans, from various perspectives, into the mathematical modeling process upfront. Badiru used the 3-D rendition of Maslow's Hierarchy of Needs (shown below) to rationalize National Needs versus Individual Needs. Integration is the key in most decision-implementation scenarios. A decision that cannot be "integratively" implemented into the local context is bound to fail.



During his conference presentation, Badiru proposed that the DEJI Systems Model could be effectively applied by NATO. The model was originally developed for product development purposes, but has been successfully applied in business, industry, academia, and government scenarios.

"Operations work best when approached from a systems perspective. This is particularly essential when an optimization framework is desired across national and geographical boundaries. In this regard, a system is a collection of interrelated elements whose collective output, together and in unison, is higher than the mere sum of the individual outputs," Badiru said. "For a systems approach to be practical, profitable, realizable, and optimizable, partnerships and collaborative frameworks must be instituted, subject to real-world constraints. Rhetoric and aspirations alone cannot achieve international goals," he further explained. The DEJI Systems Model is engendered in the graphical representation below. The concentric circles in the image convey the looping nature of elements in systems.



Badiru referenced the DEJI Systems Model as the basis for an analytic integration formulation suitable for quantitative systems optimization. "Design, in the context of NATO programs, generically covers several objectives, including planning, conceptualization, organizing, brainstorming, negotiation, and so on. The systems approach of Design leads to a structured requirement to conduct a formal Evaluation, followed by a rigorous Justification, followed by, above all, Integration," Badiru said.

"Programs often fail due to a lack of sustainable integration of efforts. The DEJI Systems Model forces a structured and rewarding approach to what could, otherwise, become disjointed efforts," Badiru offered.

2023 BY THE NUMBERS

GRADUATE SCHOOL OF ENGINEERING & MANAGEMENT

999

Total students enrolled Fall 2023

Cyber Defense in Space Systems Research

By Capt. Courtney Fleming
MS Student, Department of Electrical and Computer Engineering
Air Force Institute of Technology

The Department of Defense (DoD) heavily relies on satellites for operations ranging from navigation and communication to intelligence. It has become increasingly evident that adversaries possess both the capability and intention to target space systems via cyberattacks. A concerning observation is that, unlike their terrestrial counterparts, many space systems are not adequately fortified with cybersecurity defenses. Historically, there has been an underlying assumption that the vastness of space and isolated networks naturally provided security, which is proving to be a flawed perspective.

One potential solution to the cybersecurity challenges is to implement a space-based intrusion detection system. These systems play a pivotal role in the realm of cybersecurity, as they can either identify known attack signatures or detect anomalous network/host behavior indicative of potential breaches. However, the unique environment of space presents its own set of challenges.

Modern terrestrial intrusion detection often integrates machine learning, a mechanism that learns from recorded threats to anticipate and mitigate future ones. For space systems, a significant challenge arises due to the limited dataset of known cyberattacks, which restricts the effectiveness of such machine-learning applications.

However, ongoing AFIT research has sought to address this. Researchers are utilizing the NASA Operational Simulator for Small Satellites (NOS3) to develop a methodology for gathering data on satellite behavior during cyberattacks.

The attacks, simulated through ground-based shell scripts inspired by the SPARTA framework (https://sparta.aerospace.org/), either induce a denial-of-service attack or directly targeted satellite hardware. Metrics including CPU utilization, memory consumption, and abrupt system changes are closely observed and analyzed during experimentation.

Integrating new advanced intrusion detection system may significantly enhance space systems' security, ensuring the DoD's satellite operations remain robust against evolving cyber threats. Continued research and collaboration between partner institutions is vital to addressing the unique challenges presented by space-based operations.

240
Faculty members
Fall 2023

601
Degrees awarded
AY 2022-2023

6
Faculty patents
FY 2023

AFIT Supports International Exchange Programs, Welcomes APEP German Exchange Visitors

The Air Force Institute of Technology (AFIT) supports the National Security Strategy through engagement with our foreign partners through exchange programs. Each year AFIT hosts as many as ten persons from our international partners through the military personnel exchange program (MPEP), engineering and science exchange program (ESEP), and the administrative personnel exchange program (APEP). Countries that historically participate in these programs include Germany, South Korea, Israel, and Brazil.

As AFIT professors and research professionals create relationships, the exchange programs are an option available to build on these collaborations. AFIT encourages the opportunity to discuss on-going research and projects that transcend interests with our foreign partners, as well as build long-term relationships that are essential for promoting stability to our common goals. The exchange programs are based on agreements the U.S. government has with many of our allies. At the country level, our partner nations should contact the security cooperation office at the local embassy to present a request to enroll into the respective exchange programs. At AFIT, personnel should contact the foreign disclosure officer [FDO] (Mr. Rich Sheldon, Mr. Brian Fitch, Ms. Cassey Baumann) or the international military student-liaison officer [IMSO] (Mr. Mike Paprocki). AFIT works closely with agencies that manage these programs for the Air Force (SAF/IA, AETC/IAD, AFLR/SPI, etc.)

The exchange programs are normally one year 'internships' at AFIT. However, the MPEP is an agreement for a one-to-one officer exchange for up to three years. The current MPEP at AFIT is Lt. Col. Daniel Pamplona from Brazil, who serves as a professor in the Operations Research department within the Graduate School of Engineering and Management. The ESEP and APEP positions are one-off one-year assignments to AFIT. These exchange personnel are assigned specific research projects that serve as their assigned duty for that one-year period. A typical ESEP candidate would a post-master's level person conducting research at that respective level.

AFIT recently welcomed two APEP German exchange visitors to the Graduate School of Engineering and Management. Ms. Martina Kirchenbauer and Ms. Sarah Reinecke arrived in September 2023 for their one-year professional exchange in the U.S. APEP provides career broadening work assignments for foreign government defense personnel in U.S. defense establishments. Thus, it serves to strengthen national military and administrative capabilities, to develop and consolidate common standards, and to produce interoperable, competitive solutions for the mission-oriented equipment of the armed forces.

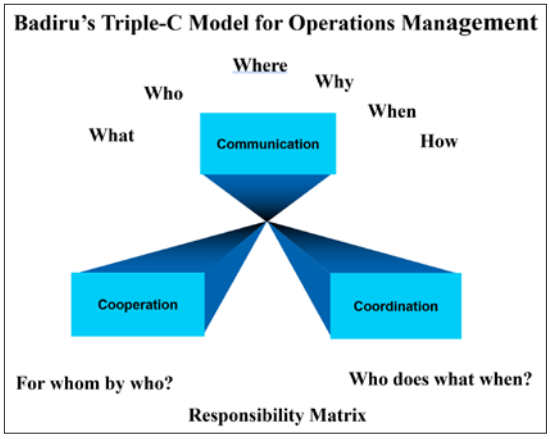
In Germany, Ms. Kirchenbauer serves as a military lawyer and assistant branch chief for the Federal Ministry of Defense and Ms. Reinecke works as a military economist Federal Office of Bundeswehr Equipment, Information Technology and In-Service Support. During their time at AFIT, they will be working on topics germane to their respective administrative roles in their home institutions. Specifically, the topics are on legal and economic aspects of operations related to German national defense

Left to right: Ms. Martina Kirchenbauer, Dr. Adedeji Badiru, and Ms. Sarah Reinecke.

Contributed photo

vis-à-vis the USA system. The topics they work on will be facilitated by Dr. Adedeji Badiru, Graduate School of Engineering and Management Dean.

"The APEP program is essential for operational coordination among allies on the international platform of respective national defense pursuits," Dr. Badiru said. Having previously supervised another German APEP visitor, (Mr. Andreas Mertens) at AFIT, Badiru is enthused about the exchange visit of Ms. Kirchenbauer and Ms. Reinecke. A great asset of the APEP program is that it opens a sustainable avenue of communication, cooperation, and coordination among allied countries. This directly aligns with Badiru's own Triple C, which is encapsulated in the graphical sketch below.



The best way for AFIT leadership and faculty to facilitate one-year exchange positions is to identify specific research projects sponsors are willing to support. In addition, if an ongoing relationship with a foreign partner currently exists and an AFIT faculty member would like to pursue an exchange option, they may share these opportunities with their foreign counterpart. Encourage foreign partners to ask their country to contact the U.S. embassy and let the local AFIT POC know the details of the request.

GSEM Distinguished Professor Award Winners

The Graduate School of Engineering and Management is proud to announce the 2023 Distinguished Professor Award winners.

Dr. Marina Ruggles-Wrenn

Professor of Aerospace Engineering
Department of Aeronautics and Astronautics

Dr. Marina Ruggles-Wrenn has excelled in all aspects as a faculty member in the Department of Aeronautics and Astronautics for more than 20 years. Before coming to AFIT, Ruggles-Wrenn had spent 15 years at Oak Ridge National Laboratory as a research engineer in their Metals and Ceramics Division.

Dr. Badiru presents the Distinguished Professor Award to Dr. Marina Ruggles-Wrenn.

Ruggles-Wrenn has authored nearly 250 presentations and publications and authored or co-authored 12 books and is the sole author of four book chapters. She has served as research advisor to 71 MS graduates and eight PhD graduates. As of summer 2023, Scopus described her work as having 2,081 citations of 115 documents, and denoted her h-index as 26. It is a noteworthy achievement that 62 of the peer-reviewed journal articles produced by Ruggles-Wrenn have been co-authored by one or more of her AFIT students. She not only sets an example for junior faculty but also develops research and writing skills for her student researchers who accept leadership roles within the U.S. Air Force and U.S. Space Force after they graduate from AFIT.

Outstanding teaching performance:
- 2019 Dean's Distinguished Teaching Professor Award
- 2008 ASA Instructor of the Quarter, AFIT Student Association
- 2007 Col Gage H. Crocker Outstanding Professor Award

Outstanding service to the institute and the profession:
- Served as Doctoral Committee Chair of ENY for over 10 years
- Served as Chair of the Graduate Materials Science (GMS) program for over 10 years
- Won the 2016 ASME Dedicated Service Award
- Won the 2016 ASME Board of Governors Award
- Won the 2003 ASME Pressure Vessel and Piping Division Distinguished Service Award

National or international honors and recognitions bestowed at the highest levels of major professional societies:
- Named Fellow of the International Association for Advanced Materials in 2022
- Named Fellow of the American Society of Mechanical Engineers in 2003
- Gave the 2019 Plenary Lecture at the 10th International Conference on High Temperature Ceramic Matrix Composites HT-CMC10
- Won the 2014 Stinson Trophy, the National Aeronautic Association
- Won the 2012 Best Paper Award – ASME International Gas Turbine Institute 2012 Turbo Expo Technical Conference

Dr. Michael Havrilla

Professor of Electrical Engineering
Department of Electrical and Computer Engineering

Dr. Michael Havrilla has been named an AFIT Distinguished Professor for his consistently strong performance within the Graduate School of Engineering and Management as well as his outstanding and sustained accomplishments within his field.

