ANNUAL REPORT

2022

The FAA's Center of Excellence for UAS Research

ASSURE

Alliance for System Safety of UAS through Research Excellence

OVERVIEW

FORWARD

The Alliance for System Safety of UAS through Research Excellence (ASSURE) has continued to provide the Federal Aviation Administration (FAA), other Civil Aviation Authorities, and standards bodies with the research necessary to inform policy, rules, and regulations supporting the safe and efficient integration of Uncrewed Aircraft Systems (UAS) in this nation's and the world's airspace. Increased UAS operations, especially in dull, dirty, and dangerous missions will help to better serve societies through increases in commerce, public safety, and other public benefits.

With the easing of COVID-19 travel restrictions, ASSURE restarted its effort to build the ASSURE network and renew collaborations internationally to harmonize regulations, guidelines, and standards worldwide. This year, ASSURE began initial efforts to build a coalition in Australia and recharged efforts in the United Kingdom and Canada. It is our hope that the sharing of research results, collaboration, and international coordination between Civil Aviation Authorities and researchers will lead to a more efficient research and regulatory effort and speed UAS integration worldwide.

At the time of this writing, ASSURE researchers are engaged in thirty-seven different FAA projects at various levels of completion from proposal to final reports and peer review. Our work with the FAA has led to other research and efforts supporting NASA, DHS, DOJ, FEMA, and NIST. These cross-agency efforts work to better integrate UAS into the nation's infrastructure to the benefit of public safety and commerce.

ASSURE was called to testify to the U.S. Senate Committee on Commerce, Science, and Transportation based on all its experience working with the FAA, other government agencies, industry, and other stakeholders. Senators were interested in how they could contribute to safely speeding and supporting the FAA in the UAS integration effort. We can expect to see the results of the testimony of the witnesses in next year's FAA Reauthorization Act.

ASSURE also served on the FAA UAS Beyond Visual Line-of-Sight (BVLOS) Operations Aviation Rulemaking Committee (ARC). The work of the ARC was completed in March and recommendations forwarded to the FAA. Based on these recommendations, the FAA sponsored ASSURE to study topics such as Right-of Way Rules, Shielded UAS Operations, GPS and ADS-B Risks, small UAS Traffic Analysis, Advanced Air Mobility (AAM) Modeling, and Flight Critical Helicopter Zones. Work continues to determine Detect-And-Avoid (DAA) performance standards and the means of compliance to enable BVLOS operations critical to the growth of uncrewed operations. Our validation and verification Safety Research Facility is reviewing and testing ASTM remote ID, collision avoidance and well-clear standards, and DAA standards for FAA approval. ASSURE continues to study operation enablers like multi aircraft control, cyber security, and certification research for operations like UAS cargo transportation, air carrier operations, and air mobility. ASSURE and the FAA continue their projects focused on the public good through our Science, Technology, Engineering, and Math (STEM) projects for under-represented minorities, and a large, multiyear, interagency effort to better integrate UAS quickly, efficiently, and safely into disaster preparation and relief operations.

This Annual Report provides highlights of the work conducted in FY 2022. Please take a moment to review our work and contact us with any ideas, suggestions, or comments.

Stephen P. Luxion

STEPHEN P. LUXION (Colonel, USAF-Retired)
Executive Director, ASSURE

ASSURE LEADERSHIP

Julie Jordan
MSU Vise President of Research
and Economic Development
julie.jordan@research.msstate.edu

Colonel Steve "Lux" Luxion (Ret)
Executive Director

sluxion@assure.msstate.edu

Billy Klauser
Deputy Director

bklauser@assure.msstate.edu

Hannah Thach
Associate Director of Research

hthach@assure.msstate.edu

LeighAlison Jones
Program Coordinator

lajones@assure.msstate.edu

Angel Moore
Program Coordinator

amoore@assure.msstate.edu

Whitley Alford
Financial Manager

whitley@hpc.msstate.edu

Sheila Ashley
Program Coordinator

sheila@hpc.msstate.edu

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 & 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, and education.

ASSURE TAG LINE:

Informing UAS policy through research

ACKNOWLEDGEMENTS

Thank you to our sponsors from the integration office led by Ms. Sabrina Saunders-Hodge, Mr. Paul Strande, and their team. Our FAA Program Management office led by Mr. Nick Lento, Mr. Hector Rea, Mr. William Oehlschlager, and the team of project managers from the Washington DC and Atlantic City areas, helped ASSURE work through all the many issues associated with the new post-pandemic normal. We would also like to welcome back Karen Davis to the Program management team. We extend special thanks to Mr. Darryl Groves, our FAA Grants Officer, who manages all the many projects, associated paperwork, and authorities.

Dr. Marty Fuller, Director of Federal Relations for ASSURE's lead university, Mississippi State, was critical to the alliance when he helped rally Congressional support to overcome some bureaucratic challenges that threatened the continuation of the alliance this fall. Thank you, Marty!
I would also like to acknowledge the amazing team that ensures that ASSURE runs so smoothly. Billy Klauser, Deputy Director; Hannah Thach, Associate Director of Research; LeighAlison Jones, Angel Moore, and Sheila Ashley Program Coordinators; and Whitley Alford, Financial Manager. Our Mississippi State team manages an extremely large lineup of universities and their many different offices and interests. This is not an easy task; I am grateful for their long hours that make the team function so well. Billy Klauser has announced that he will retire at the end of this calendar year. I would like to thank him for all his years of service to the State of Mississippi, the Mississippi State University, ASSURE, and me. As my friends in the Navy say, we wish you fair winds and following seas. Bravo Zulu Billy.

The researchers could not complete their work without the many core and affiliate universities, government, academic, and industry partners. To acknowledge every member of the many teams involved in the management and execution of the ASSURE mission is not possible in this short space. Support from these partners comes from great people who are experts in aviation, aerospace, human factors, training, maintenance, logistics, operations, finance and administration, and many others who freely give their time every day to ensure the success of this center.

Thank you!

FINANCIALS

ASSURE FUNDING SUMMARY

TOTAL FUNDING $76,639,936.64

	Award Amount	Expenditures	Remaining	Cost Share	Cost Share %
Program Office	$8,409,502.78	$6,784,593.21	$1,624,909.57	$5,339,538.78	100%
Core Schools	$68,230,433.86	$33,215,238.00	$35,015,195.86	$26,057,619.353	80%
Drexel University	$2,483,121.69	$1,393,403.12	$1,089,718.57	$764,435.63	63%
Embry-Riddle Aeronautical University	$4,964,369.13	$2,862,854.41	$2,101,514.72	$1,823,207.37	87%
Kansas State University	$3,628,705.00	$2,840,824.84	$848,833.82	$1,334,798.84	68%
Mississippi State University	$6,174,755.38	$3,267,550.91	$2,907,204.47	$2,004,789.45	87%
Montana State University	$709,062.28	$709,062.28	$0.00	$599,958.32	100%
New Mexico State University	$7,198,093.33	$2,068,815.61	$5,129,277.72	$1,763,885.39	101%
North Carolina State University	$1,377,140.39	$735,176.13	$641,964.26	$460,593.91	37%
Ohio State University	$5,222,999.21	$3,306,557.78	$1,916,441.43	$2,757,046.52	100%
Oregon State University	$3,378,962.00	$1,176,880.17	$2,202,081.83	$311,050.72	26%
Sinclair Community College	$6,000.00	$0.00	$6,000.00	$0.00	0%
University of Alabama-Huntsville	$7,217,278.43	$3,992,661.35	$3,224,617.08	$3,954,173.15	103%
University of Alaska-Fairbanks	$6,749,739.40	$858,726.62	$ 5,891,012.78	$1,327,179.133	126%
University of California-Davis	$144,730.00	$141,028.44	$3,701.56	$93,287	83%
University of Kansas	$2,881,155.86	$1,204,365.8	$1,676,790.06	$764,451.21	40%
University of North Dakota	$10,141,999.76	$4,836,072.65	$5,305,927.11	$4,227,010.83	94%
University of Vermont	$1,195,000.00	$4,906.01	$1,190,093.99	$0.00	0%
Wichita State University	$4,757,322.00	$3,816,351.88	$1,445,462.12	$3,871,751.88	81%
Totals	**$76,639,936.64**	**$39,999,831.21**	**$36,640,105.43**	**$31,397,158.133**	**83%**

FUNDING BY PROJECT

TOTAL FUNDING $76,639,936.64

	Award Amount	Expenditures	Remaining	Cost Share	Cost Share %
Program Management	$8,727,024.97	$7,100,200.58	$1,626,824.39	$5,655,146.15	100%
Projects	$8,409,502.78	$8,409,502.78	$8,409,502.78	$8,409,502.78	80%
A1: Unmanned Aircraft Integration: Certification Test to Validate sUAS Industry Consensus Standards	$299,996	$299,996	$0.00	$300,280.00	100%

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FUNDING BY PROJECT

	Award Amount	Expenditures	Remaining	Cost Share	Cost Share %
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	$284,186.03	$284,186.01	$0.02	$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	$2,203,377.79	$0.00	$2,357,156.77	126%
A17: Airborne Collision Severity Evaluation - Engine Ingestion	$1,532,252.00	$1,499,959.75	$32,292.25	$1,580,974.27	164%
A18: Small UAS Detect and Avoid Requirements Necessary for Limited BVLOS Operations: Separation Requirements and Training	$1,207,574.00	$1,196,680.62	$10,893.38	$773,195.38	100%
A19: UAS Test Data Collection and Analysis	$409,810.24	$409,627.1	$183.14	$413,558.24	101%
A20: UAS Parameters, Exceedances, Recording Rates for ASIAS	$291,681.65	$283,842.44	$7,839.21	$396,319.22	140%

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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	$1,496,808.04	$1,456,060.03	$40,748.01	$581,984.23	112%
A23: Validation of Low-Altitude Detect and Avoid Standards- Safety Research Center	$1,500,000.00	$795,901.32	$704,098.68	$268,200.86	54%
A24: UAS Safety Case Development, Process Improvement, and Data Collection	$1,479,956.87	$946,265.69	$533,691.18	$459,093.07	93%
A25: Develop Risk-Based Training and Standard for Operational Approval and Issuance	$520,084.38	$311,377.64	$208,706.74	$166,054	100%
A26: Establish UAS Pilot Proficiency Requirements	$500,000	$500,000	$0	$166,666	100%
A27: Establish risk-based thresholds for approvals needed to certify UAS for safe operation	$50,0037	$463,949.21	$36,087.79	$166,679	100%
A28: Disaster Preparedness and Response	$1,999,978.77	$1,656,521.54	$343,457.23	$960,949.72	144%
A29: STEM Outreach- UAS as a STEM Outreach Learning Platform for K-12 Students and Educators (STEM III)	$488,331.25	$442,824.79	$45,506.46	$197,017.57	85%
A31: Safety Risk and Mitigations for UAS Operations On and Around Airports	$1,481,814.00	$907,855.53	$573,958.47	$470,946.88	95%
A33: Science and Research Panel (SARP) Support	$70,383.00	$43,160.74	$27,222.26	$31,839.61	73%
A35: Identify Wake Turbelance and Flututer Testing Requirements for UAS	$1,498,921.00	$1,124,834.92	$374,086.08	$809,117.94	78%
A36: Urban Air Mobility (UAM): Safety Standards, Aircraft Certification and Impact on Market Feasibility and Growth Potentials	$1,199,922.00	$1,059,180.58	$140,741.42	$692,344.32	98%
A37: UAS Standards Tracking, Mapping, and Analysis	$499,900.00	$454,442.82	$45,457.18	$166,633.33	100%
A38: CyberSecurity and Safety Literature Review	$494,238.00	$494,103.92	$134.08	$164,745.33	63%
A40: Validation of American Society for Testing Materials (ASTM) Remote ID Standards- Safety Research Center	$750,000.00	$361,663.73	$388,336.27	$170,270.18	68%
A41: Air Carrier Operations- Investigate and Identify the Key Differences Between Commercial Air Carrier Operations and Unmanned Transport Operations	$799,745.00	$473,239.72	$326,505.28	$193,681.03	29%
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	$451,859.70	$348,123.30	$165,558.33	62%
A43: High-Bypass UAS Engine Ingestion Test	$440,000.00	$124,548.76	$315,451.24	$213,333.33	100%

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FUNDING BY PROJECT

	Award Amount	Expenditures	Remaining	Cost Share	Cost Share %
A44: Mitigating GPS and Automatic Dependent Surveillance- Broadcast (ADS-B) Risks for UAS	$830,000.00	$427,261.74	$463,691.92	$243,333.00	88%
A45: Shielded UAS Operations- Detect and Avoid (DAA)	$925,000	$483,773.28	$441,226.72	$247,826.92	80%
A46: Validation of Visual Operation Standards for Small UAS (sUAS)	$500,052.27	$253,537.54	$246,514.73	$45,720.00	19%
A47: Small UAS (sUAS) Mid-Air Collision (MAC) Likelihood	$1,059,000.00	$636,593.16	$422,406.84	$407,250.70	57%
A49: UAS Flight Data Research in support of Aviation Safety Information and Sharing (ASIAS)	$469,262.00	$232,602.84	$236,659.16	$151,105.45	97%
A50: Small Unmanned Aerial Systems (sUAS) Traffic Analysis	$2,383,602.48	$915,303.27	$1,468,299.21	$364,375.62	40%
A51: Best Engineering Practices for Automated Systems	$3,621,915.74	$776,451.40	$2,845,464.34	$317,841.67	23%
A52: Disaster Preparedness and Emergency Response Phase II	$3,278,651.80	$366,920.20	$2,911,731.60	$357,404.82	33%
A53: UAS Advanced Materials Investigation	$318,958.00	$314,425.10	$4,532.90	$285,848.27	90%
A54: Propose UAS Right-of-Way Rules for UAS Operations and Safety Recommendations (ERAU, KU, UND)	$1,393,767.00	$325,011.05	$1,068,755.95	$251,063.47	12%
A55: Identify Flight Recorder Requirements for UAS Integration into the NAS	$1,089,090.00	$186,851.45	$902,238.55	$120,764.88	17%
A56: Evaluate Unmanned Aircraft Systems (UAS) Electromagnetic Compatibility (EMC)	$975,872.70	$575,779.46	$400,093.24	$79,772.55	25%
A57: Investigate Detect and Avoid (DAA) Track Classification and Filtering	$1,513,441.00	$235,430.85	$1,278,010.15	$155,770.49	13%
A58: Illustrate the Need for UAS Cybersecurity and Risk Management	$1,869,991.00	$198,217.26	$1,671,773.74	$32,917.13	5%
A60: Evaluation of Unmanned Aircraft Systems (UAS) Integration Safety and Security Technologies in the National Airspace System (NAS) Program	$13,931,967.57	$716,816.60	$13,215,150.97	$1,758,134.88	31%
A61: STEM Outreach	$231,000.00	$0.00	$231,000.00	$0.00	0%
A62: Disaster Preparedness and Emergency Response Phase III	$2,768,070.00	$4,906.01	$2,763,163.99	$0.00	0%
Totals	**$76,639,936.64**	**$39,999,832.23**	**$36,640,104.41**	**$31,397,158.13**	**83%**

COST SHARE SUMMARY BY CONTRIBUTORS

Adaptive Aerospace Group, Inc.	$5897.34
Advanced Thermoplastic Composites	$400.00
AIM Institute	$5090.00
Airbus	$459228.00
AgentFly Software	$50000.00
ARC	$41355.58
Aria Group, Inc.	$400.00
Arlin’s Aircraft	$3,000.00
AUVSI	$15873.00
A&P Technology	$410.00
Boeing	$46,235.64
Composites One	$500.00
Composites World	$600.00
Consortium on Electromagnetics and Radio Frequencies	$2675.00
DJI	$63,285.84
DJI Research, LLC	$48,522.80
Drexel University	$525,425.63
Embry-Riddle Aeronautical University	$1,367,146.25
General Electric	$145,930.48
GFK Flight	$63,333.00
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
Jaunt Air Mobility	$500.00
K.I.M. Inc.	$51,200.00
Kansas Department of Commerce	$282,180.00
Kansas State University	$1,063,147.24
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	$2,680,526.85
Montana Aircraft	$6,000.00
Montana State University	$521,387.68
New Mexico State University	$1,763,885.39
North Carolina State University	$1,145,088.01
North Dakota Department of Commerce	$2,236,728.10
Novotech	$500.00
NUAIR	$20,923.02
Ohio State University	$1,686,390.54
Ohio/Indiana UAS Center (ODOT)	$298,188.75
Oregon State University	$236,050.72
R Cubed Engineering	$6,970.09
RFAL	$21,343.30
Rochester Institute of Technology	$48,083.34
Rockwell Collins	$4,015.80
Sandia	$2,257.00
SenseFly	$471,131.36
Sierra Nevada Corporation	$6,559.00
Simlat Software	$147,260.00
Sinclair Community College	$929,819.40
State of Kansas	$91,604.83
Skyfire Consulting	$350,000.00
Solvay	$254.00
Technion Inc	$2,591,513.84
Teijin Carbon America, Inc	$500.00
The Cirlot Agency	$116,824.90
University of Alabama in Huntsville	$2,038,270.20
University of Alaska Fairbanks	$1,327,179.13
University of California Davis	$93,287.00
University of Kansas Center for Research, Inc.	$764,451.21
University of North Dakota	$1,374,166.92
University of Vermont	$127,449.64
Unmanned Systems Group	$34,565.64
USRA, Inc	$335,467.00
Virginia Polytechnic Institute and State Unviversity	$450,580.00
Wichita State University	$3,462,258.88
Total	**$31,397,158.13**

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	$7,990,466.30
Total	**$31,397,158.13**

SUMMARY BY SOURCE

Universities	$21,604,594.68
State Contributions	$2,908,701.68
3rd Party Contributions	$6,883,861.77
Total	**$31,397,158.13**

RESEARCH STUDIES

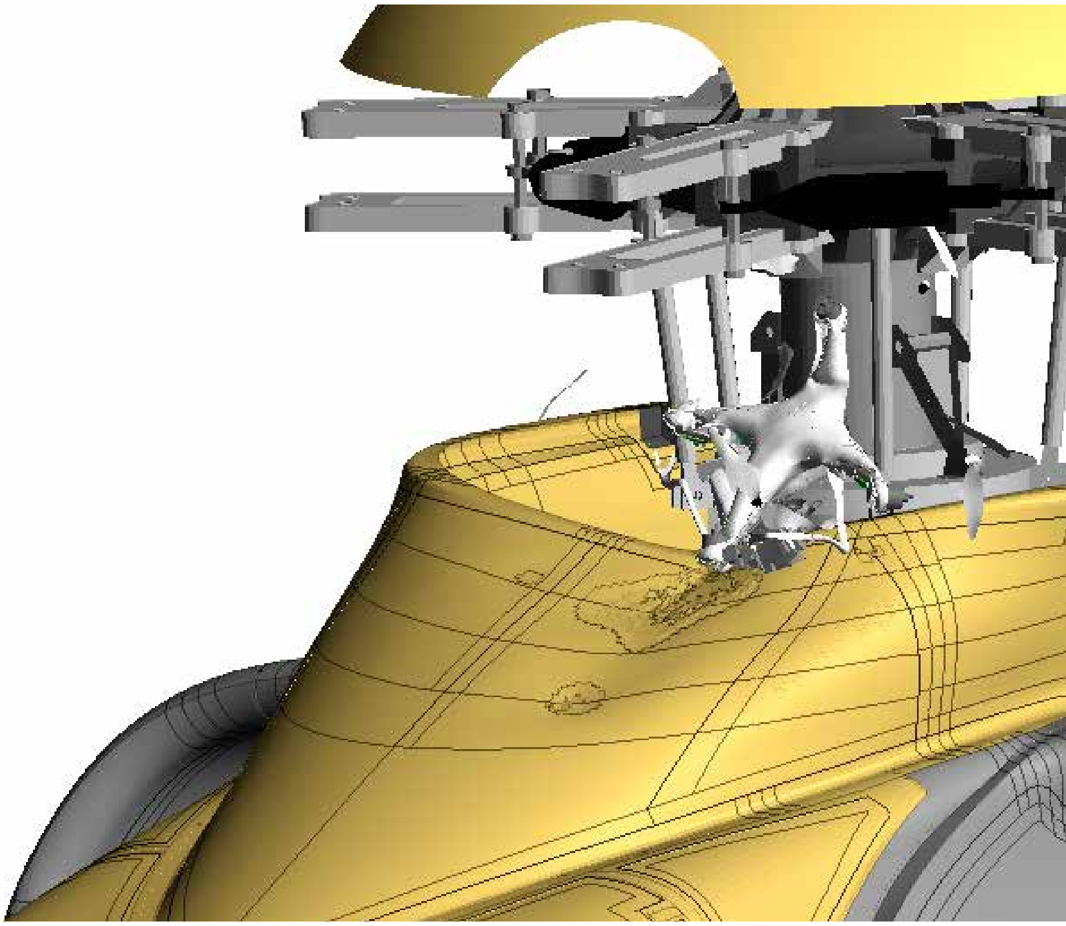
AIRBORNE COLLISION SEVERITY EVALUATION - STRUCTURAL IMPACT

LEAD

BACKGROUND

This follow-on study builds on the previous work aimed to understand the physical effects of an air-to-air collision between a small UAS (sUAS) and both a Narrow Body Commercial Aircraft and Business Jets operating under FAR 25 requirements. For this next progression of Airborne Collision Severity Evaluation work, the FAA has asked ASSURE to focus on three major research areas:

- Identify the probability of impact deflection due to the sUAS' interaction with the target aircraft's boundary layer prior to impact;
- Evaluate the severity of sUAS collisions with Rotorcraft; and
- Evaluate the severity of sUAS collisions



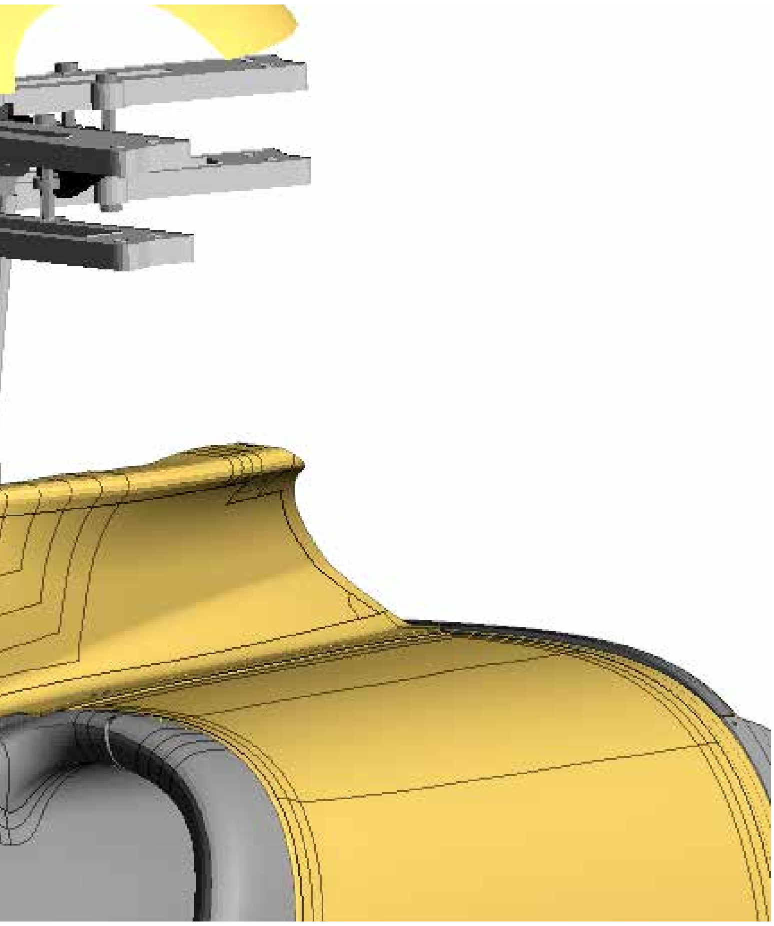
with General Aviation.

APPROACH

This project was completed this year. The study includes a peer review research task plan conducted just after the award and a review of the final report at the conclusion of the project.

Task 1 – Assessment of sUAS deflections due to aerodynamic Interaction with a commercial aircraft.

The research in Task 1 addressed whether ansUAS could be deflected by the airflow around a large transport aircraft before impacting the aircraft. NIAR and ERAU conducted near-field fluid mechanics analysis of air-to-air impact events using Computational Fluid Dynamics (CFD). These CFD analyses utilized Computer-Aided Design (CAD) models for both a representative quadcopter sUAS developed during the previous A3 Airborne Collision project and an open-source large transport category aircraft. Researchers analyzed several sUAS orientations, speeds, and impact location to understand whether or not the sUAS interaction with the target aircraft flow-field is significant enough to deflect the sUAS and change the initial impact condition reducing the risk of a worst-case scenario impact as identified during the previous A3 Airborne Collision work.



Task 2 – Evaluate the severity of sUAS collisions with Rotorcraft.

Previous ASSURE work and Task 1 of this project addressed sUAS collisions with larger commercial and business jet aircraft, usually at high altitudes. However, sUAS generally operate at lower altitudes, often sharing airspace with law enforcement, emergency medical, and other rotorcraft vehicles. In Task 2, NIAR and UAH studied sUAS collisions with 14 CFR Part 29 rotorcraft airframes, specifically rotors, blades, windshields, and tail structures. This research helped identify the damage severity for this type of sUAS airborne collisions.

Following NIAR's validated methodology, several Finite Element Models (FEM) of the main rotorcraft components were developed. To further validate these models, UAH conducted component-level and full-scale testing. Following the validation, the team performed crashworthiness structural FEA simulations and damage evaluation for mid-air collision between sUAS and rotorcraft.

Task 3 – Evaluate the severity of sUAS collisions with General Aviation.

General Aviation (GA) aircraft also operate at lower altitudes where sUAS may be present. In Task 3, the research team studied sUAS collisions with GA airframes, specifically looking at propellers, windshields, and tail structures. This research helps identify the damage severity of sUAS-GA airborne collisions. Following NIAR's validated methodology, a GA FEM was developed. The research team used the data generated by the low-velocity component-level testing from Task 2 to validate the models. MtSU conducted full-scale structural testing that was used to validate these models further. Once validated, the team performed crashworthiness structural FEA simulations and damage evaluation for mid-air collision between sUAS and General Aviation aircraft.

KEY FINDINGS

- Task 1 results show that the vertical deflections were not large enough for the sUAS to deflect away from the intended impact location for any of the three impact locations evaluated. The research team also determined that the final orientation of the sUAS at impact slightly differed from the initial orientation.
- Task 2 results show damage level 4 in the horizontal stabilizer and windshield cases at the higher impact velocities. The rest of the impact locations show some damage but of a lower severity level.
- Task 3 results provide a similar level of damage to those observed during A3, with some impact conditions resulting in level 4 damage to the aircraft structure. For instance, all the collisions against the windshield resulted in level 4 damage for the studied velocity range.

NAME & ORIGIN OF RESEARCH PERSONNEL

GERADO OLIVARES - WSU	UNITED STATES
LUIS GOMEZ - WSU	UNITED STATES
RODRIGO MARCO - WSU	SPAIN
HOA LY - WSU	VIETNAM
NATHANIEL BAUM - WSU	UNITED STATES
HARSH SHAH - WSU	INDIA
NIDHI SATHYANARAYANA - WSU	INDIA
ASWINI KONA RAVI - WSU	INDIA
AKHIL BHASIN - WSU	INDIA
RUSSEL BALDRIDGE - WSU	UNITED STATES
LUIS CASTILLO - WSU	MEXICO
ANKIT GUPTA - WSU	INDIA
GERARDO ARBOLEDA - WSU	ECUADOR
GUILLERMO CARO - WSU	SPAIN
DAVE ARTERBURN - UAH	UNITED STATES
MARK ZWIENER - UAH	UNITED STATES
CHRIS DULING - UAH	UNITED STATES
NISHANTH GOLI - UAH	INDIA
TONY DOLL - UAH	UNITED STATES
TONY WAZMANSKI - UAH	UNITED STATES
KYLE DOLL - UAH	UNITED STATES
DANIEL AIKEN - UAH	UNITED STATES
NICHOLAS BALCH - UAH	UNITED STATES
ZACH PERRIN - UAH	UNITED STATES
KELBY STARCHMAN - UAH	UNITED STATES
BRAD BAUER - UAH	UNITED STATES
MICHAEL DAVIS - UAH	UNITED STATES
JEROD ERICKSON - UAH	UNITED STATES
JAMES ROGERS - UAH	UNITED STATES
CHAD DISHON - UAH	UNITED STATES
DOUG CAIRNS - MtSU	UNITED STATES
ROBB LARSON - MtSU	UNITED STATES
FORREST ARNOLD - MtSU	UNITED STATES
BENJAMIN HAYES - MtSU	UNITED STATES
ANDREW FARR - MtSU	UNITED STATES
DANIEL MICHELS - MtSU	UNITED STATES
EDUARDO DIVO - ERAU	UNITED STATES
FARDIN KHALILI - ERAU	IRAN
RAY PRATHER - ERAU	UNITED STATES

GRADUATION OF STUDENTS

GERADO ARBOLEDA	JULY 2021
GUILLERMO CARO	DECEMBER 2021
FORREST ARNOLD	DECEMBER 2020
BENJAMIN HAYES	DECEMBER 2020
ANDREW FARR	DECEMBER 2020
DANIEL MICHELS	DECEMBER 2020

UAS AIRBORNE COLLISION SEVERITY EVALUATION - ENGINE INGESTION

The Ohio State University
LEAD

Wichita State University

The University of Alabama in Huntsville

BACKGROUND

As the number of Unmanned Aircraft Systems (UAS) sold continues to increase, the integration of UAS into the airspace is a major safety concern due to the potential for a UAS-airplane collision. Recreational UAS tend to be relatively small and have the potential to be ingested into an engine. Although the effects of a bird ingestion into an engine has been readily studied, the current tests and regulations cannot be transferred from birds to UAS. UAS key components: motor, battery, and camera, contain materials that are much denser and stiffer than ice and birds, which are typically modeled as a fluid since they are over 70% water. Preliminary work on this topic

showed that UAS can cause significantly more damage than birds.

The goals of this study are to:

- Understand what the interaction of a UAS with a representative high-bypass ratio fan (typically used in large commercial transport) will look like; and
- Define best practices and fan models for use in further studies.

APPROACH

The research is being carried out in in close collaboration with engine industry manufacturers to create Finite Element (FE) models that will capture critical features of a fan UAS impact. The ingestion simulations will be carried out in LS-DYNA, a FE analysis software that specializes in highly nonlinear transient dynamic analysis, for a variety of impact scenarios.

Task 1 – Representative High-Bypass Ratio Fan

The objective of this research task is to create a fan model that has representative structural and vibratory features of a modern high-bypass ratio fan. The fan is a representative of certain features (structural and vibratory) of a modern high-bypass ratio fan but does not match a specific fan currently in the fleet . It is 62 inches in diameter and has solid titanium blades. The blade geometry was defined with industry to ensure the blade geometry, thickness of blade, angle of blade from root to tip, etc., are representative of current industrial fans of this size. The blade material model was developed from extensive testing and validation in a previous FAA research program. The full fan model will also be analyzed to ensure it captures the critical structural and vibratory features of a representative high-bypass ratio fan during foreign object ingestion. .

The fan containment ring and nose cone are additional components included in this project to understand how they interact with the fan and UAS during the collision. These models provide reasonable geometries for the representative fan but model linear elasticity models and no failure. During the simulations these components give appropriate boundary conditions during the ingestion and enable the computation of the expected loads on these parts. This allows for the determination of cases where the greatest energy and/or strain is

imparted to these components and enables industry to focus on these cases when using their actual proprietary designs.

Task 2 – Experimental Validation of Component and Full Quadcopter Model

The objective of this task is to conduct component level tests on the key quadcopter components: the battery, motor, and camera, as well as the quadcopter, with legs and camera removed, at conditions that would occur in an engine ingestion. The quadcopter is chosen because of its popularity, and the availability of a partially validated (FE) model developed in a previous ASSURE project. The quadcopter component models need to be validated for the higher impact speeds that would occur in an engine ingestion. The impact velocities are between 400-720 knots and would be a slicing impact as opposed to a blunt force impact.

The validation tests are designed to be representative of a variety of component and full-quadcopter impacts during an engine ingestion. The testing team will launch the three UAV components and full quadcopter at two speeds in the range of 400-720 knots for component impacts and 300-425 knots for full UAV impact tests. Instead of blunt flat plate impacts, the components will impact angled titanium plates of fan-blade thickness to validate the deformation at the expected conditions during an ingestion. The batteries will be launched in a fully charged state to assess the likelihood of a fire in a slicing impact. The experiments will be filmed with a high-speed camera to ensure the kinematics and overall deformation match the computational simulations. Furthermore, additional response information will be measured on the titanium plates (e.g., strain gages), so that the response in the model can also be matched with the response in the computational simulations. Two Digital Image Correlation Systems will be used to record strain data on both sides of the titanium blades. Load cells are also installed within the blade fixture setup as an additional means to match computational simulations with the experiments.

The data from the experiments will be collected and analyzed to update the key UAS component-level models and the integrated full-UAS model. The experiments could also indicate the possibility of a fire from the UAS battery during an ingestion. Additionally, the mesh sizing of the titanium plate will also be investigated during these component impacts. This investigation will inform the choice for the fan model's mesh sizing of the blades in the region of the impact to maximize fidelity while minimizing computational cost.

Task 3 – Sensitivity Analysis of Parameters to the Ingestion

The objective of this task is to conduct a series of ingestion simulations to understand the effect of various parameters on the ingestion event. The ingestion simulations will be conducted in LS-DYNA using the updated validated UAS model in Task 2. The ingestion simulation will consist of the fan model that is fixed with the fan rotating at a prescribed speed, which will not slow down during this relatively short ingestion simulation. For the ingestion simulations, the ASSURE research team will capture failure of elements in the fan and obtain expected impact energies for the casing.

The research team will initially investigate various parameters of the ingestion including the rotational speed of the fan, the relative velocity of the UAS to the airplane, the orientation of the UAS during the impact, and the radial location of the UAS impact along the fan. Researchers will focus on the data from the ingestions concerning the failure in the elements of the fan model, the imbalance in the fan after the impact and the fan's plastic deformation as well as the energy imparted to the casing during the ingestion.

The results from these simulations will help determine a parameter space where one can determine which ingestion parameters lead to the worst outcome for the fan blades, fan disk, or containment. The data points for the blade out and bird ingestion simulations for this specific fan model will provide additional data points of events that have been extensively researched.

KEY FINDINGS

The team has worked closely with industry to create a fan assembly model that can be used for foreign object ingestion studies. In particular, the team has developed a generic high-bypass ratio fan with representative structural and vibratory characteristics of a high bypass ratio fan commonly used in commercial transport. The fan blades are held in place in the slotted disk with a retainer piece on the front side and and retainer ring on the back side to match common practice. The fan has a generic casing and nose cone that provide appropriate boundary conditions as well as a shaft that provides a visual reference for the assembly model. The initial meshes were reworked to improve stability and computational efficiency during ingestion scenarios based on initial simulations.

