
2024
ANNUAL REPORT
ASSURE

FOREWARD

As we reflect on the past year and anticipate the future, I am delighted to present ASSURE's 2024 Annual Report. This pivotal edition documents a year of transformative research endeavors, unwavering commitment to innovation, and strategic foresight into emerging opportunities.

First, I would like to welcome our newest core member to the ASSURE team, North Carolina A&T. Their expertise will add to ASSURE's rich portfolio of research talent.

Completed Research

In 2024, our research team successfully concluded a series of pivotal studies focused on enhancing the operational safety and efficiency of Unmanned Aircraft Systems (UAS). Among our completed projects are studies that address Beyond Visual Line of Sight (BVLOS) operations, including shielded operations and risk mitigations around airports. We also explored the integration of UAS in air cargo and air carrier operations, along with helicopter and small UAS crash severity analysis. These efforts have provided critical insights and strategies that are now shaping industry's best practices and regulatory frameworks.

Ongoing Research

Our current research portfolio embodies our relentless pursuit of excellence and innovation. Ongoing initiatives continue to support BVLOS operations through the development of right-of-way rules and cybersecurity measures. We are validating well-clear requirements and verifying Detect And Avoid (DAA) risk ratios, which are integral to the safe integration of UAS with manned aircraft. Additionally, we are making significant strides in understanding how UAS can be integrated into disaster preparation and recovery operations, optimizing their potential to enhance response times and operational effectiveness during emergencies.

Upcoming Research

Looking ahead, our research trajectory is poised to address pressing challenges and unlock new possibilities in the Advanced Air Mobility (AAM) sector. Upcoming projects will delve into AAM crashworthiness, further refine DAA systems, and lay the groundwork for robust human factors requirements. We will also examine medical requirements for UAS operators, ensuring that human performance meets the demands of this rapidly evolving industry and their integration with legacy systems in the nation's airspace. These initiatives are designed to position the U.S. at the forefront of sustainable and progressive UAS and AAM operations.

Leadership Transition

As we stand on the brink of these exciting advancements, I want to express my deepest gratitude to our stakeholders for their support and collaboration during my tenure. This year, we will undergo a leadership transition as I will retire from my position as Executive Director. I am confident that Hannah Thach will assume these responsibilities with distinction, guiding ASSURE through its next chapter of growth and innovation.

Together, we will continue to build on our legacy, harnessing the power of research to shape a promising and resilient future for UAS and AAM technologies.

Sincerely,

STEPHEN P. LUXION (Colonel-USAF Retired)

Executive Director

ASSURE

TABLE OF CONTENTS

**The photographs and images used throughout this report are not representative of the equipment used in testing.*

ASSURE LEADERSHIP

THIRTY OF THE WORLD'S LEADING RESEARCH INSTITUTIONS
AND MORE THAN A HUNDRED LEADING INDUSTRY AND GOVERNMENT PARTNERS COMPRISE
THE ALLIANCE FOR SYSTEM SAFETY OF UAS THROUGH RESEARCH EXCELLENCE

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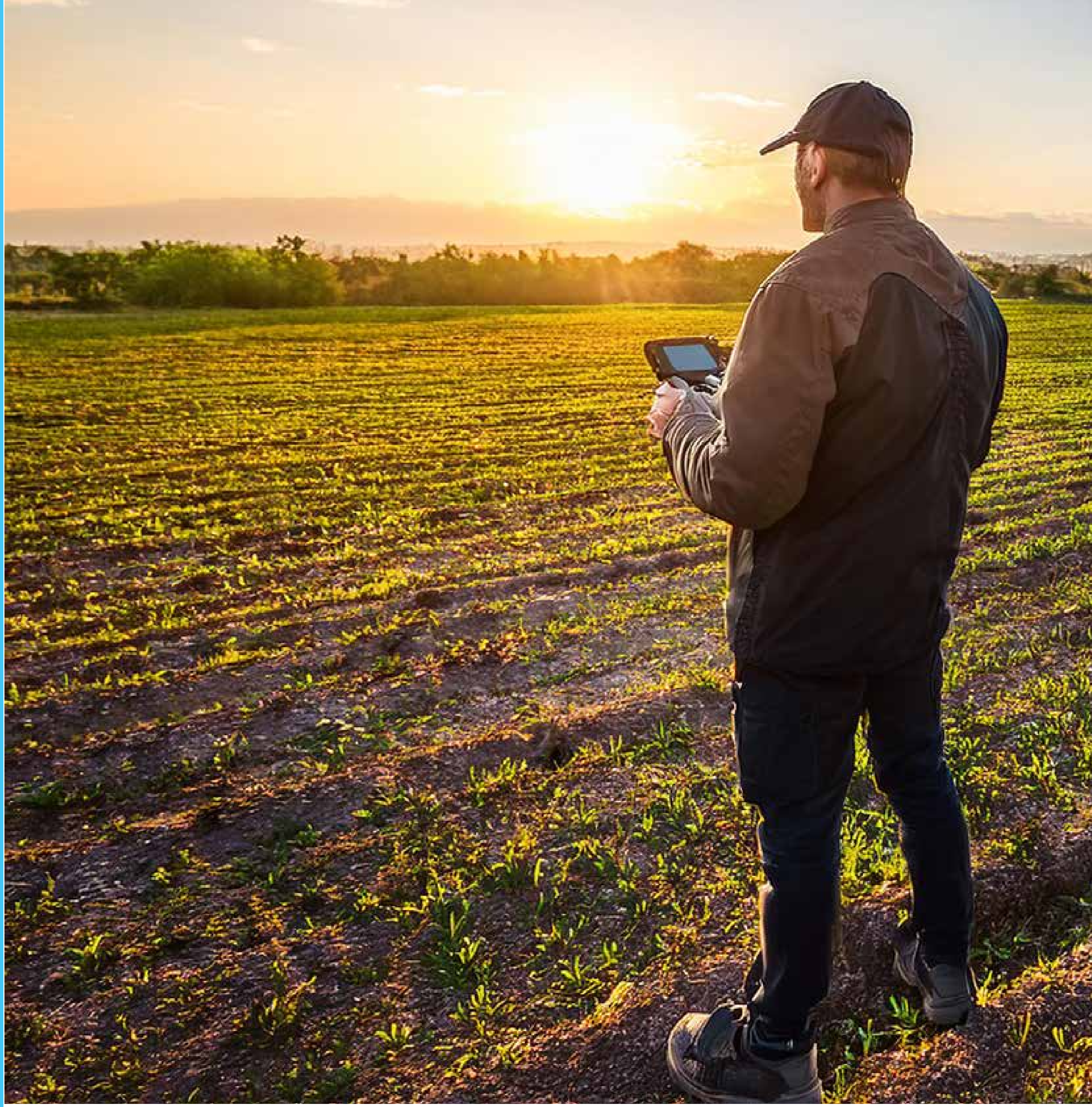
MISSION: Provide high-quality research & support to autonomy stakeholders both within the US and beyond to safely & efficiently integrate autonomous systems into the national & international infrastructure, thereby increasing commerce and overall public safety and benefit.

VISION: ASSURE is the go-to high-quality research organization and brand for working complex autonomy issues with focus on Unmanned Aircraft Systems (UAS) in policy, regulations, standards, training, operations, & education.



INFORMING UAS POLICY THROUGH RESEARCH

The FAA's Center of Excellence for UAS Research

ASSURE

Alliance for System Safety of UAS through Research Excellence

ACKNOWLEDGMENTS

As I begin my transition from my role as Executive Director, I am filled with immense gratitude and appreciation for the remarkable journey over the past nearly ten years. I have had the honor to work alongside some of the most talented and dedicated professionals in the industry at ASSURE.

To my colleagues and teammates, including the entire ASSURE leadership team at Mississippi State University, your commitment to excellence and innovation has been the cornerstone of our success. Your passion and dedication have driven our achievements and have been truly inspiring.

I would also like to extend a heartfelt thank you to the staff and leadership at Mississippi State University. Your unwavering support and collaboration with the ASSURE team have been instrumental in our accomplishments, and I am deeply grateful for your partnership.

Our university partners have provided outstanding innovative and investigative research that has been pivotal in driving our progress and success. The groundbreaking work by our researchers has pushed the boundaries of UAS technology, continuously elevating our capabilities and reputation in this dynamic field.

To our numerous industry, and government partners, thank you for your generous contributions of time, expertise, and effort. Your involvement has been integral to making ASSURE a resounding success, helping us to break new ground and set benchmarks in UAS technology and safety.

Additionally, a special thank you to our partners and sponsors at CNA, NASA, FEMA, the FAA, and NIST. Your collaboration enriches our mission and propels our vision forward.

Finally, I have full confidence in Hannah Thach as she steps into the Executive Director role. Her leadership will undoubtedly guide ASSURE to even greater achievements.

Thank you all for a remarkable decade of collaboration and innovation. It has been a privilege to work with each of you.

With deepest appreciation,

STEPHEN P. LUXION (Colonel-USAF Retired)

Executive Director

ASSURE

FINANCES

ASSURE FY24 FUNDING SUMMARY

TOTAL FUNDING : $96,916,267.04

	AWARD AMOUNT	EXPENDITURES	REMAINING	COST SHARE	COST SHARE REQUIRED	COST SHARE %
PROGRAM OFFICE	$9,897,278.78	$9,260,935.09	$636,343.69	$7,538,880.08	$6,738,314.78	100%
CORE SCHOOLS	$87,018,988.26	$61,243,857.25	$25,775,131.01	$43,450,120.30	$57,178,376.59	76%
Drexel University	$3,158,116.69	$2,875,929.14	$282,187.55	$1,649,070.36	$2,507,196.16	66%
Embry-Riddle Aeronautical University	$6,449,770.13	$4,924,951.49	$1,524,818.64	$2,675,246.02	$3,652,265.12	73%
Kansas State University	$4,946,372.00	$3,684,946.14	$1,261,425.86	$2,541,363.27	$4,754,977.69	53%
Mississippi State University	$10,859,792.38	$6,729,026.29	$4,130,766.09	$4,608,320.34	$7,233,403.13	64%
Montana State University	$709,062.28	$709,062.28	$0.00	$599,958.32	$555,653.03	108%
New Mexico State University	$8,136,193.33	$4,559,679.08	$3,576,514.25	$2,492,766.11	$3,785,106.19	66%
North Carolina State University	$1,844,740.39	$1,240,154.83	$604,585.56	$833,725.50	$1,296,572.64	64%
Ohio State University	$6,013,698.21	$5,083,776.03	$929,922.18	$3,868,906.52	$3,923,822.52	99%
Oregon State University	$3,507,173.00	$2,981,135.16	$526,037.84	$1,052,069.00	$1,376,323.00	76%
Sinclair Community College	$1,291,000.00	$468,564.65	$822,435.35	$598,756.30	$1,291,000.00	46%
University of Alabama-Huntsville	$7,992,660.86	$6,285,993.98	$1,706,666.88	$4,394,253.64	$5,466,053.10	80%
University of Alaska-Fairbanks	$7,518,589.39	$2,924,810.18	$4,593,779.21	$2,057,610.79	$3,517,543.06	58%
University of California-Davis	$144,730.00	$144,730.00	$0.00	$93,287.00	$144,730.00	64%
University of Kansas	$3,281,155.86	$2,703,004.79	$578,151.07	$1,841,843.44	$2,277,081.37	81%
University of North Dakota	$11,815,112.74	$8,394,039.93	$3,421,072.81	$5,547,348.63	$6,045,828.58	92%
University of Vermont	$1,713,600.00	$740,976.30	$972,623.70	$1,725,798.98	$1,713,600.00	101%
Wichita State University	$7,210,829.00	$6,789,796.79	$421,032.21	$6,789,796.08	$7,210,829.00	94%
Virginia Tech University	$426,392.00	$3,280.19	$423,111.81	$80,000.00	$426,392.00	19%
TOTALS	$96,916,267.04	$70,504,792.34	$26,411,474.70	$50,989,000.38	$63,916,691.37	80%

ASSURE FY24 FUNDING SUMMARY

TOTAL FUNDING $96,916,267.04

	Award Amount	Expenditures	Remaining	Cost Share	Cost Share %
PROGRAM MANAGEMENT	$10,125,800.97	$9,487,542.46	$638,258.51	$7,765,487.45	100%
PROJECTS	$86,790,466.07	$61,017,249.88	$25,773,216.19	$43,223,512.93	76%
A1: Unmanned Aircraft Integration: Certification Test to Validate sUAS Industry Consensus Standards	$299,996.00	$299,996.00	$0.00	$300,280.00	100%
A2: Small UAS Detect and Avoid Requirements Necessary for Limited Beyond Visual Line of Sight (BVLOS) Operations	$799,658.63	$799,658.63	$0.00	$799,944.34	100%
A3: UAS Airborne Collision Severity Evaluation	$1,000,000.00	$1,000,000.00	$0.00	$1,023,424.27	102%
A4: UAS Ground Collision Severity	$382,387.89	$382,387.89	$0.00	$409,098.69	107%
A5: UAS Maintenance, Modification, Repair, Inspection, Training, and Certification	$799,980.23	$799,980.23	$0.00	$829,733.21	104%
A6: Surveillance Criticality for SAA	$779,040.15	$779,040.15	$0.00	$779,040.15	100%
A7: UAS Human Factors Considerations	$717,601.08	$717,601.08	$0.00	$724,046.38	101%
A8: UAS Noise Certification	$50,000.00	$50,000.00	$0.00	$50,000.00	100%
A9: Secure Command and Control Link with Interference Mitigation	$329,996.24	$329,996.24	$0.00	$646,943.35	196%
A10: Human Factors Consideration of UAS Procedures & Control Stations	$798,182.05	$798,182.05	$0.00	$884,648.96	111%
A11: Low Altitude Operations Safety: Part 107 Waiver Request Case Study	$151,274.50	$151,274.50	$0.00	$184,588.38	122%
A12: Performance Analysis of UAS Detection Technologies Operating in Airport Environment	$284,186.01	$284,186.01	$0.00	$284,186.42	100%
A13: UAS Airborne Collision Severity Peer Review	$7,026.00	$7,026.00	$0.00	$7,026.00	100%
A14: UAS Ground Collision Severity Studies	$2,039,161.32	$2,039,161.32	$0.00	$2,274,960.61	112%
A15: Stem II	$149,982.00	$149,982.00	$0.00	$158,642.77	106%
A16: Airborne Collision Severity Evaluation - Structural Impact	$2,203,377.79	$2,203,376.77	$1.02	$2,357,156.77	126%
A17: Airborne Collision Severity Evaluation - Engine Ingestion	$1,532,132.43	$1,532,132.43	$0.00	$1,580,974.27	164%
A18: Small UAS Detect and Avoid Requirements Necessary for Limited BVLOS Operations: Separation Requirements and Training	$1,199,608.51	$1,199,608.51	$0.00	$773,195.38	100%
A19: UAS Test Data Collection and Analysis	$409,627.10	$409,627.10	$0.00	$413,558.24	101%
A20: UAS Parameters, Exceedances, Recording Rates for ASIAS	$291,681.65	$291,681.65	$0.00	$396,319.22	136%

FUNDING BY PROJECT

	Award Amount	Expenditures	Remaining	Cost Share	Cost Share %
A21: Integrating Expanded and Non-Segregated UAS Operations into the NAS: Impact on Traffic	$1,456,060.03	$1,456,060.03	$0.00	$581,984.23	112%
A23: Validation of Low-Altitude Detect and Avoid Standards- Safety Research Center	$1,379,521.49	$1,379,521.49	$0.00	$472,732.10	95%
A24: UAS Safety Case Development, Process Improvement, and Data Collection	$1,169,194.30	$1,046,436.98	$122,757.32	$492,538.20	100%
A25: Develop Risk-Based Training and Standard for Operational Approval and Issuance	$316,262.97	$316,262.97	$0.00	$166,054.00	100%
A26: Establish UAS Pilot Proficiency Requirements	$500,000.00	$500,000.00	$0.00	$166,666.00	100%
A27: Establish risk-based thresholds for approvals needed to certify UAS for safe operation	$478,277.78	$478,277.78	$0.00	$166,679.00	100%
A28: Disaster Preparedness and Response	$1,742,968.51	$1,721,897.39	$21,071.12	$962,923.16	144%
A29: STEM Outreach- UAS as a STEM Outreach Learning Platform for K-12 Students and Educators (STEM III)	$484,465.47	$466,014.56	$18,450.91	$130,269.09	57%
A31: Safety Risk and Mitigations for UAS Operations On and Around Airports	$1,865,622.43	$1,858,859.01	$6,763.42	$549,086.15	111%
A33: Science and Research Panel (SARP) Support	$70,383.00	$43,160.74	$27,222.26	$31,839.61	74%
A35: Identify Wake Turbelance and Flututer Testing Requirements for UAS	$1,479,132.51	$1,479,132.51	$0.00	$976,301.92	95%
A36: Urban Air Mobility (UAM): Safety Standards, Aircraft Certification and Impact on Market Feasibility and Growth Potentials	$1,099,817.68	$1,099,164.28	$653.40	$728,097.70	104%
A37: UAS Standards Tracking, Mapping, and Analysis	$456,559.84	$456,559.84	$0.00	$166,633.33	100%
A38: CyberSecurity and Safety Literature Review	$494,103.92	$494,103.92	$0.00	$164,745.33	63%
A40: Validation of American Society for Testing Materials (ASTM) Remote ID Standards- Safety Research Center	$451,209.48	$451,209.48	$0.00	$250,000.00	100%
A41: Air Carrier Operations- Investigate and Identify the Key Differences Between Commercial Air Carrier Operations and Unmanned Transport Operations	$799,745.00	$677,062.49	$122,682.51	$228,471.01	34%
A42: UAS Cargo Operations- From Manned Cargo to UAS Cargo Operations: Future Trends, Performance, Reliability, and Safety Characteristics Towards Integration into the NAS	$799,983.00	$791,156.79	$8,826.21	$224,582.33	84%
A43: High-Bypass UAS Engine Ingestion Test	$506,774.02	$439,757.60	$67,016.42	$213,333.33	100%
A44: Mitigating GPS and Automatic Dependent Surveillance- Broadcast (ADS-B) Risks for UAS	$874,000.00	$809,689.65	$64,310.35	$255,769.67	93%
A45: Shielded UAS Operations- Detect and Avoid (DAA)	$935,627.23	$925,611.01	$10,016.22	$365,617.33	119%
A46: Validation of Visual Operation Standards for Small UAS (sUAS)	$500,185.47	$500,184.63	$0.84	$246,666.88	100%

FUNDING BY PROJECT

	Award Amount	Expenditures	Remaining	Cost Share	Cost Share %
A47: Small UAS (sUAS) Mid-Air Collision (MAC) Likelihood	$960,786.14	$960,786.14	$0.00	$715,801.48	100%
A49: UAS Flight Data Research in support of Aviation Safety Information and Sharing (ASIAS)	$403,651.94	$348,899.37	$54,752.57	$152,047.43	97%
A50: Small Unmanned Aerial Systems (sUAS) Traffic Analysis	$2,436,407.73	$2,046,765.67	$389,642.06	$908,332.80	100%
A51: Best Engineering Practices for Automated Systems	$3,621,915.74	$2,824,276.98	$797,638.76	$1,196,983.14	85%
A52: Disaster Preparedness and Emergency Response Phase II	$3,660,673.35	$3,177,589.47	$483,083.88	$727,314.28	67%
A54: Propose UAS Right-of-Way Rules for UAS Operations and Safety Recommendations (ERAU, KU, UND)	$1,626,864.53	$1,555,280.19	$71,584.34	$688,574.86	32%
A58: Illustrate the Need for UAS Cybersecurity and Risk Management	$1,869,991.00	$1,676,130.99	$193,860.01	$444,395.23	70%
A60: Evaluation of Unmanned Aircraft Systems (UAS) Integration Safety and Security Technologies in the National Airspace System (NAS) Program	$13,972,343.80	$4,674,348.70	$9,297,995.10	$3,052,621.48	66%
A61: STEM Outreach	$231,153.42	$174,881.68	$56,271.74	$197,374.26	85%
A62: Disaster Preparedness and Emergency Response Phase III	$2,768,070.00	$1,980,172.85	$787,897.15	$2,633,761.45	95%
A64: Identify Models for Advanced Air Mobility (AAM)/ Urban Air Mobility (UAM) Safe Automation	$1,602,165.00	$1,252,474.34	$349,690.66	$1,429,639.49	89%
A65: Detect and Avoid Risk Ratio Validation	$2,351,492.79	$1,261,345.02	$1,090,147.77	$1,442,368.60	61%
A67: Determine the Collision Severity of small Unmanned Aircraft Systems (sUAS) in Flight Critical Zones of Piloted Helicopter	$1,795,948.00	$1,795,947.71	$0.29	$1,795,948.00	100%
A66: Develop Methodolgies to Inform the Integration of Advanced Air Mobility (AAM) into the National Air Space System (NAS)	$2,000,000.00	$674,275.37	$1,325,724.63	$739,430.30	37%
A68: Validate sUAS Well Clear Definition	$2,113,515.00	$758,242.66	$1,355,272.34	$1,079,067.83	51%
A71: Conduct Safety Risk Management Analysis on small Unmanned Aircraft Detect and Avoid Systems	$1,011,388.00	$278,785.66	$732,602.34	$770,552.57	76%
A73: STEM Outreach to Minority K-12 Students Using UAS as a Learning Platform	$333,045.00	$81,276.57	$251,768.43	$238,808.39	72%
A74: Increase Small UAS Conspicuity in Terminal Environments	$2,059,997.00	$41,208.70	$2,018,788.30	$288,457.88	14%
A84: Disaster Preparedness and Emergency Response Phase IV	$5,993,435.00	$0.00	$5,993,435.00	$0.00	0%
Totals	**$96,916,267.04**	**$70,504,792.34**	**$26,411,474.70**	**$50,989,000.38**	**80%**

COST SHARE SUMMARY

COST SHARE SUMMARY BY CONTRIBUTORS

Adaptive Aerospace Group, Inc.	$5,897.34
Advanced Thermoplastic Composites	$400.00
AIM Institute	$5,090.00
Airbus	$2,255,176.00
AgentFly Software	$50,000.00
ARC	$41,355.58
Aria Group, Inc.	$400.00
Arlin's Aircraft	$3,000.00
AUVSI	$15,873.00
A&P Technology	$410.00
Boeing	$46,235.64
CAN Corporation	$722,798.86
Composites One	$500.00
Composites World	$600.00
Consortium on Electromagnetics and Radio Frequencies	$2,675.00
C.R. Onsrud	$40,000.00
DJI	$63,285.84
DJI Research, LLC	$48,522.80
Drexel University	$1,368,833.64
Embry-Riddle Aeronautical University	$1,845,403.36
General Electric	$145,930.48
GFK Flight	$63,333.33
GoPro	$29,925.60
GreenSight Agronomics, Inc.	$37,777.00
Honeywell	$30,275.78
Huntsville Airport	$233,529.20
Impossible Objects	$500.00
Indemnis	$251,685.84
Intel	$113,101.60
IRIS Automation	$71,000.00
Jaunt Air Mobility	$500.00
K.I.M. Inc.	$85,280.00
Kansas Department of Commerce	$282,180.00
Kansas State University	$2,923,720.28
Keysight Technologies	$566,690.00
Keystone Aerial Surveys	$1,750.00
Kongberg Geospatial	$40,000.00
Mike Toscano	$147,500.00
Misc. External Match - Industry Funds	$310,605.12
Mississippi State University	$3,442,172.04
Montana Aircraft	$6,000.00
Montana State University	$521,387.68
911 Security	$88,781.54
Navmar Applied Sciences Corporation	$1,819,885.70
New Mexico State University	$2,492,766.11
North Carolina Department of Transportation	$288,492.81
North Carolina State University	$1,229,726.79
North Dakota Department of Commerce	$3,064,901.10
Novotech	$500.00
NUAIR	$20,923.02
Ohio State University	$1,686,390.54
Ohio/Indiana UAS Center (ODOT)	$1,410,048.75
Oregon State University	$1,018,295.72
OpenSky Network	$120,000.00
R Cubed Engineering	$6,970.09
RFAL	$21,343.30
Rochester Institute of Technology	$54,854.34
Rockwell Collins	$4,015.80
Sagetech Avionics	$52,350.00
Sandia	$2,257.00
SenseFly	$471,131.36
Sierra Nevada Corporation	$6,559.00
Simlat Software	$147,260.00
Sinclair Community College	$1,528,575.70
State of Kansas	$91,604.83
Skyfire Consulting	$350,480.00
Solvay	$254.00
Technion Inc	$4,132,708.49
Teijin Carbon America, Inc	$500.00
The Cirlot Agency	$120,237.56
Transport Canada	$531,654.00

(CONTINUED ON NEXT PAGE)

COST SHARE SUMMARY

COST SHARE SUMMARY BY CONTRIBUTORS

University of Alabama in Huntsville	$2,470,173.10
University of Alaska Fairbanks	$2,057,610.79
University of California Davis	$93,287.00
University of Kansas Center for Research, Inc.	$1,187,834.82
University of North Dakota	$1,807,210.39
University of Vermont	$1,138,147.35
Unmanned Systems Group	$34,565.64
USRA, Inc	$500,467.00
Virginia Polytechnic Institute and State University	$530,580.65
Wichita State University	**$4,584,355.08**
Total	**$50,989,000.38**

SUMMARY BY YEAR

FY16 Cost Share	$4,197,084.44
FY17 Cost Share	$4,274,690.28
FY18 Cost Share	$1,789,332.05
FY19 Cost Share	$7,863,252.88
FY20 Cost Share	$5,601,392.05
FY21 Cost Share	($319,059.87)
FY22 Cost Share	$7,990,466.31
FY23 Cost Share	$10,027,455.24
FY24 Cost Share	**$9,564,387.00**
Cumulative Cost Share	**$50,989,000.38**

SUMMARY BY SOURCE

Universities	$31,981,325.38
State Contributions	$5,137,227.49
3rd Party Contributions	$13,870,447.51
Total	**$50,989,000.38**

RESEARCH PROJECTS

SAFETY RISKS AND MITIGATIONS FOR UAS OPERATIONS ON AND AROUND AIRPORTS

A11L.UAS.72_A31

PARTICIPANTS

UNIVERSITY OF ALASKA - FAIRBANKS
KANSAS STATE UNIVERSITY
NEW MEXICO STATE UNIVERSITY
UNIVERSITY OF ALABAMA - HUNTSVILLE
UNIVERSITY OF NORTH DAKOTA

Safety Risks and Mitigations for UAS Operations On and Around Airports

Background:

There are no policies, procedures, or criteria for operating UAS on and around the airport surface while aircraft operations are in progress. Integrating UAS into the airport environment will result in National Airspace System (NAS) changes. The ATO SMS Manual indicates safety analyses are performed in response to NAS changes or existing safety issues.

A recent change incorporated within FAA Order JO 7110.65 states that Air Traffic Control (ATC) services are not provided to any UAS operating in the NAS at or below 500 ft Above Ground Level (AGL). However, ATC is not prohibited from providing services to civil and public UAS by this change.

As UAS integrate into the NAS, safety analyses should be performed to assess the risks associated with UAS operations on and around the airport surface, ensuring proper risk mitigation strategies are put in place. These safety analyses should address factors such as the integration or segregation of operational areas at airfields, signage and runway markings, communications infrastructure; approved frequencies, facilities for UAS ground control stations, external pilots near runway surfaces, and the variety and varying capabilities of UAS from small UAS through large UAS platforms and how these varied capabilities could impact airport design, function, and emergency response.

The research is intended to address gaps in knowledge that are currently a barrier to the safe, efficient, and timely integration of UAS into the NAS.

This safety and risk analysis focuses on evaluation of UAS operations on and around the airport surface. The research will identify the potential risks with regards to UAS operations near manned aircraft, communication with these UAS operators (if necessary), and Air Traffic services (if not provided). The research may inform potential changes to FAA regulations and industrial standards.

Approach:

Task 1: Literature Review

Identify relevant research and documentation in the areas of UAS performance in and around airports including Urban Air Mobility (UAM) and UAS Traffic Management (UTM) implications.

Task 2: Propose other potential areas of research beyond what is outlined in the task. Coordinate and prioritize the research to be conducted. Develop a Research Task Plan with potential increased/decreased scoping based on findings. Hold a scoping peer review with the FAA and other parties determined by the FAA to discuss the Research Task Plan and determine the appropriate scope level.

Task 3: Determine research shortfalls identified from the literature review and develop case studies to address shortfall areas. Case study methods may include, but are not limited to modeling and simulation, and flight tests to address research shortfalls.

Define the overall concept and specific use cases for conducting operations on the airport surface. This includes but is not limited to: UAS airport inspections, perimeter security, Foreign Object Debris (FOD) inspections, runway inspections, emergency response, wake turbulence separation, and large UAS takeoff and recovery. Airspace class (B, C, D, E, G, towered/non-towered) for each use-case must be considered.

The research team and the program sponsor examined the research being conducted by the FAA's William J. Hughes Technical Center and identified three use cases that were non-duplicative with the current FAA-conducted research. The three use cases and leads for each use case are:

1) Large drone operations - UAF and NMSU
2) Landside building inspections - UND
3) Emergency response - KSU

The use cases all include flight operations at local airports. Additionally, the UND team purchased ADS-B data for each airport and is simulating the effects of different hazards on the risk to other aircraft and operations on airport. The team also simulated emergencies to inform the team about the hazards and potential mitigations that needed to be implemented during flights.

Task 4: Using the FAA's ATO Safety Management System (SMS) process, identify the hazards and mitigations of the use cases. The research team developed a list of hazards and potential mitigations for the various use cases based on available literature and the teams' experiences. Each team developed a safety risk analysis that was used as the basis for the safety case included in each team's submission to DroneZone for flight permissions.

Task 5: Evaluate at least three use cases by conducting a research team SMS panel using FAA SMS policies.

After discussion with the sponsors, the research team decided to meet the SMS panel review using all of the safety analyses done in support of a pre-existing Certificate of Authorization (COA) received by UAF 2022-WSA-10342. This documentation includes all of the forms submitted into the FAA's COA Application Processing System (CAPS), previous hazard matrices calculations for the UAF SeaHunter large drone, letters of agreement, memoranda of agreement, the actual COA, and other associated documents. The research team conducted an internal analysis of the documentation provided to the FAA during COA submission and identified two places where the language in the paperwork needed to be clarified. The hazards and potential mitigations identified in the internal walkthrough were consistent with those identified by all team members during their hazards analyses. The COA included operations at Fairbanks International Airport.