U.S. Air Force photos by R.J. Oriez

Dr. Havrilla accepts the Distinguished Professor Award from Dr. Badiru.

Havrilla has won numerous Department of the Air Force (DAF) awards recognizing his contributions. He is an Antenna Measurement Techniques Association (AMTA) Fellow, recognizing his high levels of impact in electrical engineering, with a special focus on electromagnetics and low observables. Havrilla publishes consistently in high-profile conference and journal venues. In 2022 alone, he published eight conference articles, had one journal article accepted, and was an invited speaker at an additional two conferences. Havrilla continues to bring in steady funding, which reflects how highly regarded he is at the Air Force Research Laboratory (AFRL) and beyond.

Outstanding teaching performance:
Havrilla has taught numerous electromagnetics and low observables courses during his time at AFIT and these courses have been consistently well-received by students. He is a strong mentor to junior faculty and students, and never turns down the chance to collaborate on an effort or give his advice when difficult problems arise. He also gives regular tutorial sessions at conferences he attends to pass his knowledge on to the next generation of scholars.

Outstanding service to the institute and the profession:
Havrilla has held sustained and/or highly significant leadership roles at the university, regional, and/or national levels. He is member of the AMTA Board of Directors and has been a consultant for AFRL's Materials and Manufacturing and Sensors Directorates on a consistent basis since 2002. Havrilla is a frequent reviewer for numerous conferences and journals. Within AFIT, he was a member of the Graduate School's Academic Standards Committee for 12 years. He has also been the longstanding chair of the MS Electrical Engineering Electromagnetics sequence and curriculum.

National or international honors and recognitions bestowed at the highest levels of major professional societies:
Havrilla has made several contributions to various activities within the International Union of Radio Science (URSI), such as conference presentations, convening sessions and serving as chairperson, and active participation in business meetings.

Havrilla's work on electromagnetics and antenna applications spans several topics during the past two decades. He has made significant contributions on various fields in electrical engineering, from leaky-wave antennas, waveguide analysis, antenna arrays, non-destructive material parameter determination, SAR imagery, and scattering by low-observable objects.

Wetland Display to Transfer to Boonshoft Museum

According to the Ohio Environmental Protection Agency, 90 percent of Ohio's wetland resources have been destroyed or degraded since the late 18th century, through draining, filling or other modifications. Because of the valuable functions the remaining wetlands perform, many believe it is imperative to ensure that all impacts to wetlands are properly mitigated. Wetlands have been called "nature's kidneys" because of their ability to filter impurities from water. In essence, wetlands are nature's way of cleaning up many contaminants in the environment.

In 2010, an Air Force Institute of Technology and Wright State University research collaboration took place at an experimental wetland research site at Wright-Patterson Air Force Base. The AFIT portion of the joint project was led by retired AFIT Department of Systems Engineering and Management Professor, Dr. Michael Shelley. The research produced important findings which resulted in several published journal articles, and numerous conference presentations based on thesis research by 15-20 AFIT and WSU students, according to Dr. Abinash Agrawal, Professor of Earth and Environmental Sciences at Wright State University.

Collaborating scientists from both institutions demonstrated how wetlands can clean up the environment by removing toxic compounds from the groundwater and soil. Researchers found that microbes were destroying toxic chlorinated, organic compounds in the selected research site. "Chlorinated organic compounds are widespread groundwater contaminants that cause most of the groundwater pollution in this country. This contamination affects drinking water quality at hundreds of thousands of sites in the United States," said Agrawal. "Since the cost of cleaning up these sites by existing techniques range in tens of billions of dollars, a passive treatment approach by natural processes using the wetland is a cost-effective approach for groundwater remediation and site cleanup."

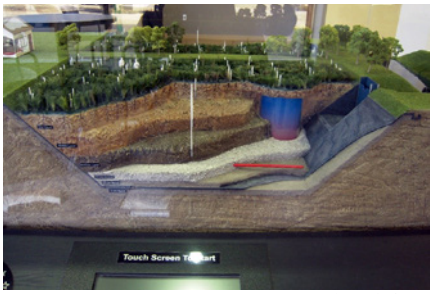
"The microbes are an integral part of the environmental system, which must be managed from a project systems perspective. Over time the systems-based project would save billions of dollars for industry, business, and the government. Sustainability is not just for the environment. Pursuits of green building, green engineering, clean water, climate research, energy conservation, eco-manufacturing, clean product design, lean production, and so on remind us of the foundational importance of sustainability in all we do," said Dr. Adedeji Badiru, AFIT Graduate School of Engineering and Management Dean.

In the mid-2000's, the then Commander of WPAFB mandated that the onsite wetland be demolished as it created an unsightly scene next to critical mission buildings on the Base, and it was creating a presence of natural wetland animals, which might cause an impediment to Base operations. The removal decision was justified, but Shelley, curator of the wetland, was distraught about the destruction of his open-land research laboratory, which he had spent years constructing and maintaining.

Contributed photo

Left to right: Ms. Arras Widorn (Audubon Society), Dean Adedeji Badiru (AFIT), Mrs. Hope Taft (Environmentalist and former First Lady of Ohio), Dr. Sakthi Kumaran Subburayatu (Central State University), and Ms. Jill Krieg-Accrocco (Boonshoft Museum).

Upon learning of the impending loss of the active research facility, Badiru, who was head of AFIT's Systems Engineering and Management Department, mandated that a scale model of the wetland should be built to visually preserve the educational content of the live wetland research area on WPAFB. After months of national searches, Shelley found a company to tackle the complex model-building work with the funding available from DERA (Defense Environmental Restoration Account).



Contributed photo

The interactive wetland display model commissioned by AFIT to preserve the educational content of a former wetland research site on WPAFB to be transferred to Boonshoft Museum.

AFIT has since been home to the interactive wetland display model that visually tells the story of how wetlands contribute to the overall health of our environmental ecosystem. Fast-forward to early 2022, the atrium of AFIT's building 646 was deemed no longer suitable for housing the wetland display due to an impending renovation of the atrium. A deadline of December 2023 was set for moving the display or dismantling it. Thus started the long search for a new home for the display.

In a fortuitous casual conversation with Mrs. Hope Taft on 14 November 2023 at the monthly meeting of BEAC (Beavercreek Environmental Advisory Committee), Badiru mentioned the plight of finding a new home for the display. Mrs. Taft, a well-known environmentalist, took on the charge full force by linking up with several potential destinations for the display. On 22 November, a viewing tour group visited AFIT to collaboratively determine the appropriate destination for the display. With a collective pledge to continue to collaboratively nurture the wetland display for general public good, the group agreed that The Boonshoft Museum of Discovery in Dayton, OH would be a fitting destination for the display. Upon completing the appropriate and legal process for equipment transfer, the display will be transferred to The Boonshoft Museum in the first quarter of 2024 where it will serve as an interactive learning display to facilitate education on the topic of wetlands.

Information for this article was obtained in part from a 2010 Wright State University Newsroom article by Richard Doty.

2023-2024 GSEM Dean's Teaching Award Winners

The Graduate School of Engineering and Management presented the academic year 2023-2024 Dean's Distinguished Teaching Professors Awards on December 7 at the Air Force Institute of Technology. Two professors were designated from each of the Graduate School's six academic departments as listed below.

U.S. Air Force photo by R.J. Oriez

Dean Adedeji Badiru, left, presented the 2023-2024 Dean's Distinguished Teaching Professors Awards on Dec. 7 at the Air Force Institute of Technology.

Department of Mathematics & Statistics (ENC)
Dr. John Jasper – Assistant Professor of Mathematics
Dr. Edward (Tony) White – Professor of Statistics

Department of Electrical and Computer Engineering (ENG)
Dr. Julie Jackson – Professor of Electrical Engineering
Maj. Jose Gutierrez Del Arroyo – Assistant Professor of Computer Science

Department of Engineering Physics (ENP)
LTC Andrew Decker – Assistant Professor of Nuclear Engineering
Dr. Juan Manfredi – Assistant Professor of Nuclear Engineering

Department of Operational Sciences (ENS)
Dr. Nathan Gaw – Assistant Professor of Data Science
Dr. Frank Ciarallo – Associate Professor of Logistics and Supply Chain Management

Department of Systems Engineering & Management (ENV)
Lt. Col. Kip Johnson – Assistant Professor of Systems Engineering
Dr. Torrey Wagner – Assistant Professor of Data Analytics

Department of Aeronautics & Astronautics (ENY)
Lt. Col. Michael Zollars – Assistant Professor of Aerospace Engineering
Dr. Kerry Hicks – Assistant Professor of Astronautical Engineering

2023 AFIT Annual Chancellor's Awards Recipients

Congratulations to the 2023 AFIT Annual Chancellor's Awards recipients from the Graduate School of Engineering and Management.

Mentorship Excellence Award

This award recognizes Airmen who have demonstrated strong mentorship to peers, leaders, and followers while at AFIT. The transformational leadership of these Airmen led to the inspirational motivation of others.

Faculty Category - Maj. Shannon Young (ENP)
Staff Category - Ms. Alicia Sprinkle (ENG)

Innovation Excellence Award

This award recognizes the Airmen who exemplify the Air Force goal of innovation while at AFIT. The award celebrates "outside-the-box" thinking that promotes innovation, creativity, and forward-thinking by our students and educators.

Senior Faculty - Lt. Col. Milo Hyde (ENP)
Senior Staff - Ms. Andrea Bakker (ENW)
Junior Staff - Mr. Andrew Mack (ENP)

Leadership Excellence Award

This award recognizes the Airmen who distinguished themselves as being exceptional leaders across an organization. The award seeks to reach beyond the traditional military leadership structure and recognizes Airmen who have led beyond their assigned team.

Senior Staff - Ms. Kelley Robinson (EN)

2023 AETC Educator of the Year Award Nominee

Congratulations to the 2023 AETC Educator of the Year Award Nominee - Officer Category

Maj. Daniel Emmons, PhD, USAF
Associate Professor of Physics

Summer Faculty Program Results in Hypersonic Vehicle Flying Qualities Assessment

Each summer, faculty from universities across the United States travel to Dayton, OH to conduct research with faculty from the Air Force Institute of Technology.