Experimental tests were conducted on key UAS components and full UAS into the leading edge of airfoil shaped titanium test pieces at speeds that would be seen in an ingestion. These tests required the development of a capability to deliver key UAS components up to 710 knots and control the delivery into a precise location in a repeatable manner. The tests also required developing a method to launch the full UAS up to 425 knots into the test article. These experiments were used to validate the key UAS components and full UAS model, which showed good overall agreement with kinematics, loads, strains, and damage level.

This work led to the development of a damage severity index for the fan rig assembly model subject to foreign object ingestion that consists of four levels. Level 1 is minor damage to the fan blades and would likely lead to minimal impact on engine performance. Level 2 is significant deformation of the blades with minimal loss of elements in the blades. Level 3 is deformation in blades and loss of blade material that leads up to an imbalance up to a single blade loss. Levels 1-3 are all within the engine certification envelope. Level 4 damage is loss of material leading to an imbalance greater than a single blade loss or disk crack initiation. The sensitivity study and phase of flight cases in this work with his particular UAS model all resulted in severity levels between levels 1-3.

Overall, the damage severity in each of the cases tracks closely with the accumulation of the overall plastic strain in the whole fan. The high fan speed case consistently has significantly more damage than the low fan speed, which is expected since the impacts happen at a much higher speed imparting more energy into the UAS and fan blades. Second, the higher radial span impact causes significantly more damage than the lower radial span impact since at the higher radial span the relative velocity between the UAS and fan blades is much higher than at the lower radial span (which are severity level 1 or 2). All the high fan speed with high radial impact cases for the UAS ingestion are severity level 3. The case that causes the most damage to the fan is the lower relative velocity case (with high fan speed and high radial span location). Finally, in comparing the orientations the 45-degree yaw orientation caused the most damage in the sensitivity study when comparing the high fan speed, high translational velocity and outer radial span case. The orientation and relative translational velocity were secondary parameters whereas the fan rotation speed and radial span impact locations were primary parameters affecting the damage in the fan.

NAME & ORIGIN OF RESEARCH PERSONNEL

KIRAN D'SOUZA	UNITED STATES
DUSHYANTHA SIRIVOLU	INDIA
ERIC KURSTA	GERMANY
TROY LYONS	UNITED STATES
MITCHELL WONG	UNITED STATES
KEATON NICHOLS	UNITED STATES
GERARDO OLIVARES	UNITED STATES
LUIS GOMEZ	UNITED STATES
HOA LY	VIETNAM
LUIS CASTILLO	MEXICO
GERARDO ARBOLEDA	ECUADOR
AKHIL BHASIN	INDIA
RODRIGO MARCO	SPAIN
CHRIS SALLIS	UNITED STATES
MARK ZWIENER	UNITED STATES
CHRIS SALLIS	UNITED STATES
NISHANTH GOLI	INDIA
TONY DOLL	UNITED STATES
TONY WAZMANSKI	UNITED STATES
KYLE DOLL	UNITED STATES
NICHOLAS BLACH	UNITED STATES
ZACH PERRIN	UNITED STATES
KELBY STARCHMAN	UNITED STATES
DANIEL AIKEN	UNITED STATES
CHAD DISHON	UNITED STATES
JAMES ROGERS	UNITED STATES
JEROD ERICKSON	UNITED STATES
NICK KRAY	UNITED STATES
STEVE CONNER	UNITED STATES
CHEIKH CISSE	SENEGAL
COSTAS VOGIATZIS	UNITED STATES
JAMES FINLAYSON	UNITED KINGDOM
DUANE REVILOCK	UNITED STATES
MIKE PEREIRA	UNITED STATES

GRADUATION OF STUDENTS

MITCHELL WONG	MAY 2023
TROY LYONS	MAY 2023
NICHOLAS BALCH	DECEMBER 2021
ZACH PERRIN	MAY 2024
KELBY STARCHMAN	MAY 2023
DANIEL AIKEN	DECEMBER 2024
GERARDO ARBOLEDA	MAY 2021

SMALL UAS DETECT AND AVOID REQUIREMENTS FOR LIMITED BEYOND VISUAL LINE OF SIGHT (BVLOS) OPERATIONS - SEPARATION REQUIREMENTS AND TESTING

LEAD

BACKGROUND

A core rule of manned aviation is very concise—see and avoid. Uncrewed Aircraft Systems (UAS) do not have the luxury of a pilot in the cockpit to see and safely avoid nearby traffic. Current solutions are to either place visual observers on the ground or use a chase plane. This limits the potential of Small UAS (sUAS) in areas such as precision agriculture, crop and wildlife monitoring, search and rescue, and linear infrastructure inspection due to safety concerns and access constraints for visual observers and chase planes.

Beyond Visual Line of Sight (BVLOS) operations with the use of Detect and Avoid (DAA)

technology resolves this issue. Groups are currently developing standards and rules for DAA that allow BLVOS operations. This effort build upon previous efforts to inform FAA regulations and industry standards addressing DAA and BVLOS operations. This ASSURE team:

- Developed an operational framework for sUAS BVLOS operations;
- Developed a separation framework;
- Explored utilization of novel technologies, such as bistatic radars;
- Developed and tested methods for evaluating DAA systems;
- Is supporting standards development for validation of DAA system performance.

APPROACH

The effort focused on four primary tasks. In addition, the researchers have updated previous results, developed a test plan, and submitted a comprehensive final report.

Task 1 – Development of an Operational Framework for sUAS BVLOS Operations—New Use Cases, Industry Focus, and Framework Expansion

This task was built upon previous research to develop an Operational Framework (OF) used for the eventual establishment of proposed operating rules, limitations, and guidelines for sUAS DAA. The researchers collected additional use case data, expanded the framework, and reviewed Radio Line-of-Sight (RLOS) distance limitations.

Task 2 – Coordination with Standards Agency to Establish Framework

In collaboration with the American Society for Testing and Materials (ASTM), the ASSURE team supported establishment of a standards framework. ASTM Special Committee F38 provides the overarching standards body, and:

- One subgroup developed proposed separation framework/standards, which includes acceptable DAA performance for maintaining well clear status.
- A second subgroup is developing testing methodologies for DAA systems to ensure safe separation, which includes consideration of the various approaches to DAA (e.g., on-board, off-board, radar, acoustics, etc.).

Task 3 – Development of Separation Framework

This task focused on how characteristics of DAA systems and UAS impact maintenance of well clear status. The team developed a fast-time simulation system. By varying across parameters of interest, including DAA system parameters and UAS parameters, the team executed > 700,000 simulations.

Simulations showed that the most impactful DAA-system parameters for maintenance of well clear are detection range and field of view. . UAS characteristics that had the greatest impact include pilot response time and airspeed. In these simulations, maintenance of well clear required detection ranges of 7000-8000 ft, even with very enabling assumptions regarding pilot response time and UAS airspeed. For acoustic sensors, this range increased to ~10,000 ft owing to the reduced speed of sound (relative to the speed of light).

Task 4 – Testing of the recommended DAA testing plan and candidate DAA systems

Flight testing was conducted to validate separation framework simulations, evaluate DAA system capabilities, and evaluate the proposed testing plan. Seven rounds of flight testing were completed.
Flight tests enabled development of a systematic approach to evaluating DAA systems that ensured safety during testing. They also drove development of best practices and supported evaluation of existing DAA systems.

KEY FINDINGS

Low-altitude sUAS use cases can be divided into 11 general use case classes, which can be organized into 47 subclasses. Key use cases include survey/mapping, imaging, environmental monitoring, patrol/security, disaster response, precision agriculture, and reconnaissance/surveillance/intelligence.

The most impactful DAA-system parameters for maintenance of well clear are detection range and field of view, while the most impactful sUAS parameters are pilot response time and airspeed. Even with very enabling assumptions regarding pilot response time and UAS airspeed, simulations show that maintenance of well clear with sUAS requires detection ranges of 7000-8000 ft. For acoustic sensors, this range increases to ~10,000 ft owing to the reduced speed of sound (relative to the speed of light).

Evaluation of a passive radar system for intruder detection was conducted. Tests indicate that real-time tracks can be produced with such a system. Comparison of those tracks with aircraft transponder data indicated close correlation. Thus, if existing signals from other transmitters exist, this approach may be a viable means for decreasing costs for ground-radar-based DAA systems.

Testing DAA system performance using encounters of sUAS and manned aircraft is challenging, as poor test design can compromise safety. Use of a modest vertical offset during testing of horizontal encounters (400 ft has been identified as an effective vertical offset) enables maintenance of safety and collection of required data. In addition to horizontal encounters, the team developed approaches where the intruder and/or UAS is climbing or descending.

Tests were used to evaluate DAA components (e.g., sensor characterization) and to evaluate overall DAA system performance. Metrics needed for evaluating DAA performance and methods for evaluating uncertainties were developed. These are being used to inform development of standards for testing DAA systems (e.g., within ASTM).

NAME & ORIGIN OF RESEARCH PERSONNEL

UNITED STATES	MARK ASKELSON - UND
UNITED STATES	JORDAN KRUEGER - UND
UNITED STATES	NAIMA KAABOUCH - UND
UNITED STATES	MICHAEL MULLINS - UND
UNITED STATES	KYLE FOERSTER - UND
UNITED STATES	ZACHARY WALLER - UND
INDIA	SREEJITH NAIR - UND
UNITED STATES	JOSEPH GUFFORD - UND
UNITED STATES	AMY STEPHENS - UND
UNITED STATES	CHRIS THEISEN - NPUASTS
UNITED STATES	JEREMY AMUNDSON - NPUASTS
UNITED STATES	DANIELLE MILLER- NPUASTS
UNITED STATES	ERIN ROESLER - NPUASTS
UNITED STATES	EVAN BOLLINGER - NPUASTS
UNITED STATES	GEE ABDULNUR - NPUASTS
UNITED STATES	JACOB DEFOREST - NPUASTS
UNITED STATES	JAKEE STOLTZ - NPUASTS
UNITED STATES	JOSEPH REILLY - NPUASTS
UNITED STATES	JULIE THEISEN - NPUAST
UNITED STATES	KRISTY BACHMAN - NPUASTS
UNITED STATES	NICOLAS FLOM - NPUASTS
UNITED STATES	SHAWN ROBERTS - NPUASTS
UNITED STATES	TREVOR WOODS - NPUASTS
UNITED STATES	HENRY CATHEY - NMSU
UNITED STATES	JOSEPH MILETTE - NMSU
UNITED STATES	TIM LOWER - NMSU
UNITED STATES	ANDREW DENNEY - NMSU
UNITED STATES	ROSS PALMER - NMSU
UNITED STATES	GAY LENZO - NMSU
UNITED STATES	ROBERT MCCOY - NMSU
UNITED STATES	JIM ROSS - NMSU
UNITED STATES	MITCHELL MATHEISON - NSMU
MEXICO	JUAN ANGEL - NMSU
UNITED STATES	CATHERINE CAHILL - UAF
UNITED STATES	NICK ADKINS - UAF
UNITED STATES	THOMAS ELMER - UAF
UNITED STATES	ROBERT PARCEL - UAF
UNITED STATES	JAMES PARRISH - UAF
UNITED STATES	LEVI PURDY - UAF
UNITED STATES	WILLIAM REMMERT - UAF
UNITED STATES	JIMMY VANG - UAF
UNITED STATES	RONALD WINNINGHAM - UAF
UNITED STATES	MATTHREW WESTHOFF - UAF
UNITED STATES	JASON WILLIAMS - UAF

NAME & ORIGIN OF RESEARCH PERSONNEL (CONT.)

KURT CARRAWAY - KSU	UNITED STATES
TOM HARRITOS - KSU	UNITED STATES
TIMOTHY BRUNER - KSU	UNITED STATES
ROBERT BURKHOLDER - OSU	UNITED STATES
RICHARD RIDGWAY - OSU	UNITED STATES
CHRISTOPHER REESE - OSU	UNITED STATES
TOM BROOKS - MSU	UNITED STATES
ALAN MARTINEZ - MSU	UNITED STATES
KYLE RYKER - MSU	UNITED STATES
DYLAN AMERSON - MSU	UNITED STATES

GRADUATION OF STUDENTS

LUCAS REILY - UND	AUGUST 2020
JOSEPH GUFFORD - UND	MAY 2023
AMY STEPHENS - UND	MAY 2023
DAVID SIMPSON - MSU	MAY 2023
REBECCA GARCIA	MAY 2023

INTEGRATING EXPANDED AND NON-SEGREGATED UAS OPERATIONS INTO THE NAS – IMPACT ON TRAFFIC TRENDS AND SAFETY

LEAD LEAD

BACKGROUND

This research provided insight into the safe integration of expanded and non-segregated sUAS operations in the NAS. The ASSURE research team collected data to characterize the current activity of sUAS in the NAS, to identify factors that influence the growth of this demand, and to forecast future demand.

As part of this research the ASSURE team developed a quantitative framework for risk-based decision making and waiver approval to meet the growing operational needs for Operations Over People and operations Beyond Visual Line Of Sight.

The research supports two critical components

of the UAS Integration Research Plan:

- Expanded Operations – Operations Over People (OOP)
- Non-Segregated Operations – Beyond Visual Line of Sight (BVLOS)

APPROACH

This research was broken down into three phases. Each phase was further divided into specific tasks. To direct this research, the ASSURE team developed a Research Task Plan (RTP) which was peer reviewed prior to the start of Phase 1. The work identified in the RTP has all been completed, with the completion of a peer review and submission of a final report to the FAA on June 30, 2022.

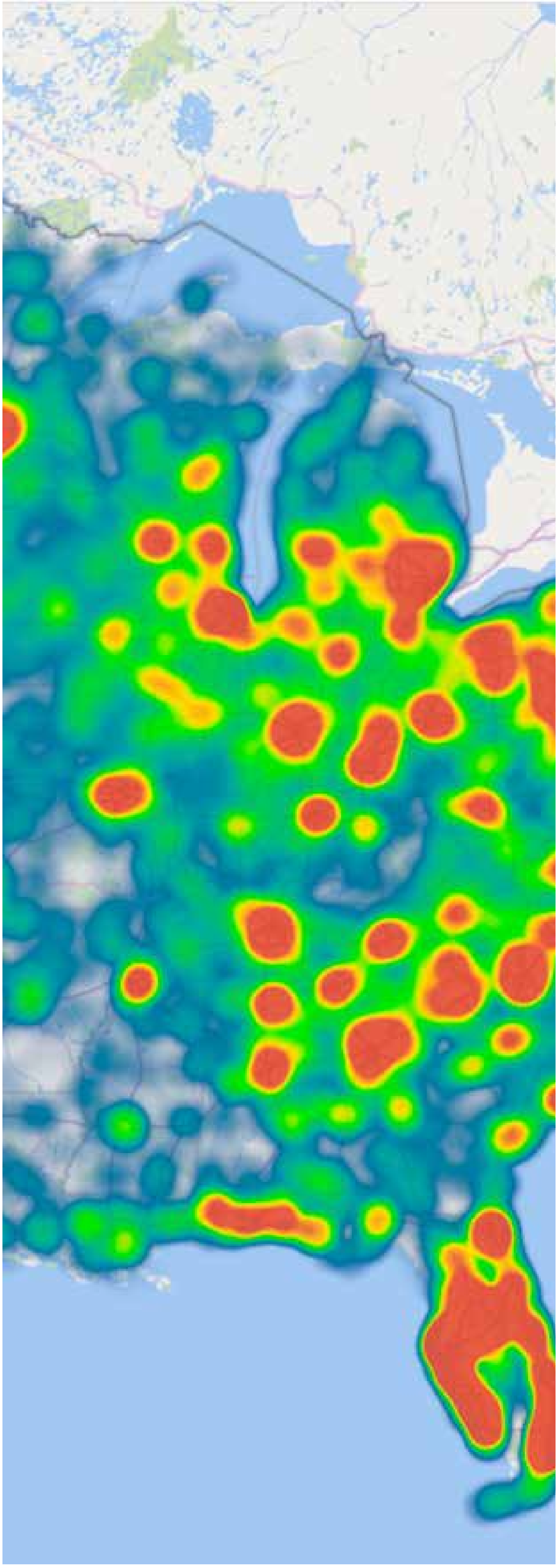
Phase 1 – Evaluation of Data and Establishment of the Quantitative Impact of Expanded Operations

The Phase 1 report characterizes findings in four areas, providing summaries of the data sets used, establishing quantitative relationships among existing trends, and explaining shifts due to different aspects of integration efforts such as waiver approvals and other regulatory changes. This includes development of a data catalog characterizing the data sets that were used in the analyses (including UAS registration, MLS, pilot certification, sightings report and flight data as well as waiver approval letters and NPRMs), a taxonomy indicating the range of operational concepts that sUAS operators want to pursue, a presentation of analysis results, and an evaluation of the validity of sightings reports.

Phase 2 – Forecast of the Future Scope of UAS Operations

In Phase 2, the researchers projected future demand for commercial sUAS traffic. They further collected data to forecast the timeline for the maturation of factors that are critical to this increase in demand and to the full integration of sUAS into the NAS.

The Phase 2 report included the forecast demand for expanded and non-segregated UAS operations, the distribution of sUAS within this demand (including type, configuration,



mission profiles, and equipage) and the the corresponding environments where the demand will occur.

Phase 3 – Definition of a Risk-Based Framework for Evaluating sUAS Operations

In Phase 3, the ASSURE team defined a predictable, repeatable, quantitative, risk-based framework for inclusion in the SMS process. This framework provides a process for making risk-based decisions that applies across the varying levels of risk associated with the operation of sUAS. An application of this framework was completed to illustrate its use and usefulness.

KEY FINDINGS

- **Phase 1** (Completed: 11/20/21)
  - Identification of relevant data sources
  - Quantitative analysis of current sUAS activity
  - Assessment of the accuracy of sightings reports
- **Phase 2** (Completed 5/1/2022)
  - Forecast of future sUAS demand
  - Forecast of maturation of key factors limiting growth of sUAS demand
- **Phase 3** (Completed 11/27/21)
  - Definition of quantitative framework for risk assessment
  - Case study illustrating application of quantitative framework

Phase 1. Evaluation of data and establishment of quantitative impact of expanded operations

In the Phase 1 report, the researchers identify the range of current and future sUAS Concepts of Operations (CONOPS) and relevant data sets to characterize current sUAS activity.

The team further provided an analysis of Part 107 waiver approval letters. This analysis underscored the barrier that risk assessments associated with the use of Detect and Avoid (DAA) technologies still present to BVLOS operations. Despite the high demand for BVLOS capability, there were very few approved waivers that utilized DAA systems. In contrast, the analysis identified successful approval of waivers for OOP.

The analysis further identified areas where current data collection practices indicate a need for future rulemaking in order to specify safety risk management data collection requirements clearly and more comprehensively.

In addition, an analysis was presented focusing on UAS detection data that was collected in the vicinity of the Dallas-Fort Worth International Airport over an 18-month period (August 2018 – January 2020) including 12,500 unique sUAS across more than 162,000 separate operations.

These detection data were used to evaluate the validity of the data available in the FAA Sightings database.

Phase 2. Forecast of the future scope of sUAS operations

The purpose of the Phase 2 research was to forecast trends in the growth of small Unmanned Aircraft System (sUAS) traffic associated with the integration of expanded and non-segregated sUAS operations into the NAS. In addition, the factors restraining such growth were identified and evaluated in terms of their urgency, difficulty of development or maturation, sensitivity to public opinion and impact on the growth of sUAS operations.

To accomplish these goals, two separate elicitations of expert opinion were conducted. For one elicitation, a set of knowledge elicitation questions was forwarded to 26 Subject Matter Experts (SMEs). Within this elicitation, these SMEs were prompted to provide their predictions regarding the growth of sUAS operations from 2024-2032. Four SMEs responded and indicated that the average number of sUAS flights per day will increase to 1,019,200 flights per day in 2024 and increase to 2,730,000 flights per day by 2032. Given the small sample size, however, it is recommended that additional data be collected in order to increase the precision associated with these estimates.

In the second knowledge elicitation study, an on-line interview was conducted involving 66 SMEs, asking them to evaluate 68 individual technologies/concepts that might affect the introduction of UAS into the NAS. Of the 22 influencing technologies and concepts that were scored as having a substantial effect on the UAS market, 45.45% were predicted to mature by the year 2027 and 90.9% were forecasted to have their critical factors addressed by 2030.

The UAH team also conducted an analysis focused on a market forecast based on the equipment/technologies, regulations, and procedures required for BVLOS missions. It was determined thatt the necessary equipment, regulations, and procedures for BVLOS operations are DAA and other forms of safety automation, remote ID, and clarity of relevant standards and regulations. The UAH team then related specific influencing technologies/concepts from the online interview focused on these categories. This analysis was used to determine the predicted timeframe where most critical factors would be addressed and when the largest market growth would be expected. Based on the results of this analysis, the UAH team estimated that a major increase in BVLOS operations will occur between the time period of late 2025 to 2030.

Phase 3. Definition of a risk-based framework for evaluating sUAS operations

The Phase 3 reports define a quantitative risk-based framework for provides an illustration of the risk-based framework focuses on the safety risks associated with flight operations with automated control of an sUAS BVLOS over people. The discussion further indicates that such a quantitative assessment based on flight operations should be considered one component of a broader Safety Risk Management Program (SRMP) and indicates the additional components required for a complete assessment of a waiver requests for an sUAS operation.

This risk-based framework incorporates a blend of statistical methods to assess safety risks associated with a proposed flight operation using sUAS. In the example presented in this report illustrating application of this framework, it is assumed that a set of relevant flight data and parachute test data has been previously collected and archived, and that the waiver applicant chooses the run the minimum required number of additional tests on his proposed sUAS model and parachute. These data are used to calculate probabilities and expected values for the three possible outcomes of interest (impact on a pedestrian, impact on the built environment, and no negative impact) and utilized in a decision matrix to demonstrate how the framework supports decision making based on the probabilities of the different negative outcomes and the associated potential consequences.

NAME & ORIGIN OF RESEARCH PERSONNEL

PHILIP SMITH - OSU	UNITED STATES
MATT MCCRINK - OSU	UNITED STATES
JIM GREGORY - OSU	UNITED STATES
GARY ALLREAD - OSU	UNITED STATES
ELLEN BASS - DU	UNITED STATES
RICHARD STANSBURY - ERAU	UNITED STATES
KIRT CARRAWAY	UNITED STATES
HENRY CATHEY - NMSU	UNITED STATES
JERRY HENDRIX - UAH	UNITED STATES
CATHERINE CAHIL - UAF	UNITED STATES
MARK ASKELSON - UND	UNITED STATES

VALIDATION OF LOW-ALTITUDE DETECT AND AVOID STANDARDS

LEAD

BACKGROUND

As UAS are integrated into low-altitude aviation operations, it is of increasing importance that there is an understanding of the implications of UAS operations on the safety of individuals on the ground, other aircraft in the air, and the environment. There has been a dramatic increase in UAS operations in recent years, and projections indicate that UAS use will continue to grow. This also means that there will be greater urgency for proper evaluation and approval of UAS operations for high-value use cases. Due to this, there is a need for further UAS research in an effort to:

- Refine previous UAS research findings,
- Improve safety methodologies,
- Develop scientific and operational best practices, and
- Recommend criteria, standards and/or methods of compliance.

In order to meet this criteria, the ASSURE UAS Safety Research Facility (SRF) will engage in multiple research efforts. An important part of reviewing operations that support full UAS integration is evaluating the reliability of aircraft. The SRF will conduct new research to create and refine a reliability testing methodology for common UAS components with a goal of predicting system-level probability of failure for a broad array of UAS makes and models. In addition to reliability testing, the SRF will also conduct new research to provide assessment, improvement, and ultimate validation of UAS safety cases and best practices. As UAS operations continue to include use-cases of increasing complexity, research in this area will be invaluable to evaluating safety cases for their effectiveness in mitigating operational risks.

An increase in UAS operations has also led to a rise in UAS-related incidents. To better understand the implications of operational risks, inform the development of regulations that reduce incidents, and provide insight into desired metrics for UAS incident reports, further research is necessary. The SRF will conduct a follow-on to past research efforts by MIT's Lincoln Laboratory in 1986-1991 to measure pilot performance. This research will validate the research done on human performance in the cockpit with respect to visual acquisition of nearby aircraft. Further research in Human Factors is necessary to ensure that operations reduce the likelihood of failure and keep operators and other individuals safe. To address this need, the SRF will follow-on to previous ASSURE Human Factors research tasks to develop recommendations for the validation and incorporation of Human Factors into specific UAS applications.

For these research endeavors to provide a better understanding of the implications of UAS operations on the safety of others in the air and on the ground, the conclusions are only effective if they inform appropriate action. For the FAA, as the regulator of airspace and air traffic, the primary focus is on ensuring acceptable levels of safety for aviation stakeholders and the public at large. The secondary focus is to minimize any potential impacts on the existing air and ground transportation systems and the environment. The outputs of this research are designed to both identify and support quality decisions for the appropriate regulatory adjustments that will enable the full integration of UAS into the National Airspace System (NAS).

APPROACH

Task 1: Literature Review

The research team will conduct a comprehensive literature review using publicly available information from academic/ industry sources. The review will document past measurements and estimates applicable to low altitude operations to inform the test plans. It will include relevant work, regulations, technical standard orders, advisory circulars, and standards as well as probability of detection curves, closest point of approach curves, and risk-ratios.

Task 2: Data Collection and Flight Operations

Subtask 2-1: Development of Flight Test Plan

UASSRF will develop and validate a flight test plan with a defined set of controlled and bounded encounters between low altitude aircraft at varying speeds and encounter geometries, while maintaining compliance with the project plan and appropriate aviation regulations and safety practices, including safe separation margins between aircraft. . In addition, the team will develop a standardized flight briefing. The subject pilots will receive the briefing alongside standardized tasks to increase in-flight workload. The work will focus on determining and validating items such as flight paths, altitudes, and timing to support encounters between manned and unmanned aircraft. The test flights will validate the efficacy of the flight test plan, communications procedures, safety measures, and data collection practices. The team will identify, recruit, and schedule subject pilots corresponding to the following qualifications: varying degrees of qualification and experience (fixed wing), qualified and current in the type of aircraft (fixed and rotary wing). The team will plan, schedule, and execute aircraft encounters by utilizing the necessary aircraft, aircrews, and equipment to support multi-aircraft flight operations.

Subtask 2-2: Data Collection

The team will collect the following data points:

- Intruder aircraft characteristics (size, color, lighting, etc.)
- Environmental conditions (visibility, impediments such as clouds/haze, winds which may affect aspect geometries, and background scenery)
- GPS tracks and time stamps for subject and intruder aircraft
- Type of traffic assistance display (for electronically assisted encounters)
- Time of traffic advisory (for verbally assisted encounters)
- Subject and intruder aircraft location, altitude, speed, the direction of flight, and encounter geometry and range between aircraft at the time of pilot visual acquisition

Subtask 2-3: Flight Test Execution

UASSRF Researchers will conduct a series of evaluation flights to generate a relevant and sufficient number of encounters to support research objectives. These encounters will include manned vs. manned (MvM) fixed wing/ helicopter and manned vs. unmanned (MvU) fixed wing/helicopter operations.

There will be two flight events per fly day, conditions and equipment permitting. Each event will consist of two fixed-wing general aviation aircraft. All fixed-wing aircraft will have a flight crew consisting of one subject pilot, one qualified safety pilot, and one human factors researcher for a total of three personnel. Every flight event will begin and end at KRNV (Cleveland Municipal Airport) with an estimated 1.2 hours of flight time. Each event has an estimated duration of 1.7 hours.

Task 3: Flight Test Analysis

The output of Task 2 will be used to complete the analysis for Task 3.

Subtask 3-1: Visual Acquisition Documentation

UASSRF researchers will correlate and document the relative geometries, distances, and closing speeds of the subject and intruder aircraft with human factors researcher's data collected in Task 2. The conditions of the flight including weather conditions and any reported restrictions/inhibitors to flight visibility will be transcribed.

Subtask 3-2: Avoidance Maneuver Determination/Modeling

The research team will calculate and plot a potential avoidance maneuver for application to the subject aircraft's track. This maneuver will, to the extent permitted by the performance envelope of the aircraft, attempt to facilitate an adjusted Closest Point of Approach (CPA) calculation if the subject and intruder aircraft had been on a collision geometry. Adjusted CPA percentile curves will be created to determine the percentile of encounters that would have violated "well clear" and Near Mid-Air Collision (NMAC) criteria.

Subtask 3-3: CPA Determination

Track data from the subject aircraft's calculated avoidance maneuver will be plotted and compared to that of the intruder aircraft's track data to predict the closest point of approach for the two aircraft. CPA calculations will be made for avoidance maneuvers for each subject aircraft where the intruder is unaware of the ownship and for the case where both aircraft maneuvered individually once their pilots saw the aircraft. Adjusted CPA percentile curves will be created to determine the percentile of encounters that would have violated "well clear" and NMAC criteria had safety offsets in flight testing been removed.

Subtask 3-4: Risk Ratio Development

UASSRF researchers will assess the relative efficacy of the observed visual acquisition performance coupled with the calculated avoidance maneuver performance to either 1) maintain "well clear" between the two aircraft, or 2) avoid an NMAC between the two aircraft.

KEY FINDINGS

After the completion of each test, Subject Pilots were asked to complete a demographics questionnaire, NASA-TLX survey, and answer interview questions. The Subject Pilors were asked questions in reference to individual encounters during the flight test, specifically:

- What were the characteristics of the aircraft that made it easy or difficult to spot?

- What were the environmental conditions that made it easy or difficult to spot?
- What were the flight conditions that made it easy or difficult to spot?
- Was there anything else that made detection easy or difficult to spot?

Pending further analysis, trending answers to the Subject Pilot's ability to easily visually acquire the intruder aircraft include, but are not limited to:

- Increased workload: trying to maintain the ownship's altitude and direction while still scanning for other aircraft or tracking another aircraft once visually acquired
- The dark shadows of a cloudy day typically make it more difficult to visually acquire the intruding aircraft against dark ground foliage
- Turbulence: When the air was more turbulent, Subject Pilots focused on maintaining altitude, which increased their workload
- Light haze obscuring the other aircraft
- Talking to the Safety Pilot, which could distract Subject Pilot from scanning for other aircraft

A camera mounted in the cockpit continuously recorded the Subject Pilots and their actions throughout each test flight. Researchers reviewed the footage after flight to determine each Subject Pilot's scan rate and compared them to the self-assessed answers from the Subject Pilots. On average, very few Subject Pilots assessed their own scanning performance similarly to the actual scanning recorded in the camera footage. Evidence of this difference in scan rates and performance can be seen in the Table 1.

	Pilot 13	Pilot 15	Pilot 16	Pilot 19
Scan Rate	43	72	97	85
Perceived Scan Rate	80	40	80	75
NASA-TLX Overall Score	49.333	27.333	26	28.333
Total Hours Flying	1040	250	560	80
Most Used Aircraft in the Last Six Months	Diamond DA-42	Diamond DA-42	Cessna 172R	Cessna 172 R
Instrument Rated	Yes	Yes	Yes	Yes

Table 1: Sample Subject Pilot scanning rate and experience data.

From this data researchers concluded that the responses from the Subject Pilots should not be used to accurately measure their actual scan rates, and instead to rely on the video data. Environmental factors that had the heaviest impact on testing were high winds and heavy rain, so test flights were controlled to be conducted on primarily clear or partially cloudy days with little to no precipitation. Seasonal changes in the geography of the land played a role in the visual acquisition of the intruder aircraft. During the winter months the expired foliage caused the land background to take on a tan-brown color, while the spring and summer months saw a darker green background. These differences saw to a variation in the ease of visual acquisition by the Subject Pilots depending on the season, as discussed previously in the Subject Pilots' interview responses.

NAME & ORIGIN OF RESEARCH PERSONNEL

KYLE RYKER	UNITED STATES
MICHAEL THOMPSON	UNITED STATES
DYLAN AMERSON	UNITED STATES
CHARLIE GAUTIER	UNITED STATES
RANIA BASSOU	MOROCCO
KARI BABSKI-REEVES, PhD	UNITED STATES
CHRIS GOODIN, PhD	UNITED STATES
LALITHA DABBIRU, PhD	INDIA
AMAR THODUPUNOORI	INDIA

GRADUATION OF STUDENTS

JACOB BUTERA	MAY 2021
DAVID SIMPSON	MAY 2021
BRIANA TAYLOR	MAY 2022

UAS SAFETY CASE DEVELOPMENT, PROCESS IMPROVEMENT, AND DATA COLLECTION

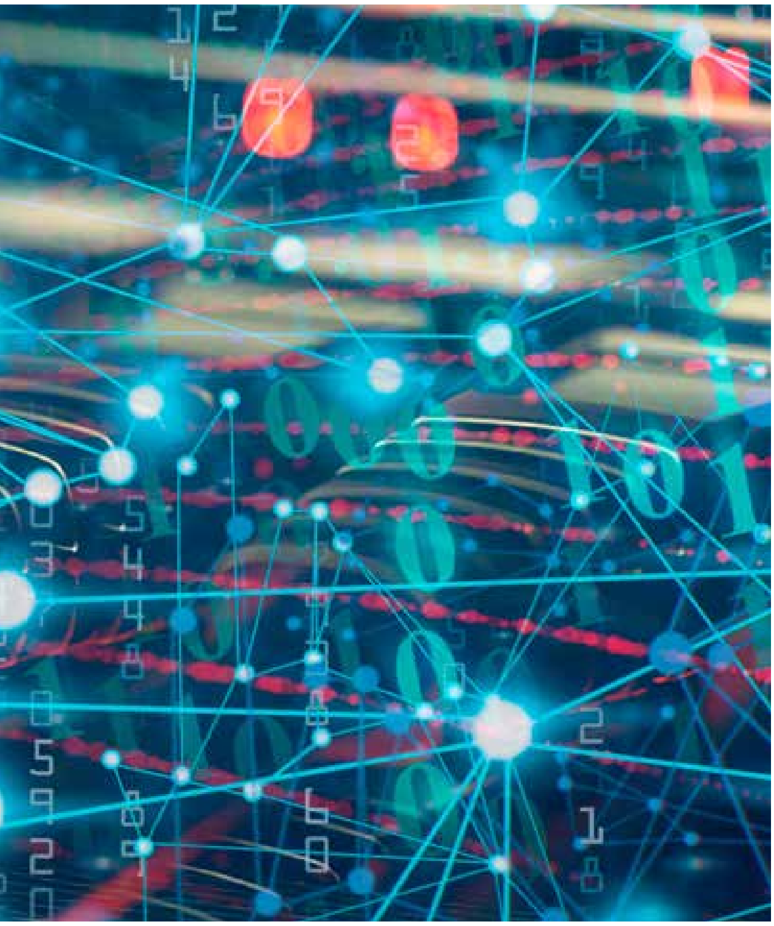
LEAD

BACKGROUND

In the 2016 FAA Extension, Section 2211 mandates the FAA to establish a UAS research and development roadmap, including estimates, schedules, and benchmarks for UAS integration. This roadmap, the UAS Integration Research Plan, will be updated on an annual basis to determine the most up to date research needs, research projects underway, and research planned to reach FAA UAS integration milestones. In support of this need and to enable more rapid production of safety cases, the A24 team is developing an enhanced data collection framework and safety analysis tools. This will inform the UAS Integration Research Plan by enabling users to

cross-check needs for UAS data/research with test data stored in the system as well as enabling analysis to determine if the data meets needs and whether additional data/testing would be required.