Task 6: Flight Testing – Propose flight testing and analysis with exit criteria for three use cases to validate the proposed mitigations.

The flight testing addressed the similarities and differences between use case hazards and mitigations based on airspace class and towered/nontowered airport operations and the uniqueness of each airport, the communications between UAS operators, ATC, and other airport users/managers during UAS operations on and around the airport surfaces, the ability of the SMS process to identify and mitigate hazards before conducting the flight operations, and the effectiveness of the policies and procedures developed by the research team for operating on and around airport surfaces. The lessons learned from the operations will inform the development of policies and procedures for these types of operations.

Key Findings:

Overall:

The Safety Risk Analyses developed for all three use cases were very similar in the hazards identified and potential mitigation strategies proposed for on-airport operations.

The Safety Risk Analyses procedures utilized by the research team were sufficient to obtain the required flight permissions from the FAA for all of the use cases.

The research team's pre-Safety Risk Management Panel analysis of the materials submitted for the large drone COA identified some areas for language improvement, but otherwise concluded that the materials submitted were sufficient to evaluate the risk of the operation.

Emergency Response Use Case:

Good communications are essential for effective deployment of the UAS during emergency operations. Pre-determined, sequenced language will assist in successful communications during emergency response operations.

Streaming video to other participants in an activity is very helpful in establishing situational awareness.

The main concern from the FAA airspace authorization processer was that for a UAS operation to occur over a movement area, it had to be closed with a NOTAM. Deploying from ARFF to a scene would therefore require a NOTAM. Alert 3's or 4's would close the airport until the determination could be made of what could be opened. AJT reviews all on-airport requests, so hopefully, they would consider an Alert 3/4 in lieu of the NOTAM closure, allowing the UAS to deploy from ARFF.

For an emergency response demonstration/training, what could be beneficial is an authorization that has a special provision with wording such as "Operations allowed only during an Alert 3/4 call, unless a NOTAM is filed at least 24 hours in advance…". This would not only allow us to conduct the demonstration for the project with a NOTAM posted, but also serve as a template for future airports hoping to conduct real-world operations in the future during an emergency call and for emergency training purposes.

Large UAS cases:

The conditions at the airport will dictate what equipment is required on a UAS operating at the airport during specified weather conditions.

Designing aircraft and operations to deal with these challenges will be essential for safe operations on airport surfaces in snowy regions.

- Small tires may not provide enough traction for high-speed taxiing.
- Differential braking is needed to control sliding.

Converted traditional cargo aircraft will have some of these issues handled (tire size, for example), but how the remote pilot or autonomy handles braking (brakes full on vs. differential braking) could create a challenge.

The process for getting all of the approvals required to operate a large drone at an airport is not clear.

An airport's not clearing of the trees in the Runway Safety Area (RSA) or Runway Object Free Area (ROFA) can inhibit drone operations at an airport.

An airport manager giving permission for a ground control station trailer to be located adjacent to a runway is not sufficient to meet FAA recommendations/regulations for that placement.

Ground NOTAMs must be issued in addition to airspace NOTAMs for placing a ground control station at different locations at an airport.

The ground control station is considered construction equipment and requires associated paperwork to be adjacent to a taxiway.

People could not believe the Cessna was the 'drone' that they heard was coming.

The autonomous aircraft learned during the flights and improved over the course of the flight test.

Rocks on a gravel runways present a challenge to autonomous (and traditional) aircraft landing on that runway.

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INVESTIGATE AND IDENTIFY THE KEY DIFFERENCES BETWEEN COMMERCIAL AIR CARRIER OPERATIONS AND UNMANNED TRANSPORT OPERATIONS

A11L.UAS.83_A41

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Investigate and Identify the Key Differences Between Commercial Air Carrier Operations and Unmanned Transport Operations

Background:

Urban Air Mobility (UAM) or autonomous UAS is anticipated to be larger than 55 lbs. Recent analysis by NASA indicates that UAS carrying up to six passengers may require a payload of 1200 lbs. According to FAA rules, UAS weighing 55 pounds or greater must be registered using the existing aircraft registration process. Larger UAS are presently flown within the National Airspace System (NAS) by federal agencies, including the Departments of Defense, Homeland Security, Interior, Energy, Agriculture, NASA, and some state and local governments, and academia. While some of these departments require certificates of authorization lasting two years, others have their own self-certification for authorizations, e.g., the Department of Defense and Customs and Border Patrol. While defense and civilian agencies are already using large UAS in the NAS, it is anticipated that these UAS may also be used for commercial purposes in the near future. One of the uses could potentially be the transportation of cargo and passengers. Continued safe integration of UAS is essential, and the FAA is taking a proactive approach to understanding trends, identifying potential markets, and forecasting the integrations of large UAS in the NAS. These forecasts are used throughout the agency for safety and investment analysis and workload planning.

Recent UAM experiments, combined with the fact that large UAS are indeed flown in the NAS today, lead to anticipation that large UAS will be used to facilitate air transportation in the future. New and additional procedures, airspace rules, and equipment standards including their performances and reliability will need to be developed and/or modified to accommodate safe integration of UAS in the NAS.

For the FAA to be prepared for this eventual transformation and integration needs, it will be essential to:

• Understand key differences with existing commercial air carrier and charter operators and likely trends in large UAS, particularly with a focus on understanding its role in transporting. passengers, both scheduled and unscheduled routine operations in short-haul (UAM) and longer-haul (autonomous UAS).

• Forecast larger UAS requiring analysis of market viability, adoption rates, technology, rules and procedures, and the anticipated trajectories into non-segregated airspaces together with anticipated timelines.

• Consider the effects of pandemics, such as COVID-19, in impacting market viability and adoption trends.

• Understand performance characteristics, reliability, and standards of larger UAS within the Air Traffic Control (ATC) serviced classes of airspace in the future.

• Understand the performance requirements of ATC to allow larger UAS to be flying in the airspaces, e.g., under what circumstances, can these large UAS fly within the Mode-C veils?

• Understand separation requirements and/or rules for integration (i.e., communication, navigation, and surveillance rules, in particular) into these airspaces.

• Understand strategic and tactical airspace clearance requests arising from UAM operations.

• Understand requirements for type design, airworthiness, and production approvals (e.g., type certificates, airworthiness certificates, and production certificates) and how changes in these may facilitate regulatory initiatives. Also, understand safety risk management requirements emanating from these integrations.

• Provide a projection of additional workforce required at towers and/or TRACON because of these anticipated changes and implications on airspace requirements, including procedures and regulations.

• Provide physical infrastructure requirements, e.g., airport redesign, vertiport, etc., to accommodate this new mode of air transportation.

To address these issues, an approach to predicting the larger (>55lb) commercial aircraft growth into the higher non-segregated altitudes (e.g., above 400ft AGL) is needed, with special emphasis on the use of these UAS in the transportation of passengers. The approach (i.e., modeling and simulation of airspaces) along with a near-term forecast is necessary to understand and prioritize NAS resources as these newer aircraft evolve in serving greater civilian and commercial needs such as air transportation. Finally, the Task Order will inform future regulatory updates to UAS right-of-way rules, detect and avoid performance standards, and collision avoidance standards.

Approach:

Task 1: Literature Review and Market Analysis

The research team conducted a literature review and market analysis focused on the technical requirements of Advanced Air Mobility (AAM) on the NAS and the potential infrastructure requirements, whereas the market analysis identified market trends, potential for industry growth, and the ramifications of establishing AAM infrastructure in rural and moderately populated areas. Completion of the literature review, market analysis, and related recommendations for this study were based upon lessons learned from prior research, including NASA-sponsored studies. Additionally, the market analysis explored questions of market demand, observed and predicted trends, and determined impacts relating to the integration of UAM into both existing and potentially novel infrastructure.

Due to similarities in subject matter and scoping, the literature reviews for A41 and A42 were linked and combined into a single document. This was done to ensure that there was no duplication of effort and to identify distinct similarities and differences between unmanned air transport and unmanned air cargo. As such, a single combined literature review document was submitted for both projects.

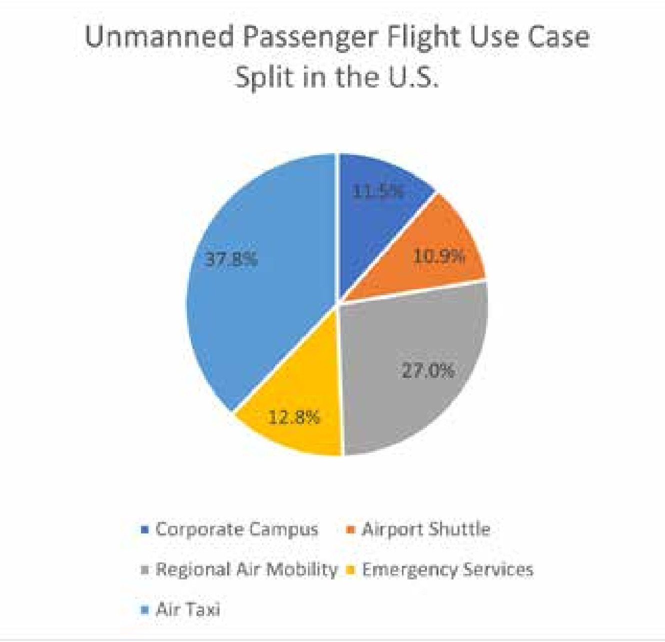

Figure 1. Unmanned Passenger Flights by Market Share (UAM Geomatics, 2021).

Task 2: Use Case Development

Use case development for Task 2 built upon the literature review and market analysis for Task 1. For this task, the research team used data from the literature and initial market analysis to generate considerations for use cases. The research team refined considerations for use cases and scoped future tasks based on the use cases chosen for further investigation. A key consideration at this stage of the project was to determine a use case or use cases, such that they were representative of likely industry trends.

Based on the market analysis, the research team considered several potential AAM use cases, including corporate campus, airport shuttle, regional air mobility, emergency services, and air taxi. Regional air mobility and air taxi cumulatively made up nearly two-thirds of the projected market shares, with air taxi garnering 37.8% and RAM following with 27%. The research team chose these use cases because they made up the most significant of the market share (Figure 1). While the team initially considered investigating additional use cases, the emphasis on air taxi and RAM was commensurate with their anticipated market shares. As such, the research team did not consider other use cases, such as airport shuttle, corporate campus travel, and emergency services for future tasks.

Task 3: Methodology

Given the variables and use cases identified in Task 2, the research team devised a research methodology that employed a two-pronged approach to answer research questions. This approach (Figure 2), offered insight into the use cases from two perspectives, seeking insight from AAM Original Equipment Manufacturers (OEMs) and those who would use the systems – i.e., the "flying public." The experiment, consisting of a two-pronged approach using interviews and a survey instrument, enabled the exploration of variables identified in previous tasks while simultaneously addressing guiding research questions. More importantly, the researchers designed the experiments such that they would shed light on areas of potential growth in AAM and highlight areas of future research.

More specifically, the research methodology consisted of:

1. A targeted interview for OEMs to identify important design and operational considerations for their systems, and

2. A survey aimed at addressing perceptions the public may hold regarding AAM, including economic considerations.

Task 4: Conduct Designed Experiments

The research team distributed a survey to gather data regarding views, opinions, and willingness to fly/pay for AAM. The team distributed the survey using a distribution service known as LUCiD. LUCiD provided a reliable method for distributing the survey across the United States, ensuring broad coverage and census-grade representative sampling. The survey also targeted the top 30 potential AAM site locations (Table 1) described in the ASSURE A36 Site Suitability Analysis. The ASSURE A36 research team found the locations listed in Table 1 to be particularly suitable for the growth and development of AAM over time.

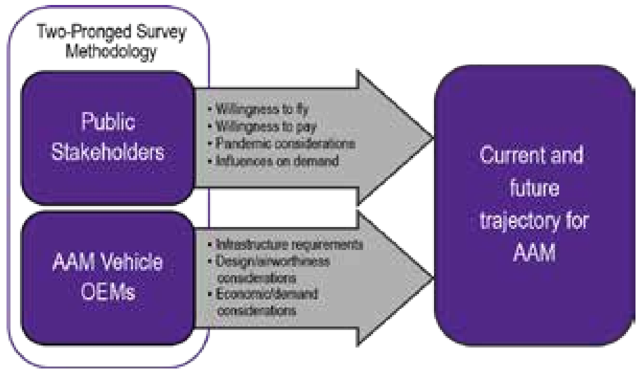

Figure 2. Two-pronged approach to exploring key variables for AAM.

ASSURE A36 AAM SITE SUITABILITY – TOP 30 LOCATIONS FOR AAM GROWTH.

Rank	Metropolitan Statistical Area
1	New York-Newark-Jersey City, NY-NJ-PA Metro Area
2	Los Angeles-Long Beach-Anaheim, CA Metro Area
3	Dallas-Fort Worth-Arlington, TX Metro Area
4	Boston-Cambridge-Newton, MA-NH Metro Area
5	San Jose-Sunnyvale-Santa Clara, CA Metro Area
6	Orlando-Kissimmee-Sanford, FL Metro Area
7	Detroit-Warren-Dearborn, MI Metro Area
8	Miami-Fort Lauderdale-Pompano Beach, FL Metro Area
9	San Francisco-Oakland-Berkeley, CA Metro Area
10	Columbus, OH Metro Area
11	Minneapolis-St. Paul-Bloomington, MN-WI Metro Area
12	Chicago-Naperville-Elgin, IL-IN-WI Metro Area
13	Bridgeport-Stamford-Norwalk, CT Metro Area
14	Washington-Arlington-Alexandria, DC-VA-MD-WV Metro Area
15	Houston-The Woodlands-Sugar Land, TX Metro Area

CONTINUE ON NEXT PAGE

Rank	Metropolitan Statistical Area
16	Riverside-San Bernardino-Ontario, CA Metro Area
17	Philadelphia-Camden-Wilmington, PA-NJ-DE-MD Metro Area
18	Indianapolis-Carmel-Anderson, IN Metro Area
19	Seattle-Tacoma-Bellevue, WA Metro Area
20	Allentown-Bethlehem-Easton, PA-NJ Metro Area
21	Atlanta-Sandy Springs-Alpharetta, GA Metro Area
22	Madison, WI Metro Area
23	Providence-Warwick, RI-MA Metro Area
24	Poughkeepsie-Newburgh-Middletown, NY Metro Area
25	Hartford-East Hartford-Middletown, CT Metro Area
26	Pittsburgh, PA Metro Area
27	Wichita, KS Metro Area
28	Portland-Vancouver-Hillsboro, OR-WA Metro Area
29	Cleveland-Elyria, OH Metro Area
30	Milwaukee-Waukesha, WI Metro Area

Figure 3 offers a snapshot of the survey distribution. The distribution of the survey correlated with the top 30 AAM sites in addition to surrounding areas, covering both coasts, southern regions of the country, and the Midwest.

Figure 3. Survey Respondent Locations.

Task 5: Economic Assessment and Methodology

The team conducted an economic impact assessment to evaluate how AAM passenger mobility will affect the US economy. This required defining the period of analysis (the duration of time for measuring impacts), isolating the determinants of economic impact (the key drivers that cause changes to the economy), developing the process to model economic impacts (building the economic model), and reporting the analysis findings. For this study, the period of analysis was determined to be from the present day through 2045.

Task 6: Final Report

The research team assembled a final report that captured each task/sub-task within the research project and captured key findings from the research. The resulting report was submitted via ASSURE and received multiple rounds of review before being submitted to the FAA sponsor for final review and acceptance in January of 2024.

Key Findings:

Primary considerations for unmanned air transport fall into the following categories:

- Airspace – Changes will be required regarding traffic management.
- Regulatory considerations – The current regulatory framework will likely require updates to accommodate new technologies, practices, and airworthiness/certification considerations to accommodate unmanned air transport aircraft.
- Automation – The shift to automation will begin by phasing out the pilot, starting with simplified vehicle operation, moving to remote operation, and ending with full automation.
- Airman certification and training – Airman certification and training must accommodate shifts in trends toward increasing automation.
- Design and airworthiness – With the large number of designs, standardization is needed, as are mechanisms to validate new technologies and approaches to aircraft design. Regulatory changes may be required, and industry standards may serve as both a means of compliance and a mechanism for defining design and airworthiness requirements.
- Unmanned Aircraft System Traffic Management (UTM) – UTM will be essential for handling traffic volumes and will likely follow a phased-in approach, beginning with low-risk (non-passenger) traffic.

- Demand is highly coupled with public acceptance.
- Public acceptance is dictated by (1) safety, and (2) privacy/security.
- Infrastructure will need significant expansion to achieve large-scale usage.
- The ability for air transport to alleviate congestion may give air transportation an edge over ground transportation. Integration with existing public transport is critical, but there is also potential for adverse effects – e.g., wait times, impact of weather, etc.
- Due to expectations, UAM can likely be more expensive

than alternative transportation modes, but it must also provide overall time savings (access and process times included).

- Congestion may give UAM an edge over ground transportation, especially in certain markets. It will likely be critical (to achieve widespread adoption of UAM) to integrate UAM access with existing public transportation networks. Note that UAM has the potential to adversely affect existing public transportation networks.
- To achieve large-scale usage, UAM infrastructure will need a significant expansion: more access points (vertiports) and electric grid upgrades to handle charging the vehicles. Access point operational efficiency will be important to maintaining low costs and significant time savings for the users.
- Regulations will also play a key role (e.g., affecting infrastructure or minimum clearances affecting climb rates and hence vehicle recharge and client wait times).
- The relative influence (or even existence) of these factors may vary significantly across various locations and demographics, making careful planning essential to successfully targeting and serving a market.
- With such an untested technology, many of these conclusions are tentative, and in places, there is still disagreement in the literature.

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FROM MANNED CARGO TO UAS CARGO OPERATIONS: FUTURE TRENDS, PERFORMANCE, RELIABILITY, AND SAFETY CHARACTERISTICS TOWARDS INTEGRATION INTO THE NAS

A11L.UAS.84_A42

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From Manned Cargo to UAS Cargo Operations: Future Trends, Performance, Reliability, and Safety Characteristics Towards Integration into the NAS

Background:

According to FAA rules, UAS weighing 55 pounds or greater must be registered using the existing aircraft registration process. Many of these aircraft are presently flown within the NAS by federal agencies, including the Departments of Defense (DoD), Homeland Security (DHS), Interior (DOI), Energy (DOE), Agriculture, NASA, and some state and local governments, and academia. In 2018, these Agencies had flown 3,784 flights (by 42 Reapers or 90 ops per aircraft per year); 494 flights (by 23 Shadows or 21 ops per aircraft per year); 362 flights (by 13 Predator A or 28 ops per aircraft per year); and 290 flights (by 3 Global Hawks and Tritons or 97 ops per aircraft per year). While some of these organizations require Certification of Authorizations (COAs) lasting two years, others have their own self-certification for authorizations, e.g., DoD, Customs and Border Patrol (CBP). While defense and civilian agencies are already using large UAS in the NAS, it is anticipated that these UAS may also be used for commercial purposes (e.g., agricultural spraying, commercial real estate, pipeline inspections, communication relay, etc.) in the near future. One of the uses could potentially be transportation of air cargo. Continued safe integration of UAS is essential, and the FAA is taking a proactive approach in understanding trends, identifying new markets, and forecasting large UAS in the NAS. These forecasts are used throughout the Agency for safety and investment analysis along with workload planning.

The FAA has observed an increasing trend in operational requests, via waiver of Part 107 regulations, for expanded UAS operations in Night Operations, Ops Over People, and Beyond Visual Line Of Sight categories in both segregated and non-segregated areas (i.e. airspace where the likelihood of encountering a manned aircraft is greater and/or demand on airspace is likely). The expanded operations typically occur within the 'segregated' domains where traffic and population density are relatively low. Consistent with the FAA's strategic approach to integration, there is increased interest (via waiver requests), and industry coordination (e.g., existing Integration Pilot Program or IPP) to migrate such operations into non-segregated areas as well.

These three future trends, i.e., large UAS (i.e., both public and anticipated commercial), sUAS transitioning into non-segregated airspaces, and gradual proliferation of sUAS in package delivery indicate that there may be more innovations in the near future. The team anticipates that large UAS will be used to facilitate cargo delivery in the near future. New and additional procedures, airspace rules, and equipment standards including their performances and reliability will need to be developed and/or modified to accommodate safe integration of UAS in the NAS.

Given these anticipated trends, it will be essential to:

- Understand trends in large UAS, particularly with a focus to understand its role in cargo delivery, both scheduled and unscheduled routine operations;
- Establish likely relationships between likely manned cargo transitioning into large UAS;
- Establish any significant change following the onset of COVID-19 and likely adoption of larger UAS in cargo carrying capabilities;
- Forecast large UAS, both civil and commercial, and transitioning sUAS requiring analysis of market including competition, technology, and the anticipated trajectories into nonsegregated airspaces together with anticipated timelines;
- Understand performance characteristics, reliability and standards of large UAS and those sUAS anticipated to transition within the ATC-serviced airspaces (G, D, E, A, B, and C in probable order of importance) over the next few years;
- Understand performance requirements of ATC to allow large UAS to be flying in the airspaces e.g., under what circumstances, can these large UAS fly within the Mode-C veils?
- Understand separation requirements and/or rules for integration (i.e., communication, navigation, surveillance, informational (CNSi) rules, in particular) into these airspaces;
- Understand requirements for type design, airworthiness and production approvals (e.g., type certificates, airworthiness certificates and production certificates); understand also how changes in these may facilitate regulatory initiatives such as MOSAIC;
- Understand safety risk management requirements for these integrations; and
- Provide projection of workforce associated with these anticipated changes and implications on airspace requirements including procedures and regulations; and
- Provide an understanding of physical infrastructure required to facilitate large UAS delivering cargo incrementally in the NAS, e.g., redesigning of airport including ramps, delivery points, etc.

To address these issues, an approach to predicting the larger (>55lb) commercial aircraft growth into the higher non-segregated altitudes (e.g., above 400ft AGL) and the migration of the sUAS into the higher non-segregated altitudes is needed, with special emphasis on the use of these UAS in transportation of air cargo. The approach (i.e., modeling and simulation of airspaces) along with near-term forecast is necessary in order to understand and prioritize NAS resources as these newer aircraft evolve in serving greater civilian and commercial needs such as air transportation of cargo.

Approach:

The approach to this project included the following tasks:

- Task 1: Literature and Market Analysis
- Task 2: Use Case Development
- Task 3: Experiment Plan
- Task 4: Conduct Designed Experiments
- Task 5: Economic Assessment and Methodology

The team prepared a survey, had it approved by school Institutional Review Boards, and sent it to 1700 live email addresses.

The survey was broken up into five sections: Current State of Air Cargo Operations; Potential for Future Air Cargo/Changes to Enable Autonomous Air Cargo; Current Market-Related Questions; Future Market-Related Questions; and End User-Related Questions (Exploring the Effects of Large/Medium UAC).

The research team organized these sections to focus on the perceived interests/lines of effort of the following target audiences: Original Equipment Manufacturers (OEM)/Air Carriers with a focus on aircraft, maintenance, etc.; Airport/Airfield Operations with a focus on infrastructure; and end users with a focus on premium for timely delivery, critical items, etc.

Within each section, the questions were grouped into 3 sets corresponding to their perceived order of importance: (1) These begin with the most critical questions for the viability of the effort (Vital); (2) followed by questions considered to be of moderate importance (Significant); (3) finally by questions of interest that would be helpful in formulating a set of well-thought strategies and recommendations (Helpful).

Additionally, the survey respondents were asked to identify their experience with the following air cargo classes:

·HLM+HRM: Heavy, Long-Range & Medium-Range (500 to >3000 nm) aircraft with payload capacities (10T to >40T)

·Regional: Regional-Range (75 – 1,000 nm) aircraft with payload capacities (1 – 10T)

·Light: Short-Range (<250 nm) aircraft with payload capacities (50 – 1,000 lb)

The team selected a subset of the questions for use during interviews with representatives from current air carriers.

The economic assessment and methodology team developed demand forecasts for three use cargo use cases: HLR/HMR, Regional/Feeder, and Light/ Vertical Takeoff and Landing (VTOL). They also developed associated demand projections to be used as the basis for the economic impact analysis. They were looking at traditional markets with partial Advance Air Mobility market capture using combination of forecasts (BTS, LMI Consulting et al., IATA, FAF) as well as new markets using a site suitability analysis and LMI Consulting forecasts.

The site suitability analysis is designed to identify the most suitable airports in the US and in each state, and rank the states in terms of suitability for the implementation of large UAS cargo.

In the site suitability analysis, the team determined that some of the most important factors for site suitability include:

- Runway lengths at VTOL gateway meet regional aircraft standards:
    - o 1,970'-3,000'
    - o 3,001-3,600'
    - o 3,601'+
- VTOL gateway is not congested with commercial operations (<1,460 commercial operations per year)
- Gateway has JetA fuel.
- Population within gateway service area
    - o SA 1 = 17 miles
    - o SA 2 = 75 miles
    - o SA 3 = 150 miles
- Highway lane miles in service area
- Elevation changes in service area
- Class G airspace available and not congested
- Existing investment(s) being made
- Someone available to unload cargo
- Location with severe or hazardous events

For regional and light use cases, the research team focused on the following to achieve a site suitability score:

- Testing for confluence of geospatial variables
- Locations with the greatest confluence of variables receive the highest score
- Each variable can be weighted individually
- The findings are based on the literature, but the literature is not complete.

- Creating a workbook tool capable of weight adjustments

Figures 1A and 1B show examples of two different weighting schemes. The red areas in Figure 1A show locations that score well with existing enabling infrastructure (runway length, fuel, near electric utility substations). The red areas in Figure 1B show locations that score well by having remotely located populations (located away from freight networks, population clusters, limited Class B airspace to interfere with ops). The areas most suitable for implementation of large UAS cargo operations are very similar under the two weighting schemes for the contiguous United States. However, the weighting schemes provide very different results for Alaska with the remote areas with populations cluster weighting scheme showing higher favorability for large drone cargo implementation in Alaska than the infrastructure readiness weighting.

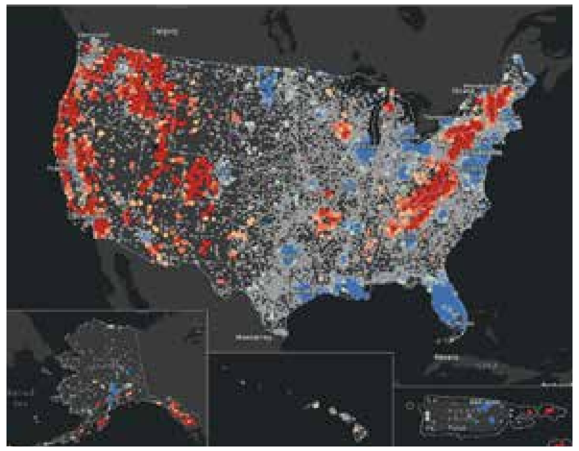

Figure 1A. "Infrastructure Readiness."

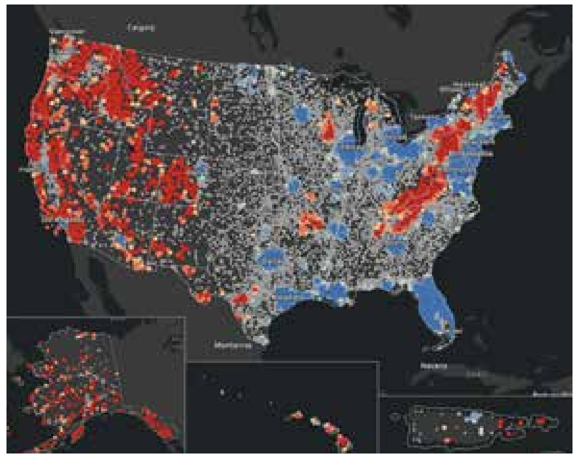

Figure 1B. "Remote Areas with Population Clusters."

These site suitability analyses and demand projections from the literature provide the basis for estimating economic impacts.

Key Findings:

The implementation of economically-feasible, large UAS cargo in remote communities will be determined by need, location, existing infrastructure, and personnel.

The areas most suitable for implementation of large UAS cargo operations as determined by the site suitability analysis are very similar under the two weighting schemes for the contiguous United States. However, the weighting schemes provide very different results for Alaska with the remote areas with populations cluster weighting scheme showing higher favorability for large drone cargo implementation in Alaska than the infrastructure readiness weighting.

Solid communications with the remote communities are essential for smooth operations in those communities. For example, it was difficult to contact the fuel provider in Galena, which could lead to an aircraft reaching a community and the infrastructure and supplies to refueling it not being available.

Rocks on gravel runways present a challenge to autonomous (and traditional) aircraft landing on some remote communities' runways.

(Continued on next page)

The personnel available to pilot and/or observe the large UAS will help determine what model (remotely piloted from one point, remotely piloted with a hand-off during flight, or autonomous) of UAS command and control will provide the most robust operations for remote communities.

Flight crew, cargo handlers, and remote community population safety and aircraft/payload security must be incorporated in the planning for remote cargo delivery.

Weather will be one of the biggest challenges in implementing year-round cargo delivery. The remote pilot in command or the autonomous system piloting the aircraft must be able to handle poor weather reporting and unexpected or unreported conditions such as high winds. The Merlin aircraft encountered high winds on an approach at an airport where the winds were listed as low/calm.

Community engagement will be essential for the acceptance of UAS cargo deliveries in remote communities.

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HIGH-BYPASS TURBOFAN UAS ENGINE INGESTION TEST

A11L.UAS.85_A43

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High-Bypass Turbofan UAS Engine Ingestion Test

Background:

The inclusion of large numbers of small UAS (sUAS) into the National Airspace System may pose unique hazards to other aircraft sharing the airspace. It is necessary to determine the potential severity of sUAS mid-air collisions with aircraft to define an Equivalent Level of Safety to manned aviation.

H.R. 636 – FAA Extension, Safety, and Security Act of 2016, Section 2212, Unmanned Aircraft Systems – Manned Aircraft Collision Research, mandated UAS research to determine the impact severity of ground and airborne collisions.

Since there is no similarity of a UAS to any other foreign body currently being regulated, understanding the severity of the ingestion event is critical to be able to estimate the extent of damage encountered in a typical incident/accident.