During the summers of 2022 and 2023, Dr. Timothy Takahashi, professor of practice in aerospace engineering at Arizona State University, worked with Dr. Grandhi and Dr. José Camberos, AFIT associate professor of aerospace engineering, on hypersonic vehicle flying qualities assessment. Their research collaboration has resulted in the authorship and/or publication of nearly a dozen papers.

"I have been particularly delighted with AFIT's hospitality during my residency on base," said Takahashi. "In particular, I thank the staff at the D'Azzo Research Library. They have been invaluable in locating papers and reports, which illuminate the development, construction and flight-test of the famous USAF/NASA X-15 hypersonic research aircraft."

Below is one of the papers that resulted from the summer faculty program.

"The AFIT Summer Faculty Program provides a great opportunity for faculty and graduate students from civilian universities to collaborate on defense focused research and learn about the extensive collaborations we have with AFRL," said Dr. Ramana Grandhi, AFIT professor of aerospace engineering. "These partnerships continue even after they return to their campuses."

Hypersonic Vehicle Flying Qualities Assessment for Multidisciplinary Analysis and Design

By Dr. Timothy Takahashi, AFIT Summer Faculty, Arizona State University, Dr. José Camberos, AFIT Associate Professor of Aerospace Engineering, and Dr. Ramana Grandhi, AFIT Professor of Aerospace Engineering

General-purpose hypersonic airframes must demonstrate satisfactory flying qualities over a broad range of speeds and altitudes. Recent collaboration between AFIT faculty, AFRL scientists and academia reexamines lessons learned from the 1950's and 60's X plane programs, the Space Shuttle Orbiter, and the X-33 demonstrator.

Abundant X-plane flight test data, archived by the USAF, gathered, and shared with our academic team, (see FIGURE 1), has allowed us to study the successes, failures and close-calls experienced by the X-1, X-2, X-15, XB-70, and various lifting bodies to understand what vehicle design features lead to inherently desirable flying qualities. In order for the next generation of engineers to advance by "standing on the shoulders of giants," we must identify which design screening methods, first invented during the golden age of X-planes, are most applicable.

FIGURE 1 – The USAF has a long legacy of X-plane concept demonstrators, flown at Edwards AFB.

X-Planes at Edwards AFB, 1947-1977.
Illustration by Mike Machat from https://flighttestmuseum.org/

Continued on next page >>

USAF historian Richard Hallion suggests that successful design must involve "the creative integration and exploitation of diverse technologies, including structures, propulsion, aerodynamics and controls." At the same time, he reminds us to remember George Santayana's famous dictum: that "those who cannot remember the past are condemned to repeat it." The USAF has a glorious past where they accomplished the first piloted Mach 1, 3 and 5+ flights (in the Bell X-1, Bell X-2, and North American X-15), albeit not without mishap and loss of life.

Notably, the history of flight dynamics cannot be separated from Dayton, OH. Perkins and Hage wrote their seminal text, "Airplane Performance, Stability and Control," during their time at Wright Field during the Second World War. They used the draft manuscript to teach officers at the Army Air Forces Engineering School, which is the precursor to today's AFIT. Their work focused on the practical attributes of applied mathematics; that is the art of using reduced-order mathematical models to design an aircraft to exhibit favorable flying qualities.

Following the War, aircraft speeds increased through the transonic regime, then supersonic to the hypersonic. With each increase, pilots and aircraft began to experience unanticipated instabilities. Sometimes, violent motions about all three axes would suddenly present; the severity of these motions could even result in the loss of the aircraft and pilot. These encounters resulted from strong "coupling dynamics" – unforeseen exchanges in kinetic energy between pitching, rolling and yawing motions characteristic of fast and slender flying machines – driven by otherwise stable inherent motions of the rigid airframe.

Engineers at Edwards AFB first puzzled over these experiences, as common flight-dynamics mathematical approximations preclude their formation. For example, the mathematics behind inertial roll coupling had not been "invented" before 1948 when W.H. Phillips of the NACA first described the possibility of energy exchange between seemingly orthogonal flight dynamics motions. After several X-series research aircraft and Century series fighters encountered severe inertial roll coupling, this work became widely known. R.E. Day, at the NASA High-Speed Research Station- Edwards AFB, further matured these ideas. Discovery of these modes led to the development of new screening methods that proved invaluable to the USAF and its contractors. Phillips' and Day's insight led to upsized vertical tails that were essential to making the F-100, F-102 and F-106 aircraft successful; they kept the peace during the height of the cold war. While MIL STD 1797A captures elements of these lessons learned, most recent Aircraft Flight Control books focus more on modern control theory and overlook these practical screening metrics.

A good example of the USAF's emerging predictive capability involved a hair-raising flight of the Bell X-1A made on December 12, 1953, by the legendary Chuck Yeager. While the X-1A is a three-axis stable aircraft, newly formulated screening criteria predicted sharply degraded controllability above Mach 2, of which Yeager was warned. Shortly after besting the world speed record with level, controlled flight at Mach 2.44, Yeager lost control of his aircraft due to emergent control coupling, as shown by static camera footage in FIGURE 2. The departure was so prolonged and intense that Yeager's helmet shattered the cockpit canopy. Recovering, after losing nearly 50,000-ft in altitude, Yeager exclaimed "those guys were so right!" While Yeager's heroic stick-and-rudder skills brought the aircraft to a safe landing, he could easily have died if he had not successfully recovered from that spin.

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Frame grabs from USAF/NACA sourced flight test camera footage as posted at https://www.youtube.com/watch?v=I7p6f6tPEuU]

FIGURE 2 – Camera Footage from Yeager's December 12, 1953, X-1A flight. a) Level Flight at M~2.4 with nose slightly elevated and wings level, b) two seconds later, the aircraft has rolled 90° to the right and begun to spin – the camera records only the sky, c) four seconds into the spin, we see the aircraft has rolled 270° and the camera captures the desert floor 75,000-ft below, d) six seconds into the spin we see that the aircraft has inverted (the Earth is in the upper frame).

Our research team, working from simple, panel-method aerodynamic models of the X-1A can easily generate the aerodynamic data needed to screen for control coupling and inertia coupling behaviors. We use the Bihrle-Weissman plot, developed first by R. Weissman, Chief of the Stability & Control Branch at Wright Laboratory, to rapidly identify regions of the flight envelope where flight maneuvers may be dangerous to execute. Indeed, General Yeager's near fatal mishap occurred just as he entered the precise area of danger as identified by our modern tools, as shown graphically in FIGURE 3. We note that the X-1A has favorable predicted lateral-directional flying qualities at or below Mach 1.94, at all likely flight attitudes the data is in the Favorable "A" region of the Evolved Bihrle-Weissman plot. Above this speed, we expect controllability to decline precipitously as most flight conditions lie within either region "F" (where flying qualities degrade) or region "B" (where control induced departure is likely).

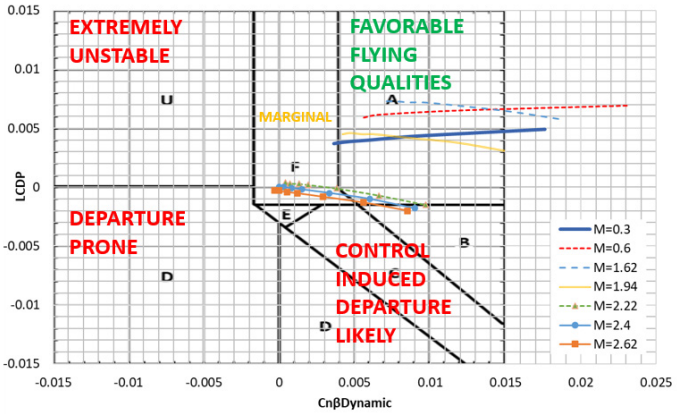

FIGURE 3 – Revised Bihrle-Weissman Chart for Bell X-1A. The aerodynamic basis to compute LCDP and CnßDynamic as a function of flight speed and attitude was predicted using modern panel-method aero codes.

Our team also assessed the 1963 Neil Armstrong flight in the X-15 which was dramatized in the opening to the 2018 movie "First Man." On flight 3-4-8, Armstrong inadvertently flew an "atmospheric skip" maneuver where the X-15 glided much further south than planned, see FIGURE 4. We have come to realize that Armstrong's "atmospheric skip" was the result of overlooked inherent lateral-directional airframe instabilities, which prevented him from properly executing his planned maneuvers, as noted in FIGURE 4. To bleed off speed, the X-15 needed to fly its atmospheric reentry in a turn at a 60-90° bank angle. In this mission, Armstrong's 4-gee pullup necessitated him to hold a very high angle-of-attack. At that point, the X-15's Spiral Divergence time constant became unsatisfactory simultaneously with the Dutch-Roll Mode going unstable. This moved its predicted flying qualities from the "A" region on the Bihrle-Weissman plot into the Unstable "U" region. Shortly thereafter, Armstrong "lost control" of bank angle, resulting in the atmospheric skip. He regained control regained control only after crossing over into the Los Angeles basin; sonic booms shook the Rose Bowl. Luckly, Armstrong had enough gliding range left to make it back to Edwards AFB without crashing into the San Gabriel Mountains. It should be no surprise that the X-15 program subsequently flew later flights with a revised ventral tail configuration that avoided these problems.

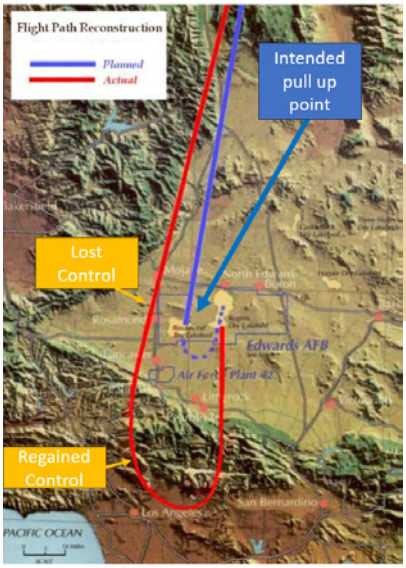

FIGURE 4 – Ground Track of Neil Armstrong's X-15 Flight 3-4-8 from 1963.

What does this insight mean for future hypersonic systems?

Today, we are blessed with access to modern digital flight control computers that can react faster, and with greater precision, than could any human pilot. These systems will be essential components, integrally designed into any forthcoming Hypersonic aircraft. If we consider a hypersonic aircraft as a cyber-physical system, we must never forget that the physical system imposes finite limits to available bandwidth and control power. Cybernetic control systems, whether classical, modern or AI powered, have only limited ability to command an unruly airframe.