This research relates to the development of the technical data requirements, test methods, risk assessments, safety risk management processes, data collection, and administrative processes/reporting used to inform safety cases in support of the UAS integration regulatory framework. Analyses of associated data will inform development of regulatory products (i.e., rules, standards, policy, etc.) needed to reach UAS integration milestones. Finally, it will facilitate querying and reporting of data in a consistent format.



APPROACH

Task 1: Initial Build of the Test Data Collection and Analysis System (TDCAS)

- Front End Data Collection System
- Development of Initial TDCAS Analysis System

Task 2: Exercise System Using Advanced Operations

Test the system using data from previously-developed safety cases and tests.

Task 3: Develop Linkage to Industry Consensus Standards, Operations Over People (OOP) Notice of Proposed Rulemaking (NPRM), Other Rulemaking, and FAA Safety Management System (SMS) Risk Management Guidance

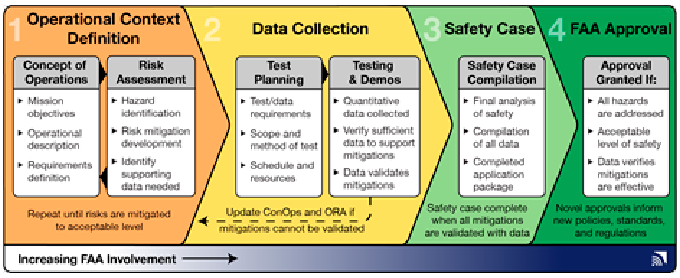
Determine how the system can be utilized to support develop of industry standards, rulemaking, and FAA SMS risk management guidance.

Task 4: Validation of TDCAS

Use an actual safety case to validate the TDCAS.

KEY FINDINGS

The need for the TDCAS is significant. An FAA analysis of safety case deficiencies illustrated that many applicants do not understand what comprises an effective safety case. The TDCAS helps alleviate this issue by providing a



framework that outlines the elements of an effective safety case. In addition, standardization of safety case structure will accelerate integration of UAS into the NAS by providing structure for both the applicant and the evaluator.

Numerous challenges exist regarding data collection. One involves provision of quantifiable data. Depending upon the format/structure used to provide data, analysis of those data can be challenging. Thus, the TDCAS has been designed to enable provision of quantifiable data that can be utilized in multiple types of analysis. In addition, a tension exists between the applicant and the evaluator in that the evaluator desires as much information as possible while the applicant desires the input process to be as easy as possible. Thus, design of the TDCAS has focused on test data elements that are needed for evaluation and the team has avoided overly burdening the applicant.

Another challenge is data ambiguity in which different users may provide the same information multiple ways (e.g., using two different names for the same aircraft). Such ambiguities present challenges at the analysisstage. When possible, the team has developed lists for data elements to ensure consistency. This is not a panacea, however, as the relatively low Technology Readiness Level (TRL) for some types of systems preclude use of lists for some data elements.

The system being developed will accelerate integration of UAS into the NAS by streamlining the safety case process for both the applicant and the reviewer. In addition, this system enables cross-cutting analyses that utilize data from multiple applicants/projects. Such cross-cutting analyses, which at times can create a tension relative to the safety case objective, enable evaluations of research progress, needs, and system performance that cannot otherwise be easily completed.

GRADUATION OF STUDENTS

ANREW KRAMER - UND	MAY 2023
MEGAN PATRICK - MSU	MAY 2022

NAME & ORIGIN OF RESEARCH PERSONNEL

MARK ASKELSON - UND	UNITED STATES
HENRY BORYSEWICZ - UND	UNITED STATES
NEIL NOWATSKI - UND	UNITED STATES
KEITH DALEN - UND	UNITED STATES
JOHN WOLD - UND	UNITED STATES
DEREK STINCHFIELD - UND	UNITED STATES
JORDAN KRUEGER - UND	UNITED STATES
ANDREW KRAMER	UNITED STATES
THOMAS JONES - VTech	UNITED STATES
PETER FRANK - VTech	UNITED STATES
JOHN COGGIN - VTech	UNITED STATES
CHRISTINE TYSOR - VTech	UNITED STATES
ZAHARY WEHR - VTech	UNITED STATES
ROBERT BRIGGS - VTech	UNITED STATES
JEREMY SPINK - VTech	UNITED STATES
NICHOLAS FLOM - NPUASTS	UNITED STATES
CHRIS THEISEN - NPUASTS	UNITED STATES
TREVOR WOODS - NPUASTS	UNITED STATES
JAKEE STOLTZ - NPUASTS	UNITED STATES
JULIE THEISEN - NPUASTS	UNITED STATES
ERIN ROESLER - NPUASTS	UNITED STATES
JEREMY AMUNDSON - NPUASTS	UNITED STATES
MATT HENRY - NPUASTS	UNITED STATES
JOSEPH REILY - NPUASTS	UNITED STATES
NEIL LUDWIG - NPUASTS	UNITED STATES
SCOTT KEANE - NPUASTS	UNITED STATES
HENRY CATHEY - NMSU	UNITED STATES
JOSEPH MILLETTE - NMSU	UNITED STATES
CATHERINE CAHIL - UAF	UNITED STATES
THOMAS ELMER - UAF	UNITED STATES
JASON WILLIAMS - UAF	UNITED STATES
EVELYN PARCELL - UAF	UNITED STATES
MATTHEW WESTOFF - UAF	UNITED STATES
RONALD (LEE) WINNINGHAM - UAF	UNITED STATES
NICHOLAS ADKINS - UAF	UNITED STATES
DR. TOM HARITOS - KSU	UNITED STATES
KURT CARRAWAY - KSU	UNITED STATES
RAJAGOPAL SUGUMAR - KSU	INDIA
TIMOTHY BRUNER -- KSU	UNITED STATES
KATHERIN SILAS - KSU	UNITED STATES
TRAVIS BALTHAZOR - KSU	UNITED STATES
ALAN MARTINEZ - KSU	UNITED STATES
JUN WANG - MSU	CHINA
LI ZHANG - MSU	UNITED STATES
JUNFENG MA - MSU	CHINA
BOUTEINA DRIOUCHE - MSU	MOROCCO
MATTHEW MCCRINK - OSU	UNITED STATES

DEVELOP RISK-BASED TRAINING AND STANDARDS FOR WAIVER REVIEW AND ISSUANCE

LEAD

BACKGROUND

Under the Federal Aviation Administration (FAA) Modernization and Reform Act of 2012, Congress tasked the FAA with integrating Unmanned Aircraft Systems (UAS) into the National Airspace System (NAS). To comply with the Congressional mandate, the FAA established a small UAS (sUAS) rule, allowing sUAS to operate in the NAS. With the passage of 14 CFR Part 107 came the capability of operators to waive specific provisions for increased operational flexibility. The FAA must closely review all waiver requests and evaluate each safety case to ensure that the safety of the NAS is not compromised by the proposed UAS flight operation. This presents challenges, as

the FAA's standard risk assessment practices do not directly translate to UAS operations. For the FAA to process Part 107 waiver requests effectively while maintaining safety in the NAS, a new scalable compliance framework for mapping risk in UAS operations is required.
This research intended to:

- Provide recommendations to the FAA on modification to 8040.4B and/or 8040.6 to incorporate a range of UAS operations.
- Develop a scalable compliance framework to assess various risk components for improved Part 107 waiver review and issuance.
- Validate the proposed scalable compliance risk assessment framework by submitting a range of waivers using the proposed system.

APPROACH

The study included a peer review of the research task plan and a review of the final report at the conclusion of the project. The study consisted of two parts running in parallel.

- Task 1 – Literature Review and Framework Development
- Task 2 – Framework Validation Case Studies

Task 1.1 - Literature Review

This task consisted of a review of relevant literature, to include FAA Order 8040.4B, FAA Order 8040.6, ASTM 3178-16, JARUS SORA, and other sources. As part of this process, the research team identified gaps and similarities between risk-assessment methodologies for developing a set of guidelines towards the development of a scalable compliance risk-assessment framework.

Task 1.2 – Framework Development

For this task, the research team used the information gathered from the literature review to develop a compliance-based risk framework for submitting and reviewing Part 107 waivers. This framework serves as a utility to establish a robust safety case and for the FAA to review Part 107 waivers in a repeatable and consistent manner. The framework developed as part of this task serves as prototype guidance for both the FAA and applicants when navigating the 14 CFR Part 107 waiver application and review process.

Task 1.3 – Develop Draft Roadmap for Low-Altitude Risk Assessment

As an added task, the research team developed a roadmap that outlined key data categories required for a low-altitude risk assessment, focusing specifically on UAS operations that take place at or below 400 ft AGL. The intent of this roadmap was to (1) identify data categories required for the FAA to complete a low-altitude risk assessment, (2) provide insight into what data exists and where these data reside, and (3) determine the research applicable to this analysis as has been conducted through previous, current, or upcoming FAA or industry standards efforts.

Task 2.1 – Tabletop Exercise for a Part 107 Waiver for Beyond Visual Line of Sight (BVLOS) with a Visual Observer (VO)

The research team performed a tabletop exercise with FAA stakeholders to explore this operational case and evaluated the risk-based framework throughout the waiver review process. This task documented gaps/shortfalls of the framework. The team identified lessons learned from the waiver review process and created a list of recommended changes to the risk-based framework.

This task afforded the utilization of the designed framework to extrapolate key variables associated with safety case articulation in the context of BVLOS with a VO; an Extended Visual Line of Sight (EVLOS) validation case. This represented the least complex validation case, and it assesses the application of the framework for a “baseline” use case for flight operations beyond 14 CFR Part 107.

Task 2.2 – Tabletop Exercise for a Part 107 Waiver for BVLOS without a VO

For this task, the research team performed a tabletop exercise with FAA stakeholders to explore this operational case and evaluate the risk-based framework throughout the waiver review process. As a key component of this task, the research team documented gaps/shortfalls of the framework. Finally, the research team identified lessons learned from the waiver review process and created a list of recommended changes to the risk-based framework.

This task addressed a waiver application with an increased risk threshold from that of Task 2-1. Thus, this exercise enabled researchers to evaluate the risk-based framework for a use case that required more scrutiny by FAA stakeholders. Specifically, the University of Alaska Fairbanks conducted a tabletop exercise with FAA stakeholders to analyze a BVLOS waiver using the framework developed in Task 1-2. They documented the details and outcomes of the tabletop exercise.

The tabletop results helped to validate the Task 1-2 framework and served as a feedback mechanism to fill in gaps identified during the exercise.

KEY FINDINGS

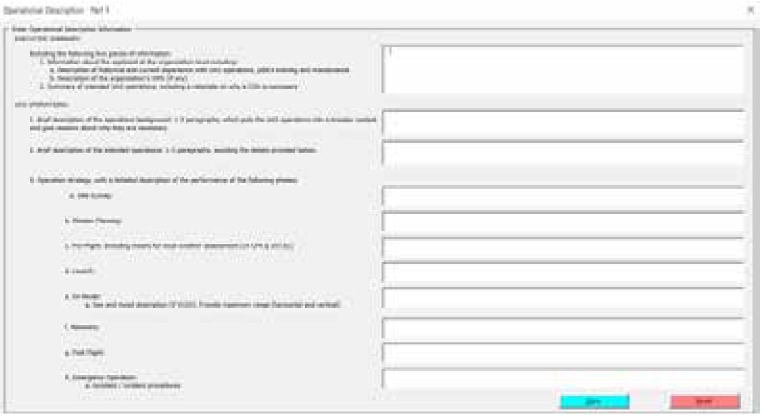
The literature review brought to light gaps in the evaluation of Part 107 waivers, and a need for standardization in the following areas:

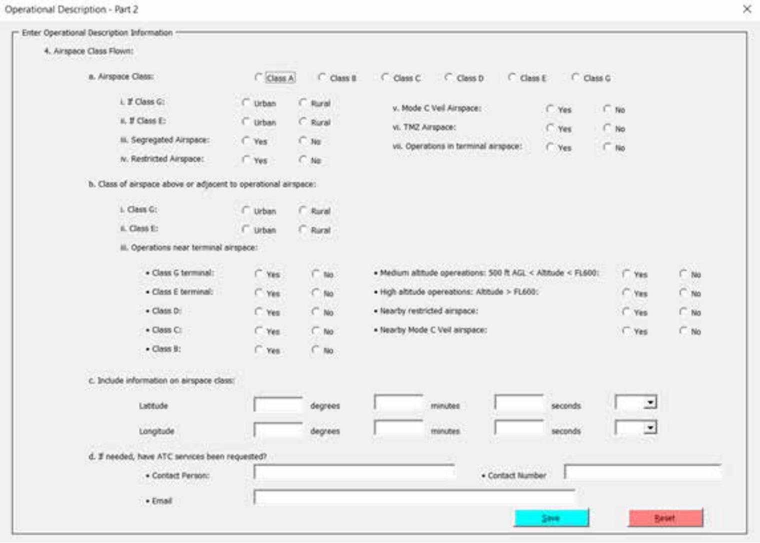
- Definitions for common SRA and concepts.
- SRA framework for stakeholders seeking Part 107 waivers that meet FAA order 8040.4B and ensure a more uniform approach to assessing and accepting risk.
- Risk matrix chart developed for use across various FAA lines of business. The risk matrix must be transparent for all stakeholders and should clearly define safety terms such as likelihood and severity consistent with the UAS operating environment.
- The framework for submitting, reviewing, and approving/denying Part 107 waivers must include compliance-based methodology where appropriate.
- Data must drive decision processes.

Task 1-2: Framework Development – Key Findings:

- A standardized framework for collecting data for Part 107 waivers, particularly for BVLOS, will aid both applicants and the FAA in processing waiver requests.
- The framework seeks to standardize data collection, building upon recognized FAA processes – e.g., COA documentation.
    - o The framework uses the same “step-by-step” methodology as the COA form.
    - o The process has been adapted to suit Part 107 waiver applications.

For this task, the research team produced a representative, prototype framework. Adding/improving functionality may provide an opportunity for future work.





Operational Description - Part 2

Enter Operational Description Information

4. Airspace Class Flown:

a. Airspace Class: ○ Class A ○ Class B ○ Class C ○ Class D ○ Class E ○ Class G

i. If Class G: ○ Urban ○ Rural
ii. If Class E: ○ Urban ○ Rural
iii. Segregated Airspace: ○ Yes ○ No
iv. Restricted Airspace: ○ Yes ○ No
v. Mode C Veil Airspace: ○ Yes ○ No
vi. TMZ Airspace: ○ Yes ○ No
vii. Operations in terminal airspace: ○ Yes ○ No

b. Class of airspace above or adjacent to operational airspace:

i. Class G: ○ Urban ○ Rural
ii. Class E: ○ Urban ○ Rural
iii. Operations near terminal airspace:

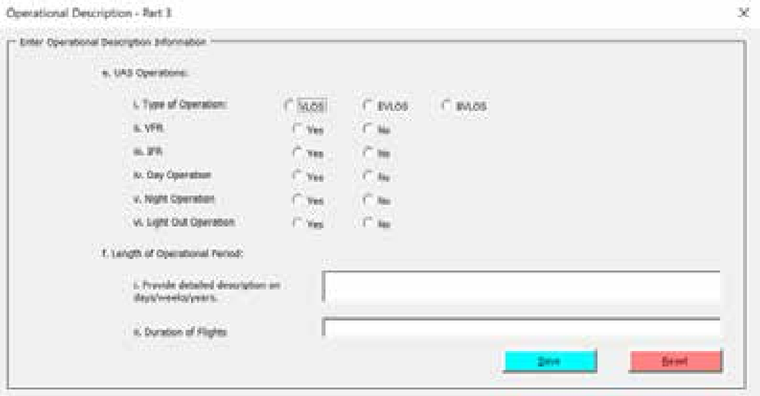
- Class G terminal: ○ Yes ○ No
- Class E terminal: ○ Yes ○ No
- Class D: ○ Yes ○ No
- Class C: ○ Yes ○ No
- Class B: ○ Yes ○ No
- Medium altitude operations: 500 ft AGL < Altitude < FL600: ○ Yes ○ No
- High altitude operations: Altitude > FL600: ○ Yes ○ No
- Nearby restricted airspace: ○ Yes ○ No
- Nearby Mode C Veil airspace: ○ Yes ○ No

c. Include information on airspace class:

Latitude degrees minutes seconds
Longitude degrees minutes seconds

d. If needed, have ATC services been requested?

- Contact Person:
- Contact Number
- Email



Operational Description - Part 3

Enter Operational Description Information

e. UAS Operations:

i. Type of Operation: ○ VLOS ○ EVLOS ○ BVLOS
ii. VFR ○ Yes ○ No
iii. IFR ○ Yes ○ No
iv. Day Operation ○ Yes ○ No
v. Night Operation ○ Yes ○ No
vi. Light Out Operation ○ Yes ○ No

f. Length of Operational Period:

i. Provide detailed description on days/weeks/years.
ii. Duration of Flights

Task 2: Validation Case Studies – Key Findings:

Validation Case studies for BVLOS with a VO (Task 2-1) and without a VO (Task 2-2) consisted of evaluating the framework developed in Task 1-2. The method used for this task was to evaluate the framework from Task 1-2 by comparing data categories in the framework to an approved BVLOS waiver previously obtained by the University of Alaska Fairbanks. The evaluation consisted of a tabletop exercise with FAA stakeholders to identify gaps in the framework and make comparisons to the approved waiver. These discussions identified gaps in the framework and areas for improvement. The University of Alaska Fairbanks led this task.

Discussions between various subject matter experts and the tabletop exercise with FAA stakeholders identified the following areas of improvement for the framework from Task 1-2.

- Add an executive summary with a high-level description of the request, such as "BVLOS with Detect and Avoid for linear infrastructure inspection."
- Add a place to input previous or similar waivers with only slight differences at the front of the waiver application and that will have almost identical waiver packages.
- Include a supporting documentation page that will include one-sentence descriptions of each uploaded supporting document.
- Allow the input of operational area instead of just a point and radius.
- Increase the information about the UAS by adding a narrative about the system. For example, if an aircraft splits into two aircraft during flight, include that fact in the narrative.
- Include a way to specify that there is an electronic observer, a crewmember tasked with monitoring the Detect and Avoid systems used to ensure airspace awareness.

Tasks 3, 4, and 5 – Reporting, Peer Review, and Program Management (Respectively) – Key Findings:

ASSURE A25 concluded with the submission of the final report, and sponsor feedback, in February of 2022. The research team reached the following conclusions resulting from the completion of the project.

- *Can existing industry standards (ASTM, JARUS SORA) inform a framework for applicants to articulate the risk components necessary for the FAA to consider Part 107 waivers?*

Industry standards can play a role in informing a framework, and they are useful in defining information that applicants should provide when submitting a waiver. This is particularly true for standards regarding SRM and ORA. Existing industry standards – e.g., ASTM F3178-16, are useful for waiver applicants who may need guidance to understand what data the FAA may need to fully understand a waiver submission.

- *What are the minimum requirements for a framework for a risk-based standard for reviewing Part 107 waivers?*

The minimum requirements for a framework for risk-based standards for review 14 CFR Part 107 waivers are heavily dependent upon data. As such, a framework for waiver submission and review must::

1. Provide guidance to applicants regarding data on their UAS and operation. Such guidance must also frame a safety case such that an applicant has the required guidance to identify the most important information – both for their benefit and that of the FAA.
2. It must present information in a manner that is easy to understand.

- *How does a risk-based standard for reviewing Part 107 waivers fit into the current waiver review process?*

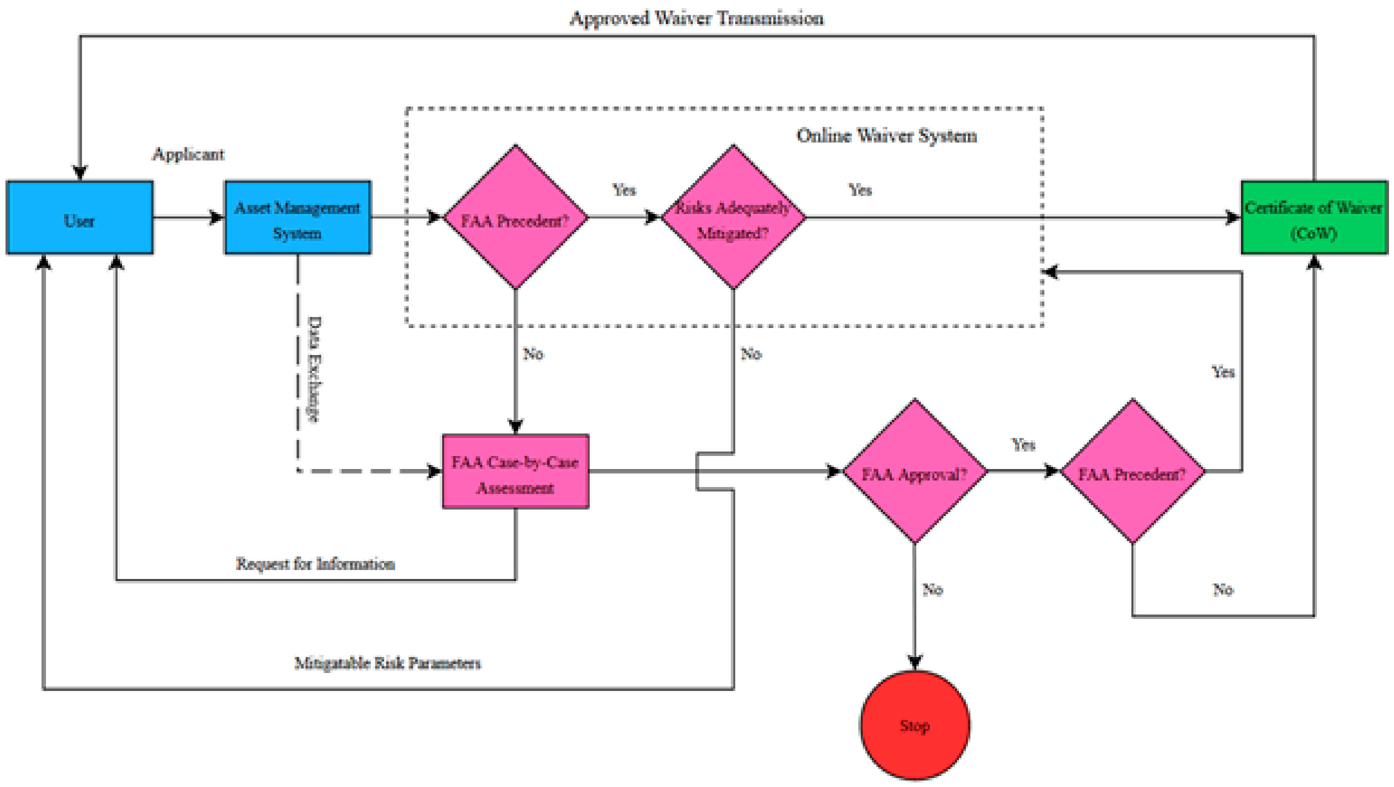
A standard for waiver review must be a part of the waiver review process, and it should be reflective of the requirements that necessary to build a safety case. This ensures that a standard is consistent, regardless of an applicant, and it would help the FAA to provide consistent decisions when granting/denying Part 107 waiver applications.

FUTURE WORK

The research team identified three primary areas to expand/improve the risk-based framework through future projects:

1. Integration into a web-based client
2. Improved data analytics
3. Linkage to other ASSURE research

As a result of this effort, the research team conceptualized the following framework for an online waiver processing ststem. This system incorporated inputs from asset management system(s) and applicant saftey cases to balance Part 107 waiver requests against existing precedent and aggregated data regarding given unmanned aircraft systems.




REALLY IS
OCKET
SCIENCE

NAME & ORIGIN OF RESEARCH PERSONNEL

TOM HARITOS - KSU	UNITED STATES
KURT CARRAWAY	UNITED STATES
TIM BRUNER - KSU	SPAIN
KATIE SILAS - KSU	VIETNAM
RAJAGOPAL SUGUMAR - KSU	UNITED STATES
PAUL SNYDER - UND	INDIA
CATHY CAHILL - UAF	INDIA

GRADUATION OF STUDENTS

JACOB KIMERER	NOVEMBER 2020

ESTABLISH PILOT PROFICIENCY REQUIREMENTS - MULTI-UAS COMPONETS

Oregon State University

LEAD

Drexel University

Kansas State University

BACKGROUND

Several organizations have identified human factors issues unique to Unmanned Aircraft Systems (UAS), including the US Air Force Accident Investigation Board, the National Transportation Safety Board, the US Department of Transportation, National Aeronautics and Space Administration, RTCA Special Committee (SC)-228, and others. This research addresses gaps in knowledge that are currently a barrier to the safe, efficient, and timely integration of systems composed of multiple UAS into the NAS, namely operation of multiple aircraft by a single pilot.

This research helps inform FAA regulations and industry standards addressing single pilot and

multiple UAS operations. This research intends to:

- Identify human factors differences, limitations and use cases for operating multiple UAS.
- Identify available control systems, capabilities, limitations, and maturity levels.
- Determine and model predicted human factors limitations.

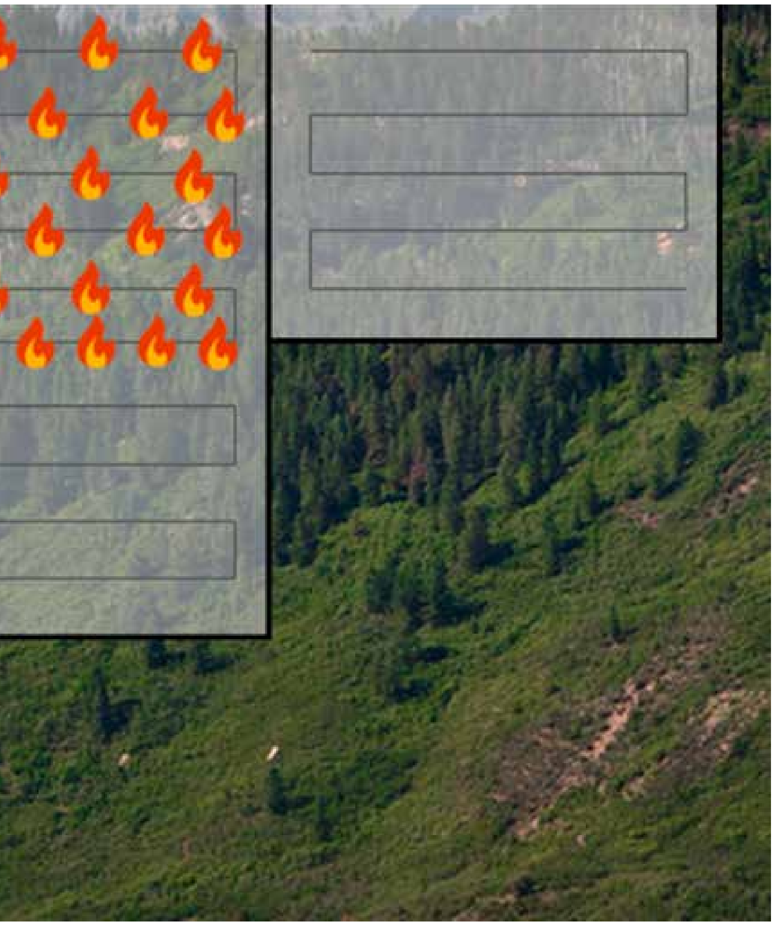
APPROACH

The project includes a peer review of the research task plan and a review of the final report at the conclusion of the project.

Task 1 & 2 – Literature Review and Gap analysis

The team's literature review report:

- Identified the relevant literature, that encompassed 205 manuscripts,
- Developed a taxonomy to use to categorize the literature,
- Categorized the literature findings, and
- Identified research gaps.



Task 3 – Assess Human Factors Limitations

This task identified the human factors limitations to monitoring multiple UAS, including potential hazards, mitigations, and controls for the mitigations, generates potential operational scenarios (use cases) and a task analysis, and metrics. This task also generated a taxonomy of open problems. This task's report captures the human factors limitations when monitoring multiple UAS. The researchers:

- Identified potential human factors limitations, including potential hazards, mitigations, and controls.
- Developed relevant operation scenarios and a task analysis that consider prior aircraft procedures. The operational loosely coupled domain (e.g., delivery) scenario included the nominal use case, thirty-four unexpected events, and ten distraction events. The tightly coupled domain (e.g., wildland fire ridgeline aerial ignition) scenarios included a nominal use case, and identified sixteen unexpected events as well as seven distraction events.
- Reviewed the existing aptitude measurements and developed a taxonomy that informs gaps for single pilot multiple UAS deployments.

Task 4 – Assess Required Aptitude

This task focused on developing computational user models that provide a predictive analysis of the human factors considerations for human Supervisors responsible for monitoring and controlling multiple UAS systems. The results from Tasks 1 and 3 were used, specifically, the task analysis and use cases directly informed the development of the computational user models. The computational models focused on the predominant human factors and training results developed during Tasks 1 and 3, but varied environmental conditions, mission duration and number of vehicles. The researchers:

- Identified IMPRINT Pro (Archer et. al, 2005) as the modeling tool being used for developing the computation models.
- Developed a model of workload to be incorporated into the IMRPINT Pro models.
- Developed the computational models, including their ability to provide a predictive analysis of human factors limitations.
    - Loosely Coupled: Nominal use case, three distraction (i.e., command and control link loss, emergency in the airspace, and mid-air collision) use cases and two distraction (i.e., fatigue and mindwandering) use cases.
    - Tightly Coupled: Nominal use case and the fatigue distraction.

KEY FINDINGS

The team identified sixty-three key findings/ gaps across the primary tasks. A list of all key findings and gaps can be found in the effort's final report.

The team's literature review's primary key findings/gaps are:

- **Flight phases:** It is well known in the aviation industry that takeoff and landing are the two most dangerous phases of flight. This literature review highlighted that very little research has focused on these flight phases, and the research has focused primarily on cruise flight. These critical phases, along with preflight, climb, descent, approach, recovery, and post-flight will need to be addressed.
- **Crew roles:** When developing crew roles, one must consider the M:N UAV ecosystem as a whole, potentially including an entire organization. Factors to consider include (1) there may be one supervisor in charge (e.g., a traditional pilot in control), or an entire crew organization, (2) how many humans are considered a part of a specific crew, and (3) what new roles need to be defined or introduced.
- **Training:** More focus is needed to define required training. Since the systems are becoming more automated, there is less need for months or weeks of training. Previous work looked at training considerations for CFR Part 107.205 remote pilots verses UAS degree programs. The future of UAS autonomy forces the ASSURE team to look closer at everyday citizens any of the M crew roles and what that training needs to encompass.
- **Systems requirements:** There is little research considering the type of system, which is broken down into two distinct groups, a single UAS or a multiple UAS structure. Factors that must be further investigated within the context of both definitions include, the maneuverabilty, weather, and system

system composition. The system composition can be further decomposed into how the system responds to communication link loss, transitions through airspace, and overall mission location (e.g., restricted airspace, or no fly zones).

- **Autonomy:** Although this gap falls under the system requirements gap, it drives the level of impact for most of the other gaps. The levels of autonomy will determine how many humans are needed, what training those humans will require, and what other system composition requirements will be necessary for safe flight.

The team's analysis of the human factors limitations identified eleven key findings/gaps. The primary finds/gaps are:

- **Use Cases:** The input from the subject matter experts may be very unique compared to what may be collected from those using other multiple UAV logistics models. As such, for the Loosely Coupled task, the developed use case is a notional use case that does not represent any specific company's UAV logistics model. Similarly, for the Tightly Coupled scenario, the developed use case is an abstracted exemplar with respect to ridgeline aerial ignition and the use of surveillance and ignition UAVs. A gap is the lack of validated use cases for a wider range of Loosely and Tightly Coupled tasks across domains for multiple UAV systems.
- **Unexpected Event Frequency:** There are no data about how frequently the unscheduled events may occur in practice. There is a gap in understanding the necessary levels of training and expertise required for addressing the unscheduled tasks when supervising multiple UAVs.
- **Multitasking Metrics:** Validated measures of multitasking for multiple UAV operations are not available. Thus, a gap is that there is no single aptitude or single validated measure that can capture all the human performance limitations related to multitasking with respect to supervising multiple UAVs.
- **Team Roles:** Teamwork may be an important skill for Supervisors and other roles. There is limited research on what type of coordination abilities may be important. Thus, a gap is determining the exact role for the human Supervisor for delegation.

The team's modeling of the loosely coupled (i.e., delivery done) and tightly coupled (i.e., ridgeline ignition) tasks resulted in forty-six key findings/gaps, many of which are specific to the use case. The primary findings/gaps are:

- **Scalability:** Assuming highly autonomous UAVs, that are capable of responding appropriately to unexpected events, does permit a single human Supervisor to manage a larger number at lower Overall Workload levels.
- **Lack of Representative Models:** The common human factors modeling tools do not incorporate human performance models that account for the Supervisor's performance when monitoring more than one or a few UAVs. The Task 1 literature review also found that no reasonable models existed. The team conducted an additional investigation into the human-robot interaction research, human visual perception literature, and the human visual scanning literature, but was unable to identify any applicable models for human performance, specifically workload that are based on real systems (i.e., not simulated systems) and objective human factors results.

A primary gap is the existence of representative models for the focus domains.

- **Model Fidelity:** The developed models are quite complex, but are unable to model the true complexity of the representative systems. Achieving a 100% match to the deployed systems is impractical; however, increasing the model complexity can provide additional insights. Further, the models can guide the design of human-in-the-loop evaluations by removing independent variables that had no impact on Supervisor Performance.

Limitations related to the UAS, autonomy, and the use case are:

- UAV characteristics, including heterogeneity of the fleet used in a mission, are rarely addressed.
- Levels of autonomy will determine staffing, training and related needs.
- Deployment domains will have different requirements that impact the Supervisor's capabilities, tasks, and training.
- Most research addresses the cruise flight phase. Phases of flight, such as ramp up and ramp down, and parameters, such as wave size are not addressed in the literature.

Limitations related to the analysis of multiple UAS supervision include:

- Modeling tools do not address all aspects of the Supervisor's performance when monitoring multiple UAVs, including task switching.
- An analysis of Supervisor workload needs to focus on all components of workload: cognitive, visual, speech, auditory, fine grained, and tactile.
- Validated objective data for workload associated with tasks are not readily available.

NAME & ORIGIN OF RESEARCH PERSONNEL

JULIE A. ADAMS	UNITED STATES
CHRISTOPHER SANCHEZ	UNITED STATES
TYLER READ	SPAIN
PATRICK URIARTE	VIETNAM
ELLEN BASS	UNITED STATES
ALLISON SANDS	INDIA
TOM HARITOS	INDIA
KATIE SILAS	INDIA
JOSEPH GLAVAN	INDIA

GRADUATION OF STUDENTS

TYLER READ	JULY 2021
PATRICK URIARTE	DECEMBER 2021

ESTABLISH RISK-BASED THRESHOLDS FOR APPROVALS NEEDED TO CERTIFY UAS FOR SAFE OPERATION

KANSAS STATE UNIVERSITY
LEAD

UND UNIVERSITY OF NORTH DAKOTA

National UAS Training and Certification Center

BACKGROUND

The FAA has taken steps toward the full integration of UAS into the National Airspace System (NAS) by considering waivers for expanded and non-segregated operations. Expanded and non-segregated operations will enable UAS operations in the same airspace as manned aircraft. Such operations will most likely involve interaction between UAS remote pilots, manned pilots, and air traffic controllers similar to how aircraft operations are conducted today under instrument flight rules.