To aid in the longevity of the information gathered during this research, high-fidelity data gathering, instrumentation, and model validation is crucial for future FAA regulatory and policy development surrounding safe UAS integration into the national airspace.

Approach:

The research will be carried out in close collaboration with the test partner and the FAA. The team will help inform and review the test plan created by the test partner. The test partner will provide the team with a model of the fan stage used in the experiment. A finite element model will be created using material models given by the test partner or will leverage the closest pre-existing material models in alignment with the recently completed computational engine ingestion research. All the reduced and processed data obtained by the test partner, including high-speed and regular-speed videos, onboard engine performance data during the test, ambient conditions, and onboard and non-contact measurement system data from systems run by the test partner, will be shared with the team for their independent analysis. The team will run computational simulations at the test conditions using LS-DYNA (a finite element analysis software that specializes in highly nonlinear transient dynamic analysis) following the best practices set forth by the LS-DYNA Aerospace Working Group. This work will provide an analysis of the fan impact to inform the overall computational modeling approach conducted in the recently completed computational engine ingestion research. The test partner will also provide a final test report and their analysis of the test event, which the research team will review based on their expertise and independent analysis. Finally, the research team will coordinate with the FAA on the overall messaging of the engine ingestion research.

Task 1: Testing Oversight

The objective of this research task is to provide testing oversight and analysis for the live engine ingestion test. Task 1 can be broken into the following sub-tasks:

Sub-Task 1.1: Test Plan Input and Review

The objective of this task is to ensure a test plan that will produce a valuable data set for answering current and future research questions related to UAS engine ingestions. This task includes coordinating with the ongoing computational research and the FAA to provide the test partner with input on the test plan. The test plan will include the planned conditions for the test (i.e., operating conditions of the engine, launch speed, location, and orientation of UAS). The test partner in consultation with the FAA/ASSURE team, will select an operational engine for the test. The test plan will also include planned measurement instrumentation and setup location. Scans of the blades pre- and post-test will also be provided to the research team for use in the computational studies. The research team will provide additional input on the measurement data that should be taken and recommendations for the setup to obtain needed data for the initial analysis and potential future work. The test partner will be responsible for the overall test plan, incorporating all the needed instrumentation and implementing the test plan to complete the test and capture all the necessary data.

Sub-Task 1.2: Post-Testing Analysis

The objective of this task is to conduct an independent post-test analysis of the engine ingestion test. The test partner will be conducting their analysis of the engine ingestion and will provide the reduced and processed measurement data from the experiment. This task is focused on reviewing the analysis of the test partner and conducting a computational simulation of the ingestion event for comparison purposes. Similar to the ingestion work in the recently completed computational research program, an ingestion analysis focused on the damage from the primary impact of the UAS with the fans will be performed to evaluate damage in the blades of the fan section. The damage from the computational simulation will be compared to the experiment. Elastic material properties will be used for the casing and nose cone to provide appropriate boundary conditions and to determine secondary impacts and loading patterns.Sub-Task 1.3: Final Test Report and Modeling Validation

The objective of this task is to provide a final test report on the research program that includes the results of both the research team and the test partner, as well as the conclusions from analyzing the engine ingestion test. Moreover, the work will also be used to validate the modeling approach used in the currently ongoing computational engine ingestion research. In particular, a comparison of the computational simulation of the ingestion with the full-scale test will be conducted. Differences in the response and damage are expected due to the prior use of the actual fan and the unknown proprietary materials processing in the construction of the actual fan. Finally, the simulated proprietary fan ingestion case and the representative fan from the computational research will also be compared to give a better frame of reference for how the damage in the representative fan compares to an actual in-service engine.

Sub-Task 1.4: Engine Research Messaging

The objective of this task is to coordinate with the FAA, test partner, ASSURE, and other stakeholders in the appropriate messaging of the research in the public release of the research findings. This task will require discussions with key stakeholders in the proper framing of the research conducted and the results obtained in the overall context of safely integrating UAS into the national airspace.

Key Findings:

The team has supported the research efforts of the test partner in identifying an outer radial span impact location with fan operating at takeoff conditions being ideally suited to understand a critical impact case. The team has also supported the UAS launcher development, which has been completed by the test partner. The test partner has successfully completed the test per the agreed-upon test plan. Preliminary analysis of the computational simulation results qualitatively matches the data from the experiment.

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SHIELDED UAS OPERATIONS: DAA

A11L.UAS.87_A45

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Shielded UAS Operations: DAA

Background:

Certain sUAS Beyond Visual Line of Sight (BVLOS) operations, such as infrastructure inspection, may be near structures that are collision hazards for manned aircraft. These types of operations that are in close proximity to manned aviation flight obstacles such that they provide significant protection from conflicts and collisions with manned aircraft are termed "shielded" operations. This effort identified risks, determined whether shielded operations can be made safe, to what degree UAS Detect and Avoid (DAA) requirements can be reduced, and recommended UAS standoff distances from manned aviation flight obstacles.

Approach:

Task 1: Literature Review and Risk Identification

The research team conducted a comprehensive literature review of shielding research, risks associated with shielded operations, and related topics.

Task 2: Shielding Classes, Risk Assessments, and Listing of Mitigations

The team identified Shielding Classes/Categories, with an emphasis on current use cases being explored (e.g., current BVLOS ARC efforts). The team identified hazards and mitigations and prioritized each.

Task 3: Analysis of DAA Requirements and Obstacle Avoidance Requirements

The team developed a simulation environment that enabled the assessment of risks and potential solutions identified in Tasks 1 and 2. Numerical simulations were be performed to analyze the competing shielding requirements to manage risks associated with flight near obstacles and to manage risks involving manned aircraft.

Task 4: Flight Test Plans

The team developed flight test plans to evaluate findings from earlier tasks.

Test 5: Tests and Reports

The team executed flight tests according to the developed test plans.

Task 6: Standards and Development

Research produced is valuable to standards development efforts. The team supported relevant standards development efforts and enhanced them by providing relevant research results.

Task 7: Final Briefing and Final Report

The research team summarized and aggregated all of the previous papers and reports into a final report package for the overall project. The final report answered previously mentioned knowledge gaps and provided clear recommendations to the FAA.

Task 8: Peer Review

The research team supported project close out.

Key Findings:

The literature review illustrated that the amount of literature that directly addresses shielded UAS operations is scarce. However, significant research has been conducted in related areas, such as aircraft operations at low altitudes and the impact of structures/objects on supporting systems (e.g., GPS).

Key factors that impact shielded operations (i.e., create risk for such operations) include:

- Manned aircraft behavior in these environments;
- Wind and turbulence effects;
- Bird densities/behaviors; and
- Impacts on supporting systems (GPS, command and control, etc.).

Shielding Classes/Categories have been identified. In addition, associated hazards and mitigations have been evaluated, with the latter being prioritized. One of the most significant challenges is determining the likelihood of events, as they depend upon airspace density (which is not generally known and is highly variable). The team has developed a proposed foundation for evaluating likelihoods associated with interactions with aircraft (loss of well clear, near mid-air collision, etc.) that is based upon probability theory. This approach has the benefits of a rich theoretical basis and the ability to translate to other metrics (e.g., risk ratio). In addition, the team is using multiple approaches (survey and data analysis) to estimate safety benefits associated with shielded operations (e.g., reduction in manned traffic density).

The team has simulated multiple hazards associated with shielded operations. These include GPS degradation, electromagnetic fields associated with power lines, and wake turbulence impacts. These simulations provide guidance regarding hazard trade-offs (flying too close to objects resulting in increased risks versus losing shielding benefits that limit interactions with manned aircraft).

Plans were developed and executed for three rounds of flight testing. These showed that different types of maneuvers have significant impacts on the time required to reach well-clear status. Placing obstacles between the UAS and the intruder, thus producing a safe state, can significantly reduce the time required to reach well-clear status and DAA system requirements. Tests also confirmed that operation near buildings can significantly deteriorate GPS performance.

This effort involved a broad set of tasks designed to deepen understanding of shielded operations. Through the execution of these tasks and the application of the numerous methods required to do so, shielded operations knowledge has been significantly enhanced, which will enable more rapid integration of sUAS into the National Airspace System.

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VALIDATION OF VISUAL OPERATION STANDARDS FOR SMALL UAS

A11L.UAS.88_A46

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Validation of Visual Operation Standards for Small UAS

Background:

The emergence of copious small Unmanned Aircraft System (sUAS) operations in the last decade, for both hobby and commercial purposes, highlighted the need for further research and reforms to current regulations. The current regulations (14 Code of Federal Regulations (CFR) Part 107) require sUAS operations to be conducted within Visual Line of Sight (VLOS) of the Remote Ppilot (RP). Due to these requirements, the RP must always maintain visual contact with the sUAS without any visual aids except for corrective lenses. Beyond Visual Line of Sight (BVLOS) operations are regularly used in military applications and are desired for commercial UAS operations. A major challenge associated with the integration of UAS operations within the National Airspace System is the ability to comply with 14 CFR § 91.111, 91.113, and 91.115, which require UAS operations to ensure collision avoidance with other traffic in the airspace. The current regulations (14 CFR § 107.31) allow for a Visual Observer (VO) to assist the RP in maintaining safety, providing an additional set of eyes to scan the airspace around the sUAS for air traffic that may pose a collision risk. The RP has the final authority in the operation of the aircraft, including commanding maneuvers, flight planning, and ensuring the overall safety of flight. Both the VO and RP serve critical roles in the operation of sUAS.

The following concerns were identified regarding capabilities as they relate to 14 CFR Part 107:

- Part 107.29, it is unknown how well VOs/RPs could avoid manned aircraft at night (e.g., a waiver to Part 107.29) or during periods of civil twilight when the sUAS is equipped with anti-collision lighting visible for at least three statute miles. It is unknown what factors VOs/RPs may encounter and how this may impact future training standards.
- Part 107.31, it is unknown how well VOs/RPs can ascertain the position of a UAS in terms of location, attitude, altitude, and direction of flight using vision unaided by any device other than corrective lenses. It is also unknown how well RPs can use visual reference information to detect and avoid other air traffic and/or collision hazards.
- Part 107.33, it is unknown what challenges may arise from VO and RP communications when a VO relays information to an RP about a perceived intruder aircraft or other potential collision hazard.
- Part 107.37, it is unknown how well VOs/RPs can give way to conflicting aircraft and avoid the creation of a collision hazard.

Task 1: Literature Review

For this task, the A46 research team reviewed the literature associated with the human visual system, human factors, and human visual performance models to establish a foundation for a methodology to investigate VO effectiveness in an Extended Visual Line Of Sight (EVLOS) environment. The team identified the most common type of visual illusions that VO/RPs could experience. There are a limited number of experiments, publicly available, that have been executed to assess the role of VO/RPs in visual detection of sUAS. The information captured in this literature review was used to plan for simulations, tests, demonstrations, and/or analysis required to assess VO/RP performance. Key takeaways from the literature include:

- The human visual system is limited by the following factors: blind spot, acuity threshold, accommodation of the eye, empty field myopia, and focal traps. The human visual system during nighttime is limited by the following factors: mesopic vision, scotopic vision, night blind spot, and dark adaptation.
- Visibility of the UAS drops to fewer than ten arc-minutes when operated over 400 ft altitude.
- VOs are poor at estimating the distance and the altitude of the sUAS and are likely to overestimate both the distance and the altitude of the sUAS.
- Key factors that affect sUAS visual detection by manned aircraft pilots include sUAS motion, the contrast of sUAS against the background, employment of vigilant scanning techniques, and scanning using the peripheral field of view.
- Pilots can experience illusions but remain spatially aware, and disorientation is the single most common cause of human-related aircraft accidents.
- Auditory information can provide an initial location estimate that the VO can use to reduce the size of the visual scan area, speeding up visual detection.
- VOs can estimate the location of an aircraft quite accurately using only auditory information.
- There are no standardized training requirements for VO; however, many universities and institutions have their own training guidelines.
- While the number of categories covered and the depth of training by subject did vary, the Test Sites and university materials reviewed had central core topics such as airspace knowledge, Certificate of Authorization requirements, waivers, FAA requirements, and communication procedures.
- VO training should identify and explain the various communication aids that may be used during an EVLOS operation when the RP and VOs may be in separate locations, as well as proper communication procedures.
- There is no one set of published standards for performing testing of Detect and Avoid systems, and there is no current uniform way to characterize the roles of the VO/RP in the broader scope of detect and avoid testing.

Task 2: Updated Research Task Plan

A key component of this work was to maintain an up-to-date Research Task Plan (RTP) to inform all stakeholders involved with this work. The research team updated the RTP as tasks were designed and completed. A final RTP was delivered as a component of this task.

Task 3: Initial Test and Analysis

This task consisted of the development and execution of experimental flight test plans. As part of this task, the research team designed, reviewed, and executed a flight test plan to investigate the effectiveness of VOs in a real-world flight environment.

The flight test plan included:

- Flight course design;
- VO Recruitment;
- Encounters; and
- Data Collection.

Task 4: Flight Test Methodology

The research team utilized a sUAS flight test campaign in Kansas to collect data associated with this experimental design. The experimental design allowed the research team to collect general information regarding VO detection performance, such as ambient noise, light levels, and individual physiological differences related to visual acuity, color deficiency, and hearing capabilities. A series of preliminary test runs of the experiment design were conducted at New Mexico State University in advance of the final data collection flights conducted in Kansas. This initial testing was used to assess personnel layout, data collection methods, flight path geometries, data gathering approaches, data analytics, and other testing elements to ensure successful testing with participants in Kansas.

Task 5: Case Study

To provide a substantial contribution through Task 5, the research delivered a lessons learned document detailing the processes, procedures, and limitations of the current methodology towards enhancing future research and flight tests in this domain. The document detailed the process and procedures followed by both KSU and NMSU toward flight testing. Limitations of the study were also documented, and recommendations for future research were provided.

Key Findings:

The A46 KSU flight tests spanned eight days with 19 participants acting as VOs. On a given day, either two or three VO stations were active. The VO stations were located about 200 ft apart from each other. The KSU flight tests utilized two different manned aircraft as intruders – the Cessna 172 Skyhawk or the Cirrus SR20. The research team processed and analyzed 157 and 183 valid runs for the C172 and SR20 intruder aircraft, respectively. The Great Shark 330 UAS was selected as the ownship in the flight tests. The UAS mission was simulated to operate about 1.25 miles north of the VO stations. The UAS mission was set to fly a box pattern flight path with a groundspeed of 45 kts and an altitude of 400 ft Above Ground Level (AGL).

The primary dependent variable in the A46 experiment design was the intruder detection distance. Table 1 provides the descriptive statistics for intruder detection distance calculated for the A46 encounters with C172 intruder aircraft, SR20 intruder aircraft, and the combined dataset. The VOs detected the intruder aircraft (C172 & SR20) at an average distance of 1.67 miles. The VOs detected the C172 intruder aircraft at an average distance of 1.90 miles and the SR20 intruder aircraft at an average of 1.46 miles.

Table 1. Descriptive statistics for intruder detection distance calculated for the KSU flight test encounters.

INTRUDER DETECTION DISTANCE [MILES]				
INTRUDER AIRCRAFT: C172 & SR20, SAMPLE SIZE = 340 RUNS				
Min.	Max.	Mean	Median	Std. Dev.
0.05	4.24	1.67	1.54	0.70
INTRUDER AIRCRAFT: C172, SAMPLE SIZE = 157 RUNS				
Min.	Max.	Mean	Median	Std. Dev.
0.05	4.24	1.90	1.69	0.81
INTRUDER AIRCRAFT: SR20, SAMPLE SIZE = 183 RUNS				
Min.	Max.	Mean	Median	Std. Dev.
0.22	3.90	1.46	1.45	0.51

Figure 1 shows the percentile distribution for intruder detection distance calculated for the A46 encounters with C172 intruder aircraft, SR20 intruder aircraft, and the combined dataset. The VOs detected the intruder aircraft (C172 & SR20) at a distance of at least 1 mile in 89.5% of the runs, a distance of at least 2 miles in 22.6% of the runs, and a distance of at least 3 miles in 3.3% of the runs. The VOs detected the C172 intruder aircraft at a distance of at least 1 mile in 90.8% of the runs, a distance of at least 2 miles in 37% of the runs, and a distance of at least 3 miles in 9.2% of the runs. The VOs detected the SR20 intruder aircraft at a distance of at least 1 mile in 88.3% of the runs, a distance of at least 2 miles in 10.5% of the runs, and a distance of at least 3 miles in 1% of the runs.

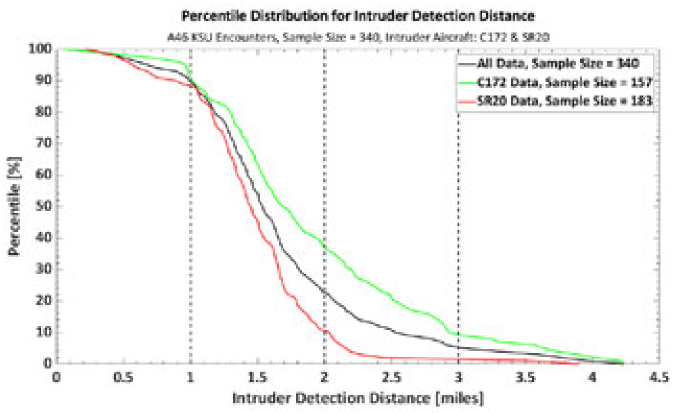

Figure 1. Percentile distribution for intruder detection distance calculated for the KSU flight test encounters.

The research team also evaluated the statistical relationship between the intruder detection distance and the independent variables in the A46 experiment design. The first independent variable investigated was the ambient light level at the time of detection. Figure 2 shows the relationship between the intruder detection distance values and the ambient light level at the time of detection. A linear regression model was computed for this data (shown in Figure 2). The coefficient of determination (R2) value for the regression model is very low (< 1), indicating a high spread for the data. The Spearman correlation (rs) value was computed to be -0.17 for this data indicating a weak negative correlation between the intruder detection distance and the ambient light level. The Spearman probability (ps) value was computed to be 0.022 (< 0.05), indicating a statistically significant relationship between the intruder detection distance and the ambient light level.

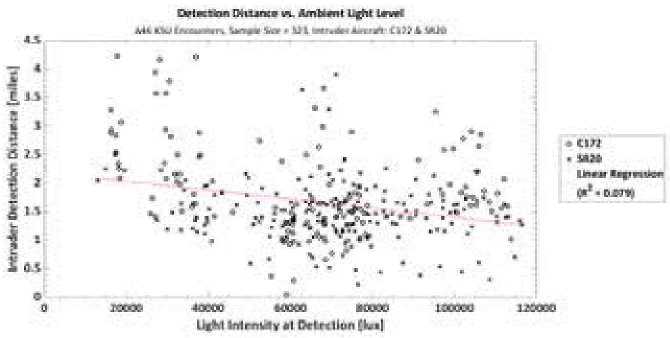

Figure 2. Scatter plot for intruder detection distance vs. light intensity at detection for the KSU flight test encounters.

The second independent variable investigated was the ambient noise level at the time of detection. Figure 3 shows the relationship between the intruder detection distance values and the ambient noise level at the time of detection, adjusted for outliers.

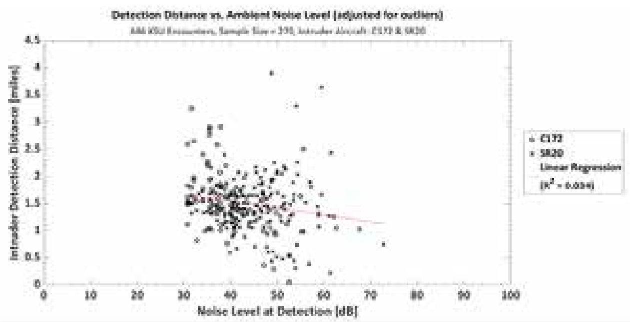

Figure 3. Scatter plot for intruder detection distance vs. noise level at detection (adjusted for outliers) for the KSU flight test encounters.

The third independent variable investigated was the VO Aviation Experience level, shown in Figure 4. The research team defined three categories for the VO Aviation Experience level – Low, Medium, and High. VOs with no prior aviation experience were categorized as Low. VOs that were remote pilots or student pilots were categorized as Medium. VOs that completed their private pilot certification were categorized as High.

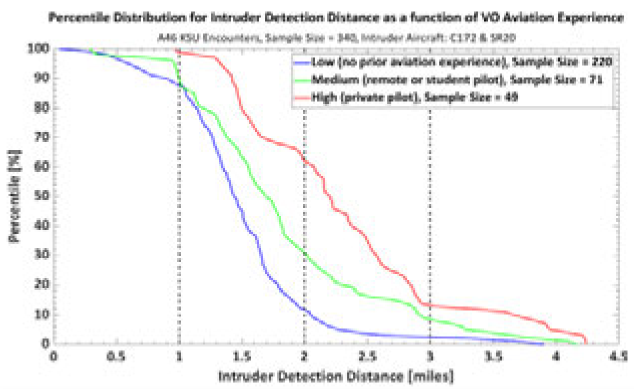

Figure 4. Percentile distribution of intruder detection distance as a function of the VO Aviation Experience categories for the KSU flight test encounters.

Figure 5 shows the percentile distribution for the intruder detection distance as a function of the VO Visual Acuity categories. The ANOVA test p-value was computed to be 0.6140 (> 0.05), indicating a statistically insignificant relationship between the intruder detection distance and the VO Visual Acuity. As seen in Figure 5, the VO detection performance was similar for the Low and High categories of VO Visual acuity. The total number of observations was 69 for the Low category and 271 for the High category.

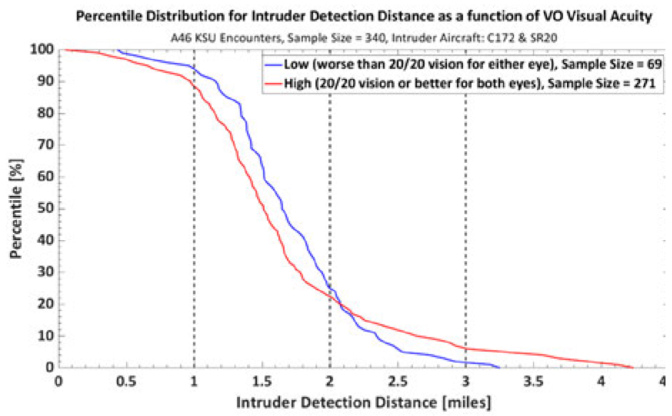

Figure 5. Percentile distribution of intruder detection distance as a function of the VO Visual Acuity categories for the KSU flight test encounters.

The fifth independent variable investigated was the intruder aircraft speed at the time of detection. Figure 6 shows the relationship between the intruder detection distance values and the intruder aircraft speed at the time of detection. A linear regression model was computed for this data (shown in Figure 6). The coefficient of determination (R2) value for the regression model is very low (< 1), indicating a high spread for the data. The Spearman correlation (rs) value was computed to be -0.18 for this data indicating a weak negative correlation between the intruder detection distance and the intruder aircraft speed. The Spearman probability (ps) value was computed to be 0.001 (< 0.05), indicating a statistically significant relationship between the intruder detection distance and the intruder aircraft speed.

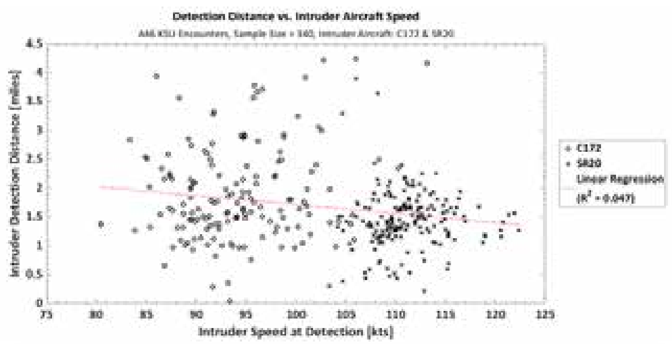

Figure 6. Scatter plot for intruder detection distance vs. intruder speed at detection for the KSU flight test encounters.

Table 2 provides the descriptive statistics for intruder speed at detection for the A46 encounters for both the C172 and SR20 intruder aircraft. The average speed for the SR20 intruder aircraft was 18% higher than the average speed for the C172 intruder aircraft. The statistical analysis suggests that a higher intruder aircraft speed degrades VO detection performance.

Table 2. Descriptive statistics for intruder speed at detection for the KSU flight test encounters.

INTRUDER SPEED AT DETECTION [KTS]				
INTRUDER AIRCRAFT: C172, SAMPLE SIZE = 157 RUNS				
Min.	Max.	Mean	Median	Std. Dev.
80.4	113.1	94.2	93.7	5.9
INTRUDER AIRCRAFT: SR20, SAMPLE SIZE = 183 RUNS				
Min.	Max.	Mean	Median	Std. Dev.
103.3	122.4	111.1	110.6	3.6

The sixth independent variable investigated was the size of the intruder aircraft. The intruder aircraft size was determined using (1) projected visual area and (2) visual angle. The following sections describe how the research team defined the visual area of the intruder aircraft, explored detection distance as a function of visual area, and accounted for visual (viewing) angles. The projected visual area for a given aircraft is a function of the aircraft's position and direction of flight with respect to the VO location. Table 3 provides the side and front projected areas that were the most relevant for the calculations again for clarity. The front and side visual areas of the Cessna 172 and SR20 aircraft are almost identical. The front visual area of the CTLS aircraft is 74.4% of the front visual area of the Cessna 172. The side visual area of the CTLS aircraft is 52.7% of the side visual area of the Cessna 172.

Table 3. Descriptive Statistics for Intruder Aircraft Speed at Detection (KSU Flight Test Encounters).

INTRUDER AIRCRAFT	VISUAL AREA – FRONT [SQ. FT]	VISUAL AREA – SIDE [SQ. FT]
NMSU - CTLS	44.81	57.43
KSU - Cessna 172	60.19	109.05
KSU - SR20	57.72	100.98

The following gives the breakdown of avoidance maneuvers suggested by the VOs for the KSU flight test encounters with the Cessna 172 intruder aircraft, SR20 intruder aircraft, and the combined dataset. The experiment limited avoidance maneuvers called out by the VOs to the vertical domain and included options for the UAS to descend, climb, or maintain its current altitude. The participants acting as VOs determined the avoidance maneuvers based on their estimate of the intruder aircraft's altitude. The participants were aware that the UAS was operating at an altitude of 400 ft AGL. The participants had no visual sight of the simulated small UAS as it had an apparent operating area approximately 1.25 miles north of the VO stations. Figure 7 depicts the breakdown of the avoidance maneuvers suggested by the VOs for the KSU flight test encounters. VOs determined that no avoidance maneuver was required and that the UAS could maintain its altitude in 57.1% of the trials. VOs suggested a descend avoidance maneuver in 34.1% of the trials and a climb avoidance maneuver in 8.8%. Figures 8a and 8b depict the breakdown for the avoidance maneuvers separately for the Cessna 172 and SR20 intruder aircraft, respectively. VOs determined avoidance maneuvers unnecessary in 48.4% and 64.5% of the Cessna 172 and SR20 intruder aircraft trials, respectively. VOs suggested a climb avoidance maneuver in 15.9% of the trials for the Cessna 172 intruder aircraft and only in 2.7% of the trials for the SR20 intruder aircraft. VOs suggested a descend avoidance maneuver in a similar percentage of trials for intruder aircraft – 35.7% for the Cessna 172 and 32.7% for the SR20. Subsequent sections discuss the effectiveness of the VO-suggested avoidance maneuvers in maintaining separation between the UAS and the intruder.

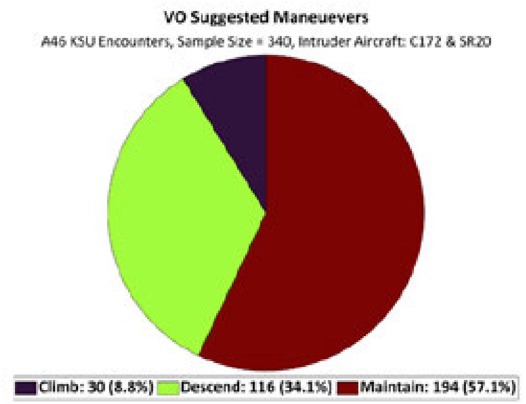

Figure 7. Breakdown of Avoidance Maneuvers Suggested by the VOs for the KSU Flight Test Encounters.

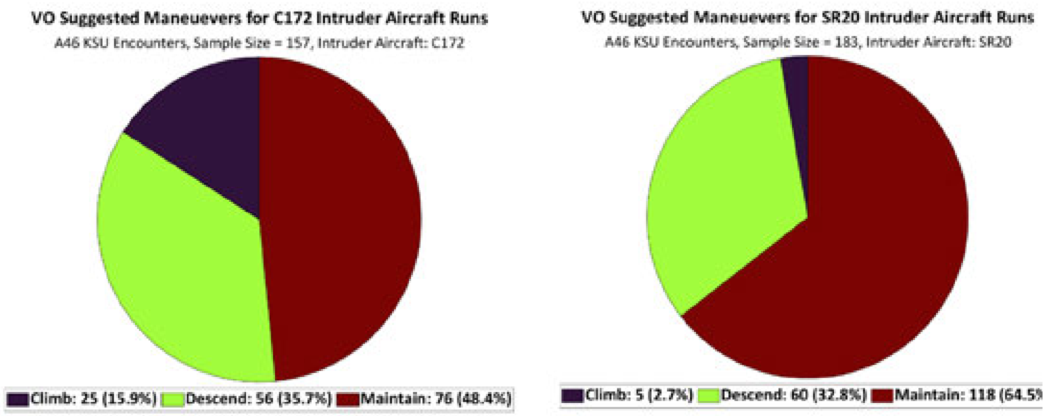

Figure 8. Breakdown of avoidance maneuvers suggested by the VOs for the KSU flight test encounters separately for each intruder aircraft (a) Cessna 172 and (b) SR20.

The research team computed the Closest Point of Approach (CPA) for both mitigated and unmitigated flight paths. The unmitigated flight path was calculated based on the assumption that the UAS operated at a constant speed of 45 knots and a constant altitude of 400 ft AGL throughout its mission flight path. At the start of every run, the position of the actual UAS flight path was used to determine the start position for the unmitigated flight path. Figure 9 shows the mitigated (actual) and unmitigated (reference) flight paths for the UAS.