IEEE Fellow Gunter Stein reminds us that "unstable systems are fundamentally, and quantifiably, more difficult to control than stable ones." Not only that but "closed-loop systems with unstable components are [at best] only locally stable." Control systems cannot stabilize a fundamentally unstable system if the fundamental instabilities exceed the available bandwidth and/or control power. While modern technology lifts bandwidth limitations arising from sensors and CPU limitations, the powerful servo motors needed to rapidly move control surfaces remain bulky and power hungry. Other bandwidth limitations stem from the airframe itself, as light-weight efficient structures offer greater flexibility than heavier designs. While designers can accurately predict vibrational modes, their frequencies and mode shapes often depend strongly on known variables such as the fuel load. As engineers, we cannot ignore these realities, but must design our systems around these limits.

Modern hypersonic systems, unlike the 1950's X-planes, will not likely participate in prolonged "envelope expansion" development programs. Modern aircraft are expected to fly well on their first flight. Our team, carefully tailoring methods and metrics first developed at Wright Field and at Edwards AFB can help make this a reality. Our tools, when employed by multi-disciplinary design teams trained in the art and science of aircraft digital engineering, can help "design out" unnecessary flight control risks arising from fundamental aerodynamic characteristics.

For further reading:

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- Weissman, R., "Preliminary Criteria for Predicting Departure Characteristics/Spin Susceptibility of Fighter-Type Aircraft," *AIAA J. Aircraft*, Vol. 10, No. 4, 1973, p. 214-219.
- Day, R.E., "Coupling Dynamics in Aircraft: A Historical Perspective," NASA SP-532, 1997.
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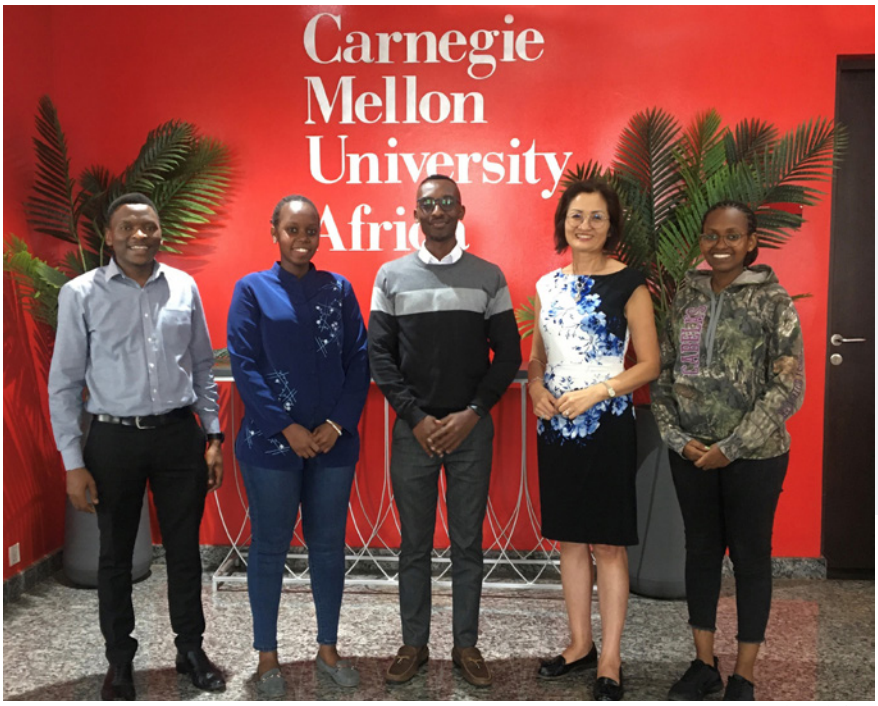


Contributed photo

Air Force Institute of Technology professor Dr. Aihua Wood traveled to Kigali, Rwanda in September to explore collaboration opportunities with Carnegie Mellon University-Africa. While there, she met with representatives from the school's Student Guild.

AFIT Explores Collaborations with CMU-Africa

By Katie Scott
Air Force Institute of Technology

Air Force Institute of Technology professor Dr. Aihua Wood traveled to Kigali, Rwanda in September to explore collaboration opportunities with Carnegie Mellon University-Africa. Established in 2011, CMU-Africa provides full-time graduate engineering education programs to more than 290 students from 21 nationalities. Notably, more than 25 percent of CMU-Africa's students are female. The college offers Master of Science degrees in electrical and computer engineering, information technology, and engineering artificial intelligence. CMU-Africa's goal is to address the critical shortage of high-quality engineering talent required to accelerate development in Africa.

AFIT's Graduate School of Engineering and Management is uniquely qualified to partner with CMU-Africa. As a nationally-recognized, Carnegie-classified High Research Activity doctoral institution, AFIT faculty teach and conduct research in the same STEM fields as CMU-Africa. As part of the visit, Wood toured the robotics and artificial intelligence laboratories, met with faculty and the Student Guild, attended a workshop on digital public infrastructure and talked with leadership from the Rwanda Space Agency.

"I was very impressed with the campus facilities and students," said Wood. "Typically, when we think of Rwanda we think of the genocide against the Tutsi, but they have really moved beyond that and it is a very energetic place with many very forward-thinking people. I feel like there is a lot of opportunity for AFIT to be involved."

While touring the robotics and artificial intelligence laboratories, Wood observed students reprogramming robotic vacuums, developing new facial recognition software, and tinkering with other new applications.

"I think it'd be really beneficial for our students to be exposed to the types of research their civilian counterparts are working on and to gain an African perspective on technology," said Wood.

Two opportunities to collaborate with CMU-Africa that Wood is investigating are the Air Force Office of Scientific Research Windows on the World and Window on Science programs. The WOW program provides opportunities for Air Force scientists and engineers to conduct full-time research at a non-government foreign laboratory, while the WOS program sponsors foreign scientists and engineers to visit Air Force scientists and engineers at USAF sites. "I would love ultimately to have students from CMU-Africa attend AFIT because they have a really great talent pool there," said Wood.

Wood was also impressed with the activities sponsored by CMU-Africa's Student Guild that focus on helping their students' mental health and feeling of belonging. She noted an opportunity for AFIT to develop a comparable program. "At AFIT, we talk about our student's mental health and all the stress that they are under, and the CMU-Africa students face similar issues," said Wood. "They have a Wellness Office that is staffed by two full-time practitioners. I think that is something we can learn from them."

While in Rwanda, Wood served as a panel member of the MentorHer Africa event discussing the topic of empowering girls and women in STEM with students from universities across the region. Through personalized mentorship, MentorHer strives to empower young girls to pursue careers in cybersecurity, governance, risk management, and compliance. "They offer 30 female college seniors an opportunity to work one-on-one with well-known international mentors and coaches for six-months," said Wood. "I was very impressed with the students. The young girls are very bright – you can see that they will become leaders in their fields."

AFIT's Greatest Ambassador

Dean Badiru Announces 2024 Retirement, Leaves Legacy of Dedication and Innovation

By Katie Scott
Air Force Institute of Technology

Dr. Adedeji Badiru, dean of the Graduate School of Engineering and Management at the Air Force Institute of Technology retires in January after 10 years in the position.

A distinguished industrial engineer, Badiru's career extends over 38 years. He joined the Graduate School of Engineering and Management in October 2006 as the head of the Systems Engineering and Management department and ascended to the dean's position in October 2013 overseeing significant achievements and transformations.

"Dr. Badiru's positive influence on AFIT's Graduate School of Engineering and Management will be felt for many years to come," said Dr. Walter Jones, AFIT director and chancellor.

Under his guidance, AFIT achieved the maximum 10-year reaffirmation of accreditation by the Higher Learning Commission and earned the esteemed designation as a National Center of Academic Excellence in Cyber Defense Research by the National Security Agency and Department of Homeland Security. Badiru fostered collaborations, notably with AFWERX, enabling AFIT faculty to contribute as subject matter experts for Secretary of the Air Force-directed programs, facilitating flexible and rapid acquisition.

"Dean Badiru is to be commended for his unflagging commitment to telling the AFIT story nationally and internationally," said Dr. Heidi Ries, AFIT provost and chief academic officer. "His efforts have significantly increased recognition of the Graduate School's outstanding academic and research contributions."

Recognizing the evolving landscape of education, Badiru spearheaded initiatives such as the establishment of the Data Analytics Research Group, the Graduate School's Teaching Evaluation Tool, and the Thesis Processing Center, transitioning traditional methods to electronic theses and dissertations.

U.S. Air Force photo by Katie Scott

The Graduate School of Engineering and Management leadership team in December 2023.

His commitment to excellence was further exemplified by creating the Center of Excellence for Teaching and Learning, later evolving into the AFIT Center of Innovation in Education, providing valuable resources for faculty development and student learning.

During Badiru's tenure as dean, the Graduate School created 12 new master's degree programs and 15 new graduate certificate programs. Notably, in 2020, he successfully led the transition of over 1,000 faculty, staff, and students to conduct more than 130 courses online, showcasing adaptability in the face of challenges. In 2021, he aligned Graduate School resources to meet the educational needs of the newly established Space Force. He served as an external reviewer for the Accreditation Board for Engineering and Technology, Inc. and brought back lessons learned to establish and lead an ABET Accreditation Advisory and Consulting Team to advance ABET initiatives in all Graduate School academic programs.

Under his strategic direction, faculty research funding nearly tripled from $16.4M in 2013 to an impressive $45.8M in 2023. This growth led to the establishment of three new research centers, fostering expertise in nuclear advancing technologies, homeland security best practices,

"Dean Badiru is to be commended for his unflagging commitment to telling the AFIT story nationally and internationally. His efforts have significantly increased recognition of the Graduate School's outstanding academic and research contributions."

— Dr. Heidi Ries, AFIT Provost and Chief Academic Officer

and digital innovation and integration. As a result, faculty published more than 6,000 refereed papers, proceedings, abstracts, books and book chapters and were awarded 57 patents.

Badiru's dedication to faculty development is evident in the creation of Graduate School-level awards and mentorship programs. Notable recognitions include faculty receiving Air Force-level Science, Technology, Engineering and Mathematics awards, Distinguished Professor honors, Fulbright Scholar selections and participation in prestigious fellowship programs.