The ASSURE research team focused on two elements of safety assurance. Research pertains to (1) pilot training standards, and (2) informing standard(s) related to aircraft performance-

based certification considerations across a range of operational approvals, documenting the FAA's type certification process for sUAS for the sake of offering feedback and mechanisms for improvement.

The theoretical and practical underpinnings established through this research aid to:

- Identify limitations associated with the current evaluation paradigm associated with sUAS pilot certification (14 CFR Part 107) and report on the potential gaps towards expanded and non-segregated operations;
- Develop a framework to capture the Knowledge, Skills, and Abilities (KSAs) required of UAS pilots by classification and category of UAS towards industry consensus standards development;
- Participate in industry consensus standards groups to translate research into a standard that provides guidance to Original Equipment Manufacturers (OEMs) for the FAA's Durability and Reliability (D&R) type certification process; and
- Document the FAA's D&R process via case study to provide feedback on the process and provide OEMs with initial guidance.

APPROACH

The research team has generated a research task plan which currently serves as a living document to guide this research effort. One of the key objectives of this research is to document the D&R process. Upon completion, the research team will submit a comprehensive final report detailing the findings and products as a component of this research.

Task 1 – Literature Review

The ASSURE Team conducted a literature review to identify existing pilot training and airworthiness certification paradigms while exploring their applicability to UAS. The team reviewed existing manned pilot certification standards in 14 CFR Part 61, regulations for sUAS, applicable airworthiness standards, and literature relating to industry consensus standards for UAS. As a result, the research team identified crucial differences in manned/unmanned regulatory structures, guidance for UAS pilot and certification standards, and additional considerations for risk assessment and airworthiness certification. These concepts will: (1) inform UAS pilot certification requirements, and (2) exercise the airworthiness certification process for UAS while following sUAS OEMs through the airworthiness and type certification process. The resulting outputs of this research will provide feedback to the FAA regarding UAS operational approvals and will aid to identify key considerations for pilot and UAS certification to mitigate risks associated with expanded flight operations beyond 14 CFR Part 107.

Task 2 – Durability and Reliability Type Certification Use Case Application

This task built upon the literature review from Task 1 and exercised the Type Certification (TC) process for the purpose of (1) documenting feedback for the FAA regarding the D&R TC process, and (2) providing guidance for OEMs pursuing a D&R type certification.

For this task, the research team, consisting of Kansas State University (KSU) and Sinclair Community College (Sinclair), collaborated with the FAA's Aircraft Certification Service (AIR-694), the Los Angeles Aircraft Certification Office (LA ACO), and multiple OEMs – e.g., senseFly and Telegrid, as they progressed through the various phases of D&R.

This task also involved participation with the ASTM F38 working group responsible for drafting the standards that provides guidance for OEMs when gathering date for the FAA's D&R type certification process.

Task 3 – Operational Training

The UAS pilot training and requirements specified by 14 CFR Part 107 are modest. The research team anticipated that more robust UAS pilot training and knowledge requirements will be needed to meet the more rigorous safety thresholds associated with expanded, non-segregated UAS flight operations. Below are two examples of common provisions included in a subset of waivers for 14 CFR §107.29 – Daylight Operation. These provisions highlight a combination of technical and training requirements often associated with UAS flight operations that reach beyond the Part 107 baseline: specifically, for operations at night. These provisions highlight the need for a combination of (1) basic technical/airworthiness requirements, and (2) pilot knowledge and skills to address enhanced levels of risk associated with more complex flight operations.

TRAINING

"Prior to conducting operations that are the subject of this Waiver, the remote PIC and VO must be trained, as described in the Waiver application, to recognize and overcome visual illusions caused by darkness, and understand physiological conditions which may degrade night vision. This training must be documented and must be presented for inspection upon request from the Administrator or an authorized representative."

TECHNICAL

"The sUA[S] must be equipped with lighted anti-collision lighting visible from a distance of no less than 3 statute miles. The intensity of the anti-collision lighting may be reduced if, because of operating conditions, it would be in the interest of safety to do so..."

The A27 research team accomplished the following regarding this task:

- Analyzed existing literature relating to UAS pilot qualifications and training.
- Constructed a framework of “go-to” KSA’s.
- Formulated links KSA’s to build operational training requirements that are suited to UAS operations beyond the scope of Part 107.
- Constructed a matrix for comparisons across 14 CFR part 107, ASTM F3266, JARUS RPC recommendations and 14 CFR Part 61 Private Pilot training elements.
- The methodology followed a “risk-based” approach, established a baseline, and afforded the opportunity to allow flexibility for certain skillsets.
- The process included classifying applicable requirements relating to their relevance of topical categories framed in JARUS RPC recommendations, and it identified parallels and gaps that may exist across differing training paradigms to identify commonalities and gaps.

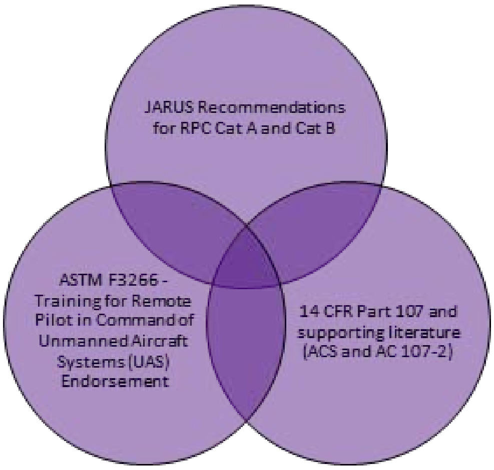


Figure 1. Methodology for defining UAS Pilot Training Requirements.

KEY FINDINGS

Task 1-1: Literature Review – Key Findings:

Relating JARUS SORA and SMS

- Many components are similar and meet SMS principles, but the JARUS SORA is not a comprehensive safety risk assessment process and in its current form, is not sufficient to meet FAA standards for developing a safety case for granting waivers.
- The SORA language focuses more on lowering risk to an “acceptable” level of risk for an operation to occur, compared to SMS principles that focuses on lowering risk to “as low as reasonably practicable”. Under SMS, it is mandatory that risk is “as low as reasonably practicable.”

Task 2-1: Procedural Documentation and Guidance – Key Findings:

This task involved tracking multiple sUAS OEMs, also referred to as applicants, through the FAA’s D&R type certification process to (1) document their experience, and (2) make recommendations to the FAA regarding D&R. As such, this component of ASSURE A27 relied on observations regarding the TC Part of this task also included providing guidance as required to assist the applicant(s) where needed.

With the conclusion of this task, the research team arrived at a series of recommendations aimed at assisting the FAA in improving the D&R process and providing additional assistance to applicants who wish to pursue a type certificate for a low-risk UAS. These recommendations stem from observations gathered during this task, and they are based on lessons learned by the applicants and the research team.

- Recommendation 1: Develop a Durability and Reliability Advisory Circular.
- Recommendation 2: Promote early [FAA] engagement with TC applicants.
- Recommendation 3: Make the D&R Means of Compliance publicly available.
- Recommendation 4: Provide a straightforward means of entry into the D&R TC process.
- Recommendation 5: Adapt industry standards, and/or revise existing industry guidance to address policy and knowledge gaps.
- Recommendation 6: Address incompatibilities with ICAO Annex 8.
- Recommendation 7: Revise estimated timelines for the D&T TC process.
- Recommendation 8: Develop status tracking system for key deliverables in the D&R TC process.
- Recommendation 9: Set limits for review periods for D&R deliverables.
- Recommendation 10: FAA stakeholders identify themselves, including their directorate and role on teleconference calls.
- Recommendation 11: Clarify sUAS maintenance requirements.

Task 2-2: ASTM D&R Working Group Participation

In addition to the research team's involvement in D&R projects, the team participated in an ASTM International working group for the development of an industry consensus standards regarding D&R. In November 2020, ASTM international published ASTM F3478-20

Standard Practice for Development of a Durability and Reliability Flight Demonstration Program for Low-Risk Unmanned Aircraft Systems (UAS) under FAA Oversight. The standard captures best practices for pursing a type certification under D&R from the standpoint of industry, and it provides guidance for applicants regarding the collection and presentation of data for demonstrating overall system reliability. A member of the KSU research team provided key insight and leadership to the working group.

Task 3 Operational Training – Key Findings:

Methodology

This task consisted of comparing remote pilot consensus standards to existing remote pilot certification standards and performing a side-by-side comparison across eight (8) subject areas. The research team identified commonalities across remote pilot certification standards/requirements form the FAA, JARUS, and ASTM.

Simplifying Assumptions

- The remote pilot training standards can be reasonably reduced to individual elements.
- The eight (8) subject areas proposed by the JARUS RPC (i.e., UAS Regulations, UAS Knowledge, Operational Procedures, etc.) adequately represent sUAS operations.
- Each element of remote pilot training can be reduced to address a single JARUS RPC subject.
- Greater element counts – i.e., training requirements, in a JARUS RPC subject will relate to the relative importance – or emphasis – of that subject

OUTCOME

The research team derived eleven (11) recommendations for UAS remote pilot training requirements for (1) BVLOS, and (2) Operations over people.

Task 4 Final Report and Project Closeout – Current Task:

The research team is currently drafting the ASSURE A27 final report in anticipation of the project concluding on December 5, 2022. The report summarizes findings from Tasks 1, 2, and 3, and it will offer a summary of key findings from the project.

NAME & ORIGIN OF RESEARCH PERSONNEL

TOM HARITOS - KSU	UNITED STATES
KURT CARRAWAY - KSU	UNITED STATES
TIM BRUNER - KSU	UNITED STATES
ZACHARY WALLER - UND	UNITED STATES
PAUL SNYDER - UND	UNITED STATES
DOUG HAMMOND - SCC	UNITED STATES
ANDREW SHEPHARD - SCC	UNITED STATES

DISASTER PREPAREDNESS AND RESPONSE USING UAS - PHASE I

THE UNIVERSITY OF ALABAMA IN HUNTSVILLE
LEAD
UNIVERSITY OF ALASKA FAIRBANKS
Oregon State University
NM STATE UNIVERSITY
MISSISSIPPI STATE UNIVERSITY
The University of Vermont
NC STATE UNIVERSITY

BACKGROUND

This research is in direct response to the FAA Reform Act of 2018 directing research into disaster use of UAS. The FAA has identified a need to better integrate UAS into the fabric of disaster response/relief aviation operations, and prevent unwanted incursion of UAS during such operations. Existing government research, sponsored by the Department of the Interior (DOI), is examining UAS use in disaster response, and this research recommends improvements to coordination and operations procedures and practices.

The FAA, as the regulator and ultimate authority of the National Airspace System (NAS), needs

to understand:

1) Are there any challenges and/or shortfalls in the current process for UAS integration into disaster efforts?
2) What changes may be made to better support the use of UAS by disaster relief agencies and support personnel?
3) What impact of such changes would have on UAS and NAS safety?

With DOI conducting their own research for responding to natural disasters, the FAA needs to understand their role in initiating procedures and how the coordination might change to ensure safety in the NAS. Coordination between these two research projects will avoid duplicative efforts across the government.

This research will look at how UAS can aid in disaster preparedness and response to different natural and human-made disasters along with emergency operations per Section 359 of the FAA Reform Act of 2018. It will focus on procedures to coordinate with the DOI, the Department of Homeland Security (DHS) including the Federal Emergency Management Agency (FEMA) and other federal, local, and state governments to ensure proper coordination during those emergencies. The research results will develop requirements, technical standards, policies, procedures, guidelines, and regulations needed to enable emergency response operations for UAS. Effective and efficient use of UAS in a disaster are the two primary goals of this project. This will offer an effective tool to assist first responders to save lives faster and accelerate personnel and infrastructure recovery.

APPROACH

This research is broken into phases each with clear research questions and objectives. This effort is Phase I and is broken down into six tasks described below. Phase II will give the research team the opportunity to exercise the findings found in Phase I and will happen in the coming years. Successful completion of this research is likely to shed important insights into interactions between human factors, technology and procedures, and will further improve regulatory processes and practices that govern UAS integration into the NAS.

Task 1: Survey of Experts for Disaster Preparedness and Response Use Case Development

The research team surveyed government experts to find the use cases for emergency preparedness and response. They included interaction with the National Incident Management System (NIMS) and the Incident Command Structure (ICS) or similar constructs or organizations that will include but not be limited to disaster response to wildfires, hurricanes, tornados, flooding, and human-made disasters. This task also considers both historical events and training/preparedness for disasters.

Task 2: Survey of Experts for Disaster Response using Manned Aircraft

In task 2, ASSURE surveyed the government to see how coordination for disaster response is done today with manned aircraft. Through FEMA/DOI/DHS and state government survey, the team determined how local and state governments use manned aircraft to respond to disasters.

Task 3: Development of the CONOPS and ORA by Disaster

The researchers developed Concepts of Operations (CONOPS) and Operations Risk Assessment (ORA) for some of the use cases that were reported on in Task 1. These CONOPS include wildfire, hurricane, tornado, flooding, earthquake, and volcanic eruptions along with oil spill, nuclear dispersion, terrorist attack, train derailment, and COVID use cases.

Task 4: Common Risks and Waivers/Exemptions for Disaster Support

ASSURE took the CONOPS and ORAs from Task 3 to determine common risks, what mitigations can be put in place for those risks amongst the different ORAs, and what waivers/exemptions would need to be in place for those operations.

Task 5: Coordination Levels amongst Federal Agencies

In Task 5, the research team determined the coordination level needed amongst federal agencies to conduct the disaster response missions with UAS instead of manned aircraft. In addition, they will determine the local and state government interactions needed for each mission chosen.

KEY FINDINGS

The research conducted under the A28 project, entitled “Disaster Preparedness and Response Using UAS,” focused on examining how UAS have been and are currently being used in emergency response scenarios. The team examined historical data on specific disasters to discern the nature of the incident, who were the responding agencies, what processes and procedures were used, what kinds of aircraft and associated equipment were involved, and what kinds of data resulted from the use of UAS. Several paths were followed in pursuing this knowledge:

·An extensive survey was conducted over several months targeting emergency responders to discern what their experience using UAS in emergency situations had been and what lessons might be learned from their experience. Regional symposia and professional conferences were used to focus on a restricted target audience.

· An evaluation of some well-documented disaster response situations was conducted using a Commercial Model-based Systems Engineering toolset to develop entity relationship diagrams. These studies provide insight into the current and previous relationships and communications among various agencies engaged in disaster response. The hope is that in Phase II of this effort, these entity relationship diagrams will enable the team to develop more efficient and effective communications and interactions among and between the members of the emergency response teams.

· The team completed a "deep dive" literature study examining 38 historical disasters ranging from floods to fires to weather events to earthquakes and tsunamis.

·A series of Concepts of Operations have been developed as possible candidates to be used in Phase II of this research program as practical exercises, workshops, table-top exercises, or other learning and teaching events. During these events, formal processes and procedures will be developed appropriate to each kind of CONOPS.

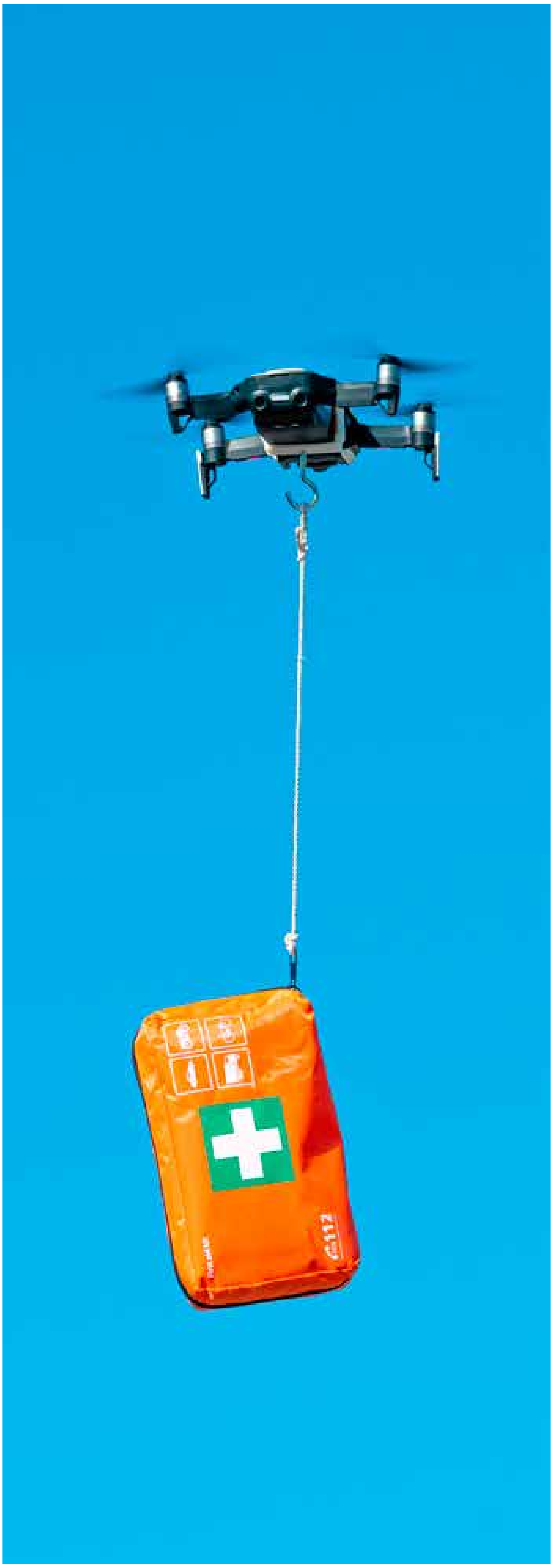
· Researchers conducted research examining the technological underpinnings that affect and enable the use of UAS in emergency response environments. The team provides an overview of some commonly used advanced technologies in emergency management/disaster response situations and discuss a number of challenges associated with some of these technologies.

· Analysis was completed looking at specific UAS Use Cases and Usage Challenges. Each of the use cases identified was analyzed analyzed in depth to determine the aspects of the use case that exposed it to risk.

· The team produced an Operational Risk Analysis focusing on the kinds of missions, equipment, and conditions associated with Disaster Response. This includes suggested mitigation measures for each unique identified risk and provides a risk rating both before and after the mitigating actions are taken. The result of this effort is a substantial compendium of information surrounding UAS in emergency situations.

· The survey results were tabulated and summarized and represent current information on the kinds of equipment currently in use by first responders, how that equipment is being used, what concerns the responders have, what training they feel in need of, and other factors to guide this team and the FAA at large in understanding the current state of UAS usage in emergency response situations. This information will be useful in guiding this team in its development of appropriate drills, exercises, and discussions in the next phase of this research.

· The case studies represent an enormous collection of historically relevant information on how events have transpired in real world emergencies and catastrophes. They also provide insight into those practices and equipment that have been successful or have failed in real situations. This insight and the sheer quantity of historical data will prove invaluable going forward as the team develops standardized practices and recommendations for future emergency responses of every category.



- The entity relationship diagrams will enable the development of more efficient and effective communications and interactions among and between the members of the emergency response teams during the practical exercises that follow in Phase II of this research.
- The use cases that the team developed were purposely created in as many categories and subcategories of disasters as could be imagined. These will form the framework of the practical exercises to follow. The variety and envisioned subcategories provide a unique catalog of conditions and situations to be confronted in both training and practical exercises in the future.
- The use cases were employed in developing risk analyses and detailed Concepts of Operations that will prove invaluable in adding layers of realistic details and options in the exercises and training materials that this research will generate in its next phase.
- The section on guidelines, policies, and procedures is expected to form a foundational library upon which the team will expand and build in Phase II for the improved management of UAS related emergency response and its body of practice.

NAME & ORIGIN OF RESEARCH PERSONN

JERRY HENDRIX - UAH	UNITED STATES
ROBERT MEAD - UAH	UNITED STATES
CASEY CALAMAIO - UAH	UNITED STATES
NISHANTH GOLI - UAH	INDIA
STEPHEN WARR - UAH	UNITED STATES
BENJAMIN NOEL - UAH	UNITED STATES
ALEXANDER MCGOWAN - UAH	UNITED STATES
JARLATH O’NEIL-DUNNE	UNITED STATES
DAVID ROSOWSKY - UVM	UNITED STATES
MANDAR DEWOOLKAR - UVM	UNITED STATES
DAVID NOVAK - UVM	UNITED STATES
JAMES SULLIVAN - UVM	UNITED STATES
MOLLY MYERS - UVM	UNITED STATES
ADAM ZYLKA - UVM	UNITED STATES
MADDY ZIMMERMAN - UVM	UNITED STATES
CATHY CAHILL - UAF	UNITED STATES
PETER WEBLEY - UAF	UNITED KINGDOM
NICK ADKINS - UAF	UNITED STATES
THOMAS ELMER - UAF	UNITED STATES
JESSICA GARRON - UAF	UNITED STATES
MICHAEL WEST - UAF	UNITED STATES
JASON WILLIAMS - UAF	UNITED STATES
JAMES PARRISH - UAF	UNITED STATES
JESSICA LARSEN - UAF	UNITED STATES
WILLIAM REMMERT - UAF	UNITED STATES
HENRY CATHEY - NMSU	UNITED STATES
JOSPEPH MILETTE - NMSU	UNITED STATES
TIM LOWER - NMSU	UNITED STATES
ANDRE DENNEY - NMSU	UNITED STATES
ROSS PALMER - NMSU	UNITED STATES
GARY LENZO - NMSU	UNITED STATES
ROBERT MCCOY - NMSU	UNITED STATES
JULIE A ADAMS - OrSU	UNITED STATES
MICHAEL OLSEN - OrSU	UNITED STATES
ERICA FISCHER - OrSU	UNITED STATES
DAE DUNG KANG - OrSU	REPUBLIC OF KOREA
JUNFENG-MA - OrSU	CHINA
ALAN MARTINEZ - MSU	UNITED STATES
EVAN ARNOLD - NCSU	UNITED STATES
DANIEL FINDLEY - NCSU	UNITED STATES
MICHAEL PICINICH - NCSU	UNITED STATES
THOMAS ZAJKOWSKI - NCSU	UNITED STATES

GRADUATION OF STUDENTS

REBECCA GARCIA - MSU	MAY 2023
MADDY ZIMMERMAN - UVM	MAY 2021

STEM OUTREACH - UAS AS A STEM OUTREACH LEARNING PLATFORM FOR K-12 STUDENTS AND EDUCATORS (STEM III)

NM STATE UNIVERSITY

LEAD

THE UNIVERSITY OF ALABAMA IN HUNTSVILLE

UNIVERSITY OF ALASKA FAIRBANKS

UC DAVIS

THE OHIO STATE UNIVERSITY

National UAS Training and Certification Center

BACKGROUND

This Science Technology, Engineering, and Math (STEM) outreach program is a continuation of previous ASSURE work. It focuses on the future Unmanned Aircraft System (UAS) workforce and the use of real-world research results from other ASSURE efforts. The outreach conducted in this program is an effective way to educate and disseminate research results. Some of the efforts are focused specifically on student instruction and some on "teaching the teachers".

The team works with a diverse demographics including urban areas, Alaskan Native, Native American, tribal communities, rural districts,

intercity, farming communities, and more.
The ASSURE research team focus is in five basic categories:

- Educator-based STEM outreach program;
- Rural community education and outreach;
- UAS centered summer camps;
- After school programs; and
- In school immersion programs.

This past year was the culmination of this STEM III effort and included lessons learned and mature outreach programs.

APPROACH

Each university has their own approach based on their local demographic and the specific categories they plan to focus on. The efforts starting in late 2019. In early 2020, all of the in-process activities for the STEM Outreach events were halted due to Covid. To address this, each school started the process to readjust the offerings. Through 2021 and all of 2022, all of the schools adjusted their programs to the new Covid reality and offered outreach that was modified, adjusted, and adapted to new teaching and instruction formats as well as providing new opportunities to fit the overall program goals. Opportunities expanded as the restrictions eased in 2022. The following sectionshighlight the key elements developed in the programs, and the 2022 accomplishments building toward task close out.

New Mexico State University – FAA STEM Program Management, Sinclair Sponsorship, and Various STEM Activities

As in previous years, NMSU continued to lead the teams STEM activities and programmatic support. Additional efforts focused on planning to offer their existing outreach activities like the UAS Roadshows and UAS Summer Camps. Demographic focus continues to be on middle school students who are primarily Hispanic and Native American.

Near the end of 2021, a number of members of the STEM III team supported and worked with the FAA Communication's Office's Jim Tice as he prepared the STEM article for the FAA. With the limited funding, NMSU was able to stretch them to offer UAS summer camps in June of

2022. The planning for summer 2022 UAS camps was coordinated through the NMSU STEM Outreach Center in the spring of 2022. Updates to curricula were ongoing. The class size was still limited from COVID-19 restrictions to 15 students per session, with a target of 60 students total. Successful summer 2022 UAS camps were completed with coordination through the NMSU STEM Outreach Center. Updates to curricula were integrated this year. Four sessions were completed; June 6 to 10 (Drone for Beginners – both AM and PM sessions); and June 20 to 24 (Drone for Beginners – AM only and Drones for Advanced Flyers – PM only). The June 6 to 10 camps were focused on students from the Gadsden Independent School District which has 97% minority enrollment. The team used indoor space in Renfro Hall to host the camps so that all flying camp was conducted safely indoors (and away from the heat!).

To support these camps, the NMSU STEM Outreach Center procured new drones, iPads, and modified curricula. Costs for these were not under this grant (this was not funded by the FAA), and came out of state funds. FAA funding paid for instructor time only. Like previous offerings, these camps were focused on establishing basic drone pilot and safety skills. Campers used plastic bricks to construct landing pads and racing gates for their drones. One of the PSL UAS Safety Analyst and drone pilot provided support. He talked to the students about being a professional in this field, his experiences, ad about the FAA ASSURE UAS research being done by NMSU. The desire is to set up for longer term post FAA support. Over the length of the program, the total outreach "touchpoints" was almost 600 connections.

University of Alabama in Huntsville (UAH) – Alabama Unmanned Systems Operations Mastery for Educators (AUSOME)

While the scope of AUSOME changed drastically due to the pandemic, a strong mutually beneficial partnership emerged with the USSRC which, in spite of the pandemic, offered a platform to showcase the "awesome" power of drones in the classroom. Beginning in February 2020 with the "National Robotics Day" and ending with the last Space Camp for Educators session in late July 2022, AUSOME demonstrations were performed with 269 students and 515 educators. AUSOME was proposed for an undergraduate research opportunity at UAH known as the Research and Creative Experience for Undergraduates (RCEU) program in the Summer of 2022. One student was down selected for mentorship with the UAH research team to support the last summer sessions with Space Camp for Educators and create a project diving into the Alabama Department of Education "Digital Literacy Requirements" to identify where UAS in the classroom could fill gaps in the standard curriculum. . While the scope of AUSOME changed due to unforeseen events, this program proved resilient in connecting educators with UAS-related training and demonstrations. The greatest result of AUSOME was the significance placed on the demonstrations with Space Camp for Educators which quickly became a staple of the program and a favorite amongst the attending teachers. The Alabama Teachers Session AUSOME demonstration of 2022 was pleased to see larger groups and demonstrate more capability. Undergraduate Summer RCEU student Matthew See supported Casey Calamaio (UAH Research Engineer) by showcasing how the digital literacy requirements for the State Department of Education could be addressed using UAS in the Classroom. UAH's initial focus was "teaching the teachers". As activities evolved the outreaches included both for students and educators. UAH collected the total numbers of students and teachers reached. Over 18 separate events were staged by the team where 192 students and 573 educators were reached.

University of Alaska Fairbanks (UAF) – The Alaska UAS Airshow

The UAF program was focused on reaching rural Native Alaskan communities. Many Alaskan communities can only be reached via air. The purpose of this activity is to fly experts from the University of Alaska Fairbanks's Alaska Center for UAS Integration (ACUASI) to schools across Alaska to teach students about UAS safety, rules, regulations, aerodynamics, and potential careers using UAS. The results of the outreach were exciting. Numerous kids and parents asked the UAF personnel if UAF had courses in drone operations and how they could get involved in UAF's drone research. The educators all wanted the UAF team to return and present to their classes. When the STEM team was able to visit more remote communities, they were able to engage with the residents and talk about the future of drones in Alaska, how drone education could help their kids stay in Alaska and have productive careers, and how UAF research, especially the ASSURE research, is helping ensure aviation safety in Alaska. With post Covid activities opening up, the UAF team had many individual outreach activities in 2022.

- November 3-4, 2021 - Nikiski Middle/High School. 3 classes of 15-20 kids each (6-8 grade).
- During the November 3-4 trip, the UAF team also conducted an outreach event at the Challenge Learning Center of Alaska for 15 kids (16-18 years old).
- January 26, 2022 - UAF conducted a STEM outreach to 62 students at Rogers Park Elementary in Anchorage.
- January 27, 2022 - Dimond High School in Anchorage (247 students).
- May 6-8, 2022 - The UAF team and members of the State of Alaska Department of Transportation and Public Facilities conducted an outreach to kids from across Southcentral Alaska during the Great Alaska Aviation Gathering in Palmer.
- May 18, 2022 – The UAF team went to Nenana to participate in the Challenger Drone Camp. The team was able to take the students to see operations of one of UAF's large drones, the DRS Sentry (13' wingspan, 280 lbs. dry weight).
- June 4, 2022 - The UAF team conducted a drone outreach as a part of the Large Animal Research Station Birthday Bash.
- May 19, 2022 - The UAF participated in the Geophysical Institute's Open House with flight simulators, hands-on drones, and one-on-one conversations about UAF's ASSURE research and what it means for aviation in the state.
- June 7-9. 14-17, and 20-22, 2022, UAF conducted drone STEM activities during three weeks of Camp Fire Alaska events at different

locations on the Kenai Peninsula and in Anchorage. Camp Fire has the advantage of bringing kids from across Alaska together so the team can reach many more kids from remote locations than per our normal outreach event.

- July 12, 2022 - Delta Junction Summer School.
- July 13, 2022 - The UAF team presented two sessions on drone uses, safety research, and rules and regulations as a part of a UAF law enforcement Summer Crime and Law Camp.
- July 13, 2022 - Cathy Cahill, ACUASI Director, presented a Summer Sessions lecture on drones, highlighting UAF's ASSURE research on BVLOS operations, cargo delivery, and operations on and around airports, as a part of the "Explore Alaska."
- July 18-20, 2022 - The UAF team conducted a drone summer camp at UAF. The summer camp includes information on drone careers, technology, rules and regulations, safety research, especially ASSURE research on BVLOS, cargo operations, and airport safety. The UAF personnel make the students to take the TRUST exam and mentor them through building a small first-person drone.
- July 29, 2022 - Ben Eielson Junior High School in Salcha.
- August 2, 2022 - UAF Day at the Tanana Valley State Fair in Fairbanks.
- August 28-31, 2022 - Valdez as a part of a UAF initiative to develop drone curricula for middle-school students.
- September 8, 2022 – hosted Pearl Creek Elementary School at UAF (120 students).

In every outreach the UAF team conducted, ASSURE research is highlighted. Over the duration of this effort, the UAF STEM team was able to reach 1,542 students and 268 educators during the 29 events conducted as a part of the project.

University of California at Davis (UCD) – STEM Summer Drone Academy

UCD created customized learning STEM Academies using UAS as a learning platform between 2018 and 2022. UCD chose to work with the Early Academic Opportunity Program (EAOP) which was part of identifying students that met STEM requirements for under-represented, non-traditional, socioeconomically disadvantaged, minority, and women students in addition to first-generation attending university students. All of the students meet these criteria. With Nathan Metzler serving as Academy Director and Lead UAS Instructor, UC Davis undergraduate students were trained to serve as co-instructors for the Academy, bringing in their UAS piloting and research experience to share with the students. Between March 2020 and June 2021 all in-person events were suspended by the school district. In July 2021, a limited in-person Academy resumed, with three full attendance events held between March and August 2022. Two field visits to area high schools were conducted in March and May, totaling over 280 attending high school students. The 2022 activities included the following:

- UCD Flight Simulator Training, February 2022.
- UCD Florin High School, Sacramento, May 13, 2022.
- UCD 5th Summer ASSURE Drone Academy, July 27-30, 2022. As part of this, representatives from the FAA presented

on aerospace careers to the Academy. The UCD Summer Drone Academy had multiple acknowledgments in the press.

One thing that was surprising was that female students were either the majority of students in a class (up to 60%) or were participating in near equal in numbers with males. Female students scored as highly as their male counterparts in competitions and were frequently the highest point scorers in drone competitions. EAOP has encouraged their participation and clearly female students responded quickly to applications and were enthusiastic participants. Breakdowns for the events were as follows:

- Florin High School STEM Assembly & Flight Demonstration (215 students), March 2022. (Asian 43%, Hispanic 32%, Black 14%, White 7%, and Other 4%).
- Dixon High School STEM Assembly & Team Flight UAS Training (70 students), May 2022. (Hispanic 56%, White 31%, Mixed Race 6%, Black 3%, Asian 2%, and Other 2%).
- UC Davis 2022 ASSURE Academy Demographics, August 2022.
  - 60% female, 40% male class ratio.
  - Students from 14 Sacramento Area schools up to 70 min-drive away. Grade distribution: 10th graders (50%) , 11th graders (38%), 12th graders (12%).
  - Latino/Spanish 29%, African American 4%, Chicano/Mexican American 21%, American/Alaskan Indian 12%, Asian 12% White/Caucasian 17%, and other 5%.

The Ohio State University (OSU) – Translating Engineering to Kindergarten Through 8th graders (TEK8) with a Focus on UAS Research

In the spring of 2021, two undergraduate students were recruited to conduct summer research in the lab as a part of the TEK8 program. Mitchell Wong was recruited by Professor Kiran D'Souza to support the ASSURE UAS Engine Ingestion research projects, and Lexi Moore was recruited by Dr. Matt McCrink to support the development of a test stand for a next generation Mars flight vehicle. Due to the ongoing COVID-19 pandemic, Mitchell Wong conducted his research virtually, while Lexi Moore did her research in-person at the Aerospace Research Center at OSU. They then both translated their research experience into a design challenge for STEM outreach in the late Fall of 2021 in the TEK8 course. Mitchell Wong delivered his design challenge with his outreach team in person to approximately 30 students in a Metro Middle School class on November 16, 2021. The student handout, facilitator guide, introductory video, and design challenge video are hosted on the TEK8 site: https://u.osu.edu/tek8/2021-design-challenges/airfoil-analysis/

Lexi Moore delivered her design challenge with her outreach team on November 30, 2021 to approximately 30 students in a Metro Middle School class. The student handout, facilitator guide, introductory video, and design challenge video are hosted on the TEK8 site: https://u.osu.edu/tek8/2021-design-challenges/abcs-of-airplanes/

In the spring of 2022, Keaton Nichols was recruited by Professor Kiran D'Souza to support the ASSURE UAS Engine Ingestion research projects, and Evan Kaullen was recruited by Dr. Matt McCrink to research a rotor thrust measurement system for a flight vehicle for

Mars. Both Keaton and Evan conducted their research in-person at the Aerospace Research Center at OSU. Then both began the TEK8 course in the Fall of 2022, where they're currently translating their research experience into design challenges for STEM outreach later in the Fall of 2022. They'll each be delivering their design challenge to approximately 30 students in a Metro Middle School class, and their design challenges will be hosted on the TEK8 website. Over the life of this program, the OSU team mentored 6 undergraduates in summer research programs related to UAS design and integration into the airspace. Three of the research projects were related to UAS design and optimization and three were focused on safety concerns related to UAS ingestion into engines.