Figure 9. Example Encounter Flight Paths for the UAS and Intruder (P1 VO Station, Run #4, Day 1- 11/01/22).

The change in CPA between mitigated and unmitigated encounters is a sound measure of the effectiveness of an avoidance maneuver. A positive value change in CPA indicates increased separation between the intruder and the UAS. The CPA represents the slant distance between the UAS and the intruder. The research team utilized the components of the CPA slant distance – horizontal and vertical miss distances to gain more insight into the effectiveness of maneuvers in both the horizontal and vertical domains.

Figure 10 shows the percentile distribution for the change in CPA slant and horizontal distances for the KSU encounters with Cessna 172 intruder aircraft, SR20 intruder aircraft, and the combined dataset. The actual UAS flight path deviated significantly from its original mission flight path in four out of the 340 runs. The research team removed these data points from their analysis, resulting in a sample size of 336.

Maneuvering the UAS increased horizontal separation between the intruder and the UAS in 52.8% of the trials. The research team defined a criterion for a maneuver to be effective in the horizontal domain when it resulted in a change in the horizontal miss distance of greater than 500 ft. The value of 500 ft also represents the radius of the cylinder used to define the Near Mid-Air Collision (NMAC) boundary. The maneuvers were effective in the horizontal domain in 14.8% of the runs for the combined dataset, 10.1% with the Cessna 172 intruder aircraft, and 18.7% with the SR20 intruder aircraft. The research team also defined a criterion for a maneuver to be detrimental in the horizontal domain when it resulted in a change in horizontal miss distance of less than -500 ft. The maneuvers were detrimental in the horizontal domain in 16.2% of the runs for the combined dataset, 16.8% with the Cessna 172 intruder aircraft, and 15.9% with the SR20 intruder aircraft.

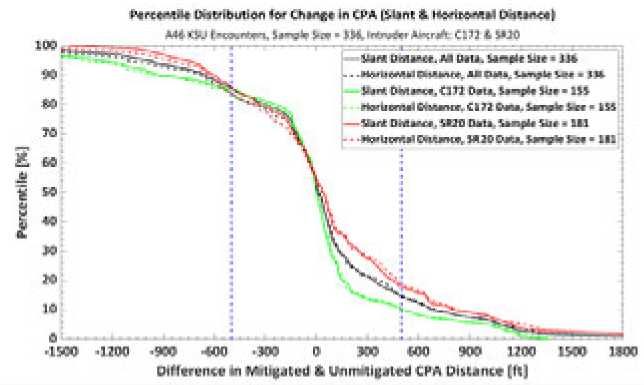

Figure 10. Percentile distribution for change in CPA (slant & horizontal distance) calculated for the KSU flight test encounters.

Figure 11 shows the percentile distribution for the change in CPA (vertical distance) for the KSU encounters with Cessna 172 intruder aircraft, SR20 intruder aircraft, and the combined dataset. The maneuvers increased the vertical separation between the intruder and the UAS in 55.3% of the runs. The criterion for a maneuver to be effective in the vertical domain was set to a change in the vertical miss distance of greater than 100 ft. The value of 100 ft also represents the height of the cylinder used to define the NMAC boundary. The maneuvers were effective in the vertical domain in 30.9% of the runs for the combined dataset, 35.2% of the runs with the Cessna 172 intruder aircraft, and 27.1% of the runs with the SR20 intruder aircraft. The criterion for a maneuver to be detrimental in the vertical domain was a change in the vertical miss distance of less than -100 ft. The maneuvers were detrimental in the vertical domain in 0.7% of the runs for the combined dataset, 1.6% of the trials with the Cessna 172 intruder aircraft, and 0% of the runs with the SR20 intruder aircraft.

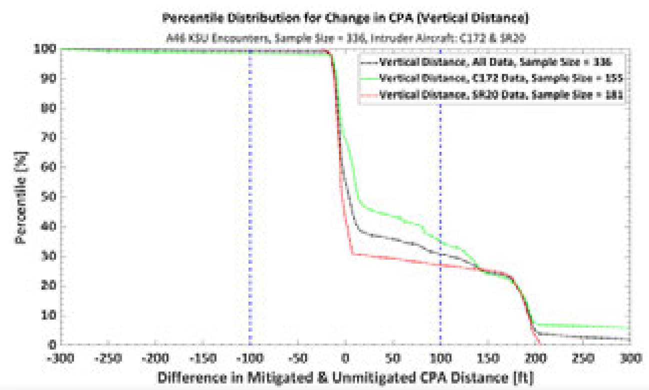

Figure 11. Percentile Distribution for Change in CPA (vertical distance) calculated for the KSU Flight Test Encounters.

Table 4 provides the Well Clear and NMAC violations count and the breakdown of the type of maneuver performed for the KSU flight test encounters. There were 193 unmitigated Well Clear violations out of the 336 valid encounters. The VOs and RPs executed avoidance maneuvers to mitigate 14.5% of the Well Clear violations. There was no reduction in the Well Clear violations count for the encounters without an avoidance maneuver. For the encounters with an avoidance maneuver, there was a reduction of 27.2% in the Well Clear violations count.

There were 54 unmitigated NMAC violations out of the 336 valid encounters. The VOs and RPs executed avoidance maneuvers to mitigate 59.3% of the NMAC violations. There was a reduction of 18.2% in the NMAC violation count for the encounters without an avoidance maneuver. For the encounters with an avoidance maneuver, there was a reduction of 87.5% in the NMAC violations count.

An important observation from this data was that the VOs determined that no avoidance maneuver was necessary in 22 out of 54 (~41%) encounters with NMAC violations. Based on these data, VOs were ineffective in estimating collision potential between an intruder and the UAS when they did not have a visual sight of the UAS. This is consistent with the Crognale (2009) study's findings, where the VOs could not accurately determine collision potential unless they saw the intruder and the UAS simultaneously.

Table 4. Well Clear and NMAC Violations for Mitigated and Unmitigated encounters in the KSU flight tests.

INTRUDER AIRCRAFT: CESSNA 172 & SR20, SAMPLE SIZE = 336 RUNS			
WELL CLEAR VIOLATIONS		**NMAC VIOLATIONS**	
Unmitigated	193	Unmitigated	54
Mitigated	165	Mitigated	22
% reduction	14.5	% reduction	59.3
WELL CLEAR VIOLATIONS (NO MANEUVER PERFORMED - MAINTAIN)		**NMAC VIOLATIONS (NO MANEUVER PERFORMED - MAINTAIN)**	
Unmitigated	90	Unmitigated	22
Mitigated	90	Mitigated	18
% reduction	0	% reduction	18.2
WELL CLEAR VIOLATIONS (MANEUVER PERFORMED – CLIMB OR DESCEND)		**NMAC VIOLATIONS (MANEUVER PERFORMED – CLIMB OR DESCEND)**	
Unmitigated	103	Unmitigated	32
Mitigated	75	Mitigated	4
% reduction	27.2	% reduction	87.5

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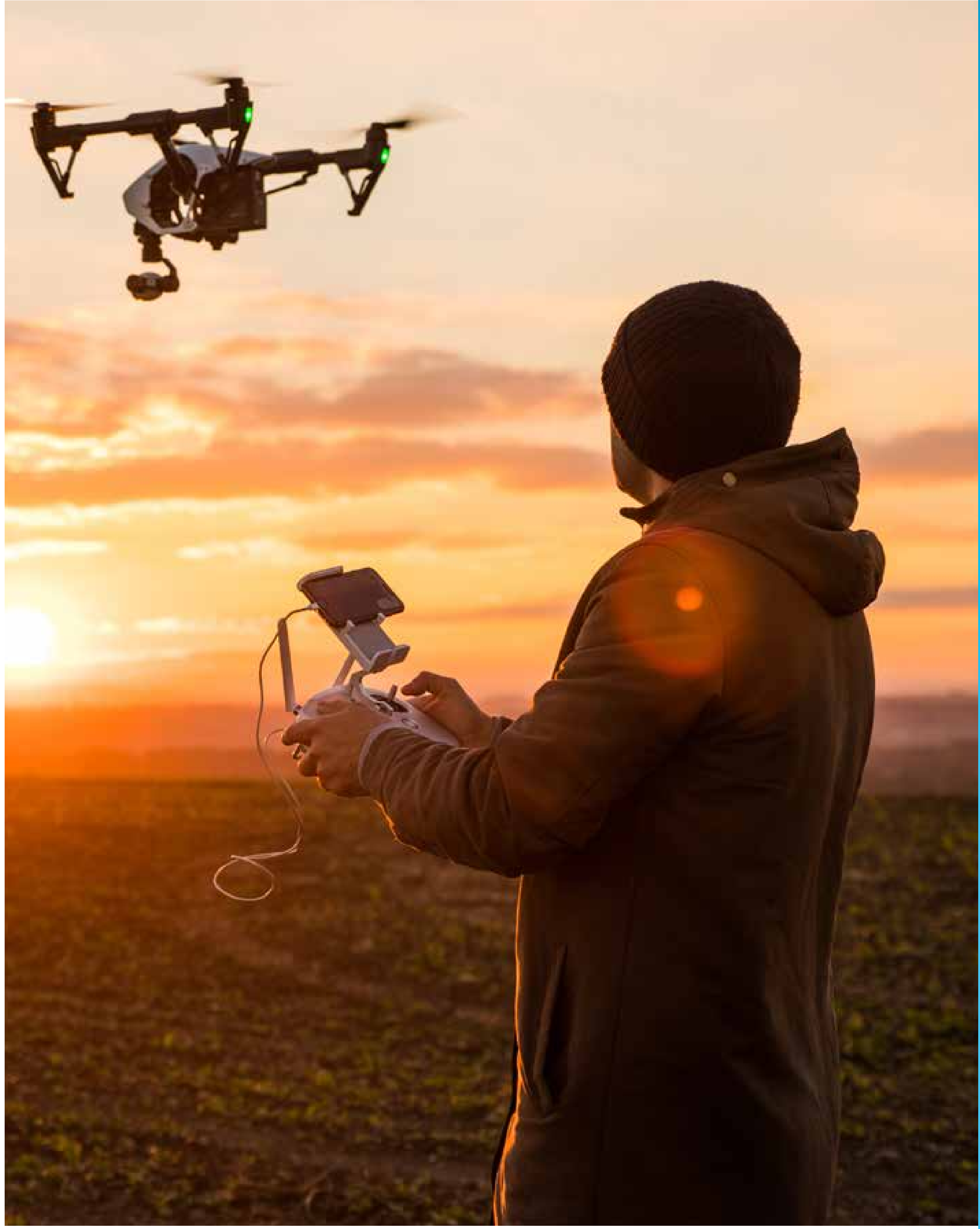

SMALL UAS TRAFFIC ANALYSIS

A11L.UAS.91_A50

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Small UAS Traffic Analysis

Background:

A report by the National Academies of Science, Engineering, and Medicine (NASEM, 2018) suggests the FAA should expand on quantitative data collection to address risk as it pertains to UAS integration as the qualitative nature of current risk management approaches implemented to address UAS risk initiates results that fail to be repeatable, predictable, scalable, and transparent. According to the NASEM report, "Assessing the Risks of Integrating Unmanned Aircraft Systems into the National Airspace System," there is an inherent need for an empirical data-driven approach to inform LEAD UAS policy decision-making. The report ascertains that successful UAS integration into the National Airspace System (NAS) is reliant on the creation of probabilistic risk assessment as "Accepting risk is far easier when the risk is well quantified by relevant empirical data." Nevertheless, the authors acknowledge the limitations associated with collecting the required empirical data, noting that such data are "expensive to collect, scarce, or non-existent, and in some cases not very reliable. . ."

For the FAA to continuously manage the safety of UAS operations in the NAS, the FAA needs to identify, assess, mitigate, and monitor safety hazards and risks. The FAA also needs to proactively plan for future sUAS growth and future aviation risks associated with integrating UAS in low-altitude airspace. The purpose of this research is to leverage near-real time and historical UAS detection data from emplaced UAS detection sensors across the country at various convenience sample locations across the NAS. The UAS traffic data analysis will be useful for monitoring the effectiveness of existing sUAS regulations. It will provide helpful information for sUAS traffic forecasts to aid in identifying and assessing future aviation risks and support policy decision-making.

Therefore, this research will serve as a foundation to address the inherent need to collect empirical data required to conduct sUAS traffic analysis that will support the FAA in conducting risk assessments and forecasting, planning, and estimating compliance rates to existing and future regulations. Analysis is desired to estimate the effectiveness of current regulations, rates of sUAS that exceed Part 107 operations, sUAS encounters with manned aircraft, sUAS operations in proximity to airports, valuable information for informing UAS Traffic Management (UTM) requirements, informing future Urban Air Mobility (UAM) route planning, market forecasts, and so forth.

This work addresses requirements in the FAA Reauthorization Act of 2018. Specifically:

- Section 342, where Congress tasked the FAA to consider "the use of models, threat assessments, probabilities, and other methods to distinguish between lawful and unlawful operations of unmanned aircraft."
- Section 44805, where Congress tasked the FAA to consider "Assessing varying levels of risk posed by different small unmanned aircraft systems and their operation and tailoring performance-based requirements to appropriately mitigate risk" before accepting consensus-based standards.
- Section 44805, where Congress tasked the FAA "To the extent not considered previously by the consensus body that crafted consensus safety standards, cost-benefit, and risk analyses of consensus safety standards that may be accepted pursuant to subsection (a) for newly designed small unmanned aircraft systems."
- Section 44807, where Congress grants special authority for the Secretary of Transportation to use a risk-based approach to determine if certain UAS may operate safely in the NAS notwithstanding completion of the comprehensive plan and rulemaking required by Section 44802 or the guidance required by Section 44806. Special authority is granted to approve beyond visual line of sight operations provided that they do not create a hazard to users of the national airspace system. If deemed safe, the Secretary shall establish requirements for the safe operation of such aircraft systems.
- Section 376, where Congress tasked the FAA to assess the use of UTM services, including "the potential for UTM services to manage unmanned aircraft systems carrying either cargo, payload, or passengers, weighing more than 55 pounds, and operating at altitudes higher than 400 feet above ground level." sUAS traffic data will help inform the amount of traffic that UTM will need to manage.
- Section 44808 directs the FAA to plan for the carriage of property by sUAS for compensation or hire. The FAA is to consider the unique characteristics of highly automated, sUAS and include requirements for the safe operation of sUAS that address airworthiness. Small UAS traffic data will help to inform sUAS package delivery requirements, such as a Beyond Visual Line of Sight sUAS detecting and avoiding another sUAS. This work effort is essential to developing policy and regulations for sUAS, including the effectiveness of sUAS detection and avoidance of other sUAS, sUAS package delivery, UTM, airspace planning, and future Urban Air Mobility plans. The research will inform the FAA on the effectiveness of Part 107 and remote identification regulations.

Approach

The revised research task plan aims to bolster the understanding of sUAS operations within the NAS using Remote Identification detection technology. With data sourced from select locations across the United States, the plan outlines a series of methodological tasks designed to provide a robust analytical framework. Specific emphasis is placed on the following objectives:

- Assessing the effectiveness of existing regulations under 14 CFR 107;

- Measuring exceedances to Part 107 operational limitations;
- Determining the state of sUAS operations and activity in proximity to aerodromes;
- Assessing the risk of potential sUAS encounters or collisions with aircraft operating within the NAS; and
- Providing findings and recommendations that may inform the development of UTM requirements and UAM route design.

The accomplishment of the aforementioned objectives should yield the following results:

- Supporting sUAS forecasting and planning processes;
- Furnishing data and analysis that supports sUAS operations risk assessment evaluations;
- Informing the development of future sUAS regulation and policy-making; and
- Creating analysis benchmarks and methodologies for assessing Remote Identification (RID) data

Task A: Analysis Tool Adaptation

This task focuses on modifying existing Unmanned Robotics Systems Analysis (URSA) Airspace Awareness analytics platform tools, enabling it to integrate, process, and display new RID datasets. These modifications will enable researchers to monitor the implementation of RID among the population of sUAS at the project's several sampling locations.

Task B: Current State of sUAS Traffic within the National Airspace System

This task delves into a descriptive analysis of current sUAS traffic based on RID data trends. The research will use the RID data to address questions surrounding traffic attributes in urban areas, estimated registration rates, and flight patterns.

Tasks C: Compliance and Exceedances of 14 CFR 107 Operational Limitations

In this task, the focus shifts to assessing compliance. The research team will assess sUAS operations adherence and exceedances to various provisions of Title 14 CFR, with emphasis on Parts 107 and 48. Through a series of subtasks, the researchers will identify exceedance rates of various operational restrictions, such as sUAS altitude, speed, line-of-sight, and other factors.

Task D: Near Aerodrome sUAS Operations & Encounter Risks with Manned Air Traffic

This task evaluates sUAS operations conducted in proximity to aerodromes. It aims to provide insights into the likelihood of near encounters between sUAS and manned aircraft and the identification of high-risk areas or "hotspots" where sUAS operations may be particularly problematic.

Task E: Forecasting Industry Growth & Potential Advanced Air Mobility Implications

This task is forward-looking, leveraging gathered data to make informed predictions about sUAS industry growth. The research team will assess strategies to improve sUAS integration and safety within the NAS. Potential implications to advanced aviation operations, such as Advanced Air Mobility and UTM, will also be assessed.

Task F: Communicating Findings

This task will focus on the dissemination of study findings, culminating in written reports, briefings, and other deliverables in accordance with grant obligations. Importantly, project research findings will be shared with industry stakeholders to inform future standards and policy formulation.

Key Findings

The research team identified several key findings:

- RID Adoption Remains Low: Data suggests that initial adoption rates for the Remote ID system remain relatively low relative to sUAS registrations. While the number of detected sUAS platforms continues to increase month-over-month, detected activity remains substantially below local platform registrations within the sample areas.
- DJI Platforms Still Dominate the Market: The research team correlated detected RID serial number data to the FAA Declaration of Compliance database. Results indicate DJI platforms made up more than 86.3% of detected platforms.
- Broadcast Module Adoption Likely Increasing: Approximately 12.8% of serial numbers within the dataset could not be correlated to a model in the FAA Declaration of Compliance database. The research team believes these serial numbers likely represent RID Broadcast Modules.
- Generally Increasing sUAS Flight Operations: During the sampling period, RID data showed generally increasing levels of flight operations. Prior research suggests that sUAS operations frequency increases during the summer months. Due to the short sample duration, it is difficult to determine if the data represents overall trending or merely seasonal variability.
- Lightweight sUAS Remain Popular: Detection data suggest lightweight sUAS platforms continue to gain popularity. Approximately 95.4% of detected sUAS weigh less than 2.5 lbs, with more than a third of those weighing less than .55 lbs.
- Most Platforms Exhibit Low-Frequency Use: Based on the sample, more than 90.0% of detected sUAS platforms were operated during a single calendar month. This finding reinforces previous research, which suggests that sUAS operators—particularly recreational operators—exhibit initial high-frequency utilization followed by discontinuation of use after the first month.
- Flight Duration Remain Low: More than 88% of detected sUAS flights lasted less than 30 minutes, with 37.6% lasting less than five minutes.
- Operators Flying Relatively Close: An evaluation of nearly 2.6M RID messages indicated more than 52% of sUAS operators flew their platforms within 0.1 NM from the operator location. The research team acknowledges that this finding may be skewed due to the relatively low effective detection range of RID signals.
- Most Platforms Flown Below 400 feet AGL: Most sUAS operations operated at compliant altitudes, with more than 79.2% of detected sUAS platforms flown at maximum altitudes of less than 400 feet AGL. Approximately 2.4% of detected sUAS flights were flown at altitudes in excess of 1,000 feet AGL, presenting a potential threat to aviation operations.
- Most sUAS Operations Occurred During Daylight Hours: The majority of sUAS operations detected in the sample occurred during daylight hours, with the peak operations times occurring between 12 pm – 9 pm, local time.

Additional findings, details, discussion, and recommendations will be included in the project's final report expected to be released at the end of the calendar year.

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BEST ENGINEERING PRACTICES FOR AUTOMATED SYSTEMS

A11L.UAS.92_A51

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Best Engineering Practices for Automated Systems

Background:

Advances in aviation are evolving towards a wider range of fully automated functions, from perception (translating raw sensor data into actionable information) to control. Many of these advances are occurring with UAS (regardless of size), in which the trend is towards assigning the human over-the-loop control and allowing automation to manage the perception-planning-control loop, operating beyond visual line of sight, and flying in more densely populated areas. It is therefore essential to establish the potential risks and benefits of increased automation in such environments and the best approaches towards maximizing safety and efficiency. System architecture must be shown to be capable of handling contingencies, failures, and degraded performance, while continuing safe flight and landing.

Approach:

Task 1: Literature Review and Structured Interviews

The team performed a broad literature review of automation failures affecting UAS, and other highly automated aviation functions that are reused or re-usable in UAS. The literature review identified root causes of automation failures for UAS operations, and other aviation systems relevant to UAS. A significant portion of the literature review focused on UAS automation failures. The team complemented the literature review with structured interviews with Subject Matter Experts (SMEs) involved in the design, testing, and use of UAS and in traditional, manned aircraft operations.

Task 2: Risk Assessment and Preliminary Mitigations

This task determined whether existing design principles, guidance, tools, methods, etc., could have prevented the faults listed in Task 1 (had they been applied), or whether they might have even contributed to these faults. It also developed appropriate risk assessment methods in light of these findings.

The researchers, and structured interviews with SMEs serving as consultants on the project, identified existing mitigations for identified root causes and contributing factors. The existing methods can be very roughly divided into specific design changes to the specific system that failed or the operational environment in which it was used, and broader design principles and methodologies.

Task 3: Develop Design Guidance and Best Engineering Practices

This task will 1) develop new guidance and engineering best practices for autonomous UAS and 2) put into practice new guidance for specific automated functions of UAS.

Task 4: Validation of Design Guidance

This task will validate the methods developed in Task 3 and apply the risk assessment methods developed in Task 2, in simulation, limited flight testing, and by expert review.

Key Findings:

This project is in its final year and is completing tasks to develop new guidance and validate the recommended guidance for the safe operation of autonomous UAS systems. In the previous year, the team completed Task 2 and the associated report, which identified preliminary mitigations for risks identified through the literature review. This report focused on the following areas related to autonomous UAS: Perception, Sensors, Control Architectures, Runtime Verification, Cyber-Physical Security, Probabilistic Risk Assessment, Robust Inference, Environmental Modeling, and Flight Testing. A few of the preliminary conclusions and outcomes from this work are as follows.

1. Perception: To address the challenges associated with the limited performance of computer vision algorithms, efforts were directed toward enhancing the performance of aerial object detection algorithms. A crucial aspect in this regard is the diversification of the training data used for detecting aerial objects, especially at significant distances. Detecting small aerial objects at extended ranges poses a significant challenge.

2. Sensors: The researchers propose a sensors test and conditions database for UAS to help keep operators and manufacturers in check, real time operations database that will include a range of acceptable outputs that will define the scope of valid data for continuous checks by the controller. Introducing hardware redundant mechanisms in UAS that would be either through redundant sensors, other sensors, or through correlation. Adhering to very stringent sensing requirement will help solve issues in actuators and automate the sensing validation process to fully automate flights with long-term external observers.

3. Control Architectures: In this work, the team developed a BO-based falsification testing framework using existing motion planning solutions and collision avoidance frameworks. The team aims to investigate to what extent the proposed testing framework, including the state-of-the-art motion planning and collision avoidance solutions, can assess safety assurance for a multi-UAS system.

4. Runtime Verification: Based on limitations identified in year 1, the team sought to develop a monitor synthesis algorithm that takes in a formal specification of an event of interest, and

a. automatically generates the monitoring code;

b. the synthesized monitor is distributed;

c. the monitor runs in real-time for most applications;

d. the monitor accounts for clock drift between the UAS' clocks; and

e. the monitor handles analog signals (i.e., continuous-time signals).

5. Cyber-Physical Security: The team sees that software is clearly extremely important throughout, and essentially another way to create the category of attacks could be just software vs non-software related. Many of the software attacks and defenses are non-specific to UAS and have rich literature behind them. For

example, some clear recommendations would be fuzz testing and static analysis of code and supply chain provenance, which are standard to almost any well-developed software.

6. Probabilistic Risk Assessment (PRA): The contribution of the Task 2 report is primarily an extension of the A21 PRA framework to one better suited to autonomous UAS Concepts of Operations (CONOPS). In particular, the proposed framework explicitly incorporates the concept of the uncertainty state vector (and associated uncertainty state space) and connects this state vector to the underlying UAS dynamics, resulting in a deterministic trajectory under those dynamics for each possible uncertainty state vector. With this mapping in hand, the extended framework expresses the unconditional probability of hazard effects in terms of several associated distributions and conditional distributions involving the uncertainty state vector, the location of the UAS, and the hazard cause. The result is a general framework suitable for PRA for autonomous UAS. The framework is illustrated by a simple example in which an automated UAS has a CONOPS involving a nonlinear path with an uncertain wind environment and hazard effect of accidentally hitting the built environment.

7. Robust Inference: The team has identified a few challenges mainly attributed to the fact that potential causes of the inference technique failure include various attacks by adversarial entities. The first challenge is that it is difficult to assign a prior probability for the occurrence of a certain attack (e.g., the probability that a GPS spoofing attack occurs). This limits the capability of the proposed framework; the team can assess only the conditional probability of risks, given that a specific attack is ongoing. To address this challenge, there is a need to develop a proper way to quantify the likelihood of each attack. Another challenge is the need to perform a large number of high-fidelity simulations to evaluate the conditional probabilities of hazards and harmful effects under various attack scenarios. While there exists a large number of diverse attack strategies (with several parameters to determine for each attack strategy), it is practically infeasible to consider all the varieties in the PRA due to the high computation cost. There is a need to develop a proper sampling method to sample a few representative attack strategies with which researchers can still perform the PRA accurately.

8. Environmental Modeling: The impact of a mitigation strategy or an emergency management system can be simulated in real-world simulation. However, extensive flight-report studies of small UAS in varying weather conditions are essential to accurately estimate the parameters of Bayesian Belief Network conditional probability. With weather being such a big factor in historical accidents, this suggests a need for greater weather monitoring for pre-flight or en-route flight planning.

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DISASTER PREPAREDNESS AND EMERGENCY RESPONSE – PHASE II

A11L.UAS.68_A52

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Disaster Preparedness and Emergency Response – Phase II

Background:

In Phase I (A28), policies, procedures, guidelines, best practices, and a coordination framework for a UAS to aid in disaster preparedness and response were developed for different natural and human-made disasters with collaboration at the local, state, and federal levels.

Approach:

This research will allow the research team to exercise, via mock events and demonstrations, the findings found in Phase I. The effort will focus on the refinement of procedures, policies, and guidelines, and will document lessons learned and training objectives.

Key Findings:

The team completed mock events for hurricane response, tornado response, flooding response, wildfire burn response, earthquake response, oil spills, and train derailments along with other minor response events using drones. There is a broad spectrum of knowledge, experience, and ability to contribute among likely first responders utilizing UAS. Similarly, there is a broad range of understanding within response organizations as to the most effective ways to use drones in disaster response situations. Key lessons included the need for disciplined UAS operations during an event, an understanding of working with national entities like the FAA and FEMA, and the danger of self-deployments. Therefore, there exists a need for a set of recognized Minimum Operational Proficiency Standards and credentialing for first responders. This allows UAS operators to be credentialed in recognition of certain minimum competencies and allows response organizations to better utilize the UAS through an understanding of operators' capabilities.

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PROPOSE UAS RIGHT-OF-WAY RULES FOR UAS OPERATIONS AND SAFETY

A11L.UAS.97_A54

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Propose UAS Right-Of-Way Rules for UAS Operations and Safety

Background:

Right-of-way rules govern the interactions between aircraft to maintain safe interactions. Right-of-way rules were derived partly from the See-and-Be-Seen safety concept, the maneuverability limitations of aircraft types to give way and other safety considerations. This research effort is to develop safety-based recommendations to the FAA for UAS right-of-way rules to better accommodate UAS integration into the National Airspace System (NAS). The research effort will also benefit UAS standards (e.g., Detect and Avoid [DAA], aircraft lighting, etc.) to improve safety and compliance with right-of-way rules. The purpose of answering the research questions is to enable the research performers to develop and propose guidance, recommendations, and/or requirements useful for:

- FAA decision-making
  - o Examples include: UAS waiver assessments, policy development, rulemaking, etc.
- industry standards development
  - o Examples include: design standards, training standards, operations and procedure standards, etc.

Approach:

Task 1: Background Report

The performer has completed a literature review on topics related to right-of-way rules for manned and unmanned aviation. The literature review included historical information and the pedigree of safety concepts that led to existing right-of-way rules, including the see-and-be-seen concept. It included domestic right-of-way rules and international right-of-way rules as applicable. It also included assumptions and other rules such as ceiling minimums or separation from clouds that existing right-of-way rules for UAS operations. The literature review included references to incidents or accidents that have occurred that were pertinent to the subject matter. The performer identified existing and future planned UAS operations that may have difficulty integrating into the NAS due to gaps in right-of-way rules. The literature review included information needed to answer the research questions listed in the background section, including research data on aircraft conspicuity, information on unmanned aircraft types, sizes, and number of aircraft, fielded and anticipated DAA systems, emerging UAS guidance decision-making capability using a range of traffic detection systems, the role of automation failures within a DAA system, industry plans and priorities for UAS integration that may impact research priorities with respect to right-of-way rules, and so forth. The literature review considered applicable Advanced Air Mobility (AAM)/Urban Air Mobility (UAM) aircraft types and concepts of operation that should be considered when recommending updates to right-of-way rules. The literature review included academic, government, and industry sources. Based on the findings in the literature review, the performers developed an initial safety hierarchy useful for understanding and justifying existing aviation right-of-way rules. The safety hierarchy included the safety rationale or concepts that lead to different right-of-way priorities and rules. The performers also identified criteria for when additional right-of-way rules might be unnecessary or burdensome. The report included sufficient coverage of the subject matter to provide a broad background, inform follow-up research tasks, and be used as a reference for safety recommendations developed by the project.