As a leader in innovation, Badiru initiated and hosted the inaugural Defense Innovation Symposium, facilitating crucial discussions on artificial intelligence, distributed and connected capabilities, and space-based operations. His co-editorship of the 2019 Defense Innovation Handbook further highlighted his commitment to advancing knowledge in these domains.

Beyond his administrative role, Badiru is a prolific author and mentor, contributing significantly to the academic community with over 40 books, 35 book chapters, 130 journal and magazine articles and more than 200 conference presentations. His trademarked "DEJI Systems Model" for systems design showcases his expertise in mathematical modeling, project analysis, economic analysis, and systems engineering.

Badiru earned a bachelor's degree in industrial engineering, master's degrees in mathematics and industrial engineering from Tennessee Technological University, and a doctoral degree in industrial engineering from the University of Central Florida. He is a registered professional engineer, a certified Project Management Professional, a Fellow of the Institute of Industrial and Systems Engineering and a Fellow of the Nigerian Academy of Engineering. He is a member of several professional associations and scholastic honor societies including the Institute for Operations Research and the Management Sciences and the American Society for Engineering Education.

His significant contributions have been recognized through numerous awards, including the Industrial Engineering and Operations Management Society International's Frederick Winslow Taylor Award in 2022, the Career Achievement in Government Award from Career Communications Group in 2021 and the second annual Taylor and Francis Lifetime Achievement Award in 2020.

As Badiru embarks on a well-deserved retirement, his legacy at AFIT remains indelible, marked by transformative leadership, scholarly contributions and unwavering dedication to excellence.

Contributed photos

Top row (l to r): AFIT library staff celebrates FEDLINK award; Dr. Badiru poses with Sergeant Major Jeffrey Morris, the first enlisted military member to earn a doctorate at AFIT.

Left: AFIT leadership and faculty pose with the RIGEX display donated to the National Museum of the USAF in April 2014. RIGEX ran successfully onboard Space Shuttle Endeavour Mission STS-123 in March 2008.

Bottom (l to r): Dr. Badiru poses with AFIT mascot Dr. Whoo; Dr. Badiru and the Additive Manufacturing Lab team in 2017.

Dean Badiru's Contributions to Graduate School Excellence

- AFIT received 10-year reaffirmation of accreditation by the Higher Learning Commission
- AFIT designated as a National Center of Academic Excellence in Cyber Defense Research
- Twelve new MS degree programs and 15 new graduate certificate programs created
- Faculty research funding nearly tripled from $16.4M in 2013 to $45.8M in 2023
- Three new research centers instituted
- Established AFIT's Center of Innovation in Education
- Facilitated creation of the Data Analytics Research Group
- Initiated Graduate School's Teaching Evaluation Tool
- Graduate School-level awards and mentorship programs established

Demonstration of Alternative Navigation Technologies on an Autonomous Aircraft

Autonomy & Navigation Technology Center

By Andrew Appleget, Josiah Watson, Jeremy Gray and Dr. Clark Taylor, ANT Center Director
Air Force Institute of Technology

INTRODUCTION

AFIT's Autonomy and Navigation Technology (ANT) Center focuses on three research thrusts: GNSS-based navigation, navigation without GNSS, and autonomous systems. In this article, we describe flight tests recently performed for our ANT Hill project that combines all three research thrusts.

Global Navigation Satellite Systems (GNSSs) have been the standard source of positioning and timing for a multitude of applications leading to an over-reliance on its capabilities and a notable reduction in performance or interoperability when it is unavailable. The emerging threats to satellite navigation, and to the Global Positioning System (GPS) in particular, necessitate the development of modular navigation architectures that can utilize complementary methods (e.g. vision, signals of opportunity, magnetic anomalies) alongside or in the absence of GNSS.

NAVIGATION TEST BED

Modular Open Systems Approach (MOSA)

One of the primary objectives of this research is to develop a reusable test bed for future research and demonstrate the feasibility of a MOSA-based navigation system. MOSA relies on clearly defined interfaces between system components, which allows any implementation that meets these interface requirements to be "plugged into" that system component slot.

The ANT center has been involved in the development of the All Source Positioning and Navigation (ASPN) data standard which defines interface data for navigation messages. The All Source Positioning and Navigation (ASPN) version 2.2 message standard was used for all navigation messages, which were serialized and transported using Lightweight Communications and Marshalling (LCM) [1]. For each sensor, a driver was developed to convert the sensor's propriety data format to ASPN and publish it to the LCM network bus. The navigation filter code unpacked the transmitted ASPN-LCM measurements and converted them to the ASPN-Python classes supported by a NavTK filter (a software package designed specifically to enable MOSA-based navigation systems.) The filter estimate was published over LCM for use by the autopilot via its driver.

Software Development and Deployment Infrastructure

This research required many different sensors, each with proprietary commands and data formats. In addition, integrating code from multiple developers and using different CPU architectures for development (x86 64) and deployment (Advanced RISC Machine (ARM)-64) meant that a modular approach was needed to manage this complexity. Figure 1 depicts the layout and architecture of the filter platform used on the aircraft.

Due to each software component requiring different dependencies and versions, each component was developed and deployed inside a separate virtual container. Virtual containers are similar to virtual machines in that each creates an isolated environment that allows applications to be installed and run on the same physical hardware without interfering with one another. However, because containers only create a separate file system, instead of also creating a separate operating system kernel, they are faster and smaller in size than virtual machines. Using individual containers for each component had many tangible benefits. First, the development environment was consistent over time and could be easily installed and used on other devices. This greatly reduced the amount of troubleshooting required during development and system integration. With each of the components being deployed in containers, they could be easily added to or moved between the payload's two Nvidia Jetson Xavier NX computers (e.g. if one was experiencing high CPU usage). Finally, using containers allowed the code to be developed on x86 64-based laptops and easily deployed to the ARM-based payload computers. This research used Docker Community Edition to create and manage containers. A combination of Docker Compose and Linux's System Daemon (systemd) services were used to selectively run the components during flight testing.

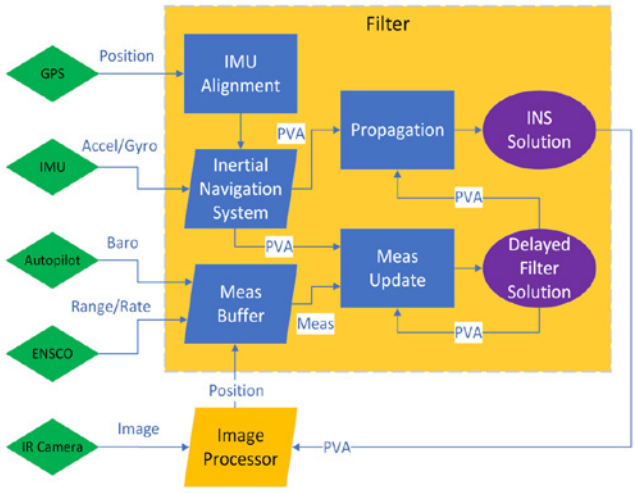


Figure 1: Filter layout and architecture

The filter code used was primarily developed in Python utilizing the NavTK library. The script consisted of NavTK class objects to model an Extended Kalman Filter (EKF) with states, measurements, and the filter engine itself. The library mechanized the inertial measurements to produce a trajectory that was then corrected with measurements from other sensors. This research added a measurement buffer to receive messages via LCM, prepare them for the filter, and re-order them based on the measurement time. The filter was configured to lag behind the current time, which allowed the measurement buffer to handle messages that were received out of order. When a new measurement was ready, it was requested by the filter engine which dispatched it to the appropriate measurement processor to perform an update. The filter state was then requested and published to the LCM bus at a constant rate to be consumed by the autopilot.

Sensors Used

When GNSS is not available, some complementary sensors must be used to determine the position and attitude (pose) of the SUAS. While describing each of these hardware sensors is beyond the scope of this article, a brief list and description of each hardware component is as follows:

- **Inertial Sensors:** When GNSS is available, we use a NovAtel PwrPak7 receiver to give us the true position and attitude of the UAV. When GNSS is not available, the NovAtel gives us the raw inertial data from an inertial measurement unit.
- **Ranging Radio:** We used an ENSCO TCR-D 421 ranging radio on the UAV, with 3 similar radios at known locations on the ground. This sensor provides both range and range rate measurements to the corresponding radios on the ground.
- **IR camera:** A Teledyne FLIR Boson 640 IR camera, fixed to the plane facing directly downward, coupled with an algorithm by Veth Research Associates, LLC (VRA) and based upon research in [2] and [3], provided location estimates to our filter.
- **Barometer:** A barometer for measuring atmospheric pressure is used to measure the altitude of the UAV.

Avionics and External Navigation Integration

The avionics system consisted of a Pixhawk 2 autopilot running ArduPilot firmware. During typical non-contested operations, the autopilot performs sensor fusion via its EKF to provide states to its control system for autonomous waypoint following. If GNSS is contested, the autopilot does not have a source for position information and will become increasingly more uncertain about its horizontal position, meaning an external navigation solution would need to be provided. The problem then is how to inject a navigation solution into an autopilot not designed to take complementary navigation inputs.

Figure 2: SUAS Cub on the flight line (left); SUAS Cub payload (right)

There were three possible solutions to this problem. The most intuitive solution was to circumvent the autopilot navigation filter and provide the NavTK filter states directly to the controller. This would require the calculation of additional filter states, significant rework of the autopilot firmware, and additional effort to obtain flight approvals. The second solution was to encode the filter states as a GPS L1 signal using a Jackson Labs GNSS transcoder. This solution is more elegant and easier to integrate into existing systems, however at the time of this research this technology was not ready for use. The solution that was implemented for this research was to encode the filter states as a National Marine Electronics Association (NMEA) message and send it via serial connection to the autopilot's external GNSS receiver port. This stand-in for an external GNSS receiver enabled the autopilot to update its EKF based on the external filter states.

A consideration made when developing this method was to investigate the effects of injecting the external filter solution into the Pixhawk filter which is expecting a GNSS measurement. The ArduPilot firmware can be run as a software-in-the-loop (SITL) simulation which is identical to the firmware flown with a physics simulator. A test was conducted using the SITL simulation to see the effects of AWGN to the GPS input. To accomplish this, the truth from the physics simulation was pragmatically acquired, corrupted, then injected back into the autopilot. It was found that the autopilot, with proper configuration, was resilient to noise which was orders of magnitude larger than that expected by our navigation system.

The proposed injection method also introduces latency from sensor acquisition to solution injection on the order of 100ms-200ms. The autopilot expects and can accommodate latency with a simple parameter change, however, it does expect the measurement at a constant rate. To accommodate this in addition to slower processes like the image position solution, the filter was designed to provide a 500ms delayed solution at a constant rate of 10Hz.