Sinclair College National UAS Training and Certification Center – Interactive Middle School UAS Introduction and Simulation Experience

Sinclair's "Interactive Middle School UAS Introduction and Simulation Experience" had the focus of STEM outreach to large number of students through immersive experiences. 2022 continued with a large number of outreach activities. There were a number of different camps offered over the life of this program. The air camps included elementary school camp (grades 4-6); middle school camp (grades 7-9); high school camp (grades 10-12); and teacher camp. It should be noted that the camp sessions incorporated the ASSURE STEM research slides into the air camp and other events. Several highlights based on observation or data provided by partners are as follows:

- Dayton Early College Academy UAS Camps – The Dayton Early College Academy primarily serves minority populations in Dayton, Ohio. The three-day UAS camp organized and hosted by Sinclair in 2021 included 12 disadvantaged and minority middle and high school students, while 14 included in the three-day camp hosted in 2022.
- Air Camp – Air Camp provided a demographic report for the participants in events at Sinclair in 2021, which noted 24 of 118 elementary students, 31 of 69 middle school students, 19 of 67 high school students, and 13 of 70 teachers were drawn from minority ethnic populations. A report from Air Camp was not provided for 2022 at the time of this report. However, the proportions were similar.
- SOFWOLF – The participants in the SOFWOLF DRONE WOLF UAS camp were all Gold Star children, who are the children or step-children of fallen soldiers or first responders. Sinclair's team traveled to the Provo, Utah region to support the camp, which included provision of a remote pilot ground school, UAS flight operations and demonstrations, and other hands-on activities in addition to the standard project presentation and UAS simulation experience.

The specific outreach activities this year included the following:

- *28 Jan 22 – Cedar Cliff Middle School (66 students)*
- *25-27 Feb 22 – National Museum of the USAF (206 students)*
- *19 Apr 22 – Greenview Middle School (97 students)*
- *27-29 Apr 22 – Warner Middle School (242 students)*
- *4 May 22 – Dayton Metro Library (53 students)*
- *23-24 May 22 – Van Cleve Middle School (316 students)*
- *13-14 June 22 – Air Camp (Sinclair) (37 students)*
- *29 Jun 22 – Air Camp (Sinclair) (50 students)*
- *11-12 July 22 – Air Camp (Sinclair) (33 students)*
- *13 Jul 22 – Air Camp (Sinclair) (48 students)*
- *19 Jul 22 – Air Camp (Sinclair) (40 students)*
- *19-21 July 22 – Wright Brothers Institute (8 students)*
- *20 Jul 22 – Air Camp (Sinclair) (49 students)*
- *26-28 July 22 – Dayton Early College Academy (Sinclair) (14 students)*
- *2-4 August 22 – WACO Aviation Learning Center (16 students)*

At the conclusion of the effort, Sinclair had completed 148 outreach days, reaching 9,168 total participants who were provided with the project presentation and RealFlight simulation experience. Efforts were made to reach schools across a range of locations and economic demographic conditions, as well as to participate in public access events in underserved areas including west Dayton.

KEY FINDINGS

The diversity of students, communities, and teachers reached was significant. The summary numbers show that almost 12,000 students were reached over the period of this grant. Over 650 teachers/educators were exposed to UAS, with many given the tools the take this back to their communities to expand the impact.

University of Alabama Huntsville:

- Teaming with Space Camp for Educators, hundreds for teachers in Alabama were educated about drone and how these tools can be used in the classroom.
- Working with the Civil Air Patrol Alabama Wing Summer Encampment, the UAS Aerospace Education Activity included an “sUAS Solo Achievement.”
- Over the duration of this effort, UAH had 192 students/contacts and reached 57 teachers.

University of Alaska Fairbanks

- COVID-19 impacts, and the inability to go into the remote communities made UAF adjust programs to still deliver high value content through camps, other school visits, and Campfire Alaska.
- Flight simulators and the UAS "petting zoo" were central to these outreach activities.
- Over the duration of this effort, UAF had 1,542 students/contacts and reached 268 teachers.

Ohio State University

- Six OSU students supported real world research projects that were part of OSU's ASSURE research work including Airborne Collision Repair, Drone Building, Airfoil Analysis, ABCs of Airplanes, UAS ingestion, and UAS design.
- The six students developed design challenges for middle school students.
- Over the duration of this effort, OSU had 105 students/contacts and reached 22 teachers.

University of California at Davis

- UCD conducted multiple Summer Drone Academies that targeted low income and underserved groups.
- UCD brought in guest speakers from the FAA and others as well as used biology inspired aviation (insects and birds) to teach flight principals.
- Over the duration of this effort, UCD had 35 students/contacts and reached 4 teachers.

Sinclair College

- Sinclair's Interactive Middle School UAS Introduction and Simulation Experience completed 148 outreach days, reaching 9,168 total participants.
- Additional activities included the Dayton Early College Academy UAS Camps, Air Camp, and SOFWOLF.
- Over the duration of this effort, Sinclair had 9,168 students/contacts and reached 30 teachers.

New Mexico State University

- NMSU summer camps reached 80 students from underrepresented groups over two summers.
- Multiple other outreaches and hands on events made almost "touchpoint" connections.
- Over the duration of this effort, NMSU had 580 students/contacts.

NAME & ORIGIN OF RESEARCH PERSONNEL

JOSEPH MILLETTE - NMSU	UNITED STATES
JENNIFER BJORAKER - NMSU	UNITED STATES
ANDREW DENNEY - NMSU	UNITED STATES
ROSS PALMER - NMSU	UNITED STATES
GAY LENZO - NMSU	UNITED STATES
MITCHELL MATHEISON - NMSU	UNITED STATES
ROBERT MCCOY - NMSU	UNITED STATES
TIM LOWER - NMSU	UNITED STATES
JUAN ANGEL - NMSU	MEXICO
JERRY HENDRIX - UAH	UNITED STATES
CASEY CALAMAIO - UAH	UNITED STATES
KAY TAYLOR - US SPACE AND ROCKET CENTER	UNITED STATES
ANN LOTT - AMSTI	UNITED STATES
AUSTIN WORCESTER - CIVIL AIR PATROL	UNITED STATES
LEO ROBADEY - SKYWARD, INC	UNITED STATES
CATHERINE CAHILL - UAF	UNITED STATES
NICHOLAS ADKINS - UAF	UNITED STATES
MICHAEL HATFIELD- UAF	UNITED STATES
WILLIAM REMMERT - UAF	UNITED STATES
JOELLA PETERSEN - GILA	UNITED STATES
NORMAN COSGROVE - DELTA JUNCTION SCHOOLS	UNITED STATES
JANE TEAGUE - ALASKA GATEWAY SCHOOL DISTRICT	UNITED STATES
SUSAN USTIN - UCD	UNITED STATES
NATHAN METZLER - UCD	UNITED STATES
KIRAN D'SOUZA - OSU	UNITED STATES
MATT MCCRINK - OSU	UNITED STATES
DUSHYANTH SIRIVOLU - OSU	INDIA
FREEMAN GAO	UNITED STATES
YUTO NAKAHATA - OSU	UNITED STATES/JAPAN
LEXI MOORE - OSU	UNITED STATES
MITCHELL WONG - OSU	UNITED STATES
JEFFERY MILLER - SCC	UNITED STATES
ANDREW SHEPHERD - SCC	UNITED STATES
DOUG HAMMON - SCC	UNITED STATES
SETH SCHWARTZ - SCC	UNITED STATES
CHARLES REED - SCC	UNITED STATES
ALEXANDER CATALAN - SCC	UNITED STATES
SAMUEL HECKEL - SCC	UNITED STATES
TERRY CLAWSON - SCC	UNITED STATES
AMANDA WARREN - SCC	UNITED STATES
ETHAN WEST - SCC	UNITED STATES

SAFETY RISKS AND MITIGATIONS FOR UAS OPERATIONS ON AND AROUND AIRPORTS

LEAD

BACKGROUND

There are no policies, procedures, or criteria for operating Unmanned Aircraft Systems (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 Air Traffic Organization (ATO) Safety Management System (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

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.

This safety and risk analysis will focus 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 ATC services (if not provided). The research may inform potential changes to FAA regulations (such as 7110.65) and industrial standards.

APPROACH

Task 1 – Literature Review

The team identified 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. This review included the following areas:

- UAS physical/aerodynamic response to upsets and perturbations, including those caused by encounters with wake vortices for numerous different types of UAS (i.e. rotorcraft, fixed wing, sUAS, etc.)
- Consider loss of link, drop link, fly-away, and Remote Pilot in Command (RPIC) loss of situational awareness.
- Publicly available SMS studies.
- Publicly available level of upset to the UAS aircraft that will cause loss of link or drop link with the remote pilot.
- Automated response considerations in the event of off-nominal events.
- Consult with the FAA to incorporate Science and Research Panel (SARP) considerations.
- Consider prior research on SMS including research conducted by ASSURE.

The Literature Review was completed during FY21.

Task 2 – The team proposed other potential areas of research beyond what is outlined in the task. They coordinated and prioritized the research to be conducted. The team developed a Research Task Plan with potential increased/ decreased scoping based on findings

The Research Task Plan was completed during FY21 and was revised in FY22 to address the selected use cases. The FAA Program Managers, sponsors, and research team decided that a scoping peer review was not needed due to the significant subject matter expert input into the research.

Task 3 – The team determined research shortfalls identified from the literature review and developed 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.

The team defined 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
- Large UAS takeoff and recovery

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 (Fairbanks International Airport [AK], Grand Forks International Airport [ND], and Salina Regional Airport [KSU]). 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.

Task 4 – Using the FAA's ATO SMS process, the team identified the hazards and mitigations of the use cases, considering publicly available hazards and mitigations from prior FAA waivers, exemptions, federal register notices, IPP results, and the FAA's report to the White House on the IPPs.

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 includes operations at Fairbanks International Airport. The research team prepared to conduct a paper SMS panel on October 4, 2022.

Task 6 – Flight Testing – The team will propose flight testing and analysis with exit criteria for three use cases to validate the proposed mitigations.

Flight testing will be conducted at airports appropriate to each unique use case. The universities associated with this project all have relationships with airports of different airspace classes and tower conditions, so testing use cases across multiple airspace classes and tower conditions, so testing use cases across multiple airspace classes is possible with this research team. The flight operations will be conducted under the auspices of the three FAA UAS Test Sites (the University of Alaska UAS Test Site, the New Mexico State University UAS Flight Test Center, and the Northern Plains UAS Test Site) identified for conducting ASSURE flight testing and will focus on the primary airports used by these Test Sites. However, UAH and KSU have access to airports under additional types of airspace classes, such as the Class C Huntsville International Airport, so flight testing may occur at those airports depending on the use case.

Several fundamental items that require flight testing are: 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 prior to 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 research team conducted a large drone operation using UAF's DRS Sentry HP (13' wingspan, 280 lbs dry weight) drone at Fairbanks International Airport (towered, Class D) on May 22, 2022 using the COA used for the SMS review panel. The flight lasted 32 minutes and the Sentry was completely integrated into the air traffic operating in the pattern at the airport. Fairbanks ATC personnel called the flight 'seamless' and a flight instructor operating in the pattern with the Sentry stated that the Sentry acted like any other aircraft in terms of communications and flight behavior in the pattern. The UAF team conducted taxi tests with the aircraft and Fairbanks International Airport and ATC Tower personnel two days prior to the actual flight to ensure that everyone was comfortable with how the drone was going to operate on the airport surfaces prior to flight. The results of the operations will be incorporated into the final report and lessons learned about risks and mitigations will be explicitly detailed in the report.

The UND and KSU teams completed their safety risk assessments, developed their concept of operations, and submitted their flight permission requests into DroneZone. The expectation is that the teams will conduct flight operations early in FY23.

UAF prepared to fly their Griffon Aerospace Outlaw SeaHunter (16’ wingspan, 300 lbs maximum take-off weight, twin-engine) drone from Fairbanks International Airport 40 miles to the Nenana Municipal Airport. The flight is to be conducted on COA 2022-WSA-10408 early in FY23.

The UND, KSU, and UAF teams all submitted their flight test cards for approval prior to the flights.

KEY FINDINGS

As reported in the FY21 annual report, key conclusions from the Literature Review include:

- The current regulatory language does not maturely or robustly address the use of UAS on or around an airport.
- UAS operators must use processes involving special waiver or authorization for the various operations close to or within the airport environment.
- While there is data reflecting the various considerations or hazards related to UAS flight on and around airports, there is little safety assurance data from completed safety cases.
- Use cases are often not documented in technical detail; they are operationally led. Therefore, there is no expectation for detailed documentation of processes, procedures, and results.
- Facility and asset management, parts delivery, and construction monitoring UAS use cases have occurred, but there are no significant published details related to the parameters or the outcomes. In contrast, wildlife management and aircraft inspections UAS use cases have more documented occurrences showing the viability of the use of UASs.
- Many inspection elements for CFR Part 139 inspections/compliance (ex. fence line inspection, facility security, etc.) are addressed in the general literature with few specific references to on airport operations.
- Pavement, ramp/runway, and airfield inspections provided a number of documented applications with procedures and processes and are mature enough that companies are performing these services commercially. • Although many state and federal agencies are conducting research, the research team found it difficult to get information regarding ongoing collaboration between agencies.

While the literature review provides a resource on maturity of many operations, the literatureavailable clearly did not:

- Identify the existing standards used prior to UAS use to meet the use case need.
- Reflect documentation regarding how

UAS will meet or exceed the current standard for the given use case.

- Identify established metrics to be used to demonstrate an increase in efficiency, safety, or effectiveness by using a UAS to complete the given case on or around the airport.

During FY22 the team identified the following key findings:

- There is significant research on operations on and around airports being conducted by the FAA's William J. Hughes Technical Center that should be identified prior to suggesting potential research use cases to reduce the chance for duplicative efforts.
- Large drones are not the focus of most FAA research, so any large drone operations will contribute important information about the integration of the drones at airports and in the NAS.
- The hazards and potential mitigations for small and large drone operations on and around airports are very similar.
- Operational drone programs have similar experiences and have developed similar mitigation methods through refining their operations.
- Operational drone programs have developed safety documents, policies, and procedures that are living entities and constantly revised to incorporate improved technologies and ways of mitigating risks.
- Even if an operational team has support from the local airport to conduct operations, the process may be held up by questions or personnel at other levels of the approval process.

NAME & ORIGIN OF RESEARCH PERSONNEL

CATHERINE CAHILL - UAF	UNITED STATES
NICHOLAS ADKINS - UAF	UNITED STATES
JASON WILLIAMS - UAF	UNITED STATES
THOMAS ELMER - UAF	UNITED STATES
MATTHEW WESTHOFF - UAF	UNITED STATES
EVELYN (formerly TREVOR) PARCELL - UAF	UNITED STATES
RONALD (LEE) WINNINGHAM - UAF	UNITED STATES
ANDREW WENTWORTH - UAF	UNITED STATES
TOM HARITOS - KSU	UNITED STATES
KURT CARRAWAY - KSU	UNITED STATES
KATHERINE SILAS - KSU	UNITED STATES
TIMOTHY BRUNER - KSU	UNITED STATES
RAJAGOPAL SUGUMAR - KSU	INDIA
TRAVIS BALTHAZOR - KSU	UNITED STATES
MIKE KUNI - KSU	UNITED STATES
KENTON DREILING - KSU	UNITED STATES
HENRY CATHEY - NMSU	UNITED STATES
JOSEPH MILLETTE - NMSU	UNITED STATES
MITCHELL MATHEISON - NMSU	UNITED STATES
TIM LOWER - NMSU	UNITED STATES
JERRY HENDRIX - UAH	UNITED STATES
JUSTIN HARRISON - UAH	UNITED STATES
STEPHEN WARR - UAH	UNITED STATES
BENJAMIN NOEL - UAH	UNITED STATES
NISHANTH GOLI - UAH	INDIA
ROBERT MEAD - UAH	UNITED STATES
CASEY CALAMAIO - UAH	UNITED STATES
PAUL SNYDER - UND	UNITED STATES
KIM KENVILLE - UND	UNITED STATES
GARY ULLRICH - UND	UNITED STATES
DANIEL MYLES - UND	UNITED STATES
JAMES MOE - UND	UNITED STATES
SREEJITH VIDHYDARAN NAIR - UND	INDIA
CRAIG CARLSON - UND	UNITED STATES
BRAIN SHAMBLEN - UND	UNITED STATES

IDENTIFY WAKE TURBULENCE AND FLUTTER TESTING REQUIREMENTS FOR UAS

LEAD

BACKGROUND

The research team is working together to support the Federal Aviation Administration (FAA) effort to establish rules for mitigation of risks due to sUAS upset caused by wake vortex encounters, and flutter flight testing of small Unmanned Aircraft Systems (sUAS) to establish risks due to sUAS upset due to flutter.

Although the FAA has started the wake turbulence re-categorization (RECAT), the current regulation put all the aircraft with the Maximum Takeoff Weight (MTOW) less than 15,500 lbs as Category F. New detailed separation rules and guidance to UAS/airport operators are needed to guide safe UAS operations in controlled or uncontrolled

including at or around airports, ranging from large passenger UAS (e.g., Kitty Hawk Cora UAS, ~4,000 lbs) to small package delivery UASs (less than 50 lbs).

APPROACH

Task 1: Literature Review

The team will conduct a literature review to identify new research in the areas of wake turbulence effects on UAS and UAS flutter. This will include:

- Information available from the open literature as well as FAA, NASA and DOT, which have conducted extensive characterization of wake turbulence hazards at major US airports;
- Current state of the art in controlled velocity gust facilities;

Task 2: Determine research shortfalls identified from the literature review.

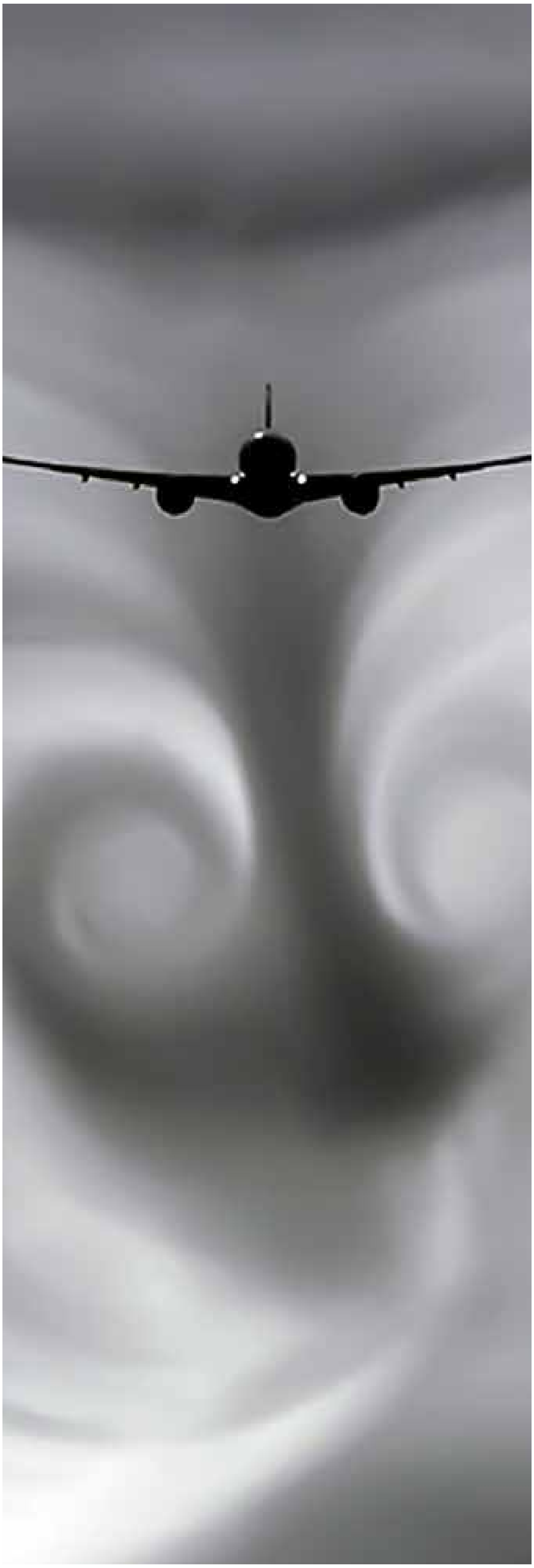
The team will develop case studies to address shortfall areas. Case studies will include scenarios of UAS wake vortex encounters:

- With a range of manned aircraft (business jets, regional jets, and large passenger jets.
- By a wide range of UAS weights and types (fixed-wing, multirotors (including air taxi) and the emerging vertical takeoff class.
- UAS physical/aerodynamic response to aerodynamic perturbations, including those caused by encounters with wake vortices, for different types of UAS (multirotor, fixed wing, VTOL and rotorcraft);

Task 3: Analyze and assess the severity of UAS response to encountering various strengths of wake vortices.

Task 4: Conduct assessments and provide safety analysis considerations for FAA policy, guidance, and procedures for wake turbulence mitigation for UAS.

- Conduct an upset severity assessment of several UAS aircraft and wake vortex encounters. Perform this assessment for generic operations in the airport environment and selected (to be identified later) operations. Based upon severity assessments, provide suggested operational limitations, restrictions, and/or mitigations for generic operations in the airport environment



- Develop and recommend processes and procedures to be used in the evaluation of sUAS operations associated with potential wake vortex encounters.

Task 5: Conduct a peer review to ensure public availability of the research.

KEY FINDINGS

Literature Review/Gaps Analysis

The literature review and gaps analysis was conducted and vetted by the FAA. Subsequently, as Stakeholder Technical Review was hosted by the FAA to further study the gaps analysis findings.

- **Wake vortex modelling**

The team identified the existing wake vortex velocity field theories and mathematical models. For the evolution of wakes, NASA's Aircraft Vortex Spacing System (AVOSS) Fast-Time Wake Prediction Models software "suitcase" has been determined to include the most sophisticated theories for wake strength decay as well as wake position over time, considering atmospheric influences such as cross-wind and the natural sinking of a wake.

The suitcase consists of stand-alone models that include AVOSS Prediction Algorithm (APA) versions 3.2, and 3.4, which utilize the Sarpkaya out of ground effect (OGE) decay model. The suitcase also includes the TASS Derived Algorithms for Wake Prediction (TDAWP) version 1.0 and 2.1 that use the APA framework, but OGE decay is derived from theoretical studies with the Terminal Area Simulation System (TASS).

This software suite has been provided by NASA and is being stood up at KU. For estimating the air velocities within a wake, the Burnham-Hallock model has been adopted. The combination of AVOSS and the Burnham-Hallock model have been trusted by NASA and the FAA to predict the effect of wake encounters for large aircraft to, with adequate safety factors, set separation distances for large aircraft arriving at and departing from airports.

- **UAS dynamic characteristics during wake encounter and upset conditions**

The team found a small number of flight test accounts of the effect of the wake vortex produced by a leading aircraft on a closely-following aircraft or rotorcraft. However, there is only one known prior research effort to predict UAS upset due to a wake encounter. That study, conducted by one of the members of the research team, addressed the effect of a leading sUAS vortex on a closely-following sUAS. However, there was no study found to cover the effect of an evolved wake vortex from a large aircraft on sUAS.

- **UAS upset due to flutter**

The team found that there is a rich history of analysis and test for large aircraft wings. However, there was no prior art found for sUAS, which have dramatically different structural configurations.

Assessment of the severity of UAS response to encountering wake vortices

Multiple mathematical models of UAS flight dynamics have been used to simulate the response of multiple UAS types flying through a simulated wake vortex pair. The air velocity profile for these sumulations is derived from Burnham-Hallock model for a range of circulations (vortex strength) characteristic of the vortices generated by commercial aircraft.

The flight dynamics models used for fixed wing UAS include the vortex lattice method and a number of variations of the “aerodynamic coefficient build-up modelling method”. Flights have been simulated through wake vortex pairs at a number of approach paths ranging from along the axis of a vortex to at a right angle to the vortex axis. The simulated air velocity fields are all based on the Burnham-Hallock model. Some simulations are with only an “inner loop” controller (attitude control) while others are with control algorithms with a range of robustness. Flight dynamic simulations for multirotor UAS encountering a wake vortex have also been conducted using a rotor lift-based dynamics model.

Wind machines have been used to simulate air velocity fields which represent a small number of wake vortex encounter geometries. One facility uses a bank of laterally-spaced wind machines providing a steady or linearly-varying cross-wind. Another facility uses a pair of wind machines producing encounter velocities oriented 45 degrees to the horizon, providing a wind field with a vertical component.

Both fixed-wing and multirotor UAS have been flown through the physically-simulated wake vortex encounters created by the wind machines. The flight responses, including some loss of control or near-loss of control events, have been compared with what has been predicted by the simulations of UAS response. For fixed-wing UAS, a study of the effects of controller robustness has been conducted.

A number of candidate metrics to assess UAS Loss of Control (LOC) have been studied. For both fixed wing and multirotor, some simple metrics have focused on departures of attitudes and rates of change in attitude. Others consider limits on control authority, much like the leading metric for large aircraft, the oft-cited “roll control ratio”. Some effort has also been spent on novel metrics such as noting departure from expected behavior, as assessed by noting changes in “normal” and “abnormal” correlations between aircraft states, for instance, pitch rate and elevator deflection.

Safety analysis considerations for FAA policy, guidance, and procedures for wake turbulence mitigation for UAS

Wake vortex core strength, dissipation, settling (sinking) and drifting (laterally) has been modelled based on techniques used in the NASA AVOSS software suite. The severity of the environmental risk to UAS wake vortex encounter has been proposed to be based on the definition of envelopes of airspace within which the circulation exceeds a range of prescribed levels based on the vortex modelling. The overall severity of risk of upset is based on defining the circulation strength for which a UAS has been predicted to avoid loss of control. In this way, the volume of airspace through which that UAS can safely fly can be predicted. The prediction of the circulation strength leading to upset may be based on a number of competing simulations with a range of control authority and controller robustness—from a simple attitude hold controller to a trained AI-based controller. Perhaps equally important for the robustness assessments is propulsion capability and, specifically, the extent of available power to recover from upset.

NAME & ORIGIN OF RESEARCH PERSONNEL

MARK S. EWING	UNITED STATES
MATTHEW MCCRINK	UNITED STATES
SHAWN KESHMIRI	IRAN
ZHI JIAN WANG	PRC
ZHONGQUAN ZHENG	PRC
HAIYANG CHAO	PRC
HUIXUAN WU	PRC
DHUREE SETH	INDIA
ANASTASIA BYRD	RUSSIA
AARON MCKINNIS	UNITED STATES
JEFF XU	UNITED STATES
ZHENGHAO LIN	PRC
JUSTIN MATT	UNITED STATES
HAROLD FLANAGAN	UNITED STATES
TYLER FLOYD ANDREW	UNITED STATES
GABRIEL HARRISON BERNART-SHENK	UNITED STATES
VISHVAS SHARMA	INDIA
BRENNAN MICHAEL WHEATLEY	UNITED STATES
JULIAN MARCOS MORENO	UNITED STATES
BENJAMIN CHARLES SVOBODA	UNITED STATES
ALEXANDRE JULIAN ZUGAZAGOITIA	UNITED STATES
MOSERRUF SHAWON	BANGLADESH
ROSS HEIDERSBACH	UNITED STATES

GRADUATION OF STUDENTS

HARRY FLANNAGAN	MAY 2021
ANASTASIA BOYD	MAY 2021
SHARMA VISHVAS	MAY 2021
JULIAN MORENO	MAY 2021
ALEXANDRE ZUGAZAGOITIA	MAY 2021
BRENNAN WHEATLEY	MAY 2021
BENJAMIN SVOBODA	MAY 2021
TYLER FLOYD	MAY 2021

Urban Air Mobility: Safety Standards, Aircraft Certification and Impact on Market Feasibility and Growth Potentials

Wichita State University
LEAD

Mississippi State University

NC State University

Embry-Riddle Aeronautical University

BACKGROUND

In the FAA Modernization and Reform Act of 2012, Congress tasked the FAA with integrating Unmanned Aerial Systems (UASs) into the National Airspace System (NAS). To comply with the Congressional mandate, the FAA established a Small Unmanned Aerial System (sUAS) rule, published within the Code of Federal Regulations as 14 CFR Part 107. At its core, the present research proposal is a basic, and an early-stage applied study for understanding Urban Air Mobility (UAM) operations in the NAS. Designed as a short-term research project, the results will likely yield effective and quantitative metrics in evaluating UAM, becoming a further step towards the UAM integration into the NAS. Moreover, identifying the volume and magnitude of UAM is essential for understanding the safety implications and prioritization of the Agency resources. Thus, the proposed research is designed to capture the following characteristics of the market's potential together with the implications on resources:

- Potential size and growth of the market at the local and/or national level;

- Economic feasibility, including price points at which individual market becomes viable;
- Anticipated cost to enter the market, considering factors such as vehicle acquisition and life cycle, operation liability, maintenance and replacement, and upgrade schedules;
- Customer segments (eg., regular business commuters, ad hoc travelers, etc.) for UAM viability;
- Characteristics of population density, traffic patterns including congestion, affordability, and preferred locations;
- Competition for UAM transportation or services (e.g., driverless cars and multi-modal transportation options, on-demand ride-hailing services, virtual presence, etc.), providing cost comparisons where applicable;
- Ground infrastructure requirements, legal and management strategies consistent with the envisioned UAM network, and connectivity to other transportation modalities as needed for efficient, "door-to-door" travel, and unplanned landing sites.

Furthermore, as part of the 14 CFR Part 107 rulemaking effort, the FAA selected the American Society for Testing and Materials (ASTM) to establish a set of standards for airworthiness, maintenance, and operation. Understanding safety requirements for UAM, drawing upon the lessons learned from 14 CFR Part 107, will require identifying barriers for additional demands on the NAS. While some of the existing constraints have been documented, detailed analyses are presently unavailable, and the implications on UAM emergence and its penetration are unclear. For example, it is not evident how UAM:

- May impose a demand on additional Air Traffic Control infrastructure, including airspace and workload on controllers?
- May require a new paradigm to integrate with UAS Traffic Management (UTM) and/or Advance Traffic Management (ATM)?
- May impose a demand on regulatory requirements, including standards for airworthiness, certifications for design, maintenance, and operations for vehicle-level and system-level safety and security?
- Will it be resilient to a wide range of disruptions, including weather and localized sub-system failures such as GPS?
- Will it economically scale to high-demand operations with minimal fixed costs?
- Will support user flexibility and decision-making, including demands emanating from emerging UTM?

This research will identify weaknesses and develop a framework to make the standards more robust, and increase the safety of potential UAM operations in the NAS.

APPROACH

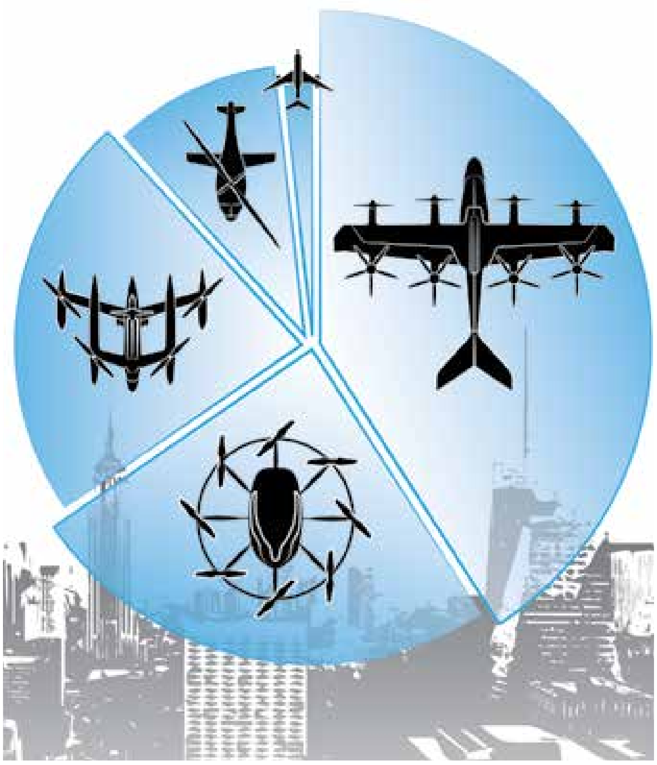
WP 1: Evaluation of UAM Market Potential: Economic Feasibly, Potential Size and Growth, Characteristics of Population, and Ground Infrastructure

UAM is rapidly evolving, providing accelerated mobility for people, goods, and services. Worldwide market projections for various UAM use cases estimate hundreds of billions of dollars in business sales and associated economic activity. Business leaders, policymakers, and public stakeholders all stand to benefit from understanding the economic feasibility of a fully integrated UAM ecosystem.

This research will evaluate the potential market size and growth associated with discrete scenarios of technology and infrastructure investment. The market analyses will evaluate primary and support businesses in key market segments, including an analysis of existing revenue, projected growth, and changes in demand based on various technology and infrastructure investments. The research team has access to ESRI's Business Analyst dataset, featuring more than 12 million businesses classified by North American Industry Classification System code and geographically referenced to a point location. This dataset will be leveraged to conduct the market analysis and visualize the economic findings.

WP 2: Airworthiness regulations and their applicability to UAM aircraft certification

Safety is a fundamental condition for UAM activities to be accepted by regulators, users, and the general public. The use of UAM vehicles for the transport of passengers will strain the certification process since they bring new technical challenges that were not considered within the current regulations. For instance, some of the UAM vehicles might have airworthiness certification requirements that are not addressed by either14 CFR Part 23 (General Aviation Fixed-Wings) or Part 27 (Rotorcraft).



The non-conventional architectures, single or distributed electric propulsion, complex battery systems, autonomous flight, noise, etc.. are some of the challenges these UAM vehicles present; identifying these challenges will provide useful information for certification requirements. Furthermore, due to the broad spectrum of vehicle architecture and propulsion systems, different subcategories might need to be defined within the regulations.

WP 3: Evaluation of UAM integration on the National Aerospace System – Air Traffic Control and Operations

This research task shall investigate the impact of UAM on the NAS as new operations are integrated into either traditional ATM systems and procedures and/or into the UTM framework.

KEY FINDINGS

The research team has identified the following key findings from the literature review and preliminary market analysis:

- UTM is a necessity.
- A large market with high demand exists for UAM services and UAS deliveries.
- The UAM and UAS market come with several infrastructure and regulatory challenges.
- UAM development is a prominent goal internationally.
- Multi-modal interfaces are critical infrastructure for UAM.