Task 2: UAS Gap Prioritization, UAS Safety Hierarchy, and Recommendations

The performers assessed identified gaps in right-of-way rules and prioritized them based on industry needs, safety considerations, the ability of the researchers to provide meaningful data to help the FAA close those gaps, or other applicable criteria. The performers further developed the safety hierarchy to expand it to encompass a wide diversity of UAS operations and DAA capabilities. They used the expanded safety hierarchy and safety justifications to propose new right-of-way rules for UAS operations in areas where there are gaps. The performer also identified and prioritized the research needed to address gaps in UAS right-of-way rules. The performers peer-reviewed the prioritization of gaps in right-of-way rules as well as the proposed safety hierarchy and its justifications, any newly proposed right-of-way rules for UAS operations, and areas of research needed to close gaps with applicable subject matter experts.

Task 3: Research Planning

In coordination with the FAA sponsors, the performers have prioritized research to be conducted in follow-on tasks based on available resources, project schedules, industry needs, safety considerations, and other applicable criteria that are needed to address the gaps in UAS right-of-way rules. Based on the research prioritization, the researchers developed a simulation plan and initial flight test plans to validate right-of-way rule recommendations or to collect the needed information to make right-of-way rule recommendations. Some of the research plans included:

- Simulations to validate proposed right-of-way rules using physics-based simulations of UAS and manned aircraft maneuvering, including expected computational decision-making and communication latencies and automation failures.
- Simulations in Task 3 included both single and multiple-UAS interactions with other UAS or manned aircraft, focused primarily on Beyond Visual Line Of Sight (BVLOS) and below

400 Above Ground Level (AGL). The simulation plan focused on three areas:

- o General Interactions - specifically related to existing right-of-way rules determined the effectiveness of those rules related to interaction with UAS and manned aircraft.
- o Reserved Airspace Concept (RAC) or Non-ADS-B Reserved Airspace (NARA) – In Task 2, it was identified that a reserved airspace concept that gave equal opportunity for access to both UAS and manned aircraft may be a possible solution for certain BVLOS operations below 400ft AGL. Testing of this concept was primarily conducted through physics-based simulations.
- o Use of Remote Identification (RID) – researching the effectiveness of RID to be used to inform and assist in filling the gaps of current right-of-way rules.

- Test Cards were developed from the initial flight test plan for the General Interactions area. The flight tests (Task 4) were to further validate proposed right-of-way rules in those areas where physics-based simulations are unable to inform the researchers. In the initial flight test plans, the performer identified the necessary tools and techniques to precisely capture the test conditions; the data to be collected; and how the data will be analyzed.

Task 4: Flight Test

The research team developed a comprehensive flight test plan for testing sUAS and manned aircraft encounters across multiple locations. Each team created specific flight test cards to execute tests at their sites, focusing on refining and validating initial recommendations.

Three rounds of testing were conducted:

- Round 1: Focused on standard geometric encounters (e.g., head-on, converging, overtaking) between various combinations of sUAS and manned aircraft, following proposed right-of-way rules.
- Round 2: Tested the RAC/NARA.
- Round 3: Focused on RID, using simulation and flight testing to address gaps.

The research team identified and proposed the following themes that would influence the final recommendations:

- Specifications on the maneuverability and handling characteristics of small UAS (sUAS) to ensure separation standards are met.
- Specifications on the accuracy of sUAS technology for BVLOS operations, such as maintaining altitude or location accuracy.
- Specifications on crew reaction times to perform collision avoidance maneuvers, such as a descending turn to remain well clear.
- Specifications on separation standards for DAA systems to provide adequate collision warnings based on the speed of two aircraft, whether between two sUAS or an sUAS and a manned aircraft, to prevent Near Mid-Air Collisions (NMAC) or well-clear violations.
- Specifications for reserving certain airspace to allow short-term commercialization of sUAS operations while ensuring fair airspace use for all users.
- Current minimum regulatory requirements for RID systems to adequately separate sUAS from other sUAS traffic in BVLOS scenarios.
- Well-Clear (WC) and small NMAC distances, both vertically and horizontally, need to be defined for sUAS when passing manned aircraft and other sUAS.
- Manned aircraft cannot effectively visually identify sUAS, placing the burden of detection and avoidance on BVLOS sUAS aircraft.

Task 5: Final Briefing and Final Report

The performer summarized and aggregated all of the previous papers and reports into a final report package for the overall project. The final report focused on updating right-of-way rules for sUAS in the NAS, for operating BVLOS below 400 feet. Through literature reviews, gap analyses, simulations, and flight tests, the report provided data-driven recommendations to assist in validating and revising existing right-of-way rules to accommodate modern UAS technologies including DAA systems and RID. A key proposal was the creation of NARA to segregate UAS from non-cooperative aircraft, ensuring safety and equitable access. The report outlined over 40 right-of-way recommendations, addressing various encounter scenarios, including head-on, overtaking, and emergency situations involving sUAS, swarms, and manned aircraft. For each recommendation, a rationale was given that provided the justification and reasoning behind the recommendations alongside the specific data source from the published reports of previous tasks. It also identified regulatory gaps and called for further research to support safe UAS integration, with a focus on BVLOS operations. In summary, the report offered practical guidelines for enhancing airspace safety while promoting the efficient integration of sUAS into the NAS.

Key Findings:

Reserved Airspace Concept or Non-ADS-B Reservable Airspace. The research team developed the RAC, also referred to as NARA, to create segregated airspace below 400 feet AGL for safe UAS and manned aircraft operations. This concept enables equitable access to airspace for both sUAS and non-ADS-B-equipped manned craft through preflight reservations.

Key aspects of the concept include:

- **Airspace Reservation: sUAS or non-ADS-B manned aircraft can reserve airspace, preventing interactions between aircraft that cannot detect each other.**
- **Safety: UAS flying BVLOS must have systems to detect non-cooperative aircraft or if in a NARA reserved by UAS, the UAS would only have to identify manned aircraft transmitting ADS-B out.**
- **Equitable Access: Both sUAS and manned aircraft can reserve airspace on a first-come, first-served basis, ensuring balanced use.**
- **Implementation: The system could be integrated with existing tools like LAANC or NOTAMs, enhancing airspace management and safety.**
- **Right-of-Way: Standard right-of-way rules remain unchanged by the NARA system**

This approach aims to enable safe BVLOS sUAS operations while maintaining fair access and protecting non-cooperative aircraft in low-altitude airspace. Furthermore, the researchers recommend the system as a near-term solution to enhance airspace safety and enable broader UAS integration.

Right-of-Way Safety Hierarchy:

The research team proposed the following safety hierarchy and applied it to right-of-way evaluations:

- **Protection of human life—An sUAS may not allow a human onboard or in another aircraft to be harmed through maneuvering or inaction.**
- **The burden to avoid shifts to the aircraft or person who can see/sense and avoid.**
- **Ensures consistency with existing right-of-way rules and allows safe integration of the sUAS into the NAS.**
- **Considers environmental/external influences, such as the boundary of operations.**

Recommendations for RoW Rules :

The performers presented specific recommendations that provide standardized rules for general interaction scenarios, including head-on, converging, overtaking, and in-distress situations between sUAS, swarms, and manned aircraft. Additionally, the research team addressed right-of-way influencers such as the use of RID, human factors, safety volumes like sNMAC, and various technology improvements. Other key considerations include RAC/NARA airspace recommendations, operations above 400ft AGL, GPS accuracy, and handling characteristics of sUAS, such as speed, rate of turn, vertical speed as well as environmental conditions such as wind and turbulence. The rationale for each of those recommendations clarifies the logic, addresses challenges, and supports the recommendations with evidence from detailed research references.

Future Research Recommendations:

The researchers proposed several recommendations for improving right-of-way in BVLOS operations below 400 feet AGL. These include developing standards for minimum GPS accuracy, terrain data integration, and RID capabilities. The team also evaluated small NMAC requirements and identified considerations for small WC standards for sUAS, establishing performance standards for sUAS handling, and requiring specific reaction times for avoidance maneuvers. Additionally, the team recommended expanding ADS-B requirements, improving DAA interface designs, and conducting further research on multi-robot and swarm response scenarios as well as for AAM/UAM vehicles and larger than small UAS.

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IDENTIFY FLIGHT RECORDER REQUIREMENTS FOR UAS INTEGRATION INTO THE NAS

A11L.UAS.101_A55

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Identify Flight Recorder Requirements For UAS Integration Into The NAS

Background:

UAS operations are expected to evolve towards vehicles with a range of automated functions that could be capable of delivering cargo and/or routinely transporting passengers. To ensure that UAS operations are safe as they evolve, it is important to learn from past accidents and incidents. Currently, the aviation industry uses technologies to get the most relevant information regarding aircraft accidents and incidents for a large number of manned aircraft operations. One of these technologies is the Flight Data Recorder (FDR), which collects aircraft state and performance data. The second technology is the Cockpit Voice Recorder (CVR), which collects communication to and from crewmembers. FDR and CVR-like capabilities will need to be used in UAS, but certain adjustments due to operational requirements and constraints will need to be taken into consideration. The American National Standards Institute Unmanned Aircraft Systems Standardization Collaborative standardization roadmap v2.0 determined that there are knowledge gaps regarding flight data and voice recorders for UAS. Some of these gaps include size requirements based on the class of UAS, test procedures for crash survival, methods for recording data on the aircraft and control station, and the minimum data required. This project is intended to inform FAA decisions regarding data recorder technologies for UAS. This effort will inform FAA members writing FDR and CVR standards for UAS in industry-accepted documents such as EUROCAE document ED-112B which is being revised at this time. It will also inform ASTM design standards for UAS that will need to incorporate data recorders into UAS designs.

Approach:

Task 1: Literature Review of existing data recorder standards, technologies, and unique data recorder requirements for UAS and UAM aircraft

The team performed a literature review on data recorders that include existing industry standards, EUROCAE workgroup proposals for UAS, regulations, orders, policy, past research, and data recorder technologies. Also, the literature review included a search of UAS accidents and incidents to inform unique data recorder needs for UAS and UAM aircraft. The literature review also included the test methods and metrics for data recorder survivability (e.g., kinetic energy at impact, fire potential, temperature, vibrations, etc.). The literature review of existing data recorder standards, technologies, and unique recorder design requirements based on UAS and UAM aircraft provided recommendations for future study based on identified knowledge gaps in current flight and voice recorder technologies and requirements to a different class of UAS.

Reviewing aspects of standards, regulations, orders, policies, reports, and past research included the following areas:

- Design, operation, and market of UAS and manned aircraft;
- Flight and voice recorder on manned aircraft and how they relate to UAS;
- Accidents and incidents processing on UAS and manned aircraft; and
- Test methods or metrics for evaluating the data recorder survivability.

Task 2: Assess and Develop Proposed Data Recorder Requirements

Based on Task 1, researchers evaluated any standards or proposed data recorder requirements from EUROCAE and ASTM for sUAS, medium-sized UAS, large UAS, and Urban Air Mobility (UAM) aircraft. Researchers evaluated proposals for safety benefits and whether the proposal adequately addresses the data needed to assess accidents and incidents for different types of UAS and UAM aircraft and their unique operations (e.g. automation, Detect and Avoid, package delivery, etc.). In addition to safety benefits, the researchers also considered cost, size, weight, power, and ease of implementation for the various proposals and standards. The researchers developed and proposed their own data recorder requirements if industry standards or proposals did not exist or if they felt that proposals did not adequately consider safety benefits, cost, size, weight, power, and ease of implementation for different types of UAS and UAM aircraft.

Leveraging previous work conducted by the National Institute for Aviation Research (NIAR) on incident/accident reconstructions to support National Transportation Safety Board investigations, researchers developed and proposed a minimum set of data channels and sampling rates required to conduct future UAS accident/incident investigations. Researchers also developed an accident reconstruction demonstration example using NIAR's methods to support an accident investigation process. The purpose of this demonstration was to identify and validate the minimum amount of data channels required to conduct an accident investigation analysis and for the FAA to visualize what type of information they may get with the proposed data channels and sampling rates.

Task 3: Crash Survivability of UAS Data Recorders

Based on the inputs from previous tasks, the team followed existing test procedures to evaluate the survivability of flight data recorders for sUAS and medium-sized UAS. In this task, researchers identified at least two commercially available UAS data recorders (one for smaller UAS (ex. SD Card within small survivable lightweight housing) and one for larger UAS) and conducted a series of computational and/or experimental tests to evaluate the proposed crash survivability criteria.

Task 4: Update Assessments and Proposals for Data Recorder Requirements

Based on the results and lessons learned from testing, the team updated previous data recorder assessments and proposed requirements.

KEY FINDINGS

CATEGORY	FINDINGS AND RECOMMENDATIONS
Main Recommendations	**Adopt FDR Parameters from Deliverable 4:** Integrate Deliverable 4's FDR parameters as the UAS FDR standard. **Standardize Data Formats:** Establish a universal file format for FDR data. **Enhance Encoding and Decoding Techniques:** Optimize FDR data encoding and decoding methods. **Record Ground Control Communications:** Implement recording protocols for all ground control station communications. **Allow SD Cards for Small UAS FDRs:** Recognize SD cards as a viable data storage solution for small UAS FDRs.
Needs Further Development	**Define FDR Parameters for Autonomous Missions:** Tailor FDR parameters for high-autonomy UAS missions. **Verify Encoding and Decoding Methods:** Investigate and improve FDR data encoding/decoding. **Collaborate on Regulatory Harmonization:** Work with regulatory bodies to harmonize UAS FDR standards globally.
Future Research	**Assess FDR Survivability:** Evaluate sUAS FDR resilience under various hazardous conditions. **Develop Dynamic Mechanical Tests:** Create protocols to simulate sUAS crash conditions. **Expand Numerical Simulations:** Investigate the influence of FDR placement within sUAS on crash survivability. **Build Robust Finite Element Models**: Construct advanced finite element models to inform durable FDR designs.

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INVESTIGATE DETECT AND AVOID (DAA) TRACK CLASSIFICATION AND FILTERING

A11L.UAS.100_A57

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Investigate Detect and Avoid (DAA) Track Classification and Filtering

Background:

Developing robust Detect and Avoid (DAA) systems is a key requirement for enabling routine beyond visual line of sight missions in the national airspace system. A hurdle to their widespread adoption is a lack of track classification performance requirements related to the publication of false or misleading information. The impact of such tracks on UAS incorporating autonomous response abilities, and those relying on human in the loop for deconfliction is unknown and may pose a significant hazard if unmitigated. This research task will therefore focus on developing validated risk models to understand the impact of track classifier performance and DAA clutter densities on overall system safety for a range of vehicle sizes (UAS to advanced air mobility), and equipage/operational scenarios. Briefly, the proposed research has been divided into two phases, with the first focusing on the detailed literature review and risk model development necessary to identify key hazards and risks associated with track clutter provided by both ground-based and airborne DAA systems. The risk models will be assessed in Phase 2 through simulation using representative DAA systems with UAS operated as fully autonomous agents and by human operators to assess task saturation and downstream systemwide effects. Ultimately, track classifier performance metrics will be proposed to and disseminated to ASTM and RTCA standards bodies as well as to the FAA for inclusion in forthcoming rulemaking processes. Currently, the FAA does not distinguish between misleading information caused by faulty hardware/software or misclassified tracks within DAA system safety assessments. This work will inform possible updates to FAA safety assessments for DAA systems and their operations.

Approach:

Task 1: Literature Review & Risk Identification.

The team conducted a literature review incorporating academic, industry, and standards body research to identify key sources of risk and uncertainty affecting air picture cleanliness.

Task 2: Risk Assessment.

The risk analysis process assigned a likelihood and severity of the risks identified in Task 1. These metrics were used to prioritize the risk assessment based on the DAA architecture and/or operations. As part of this process, common safety analysis tools such as functional hazard analysis, failure modes, effects, criticality analysis, or fault trees were used. Additionally, categorization and identification of the impact of misleading information on overall system risk was investigated.

Mitigations to the prioritized risks were developed. The mitigations were sorted into categories like the risks and assessed for feasibility, utility, and effectiveness at a qualitative level.

The risk prioritization and mitigation development tasks heavily informed requirements and metrics development. Specifically, the team developed requirements/metrics to guide air picture cleanliness, classification performance requirements, data filtering, and human factors for DAA systems. These requirements/metrics were assessed for applicability across UAS mission and DAA system types. Developed requirements and metrics will be shared with applicable ASTM and RTCA standards committees for industry feedback solicitation.

A summary report for the risk assessment study was provided with key recommendations regarding prioritization, mitigation, and requirements outlined.

Task 3: DAA System Performance and Test Planning.

A test plan was developed focusing on air picture modeling. Scenarios were developed to verify/validate developed air cleanliness, classification performance, and data filtering requirements and metrics using notional DAA system models/architectures identified in Task 1. A DAA package such as ACAS-Xu/sXu was used to characterize DAA system performance and help evaluate the developed air cleanliness, classification performance, and data filtering requirements.

Task 4: Peer Review / Feedback from Standards Bodies.

The test plans and risk assessments were evaluated by peer review. Feedback from this process was used in the refinement of the encounter scenarios considered in the Phase 2 research. The team worked with the FAA to identify key stakeholders for the peer review process. Feedback was used to update the requirements definition.

Task 5: Scenario and Subsystem Model Refinement.

Phase 1 of this project culminated with an FAA and industry review of developed and prioritized risks, risk mitigations, and requirements/metrics associated with air picture cleanliness, classification performance requirements, data filtering, and human factors for DAA systems. During Phase 2, the team reviewed feedback and updated risks, risk mitigations, and requirements/metrics accordingly.

After the team developed mature risks/metrics for DAA system and associated performance, the team developed encounter scenarios to fully understand and exercise the interaction of developed performance requirements/metrics and risks to DAA systems. The encounter scenarios were tailored to align with the prioritization of risks, risk mitigations, and requirements/metrics. Encounter scenarios covered multiple facets of DAA systems including autonomy (human-in-the-loop to fully autonomous), aircraft size and associated performance (sUAS to large scale drones), and UAS mission types (package delivery, inspection, reconnaissance), etc. Additionally, encounter scenarios were exercised in a variety of airspace densities (sparse to dense) and misleading surveillance information rates (low to high) to understand the impact on performance requirements/metrics and risks to DAA systems for a combination of airspace densities and misleading surveillance information.

Task 6: Modeling and Simulation Evaluation.

The encounter scenarios outlined in Task 5 were used to develop representative sensor models for ground and airborne DAA systems. These were high-level models designed to incorporate variable levels of uncertainty in both position false-track rates associated with exercising the downstream DAA responses from both pilot in the loop and autonomous vehicle responses.

Data was collected from representative DAA systems currently emplaced to assess clutter performance, track classification and filtering performance, and provide repeatable test scenarios for evaluation in the modeling and simulation framework. These clutter representations were non-dimensionalized to allow for extrapolation to the encounter scenarios developed in Task 5.

The reduced order models corresponding to different airspace characterization sensors and systems were integrated into the modeling and simulation environment. The team has extensive experience in performing this type of integration work based on existing UAS traffic management DAA systems.

Task 7: Simulation Data Analysis and Gap Report.

A test report capturing the totality of testing performed in Tasks 3 and 6 was generated. The results cover the verification/validation of developed requirements/performance metrics relating to air picture usability and air picture cleanliness, (surveillance operating limitations, classification performance, data filtering), and human factors.

Task 8: Final Report.

A final report and briefing will be created at the end of the program. The report will summarize and aggregate all previous work performed into a final report package. The report will address knowledge gaps and research findings from executed tasks. The report will also provide recommendations to the FAA, ASTM, and RTCA including proposed requirements performance metrics, guidance, and test methods for industry standards. The report will provide supporting rationale, safety arguments, analysis, test results, and discussion that support the proposed requirements and recommendations. Finally, the report will address how project results can be used to inform policy, regulations, etc. and provide recommendations for future research.

Key Findings:

The team has developed simulation-based models that capture key interactions between the sources of clutter, and the identified risks which include increased pilot workload, or potential failures of the DAA alerting systems. The team has captured real clutter data from a variety of ground and airborne sensors which capture a wide range of noise sources such as weather, birds, ground clutter, etc. Using this data and simulated encounter geometries used as test cases for the development of ACAS-sXU, the team has quantified the increases in numerous safety metrics such as near midair collision, Loss of Well Clear, etc. as a function of the superimposed clutter density. In parallel with this effort, ERAU has developed a unified simulation engine to incorporate various sensor models and provide both real and fast-time simulations for the assessment of clutter density. This model has been architected to interface with DAA services provided by CAL Analytics which allows for rapid selection of different DAA algorithms to capture potential failure modes of the DAA service due to improper or erroneous cuing.

In the last year, the team has refocused on capturing impacts on airspace usability and safety in the terminal environment. The team has utilized the MIT terminal encounter dataset to select 20,000 encounters (both alerting and non-alerting) to capture clutter impacts on Instrument Flight Rules (IFR) approaches. These tests use a similar fast-time simulation environment to that previously outlined, with the addition of a DADELUS DAA system to enable the ownship to return to course after an avoidance maneuver. Initial results indicate that even small levels of clutter have a dramatic impact on the number of missed approaches and NMACs occurring in the constrained environment of an IFR approach. The team is currently finalizing the statistics for these encounters for inclusion in the final report.

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ILLUSTRATE THE NEED FOR UAS CYBERSECURITY OVERSIGHT AND RISK MANAGEMENT

A11L.UAS.95_A58

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Illustrate the Need for UAS Cybersecurity Oversight and Risk Management

Background:

As per the GAO publication "GAO-19-105: Agencies Need to Improve Implementation of Federal Approach to Securing Systems and Protecting against Intrusions," agencies throughout the Federal Government were found to be at risk or high risk for cybersecurity gaps. This project addresses the need for UAS Cybersecurity Oversight and Risk Management as it pertains to the relationship between the national airspace system and FAA systems.

Approach:

Task 1: Literature Review and Industry Engagement

Review all publicly available information concerning the IG, GAO, and other reports that delineate risk management assessment elements, concerns, and best practices. Example: In GAO-19-105, the executive summary highlighted five core security functions that federal agencies were evaluated on (Identify, Protect, Detect, Respond, and Recover). The team worked from the GAO-19-105 with additional emphasis on cyberphysical issues common in UAS environments. The team worked with industry partners in early stages of the effort to explore standards and processes common to their workflows.

Task 2: UAS Cybersecurity Oversight and Risk Management

The performers will create a Tool or a Process that will provide a guide for the FAA to create a UAS Cybersecurity Oversight and Risk Management Program that will help facilitate best practices in the execution of such duties. To achieve this, the researchers are mapping static analysis, dynamic analysis, and code retargeting to UAS-specific cybersecurity tasks. The resulting framework will provide a roadmap for applying a framework to operational systems.

Task 3: Test Cybersecurity Oversight Tool or Process

The team will test the UAS Cybersecurity Oversight and Risk Management Tool or Process created in Task 2. Researchers will develop cybersecurity scenarios to be tested against the Tool or Process in either a table-top simulation or live-test event. To achieve this, researchers engaged in several demonstrations during technical interchange meetings with sponsors. These demonstrations showed cyberattacks ranging from sensor spoofing to malware injection applied to various aerospace platforms. These demonstrations will be included in the framework as examples linked to both attacks and mitigation tools.

Task 4: Peer Reviewed Final Report and Final Briefing

The performers will write a final report documenting:

1. The Cybersecurity Oversight Process;

2. The process and results of testing the Cybersecurity Oversight Process; and

3. Areas of need and future research.

The framework will take the form of attack descriptions, attack mitigations, and links to tools. The objective is to provide a map from known cyberattacks to mechanisms – tools, redesign, models – for mitigating the attack. Other than demonstration results, there are no software deliverables planned.

Key Findings:

The literature survey built upon work from the A38 report detailing cybersecurity risks for UAS operations. The A38 report classifies threats by severity and likelihood. The team is identifying threats that specifically impact airspace. Specifically, the operation of the UAS and the safety of other nearby aircraft. Additionally, the team is including a malware survey for embedded systems and a review of the GAO-19-105 framework and the NIST framework with application to UAS operations.

The framework starts from the A38 report detailing risks and addresses attacks associated with those risks that: (i) impact the airspace; and (ii) were judged most serious and most common. Researchers augmented the A38 report findings with additional information from the literature survey and industry interactions. With a set of attacks in hand, the team set about defining each attack in a manner approachable by UAS engineers. Specifically, the team seeks to provide a high-level description of the attack mechanism, its impacts on airspace, and identify flight operations where the UAS is vulnerable to the attack.

Each attack is linked to one or more known mechanisms for mitigation. These may include static analysis, dynamic analysis and observation, and code refactoring. Static analysis techniques include the application of tools that treat software as a mathematical object to infer properties. Such techniques include symbolic theorem proving, model checking, SAT/SMT solving, memory usage analysis, and type checking. Dynamic techniques include those approaches that monitor executing systems through simulation, testing, or monitoring. Such techniques directly observe the properties of running systems. Finally, code refactoring involves bug fixing and replacing existing code. Such techniques include using modern languages and environments, rewriting vulnerable code, and replacing libraries.

Each mitigation is linked to existing tools implementing the technique. Tool descriptions will include links to available public domain and commercial software implementations as well as tutorials and usage guides. Where available the team will include presentation materials and demonstrations from technical interchange meetings that demonstrate mitigation in action. These demonstrations also serve as a means for demonstration of the framework on actual systems and subsystems.

Results from the investigations continue to be shared at team meetings and at semi-annual program management review meetings. These results clearly demonstrate the need for a framework that mitigates cyberattacks impacting UAS in public airspace. Furthermore, they show a need to consider cybersecurity issues from high-level requirements through implementation. Following feedback from sponsors and collaborators, the team is confident the framework will satisfy a need to mitigate cybersecurity issues in UAS platforms. The sole task moving forward is completing the framework document. Specifically, completing descriptions of attacks, completing descriptions of mitigations, identifying links to tools, and providing pathways from attacks to solutions.

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EVALUATION OF UAS INTEGRATION SAFETY AND SECURITY TECHNOLOGIES IN THE NAS PROGRAM

A11L.UAS.90_A60

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Evaluation of UAS Integration Safety and Security Technologies in the NAS Program

Background:

This research will support the development of cross-agency standards against which to test prospective UAS integration safety and security technologies including:

- Ensuring the efficacy and safety of the system;
- Ensuring the systems do not adversely affect or interfere with airborne avionics, Communications, Navigation, and Surveillance (CNS) systems, Air Traffic Management (ATM) systems, and other ground-based infrastructure such as lighting;
- Assessing the efficacy and safety of integrated platforms such as Common Operating Picture and UAS Traffic Management systems;
- Ensuring the efficacy and safety of technologies, sensors, and systems for differentiating between legitimate UAS and unauthorized UAS;
- Ensuring the systems deployed do not adversely impact or interfere with each other; and
- Ensuring the systems do not interfere with first responder communications systems or adversely impact or interfere with the safe and efficient first responder operations.

This research will support development aimed at solutions for critical national security problems affiliated with the hazardous and malicious operation of UAS. This development of solutions is in the form of cross-agency standards against which to test UAS integration safety and security technologies.

This effort will apply prior research data obtained under the ASSURE COE Grant Program tasks:

- Demonstrate test methodologies and provide technical approaches for evaluating UAS safety and security technologies in the NAS to include airborne avionics, CNS systems, ATM systems, and other ground-based infrastructure such as lighting;
- Develop and analyze the efficacy and safety of technologies, sensors, and systems for differentiating between manned aircraft, legitimate UAS, and unauthorized UAS.

Rescope:

On February 8th, 2024 the research team received direction from the FAA calling for a rescope for the A60 project. The updates to project tasks are as follows:

Task 1, UAS Flight Operations, was reduced to include only three, two-week flight test campaigns. This includes descoping testing efforts to Detect, Track, and Identify (DTI) systems and technologies only.

Task 2, Analysis and Recommendations for UAS Integration Safety and Security Technologies, is requested to be removed from this research effort due to anticipated changes in the 2023 FAA Reauthorization Act.

Task 3, Final Report, is requested to be removed as it is no longer required again due to anticipated changes in the 2023 FAA Reauthorization Act.

On February 29th, 2024 the ASSURE A60 team received direction from the FAA on updated priorities to develop a new test plan after the rescope of the project.

- Determine interference of CNS of air and ground components and ATM (UART, ADS-B, VOR, TACAN, VORTAC, ILS, and RADAR). Identify the types and levels of interference including distance from the DTI system, if any.
- Determine if DTI systems cause interference with First Responder radio communications and emergency navigation systems and if First Responder radio communications interfere with the DTI systems themselves. In addition, if testing multiple DTI systems at one time, do these systems interfere with each other.
- Evaluate impacts of DTI systems on remote identification (Remote ID) systems and technologies. How can DTI and RID be used to differentiate authorized vs unauthorized UAS? MSU conducted testing of transmission ranges within the A56 project. Suggest leveraging existing data and systems of external RID and internal RID (aircraft with built in RID) and the effects of the DTI systems on the RID transmission.
- Document impacts of lost UAS link impacts (1) the DTIs ability to continue to detect, track and identify; and (2) does 'loss of link' change what the DTI systems (depending on the system) reports to the operator.
- Human Factors Issues: Document and determine human interface issues and system false alarm rates and the impacts to operators' confidence levels of each system.
- Test systems in high-density WI-FI or other high-frequency noise environment (specifically urban environments) to determine any performance impacts to the DTI systems. Provide information on what kind of frequency "noise" and physical infrastructure, if any, would limit or interfere with the detection system.
- Analyze any impacts to the DTI systems associated with high electromagnetic interference and provide options to lessen and alleviate interference impacts.
- The FAA requests the ASSURE Team, if possible, to test how the equipment may operate during times of high electromagnetic

interference such as during and after various solar events. Document any impacts to the system itself, if there are any impacts to the system calibration that need to be adjusted, any impacts to the type of UAS it can identify, etc.

- The FAA requests the ASSURE team as part of their analysis to provide recommendations for minimizing the impacts of electromagnetic interference on these systems as well as any suggestions of how to respond to an electromagnetic event.
- Determine probability of detection by platform as well as by frequency including false alarm detection rates. Provide information on what factors impacted probability of detection.
- Determine if moisture content in the soil and in the air impacts the detection systems. Identify any potential impacts to system operability and data identification.
- Compare flight log information (download from UAS) to what the DTI system recorded. Evaluate aircraft position reporting performance by comparing onboard data of UAS flight logs to an independent flight tracking system. (Altitude, airspeed, location/position). May illustrate requirements for RID accuracy and return to home functions.

The team has reviewed and integrated the specific project priorities into the Master Test Plan. The project team will ensure the collection of requested data through the A60 flight campaigns.