Airframe

The payload and avionics were integrated on a hobbyist one-third-scale Cub. The loiter time, using a gas engine and batteries for the electronics, was 75 minutes. Figure 2 depicts the SUAS airframe and integrated payload.

DATA COLLECTION AND FLIGHT PLAN

The flight test and data collection were conducted at WSMR, NM during the 2021 PNTAX test event. Between each of the jamming scenarios, there were benign periods when GNSS signals were available and uncontested. Throughout the duration of the flight, the computer on the aircraft recorded both the measurements from individual sensors as well as the overall filter solution at a given timestamp. The SUAS flew two primary flight patterns: a circular loiter pattern and a box-shaped pattern determined by 4 waypoints. With the exception of take-off and landing, the aircraft was set to fly in autopilot mode. Additionally, the aircraft flew at three different altitudes (approximately 500, then 600, then 400 m) while it was in autopilot mode, for a given amount of time.

RESULTS

The following analysis consists of two parts, one for each scenario: the benign period before and the time during the jamming scenario.

Benign Performance

During the benign period the filter solution was compared against the truth data from the NovAtel receiver's tightly-coupled solution, linearly interpolated to the time of the filter solutions. Figure 3 depicts the filter error from the time of first alignment to the beginning of the jamming scenario. The filter error was compared against its 2σ covariance bound.

Continued on next page

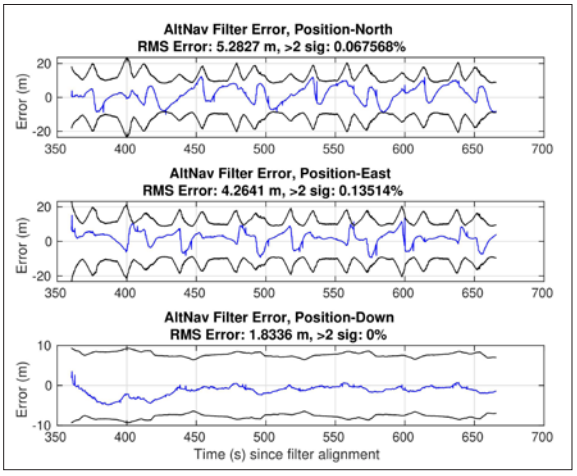


Figure 3: Filter position error in NED during the benign period

Demonstration of Alternative Navigation Technologies (Continued)

During the steady-state period (350 seconds after takeoff), the filter position error appeared to remain within the 2σ bound for more than 95% of the time as expected for a Gaussian error distribution. The Distance Root Mean Square (RMS) horizontal error of the filter was 6.79 m, while the RMS vertical error was 1.83 m.

Performance During Jamming Scenario

During the jamming scenario, the NovAtel receiver was unable to maintain a solution due to GNSS signals being strongly contested. Consequently, there is no truth data with which to compare the filter solution. From visual observations, however, the flight appeared to keep to is assigned path without manual intervention. In addition, we can observe the residuals from the different measurements being used and see if they consistent even without GNSS signals.

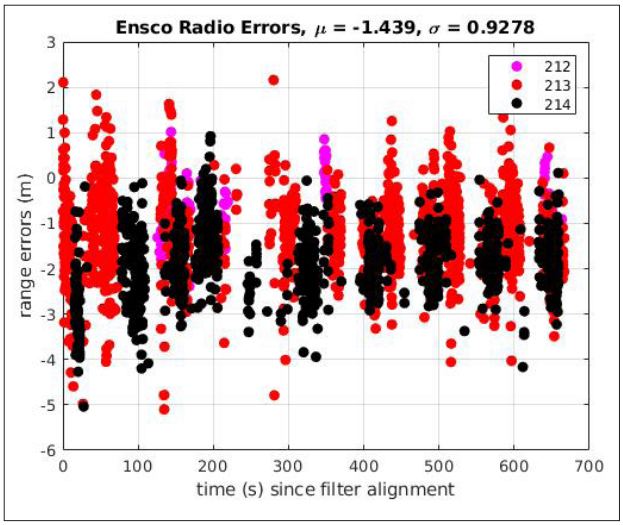
There are two main contributing factors to measurement residuals: the filter solution and the measurement itself. If the error distributions of the measurements are assumed to remain consistent, it can be reasoned that the filter performance can be indirectly assessed via the measurement residuals in the absence of truth data. The error characterization of the sensors during the benign period can be compared with the errors during jamming and compared to see if the aircraft is maintaining accurate position estimates. Figure 4 depicts the residuals of the ENSCO radio measurements throughout the duration of the data collection, including both the benign and contested periods.

From observation of this data, it can be concluded, with a 95% confidence, assuming that the error distribution of the ranging radios' measurements remains consistent, that the filter during the jamming performed to within a 11 m error budget. These values are derived from the maximum measurement error of 5 m observed for the radio measurements during the benign period and a 2σ value of 6 m for the measurement residuals of the radio ranges during the steady-state phase of the flight. Additionally, the aircraft did not visibly deviate from the flight plan during the duration of the flight.

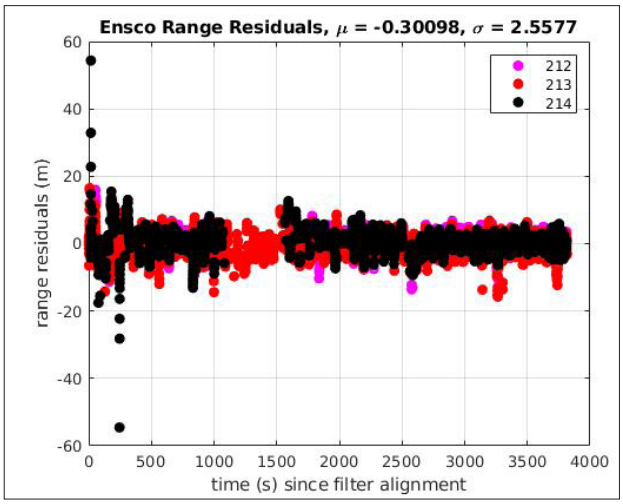
CONCLUSIONS AND FUTURE WORK

This research demonstrates that in the absence of GNSS navigation, a complementary navigation solution can be developed in support of steering an SUAS aircraft via a closed control loop in an unmodified commercial off-the-shelf (COTS) autopilot. With 95% confidence, the overall filter solution did not drift by more than 11 m, constraining the overall filter solution. To our knowledge, this is the first time a completely GNSS-denied navigation solution has been used in a closed loop on a fixed wing, autonomous aircraft.

Figure 4: Comparison of ranging residuals during and without jamming.



Ranging radio residuals during benign period



Ranging radio residuals during the jamming period

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[2] T. Machin, J. Raquet, D. Jacques, and D. Venable, "Real-time implementation of vision-aided navigation for small fixed-wing unmanned aerial systems," in *Proceedings of the 29th International Technical Meeting of the Satellite Division of The Institute of Navigation (ION GNSS+ 2016)*, Portland, OR, September 2016, pp. 1305–1311.

[3] D. T. Venable, "Improving real-world performance of vision aided navigation in a flight environment," Ph.D. dissertation, Air Force Institute of Technology, September 2016.

LEARN MORE ONLINE:

This article was first published by Inside GNSS and edited for length in the AFIT Engineer. Read the complete story at:

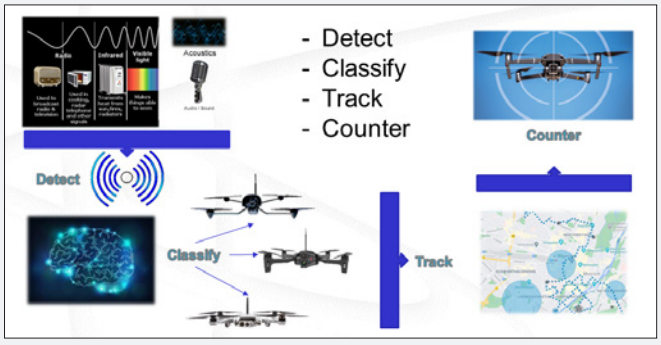
https://insidegnss.com/navigating-a-suas-without-gnss/

SMALL UNMANNED AERIAL SYSTEMS

AFIT Researches Deep Learning Techniques Using Multi-modal Sensors to Support DoD's Counter-sUAS Strategy

By Maj. Anthony Brunson, USAF
AFIT Graduate Student
Department of Electrical and Computer Engineering
Air Force Institute of Technology

The Air Force Institute of Technology has partnered with the Air Force Research Laboratory (AFRL) to research and develop new techniques to detect, classify, track, and counter Small Unmanned Aerial Systems (sUAS). With the rise of sUAS use for military use including reconnaissance, and attack, the Department of Defense has published the Counter-sUAS Strategy. The implementation of this strategy is being championed by all branches of the military. AFIT's role is in researching new Deep Learning techniques using multi-modal sensors, including audio, visual, and infrared. Since 2021, AFIT has focused on building models which detect loose ranges of drones using pre-recorded audio. 2023 marked an inflection point in which phase two began where video of drones was added to the arsenal of detection techniques. The fusion of these two data sources provides valuable insight into our ability to accurately detect the location of a drone down to the meter. Phase three is comprised of real-time detection and tracking, and is planned to be completed by the end of calendar year 2023.



In the first phase of our research, audio recorded on consumer cell phones was processed through various machine learning models yielding detection accuracies of 87.5% and range prediction accuracies of 80.1% within 20 meters. Each observation was 256 milliseconds of data. It was found that the largest error in detection was at the threshold between classes, and at the maximum range boundary bordering on undetectability. We hypothesize that the error rate can be reduced by increasing the number of milliseconds between observations to a range that will maximize the difference between each observation. For example, a sUAS will travel farther in 760 milliseconds than 256 milliseconds, resulting in a larger change in the audio footprint over that time. This difference may result in more accurate predictions due to each class boundary containing larger changes between each border.

The second phase includes building a multi-node network capable of recording audio and video. To capture data, an array of 12 low-cost Raspberry Pi's are configured with a microphone and camera, and loaded with a custom Python script that uses Python's RPyC library to communicate with a central command station that sends record commands to all nodes asynchronously. Completed recordings are then sent from the nodes to the command station automatically upon completion for analysis.