NAME & ORIGIN OF RESEARCH PERSONNEL

GERARDO OLIVARES - WSU	UNITED STATES
LUIS GOMEZ - WSU	UNITED STATES
HARSH SHAH - WSU	INDIA
AARON KUENN - WSU	UNITED STATES
HOA LY -WSU	VIETMAN
VINCENT ROBOINSON - WSU	COLOMBIA
GUILLLERMO CARO - WSU	SPAIN
ROHAN DANTULURI - WSU	INDIA
CHRISOPHER BOONE - MSU	UNITED STATES
CHRISTIAN LEE BOWMAN - MSU	UNITED STATES
STEPHEN L FRANCE - MSU	UNITED STATES
CADEN TEER - MSU	UNITED STATES
ALAN MARTINEZ - MSU	UNITED STATES
BOUTEINA DRIOUCHE - MSU	MOROCCO
DANIEL FINDLEY - NCSU	UNITED STATES
EVAN ARNOLD - NCSU	UNITED STATES
JOY DAVIS - NCSU	UNITED STATES
DENNIS CHASE NICHOLAS - NCSU	UNITED STATES
STEVE BERT - NCSU	UNITED STATES
TAO LI - NCSU	CHINA
EMELINE MCCALEB - NCSU	UNITED STATES
MICHAEL PICINICH - NCSU	UNITED STATES
JAMES POSLUSNY - NCSU	UNITED STATES
NUPUR JAIN - NCSU	UNITED STATES
PAYAL UMASHANKAR ASHTANKAR - NCSU	INDIA
CHARLIE CASTILLO - NCSU	UNITED STATES
RYAN HASSETT - NCSU	UNITED STATES
RICHARD STEVEN STANSBURY - ERAU	UNITED STATES
WILLIAM COYNE - ERAU	UNITED STATES
CLYDE RINKINEN - ERAU	UNITED STATES
MAALIYAH BOWDEN -ERAU	UNITED STATES
RANDON SENN - ERAU	UNITED STATES
MYKYTA ZHYLA - ERAU	UKRAINE
FIDJIMATA ISSOUFOU - ERAU	NIGER
NEERAJ NAIK - ERAU	INDIA

GRADUATION OF STUDENTS

DECEMBER 2021	GUILLERMO CARO
DECEMBER 2021	ROHAN DANTULURI
MAY 2023	CHRISTIAN LEE BOWMAN
MAY 2024	MAALIYAH BOWDEN
MAY 2023	RANDON SENN
MAY 2022	MYKYTA ZHYLA
MAY 2021	MICHAEL PICINICH
MAY 2021	JAMES POSLUSNY
MAY 2022	NUPUR JAIN
DECEMBER 2021	PAYAL UMASHANKAR ASHTANKAR
MAY 2022	CHARLIE CASTILLO
MAY 2022	RYAN HASSETT
MAY 2022	RADIMATA ISSOUFOU
MAY 2022	NEERAJ NAIK

UAS STANDARDS TRACKING, MAPPING, AND ANALYSIS

EMBRY-RIDDLE Aeronautical University
LEAD

UND UNIVERSITY OF NORTH DAKOTA

BACKGROUND

Unmanned Aircraft Systems (UAS) technology is evolving rapidly and the FAA is working to keep pace with industry and to integrate UAS into the National Airspace System (NAS). A gap in UAS integration is having standards developed by industry which the FAA can use for policy and rulemaking activity. When all current standards and standards in development are identified and cataloged, research leading to future standards can be identified. The FAA needs to map standards to clearly defined future research projects.

The American National Standards Institute (ANSI) is involved in several ongoing UAS

UAS standards development efforts, including RTCA Special Committee-228, ASTM, SAE, and others. In September 2017, ANSI launched the Unmanned Aircraft Systems Standardization Collaborative (UASSC). The UASSC was established to coordinate and accelerate the development of the standards and conformity assessment programs needed to facilitate the safe integration of UAS into the NAS of the United States, with international coordination and adaptability. The UASSC was not chartered to write standards.

In December 2018, the UASSC published the Standardization Roadmap for Unmanned Aircraft Systems, Version 1.0 ("roadmap"). In it, UASSC identified existing standards and standards in development, assessed gaps, and made recommendations for priority areas where there is a perceived need for additional standardization and/or pre-standardization R&D.

Since standards development is an ongoing work, and there is an urgent need in their development to enable UAS operations in the NAS, in September 2019, UASSC was commissioned to produce version 2.0 of the "roadmap".

APPROACH

Task 1: Literature Review on completed standards mapping describing work completed. Identify industry standards that are needed to support UAS integration.

Task 2: Propose other potential areas of research beyond what is outlined in the tasks. 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. The sponsor, based on other areas identified, will select research that meets the FAA's immediate needs based on the cost estimate.

Task 3: Map ANSI's UAS standards roadmap to the FAA critical path defined in the FAA's UAS Integration Research Plan (UIRP) 2018-2023. Identify research gaps. FAA will provide, to the maximum extent possible, their current standards tracking information. This task will follow the research task plan developed in Task 2.

Task 4: Based on the prior tasks, align standards and gaps with UIRP and ANSI UAS Roadmap, then prioritize the requirements list. Address the following, specifically:

- Identify the immediate standards needed for the FAA to enable operations
- Tie in current, past, and future standards development
- Analyze the standards roadmap developed by ANSI
- Analysis must include International UAS standards

KEY FINDINGS

The team summarizes its key findings as follows:

- It recommends an FAA standards conference to bring stakeholders together from the FAA, industry, and SDOs to identify standards development activities and their research needs.
- Software tools such as a centralized, online searchable repository of standards (past, in development, and planed) would assist FAA stakeholders in identifying standards gaps.
    - -Developing similar tools for standards-focused research tracking is also recommended.
    - -The team developed prototype database tools, but did not support multiple user access.
- Not all standards and critical research gaps are UAS-specific. Some also serve manned aviation as well such as the certification of automation software that employs artificial intelligence.
- Identifying research and research findings conducted by original equipment manufacturers was limited.
- A searchable database is also recommended to track the FAA's past and current UAS standards related research activities expanding upon the worksheet developed by the team to track ASSURE research project information.
- The team recommends that the FAA decompose their proposed future UAS capabilities and subcapabilities further to the subsystem or equipment level to aid in assessing the coverage of existing standards and the identification of standards gaps.
- Research prioritization did not occur during this study because the FAA identified that it would be responsible for developing such prioritization criteria.
- SDO engagement would benefit from a common set of survey / interview questions with tools to ensure consistent data collection.

The team found the following challenges of SDO engagement:

- No two SDOs are the same. There are different stakeholder communities, mission/ value/goals, committee structure, standards tracking methods, schedules, strategic planning, lingo, etc.
- Some standard development efforts are organization driven while others are committee driven.
- Organization-driven efforts tend to have activities tied to long-term plan and have SDO staff members directly engaged with standard activity progress and needs.
- Committee-driven activities can require more direct engagement with committees and/or working groups

- Information provided by SDOs to the team were at varying levels of detail/ completeness.
- Familiarity with the FAA's roadmap for future UAS capabilities within the FAA's UIRP are not widely known among the surveyed SDOs.

NAME & ORIGIN OF RESEARCH PERSONNEL

RICHARD STANSBURY	UNITED STATES
SCOTT BURGESS	UNITED STATES
KRISTINE KIERNAN	UNITED STATES
NEERAJ NIAK	INDIA
FASIJMATA ISSOUFOU	NIGER
KAYLA BOCCUZZO	UNITED STATES
GURVIR BAWA	INDIA
CHANDRA TEJA TIRIVEEDHI	INDIA

GRADUATION OF STUDENTS

CHANDRA TEJA TIRIVEEDHI	DECEMBER 2021
FADIJMATA ISSOUFOU	MAY 2022

UAS CYBER SECURITY AND SAFETY LITERATURE REVIEW

LEAD

BACKGROUND

The FAA manages air traffic control through a complex network of information systems and air traffic control facilities. The FAA is currently modernizing its air traffic control operations through the implementation of the Next Generation Air Transportation System (NextGen) that includes digital communications between controllers and pilots—known as DataComm—and other technologies including satellite-based systems for tracking and managing aircraft. Given this increased reliance on digital systems, rapidly evolving cyber threats from both internal and external sources could threaten the connectivity and operations of an increasingly

increasingly complex aviation infrastructure. Recognizing the need for a cybersecurity strategy and a plan to address the emerging and evolving cyber threats to the National Airspace System (NAS), FAA has initiated steps to develop a comprehensive and strategic cybersecurity framework for FAA's operations.

However, currently, there are no agency guidelines that provide a framework or direction on how to properly assess, identify, and mitigate cybersecurity or safety risks specifically for UAS or related systems as they are integrated into the NAS. The development of a guide or framework will establish cross-organization UAS cybersecurity risk management and complement FAA's efforts for securing NAS.

This is important as the FAA Strategic Plan (2019-2022) forecasts that small UAS (less than 55 lbs) model fleet will more than double in size over the next five years from 1.1 million to over 2.4 million. It also projects that by 2022 small UAS non-model fleet will likely grow to over 450K from the current ~100K units. These increases would lead to a need for significant communication and coordination, and consequently would expose them to significant cyber threat risks.

This literature review will establish baseline information to inform the FAA's approach to cybersecurity issues for UAS and UAS integration into the NAS.

APPROACH

Task 1: Conduct a literature review on cybersecurity and the impact it will have on UAS in the NAS.

This task consists of a review of relevant academic and non-academic literature concerning cybersecurity issues in UAS, UAS interactions within the NAS, and their potential impact. The review will cover the following areas in the development, deployment, and operation of UAS:

- The use-cases and operations of UAS to understand the scope of their deployments and their integration with the NAS.
- Survey to identify common UAS platforms, covering hardware, software (including firmware, operating systems,

middleware etc.) and communication and coordination protocols. This can be useful to highlight the impact of platform choices on extent of attack surface and the cost of attacking them.

- Review of literature (academic and non-academic) concerning cybersecurity issues in UAS (and related/proxy systems) including UAS platforms, UAS interactions within the NAS, and standardization efforts such as the NIST Cybersecurity framework and NIST critical infrastructure cybersecurity framework. The vulnerabilities and directives from the latter might apply to the UAS scenario.
- Survey of approaches for managing and mitigating identified risks and vulnerabilities including review of standards and frameworks like NIST Cybersecurity framework and NIST critical infrastructure cybersecurity framework, and the FAA's cybersecurity framework for NAS.
- Identifying government agencies and other organizations that operate a comparatively large number of UAS in the NAS, as the identified cyber-security risks and surveyed mitigations will affect these agencies more than others.
- Categorizing the findings from the literature review, specifically categorizing the risks emanating from the integration of UAS into the NAS.

Task 2: Other potential cybersecurity research areas

This task will focus on identifying potential areas of research beyond what is outlined in the tasks of this project. Preliminary findings from Task 1 along with a scoping peer review with FAA and other parties determined by FAA will inform this task.

Task 3: Conduct a study to determine the general cyber-security use cases for UAS

As was discussed in Task 1, understanding the different use cases for UAS and their integration into NAS is a critical step in understanding the impact of UAS cybersecurity concerns on NAS. The researchers will build on i) the UAS use cases identified in Task 1, and ii) the cybersecurity vulnerabilities in UAS to develop a preliminary set of general cyber-security use cases for UAS.

Task 4: Identify common risks, impact and mitigations

This task will build on the different preliminary cyber-security uses cases for UAS (from Task 3) to identify the operations in each case and common cyber-security risks to these operations. Further, the results from Task 1 effort reviewing the strategies for cybersecurity mitigations to determine what mitigations can be put in place to manage the identified risks.

KEY FINDINGS

UAS Use cases: UAS use cases from previous ASSURE tasks A2 and A18 were reviewed for applicability to the A38 UAS cybersecurity literature review task. Additional set of use cases were also documented. The overall use case taxonomy generated was appropriate for assessing common markets and approaches, but from a cyber security standpoint, it is common elements related to the planning, operation, command, control, imaging, data, etc. that are the best approach for assessment.

The use cases previously generated were broken down into the flight operation in terms

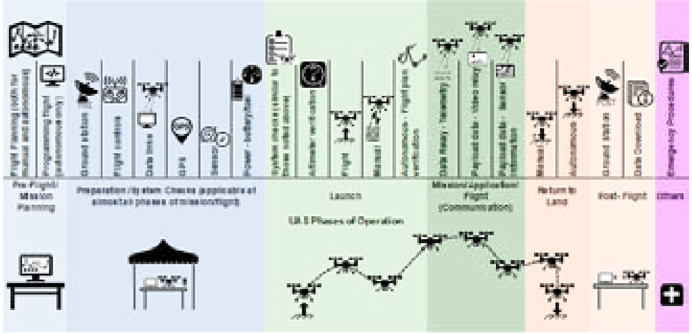


Figure 1. UAS Operation Phases.

of the "muscle movements" for use cases. The flight process for all missions and use cases was presented. This should serve as a starting point to highlight classes of vulnerabilities and points of vulnerability under the broader use case categories. This can serve as a starting point to map specific vulnerabilities to each type of operation and when (timing) in the operation it might be applicable.

Common UAS Platforms: A survey of common UAS platforms comprising the current commercially available small UAS market was performed to identify common sUAS platforms, covering hardware, software (including firmware, operating systems, middleware etc.) and communication and coordination protocols, as well as commercially available components used for construction of sUAS (including flight controllers, processors, actuators, etc.). The rationale for this sub-task was to determine specific vulnerabilities of common UAS platforms and UAS modules and observe whether any patterns of cybersecurity vulnerability emerge when searching a representative sample. Any patterns that emerged can inform threat landscape in terms of scope of vulnerability and magnitude of risk. The team compiled a list of 160 commercially available UAS platforms. It was harder to obtain software/hardware configurations for commercial UAS platforms. So the team also investigated modular components used for building UAS. Key modular components included flight controllers (both PixHawk based and Non-PixHawk based), GPS modules, etc.

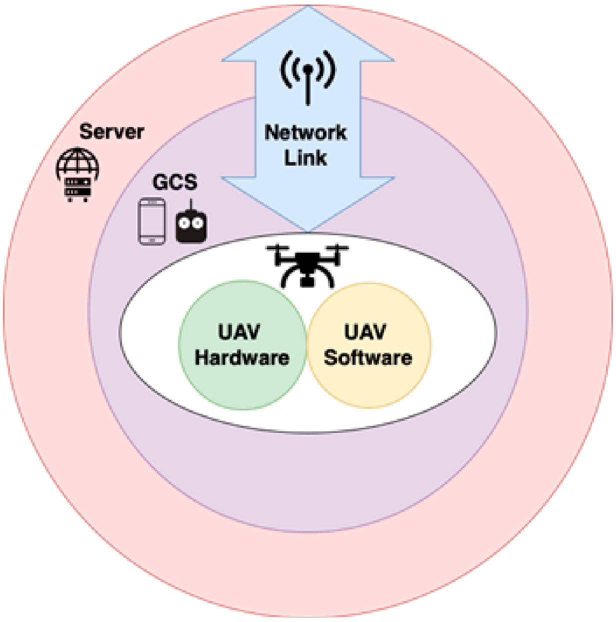


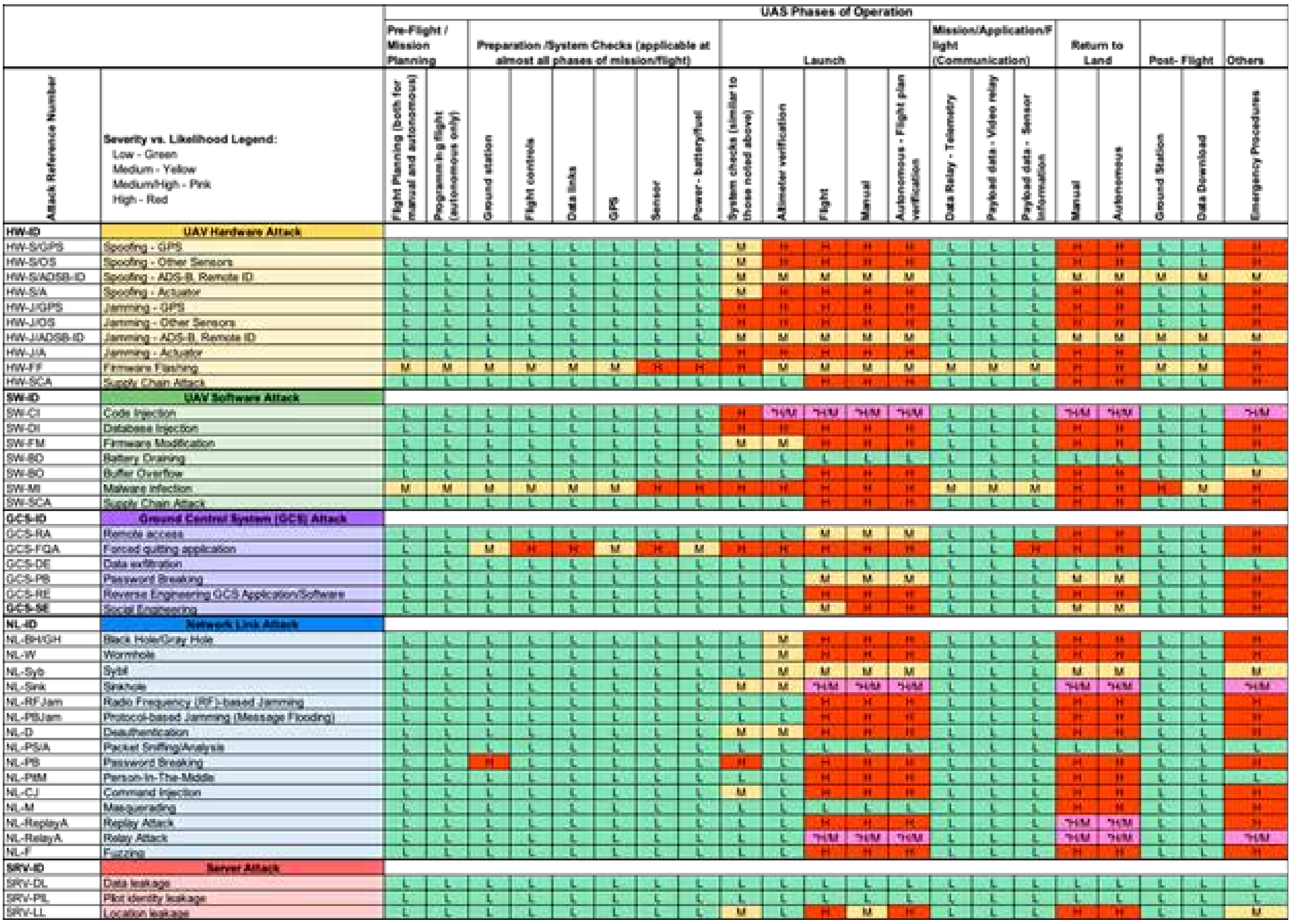
Figure 2. UAS Components.

Literature Review: The team gathered a corpus of 1294 papers from key technical databases (using a three-stage refining process. In stage 1, the team used automated software (web crawlers or REST API interfaces) to search the technical databases using selected key-words and collected more than 25000 papers. In stage 2, the team whittled this initial wide-net corpus to about 6833 papers by prioritizing papers with more key-word pair matches and hence the more relevant ones and reviewed their abstracts for relevance. The team ended up with 1294 papers for a more detailed review in stage 3. The team was able to complete a full detailed review of 550 papers in stage 3 within the project time constraints.

Through this detailed review of nearly 550 academic articles, the team identified 41 potential cybersecurity threats to UAS and categorized them into five groups corresponding to the five main components in a UAS ecosystem, namely, UAS (or UAV) hardware (including sensors), UAS software (including firmware), Network, Ground Control Station, and Cloud/Server backend (for Internet connected UAS).

Cybersecurity Risk Assessment for UAS Operations: The team also took the first steps towards cyber risk assessment by performing a preliminary risk assessment for each phase of UAS operation from the 41 identified potential cybersecurity threats using FAA's Safety Management System (SMS) framework (see Figure 3).

Cybersecurity Threats to UAS Use Cases and Potential Mitigations: For assessing the cybersecurity threats to these use cases the team organized them into eight categories using three attributes, namely, autonomy, operational range and UAS collaboration, and identified relevant cyber threats to these use case groups. The project team also identified mitigative measures against the identified threats through both literature review (see Figure 4) and a preliminary review of NIST standards (See Table 1).



		UAS Phases of Operation																				
		Pre-Flight / Mission Planning		Preparation /System Checks (applicable at almost all phases of mission/flight)						Launch					Mission/Application/Flight (Communication)			Return to Land		Post- Flight		Others
Attack Reference Number	Severity vs. Likelihood Legend: Low - Green Medium - Yellow Medium/High - Pink High - Red	Flight Planning (both for manual and autonomous)	Programming flight (autonomous only)	Ground station	Flight controls	Data links	GPS	Sensor	Power - battery/fuel	System checks (similar to those noted above)	Altimeter verification	Flight	Manual	Autonomous - Flight plan verification	Data Relay - Telemetry	Payload data - Video relay	Payload data - Sensor information	Manual	Autonomous	Ground Station	Data Download	Emergency Procedures
HW-ID	UAV Hardware Attack																					
HW-S/GPS	Spoofing - GPS	L	L	L	L	L	L	L	L	M	H	H	H	H	L	L	L	H	H	L	L	H
HW-S/OS	Spoofing - Other Sensors	L	L	L	L	L	L	L	L	M	H	H	H	H	L	L	L	H	H	L	L	H
HW-S/ADSB-ID	Spoofing - ADS-B, Remote ID	L	L	L	L	L	L	L	L	M	M	M	M	M	L	L	L	M	M	M	M	M
HW-S/A	Spoofing - Actuator	L	L	L	L	L	L	L	L	M	H	H	H	H	L	L	L	H	H	L	L	H
HW-J/GPS	Jamming - GPS	L	L	L	L	L	L	L	L	H	H	H	H	H	L	L	L	H	H	L	L	H
HW-J/OS	Jamming - Other Sensors	L	L	L	L	L	L	L	L	H	H	H	H	H	L	L	L	H	H	L	L	H
HW-J/ADSB-ID	Jamming - ADS-B, Remote ID	L	L	L	L	L	L	L	L	M	M	M	M	M	L	L	L	M	M	M	M	M
HW-J/A	Jamming - Actuator	L	L	L	L	L	L	L	L	H	H	H	H	H	L	L	L	H	H	L	L	H
HW-FF	Firmware Flashing	M	M	M	M	M	M	H	H	H	M	M	M	M	M	M	M	H	H	M	M	H
HW-SCA	Supply Chain Attack	L	L	L	L	L	L	L	L	L	L	H	H	H	L	L	L	H	H	L	L	H
SW-ID	UAV Software Attack																					
SW-CI	Code Injection	L	L	L	L	L	L	L	L	H	*H/M	*H/M	*H/M	*H/M	L	L	L	*H/M	*H/M	L	L	*H/M
SW-DI	Database Injection	L	L	L	L	L	L	L	L	H	H	H	H	H	L	L	L	H	H	L	L	H
SW-FM	Firmware Modification	L	L	L	L	L	L	L	L	M	M	H	H	H	L	L	L	H	H	L	L	H
SW-BD	Battery Draining	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
SW-BO	Buffer Overflow	L	L	L	L	L	L	L	L	L	L	H	H	H	L	L	L	H	H	L	L	M
SW-MI	Malware infection	M	M	M	M	M	M	H	H	H	H	H	H	H	M	M	M	H	H	H	M	H
SW-SCA	Supply Chain Attack	L	L	L	L	L	L	L	L	L	L	H	H	H	L	L	L	H	H	L	L	H
GCS-ID	Ground Control System (GCS) Attack																					
GCS-RA	Remote access	L	L	L	L	L	L	L	L	L	L	M	M	M	L	L	L	H	H	L	L	H
GCS-FQA	Forced quitting application	L	L	M	H	H	M	H	M	H	H	H	H	H	L	L	H	H	H	L	L	H
GCS-DE	Data exfiltration	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
GCS-PB	Password Breaking	L	L	L	L	L	L	L	L	L	L	M	M	M	L	L	L	M	M	L	L	H
GCS-RE	Reverse Engineering GCS Application/Software	L	L	L	L	L	L	L	L	L	L	H	H	H	L	L	L	H	H	L	L	H
GCS-SE	Social Engineering	L	L	L	L	L	L	L	L	L	L	M	H	H	L	L	L	M	M	L	L	H
NL-ID	Network Link Attack																					
NL-BH/GH	Black Hole/Gray Hole	L	L	L	L	L	L	L	L	L	M	H	H	H	L	L	L	H	H	L	L	H
NL-W	Wormhole	L	L	L	L	L	L	L	L	L	M	H	H	H	L	L	L	H	H	L	L	H
NL-Syb	Sybil	L	L	L	L	L	L	L	L	L	M	M	M	M	L	L	L	M	M	L	L	M
NL-Sink	Sinkhole	L	L	L	L	L	L	L	L	M	M	*H/M	*H/M	*H/M	L	L	L	*H/M	*H/M	L	L	*H/M
NL-RFJam	Radio Frequency (RF)-based Jamming	L	L	L	L	L	L	L	L	L	L	H	H	H	L	L	L	H	H	L	L	H
NL-PBJam	Protocol-based Jamming (Message Flooding)	L	L	L	L	L	L	L	L	L	L	H	H	H	L	L	L	H	H	L	L	H
NL-D	Deauthentication	L	L	L	L	L	L	L	L	M	M	H	H	H	L	L	L	H	H	L	L	H
NL-PS/A	Packet Sniffing/Analysis	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
NL-PB	Password Breaking	L	L	H	L	L	L	L	L	H	L	H	H	H	L	L	L	H	H	L	L	H
NL-PitM	Person-In-The-Middle	L	L	L	L	L	L	L	L	L	L	H	H	H	L	L	L	H	H	L	L	L
NL-CJ	Command Injection	L	L	L	L	L	L	L	L	M	L	H	H	H	L	L	L	H	H	L	L	H
NL-M	Masquerading	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	H	H	L	L	H
NL-ReplayA	Replay Attack	L	L	L	L	L	L	L	L	L	L	H	H	H	L	L	L	*H/M	*H/M	L	L	H
NL-RelayA	Relay Attack	L	L	L	L	L	L	L	L	L	L	*H/M	*H/M	*H/M	L	L	L	*H/M	*H/M	L	L	*H/M
NL-F	Fuzzing	L	L	L	L	L	L	L	L	L	L	H	H	H	L	L	L	H	H	L	L	H
SRV-ID	Server Attack																					
SRV-DL	Data leakage	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
SRV-PIL	Pilot identity leakage	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
SRV-LL	Location leakage	L	L	L	L	L	L	L	L	M	L	H	M	H	L	L	L	H	H	L	L	M

Figure 3. Attack Type and Likelihood vs. Severity by UAS Operational Phases.

Table 1. Attacks, Frameworks, and Mitigation Strategies.

Attack Reference	Framework	Mitigation Strategy
		UAV Hardware Attack
HW-S/*	NISTIR 8323	Identity verficiation, data verification, and validation of Positioning, Navigation, and Timing components
HW-J/*	NISTIR 8323	Software and hardware can be integrated into the system and critical infrastructure componets to detect and mitigate GNSS jamming and spoofing events and preserve data availability, continuity, and integrity.
HW-FF	NIST SP 800-193	Firmware update images should be signed using an approved digital signature algorithm. The flash regions that contain device firmware should be protected so that it is modifiable only through an authenticated update mechanism to ensure the authenticity and integrity of the firmware update. The protection mechanisms shall ensure that authenticated update mechanisms are not bypassed. If Critical Platform Firmware uses RAM for temporary data storage, then this memory shall be protected from software running on the Platform until the data's use is complete.
HW-SCA	NIST SP 800-161	Establish an organization governance structure that ICT SCRM requirements and incorporates these requirements into the organizational policies. Perform internal checks and balances to assure compliance with security and quality requirements.
		UAV Software Attack
SW-CI	NIST SP 800-44	Use secure programming practices and maintain secure configuration through application. Software, OS, web servers, firewalls, packet filtering routers and proxy should be periodically scanned for vulnerability
SW-DI	NISTIR 7682	Check the values in every field of a web form, looking for any characters that should not be in that type of data, and looking for patterns that look like database commands. Monitor the logs of the database server, looking for anomalous queries coming from the web server.
SW-FM	NIST SP 800-147	Use digital signatures for secure BIOS authentication. Authenticated BISO update mechanism should be an exclusive mechanism for modification of system BIOS with proper authentication mechanism.
SW-BD	NIST SP 800-53	Use an Uninterruptible Power Supply (UPS) that provides emergency power when there is a failure of the main power source. The battery duration of most UPS is short but provides sufficient time to start a standby power source such as a backup generator or properly shut down the system or perform emergency procedures.
SW-BO	NIST SP 800-218	Collect, protect, and regularly check provenance data for all software deployed in each environment, and determine if any of the software or their dependencies have new known vulnerabilities. Review and approve all changes made to the code after the code has been automatically scanned for vulnerabilities and any issues have been remediated. Periodically scan the software for buffer overflow flaws. Review and evaluate third-party software components in the context of their expected use.

Attack Reference	Framework	Mitigation Strategy
SW-MI	NISTIR SP 800-83	Scanning of media from outside of the organization for malware before they can be used. Restricting or prohibiting the use of unnecessary software, such as user applications that are often used to transfer malware. Using security automation technologies with OS and application configuration checklists to help administrators secure hosts consistently and effectively.
SW-CI	NISTIR SP 800-161	Similar to HW-SCA
		Ground Control System (GCS) Attack
GCS-RA	NIST SP 800-53	Employ automated mechanisms to facilitate the monitoring and control of remote access methods. Uses encryption to protect the confidentiality of remote access sessions.
GCS-FQA	NIST Special Publication 800-83	Use antivirus software, intrusion prevention software, firewall, content filtering/inspection and application whitelisting.
GCS-DE	ICS Advisory (ICSA-19-015-01)	Minimize network exposure for all control system devices and/or systems and ensure that they are not accessible from the Internet.
GCS-PB	NIST SP 800-53	Use secure passwords and passphrase. Passwords should have minimum length and be followed by either biometric authentication or two factor authentication. Stored passwords should be using an approved salted key derivate function, preferably a keyed hash.
GCS-RE	NIST CYBERSECURITY WHITE PAPER on Mitigating the Risk of Software Vulnerabilities by Adopting a Secure Software Development Framework (SSDF)	Perform peer review of code, to check code for backdoors and other malicious content. Use automated tools to identify and remediate documented and verified unsafe software practices on a continuous basis as human-readable code is checked into the code repository.
GCS-SE	NIST Special Publication 800-63B	Avoid use of authenticators that present a risk of social engineering of third parties such as customer service agents.
		Network Link Attack
NL-BH/GH	NIST Special Publication 800-189	Monitor the rate of queries/requests per source address and detect if an abnormally high volume of responses is headed to the same destination (i.e., same IP address).
NL-W	NIST SP 800-189	Similar to NL-BL/GH
NL-Syb	NISTIR 8301	Sybil attack resistance is achieved, respectively, through built-in crypto economic incentives that enable nodes to work together in zero-trust environments and through access control, wherein nodes must be authorized by system owners or consortium members.

Attack Reference	Framework	Mitigation Strategy
NL-Sink	NIST Special Publication 800-83	Different situations necessitate various combinations of eradication techniques. The most common tools for eradication are antivirus software, spyware detection and removal utilities, and patch management software. Providing instructions and software updates to users works in some cases.
NL-RFJa	NISTIR 8323	Similar to HW-J/*
NL-PBJa	NISTIR 8301	Similar to HW-J/*
NL-D	NIST Interagency report 7316	Use an access control list and access control matrix. Implement Separation of duty (SOD) where no user should be given enough privileges to misuse the system.
NL-PS/A	NIST Special Publication 800-83	Use antivirus, firewalls, application whitelisting sandboxing techniques. Eliminating unsecured file shares, which are a common way for malware to spread.
NL-PB	NIST Special Publication 800-63B	Use an authenticator with high entropy authenticator secret. Store memorized secrets in a salted, hashed form including a keyed hash.
NL-PitM	NIST Special Publication 800-63B	Communication between the claimant and verifier should be via an authenticated protected channel to provide confidentiality of the authenticator output.
NL-M	NIST SP 800-123	Remove or disable unneeded default accounts, disable non interactive accounts. Create user groups, configure automated time synchronization. Implement strong organization password policy.
NL-ReplayA	NIST SP 800-63-3	Use nonce that is used as challenge in challenge-response authentication protocol that are not repeated.
NL-RelayA	NIST CVE-2017-12819	Locate control system networks and remote devices behind firewalls and isolate them from the business network. When remote access is required, use secure methods, such as Virtual Private Networks (VPNs), recognizing that VPNs may have vulnerabilities and should be updated to the most current version available.
NL-F	NISTIR 8397, NIST SP 800-95, and NIST SP 800-53B	A type of dynamic analysis, known as fuzz testing, induces program failures by deliberately introducing malformed or random data into software programs. Fuzz testing strategies are derived from the intended use of applications and the functional and design specifications for the applications. To understand the scope of dynamic code analysis and the assurance provided, organizations may also consider conducting code coverage analysis and/or concordance analysis.
		Server Attack
SRV-DL	ICS Advisory (ICSA-19-015-01)	Similar to GCS-DE
SRV-PIL	NIST Special Publication 800-63A	Use a Credential Service Provider (CSP) that validates personal details in the evidence with the issuer or other authoritative source. It verifies identity evidence and biometric of applicant against information obtained from issuer or other authoritative source.
SRV-LL	ICS Advisory (ICSA-19-015-01)	Similar to GCS-DE

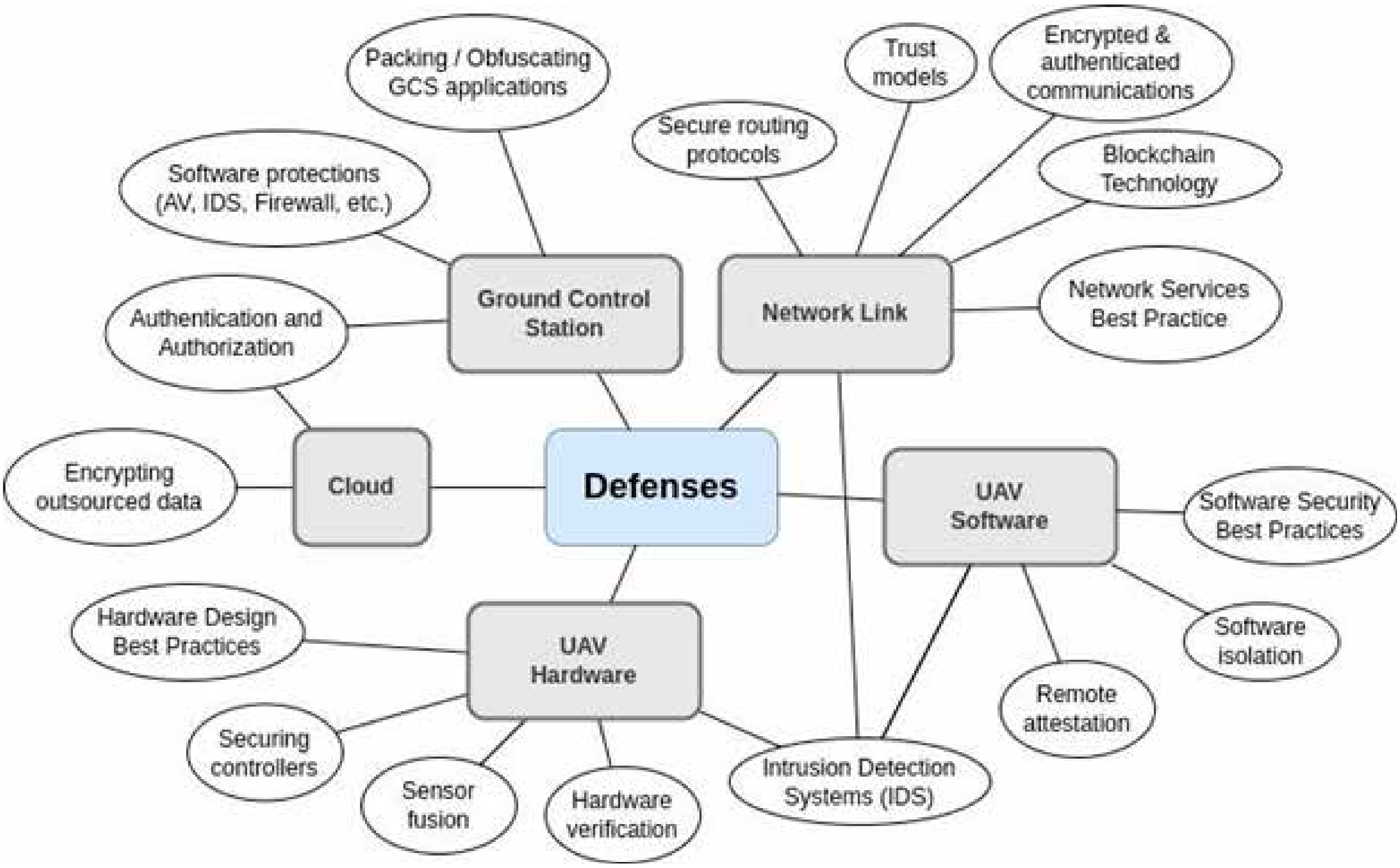


Figure 4. Defense Strategies for UAS.