Test Site Locations:

The ASSURE A60 project team submitted a list of 10 potential test site locations that would satisfy a majority of the requested characteristics. The test site locations were presented and discussed with the FAA. The FAA selected three primary test locations with an alternative test site. The primary test sites are Cape May (Ferry Terminal), NJ; Camp Grafton, ND; and Santa Teresa, NM; with an alternate location at Starr Forest, MS. These test site locations represent real-world testing of DTI systems while not negatively impacting aviation operations in the NAS and are a reduced risk to the general public. The specific test dates of the flight campaigns at each test site are to be determined but will not exceed a two-week period.

Approach:

The ASSURE A60 project will evaluate UAS DTI systems to determine their effectiveness. The project will document any impact the DTI systems have upon critical NAS, first responder infrastructure, CNS systems, ATM systems, ground-based infrastructure lighting, location beacons, weather reporting system, etc. to determine if the DTI systems are truly passive.

The project will conduct three, two-week flight campaigns to determine the effectiveness of the DTI systems against a designated intruder aircraft in the designated test area. The test locations were chosen to represent different aspects of temperature, humidity, elevation, population density, and radio frequency background.

The project will also evaluate the impact of the DTI systems on remote identification systems and associated technologies. This will assess the ability of the DTI systems to identify UAS with external RID and built-in RID systems in an attempt to differentiate the authorized vs. unauthorized UAS. Testing will determine if UAS detection systems can identify and provide data to effectively identify manned aircraft, lawfully operating UAS, and unlawfully operating UAS.

Universities participating in the project will bring a fleet of over 130 UAS to the flight campaign. This fleet of UAS is representative of the diversity in UAS such as materials used in the construction of UAS, powerplants, communication protocols, radio frequencies, and method of flight. The UAS are representative of the most common, commercial off-the-shelf models to exotic do-it-yourself models constructed of common materials. The makeup of the UAS test fleet is representative of the most popular UAS along with the most likely UAS encounters in the real world outside of test environments to gain the best data set from the DTI systems. The FAA has authorized the purchase and deployment of foreign UAS that represent a majority of the UAS population that may be encountered by a DTI system.

The team will conduct UAS flight operations demonstrating the various flight characteristics and scenarios developed to assess the detection, tracking, and identification systems' effects on the safety systems of the NAS. The data generated during these flight tests will be used to determine limitations, assess capabilities, develop procedures, and analyze the efficacy of UAS integration safety and security technologies, sensors, and systems.

The research team conducting this project includes the leaders of three of the seven FAA UAS Test Sites (i.e., the New Mexico UAS Flight Test Site, the Northern Plains UAS Test Site, and the University of Alaska UAS Test Site), who will oversee all flight operations. This oversight allows the research team to easily comply with the requirement that the project meets the FAA UAS Test Site Other Transaction Agreement Modification 4, Article 3 – Privacy because the Test Sites already comply with this requirement in their planning and flight operations. Additionally, the Test Site teams are highly experienced in planning and safely executing challenging UAS operations under a wide variety of conditions. The team also includes the leaders of the DHS Science and Technology Small Unmanned Aircraft Systems Demonstration Range Facility at MSU and the Unmanned Aircraft Systems Program at UAH, which is partnered with Huntsville International Airport, one of the four airports chosen by the FAA to host a UAS Detection and Mitigation Research Program Test Site.

Urban Spectrum Assessment:

Each test site location will have a background spectrum assessment completed. This will identify the baseline spectrum present at the test site before any introduction of a DTI vendor.

An urban spectrum assessment was completed at Doña Ana Community College Sunland Park, NM, acquired on September 12, 2024. This is the background spectrum sample for the Santa Teresa, NM, test site location. Per the draft Mission Test Plan for A60, two performance metrics relate to measurements at the time of the testing. Below are the supposed assessments. The first round of measurements focuses on a wider background spectrum between 0.15 MHz to 5.0 GHz. The program goal is to "Determine interference of CNS of air and ground components and ATM (UART, ADS-B, VOR, TACAN, VORTAC, ILS, and RADAR)" – the list of systems look at frequencies where there may be issues.

Metric

#12

Pre-DTI (Detect, Track, Identify)

- Baseline RF Environment Spectral Analysis;
- Conduct spectrum analysis of the environment before DTI system activation;
- Measure from 0.15 MHz to 5 GHz for 5 minutes prior to DTI system activation to establish baseline values;
- Perform daily.

Metric #13

- DTI;
- RF Environment Spectral Analysis during activation;
- Conduct spectrum analysis of the environment during DTI system activation and employment;
- Measure from 0.15 MHz to 5 GHz for 5 minutes prior to DTI system activation;
- Compare pre and post activation spectral analysis reports to determine if DTI system impacts RF environment beyond 47 CFR 15.107 subpart B permitted levels;

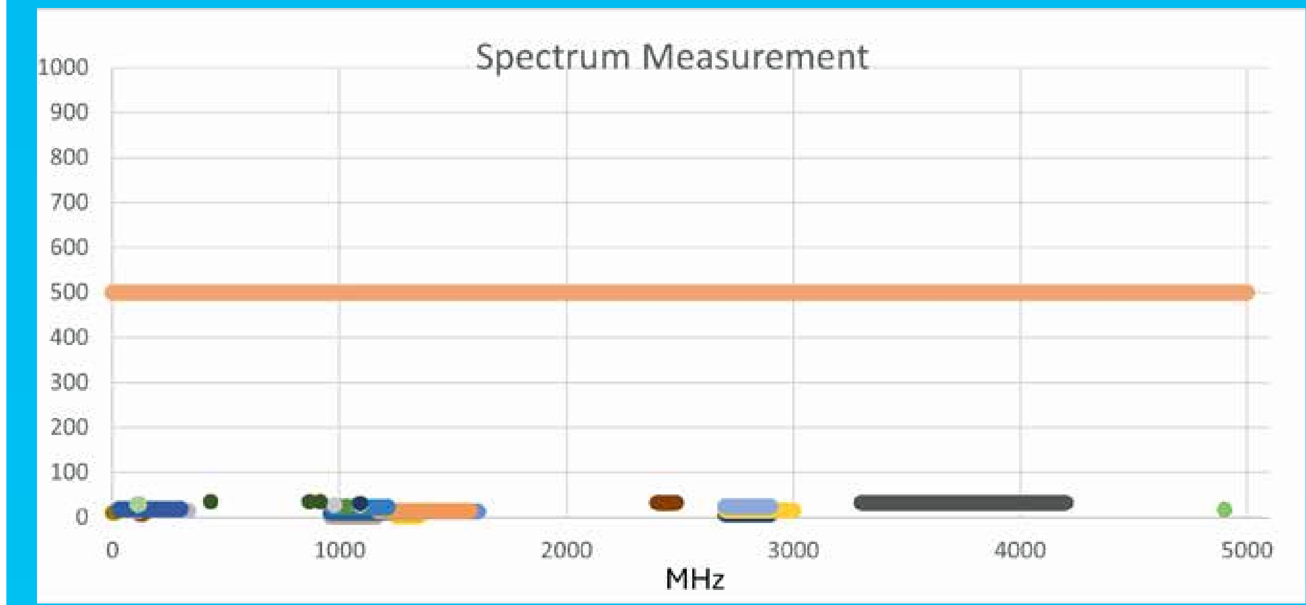


FIGURE 1. RF SPECTRUM MEASUREMENT RANGE VERSUS FAA ALLOCATED FREQUENCIES (0.15 MHZ TO 5.0 GHZ).

DTI Vendors:

Seven vendors have completed all requested documentation to participate in the A60 flight campaigns. These vendors may not be present at every flight campaign. The research team has provided vendor system names to the FAA. National Park names will be used for vendor anonymity.

Vendor Data Processing:

The ASSURE A60 data management team has developed a software data processing pipeline to handle the data generated from the DTI vendors and the truth ground data from the UAS. This will allow the team to process data generated each day during the flight campaigns significantly reducing the data processing time.

All A60 campaign vendor data and UAS telemetry logs will be imported, processed, and analyzed using the ITS-toolkit module. This model design details the vendor data integration plan and UAS data integration plan using the ITS-toolkit. Figure 2 illustrates the top-level schematic of the ITS-toolkit data flow architecture.

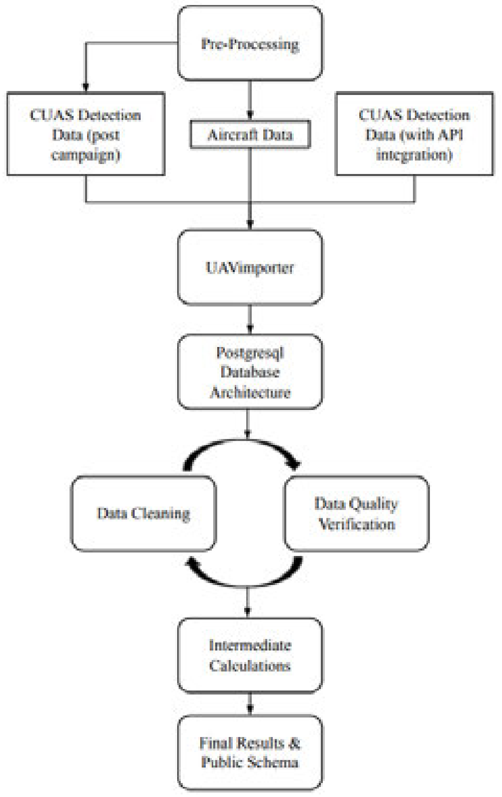
Flight Campaigns:

The Master Test Plan (MTP) was completed and submitted. The A60 ASSURE project team will develop MTP appendices for each proposed test site location. These appendices will be submitted to the FAA for review and approval.

Tentative dates have been identified to allow for logistical planning. These dates will be finalized once the MTP has been approved or revised as necessary. It is expected that the flight campaigns will be conducted as follows:

Cape May (Ferry Terminal), NJ	April 2025
Camp Grafton, ND	May 2025
Santa Teresa, NM	June 2025

These dates and locations are subject to change based on feedback from the FAA MTP review. Work will continue to support the flight campaigns at the test site locations pending feedback from the FAA on the MTP.



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CONDUCT STEM OUTREACH TO MINORITY K-12 STUDENTS USING UAS AS A LEARNING PLATFORM

A11L.UAS.53_A61

PARTICIPANTS

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KANSAS STATE UNIVERSITY

SINCLAIR COLLEGE

Conduct STEM Outreach to Minority K-12 Students Using UAS as a Learning Platform

Background:

Science, Technology, Engineering, and Mathematics (STEM) career opportunities are projected to outpace the growth of career opportunities in non-STEM fields. A STEM-capable workforce is key to meet this demand. While the STEM field has more job opportunities and often higher wages, key groups, such as women and minorities, are underrepresented in STEM. To make STEM opportunities more accessible to underrepresented groups and to contribute to creating the next generation's interest in the UAS field, the FAA UAS Center of Excellence (COE) is conducting STEM activities using UAS as the central learning platform. This project falls within the COE's mandate to educate and strategically facilitate the distribution of ASSURE research. This past research distribution will include as a minimum UAS engine ingestion, air mobility, cyber security, etc. The long-term goal of the project is to ignite an interest in UAS/STEM and, therefore, nurture part of the possible future UAS workforce.

Approach:

In keeping with Phases 1-3 of the STEM efforts funded by the FAA through ASSURE, each school was in control of their specific approach to address the two main tasks: UAS Roadshows and Summer Camps. The schools were able to add additional outreach opportunities through an ad hoc task to cover events not initially planned at the time of the proposal.

NC State University

NC State, the lead university for this effort, handled the programmatic support for the project through meeting updates. NC State was already active in K12 STEM education through myriad on and off-campus programs. This funding allowed for increased capacity and a greater focus on UAS and aviation subjects within the broader STEM initiatives. In addition, many NC State programs already supported the FAA's focus on minority and under-resourced communities with respect to diversity in STEM fields.

In partnership with the NC Department of Transportation's Division of Aviation, NC State supported the Aviation Career Education (ACE) Academies to serve as the Roadshow events. This grant program hosts middle and high school students at local public airports in North Carolina. Many of these camps took place in rural regions and counties and highlighted the aviation industry, UAS, and related fields of study and work opportunities in those communities.

Two summer camp programs were supported through this project, both of which are ongoing university initiatives. The TRIO Pre-college program at NC State hosts a STEM Summer Camp for under-resourced high school students from across North Carolina. This program is one of only three others nationwide approved to host a NAF Future Ready Scholars Academy. While these camps are traditionally based on broad STEM topics, this funding increased the focus on aviation and UAS, and career opportunities in those industries. The Science House is another on-campus outreach unit with several STEM opportunities for middle and high school students. One of which, the Catalyst program, provides both weeklong summer camps and Saturday activities during the school year to students with disabilities. The priority is to help educate and prepare these students to participate in a growing STEM workforce.

Finally, NC State was able to work with a local school – Reedy Creek Magnet Middle – to expand the UAS curriculum in their Mechatronics courses. Through five days of combined instructional and hands-on experience, these students were able to learn basic aerodynamic and aviation principles and fly multiple UAS platforms under direct supervision of a Part 107 pilot.

Kansas State University

Most employees in STEM fields are comprised of white males; the aviation industry is no exception. To help draw a more diverse level of interest in aviation career options, KSU proposed a mix of virtual and face-to-face engagements with middle school teachers and students from underrepresented communities in the state of Kansas. KSU targeted partnerships with schools with large percentages of Hispanic and Black students. Ultimately, eight schools were selected in Kansas City, Topeka, and Salina.

The objective is to motivate the next generation of UAS pilots and aviation leaders by exposing students to UAS recreational activities and career options. Student learning outcomes include: comprehending fundamentals of safe flight operations; understanding the delineation between hobbyist and commercial operations; successfully completing the FAA Recreational UAS Safety Test to become a recreational flyer; exploring recreational flyer and modeler community-based organizations in their local area; building, maintaining, and flying micro drone racing kits indoors; exploring basic flight fundamentals on a multirotor UAS; and participating in friendly competitions within their school and other schools.

During the Spring 2023 semester, KSU traveled to eight schools in Kansas City, Topeka, and Salina to introduce UAS to middle school students. These roadshows allowed students and educators to better understand commercially used UAS and the various career opportunities. The roadshows served as a means of identifying which schools would best benefit from the addition of a UAS curriculum. KSU used this opportunity to introduce the Drones in School program to educators and showcase its benefits. KSU procured two Startup Packages from Drones in School and a Race Gate Bundle to demonstrate at the roadshows how a race is flown and some of the equipment provided.

Building on the roadshow experience, KSU visited partner schools in Kansas City, Topeka, and Salina for a series of two-day camps. Holding summer camps at the school's locations facilitated student and teacher travel logistics while maximizing available KSU resources to provide them with a fun, exciting, and informative experience.

Summer camps consisted of two full-day sessions with students learning and doing activities. During camp, students earned their FAA TRUST Certificate, learned about AMA fields, flew simulations, and learned basic aerodynamics.

To prepare for STEM outreach, the teachers at designated partner schools were trained in the Drones in School curriculum to allow them to plan on implementing it into their curricula or incorporating it into after-school programs for the Fall 2023 semester. Two of these schools have integrated the Drones in School program into their regular curriculum.

During the Fall 2023 semester, the pre-selected schools began the Drones in School UAS curriculum, focused on the Emax Tinyhawk III FPV Racing Drone. The curriculum revolves around core STEM components while simultaneously allowing flexibility in accommodating different focus areas, school and student resources, and adjustments to the included competition aspect. Students were placed into teams of two to six members consisting of a Project Manager, Manufacturing Engineer, Design Engineer, Drone Technician, Graphic Designer, and Marketing Coordinator. Members worked together to complete milestones leading up to a race and continued improving as they progressed through the semester. The layout of this curriculum guided students through a close representation of how a business formulates an idea, researches solutions, tests selected solutions, markets a product, and improves the design based on needs.

The eight selected schools were not required to purchase equipment to complete the curriculum or compete in races with the other eight schools. Each school was provided with multiple drone kits and an assortment of spare parts and batteries. Furthermore, each school received a racing gate and flag bundle for practicing and competing. All racing events were held virtually, with students flying the standardized course head-to-head against other teams in a double-elimination style bracket. Points were awarded to teams based on their bracket results, with an overall race champion named at the end of the event along with overall placings. Schools posted their teams' results on an online form where they can also view other schools' results.

Other champion titles include Design and Engineering, Portfolio and Team Display, and Marketing Video Champion. With each event, teams must complete and submit an engineering and design task, create a portfolio and team display, and produce a marketing video. Judges will assess these elements using a provided scoring sheet and announce winners at the end of each event. During the final events in November 2023, KSU traveled to each school to watch and assist with judging the various components.

Sinclair College

Sinclair College, enabled through its National UAS Training and Certification Center, remains very active in UAS-related STEM education. This has been partially supported through the ASSURE STEM projects, as well as participation in many separate college-hosted events or off-campus camps and hands-on activities. Additional support through this project enabled Sinclair to expand efforts to reach diverse students through directly hosted events and collaborations with partnering organizations.

Sinclair continued with off-campus engagement in middle-school classrooms, as well as museums and community events, through the provision of UAS applications, technologies, and careers briefings, coupled with RealFlight UAS simulation experiences leveraging Sinclair laptops or deployed Mobile or Tactical Ground Control Stations. The network of schools and sites developed throughout the STEM III effort was leveraged to identify locations for these opportunities during the STEM IV project. Specifically during the project, Sinclair completed 20 outreach days at middle and high schools reaching 2,345 students and teachers. Sinclair also completed five outreach days during TechFest hosted at Sinclair, the Micro Drone Races hosted at the National Museum of the United States Air Force, and the Northeast Ohio Regional Airport Aviation Career Day reaching an additional 955 students. Finally, Sinclair organized and hosted UAS-focused camps coordinated with various organizations to facilitate the Dayton Early College Academy Drone Camp; Air Camp Elementary School, Middle School, High School, and Teacher Camps; Wright Brothers Institute High School UAS Camp; WACO Aviation Learning Center Middle and High School Drone Camps. These 12 separate camps over 15 dates reached 435 students and teachers.

Overall, Sinclair engaged with a total of 3,735 students, teachers, and members of the general public throughout Ohio between October 2022 and August 2023. Of note, highlights of ASSURE research projects were included in the presentation portions of each event to raise awareness of the important work occurring through the COE.

Key Findings:

NC State University

- Completed 11 aviation camps with NC DOT at airports across the state, highlighting aviation career opportunities in rural areas.
- Supported two NCSU initiatives for high school students with disabilities.
- Throughout the A61 STEM IV effort, NCSU had 835 students/contacts.

Kansas State University

- Middle School Roadshows focused on underrepresented urban schools in Kansas City, Topeka, and Salina to introduce UAS, leading to a two-day summer camp at each school where students earned FAA TRUST certificates.
- Drones in School partnership provided students with microdrone kits in a team setting to compete in indoor First-Person View races.
- Throughout the A61 STEM IV effort, KSU had 16,439 students/contacts.

Sinclair College

- Completed 20 outreach days at middle and high schools reaching 2,345 students and teachers.
- Completed five outreach days during TechFest hosted at Sinclair, the Micro Drone Races hosted at the National Museum of the United States Air Force, and the Northeast Ohio Regional Airport Aviation Career Day reaching 955 students and the general public.
- Organized and hosted 12 separate elementary, middle, and high school student and teacher camps over 15 days reaching 435 participants in collaboration with various organizations to facilitate the Dayton Early College Academy Drone Camp; Air Camp Elementary School, Middle School, High School, and Teacher Camps; Wright Brothers Institute High School UAS Camp; WACO Aviation Learning Center Middle and High School Drone Camps..
- Throughout the A61 STEM IV effort, Sinclair engaged with 3,735 students, teachers, and members of the broader public.

Final Statistics

- Completed a total of 97 outreach events engaging 20,912 students and 97 educators.

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DISASTER PREPAREDNESS AND EMERGENCY RESPONSE – PHASE III

A11L.UAS.68_A62

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Disaster Preparedness and Emergency Response – Phase III

Background:

There is a need for research that will explore the use of UAS in providing effective and efficient responses to different natural and human-made disasters and emergencies. The needed research must focus on procedures to coordinate with UAS operators from within federal agencies such as the Department of the Interior and Homeland Security(including the Federal Emergency Management Agency), as well as local and state disaster preparedness and emergency response organizations, to ensure proper coordination during those emergencies. The results will help inform requirements, technical standards, and regulations needed to enable disaster preparedness and emergency response and recovery operations for UAS. This research will also develop a database with data collected during the project to be analyzed to produce various key performance measures and metrics that characterize how overall pilot proficiency in a flight environment.

Approach:

UAS Disaster Preparedness and Emergency Response Research Phase III will build off of the results, findings, and lessons learned from A28/Phase I and A52/Phase II.

Key Findings:

This project has completed several analyses and trade studies focused on supporting technological solutions enabling expanded operations and looking at additional use cases, legislative policies, data sharing and storage, and domestic and international outreach. There has also been database collection and more flight testing and exercises focused on disasters.

Some findings include the completion of a peer review focusing on the need for technological advancements (Common Operational Pictures, Radars, and Internet Capabilities like Starlink), exercises including tornado drills, hurricane drills, coverage of music festivals, the development of a Minimum Operational Proficiency Standards exercise, and the development of a prototype database collector. During this time some of the team supported the response to real-life floods and tornados. The team also supported the development of future proof focusing on Drones as a First Responder. The team also identified new UAS disaster use scenarios:

- Animal, Agricultural, and Food Related Disasters,
- Site protection (recovery),
- Debris management (safety and recovery),
- Water, wastewater, dams (seepage and internal erosion – subset of flooding or unique use case),
- Coastal hazards (response),
- Addressing vulnerable populations (people with disabilities, pediatrics, children, seniors, etc.),
- Evidence collection,
- Historic preservation considerations/compliance,
- Highway disasters (iced roads, fog, sinkholes, etc.),
- Bridge collapse,
- Landslide, and
- Avalanche (both natural and human-caused).

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IDENTIFY MODELS FOR ADVANCED AIR MOBILITY (AAM)/URBAN AIR MOBILITY (UAM) SAFE AUTOMATION

A11L.UAS.98_A64

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Identify Models for Advanced Air Mobility (AAM)/Urban Air Mobility (UAM) Safe Automation

Background:

Advanced Air Mobility (AAM) and Urban Air Mobility (UAM) operations are expected to involve significant amounts of machine automation for operations to be profitable. The focus of this project is on UAS used for passenger transport and cargo delivery in urban areas. This research will evaluate AAM/UAM core technology, system architecture, automation design, and system functional concepts to aid the FAA and industry standards development organizations in creating paths forward for these new operational capabilities.

Approach:

The research consists of three tasks:

Task 1: Background Report. A literature review has been conducted that includes consideration of AAM/UAM automation, human-automation interaction, aircraft system architectures, and concepts of operation, as well as standards, regulation, certification, and policy.

Task 2: Risk and Technology Assessments. A range of alternative safety risk assessment methods will be applied to develop case studies for different UAM/AAM subsystems to evaluate their use in addressing UAM automation capabilities. This experience will then be used to recommend an integrated approach for safety risk assessment that takes advantage of the strengths of a combination of these safety risk assessment methods.

Task 3: Forming Recommendations. Gaps and roadblocks to realizing future AAM/UAM operational capabilities will be identified. A technology path, a standards development path, and an FAA policy and standards path will each be developed to enable the advancement from current capabilities to future AAM/UAM capabilities at full maturity.

Key Findings:

The report for Task 2 was completed during this project year. This report addresses risk and technology assessment in the context of Urban Air Mobility (UAM). This included:

- Phase 1: Application and assessment of qualitative risk assessment methods.
- Phase 2: Quantitative risk assessment.

Qualitative risk assessments were completed for a range of subsystems requiring automation support to ensure safety:

1. Detect and Avoid.
2. Power and propulsion.
3. Airspace and vertiport design.
4. Flight planning (ground objects; individual aircraft and aircraft sharing airspace), strategic deconfliction and preflight checks.
5. Communications.
6. Navigation.
7. Standards, regulation, certification, and policy.
8. Concept of Operations and system architecture.
9. Autonomous command and control.
10. Human-automation interaction and human-human interactions.

The report concludes that qualitative Risk Assessment (RA) methodologies are beneficial to AAM/UAM on account of their ability to uncover possible hazards and risks that may not have been otherwise easily discovered. Many such methodologies in the literature are reviewed as several of them apply to the context of AAM/UAM. This conclusion is supported by empirical studies, e.g., "A recent case study comparing FMEA [Failure Modes and Effects Analysis] and STAMP [System-Theoretic Accident Model and Processes] found that STPA [System-Theoretic Process Analysis] found 27% of hazards that were missed by FMEA. However, FMEA found 30% of hazards that were missed by STPA." [Thomas, STAMP]. It was concluded that multiple integrated qualitative RA methodologies should be employed in the design and operation of AAM/UAM.

The report also demonstrates how quantitative RA methodologies are important in the context of AAM/UAM. As the name implies, these methodologies can provide quantitative measures of risk. Thus, a second key insight of this report is that quantitative RAs for AAM/UAM are both feasible and insightful for important contexts by leveraging quantitative estimates on key inputs from subject matter experts. This process is demonstrated in the domain of flight scheduling and strategic deconfliction. The analysis concludes that the hazard likelihood in this scenario is substantial without effective mitigations, and serves to highlight the potential of quantitative RA methods to play an integral role in the evaluation of proposed AAM/UAM operations.

Task 3 focuses on the description of a technology path and an FAA policy and standards path to enable the advancement from current capabilities to future UAM capabilities at full maturity. The emphasis is on the use of remote pilots with increasing levels of automation support. Associated gaps and roadblocks also will be identified. Draft sections on the following areas completed:

- Preflight planning and strategic deconfliction
- Detect and Avoid (DAA)
- Vertiports

This analysis is organized based on four timeframes:

- Initial Operations Phase 1 (pilots onboard with airspace and procedures as defined in FAA UAM implementation plan (I28)).

- Initial Operations Phase 2 (remote pilots and pilots onboard with airspace and procedures as defined in FAA UAM implementation plan (I28)).

- Midterm Operations (remote pilots with one pilot per aircraft and pilots onboard with structured airspace).

- Mature Operations (remote pilots with the possibility of one pilot providing supervision and control for more than one aircraft and other aircraft with pilots onboard with structured airspace). Increased autonomy for routine navigation and DAA will be required.

As an example of results, the analysis of gaps associated with the technology path for DAA has raised several questions that are indicated more fully in the attached slideshow. Note that these are preliminary conclusions that will be evaluated and refined based on interviews. This includes:

- DAA capabilities that have been developed or are under development for UAM aircraft to support remote pilot operations are based on the airspace design and procedures as defined in the FAA UAM implementation plan (I28). Several potential considerations need to be addressed more fully to enable such remote pilot operations:

    o The impact of ground clutter and airborne obstacles (birds) on false alarms and avoidance maneuvers generated by DAA software.

    o When communication is lost, routine navigation and DAA must be handled autonomously by aircraft. Performance associated with the full range of use cases/scenarios needs to be evaluated (including trajectory resolution when there is airborne holding or go-arounds and including control of the sequencing of arrivals).

    o Conditions need to be defined under which DAA maneuvers are initiated by the onboard or remote pilot vs. autonomous initiation and control by the DAA software. This applies to Midterm and Mature operations as well as Phase 2 Initial operations.

- For Midterm and Mature operations, the integration of routine navigation control functions with DAA needs to be defined. Navigation control functions also need to be developed for return to mission after a DAA maneuver has been completed.

- Based on available information assembled thus far and an interview with a member of the ASTM PSU Interoperability Committee:

o When traffic demand reaches a high enough level, demand will have to be controlled to provide sufficient wiggle room to enable acceptable trajectory solutions for DAA. It is not clear that a process has been defined to determine whether, when, and how this will be determined and accomplished.

    o DAA capabilities that have been developed or are under development for UAM aircraft do not consider the constraints that structured airspace will place on the design and functioning of DAA software and associated procedures. These requirements are not being considered by ASTM committees at present (and there is no indication that the research community or other committees are focused on this). The nature of such structured airspace needs to consider structure in enroute airspace and vertiport airspace.

    o There are different proposals for how to structure airspace for Midterm and Mature Operations. Decisions need to be made.

    o DAA requirements need to be considered relative to autonomous control of DAA by the aircraft for Mature (and possibly Midterm) operations. As part of this the use cases/scenarios need to be fully defined for both enroute and arrival phases of flight.

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DETECT AND AVOID RISK RATIO VALIDATION

A11L.UAS.105_A65

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Detect and Avoid Risk Ratio Validation

Background:

The intended function of Detect and Avoid (DAA) systems is to serve as an alternate means of compliance to the duties of an onboard pilot to see-and-avoid other aircraft (Part 91.111, Part 91.113). This research will measure onboard pilot visual performance in seeing other aircraft in Class E, Class G, and in terminal airspace environments. Visual performance will be combined with simulated avoidance maneuvers to estimate pilot risk ratio performance in seeing and avoiding other aircraft. Pilot risk ratio values will then be used as part of the verification and validation of DAA risk ratio targets for a variety of UAS and Air Mobility (AM) operations. This research is necessary to derive minimum safety performance requirements so that DAA systems can be used as an adequate alternate means of compliance to existing aviation regulations. The validation effort will also ensure that DAA risk ratio thresholds are adequate such that when an onboard pilot encounters a drone supported with DAA, that the onboard pilot does not experience greater collision likelihood than when encountering another aircraft with an onboard pilot.

The research requirement will address gaps in knowledge that are currently a barrier to validating safety performance thresholds for DAA systems which are required for the safe, efficient, and timely integration of UAS into the National Airspace System.

Approach:

Task 1: Flight Test Planning

The UASSRF reviewed past research projects including ASSURE project A23 "Validation of Low-Altitude Detect and Avoid Standards" to inform flight testing efforts to measure see-and-avoid and see-and-be-seen pilot performance. The research team performed a Flight Test Effort Review to address the adequacy or need for refinement and validation for see-and-avoid and see-and-be-seen pilot performance. The output from Task 1 was used to plan and execute forthcoming tasks.

Task 2: Simulation and Analysis Planning

The UASSRF performed a Risk Ratio Development Review of available and relevant literature on the development of Risk ratios within the ASSURE A23 project and other research and determined if they are adequate or need further refinement.