The final phase will integrate the audio and video techniques to detect drones in real-time. The cutting edge to deep learning is the ability to make at or near real-time predictions. You Only Look Once (YOLO) is one technique used for real-time object detection from imagery. Using Picamera as the data collection source, data is streamed through YOLO and drone detection is output. Since we also require 3D positioning of drones, our research focuses on extending the detection mechanism to also include range predictions based on pixel size within each frame. The predictions generated from audio data will include triangulation of position based on sound. The fusion of these techniques will be the foundation for obtaining GPS coordinates and altitude of drones in the sky.

This research is foundational to the elimination of weaponized drones from the sky. In two short years, large strides have been made towards the ultimate goal of countering and defeating sUASs. Given the current world events and expansion of sUAS use to include swarms being sent into countries to neutralize people and infrastructure, it is vital that this research continues to enhance the capabilities of AFRL, the United States Air Force, and the Department of Defense.

Since 2021, AFIT has focused on building models which detect loose ranges of drones using pre-recorded audio. 2023 marked an inflection point in which phase two began where video of drones was added to the arsenal of detection techniques.

Contributed photo

ANT Center Collaborates on DAF-MIT AI Accelerator MagNav Project

Faculty and staff from AFIT's Autonomy and Navigation Center were critical partners in the Department of the Air Force-Massachusetts Institute of Technology (DAF-MIT) Artificial Intelligence Accelerator (AIA) MagNav project described in the article on the next page. The ANT Center has been involved in the MagNav project from the beginning and is based on research by former AFIT professor and alum Dr. Aaron Canciani (PhD Electrical Engineering, 2016 and M.S. Electrical Engineering, 2012).

AFIT assistant research professor Dr. Aaron Nielsen has worked closely with the AIA team and Air Mobility Command to prepare and demonstrate MagNav on the C-17, starting in the summer of 2021 with assistance from the 445th Airlift Wing. During several rounds of ground and in-flight measurements, Nielsen and engineers Jonnathan Bonifaz and Tristan Williams set up and configured the Mag-In-A-Box to collect and stream real-time magnetic data for calibration and navigation.

Left to right: Brandon Blakely, Andy Appelget, Tristan Williams, Jonnathan Bonifaz, Richard Nyquist, and Jeremy Gray.

Contributed photo

ANT CENTER
AUTONOMY & NAVIGATION TECHNOLOGY

Read about the ANT Center's expertise and guidance provided during the AIA MagNav project. >>

MagNav Project Successfully Collects Realtime Streaming Data for Magnetic Navigation

CAMBRIDGE, Mass. (AFNS)-- In a groundbreaking achievement, the Department of the Air Force-Massachusetts Institute of Technology Artificial Intelligence Accelerator, or AIA, MagNav project recently collected magnetic navigation information, or MagNav, on the C-17A Globemaster III in flight, successfully advancing an alternative to GPS-based navigation on Department of Defense aircraft.

The AIA MagNav team, in conjunction with personnel from MIT, MIT Lincoln Laboratory, the Air Force Research Laboratory Sensors Directorate and the Air Force Institute of Technology Autonomy and Navigation Center, flew three Travis Air Force Base, California, C-17 sorties to the test complex at Edwards AFB, California, during exercise Golden Phoenix, May 11-15.

The team harnessed the power of AI and machine learning through the AIA's calibration and positioning neural network, which was trained during flight in a matter of minutes on a commercially-available laptop. The team leveraged transfer learning from AI models built on previously collected C-17 data, which significantly accelerated the neural network training process.

Travis AFB's 60th Air Mobility Wing provided the AIA with aircraft to build and train the prototype MagNav system, while also executing a maximum generation event or 'elephant walk' as part of exercise Golden Phoenix, Travis AFB's showcase of readiness and interoperability. The navigation experimentation addressed one of the four critical capability gaps identified by Gen. Mike Minihan, commander, Air Mobility Command.

To achieve this milestone, the MagNav team leveraged global collaboration through its Magnetic Navigation Open Challenge, which involves contributors from around the world through its open-source software library. This collaboration improved the AIA's neural network architecture that removes magnetic noise generated by the aircraft to derive position by comparison to a known magnetic map. The technical report, soon to be presented to the U.S. government, will provide details on the system's navigation accuracy and inform MagNav experiments for other DoD platforms, including aircraft, submarines, hypersonic glide vehicles and small unmanned aerial systems.

Maj. Kyle McAlpin, AIA MagNav liaison, expressed enthusiasm for the successful outcome, stating, "Every pilot fears single points of failure. Our strategy documents lament the DoD's over-reliance on GPS, a single point of failure in our ability to navigate precisely. The next fight demands unassailable positioning and navigation. We can achieve that by augmenting GPS with alternatives like celestial navigation, signals of opportunity, visual navigation, and magnetic navigation. This week, we took an important step towards making one of those modalities a reality by transitioning MagNav from the minds of MIT and MIT Lincoln Laboratory onto an operational aircraft, blazing the trail for our sister services and expansion to new platforms."

The successful demonstration of MagNav on C-17 data marks a significant milestone in advancing navigation capabilities for the U.S. Air Force. The groundbreaking collaboration between AIA, MIT, MIT Lincoln Laboratory, and other partners paves the way for further innovation in navigation technologies, benefiting not only the Air Force but also the broader aviation community.

Based on an article originally published May 26, 2023 by the Department of the Air Force-Massachusetts Institute of Technology.

Contributed photo

MagNav equipment is loaded on the back of a C-17A Globemaster III, ready for realistic data collection on Defense Department aircraft, during exercise Golden Phoenix, May 11-15, 2023.

Contributed photos

A simulated refueling approach above WPAFB using a USAF Boom. This closed-loop simulation leverages a 3D virtual world where synthetic vision sensors placed on the tanker let researchers generate geometrically accurate imagery of an entire refueling approach. This imagery is then processed in real time to drive the tanker's actions and reactions towards successful aerial refueling.

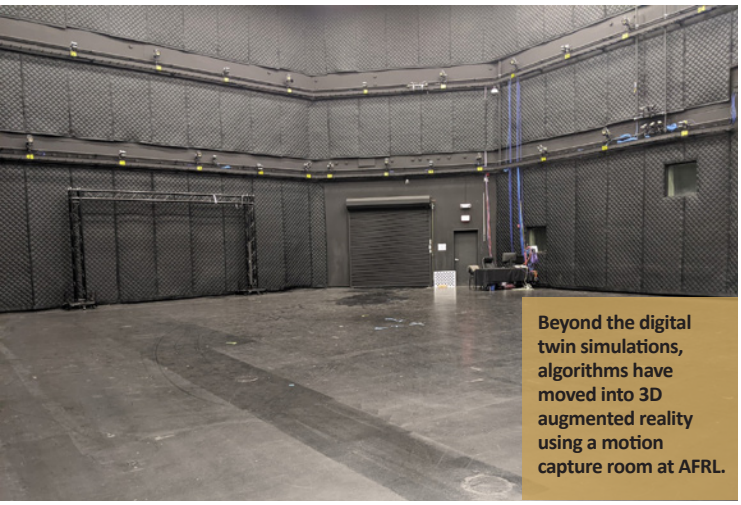
Autonomous Aerial Refueling

ANT Center High-Impact Research

The Autonomy and Navigation Technology (ANT) Center is a forward-looking research center seeking to identify and solve tomorrow's most challenging navigation and autonomous and cooperative control problems. The ANT Center's goal is to develop navigation technology that ensures we can navigate anywhere, anytime, using anything. The ANT Center focuses on three research thrusts: autonomous and cooperative systems, non-GPS precision navigation, and robust GPS navigation/NAVWAR.

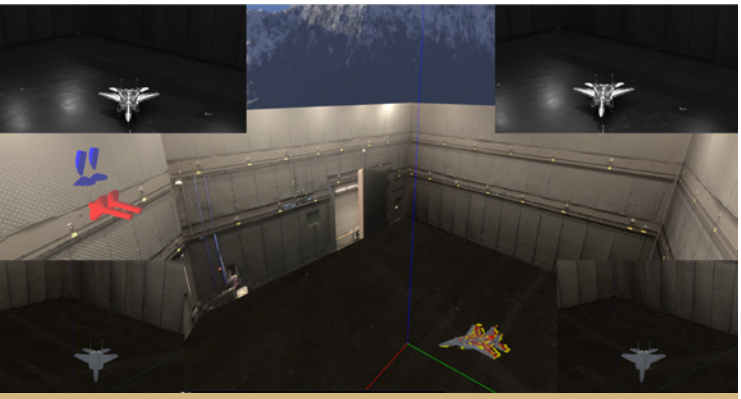
Under Air Force Research Laboratory (AFRL) sponsorship, the ANT Center designed and built a GPS-based relative navigation system that determines cm-level relative positions between two flying aircraft. The Center also developed autonomous formation flight control algorithms and successfully flew the entire system at the USAF Test Pilot School, accomplishing the first fully autonomous precision formation flight appropriate for aerial refueling. ANT Center's research has established AFIT as a DoD leader in autonomy and automation for aerial refueling. Read about the Center's ground-breaking aerial refueling research on the next page. >>

Students and faculty have successfully incorporated innovative technologies such as **3D simulation, artificial intelligence, and machine learning** into ongoing autonomous aerial refueling research projects at AFIT.



Beyond the digital twin simulations, algorithms have moved into 3D augmented reality using a motion capture room at AFRL.

The physical nose cone in the motion capture room. The probe on the nose is guided into the drogue basket by the algorithm.



Above: The 1/7 scale aircraft approaching a pair of cameras.

Right: A simulated refueling approach using a Probe and drogue. The Drogue approach is leveraged by smaller aircraft.

Within AFIT's Department of Electrical and Computer Engineering, the Autonomy and Navigation Technology (ANT) Center conducts research and teaches courses in support of the Department of Defense's (DoD) most important research areas. Foremost among these are Autonomy and Navigation. Specifically, over the past eight years, AFIT has been working with the Air Force Research Laboratory (AFRL), the U.S. Navy, and other sponsors to automate aerial refueling for both manned and unmanned systems.

By leveraging a digital twin within a virtual world, our engineers, researchers, and students create 3D simulations of aerial refueling approaches. In these virtual simulations, we leverage accurate 3D models of our aircraft and simulate millions of aerial refueling approaches. During each approach our virtual vision sensors capture realistic imagery from many vantage points mounted on the aircraft. Our research efforts have resulted in several real-time algorithms that consume this imagery and compute a visual relative navigation solution. This solution provides the position and orientation between the tanker and receiver – the requisite information needed to guide the aircraft together for successful mating and fuel transfer.