While the project covered a lot of ground in a short amount of time, the assessment of cybersecurity risks and the identification of mitigation measures is necessarily preliminary and needs to be treated as such. A more thorough and detailed assessment of cybersecurity risks and their impact needs to be undertaken to help FAA better manage the risks associated with integration of UAS.

NAME & ORIGIN OF RESEARCH PERSONNEL

RAKESH BOBBA	UNITED STATES (INDIA)
YEONGJIN JANG	REPUBLIC OF KOREA
HOUSSAM ABBAS	UNITED STATES (LEBANON)
JULIE ADAMS	UNITED STATES
MATTHEW JANSEN	UNITED STATES
JINHONG CHOI	REPUBLIC OF KOREA
LENI HALAAPIAPI	UNITED STATES
CHRISTINE BRECKENRIDGE	UNITED STATES
RICHARD PALPHREY	UNITED STATES
NIRAJ BASNET	UNITED STATES
CONNOR KURTZ	UNITED STATES
HENRY CATHEY	UNITED STATES
SATYAJAYANT MISRA	UNITED STATES (INDIA)
ROOPA VISWANATHAN	INDIA
MOHAMMED ABABNEH	JORDAN
SHARAD SHRESTHA	NEPAL
JOE VACEK	UNITED STATES
PAUL SNYDER	UNITED STATES
NAIMA KAABOUCH	UNITED STATES
AMANDA BRANDT	UNITED STATES
DAVID HERTZ	UNITED STATES

GRADUATION OF STUDENTS

NIRAJ BASNET	FALL 2020
CONNOR KURTZ	SPRING 2021

VALIDATION OF ASTM REMOTE IDENTIFICATION STANDARDS

LEAD

BACKGROUND

The Unmanned Aircraft System Safety Research Facility's (UASSRF)'s work will be used exclusively by the FAA to demonstrate whether Unmanned Aircraft Systems (UAS) Remote Identification Broadcast (RID-Broadcast) standards can meet the intent to satisfy cooperative Detect and Avoid for sUAS to sUAS encounters. This task will also assess how UAS RID-Broadcast standards may satisfy stakeholder needs and policy decisions. This work will provide the FAA with information necessary to develop rules and policy related to UAS RID. This work will be used to develop preliminary, internal, FAA documents to support standards development, policy

decisions, and/or rulemaking.

The establishment of safe Detect and Avoid performance for sUAS-to-sUAS encounters is intended to support safe Beyond Visual Line of Sight (BVLOS) operations of UAS in the national airspace system.

APPROACH

Baseline performance (range, reliability, accuracy, impact of environmental factors) of RID-Broadcast equipment (Wi-Fi, Bluetooth 4 and Bluetooth 5) will be evaluated through simulation, demonstration, and analysis to determine the expected reliable performance range of such systems in airborne applications.

Task 1: Program Management

The UASSRF will manage this eddort to ensure all tasks are in alignment with the tasks. The UASSRF will coordinate with the FAA through Program Management Reviews, Technology Interchange Meetings, interim reports, e-mails, and telephone meetings as appropriate to ensure the research validation objectives are being met.

Task 2: Literature Review (Completed)

The UASSRF conducted a literature review of the FAA Notice of Proposed Rulemaking for UAS Remote Identification/RID Rule, the ASTM Remote Identification standard, academic/industry sources, publicly available information online, and other available sources. The literature review identified and documented RID stakeholders and their associated needs from RID broadcasts and also identified potential expanded uses of RID-Broadcast technologies and their stakeholders not listed in the NPRM/RID Rule.

Task 3: Simulation, Demonstration, and Analysis Plan (Completed)

Task three involved:

- Remote ID Assessment
- Flight Test Plan
- Data Collection and Analysis
- Draft Simulation, Demonstration, and Analysis Plan Peer Review Meeting
- Final Simulation, Demonstration, and Analysis Plan

Task 4: Simulaltion, Demonstration, and Analysis Plan Execution (Completed)

Task 4 involved comprehensive reports from simulation, assessments, testing, demonstrations, and analysis.

Task 5: Final Report Package and Briefing (In Progress)
The UASSRF will summarize and aggregate the plans, results and reports executed during this task into a final report for the overall effort. Conclusions and findings will be mapped to project objectives and clear identification and explanations will be provided when research objectives were not satisfied by the activities undertaken.

KEY FINDINGS

The UASSRF completed a multitude of tests within the past year using three different remote ID systems. Range tests were conducted with the Parrot ANAFI (WiFi Beacon), Dronetag Mini Production Model (Bluetooth), and Aerobits idME (Bluetooth). The Dronetag Bluetooth module underwent a series of range tests to explore the difference in performance when an external antenna is added to the module. Additionally, the Dronetag Bluetooth module was tested at lower horizontal ranges. These tests were performed at the minimum rate and power level provided in the ASTM RID standard. Analysis of these results show range limitations of the WiFi systems when compared to the performance of the Bluetooth systems. There were also noticeable trends in the decrease of the number of messages received as ranges near 1000m. Researchers have repeatably seen a decrease around 700m when using the external Bluetooth module.

A directionality test was performed on the Dronetag module to determine the impact, if any, orientation may have on the reception rate. The Dronetag module was placed on an sUAS and oriented at true North, South, East, and West, and changed in increments of 9 degrees between each cardinal direction.

A range test in an altered RF environment was recently conducted to determine the impact the RF noise floor may have on a Bluetooth RID system. For this test, data was collected at three different distances over a period of time in which it was predicted that the RF environment would degrade.

The final test accomplished under the A40 effort was a series of encounters between a manned aircraft and an sUAS equipped RID. This test was broken down into two separate tests. The first was a series of “ground encounters” where a manned aircraft with an RID receiver was stationary on the ground while the drone flew a series of paths above the aircraft. The second test was a series of “air encounters” in which the drone hovered at 400 feet above ground level while an aircraft flew a series of paths above it at an altitude of 1000 feet. This test was conducted with both the Bluetooth and WiFi Beacon systems. The data for this test is currently being analyzed, but initial results have shown potential degradation in the performance of the systems during the air-based encounters as well as a decrease in the performance for the WiFi system during the ground-based encounters.

The UASSRF is currently organizing and analyzing all data from the tests for further analysis. In addition, the final report process has begun as the team starts to draw conclusions from the analyzed data. The final report is expected to be submitted by the end of 2022.

NAME & ORIGIN OF RESEARCH PERSONNEL

CADEN TEER	UNITED STATES
DYLAN AMERSON	UNITED STATES
AUDREY THOMPSON	UNITED STATES
LINDA ARNOLDUS	UNITED STATES

GRADUATION OF STUDENTS

MAJKA WILCZYNSKI	SPRING 2021
MEGAN PATRICK	FALL 2021

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

Kansas State University
LEAD

University of Alaska Fairbanks

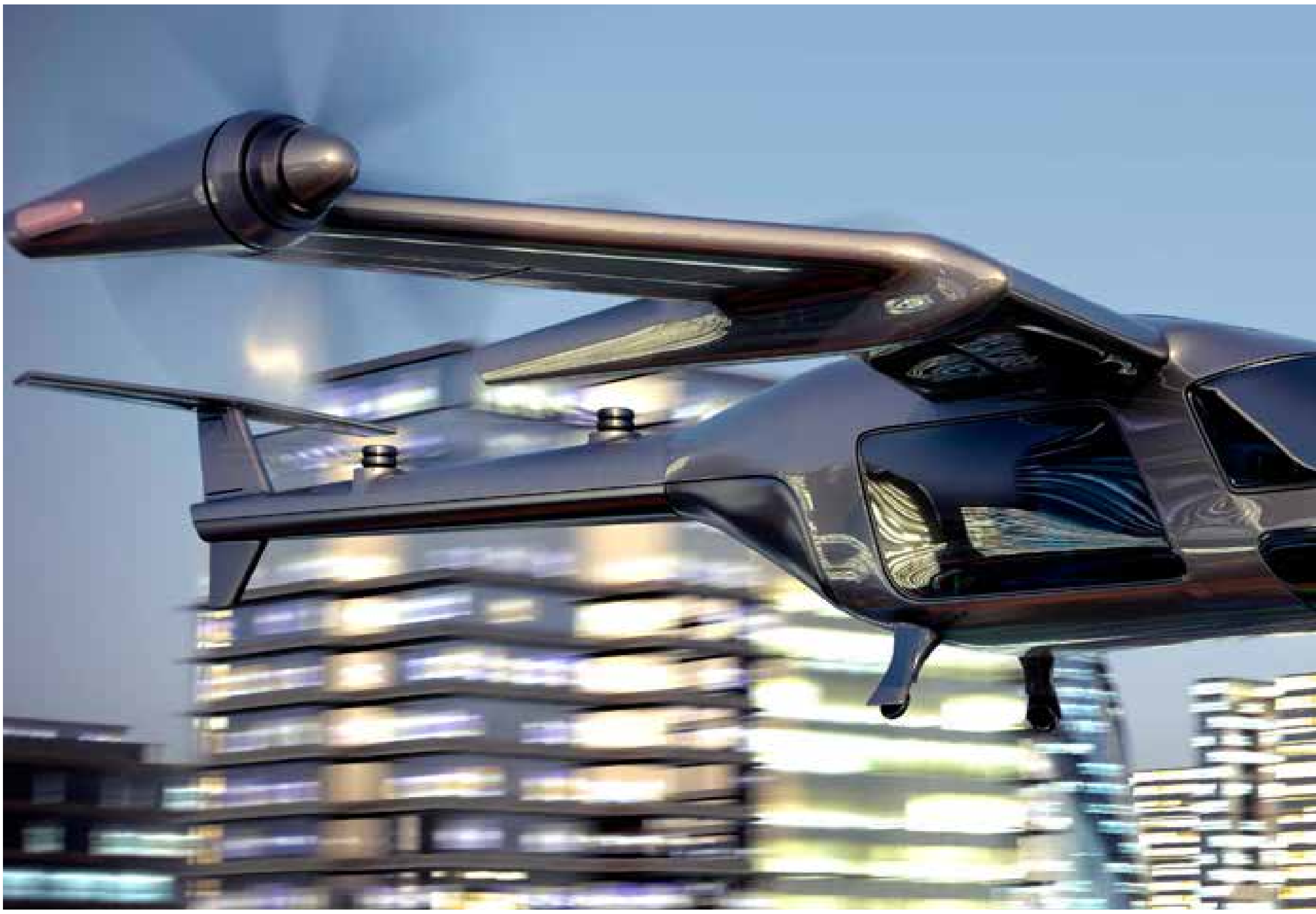
NC State University

The Ohio State University

University of North Dakota

BACKGROUND

It is anticipated that Urban Air Mobility (UAM) or autonomous UAS will 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. Presently, federal agencies operate larger UAS operate within the NAS, including the Departments of Defense (DoD), Homeland Security (DHS), Interior (DOI), Energy (DOE), Agriculture, NASA, some state and local governments, and academia. While some departments require Certificates of Authorization (COAs) lasting two years, others



have their own self-certification for authorizations, e.g., DoD and Customs and Border Patrol (CBP). While defense and civilian agencies are already using large UAS in the National Airspace System (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 transportation of cargo and passengers. Continued safe integration of UAS is essential, and the FAA is taking a proactive approach in understanding trends, identifying potential markets, and forecasting the integrations of large UAS in the NAS. The FAA uses these forecasts for safety and investment analysis along with workload planning.

Recent experiments of UAM combined with the fact that certain types of operators fly large UAS in the NAS today, lead us to anticipate that large UAS will facilitate air transportation in the future. New and additional procedures, airspace rules, and equipment standards including their performances and reliability will be needed 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 is essential to:

- Understand key differences with existing commercial air carrier and charter operators and trends in large UAS, particularly with a focus to understand its role in transporting passengers, both scheduled and unscheduled routine operations in short haul (UAM) and longer haul (autonomous UAS),
- Forecasting 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,
- Consideration of 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 ATC-serviced airspaces (i.e., G, D, E, A, B, and C) in the future,
- Understand 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); understand also how changes in these may facilitate regulatory initiatives; Understand safety risk management requirements emanating from these integrations,
- Provide projection of additional workforce required at towers and/or TRACON because of these anticipated changes and implications on airspace requirements including procedures and regulations; and
- Provide physical infrastructure requirements, e.g., airport redesign, vertiport, etc., to accommodate this new mode of air transportation.

To address these issues, the FAA needs an approach to forecast large (>55lb) commercial aircraft growth into the higher non-segregated altitudes (e.g., above 400ft AGL), with special emphasis on the use of these UAS in transportation of passengers. The approach (i.e., modeling and simulation of airspaces) along with 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, this effort will inform future regulatory updates to UAS right-of-way rules, DAA performance standards, and collision avoidance standards.

APPROACH

Task 1: Literature Review and Market Analysis

The research team conducted a literature review and market analysis aimed at addressing the research questions. The literature review focused on technical requirements of 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 literature review, market analysis, and related recommendations for this study should were based upon lessons learned from prior research including NASA-sponsored studies. Additionally, the market analysis explores questions of market demand, observe/predict trends, and determine impacts relating to the integration of UAM into both existing and potentially novel infrastructure.

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

Task 2: Use Case Development

Using outputs from the literature review and market analysis, the research team determined the scope of use cases such that they were (1) representative of applicable market and technical trends for UAM, and (2) allowed the team to complete research tasks within the allotted period of performance. This task also enabled the research team to focus the scope on specific topics of interest that arose from the literature review and/or market analysis.

Task 3: Experiment Plan

The development of an experiment plan as part of this task informed research activities within subsequent tasks. The experimental plan identified the key issues in each use case from Task 2 and described experiments to quantify the effects of those factors on the specific use cases. Experimental methods consist of (1) interviews with AAM Original Equipment Manufacturers (OEMs) to identify their perceptions and challenges with brining a system to market, and (2) a survey of the "flying public" to gather perceptions about willingness to pay and willingness to use AAM vehicles. These experimental methods align with research goals and support follow-on tasks, such as Task 5 – Economic Assessment and Methodology. The research team may potentially use findings from these experiments to independently validate findings from Task 5.

Task 4: Conduct Designed Experiments

This task consists of performing experiments in accordance with the plan developed as part of Task 3. As part of this task, the team seeks to answer key research questions framed within Tasks 1 and 2 in a manner that follows the experiment plan from the previous task. This task is currently in progress.

Task 5: Economic Assessment and Methodology

In addition to research tasks associated with Task 4, the performer devised a methodology for assessing the economic impact of UAM and unmanned passenger transport. The economic assessment methodology devised as part of this task took input from key research findings from Task 1. A key output of this task incorporated supporting data considering direct, indirect, and induced benefits of UAM and unmanned passenger transport.

KEY FINDINGS

Task 1: Literature Review and Market Analysis – Key Findings

- Primary considerations for unmanned air transport fall into the following categories:
    - Airspace considerations,
    - Regulatory considerations,
    - Automation,
    - Airman certification and training,
    - Design and airworthiness,
    - Unmanned Traffic Management (UTM), and
    - Economic considerations.
- **Airspace** – Traffic management will require changes to the airspace.
- **Regulatory considerations** – The current regulatory framework will require updates to accommodate innovative 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 (SVO), moving to remote operation, and ending with full automation.
- **Airman certification and training** – Airman certification and training must accommodate shifts in trends towards 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.
- Economic Considerations
    - 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 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.

- 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 as well (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.

Task 2: Use Case Development – Key Findings:

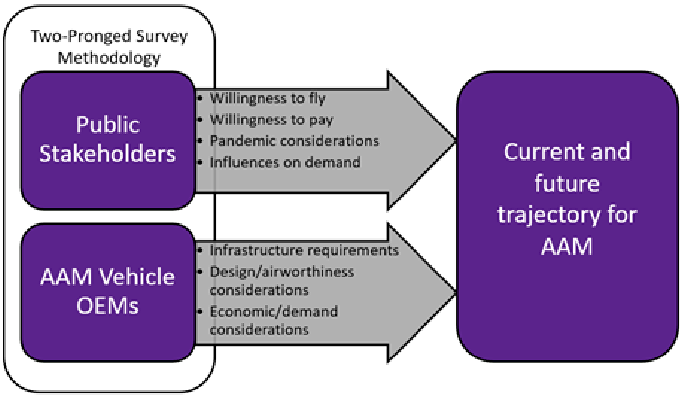
Use Case Development consisted of an assessment of the market analysis from Task 1-2 and identifying the most prominent use cases for further exploration in following tasks. The data from Task 1-2 highlighted the following use cases as having the largest market shares, and thus, warranted deeper investigation for this project:

1. Air Taxi (37.8% of projected AAM market share)
2. Regional Air Mobility (RAM) (27.0% of projected AAM market share)

The research team completed additional descriptions of use cases and detailed use case scoping within the experiment plan as part of Task 3. This ensured the research plan captured the use cases and ensured that any experiments, surveys, or economic assessments were properly defined and scoped.

Task 3: Experiment Plan – Key Findings:

The experiment plan drafted for Task 3 captured details from Tasks 1 – 2, including a focus on economic considerations and use cases the research team identified in previous tasks. The experiment plan described a methodology related to (1) the market analysis, and (2) use cases for air taxi and RAM as identified in detailed use case descriptions. The experiment plan captured the experiment design, consisting of an interview and survey element. The interview element identified AAM OEM perspectives on the development of their systems, and the survey element targeted the general public's willingness to pay/fly under given circumstances.



The outputs from this task informed Task 4 - ConductDesigned Experiments and Task 5 - Economic Assessment and Methodology. A key output of this task was the research team securing six interviews with AAM OEMs at an

Task 4: Conduct Designed Experiments – Key Findings:

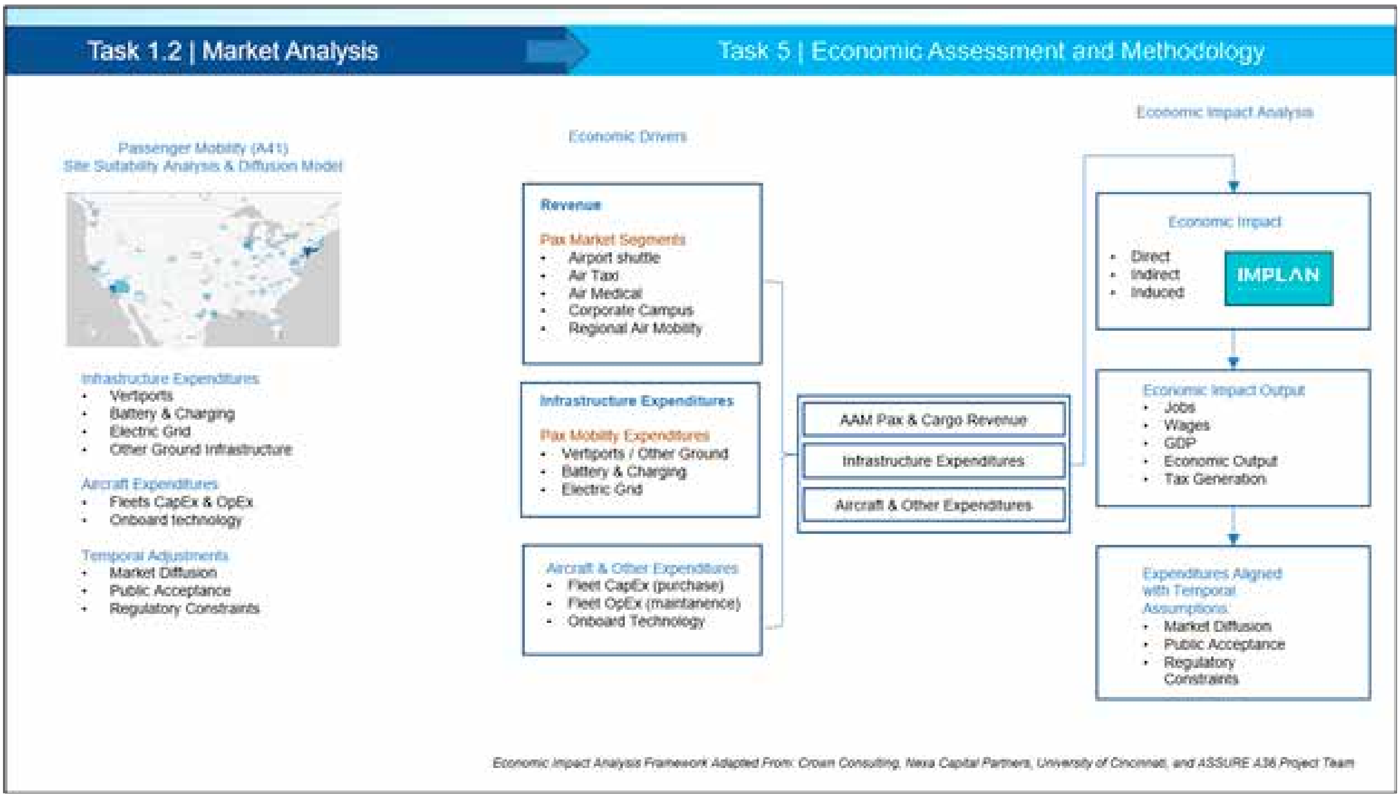
This task is still ongoing at the time of this report. The research team has collected six interviews from prominent AAM OEMs and is in the process of securing the services of a survey company to obtain a panel of 5,000 respondents for a survey on AAM usage, cost, and public perception.

Task 5: Economic Assessment and Methodology – Key Findings:

Findings from the economic assessment and methodology identified a projected path for the growth and development of AAM (work plan), and it outlined an economic assessment framework that highlighted key considerations and focus areas for AAM growth, as shown in the graphic below.

The economic assessment used IMPLAN to generate direct, indirect, and induced impacts for AAM. These impacts included jobs, wages, economic output, and expenditures on infrastructure, fleet growth, and other elements of AAM. Some key findings of Task 5 include:

- An estimated 390M to 660M AAM passenger trips between 2022 and 2045. This includes potential direct impacts of $54.4 - $90.6B in AAM passenger flight sales.
- Estimates of a direct impact of $35.B - $5.9B in VTOL purchase and maintenance expenditures between now and 2045, with fleet purchases and maintenance having a substantial economic impact.
- Projected estimates show between 650 and 1,090 vertiports in operation between now and 2045. Expenditures on vertiport construction and maintenance are expected to represent a direct impact of $31.B - $5.2B.



Economic Impact Analysis Framework Adapted From: Crown Consulting, Nexa Capital Partners, University of Cincinnati, and ASSURE A36 Project Team

The research team will include an in-depth analysis of the economic assessment and methodology in the project's final report. This will include any relevant appendices and data generated as part of Task 5.

NAME & ORIGIN OF RESEARCH PERSONNEL

TOM HARITOS - KSU	UNITED STATES
KURT CARRAWAY - KSU	UNITED STATES
TIM BRUNER - KSU	UNITED STATES
KATIE SILAS - KSU	UNITED STATES
RAJAGOPAL SUGUMAR - KSU	UNITED STATES
CATHERINE CAHILL - UAF	UNITED STATES
EVAN ARNOLD - NCSU	UNITED STATES
MATT MCCRINK - OSU	UNITED STATES
MARK JOHNSON - UND	UNITED STATES

GRADUATION OF STUDENTS

MICHAEL KERR	2025

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

LEAD

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.

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.

Recently, the FAA has issued two Part 135 certifications. UPS Flight Forward, Inc., a participant in the IPP, became the first company to receive a Standard Part 135 air carrier certificate to operate a drone aircraft to deliver packages by drone with its Part 135 certification. On September 27, 2019, it flew medical supplies at WakeMed's hospital campus in Raleigh, NC. The FAA also issued a Part 135 Single pilot air carrier certificate for drone operations to Wing Aviation, LLC in April 2019. On Oct. 18, 2019, Wing delivered packages, over-the-counter medication, snacks, and gifts to residents of Christiansburg, Virginia.

These three future trends, 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 researchers anticipate 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 unmanned 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 (i.e., 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

Task 1: Literature and Market Analysis

The performer will conduct a literature review and market analysis aimed at addressing the research questions relating to the implementation of large UAS cargo carrying. The literature review will focus on technical requirements of conducting cargo carrying operations in the NAS using large UAS, including the technology transition needed to allow autonomous operations, and the potential infrastructure requirements needed to facilitate deliveries. The market analysis will identify market trends, potential for industry growth, cost comparisons with ground-based and current aircraft-based cargo deliveries, and the ramifications of establishing or adapting current cargo infrastructure in rural and moderately populated areas. The market analysis will explicitly examine the impact of COVID-19 on cargo delivery in Alaska, especially the potential for large UAS cargo operations to meet rural community needs for supplies while limiting the spread of the virus through human interactions. Completion of literature review, market analysis, and related recommendations for this study should be based upon lessons learned from prior research, including NASA UTM research.

Task 2: Use Case Development

Using outputs from the literature review and market analysis, the performer will determine the scope of use cases such that they (1) are representative of applicable market and technical trends for cargo delivery by large UAS, and (2) allow for research tasks to be completed within the allotted period of performance and budgetary constraints.

Task 3: Experiment Plan

The development of an experiment plan as part of this task informs research activities carried out in Task 4. The experiment plan will identify the key issues that need to be addressed in each use case identified in Task 2 and design experiments that are tailored to quantify the effects of those factors on the specific use case. Because the experiments will be tailored for each use case, until the use cases are determined, the experiments cannot be specified. However, some potential types of experiments that may be considered are: surveys of current activities and perceptions, simulations of aircraft operations or technologies, safety case development and Certificate of Authorization submission, lab or flight tests of specified technologies, mining of data from current manned operations, economic modeling, and projections of supporting technology growth, such as increased cellular and satellite coverage

Task 4: Conduct Designed Experiments

Task 4 consists of performing experiments in accordance with the plan developed as part of Task 3. As part of this task, the performer will seek to answer key research questions that are scoped within Task 2 in a manner that follows the experiment plan from the previous task.

Task 5: Economic Assessment and Methodology

In addition to research tasks associated with Task 4, the performer will devise a

methodology for assessing the economic impact of implementing air cargo transport by large UAS. The economic assessment methodology devised as part of this task should take input from key research findings from Task 1. A key output of this task will be a methodology and supporting data considering direct, indirect, and induced benefits of large UAS air cargo.

KEY FINDINGS

While conducting the literature review, the research team identified the following key findings:

- A great deal of the information that exists for the integration and logistical implementation of cargo-capable UAS operating at an airport is conceptual.
- Based on the material available, and with the limitations imposed on flying organizations, the areas being tested have not produced information significant or relevant enough to adequately determine best practices for integration and logistics certification of cargo UAS at a functional multi-role airport.
- The following subject areas are particularly relevant when discussing both the evolution and integration of unmanned aircraft cargo delivery:
    - Airspace
    - Regulations
    - Automation
    - Airman Certification and Training
    - Design and Airworthiness
    - Unmanned Traffic Management
    - Economic Analysis
- Trends towards adoption and the impact of integration, particularly in Alaska, offer insight into the current state of the industry and hints of where areas of growth

may occur.

- Variables that influence unmanned air cargo demand include:
  - Product inventories relative to sales volumes
  - The relative attractiveness of air cargo relative to other modes of transport
  - Regulatory barriers to entry.
- Looking to the future, growth trends should be considered by evaluating domestic and international economic variables, including trends in the air cargo industry, trade flows, domestic and international economic output, supply chain efficiencies, and projected growth.

During the past year, the research team identified the following key findings:

Key areas that must be addressed in a market analysis of Advanced Air Mobility (AAM), especially Unmanned Air Cargo (UAC) are:

- **Target markets:** explanation of customer segments and market locations.
- **Potential demand:** explanation of potential size and growth of AAM air cargo markets.
- **Competition:** which transport sectors will compete with AAM cargo markets.
- **Market Feasibility:** price/congestion points at which markets become viable, costs to enter the market; does feasibility change when affected by pandemics.
- **Market Transition:** characteristics of transition from piloted UAS to fully autonomous.
- **Other Market Factors:** public acceptance, infrastructure, legal frameworks, supply chain, and other variables that affect market penetration.

The team identified in the market analysis that there is a need to address the following air cargo market segments in surveys and analysis:

- Light (range <200 nm; payload 50-1,000 lbs) – substitute for local freight market; assume predominantly conducted with no runways (VTOL)
- Heavy Medium Range (HMR - Heavy medium range, range 500-3,000 nm, >10T payload) and Heavy Long Range (HLR - range >3,000 nm, payload: >40T) – handle together; preliminary estimates are 10-15 years to fully autonomous
- Regional (range: 75-1,000 nm, payload: 1-10T) – substitute for regional freight market; assume it is going to fall between the two other cases; expedited freight is part of its niche

The economic assessment and methodology used to assess these air cargo market assessments needs to focus on the economic drivers of:

- Revenue by air cargo market segments (HLR and HMR, regional, and light)
- Ground infrastructure expenditures (airports, heliports, vertiports, battery & charging, electric grid, loading/unloading, intermodal enabling)
- Aircraft expenditures (OEM fleets, supply chain components, and maintenance, repair, and overhaul)

The nature of the infrastructure and jobs supporting UAC at airports that will be serviced by drones will vary significantly by the type of airport and its location, so assessments of ground infrastructure expenditure and aircraft expenditures cannot be generalized to a single representative airport type. For example, the types of infrastructure needed to support a regional airport on the power grid and road system in Nevada will be different from those needed to support a similar-sized regional airport off the power grid and road system in Alaska. These differences will drive the types of aircraft that can conduct UAC operations at the airport.

The output from the economic assessment and methodology must include the following information for the end users of the technology to assess the economic viability of the technology over traditional air cargo operations:

- Economic Impact (direct, indirect, and induced)
- Economic Impact Output (jobs, wages, gross domestic product, economic output, and tax generation)
- Expenditures aligned with temporal assumptions (market diffusion, public acceptance, and regulatory constraints)

NAME & ORIGIN OF RESEARCH PERSONNEL

CATHERINE CAHILL - UAF	UNITED STATES
JAMES PARRIS - UAF	UNITED STATES
TOM HARITOS - KSU	UNITED STATES
KURT CARRAWAY - KSU	UNITED STATES
TIM BRUNER - KSU	UNITED STATES
KATIE SILAS - KSU	UNITED STATES
NOAH ENDRESHAK - KSU	UNITED STATES
RAJAGOPAL SUGUMAR - KSU	INDIA
DANIEL FINDLEY - NCSU	UNITED STATES
EVAN ARNOLD - NCSU	UNITED STATES
CHASE NICHOLAS - NCSU	UNITED STATES
STEVE BERT - NCSU	UNITED STATES
MATTHEW MCCRINK - OSU	UNITED STATES
RYAN HASSETT - NCSU	UNITED STATES
NATHAN WEBB - OSU	UNITED STATES
JERRY HENDRIX - UAH	UNITED STATES
JUSTIN HARRISON - UAH	UNITED STATES
STEPHEN WARR - UAH	UNITED STATES
BENJAMIN NOEL - UAH	UNITED STATES
NISHANTH GOLI - UAH	INDIA
ROBERT MEAD- UAH	UNITED STATES
CASEY CALAMAIO - UAH	UNITED STATES
MARK JOHNSON - UND	UNITED STATES
ROBBIE LUNNIE - UND	UNITED STATES
NOAH GUNTER - UND	UNITED STATES

HIGH-BYPASS TURBOFAN UAS ENGINE INGESTION TEST

The Ohio State University

Wichita State University National Institute for Aviation Research

LEAD

BACKGROUND

Inclusion of large numbers of small Unmanned Aircraft Systems (sUAS) into the National Airspace System (NAS) 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.

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 NAS.

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 team will be provided with a model of the fan stage used in the experiment by the test partner. A Finite Element (FE) 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 current modeling approach in the ongoing 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 conditions of the test 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 ongoing computational engine ingestion research. The test partner will also provide a final test report and their analysis of the test event, which will be reviewed by the research team based on their expertise and independent analysis. Finally, the research team will coordinate with the FAA on the overall messaging on the engine ingestion research.

Task 0: Live Engine Test Program Management

The research will be carried out in close collaboration with the test partner and the FAA. This task is focused on the coordination efforts to keep the FAA informed and up to date on the research throughout the course of the research program through Program Management Reviews, Technical Interchange

Meetings, interim reports, e-mails, and telephone meetings as appropriate to ensure the research validation objectives are being met.

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 and 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 own 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 ongoing 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 pattern.

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 both the research team and the test partner's results and 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 acquired the engine and are working on engine control and extracting engine data from the test.

NAME & ORIGIN OF RESEARCH PERSONNEL

KIRAN D'SOUZA	UNITED STATES
DUSHYANTH SIRIVOLU	INDIA
ERIC KIRSTAK	GERMANY
RASHID MATTAR	UNITED STATES
MITCHELL WONG	UNITED STATES
GERARDO OLIVARES	UNITED STATES
LUIS GOMEZ	UNITED STATES
HOA LY	VIETNAM
LUIS CASTILLO	MEXICO
AKHIL BHASIN	INDIA

GRADUATION OF STUDENTS

RASHID MATTAR	MAY 2023
MITCHELL WONG	MAY 2023

MITIGATING GPS AND ADS-B RISKS FOR UAS

LEAD

BACKGROUND

Unvalidated or unavailable GPS and "ADS-B In" data poses security and safety risks to automated UAS navigation and to Detect and Avoid (DAA) operations. Erroneous, spoofed, jammed, or drop-outs of GPS data may result in unmanned aircraft position and navigation being incorrect. This may result in a fly away beyond radio control, flight into infrastructure, or flight into controlled airspace. Erroneous, spoofed, jammed, or drop-outs of "ADSB-In" data may result in automated unmanned aircraft being unable to detect and avoid other aircraft or result in detecting and avoiding illusionary aircraft. For automated DAA, a false ADS-B track can potentially be used to corral

the unmanned aircraft to fly towards controlled airspace, structures, terrain, and so on. This research is necessary to enable safe and secure automated sUAS navigation and safe and secure automated sUAS DAA operations. Goals for the project include reports and recommendations useful for FAA policy development and UAS standards development. It is expected that this information will be used to better understand the risks, potential mitigations, and help the FAA to reassess and refine FAA policy with respect to validation of ADS-B data. The research may lead to new navigation requirements related to GPS as well.