The UASSRF found previous Risk Ratio development efforts to need the following:

-More variety of encounter data (variety of geometries, closure rates, intruder types);

-Realistic pilot delay and response (previous research assumed large delay, and non-aggressive maneuvers for simulated pilots);

-Using the outputs from the risk ratio development review, the UASSRF, in conjunction with the FAA and other relevant stakeholders produced plans to address these inadequacies.

Task 3: Planning for Risk Ratio Tables and Tools to support Industry Standards

The UASSRF continues to coordinate with DAA industry standard workgroups and committees to understand how risk ratio tables in the ASTM work item 62668 appendix were created to update them accordingly. The UASSRF planned for the creation of a new appendix for the new ASTM work item 69690 tailored to current industry needs. The UASSRF planned for the creation of DAA simulation tools to be used in industry and standards bodies for DAA risk ratio analysis.

Task 4: Follow-on Planning

Throughout this effort, the UASSRF updated flight test plans with new flight path geometries to generate additional encounter types. Additionally, the simulation, analysis, risk ratio tools were considered, and a follow-on whitepaper was created to suit the needs of that effort. This follow-on effort would be primarily simulation focused opposed to the large flight-testing effort of this project and use the data generated from this project to take a deep dive into the pilot scan patterns to determine their effects on the overall risk ratio values. The whitepaper was sent to ASSURE and is currently under review.

Task 5: Plan Execution & Reporting

The UASSRF executed the plans approved by the FAA and documented activities in the reports. Reports included the measured data, results, interpretation of the results, and lessons learned. The results were reviewed by the appropriate subject matter experts and made available to the FAA for review, feedback, and adjudication. This process allowed the research team to collaborate with the FAA to ensure that the project was going in the correct direction per the FAA's goals.

Task 6: Final Report & Briefing

The UASSRF summarized the efforts of the project and results into the final report package for the overall project that answers the research questions and provides risk ratio targets supported by rigorous flight test data, simulation, and analysis. The report included an assessment of proposed well clear distances and DAA encounter sets when proposing risk ratio targets with recommendations to the FAA, ASTM, and RTCA. The report included the steps that the research team took to develop and execute the plans in the project to allow for the repeatability necessary when proposing test methods for industry standards. The report discussed how project outcomes can be used to inform policy, regulations, advisory circulars, industry consensus standards and recommendations for future research. The final report has been reviewed by the FAA and their feedback was adjudicated in the final report submission.

Key Findings:

Previous A23 research analyzed pilots' ability to see other pilots by using three action cameras. Two cameras faced out of the cockpit while one faced toward the pilot. This allowed researchers to manually determine when and where pilots visually acquired the intruder aircraft. Because this step needed to be done manually, it was a very time-consuming process that required a substantial amount of personnel. Additionally, using three cameras on every flight event required that extra batteries and storage solutions were included to keep things running smoothly which had a huge impact on researcher workload for the project. When developing the plan for A65, the team decided to research new eye-tracking technology and found Tobii, a Swedish company that specializes in eye-tracking solutions for consumers and industry. The team purchased two sets of Tobii Pro Glasses 3 and used those glasses in a series of practice flights to ensure that they would be a good replacement for the three cockpit cameras. During A65, the glasses allowed researchers to minimize the amount of equipment needed for a flight event which lowered workload. The glasses also allow for more efficient and accurate analyses after flight events. The only drawback to using eye-tracking glasses with such a large and diverse group of test participants is the likelihood of the participant requiring prescription lenses. In those cases, the Tobii glasses were not used for those individuals. Even with the limitations of the system, these glasses have minimized errors in the analysis and allowed for an expanded analysis dedicated to pilot scan patterns.

Throughout the flight-testing campaign for A65, the research team participated in nine flight events with the help of Delta State University's commercial aviation program acting as safety pilots and test subjects. The first test in July 2023 produced head-on and overtake encounters while also allowing the researchers to obtain data with the eye-tracking glasses and practice installing them and following the data collection procedures. The second flight test event in September 2023 consisted purely of overtake encounters between a Cirrus SR20 (ownship) and a Cessna 172 (intruder), with 66 being recorded in the field, and 60 deemed usable during the analysis phase. The third and fourth flight events utilized a rotorcraft as the intruder and a Cessna 172 as the ownship, these events occurred in November 2023 and January 2024 and presented 33 usable test points for analysis with various encounter geometries including head-ons, crossings, and overtakes. The remaining flight tests occurred between March 2024 and August 2024 and were solely focused on capturing overtake encounters between a Cessna 172 ownship and Raspet Flight Research Laboratory's 60% Clipped Wing Cub Group 3 UAS intruder, known as the MicroCub. The first couple of weeks of flight testing presented issues with timing for the encounter to occur so the team redesigned the flight paths for the remaining flights and concluded with 50 usable UAS overtake encounters for the analysis.

The analysis for the flight test data was divided into three sections for the researchers to divide and concur on generating results. Firstly, the participant surveys and raw flight test data was processed to generate participant demographic charts, environmental factors for each flight test, and the pilot visual acquisition analysis. Through the visual acquisition analysis, it was found that for the manned fixed wing intruder overtakes, 55 out of the 60 pilots were able to see the intruder aircraft during an encounter leg. The rotorcraft overtakes showed a 45% chance that a pilot would acquire the rotorcraft during those encounters. Similarly, the UAS encounters yielded a 44% success rate that a pilot would be able to see the intruder during an encounter leg. Due to the size of the MicroCub, the visual acquisition distances for the encounters were much lower than both the rotorcraft and the fixed wing encounters with 15 visual acquisitions occurring within the well clear volume of 2000 ft.

The second portion of the data was dedicated to the eye-tracking data captured by the Tobii glasses. This study was extensive and utilized metrics such as 2D and 3D gaze points, gaze direction, pupil position, pupil diameter, and fixation points to develop hypotheses for comparing pilot experience to scan patterns and factors for determining if a pilot is more or less likely to see a given aircraft in a given encounter scenario. A few of the hypotheses derived from this research include the theory that scan patterns for pilots differ significantly in different phases of flight, pilots with more years of experience and more engine hours exhibit a broader scan pattern than less experienced pilots, and encounter type (post visual acquisition) has a large effect on pilot workload.

The third portion of the data was incorporated into an open-source fast-time simulator developed for this research effort. This simulation used the intruder and ownship aircraft track logs with the visual acquisition data paired with the MIT-LL encounter set. The risk ratios were derived from these encounters for different parameters including three intruder types, four delay times, four turn rates, two avoidance combinations, and seven beta values. The test was run ten times with the combination of parameters resulting in a total of 224,000 simulated encounters each with their own specific risk ratio value depending on the given parameters. This analysis also recalculated beta for each intruder type as well as included the previous project A23's flight test data to determine the optimal beta value for flight test gathered by the research team throughout A23 and A65. Through this analysis, the optimal beta was found to be β=2859±486 based on the average of beta values from the different intruder and encounter types. Future work could determine specific beta values for specific intruders or encounter geometry by limiting pilot selection to limit the differences in pilot scan strategies and keeping the same intruder aircraft for all testing.

MSU Co-chaired the ASTM F38.01 Working Group 62669 for the development of test methods standard for testing and simulating DAA systems. As part of that role, MSU attended and led weekly technical interchanges to work through the complicated nuances of adequately, and appropriately, testing DAA systems. Over the year, the group finalized an approach to matching simulation results to a much smaller pool of flight test results. The team also attended and led sessions during the Spring Face-to-Face in Washington, D.C. in April 2023, and in Conshohocken, PA, in 2022. MSU continues to co-chair and support ASTM groups as part of the requirement to engage with industry established by ASSURE requests for proposals. "ASTM Standard Guide for Testing Detect and Avoid Systems" is being resubmitted for ballot in September of 2024 and is expected to be published by the end of 2024 if there are no negative comments on this round of the ballot.

With A65 in its final reporting and closeout phase, MSU has begun determining areas for continued research. The team would like to pursue more research with the eye-tracking data obtained from the flight testing of A65 and implement the data into the fast-time simulation developed for this project. The team would plan to develop a continuous time Markov chain model to estimate a pilot's expected number and duration of gaze points at specific locations in the cockpit to quantify the pilot's cognitive workload during the flight. This research could also give more insights into the pilot factor, beta, in visual acquisition and determine its correlation with encounter geometry. Incorporating the eye-tracking data into the simulation could improve the prediction of risk ratios for encounters based on actual pilot field of view which could in turn help to update pilot training programs with guidance to help enhance pilot's cognitive efficiency. Finally, the simulator could also be modified to include UAS DAA sensors to improve the prediction for the "both aircraft avoiding" scenarios and used to estimate the risk ratio when one aircraft is unmanned by creating a sensing model similar to the visual acquisition model used in this study. This research is becoming increasingly important in the National Airspace System as the presence of UAS increases.

Figure 1. Researcher Calibrating Tobii Eye-Tracking Glasses.

Figure 2. Delta State University Flight Instructors and MSU Researchers pose with the test aircraft (Cessna 172).

Figure 3. 60% Scale Clipped Wing Cub (MicroCub).

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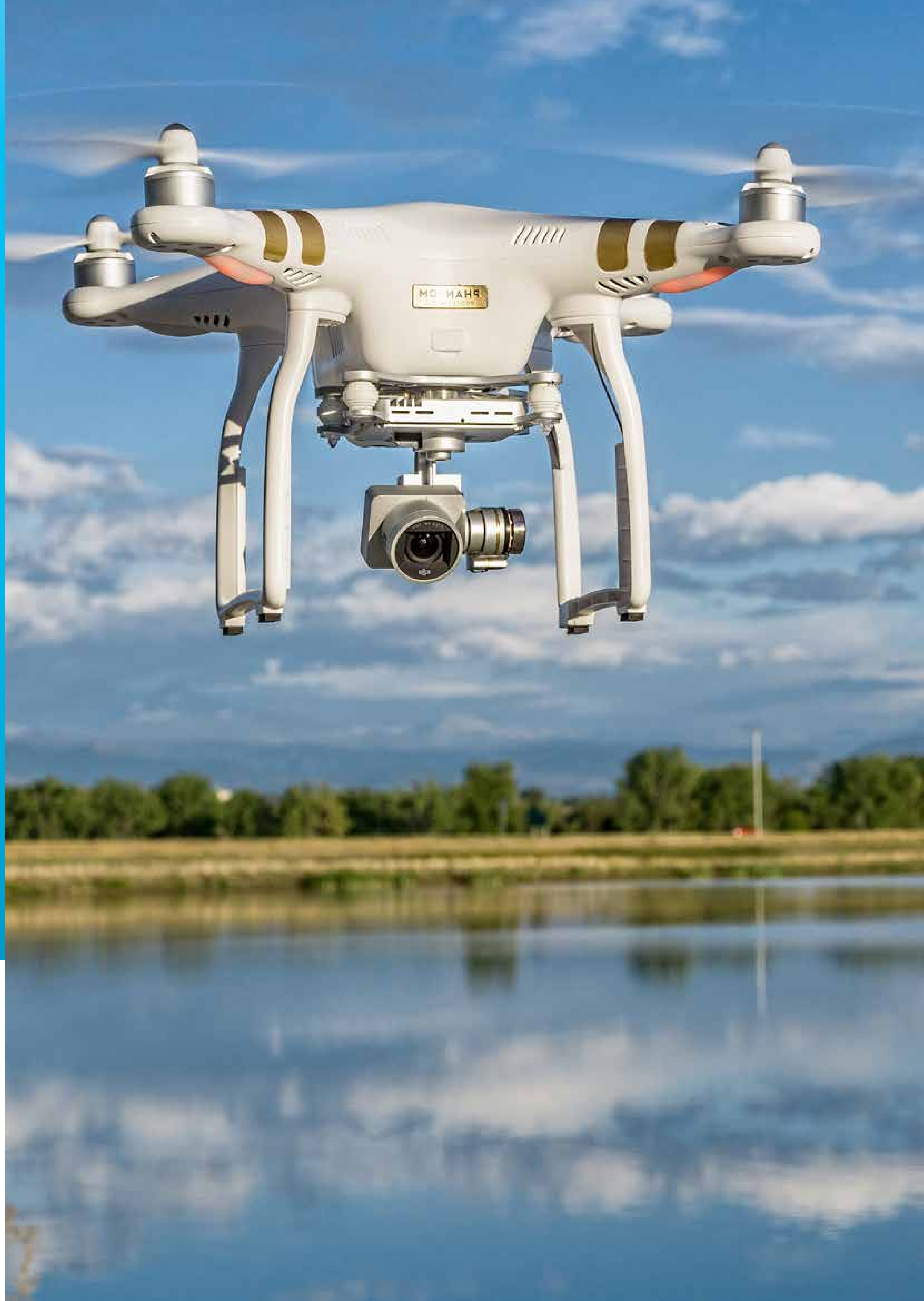

DEVELOP METHODOLOGIES TO INFORM THE INTEGRATION OF ADVANCED AIR MOBILITY (AAM) INTO THE NATIONAL AIR SPACE SYSTEM (NAS)

A11L.UAS.106_A66

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Develop Methodologies to Inform the Integration of Advanced Air Mobility (AAM) into the National Air Space System (NAS)

Background:

The Office of Aviation Policy and Plans (APO) has a commercial aviation forecasting process and methodology – known as the Terminal Area Forecast – Modernized (TAF-M). Overall, TAF-M projects airport enplanements and operations based on a flow of passengers passing through a network of airports with substantial commercial activities. The forecast currently assumes that the network of passenger flows and aircraft serving them, drawn from these 230 airports that form the nodes of the network, do not change over the horizon of the forecast. In other words, the underlying network in TAF-M is assumed to be fixed. Under the current structure of the aviation industry, this assumption is reasonable, but as Part 135 Advanced Air Mobility (AAM)/Urban Air Mobility (UAM) commercial transportation services begin to merge with traditional aircraft, the industry will mature with new entrants proposing services across the National Air Space System (NAS). Activities at smaller regional airports at the periphery of metropolitan areas (e.g., Class D airports) are likely to see rapid increases in commercial activity in support of the expanding network. This could push smaller airports over the TAF-M commercial activities' threshold of 100,000 annual Part 121 enplanements. Alternatively, as regional airports begin expanding services due to emerging Part 135 AAM/UAM commercial transportation operations, Part 121 services in established core commercial airports could decline. Furthermore, this could flex the nodes at established TAF-M airports. These, in turn, will result in a network that is flexible. From a research perspective, it is important to understand the extent to which such maturation (i.e., Class D airports qualifying to become a node in TAF-M commercial airport network; and/or commercial airport losing services due to expanding Class D airports services thus losing their previous node positions) is likely via Part 135 AAM/UAM activities in the NAS.

Based on the empirical research and findings of this grant, APO plans to improve, implement, and incorporate the forecasting model that is dedicated to predicting commercial-aviation network expansion and contraction by accounting for Part 135 AAM/UAM commercial transportation service activities. The new model would allow inactive nodes – airports without substantial economic activities – to become active, as well as active nodes to become inactive, due to Part 135 AAM/UAM commercial transportation services attracting and dispersing passenger flows respectively. The flexibility of the network, the key research focus, will facilitate the relaxing of the assumption that the network does not change over the forecast time horizon. This will allow the FAA to account for the growth of AAM and its impact on the NAS and assist the FAA with resource allocation and continued safe integration.

Approach:

The approach to this project includes the following tasks:

Task 1: Flexible Network Analytical Framework

Task 2: Develop a Flexible Network Commercial-Aviation Methodology

Task 3: Develop an A66 AAM/UAM Transportation Integration Forecast Methodology

Task 4: Review and Expansion of A36 Metropolitan Ranking Methodology

Task 5: Integration of Metro-Specific Parameters into A66 AAM/UAM Transportation Integration Forecast Methodology

Task 6: Generate Analytical Framework for the A66 AAM/UAM Transportation Integration Forecast Methodology

Task 1 FY24 Activities:

The research team conducted a thorough review of the current TAF-M Methodology utilized by the FAA to project future Part 121 air traffic and operations. This process involved identifying and understanding the underlying principles, assumptions, and parameters that govern the TAF-M Part 121 forecasts. As part of this process, the research team reproduced TAF-M operations using Python scripts to ensure the methodology could be applied programmatically and accurately replicated. Subsequently, the research team also conceptualized the input and output structure for the proposed Terminal Area Forecast – Modernized 2 (TAF-M2) model which would account for potential Part 121 enplanement shifts resulting from the introduction of Part 135 AAM/UAM commercial transportation services into the NAS. Through this exercise, a comprehensive conceptual framework was developed to demonstrate how Part 135 AAM/UAM commercial transportation services could potentially interact with the TAF-M2 model.

Task 2 FY24 Activities:

The research team began archiving data pertaining to the TAF-M2 Methodology developed through Task 3. These data will be utilized by the research team to conduct a limited implementation of the TAF-M2 Methodology in Q1 FY25 to produce a 25-Year Forecast of Part 121 Enplanements for the Los Angeles Combined Statistical Area (CSA).

Task 3 FY24 Activities:

The research team conducted a literature review about passenger choice modeling related to ground transportation access and airport preference. Upon completion of this literature review, the research team developed a three-phase methodology to assess how the introduction of Part 135 AAM/UAM commercial transportation services as an airport access mode may shift Part

121 enplanements among airports within select US CSAs. The phases, outlined below, collectively reflect the proposed TAF-M2 Methodology. Through this process, the research team identified appropriate data sources for each variable involved in the methodology.

Phase I: TAF-M Part 121 Enplanement Forecasts

Utilizing the existing TAF-M Methodology, 25-Year Forecasts of annual Part 121 enplanement estimates will be constructed for each selected US Metropolitan Statistical Area (MSA), as well as for each airport within each selected US MSA. These forecasts will serve as a baseline of annual Part 121 enplanement estimates through 2050 based on the assumption that AAM/UAM airport access services are not introduced within the selected US MSA during the forecast period.

Phase II: AAM/UAM Transportation Integration Forecasts

Next, the A66 AAM/UAM Transportation Integration Forecast Methodology will be applied to determine the extent of potential annual Part 121 enplanement shifts between airports within each selected US metropolitan area due to the introduction of Part 135 AAM/UAM airport access services into respective metropolitan urban transportation systems. To this end, a nested logit model will be utilized to estimate the appropriate weights of annual Part 121 enplanement shifts for each airport within each selected US CSA based on factors that influence discrete passenger choices pertaining to: a) airport access mode; and b) airport preference.

Phase III: TAF-M2 Part 121 Enplanement Forecasts

Finally, TAF-M2 25-Year Forecasts of annual Part 121 enplanement estimates will be constructed for each airport within each selected US CSA by utilizing a forward induction approach. Annual airport-level weights developed through the A66 AAM/UAM Transportation Integration Forecast Methodology will be iteratively applied to annual MSA-level Part 121 enplanement estimates developed through the TAF-M Methodology. The TAF-M2 forecasts will serve as a counterfactual of annual Part 121 enplanement estimates through 2050 based on the assumption that Part 135 AAM/UAM airport access services are introduced in the immediate future within the selected US CSAs.

In addition to the above methodology, the research team submitted sample flight telemetries which would accompany the TAF-M2 25-Year Forecasts, as well as documentation containing explanations of the parameters and assumptions used to generate the sample flight telemetries. As the TAF-M2 Methodology was not yet implemented, the research team utilized TAF-M Part 121 enplanement projections and A36 Part 135 enplanement projections to develop the sample flight telemetries.

Task 4 FY24 Activities:

The research team conducted a literature review about existing methodologies and variables that should be considered when ranking US CSAs based on the potential for Part 135 AAM/UAM commercial transportation service integration and expansion, concluding the project would adopt an expanded version of the A36/A41 Simple Multi-Attribute Rating Technique to reassess Part 135 AAM/UAM site suitability. In doing so, key variables pertaining to urban structure, economic scale, congestion and travel time, market readiness, and existing short-haul markets were retained from the A36/A41 projects. Additional variables identified by the literature as important indicators of Part 135 AAM/UAM commercial transportation service adoption, such as average personal income, were noted for inclusion within the expanded site suitability analysis. Through this process, the research team identified appropriate data sources for each variable to be leveraged in the expanded site suitability analysis occurring in FY25.

Key Findings:

As this project focuses on the development, refinement, and implementation of a flexible commercial-aviation network methodology, it is still too early to report key findings. Thus far, research activities for this project have consisted of a) literature reviews pertaining to key factors associated with AAM/UAM adoption, airport access mode choice, and airport preference; b) identification and acquisition of relevant data; and c) development and refinement of methodological procedures. Subsequent research activities will consist of the implementation of the TAF-M2 Methodology which will provide 25-Year forecasts depicting how potential passenger flow shifts among airports within select US CSAs shift Part 121 enplanements, as well as the development of a data generation tool to assess how user-defined scenarios would impact Part 121 enplanements.

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COLLISION SEVERITY OF SUAS IN FLIGHT CRITICAL ZONES OF PILOTED HELICOPTER

A11L.UAS.115_A67

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Collision Severity of sUAS in Flight Critical Zones of Piloted Helicopter

Background:

The FAA needs to evaluate the severity and likelihood of collisions between sUAS and manned aviation. As research continues to establish critical risk assessments for operational approvals of sUAS, the investigation of the severity of the impact of large sUAS with helicopters has yet to be quantified. With the FAA beginning to integrate Advanced Air Mobility (AAM)/Urban Air Mobility (UAM) operations into the National Airspace System (NAS), these sUAS to helicopter collision severity and risk assessments will inform future policy and operational development. The FAA will then utilize these findings to help support SMS assessments.

The research effort investigated the severity metrics of the collision between multi-rotor and fixed-wing sUAS, weighing 2.7, 4, 10, 25, or 55 pounds with a manned helicopter during key phases of flight, such as hover, forward flight, and cruise. Recommendations from this research will help ATO guide future research of AAM/UAM. Prior collision severity research performed by ASSURE, Task A16, focused on larger Part 29 helicopters encountering relatively small sUAS (2.7lb (Quadcopter) and 4lb (Fixed Wing)). Research conducted under this current requirement addresses encounters with that same small sUAS, as well as larger (10 lbs./25 lbs./55 lbs.)) sUAS, impacting medium-size Part 27 helicopters that are more representative of those found in the current NAS, specifically examining impacts in the following locations:

1. Horizontal Stabilizer
2. Vertical Stabilizer
3. Mast
4. Main Blade
5. Windshield
6. Nose

Three different collision speed scenarios were considered:

1. Forward flight at a collision speed of 94 kts. (Medium).
2. Cruise flight at a collision speed of 149 kts. (Max).
3. Hover condition with a speed of collision of 39 kts.

To accelerate results, the lessons learned, and the sUAS Finite Element Models (FEM) developed in the previous ASSURE Task A16 were used for analysis where possible. This research project started in November 2022 and was completed by July 2024.

Approach:

Task A16 focused on Part 29 helicopters encountering smaller 2.7 and 4 lbs sUAS. This phase addressed those same size sUAS (2.7 and 4 lbs) and larger sUAS (10, 25, and 55 lbs) impacting a medium-sized Part 27 helicopter, specifically looking at windshields, main rotor blade, rear servo, cowling, nose, and horizontal stabilizer structures.

Task 1 – Research Task Plan and Helicopter Purchasing Process.

NIAR located and purchased a structurally complete medium-sized Part 27 helicopter (Robinson R44).

Task 2 – Helicopter Reverse Engineering.

The medium-sized Part 27 helicopter purchased during Task I was reverse-engineered to create a Computer Aided Design (CAD) and Finite Element (FE) model representing its major structural components. The reverse engineering process was divided into five major tasks:

1. Scanning
2. Hand Measurements and Repair Manual
3. Weight Documentation
4. CAD Model Development
5. Material and Fastener Reverse Engineering

Task 3 – Helicopter Finite Element Model.

The 3D CAD model of the medium-sized Part 27 helicopter developed on Task II was used to generate the detailed FEM for collision severity analysis. NIAR's internal processes and the building block approach were used to generate the detailed finite element model of the helicopter. Figure 1 outlines the process used for generating the helicopter FEM.

Figure 1. Flow chart for FEM.

Tasks 4 through 7 – Collision Evaluation with eight sUAS.

NIAR set up and evaluated load cases for 2.7, 10, 25, 55 lbs quadcopters and 4, 12, 25, 55 lbs fixed-wing sUAS in these tasks. Six impact locations and three impact velocities were considered for each sUAS, resulting in a total of 144 collision cases.

A set of criteria was established to categorize the results of each collision case relative to one another. The lowest damage category, Level 1, generally corresponds to minimal localized damage. The next category, Level 2, represents significant visible damage to the external surface of the aircraft, with some internal component damage but no appreciable skin rupture. The third category, Level 3, describes impact events where the aircraft's outer surface is compromised in a way that could allow ingress of foreign objects into the airframe, with some damage to the substructure. Finally, Level 4 indicates damage that includes all preceding aspects, extensive damage to internal components, and possibly compromising damage to the primary structure. In addition to these severity levels, the same evaluation criterion followed for Task A16 was used to evaluate the level of damage on the main rotor blade for this Part 27 helicopter.

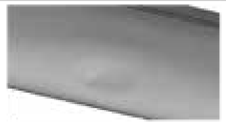
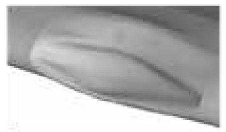
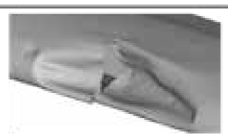
Severity	Description	Example
Level 1	• The airframe is undamaged. • Small deformations.	
Level 2	• Extensive permanent deformation on external surfaces. • Some deformation in internal structure. • No failure of skin.	
Level 3	• Skin fracture. • Penetration of at least one component into the airframe.	
Level 4	• Failure of the primary structure.	

Figure 2. Severity Levels.

Task 8 – Final Report – Collision Evaluation.

The research completed throughout Tasks 1 to 7 was summarized into one single project report delivered on August 2024.

Key Findings:

The results of the 135 impact scenarios analyzed corresponding to the quadcopter and fixed-wing sUAS architectures from 2.7 lbs. to 55 lbs. are summarized in Figure 3. Nine cases were not analyzed because the collision was not geometrically feasible. An example of mid-air collision evaluation analysis is shown in Figure 4. The following key findings affect the severity classification of the impact events:

1. There is a clear trend with the increase of sUAS mass and impact velocity on the severity outcome. There is less severity for smaller mass sUAS and lower impact velocities.
2. Nonetheless, it should be noted that the architecture and construction of the sUAS also influence the severity levels significantly:
   a. Direct impact with stiff components (i.e., the motors) increases stress concentration and larger damage to the impacted structure.
3. From a severity level point of view, the most critical impact location is the windshield. All sUAS impacts result in severity level 4 when the speed is greater than 39 knots (hover). Some sUAS (F12, Q55, and F55) produced a level 4 severity at hover speed. This is related to the fact that conventional Part 27 rotorcraft windshields are not bird-strike resistant.
4. The main source of severity for main rotor blade impacts is the weight and size of sUAS. This is due to the blade rotational speed being the largest component of the relative impact velocity.
   a. Larger sUAS impacts do not result in direct damage to the blade, as opposed to small-size UAS with their stiff components (i.e., motors). However, they create excessive blade bending and twisting, which could lead to unrecoverable loss of control.
5. Any impact on the tail rotor will likely result in the tail rotor skin debonding, leading to loss of control. This occurred even on secondary impacts with the foam wings of the 4 lbs. fixed-wing sUAS.
6. Impact with the nose at hover speed (39 knots) is the least severe. All sUAS were deflected at hover speed, which resulted in minimal damage to the rotorcraft skin.
   a. However, impacts at higher speeds (149 knots) with the larger sUAS (25 and 55 lbs.) result in loss of structural integrity in the forward fuselage.
7. Impacts with the mast do not result in sUAS penetration or severe structural damage. However, A level 4 severity was assigned to cases where the swash plate links are pinched or compressed, which could interfere with pilot control of the aircraft.

Impact cases on the windshield and the main rotor blade were compared to actual sUAS mid-air collisions. The observed damage in the analysis correlates well with the actual event observations, as highlighted in Figure 5. These events are used as additional validation data points and add confidence to the analysis results.

Overall, the small size and type of construction utilized in the Part 27 rotorcraft results in severe damage when there is a mid-air collision with larger sUAS (25 and 55 lbs.). Conversely, impacts with sUAS less than 10 lbs. are less severe, even at higher speeds (149 knots). The findings from this research may be used to conservatively define airborne hazard severity thresholds for collisions between sUAS of several sizes and weights and a Part 27 rotorcraft.

UAS\Impact Area	Horizontal Stabilizer			Vertical Stabilizer			Mast			Nose			Windshield			Blade		
	Hover	Medium	Cruise	Hover	Medium	Cruise	Hover	Medium	Cruise	Hover	Medium	Cruise	Hover	Medium	Cruise	Hover	Medium	Cruise
Q2.7	1	2	3	1	2	3	1	2	2	2	3	3	1	4	4	2	2	2
F4	2	2	3	4	4	4	1	2	3	2	3	3	1	4	4	3	3	3
Q10	2	3	4	2	3	4	2	2	3	2	3	3	4	4	4	3	3	3
F12	-	-	-	4	4	4	2	2	3	2	3	3	2	4	4	4	4	4
Q25	2	4	4	2	3	4	2	3	4	2	3	4	2	4	4	4	4	4
F25	-	-	-	4	4	4	2	3	4	2	3	4	3	4	4	4	4	4
Q55	3	4	4	4	4	4	3	4	4	2	4	4	4	4	4	4	4	4
F55	-	-	-	4	4	4	4	4	4	2	4	4	4	4	4	4	4	4

Figure 3. Simulation Severity Matrix – Summary.