AFIT has partnered with AFRL, the U.S. Navy, and large DoD contractors to develop, test, and increase the technology readiness level (TRL) of these algorithms. AFIT has conducted multiple flight tests at Edwards AFB in California and has additional flight test scheduled. This family of algorithms has successfully automated Boom operation in experimental flight tests and continues to find new applications in other forms to automation and autonomous operation.

Over 26 master's and PhD students have worked on this project since 2015 establishing AFIT as a DoD leader in Autonomy and Automation for Aerial Refueling. Currently, PhD students Maj. Derek Worth and Maj. Jeffery Choate are applying artificial intelligence and machine learning to this domain and successfully achieving the most accurate results yet. Typically, pose estimates are within several centimeters of truth. Additionally, master's students Lt. Dawson Friesenhahn and Lt. Joshua Krutz are developing novel methods to improve our augmented reality and motion capture tools – enabling AFIT to blend virtual reality with physical experiments in novel ways. This ANT Center project is led by Dr. Scott Nykl, Associate Professor of Computer Science, and Dr. Clark Taylor, ANT Center Director and Associate Professor of Computer Engineering.

AFIT Alum Nominated to Grade of Lt. General

AFIT alum Maj. Gen. Douglas Schiess (Master of Space Systems, 2004) has been nominated to the grade of Lt. Gen. and assignment to Commander, U.S. Space Forces – Space; and United States Space Command's Combined Joint Force Space Component Commander, Vandenberg SFB, CA.

In this role, Lt. Gen. Schiess leads thousands of joint and combined personnel across 70 tactical units with a mission to plan, integrate, conduct and assess global space operations in order to deliver combat relevant space effects in, from, and to space for Combatant Commanders, Coalition partners, the Joint Force and the nation. The General plans and executes space operations through two command and control deltas and exercises operational control of assigned and attached U.S. Space Forces including all or portions of six operational deltas. Additionally, Lt. Gen. Schiess controls five distinct and geographically dispersed operations centers, including the Combined Space Operations Center at Vandenberg SFB, California; the National Space Defense Center at Schriever SFB, Colorado; the Missile Warning Center at Cheyenne Mountain Space Force Station, Colorado; the Joint Overhead Persistent Infrared Planning Center at Buckley SFB, Colorado; and the Joint Navigation Warfare Center at Kirtland AFB, New Mexico.

Lt. Gen. Douglas Schiess

Lt. Gen. Schiess entered the Air Force as a Distinguished Graduate of the Air Force Reserve Officer Training Corps at the University of California, Los Angeles in 1992, and transferred to the United States Space Force in 2022. He has commanded the 4th Space Operations Squadron at Schriever AFB, Colorado; the 45th Operations Group at Cape Canaveral Air Force Station, Florida; the 21st Space Wing at Peterson AFB, Colorado; and the 45th Space Wing at Patrick AFB, Florida. He deployed to Al Udeid Air Base, Qatar, in support of operations Enduring Freedom, Resolute Support, and Inherent Resolve.

His staff assignments include Headquarters Air Force Space Command, Headquarters Space Operations Command, the Air Staff and Office of the Secretary of the Air Force. Prior to his current assignment, Lt. Gen. Schiess was the Commander, Combined Force Space Component Command and Vice Commander, Space Operations Command.

AFIT ALUMNI BY THE NUMBERS

35 TOTAL ACTIVE DUTY GENERAL OFFICERS

3 Lieutenant Generals
+3 Lt. Gen. Select

13 Major Generals
+1 Maj. Gen. Select

11 Brigadier Generals
+5 Brig. Gen. Select

AFIT Alum Kelly "Scott" Bellamy Accepts Service to America Medal

AFIT alum Kelly "Scott" Bellamy and the NASA Double Asteroid Redirection Test Team recently won the 2023 Samuel J. Heyman Service to America Medal, also known as the Sammies, honoring outstanding federal employees who are addressing many of the country's greatest challenges. He and his team were honored for achieving a first-of-its-kind breakthrough in the field of science, technology and environment.

Bellamy received his M.S. Operations Research degree from AFIT in 1999. He is a mission manager in the Planetary Missions Program Office at NASA's Marshall Space Flight Center and currently oversees aspects of the agency's Double Asteroid Redirection Test, or DART, the world's first planetary defense test mission. The team successfully altered the orbit of an asteroid, providing the first-ever planetary defense test that could protect Earth from celestial threats.

Bellamy served in the Air Force for 25 years before joining NASA full time in 2013. He served as the mission manager for the project, ensuring team members were working in lockstep and had the resources they needed.

Information obtained from https://servicetoamericamedals.org/

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LEARN MORE ONLINE:
https://e.AFIT.edu/451lmc

NASA photo

AFIT alum Kelly "Scott" Bellamy was recently honored with the 2023 Samuel J. Heyman Service to America Medal for his work at NASA.

AFIT ALUMNI NEWS BRIEFS

AFIT alum Lt. Col. Anna Gunn-Golkin selected as a 2023-2024 White House Fellow

Anna Gunn-Golkin is from Cherry Hill, New Jersey, and is placed at the Office of the Second Gentleman. She is a Lieutenant Colonel in the U.S. Space Force, having most recently served as the Commander of the 3d Test and Evaluation Squadron, leading a team of over one hundred Guardians in the development and execution of first-of-kind missions to protect and defend space capabilities. Anna taught astrodynamics and rocket propulsion at the U.S. Air Force Academy and served as both a Flight Test Engineer and Program Manager for multiple aerospace systems that enable missions of the highest national priority. She is deeply committed to STEM outreach. Anna received a B.S. in Astronautical Engineering from the U.S. Air Force Academy, an M.S. in Astronautical Engineering from the Air Force Institute of Technology in 2006, and she is a distinguished graduate of the Air Force Test Pilot School.

AFIT Alum's Contributions Remembered

Dr. James Mitchell

AFIT alum **Dr. James Mitchell**'s (M.S. Aeronautical Engineering, 1955) contributions to the Arnold Engineering Development Complex are remembered following his passing June 28 at the age of 91. Mitchell was an internationally-recognized expert in aerospace ground testing and was a former U.S. member on the Propulsion and Energetics Panel of the Advisory Group for Aerospace Research and Development, the technical arm of NATO. He is credited with campaigning to reduce the cost of testing at AEDC while improving test and evaluation quality. Mitchell was honored as an AEDC Fellow in 1989.

During his career, Mitchell was credited with more than 30 major publications, technical papers and seminars relating to aeronautics ground testing. Along with his time on the AGARD Propulsion and Energetics Panel, he served on more than 20 of the nation's most prestigious advisory boards, study groups and governmental agency committees, including the Air Force Scientific Advisory Board and the National Research Council Aeronautics and Space Engineering Board Committee for review of aeronautical and space facilities.
>>Read the full story at: https://e.AFIT.edu/SNQ8llLS

AFIT Alum Speaks at AFRL Inspire Event

AFIT alum **Lt. Col. (ret) James "Sass" Bieryla** (M.S. Electrical Science (IDE), 2007) was one of the speakers at AFRL Inspire – a series of TEDx-style talks designed to inspire listeners and highlight the passion, innovation and pioneering spirit of AFRL's science and technology workforce. **A recording of AFRL Inspire 2023 livestream is available on AFRL's YouTube channel at: https://www.youtube.com/watch?v=PQVUPxtTX8I.**

Alum First Guardian to Receive Coast Guard Arctic Service Medal

AFIT alum **Capt. Henry Cho** (M.S. Electrical Engineering, 2021) made history as the first U.S. Space Force Guardian to receive the Coast Guard Arctic Service Medal by spending 21 freezing cold days in the Arctic aboard the U.S. Coast Guard Cutter Healy (WAGB-20). He was there working on a project that this a collaboration between AFRL, AFIT and the USCG Research and Development Center and is sponsored in part by the Air Force Office of Scientific Research.
>>Read the full story at: https://e.AFIT.edu/TTdd41ZZ

Alum and Former Associate Dean Wins Space Stewardship Award

AFIT alum, **Col. (ret) Thomas "TS" Kelso** (M.S. Space Operations, 1982) received the 2023 SpaceNews Icon Award for Space Stewardship. Kelso served as an assistant professor of space operations and associate dean of the Graduate School of Engineering at AFIT.

While leading the U.S. Air Force Space Command's Space Analysis Center in the early 2000s, Kelso became acutely aware of the U.S. military's overwhelming reliance on commercial communications satellites and the fact that the Defense Department was not screening them for potential collisions in geostationary orbit. After retiring from the Air Force, he developed online tools to identify conjunctions and helped establish the Space Data Association, an international organization that enables satellite operators to share ephemeris data and maneuver plans securely, as well as the Space Data Center, which assesses collision risks and issues warnings. **>>Read the full story at: https://spacenews.com/the-2023-spacenews-icon-awards-winners/**

Lieutenant's Journey from USAFA to Miss Colorado to Harvard

2nd Lt. Madison Marsh

2nd Lt. Madison Marsh was crowned Miss Colorado in May 2023 just before graduating from the United States Air Force Academy and commissioning as an Air Force Officer. Currently, she is in a master's degree program at the Harvard Kennedy School through the Air Force Institute of Technology's Civilian Institution Programs and preparing to compete in the Miss USA pageant in 2024.

Marsh studied physics with a focus in astronomy at USAFA. She interned with NASA researching gamma ray bursts and worked with the Etelman Observatory in the U.S. Virgin Islands where she conducted limiting magnitude studies with the Virgin Islands Robotic Telescope.
>>Read the full story at: https://e.AFIT.edu/SSll593

CALENDAR EVENTS

DECEMBER 2023

AFIT Graduate School Fall Quarter Classes End
8 Dec 2023 I AFIT Campus, WPAFB, OH

AFIT Graduate School Fall Degree Conferral (No Ceremony)
21 Dec 2023 I AFIT Campus, WPAFB, OH

JANUARY 2024

AFIT Graduate School Winter Quarter Classes Begin
2 Jan 2024 I AFIT Campus, WPAFB, OH

FEBRUARY 2024

AFIT Graduate School Spring Quarter Registration Begins
5 Feb 2024 I AFIT Campus, WPAFB, OH

MARCH 2024

AFIT Graduate School Winter Quarter Classes End
8 Mar 2024 I AFIT Campus, WPAFB, OH

AFIT Graduate School Commencement Ceremony
21 Mar 2024 I WPAFB, OH

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MISSION
To produce outstanding technical leaders in the Department of Defense by providing superior graduate education built on defense-focused research.

VISION
To be internationally recognized as the school of choice in engineering and applied science for defense-focused and research-based graduate education.

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