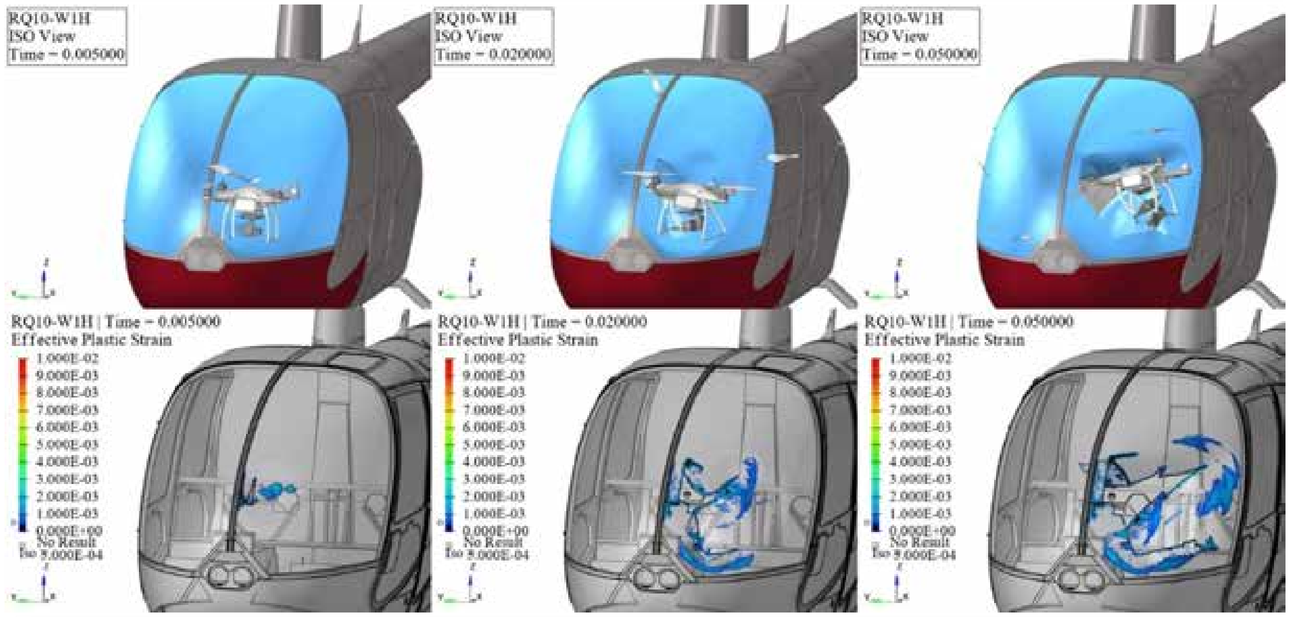


Figure 4. Simulation Severity Matrix – Summary.

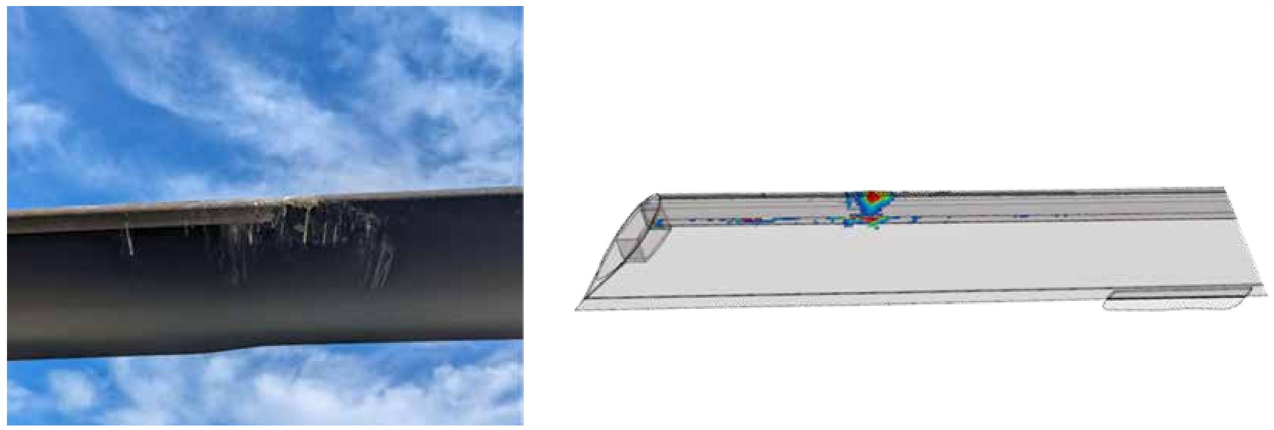


Figure 5. Comparison of an actual mid-air collision event vs. FE Analysis.

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VALIDATE SUAS DAA WELL CLEAR REQUIREMENTS

A11L.UAS.117_A68

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Validate sUAS DAA Well Clear Requirements

Background:

Detect and Avoid (DAA) industry standards have proposed separation criteria to satisfy regulatory well clear requirements for sUAS DAA operations that maintain separation from manned aircraft. SUAS DAA well clear separation criteria are often supported by unmitigated simulation analysis but have yet to be assessed holistically for compliance with regulatory right-of-way rules, good human factors engineering, remote pilot usability, DAA surveillance limitations, mitigated simulation analysis that includes the DAA system, harmonization with proposed risk ratio values, behavior acceptance by other pilots to not interfere with manned aircraft operations, and so forth.

Approach:

This project will assess, refine (if necessary), and validate well clear separation criteria for a variety of sUAS operations that avoid manned air traffic. This project will also assess smaller separation criteria that is suitable for interactions between two sUAS for a variety of interactions near and away from flight obstacles at low altitudes. The project will be divided into three phases:

Phase 1: Background Report

Task 1.1: Background Report

Phase 2: Creation of Planning Documents

Task 2.1: sUAS Well Clear Volume Validation

Task 2.2: Right of Way Quantification

Task 2.3: Remote Identification Field Testing

Task 2.4: UTM Service Field Testing

Phase 3: Test Plan Execution

Task 3.1: sUAS Well Clear Volume Validation

Task 3.2: Right-of-Way Quantification

Task 3.3: Remote Identification Field Testing

Task 3.4: UTM Services Field Testing

Task 3.5: Final Briefing and Report

Key Findings: The team has completed Phase 1 of the project in which they conducted a thorough review of international, US government, and industry standards work to create well clear separation criteria for DAA systems. It was found that the proposed criteria have not been supported by mitigated simulation analysis that includes the DAA system and are yet to be assessed for compliance with regulatory right of way rules and remote pilot usability.

The team has also completed Phase 2 of the project. Comprehensive work plans have been developed with the common objective of refining and/or validating well-clear separation criteria and proposing and/or validating sUAS-sUAS separation criteria.

The team is currently in the test plan execution phase where the approved test, simulation, and analysis will be executed for each topic produced in Phase 2.

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CONDUCT SAFETY RISK MANAGEMENT ANALYSIS ON SMALL UNMANNED AIRCRAFT DETECT AND AVOID SYSTEMS

A11L.UAS.120_A71

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Conduct Safety Risk Management Analysis on Small Unmanned Aircraft Detect and Avoid Systems

Background:

Safety management policy and requirements established by the FAA are mandated in FAA Order 8000.369: Safety Management Systems. FAA Order 8040.4B: Safety Risk Management (SRM) Policy establishes the requirements for an SRM program and conducting SRM within an organization. According to the National Academies of Sciences (2018), the systematic approach to safety risk management has achieved a high level of safety for all users of the National Airspace System. Unfortunately, the agency's current safety risk management approaches are qualitative and subjective. Additionally, most safety risk management processes currently used in aviation to create a Safety Risk Management Document (SRMD) analysis were initially intended for the safety assurance of manned aircraft and not unmanned systems. Proposed methodology refinements when creating an SRMD are needed to support risk management for UAS and Detect and Avoid (DAA) Systems. The project will focus on SRM processes for UAS with a primary lens on DAA risk assessment to propose recommendations towards refined SRM processes and SRMD for DAA systems.

Knowledge Gaps/Research Questions

1. Through a sensitivity analysis, what portions of a DAA system design are most critical when it comes to mitigating collision risks?
2. Does this change for different DAA architectures or operations such as Airborne DAA, Ground Based DAA, UAS traffic management Surveillance Services as part of a DAA system, automated or manual DAA maneuvers, and Multi-vehicle DAA architectures and operations?
3. What risk assessment tools are recommended for industry DAA risk management?
4. Are they [risk assessment tools] different than the risk assessment tools recommended for FAA use?
5. What does a sensitivity analysis reveal about the effects of loss of link on DAA performance when considering different DAA architectures and operations?

Examples include Ground Based vs Airborne, Manual vs Automated avoidance, en-route vs terminal operations, etc.

6. How should a suitable standard/accepted risk assessment on a DAA system be structured to provide meaningful insights into system design, performance, and safety optimization?
7. What variables or aspects of system design have the greatest impact?
8. What safety metrics are recommended for meaningful DAA system safety assessments? Consider assurance, performance, and system-to-system interactions.
9. What input-processing-output models or diagrams are most useful for identifying potential hazards?
10. How could guidance for SRMD assessments and UAS SRM policy be updated to satisfy the original intent of safety risk management and the risk management cycle?
11. What risk assessment tools and metrics are recommended for DAA system safety assessments?
12. What guidance is recommended for distinguishing between system safety and system-of-systems safety?
13. What risks are unique or more critical to different DAA systems? Consider a variety of different DAA systems and DAA operations.
14. How can SRM assessments better inform DAA standards and DAA development (as intended in the SRM cycle) rather than be an activity that is conducted after the design standard or system development is complete?

Approach:

Task 1: Issue Report

The research team drafted an issue paper that explores DAA system functions and operations against the backdrop of the SRM process. This approach helped identify issues and gaps in the SRM process that pose challenges to assessing risks associated with DAA systems and their operation. Framing this issue paper in terms of the SRM process – describing the system, identifying hazards, assessing risk, analyzing risk, and controlling risk – provided a rational way to look for issues and gaps in the SRM process and its application to DAA systems. This approach and the associated issues and gaps identified via the issue paper establish a framework for future research tasks.

Key Findings

Task 1: Issue Report

1. There are no universally accepted reliability metrics for DAA systems.
2. There are currently no accepted standards for assessing the risk associated with DAA systems.
3. Data required to assess the risk associated with DAA systems is often incomplete, inaccurate, or unavailable.
4. Models driven by reliable data and a robust analytical framework are essential to assessing the risk associated with DAA systems.
5. The evolution of DAA technologies is occurring rapidly and extends beyond the current UAS operational guidance.

6. There is a need for effective verification and validation of DAA systems to ensure reliability.
7. Guidance and standards are needed to define and apply risk controls for DAA systems.

Task 2: Draft Hazard Identification and Risk Assessment Processes for DAA Systems and Operations

Task 2 builds upon Task 1, facilitating the development of hazard identification and risk assessment processes for (1) DAA systems and (2) operations. Additionally, safety risk assessment templates will be developed. These templates should consider baseline DAA system functions and address issues identified in Task 1 to the greatest extent possible. This task is currently in progress.

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CONDUCT SCIENCE TECHNOLOGY ENGINEERING AND MATH (STEM) OUTREACH TO MINORITY K-12 STUDENTS USING UAS AS A LEARNING PLATFORM PHASE V

A11L.UAS.53_A73

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OREGON STATE UNIVERSITY

VIRGINIA TECH

Conduct Science Technology Engineering and Math (STEM) Outreach to Minority K-12 Students Using UAS as a Learning Platform Phase V

Background:

Science, Technology, Engineering, and Mathematics (STEM) career opportunities are projected to outpace the growth of career opportunities in non-STEM fields. A STEM capable workforce is key to meet this demand. While the STEM field has more job opportunities and often higher wages, key groups, such as women and minorities, are underrepresented in STEM. To make STEM opportunities more accessible to underrepresented groups and to contribute to creating the next generation's interest in the UAS field, ASSURE is conducting STEM activities using UAS as the central learning platform. This project falls within the COE's mandate to educate and strategically facilitate the distribution of ASSURE research. This past research distribution will include, as a minimum, UAS engine ingestion, air mobility, and cyber security, etc. The long-term goal of the project is to ignite an interest in UAS/STEM and, therefore, nurture part of the possible future UAS workforce.

Approach:

In keeping with Phases 1-4 of the STEM efforts funded by the FAA through ASSURE, each school was in control of their own specific approach to address the two main tasks: UAS Roadshows and Summer Camps. The schools were able to add additional outreach opportunities through an ad hoc task to cover events not initially planned at the time of the proposal.

NC State University

NC State continued to serve as the lead university for Phase V and handled the programmatic support for the project through technical interchange meetings and program management review updates. Building on activities supported during the previous STEM grant, the team was active in partnerships both on and off campus with the NC Department of Transportation's (DOT's) Division of Aviation (DOA) and several programs within The Science House and the TRIO Early College Program.

For the third year, NC State was able to support the DOA's Aviation Career Education Academy grant program which hosts middle and high school students at local public airports in North Carolina. During the summer 2024 camps, the university took on a larger role, aiding with both the drone flight demonstrations and providing the bulk of the DOT's career opportunity presentation. Camps were offered to select hands-on experiences from the following options: indoor flying with small trainer drones, indoor (hangar) or outdoor flights with a small UAS, and drone simulators deployed via laptops. There were eight total awards provided to seven unique airports across the state. Each camp is individually organized and the support from this program makes up only a small portion of the total curriculum. Some of the other activities the students participated in included manned aircraft tours in hangars and first flights in smaller general aviation planes.

Through the TRIO program, one of the new highlights for this year was a curriculum involving block programming for command and control. Students were tasked in small groups with exploring basic commands to navigate the aircraft through a series of increasingly difficult prompts. Finally, each student was required to design and run a program on their own that would spell out the first letter of their first name. This open-ended mission allowed for creativity and problem-solving skills development and quite a lot of trial and error.

In support of all outreach activities under this award, the university was able to make capital improvements to the UAS fleet through the acquisition of aircraft and supporting supplies to provide students with the best and latest technologies. Several additional events are planned through the remainder of this effort.

Oregon State University

Oregon State University (OrSU) hosted several outreach events focused on providing both hands-on activities using drones and participating in various career fairs and open houses where the OrSU team introduced drone use for various civil and construction engineering applications. Overall, over 1,050 students including those from underrepresented groups attended these events.

The hands-on activities included assembling drones from the components, test-flying the assembled drones, and spoofing the onboard sensors of drones. The activities are designed to provide K-12 students with opportunities to learn the basic principles of drone flight as well as the security concerns related to sensor spoofing attacks on drones. Oregon State supported the STEAM Night event at Blodgett Elementary School (Philomath, OR) by providing hands-on activities to K-4 students. Blodgett Elementary School serves an under-resourced community in a rural area and has a small enrollment (less than 40 students in total). In collaboration with the College of Engineering at Oregon State, the Oregon State team was able to provide hands-on activities to diverse groups of students who are underrepresented in STEM. In the Beaver Achiever Camp hosted at the Oregon State Corvallis campus, Oregon State provided hands-on activities to African American middle school students and their teachers. In the Engineering Migrant Institute program hosted at the Oregon State Corvallis campus, high school migrant students participated in hands-on activities. In the Oregon State Juntos program, Latinx high school students were introduced to drones.

In partnership with OrSU outreach programs, the team participated and presented at various career fairs and open houses in Corvallis, Salem, and Portland, Oregon. The OrSU team prepared a poster, fliers, and a presentation describing various drone applications in the construction industry such as construction progress monitoring, aerial surveying, safety inspections, and structural inspections among others. Some of these career events were organized by trade associations while some of them were organized by various high schools in Oregon and OrSU.

Virginia Tech

This summer, Virginia Tech's (VT's) Mid-Atlantic Aviation Partnership (MAAP) engaged in several STEM outreach activities aimed at underrepresented communities, using UAS as a platform to ignite interest in STEM fields. These efforts align with the ASSURE mission to educate and distribute research in the UAS sector.

Summer Camps: VT conducted two week-long summer camps, each hosting approximately 40 students. One camp took place on VT's Blacksburg campus, in partnership with the VT Center for the Enhancement of Engineering Diversity, Wing Aviation, VT's Engineering Department, and VT Institute for Critical Technology and Applied Science. This residential camp allowed students to fully immerse themselves in the university experience. The other camp was held in Alexandria, VA, in collaboration with the K-12 programming at the VT Innovation Campus and industry sponsors. While the students in Alexandria returned home each evening, the camp maintained a strong focus on UAS and STEM education.

Both camps were designed to engage underserved communities. Students had the unique opportunity to build their own drones from individual components and earn their FAA TRUST certification. Throughout the week, they also heard from speakers in the drone industry, toured drone-related businesses, and spent significant time flying drones under the supervision of Part 107 certified pilots. The culmination of both camps was a showcase event at the VT Drone Park, where students test-flew their custom-built drones and participated in a flight competition.

Outreach Events: In addition to the summer camps, VT conducted a presentation for around 80 students at Christiansburg Middle School, introducing them to UAS technology and the cutting-edge research MAAP is involved in. VT also plans to host a site visit at Wing Aviation for a local Cub Scout Pack, which includes youth from kindergarten to fifth grade. This will further expand outreach to youth interested in aviation and drone technologies.

These initiatives were made possible through funding from the FAA ASSURE's A73 program, which supported MAAP's efforts to contribute to the next generation of the UAS workforce. The combination of hands-on learning, industry exposure, and mentorship through these programs is designed to foster a long-term interest in UAS and STEM fields.

Key Findings:

NC State University

- Completed eight aviation camps with NC DOT at airports across the state, highlighting aviation career opportunities with a specific emphasis on rural areas. This program reached a total of 260 students.
- Supported multiple NC State initiatives including the Catalyst program for high school students with disabilities, the TRIO Pre College Program, and the Drone Wolves camp.

Oregon State University

- Completed two hands-on activities using drones, where middle school students with underrepresented backgrounds (African American and Hispanic students) participated.
- Supported six career fairs and open houses hosted by various trade associations, high schools, and OrSU, highlighting drone use for various applications in the construction industry including progress monitoring and inspections.
- Throughout the A73 STEM effort, OrSU had 1050 students/ contacts.

Virginia Tech

- Completed two week-long summer camps for middle school aged students in underserved communities.
- Presented to local middle school robotics students on research in the drone industry.
- Plan to conduct site visits at Wing Aviation with local communities and schools.

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INCREASE SMALL UAS CONSPICUITY IN TERMINAL ENVIRONMENTS

A11L.UAS.128_A74

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Increase Small UAS Conspicuity in Terminal Environments

Background:

Approved and/or unauthorized sUAS operations are increasing in frequency in FAA terminal environments. The ability of a UAS Pilot In Command, a UAS observer, and terminal air traffic controllers to clearly see UAS in operation supports the safe separation of the UAS from manned aircraft. Varied lighting schemes can increase the conspicuity of sUAS and thereby increase national airspace system safety.

The operation of small UAS (sUAS) within the terminal area of an airport poses an added risk of potentially hazardous encounters with air traffic. The concentration of air traffic arrivals, departures, overflights, and other near-airport aircraft operations necessitate rapid visual detection and recognition of all aerial traffic—including sUAS—to enable effective see-and-avoid by other aircraft crews and de-confliction by air traffic controllers.

The purpose of this human factors research is to identify factors that increase the human visual conspicuity of sUAS operating within the terminal area of an airport. Williams et al. (2022) performed a computer-based study evaluating a series of independent variables, including sUAS lighting colors, flash rates, background environment, relative movement patterns, time of day, environmental conditions, and other factors. The findings of the Williams et al. (2022) study form the basis of this research project.

A comprehensive literature review revealed 11 general factors that influenced visual conspicuity, including: 1) Background conditions; 2) Environmental lighting; 3) Light flashing frequency; 4) Light intensity; 5) Light color; 6) Meteorological conditions; 7) Movement/Hovering; 8) [Vehicle] size; 9) Vehicle color; 10) Visibility distance (as perceived from the ground); and, 11) Visibility distance (as perceived from an elevated tower). Based on the factors identified in the literature review, the research team recommends prioritization of seven consolidated variables for field testing: 1) Environmental Conditions; 2) Light Flashing Frequency; 3) Light Intensity; 4) Lighting Color; 5) Meteorological Conditions; 6) Human Factors; and, 7) Night Operations.

Approach:

A field experiment will be conducted at various sUAS testing sites across the US to assess sUAS visibility factors for ecological validity. This approach will evaluate all selected testing factors to determine their impact on platform visibility in natural, real-world settings. The research team will recruit UAS operators to participate in field testing. The research team will establish a series of flight testing procedures supporting the evaluation of selected visibility conditions under different operational parameters.

Detailed testing conditions, testing locations, sampling, and other methodological and analysis procedures will be detailed in a Research Task Plan provided to the FAA for approval before execution of the flight testing phase of the project. It is anticipated that the findings of this human factors research project will provide scientific benchmarks of various factors that influence sUAS visual conspicuity and inform the development of UAS policy for sUAS operations being conducted within the terminal environment to enhance operational safety for sUAS operating in the National Airspace System.

The research team will perform the following tasks in support of this project:

Task A: Literature Review & Gap Analysis

The project team will update the existing Annotated Bibliography literature search published by the Civil Aerospace Medical Institute, which focuses on methods to increase the conspicuity of sUAS by manipulating lighting schemes (colors and flash rates) on the UAS.

Task B: Identify Effects of Fixed Distances and Positions to Observer

Researchers will perform flight testing to determine the threshold and parameters affecting sUAS conspicuity in the terminal environment from fixed viewpoints at different distances. The fixed viewpoints include perspectives from a Visual Observer and an Air Traffic Controller operating from an elevated tower.

Task C: Identify Effects of sUAS Vehicle Size & Weight

Flight testing will be conducted to identify the sUAS vehicle's physical parameters' impact on the vehicle's conspicuity and its ability to hover for a quadcopter or similar rotorcraft configuration.

Task D: Identify Effects of the sUAS Lighting System

The research team will perform flight testing to identify the impact of the sUAS lighting system on its conspicuity, including vehicle color, color patterns, light intensity, and light flashing frequencies.

Task E: Identify Effects of Observer Environmental Lighting

Flight testing will be performed to identify the effects of observer ambient environmental lighting conditions on sUAS conspicuity, such as day, night, civil twilight light, nautical twilight light, and astronautical twilight lighting.

Task F: Identify Effects of Observer Environmental Meteorological Conditions

The research team will perform testing to identify the effects of observer environmental meteorological conditions, such as clear skies, overcast conditions, and other atmospheric obscurations, on UAS conspicuity in the terminal environment.

Task G: Identify Effects of Observer Visual Background Conditions

The project team will determine the effect of observer visual background conditions on sUAS conspicuity in the terminal environment, such as in the presence of blue sky, grey sky, night sky, green landscape, brown landscape, and other related factors.

Task H: Final Reporting on sUAS Conspicuity

The research team will aggregate and summarize the findings of flight testing into a comprehensive report, providing recommendations to inform the FAA about conditions that influence the visual conspicuity of small unmanned aircraft systems to support the safe integration of these platforms into the National Airspace System.

Project Status

This project is currently in progress. The research team has completed the Literature Review and Gap Analysis delivery and is actively collaborating with agency stakeholders to establish flight testing protocols. Further information will be delivered in the Research Task Plan and subsequent project reporting.

RESEARCH PERSONNEL

NAME	ORIGIN
Ryan Wallace, ERAU	United States
Stephen Rice, ERAU	United States
Scott Winter, ERAU	United States
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Kenneth Common, NMSU	United States
Joshua Fisher, NMSU	United States
Juan Angel, NMSU	United States
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Katie Ragnoli, KSU	United States
Tim Bruner, KSU	United States
Kurt Carraway, KSU	United States
Spencer Schrader, KSU	United States

GRADUATION OF STUDENTS:

NAME	GRADUATION DATE
Sang-A Lee, ERAU	May 2026
Ryan Lange, ERAU	Dec 2024

FUTURE RESEARCH

UPCOMING RESEARCH

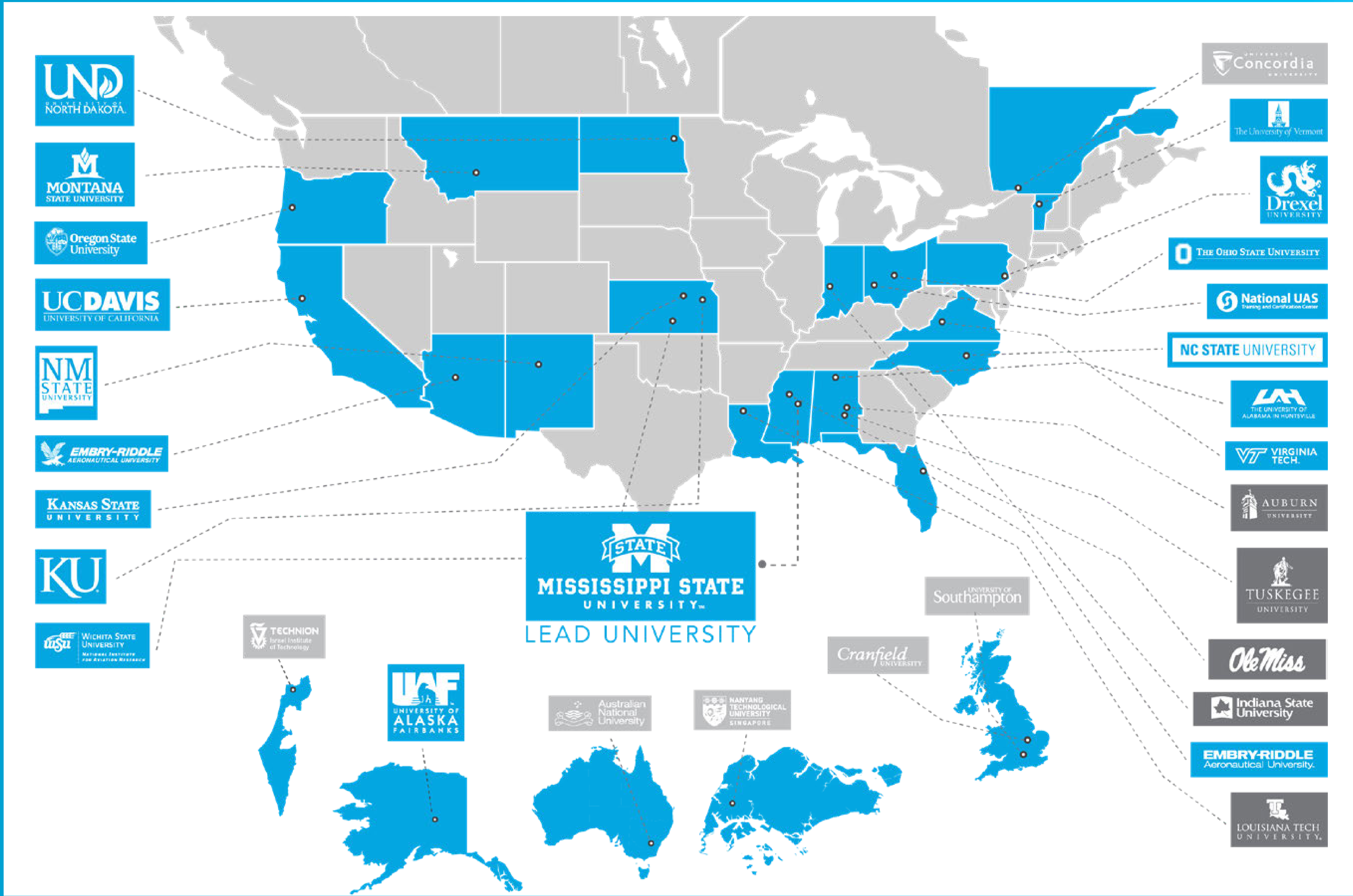
- A11L.UAS.102_A78: Evaluate the Applicability of Crashworthiness Standards for Urban Air Mobility
- A11L.UAS.113_A80: Develop Bird Strike Avoidance Requirements for Remotely Piloted Advanced Air Mobility Operations
- A11L.UAS.114_A81: Develop small Unmanned Aircraft Detect and Avoid Human Factors Requirements
- A11L.UAS.112_A82: Develop a Data Driven Framework to Inform Safety Risk Management (SRM) Mitigation Credit Estimates
- A11L.UAS.122_A83: Analyze Drone Traffic
- A11L.UAS.68_A84: Disaster Preparedness and Emergency Response Phase IV
- A11L.UAS.135_A85: Develop Models to Inform AAM Operational Risk Assessment
- A11L.UAS.85_A86: High-Bypass UAS Engine Ingestion Phase II
- A11L.UAS.53_A88: Conduct Science Technology Engineering and Math (STEM) Outreach to Minority K-12 Students Using UAS as a Learning Platform Phase VI

SIGNIFICANT EVENTS

UAS Center of Excellence (COE) Selection announced by FAA Administrator Huerta	**May 2015**
UAS COE Kick-Off Meeting	**June 2015**
Initial Research Grants Awarded	**September 2015**
World of Drones and Robotics - London, England	October 2022
International Roundtable - Virtual	November 2022
Aerial Evolution Canada 2022 Conference & Exhibition - Calgary, Canada	November 2022
CASA Meeting - Brisbane, Australia	November 2022
CAA NZ Meeting - Wellington, New Zealand	November 2022
International Roundtable - Virtual	January 2023
International Roundtable - Virtual	March 2023
Program Management Review - Wichita, KS	March 2023
CORUS-XUAM Workshop - Bari, Italy	March 2023
Advanced Aviation Innovation Summit - Washington DC	April 2023

SIGNIFICANT EVENTS

XPONENTIAL - Denver, CO	May 2023
NZ World of Drones and Robotics Conference - Auckland, New Zealand	May 2023
FAA Drone and AAM Conference - Baltimore, MD	August 2023
NASA ULI - Boston, MA	August 2023
Global Autonomous Systems Conference - Anchorage, AK	August 2023
Counter-UAS Summit - Alexandria, VA	August 2023
Program Management Review - Columbus, OH	September 2023
Commercial Drone Exhibition - Las Vegas, NV	September 2023
Unmanned Systems, West - San Diego, CA	September 2023
ICAO Drone Enable – Montreal, Canada	December 2023
Jarlath O'Neil-Dunne Memorial – Burlington, VT	January 2024
NIST Public Safety Communications Research (PSCR) UAS Workshop – Gaithersburg, MD	February 2024
Program Management Review – Arlington, VA	April 2024
XPONETIAL – San Diego, CA	May 2024
Western Regional Partnership Principles Meeting – Beaver Creek, CO	May 2024
Future Proof UAS – Huntsville, AL	May 2024
FAA Drone & Advanced Air Mobility Symposium – Baltimore, MD	July 2024
Global Autonomous Systems Conference – Anchorage, AK	August 2024
Commercial Drone Expo – Las Vegas, NV	September 2024
ICAO AAM Symposium – Montreal, Canada	September 2024
NATO Innovation Conference – Setubal, Portugal	September 2024



THE ASSURE UNIVERSITY COALITION

The FAA's Center of Excellence for UAS Research

ASSURE

Alliance for System Safety of UAS through Research Excellence