APPROACH

Task 1: Literature Review and Risk Assessment

- The performer will conduct a literature review and meta-analysis that identifies the potential safety and security risks of relying on GPS and ADS-B data used for UAS operations.

- The literature review will include scholarly, government, and industry sources.
- The literature review will include signal dropouts, jamming, spoofing, erroneous data, and other potential causes that may result in safety or security risks to UAS operations that rely on GPS and ADS-B data.
- Based on the literature review, the performer will conduct safety and security risk assessments for a variety of potential UAS operations that rely on GPS and ADS-B data.
- The performer should also confer with industry standards bodies to see what work has already been done and what their needs are in this area for standards development.

Task 2: Identification of Potential Mitigations

- Based on the risk assessment in Task 1, the performer will conduct a market survey of market solutions to mitigate loss of GPS and loss of ADS-B data.
- The performer will also conduct a market survey of market solutions to mitigate unvalidated GPS and unvalidated ADS-B In data.
- The market surveys will include estimated costs, ease of implementation, and a preliminary assessment of the effectiveness of market solutions to mitigate the various risks identified in Task 1 for the various UAS operations.

- GPS mitigation strategies for denied and/or jammed environments will be explored and potential solution proposed.
- Cybersecurity and counterintelligence measures will also be explored to decrease the risk of disruption or takeover.
- Examination of recorded ABS-B data will be conducted to expose potential risks and provide guidance on mitigation schemes.

Task 3: Planning and Testing and Demonstration of Mitigations

- The performer will prioritize the mitigations in Task 2 for further analysis based on those that show the most promise for reducing risks while remaining cost effective and implementable.
- Particular emphasis will be placed on prioritizing mitigations that support sUAS operations and could be tested in Task 4.
- Current testing plan(s) assume the use of Part 107 type aircraft.
- Plan(s) including the use of simulated flight data will be a significant source of test data for evaluation. Simulated flight data will provide many more scenarios and encounters that can be physically flown, thereby highlighting significant outcomes and solutions.
- The inclusion of testing environments where weak or jammed GPS signals are available is planned.

Task 4: Task 4: Test, Analysis, and Demonstration Report(s)

The performer will conduct the test, analysis, and/or demonstrations (including simulated flight data) from approved plans. Document the outcomes and what was done in report(s). Reports will interpret the significance of outcomes and how they answer the research questions. The reports will provide initial preliminary recommendations for standards bodies and the FAA to consider

Task 5: Task 5: Final Briefing and Final Report

The performer will summarize and aggregate all of the previous papers and reports (into a final report package for the overall research effort. The Final Report should answer the research questions and provide recommendations to the FAA and standards bodies. The report should discuss how research outcomes can be used to inform policy, regulations, TSOs, advisory circulars, UAS standards, and DAA standards.

Task 6: Peer Review

There will be a peer review of the final report to ensure public availability of the research within 30 days of the final report delivery.

KEY FINDINGS

This project begun on May 1, 2021. Reports will be delivered throughout the 24-month period of performance, and the final report will be delivered to the FAA for peer review in May 2023. A summary of the Task 1 and Task 2 reports is included. The Task 3 report has been submitted and is being processed by the FAA, but a brief summary overview is included. Current activities are on Task 4.

Task 1

The Literature Review and Risk Assessment Report fulfills Task 1 for this effort. It provided a a literature review and meta-analysis that identified the potential safety and security risks of relying on GPS and ADS-B data used for UAS operations. It is divided into three areas of investigation: signal dropouts and erroneous data, jamming, and spoofing that may result in safety or security risks to UAS operations that rely on GPS and ADS-B data. Based on the information gathered, a safety and security risk assessments of potential UAS operations that rely on GPS and ADS-B data is presented.

A summary of the risk assessments is provided using the Safety Management System (SMS) Air Traffic Organization (ATO) SMS Manual and Safety Risk Management Guidance for System Acquisitions (SRMGSA). This manual provides guidelines to assess the severity and likelihood of identified risks. The risk assessment is broken into four classifications: Part 107 Operations, Beyond Visual Line Of Sight (BVLOS), Urban Areas, and Near Airports. For each category, the severity and likelihood probability, associated references, and mitigation schemes associated with the increasing risk profile is presented. Part 107 Operations specifies a near pristine risk level, or the best-case scenario and will serve as the base reference for the increasing risks in the other environments. BVLOS is the next category as it is a crucial for many UAS operations and is of great importance to the UAS community. Urban area operations represent a unique case due to signal interruptions and other artifacts along with the density of humans and infrastructure. Near airports operations represents another unique situation due to the air traffic density and potential impacts to commercial airline traffic.

Table 1 is a summary of the risk levels for the 6 classes and 4 classifications of operations in a table format to illustrate continuum of risk levels in the various combinations.

RISK	PART 107	ROVAL BVLOS	URBAN BVLOS	NEAR AIRPORT BVLOS
ADS-B Dropout	LOW	MEDIUM	MEDIUM	HIGH
GPS Dropout	LOW	MEDIUM	HIGH	HIGH
ADS-B Signal Jamming	LOW	LOW	MEDIUM	HIGH
GPS Signal Jamming	LOW	LOW	MED/HIGH	HIGH
ADS-B Signal Spoofing	LOW	MEDIUM	MED/HIGH	HIGH
GPS Signal Spoofing	LOW	MED/HIGH	MED/HIGH	HIGH

Table 1. Summary of the risk levels for the 6 classes and 4 classifications of operations.

From this analysis it is evident that the only low risk situations occur with operations in the Part 107 conditions. This was expected due to the nature of Part 107 and the current operability allowed by the FAA. In the medium risk category, most of the operating environments are in the BVLOS operations. This is also expected since both cases can be allowed by using a FAA waiver process to allow operations in these areas. The waiver and potentially other situations may be mitigated using additional processes, procedures, and technology to reduce the risk to a lower acceptable level. The high risk category contains mainly urban and near airport operations. These areas result in high risk operations and significant mitigation schemes are needed to reduce the risk to an acceptable level.

BVLOS operations are of special interest as these are in great demand from operators and industry. Mitigating BVLOS operations flying at low altitudes and conducting long linear infrastructure inspection, agriculture operations, package delivery, or aerial surveillance are focus areas. As mitigation strategies are found and evaluated the impact of them as well as the costs associated will be assessed. There is a desire to minimize cost and weight while still providing a high level of safety. These operations do have significant potential for adverse outcomes, however several mitigation techniques show promise as tools to be used in conjunction with regulatory requirements.

Task 2

Based on the risk assessment in Task 1, a market survey of market solutions to mitigate loss of GPS and loss of ADS-B data will be conducted as part of Task 2. The work will focus on reducing those medium risk operations to an acceptable level. However, these and other mitigations found may also offer solutions to the high risk operations. An assessment of whether there are other potential methods, operational mitigations, strategic mitigations, or other means for addressing potential safety and security risks will be completed. GPS mitigation strategies for denied and/or jammed environments will be explored and potential solution proposed. Cybersecurity and counterintelligence measures will also be explored to decrease the risk of disruption or takeover. Examination of recorded ABS-B data will be conducted to expose potential risks and provide guidance on mitigation schemes will also be included.

This Identification of Potential Mitigations report fulfills Task 2 for this effort. Examination of recorded ABS-B data was conducted to expose potential risks and provide guidance on mitigation schemes. The examination reveals dropouts and anomalies that occur in flight operations. Based on the risk assessments in Task 1, the performer conducted a market survey of market solutions to mitigate loss of GPS and loss of ADS-B data as well as a market survey of market solutions to mitigate unvalidated GPS and unvalidated ADS-B In data. The market surveys include estimated costs, ease of implementation, and a preliminary assessment of the effectiveness of market solutions to mitigate the various risks identified in Task 1.

The mitigation strategies identified were evaluated using an assessment tool to provide a metric to the overall effectiveness. The proposed assessment metrics assessed the overall effectiveness of mitigation schemes. Five things were evaluated to quantify the overall score to rank the proposed methods. These factors were:

1.) Cost
2.) Technical Readiness
3.) Ease of Implementation/Use
4.) Size, Weight, and Power (SWaP)
5.) Impact

Each factor was ranked with a numerical score from 1 to 5, with 1 being the "worst" and 5 being the "best" in each category. A detailed guide for each ranked factor is provided based on the effectiveness of the implementation of the mitigation scheme on a small UAS. Therefore, the factors are the added impact on the "standard' operating configuration.

The cumulative score of the ranked factors generates a value that is indicative to the overall effectiveness. Each factor in the total score has an equal weighting and the sum of all ranking produced the overall score. A scoring breakdown is color coded to outstanding, high, medium, or low value to indicate the overall effectiveness, as shown in Table 2.

SCORE	EFFECTIVENESS
5-10	LOW
10-15	MEDIUM
15-20	HIGH
20-25	OUTSTANDING

Table 2. Potential mitigation effectiveness scoring system.

MITIGATIONS SCHEME	CONDITION	ASSESSMENT SCORE	EFFECTIVENESS
AI Path Prediction	Drop Outs	13	MEDIUM
Optical Flow	Jamming	16	HIGH
Geomagnetic Navigation	Jamming	14	MEDIUM
Cellular Signal Navigation	Jamming	15	HIGH
Wi-Fi Navigation	Jamming	12	MEDIUM
ECD	Spoofing	17	🟨

Table 3. Summary of the GPS and ADS-8 risk mitigation methods.

The scoring system provides a numerical score to aid in overall effectiveness, however this score is to be used for a guide to aid in identifying mitigation strategies with high effectiveness in the current state of development. Some mitigation strategies may have great potential but are early in their development. These strategies, that perhaps do not score high at this time, may have the potential to have a great impact with further development.

Several mitigation schemes were evaluated for their effectiveness in jamming and spoofing conditions. The mitigation schemes evaluated were optical flow, geomagnetic navigation, cellular signal navigation, WIFI navigation, and ECD method. The findings are summarized in Table 3.

The study of these six systems indicate that most have an overall high effectiveness rating, while having varying effectiveness in each of the five factors scored. It is the team's opinion that flight and simulation testing should continue on all six of the mitigation methods and continued efforts be made in identifying dropouts and erroneous data in the current data sets along with new data sets obtained.

Task 3

This Planning the Testing and Demonstration of Mitigations report will fulfill Task 3 for this effort. It is currently being evaluated by the FAA for any edits and/or changes. It prioritizes the mitigations in Task 2 for further analysis based on those that show the most promise for reducing risks while remaining cost effective and implementable. It places particular emphasis on prioritizing mitigations that support sUAS operations that will be tested in Task 4. The use of simulated flight data is included as a significant source of test data for evaluation.

The report contains a test plan for UAS navigation anomalies including dropouts and erroneous data, GPS and ADS-B signal jamming, and GPS and ADS-B signal spoofing. The UAS anomalies chapter focused on using ADS-B data sets to identify ADS-B anomalies that would result in ceasing operations and to identify the scenarios that are most common. With this data the use of hybrid machine learning models will be explored. For the jamming chapter, the evaluation of the capabilities, advantages, and limitations of OPNAV and GNAV techniques will be tested using both flight and simulated data. In addition, a test is developed to record and utilize nearby LTE/4G cellular signals to inform a GNSS-independent positioning solution from a UAS-based receiver. For the spoofing chapter, the ECD method is used in a simulation environment that will produce data to assess its effectiveness in a challenging scenario.

With the test plan outlined in this Task 3 report, significant flight and simulator data will be acquired to best inform on the capabilities and weaknesses of GPS and ADS-B data.

NAME & ORIGIN OF RESEARCH PERSONNEL

WILLIAM SEMKE - UND	UNITED STATES
PRAKASH RANGANATHAN - UND	UNITED STATES
RYAN ADAMS - UND	UNITED STATES
KURT CARRAWAY - KSU	UNITED STATES
RANDALL NICHOLS - KSU	UNITED STATES
HEVER MONCAYO - ERAU	UNITED STATES
CHRIS JANKE - ERAU	UNITED STATES
JIHYE PARK - OrSU	UNITED STATES
CATHY CAHILL - UAF	UNITED STATES
JOEL BRANN - UAF	UNITED STATES
BREMNER NICKISCH - UAF	UNITED STATES
ZACH BARNES - UAF	UNITED STATES
WILL REMMERT - UAF	UNITED STATES
NIROOP SUGUNARAJ - UND	INDIA
ZAKARIA EL MRABET - IND	MOROCCO
JAYA PREETHI MOHAN - UND	INDIA
AKSHAY RAM RAMACHANDRA - UND	INDIA
BARATHWAJA SUBASH CHANDAR - UND	INDIA
ANTON SKURDAL - UND	UNITED STATES
ANDREI CUENCA - ERUA	COLUMBIA
EDUARDO MORILLO -ERAU	ECUADOR
TATIANA GUTIERREZ - ERAU	COLUMBIA
STEPHEN BRUTCH - ERAU	UNITED STATES
WESTON HUSTACE - OrSU	UNITED STATES

GRADUATION OF STUDENTS

NIROOP SUGUNARAJ	DECEMBER 2021

SHIELDED UAS OPERATIONS : DETECT AND AVOID (DAA)

LEAD

BACKGROUND

Certain small UAS (sUAS) Beyond Visual Line of Sight (BVLOS) operations, such as structural inspection, may be in close proximity to structures that are collision hazards for manned aircraft. These types of operations that are in close proximity to crewed aviation flight obstacles such that they provide significant protection from conflicts and collisions with manned aircraft are termed "shielded" operations. This work effort is intended to identify risks and recommend solutions to the FAA that enable shielded UAS operations. This effort will identify risks, determine whether shielded operations can be made safe, to what degree UAS Detect and Avoid requirements

can be reduced, and recommend 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, of risks associated with shielded operations, and related topics.

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

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

Task 3: Analysis of DAA Requirements and Obstacle Avoidance Requirements

This involves development of a simulation environment that allows assessment of risks and potential solutions identified in Tasks 1 and 2. Numerical simulations will be performed to analyze the competing shielding requirements to manage risks associated with flight near obstacles and to manage risks involving crewed aircraft.

Task 4: Flight Test Plans

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

Test 5: Tests and Reports

The team will carry out flight tests according to the developed test plans.

Task 6: Standards and Development

Research produced herein will be valuable to standards development efforts. The team will participate in relevant standards development efforts and will enhance them by providing relevant research results.

Task 7: Final Briefing and Final Report

The research team will summarize and aggregate all of the previous papers and reports (excluding meeting notes) into a final report package for the overall project. The Final Report will answer the previously mentioned knowledge gaps and provide clear recommendations to the FAA.

Task 8: Peer Review

The research team will support a peer review of the final report to ensure public availability of the research within 30 days of the final report delivery.

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:

- Crewed aircraft behavior in these environments
- Wind and turbulence effects
- Bird densities/behaviors
- 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 likelihood of events, as they depend upon airspace density (which is not generally known and highly variable). The team has developed a proposed foundation for evaluating likelihoods associated with interactions with crewed 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) to estimate safety benefits associated with shielded operations (e.g., reduction in crewed 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 crewed aircraft).

NAME & ORIGIN OF RESEARCH PERSONNEL

MARK ASKELSON - UND	UNITED STATES
NAIMA KAABOUCH	UNITED STATES
GARY ULLRICH - UND	UNITED STATES
JOSEPH VACEK - UND	UNITED STATES
JORDAN KRUEGER - UND	UNITED STATES
SREEJITH NAIR - UND	INDIA
CHRIS THEISEN - NPUASTS	UNITED STATES
JAKEE STOLTZ - NPUASTS	UNITED STATES
TREVOR WOODS - NPUASTS	UNITED STATES
HENRY CATHEY - NMSU	UNITED STATES
JOSEPH MILLETTE - NMSU	UNITED STATES
MITCHELL MATHEISON - NMSU	UNITED STATES
TIM LOWER - NMSU	UNITED STATES
DR TOM HARITOS - KSU	UNITED STATES
KURT CARRAWAY - KSU	UNITED STATES
RAJAGOPAL SUGUMAR - KSU	INDIA
TIMOTHY BRUNER - KSU	UNITED STATES
KATHERINE SILAS - KSU	UNITED STATES
HEVER MONCAYO - ERAU	US CITIZEN
EVAN ARNOLD - NCSU	UNITED STATES
DANIEL FINDLEY - NCSU	UNITED STATES
CHASE NICHOLAS - NCSU	UNITED STATES

GRADUATION OF STUDENTS

NOAH ENDRESHAK - KSU	MAY 2022
TATIANA GUTIERREZ - ERAU	MAY 2024
EDUARDO MORILLO - ERAU	DECEMBER 2022

VALIDATION OF VISUAL OPERATION STANDARDS FOR SMALL UAS (sUAS)

LEAD

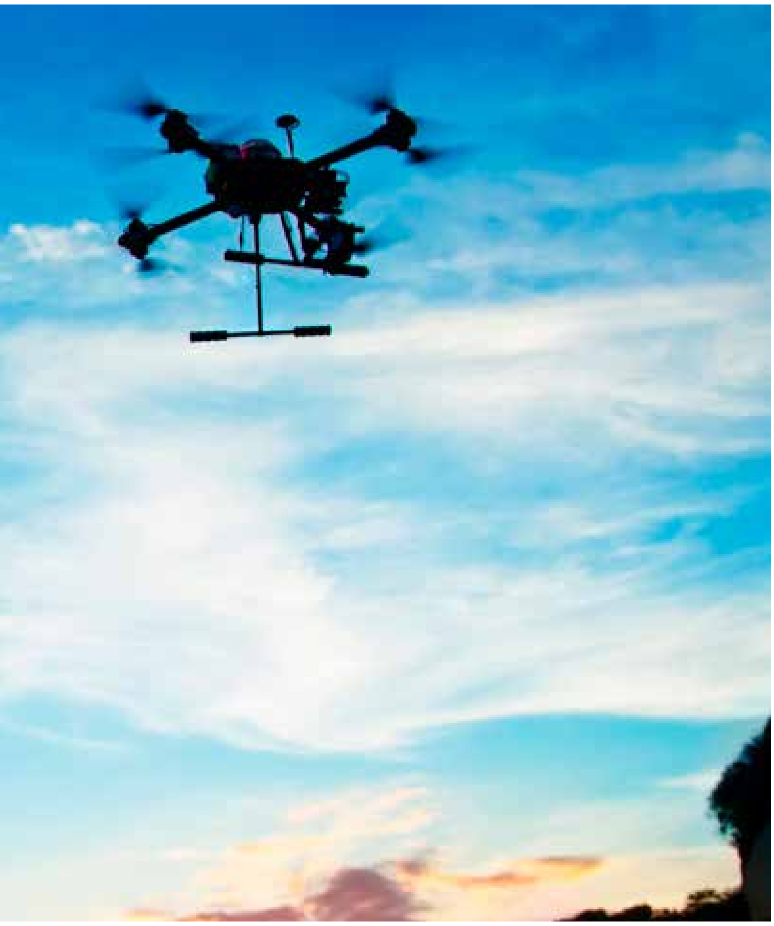
BACKGROUND

Under the auspices of the FAA Reauthorization Act (H.R. 302), Section 44806 states that the FAA is (a)(2) “to provide guidance on public agency’s responsibilities when operating an unmanned aircraft…” and (b)(2)(C)(i) “allow a government public safety agency to operate an unmanned aircraft weighing 4.4 pounds or less if that unmanned aircraft is operated within or beyond the visual line of sight of the operator.” In accordance with Section 44807, a risk-based approach will be used to assess unmanned aircraft systems. This risk assessment of UAS operations is to ensure that UAS operated within or beyond line of sight, or operation during the day or night, do not

impose a hazard to users of the national airspace system or to the general public. In addition, Section 44809 states that recreational operations are to be flown within visual line of sight and that the FAA should create aeronautical knowledge and safety tests.

The following concerns have been identified regarding Visual Observer (VO) capabilities as they relate to 14 CFR Part 107:

- Part 107.29, it is unknown how well VOs/Remote Pilots (RP) are able to 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 3 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 are able to ascertain the position of an unmanned aircraft 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 are able to 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 are able to give way to conflicting aircraft and avoid the creation of a collision hazard.

Recent experience with sUAS flight tests and a theoretic assessment of visual limitations revealed potential challenges and optical illusions that may arise for VO/RP line of sight operations. The purpose of this research is to assess the performance ability of VOs/RPs to meet the above Part 107 requirements, understand the various challenges that could be encountered during operations in an effort to create VO/RP training recommendations for visual line of sight operations, and to provide information for potential future updates to Part 107 regulations.

APPROACH

Task 1: Literature Review

The research team conducted a literature review of relevant material to address key concerns that are within the scope of this research, as defined within Sections 1.0 and 2.0 of this proposal, to include relevant literature provided by the sponsor and AUS-300. The performer reviewed literature pertaining to requirements for visual observers, including literature on their roles/functions and limitations. The literature review performed in this task will inform future tasks and assist in scoping this research. The following is a list of some of the key findings from the literature review:

Key Findings from the Literature Review

- 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.
- Most sUAS are unlikely to be seen beyond 4,000 ft.
- 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 may be able to 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 revealed central core topics such as airspace knowledge, COA 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 RPIC 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 DAA testing.

Task 2: Updated Research Task Plan

The research team will continue to update the Research Task Plan (RTP) based upon findings from the literature review in Task 1 and the outcomes associated with the initial test and analysis executed as a component of Task 3. The project team will revise the RTP accordingly. The updated research task plan will reflect findings that steer the goals/objectives of this

research for Tasks 4 – 7.

Task 3: Initial Test and Analysis

Task 3 consisted of the development and execution of test plans guided by research findings from the literature review in Task 1. As part of this task, the research team developed, reviewed, and executed a test plan that sought to answer key research questions. For the peer review element(s) of this task, subject matter experts (SMEs) with knowledge in flight test, human factors, design of experiments, and visual detection were used. A list of these SMEs will be included in project deliverables.

With this task, the research team developed Flight Test Plans (FTPs) for demonstrating visual limitations, and environmental constraints to quantify the safety of Visual Line of Sight (VLOS) and Extended Visual Line of Sight (EVLOS) operations.

- FTPs included encounters between manned and unmanned aircraft. Images, videos, and other data will be collected with the intent to address FAA knowledge gaps, to inform VO training standards, and to validate applicable VO standards. FTPs will collect data to quantify the safety performance of VOs/RPs to keep unmanned aircraft visually separated from manned aircraft when aircraft are approaching one another.

FTPs included:

1. Flight course design: flight paths, altitudes, and timing. Develop safety mitigations that support safe flight testing.
2. Pilot Recruitment: Identify, recruit, and schedule manned with adequate ranges of qualifications and experience.
3. Encounters: The unmanned aircraft encounters with other aircraft were planned, scheduled, and executed. Encounters were evaluated for safety and all flight paths maintained adequate vertical and/or horizontal separation. Encounters were structured to facilitate the collection of data to address FAA knowledge gaps.
4. Data Collection: The necessary tools and techniques were identified to precisely capture the following:

1. Images and videos that can be referenced for safety discussions about VLOS operations.
2. The test conditions and measurements that are important for quantifying VLOS safety performance.
3. The encounter parameters of the UA and aircraft for encounters. Examples include:

- The encounter geometries, altitudes, and the closing rate between UA and aircraft.
- Vertical and lateral separation between UA and aircraft at the closest point of approach (CPA) during the encounter.

The research team defined a plan to document the process for analysis of collected data to address FAA knowledge gaps. Analysis plans were developed before testing was conducted to ensure that the correct data was collected during testing.

The research team held a scoping peer review with the FAA and other parties determined by the FAA to discuss the FTP and data analysis plan to determine the appropriate methods. The sponsor, based on other areas identified, selected components of the FTP and data analysis plan that met the FAA immediate needs and were appropriate to the project scope. This task consisted of (1) a review of the draft flight test plan by the sponsor, performers, and select SMEs, and (2) a review of the data analysis plan.

The research team implemented the FAA approved FTP to gather requisite data to answer the research questions. These initial flight tests are precursors to follow-on testing that occurs in Task 4. As such, initial flight tests were aimed at validating methodology and further refinement of plans to ensure useful, valid data collection.

The quantitative results from the initial flight testing included:

- Visual Acquisition Distance (VAD) (calculated based on GPS data at the time of detection by VO)
- Altitude of intruder aircraft at the time of detection
- Apparent size of intruder aircraft at the time of detection in visual arcs
- Response time to initially visually acquire the intruder aircraft
- Response time to suggest a maneuver to deconflict/avoid intruder aircraft
- Time to evaluate and “confirm” maneuver
- Time for maneuver to be completed, if any, performed
- Encounter Parameters:
  - Closest Point of Approach (CPA)
  - Horizontal Miss Distance (HMD)
  - Vertical Miss Distance (VMD)
  - Status of Well Clear and NMAC violation

A preliminary analysis of the results of 143 intruder aircraft detections is shown in Table 1 below. Each detection represents one flyover of an intruder aircraft over the test zone. At two miles out, about 5% of the intruder aircraft were detected; at a mile out, about 56% of the intruder aircraft were detected. By the time the intruder aircraft was half a mile out, 95% were detected.

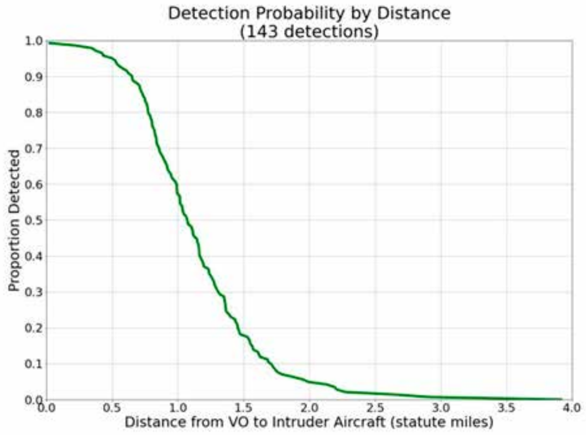


Figure 1. Detection Probability by Distance.

Task 4: Flight Tests

Flight tests for data collection and analysis that align with finalized flight test and data analysis plans developed in Task 3. Flight tests for this task seek to answer key research questions through data collection and analysis. The research team is scheduled to conduct flight test through November 2022.

Task 5: Case Study

Using the research results and developed recommendations, the research team will submit a Part 107 waiver application to the FAA for an EVLOS operation and document the process. The performer will document first-round follow-up questions that the FAA has from the waiver application as these may be valuable for future research. Outcomes of this case study will be captured in a task report.

NAME & ORIGIN OF RESEARCH PERSONNEL

TOM HARITOS PhD - KSU	UNITED STATES
KURT CARRAWAY - KSU	UNITED STATES
KATIE SILAS - KSU	UNITED STATES
TIMOTHY BRUNER - KSU	UNITED STATES
MICHAEL KERR - KSU	UNITED STATES
GERARDO OLIVARES PhD - WSU	UNITED STATES
LUIS GOMEZ - WSU	UNITED STATES
HARSH SHAH - WSU	INDIA
HENRY CATHEY - NMSU	UNITED STATES
JUSTIN MACDONALD PhD -	UNITED STATES
MICHAEL THOMPSON - MSU	UNITED STATES
DYLAN AMERSON - MSU	UNITED STATES

GRADUATION OF STUDENTS

MICHAEL KERR	2025

SMALL UAS (sUAS) MID-AIR COLLISION (MAC) LIKELIHOOD

Wichita State University National Institute for Aviation Research
LEAD

Kansas State University

Embry-Riddle Aeronautical University

KU

BACKGROUND

The primary goal of regulating Unmanned Air Systems (UAS) operations in the National Airspace System (NAS) is to ensure an appropriate level of safety. National aviation agencies quantify this goal as an "Equivalent Level of Safety" (ELOS) compared to manned aviation. There are significant key differences between manned and unmanned aviation that do not only lay in the separation of the pilot from the cockpit and the level of automation introduced but also in the variety of architectures and materials used for the construction of UAS. These differences could introduce new failure modes and, as a result, an increased perceived risk that needs to be

evaluated. Any UAS operation or test must show a level of risk to human life no more significant than that of an operation or test of a piloted aircraft according to the ELOS definition of the Range Commanders Council in its guidance on UAS operations.

The aforementioned metrics provide statistical probabilities of UAS mid-air collisions according to specific parameters defined for the evaluation. It should be noted that not all collisions lead to catastrophic accidents. The large variability of UAS sizes and the fact that not all the aircraft systems are critical for remaining airborne means that the aircraft involved may survive certain collisions. The risk assessment to develop an Airborne Collision Unmanned Aircraft Systems Impact Severity Classification can be divided into three elements:

- **Estimation of the probability of mid-air collision** between UAS and manned aircraft. This will be a function of the operating airspace, aircraft operating within the airspace, and the UAS configurations operating within the shared airspace. Mitigation performance of a generic DAA system will also be evaluated and compared to the results from the unmitigated MAC analysis.
- **Evaluation of damage potential for typical UAS** (classes based on weight, architecture, and operational characteristics [altitude, velocity]) mid-air collisions scenarios per manned aircraft class (commercial, general aviation, rotorcraft…) to assess the damage severity to manned aircraft. The research aims to evaluate the severity of a typical quad and fixed-wing sUAS airborne collision with a manned aircraft. Mitigated and unmitigated results can be assessed to understand the performance of the DAA on decreasing the likelihood of a MAC and decreasing MAC severity.
- Once the probability of an airborne collision is determined, **the damage models can be combined with the probabilistic collision models to define an appropriate Equivalent Level of Safety criteria.**

APPROACH

Task 1: Literature Review

The research team will identify relevant research and documentation in the areas of UAS Mid-Air Collision (MAC) with manned aircraft. It will include a historical analysis of sUAS MAC events and bird strike risk with manned aircraft. This information will be used for planning simulations, tests, demonstrations, and/or analysis needed to assess MACs and validate related standards.

Task 2: Unmitigated MAC Probability

The researchers will investigate and develop detailed unmitigated MAC probability estimations using MIT LL encounter sets and/or other datasets identified in the literature review. These datasets shall include a variety of representative sUAS as well as general aviation and commercial aircraft. These are encounters without the use of a Detect And Avoid (DAA) system. This research will include collision probabilities with individual parts of a manned aircraft (i.e., wings, canopy, rudder, elevator, and others).

Task 3: Mitigated MAC probability

The researchers will investigate and develop detailed mitigated MAC probabilities instead of unmitigated MAC probabilities. These are encounters with a DAA system to mitigate MAC probability. The researchers will investigate the impact of sUAS DAA system capabilities in reducing the probability of collision between an sUAS and a manned aircraft. ACAS sXu V4R1 is the DAA algorithm used for the mitigated analysis. Additionally, the research will identify the surveillance sources required on-board and/or off-board the sUAS.

Task 4: sUAS Unmitigated and Mitigated MAC Risk Assessment for GA and Commercial aircraft

The researchers will combine the unmitigated and mitigated MAC probability analysis with other collision severity studies to produce a risk assessment to manned aircraft. The research will leverage previous collision severity studies conducted and/or sponsored by the FAA. A risk-scoring system will be used to classify the severity of the MAC events. The severity scoring system will be based on previous ASSURE and FAA work relating sUAS mass, type, and velocity to the damage observed on the aircraft. In addition, the research team will combine the mitigated MAC probability analysis with other collision severity studies to produce a risk assessment to manned aircraft. Commonly accepted metrics, such as Loss of well-clear Ratio (LR) and Risk Ratio (RR), will be calculated for each encounter set.

Task 5: Comparative risk assessments with other aviation risks to include bird strikes

The research team will leverage existing risk assessment studies previously performed and/or sponsored by the FAA on risk assessment of bird strike to compare the risk to manned aircraft of an sUAS vs. a bird strike of similar weight in terms of severity and frequency. The research will estimate the economic impact if enough information is available.

KEY FINDINGS

The research team generated 3 million encounters utilizing MIT LL encounter models. These encounters were evaluated without mitigation (no DAA system) and with ACAS sXu (DAA system). Generic cooperative and non-cooperative sensors were used in the analysis. The sensor errors were modeled according to RTCA SC-127 *Minimum Operational*

Standards for Airborne Collision Avoidance System sXu (ACAS sXu) (DO-396). Some of the key findings include:

- ACAS sXu meets the Near Mid-Air Collision (NMAC) and Loss of Well Clear (LoWC) ratio safety targets specified in ASTM F3442-20.
- ACAS sXu mitigated all MACs in the cooperative encounter sets.
- ACAS sXu mitigated approximately 95% to 98% MACs in the non-cooperative encounter sets.
- ACAS sXu also provides a net benefit in reducing *P(MAC|NMAC)*. MAC ratios were estimated between 0.55 and 0.25 for all the aircraft pairs analyzed.
- 4 Manned aircraft models and 6 sUAS models were used during the collision detection. These models originated from previous ASSURE research programs

The research team is currently evaluating the severity of the MACs. This will be accomplished by utilizing results from previous ASSURE research programs as a baseline that will be extrapolated to all MACs recorded in the *Small UAS (sUAS) Mid-Air Collision (MAC) Likelihood* research program. The final report will be delivered to the FAA for peer review in December 2022.

NAME & ORIGIN OF RESEARCH PERSONNEL

GERARDO OLIVARES - WSU	UNITED STATES
LUIS GOMEZ - WSU	UNITED STATES
ARMANDO DE ABREU - WSU	PORTUGAL
HARSH SHAH - WSU	INDIA
GERARDO ARBOLEDA - WSU	ECUADOR
DEEPAK SINGH - WSU	NEPAL
RYAN WALLACE - ERAU	UNITED STATES
DOTHANG TRUONG - ERAU	UNITED STATES
SCOTT WINTER - ERAU	UNITED STATES
DAVID CROSS - ERAU	UNITED STATES
SANG-A LEE - ERAU	UNITED STATES
TOM HARITOS - KSU	UNITED STATES
KURT CARRAWAY - KSU	UNITED STATES
RAJAGOPAL SUGUMAR - KSU	INDIA
TIMOTHY BRUNER - KSU	UNITED STATES
KATIE SILAS - KSU	UNITED STATES
MARK EWING - KU	UNITED STATES
SHAWN KESHMIRI - KU	UNITED STATES
AARON MCKINNIS - KU	UNITED STATES
ANASTASIA BYRD - KU	UNITED STATES

GRADUATION OF STUDENTS

DEEPAK SINGH	MAY 2023
GERARDO ARBOLEDA	JULY 2021
AARON MCKINNIS	MAY 2023

UAS FLIGHT DATA RESEARCH IN SUPPORT OF ASIAS

UNIVERSITY OF NORTH DAKOTA
EMBRY-RIDDLE Aeronautical University
LEAD

RIT | Rochester Institute of Technology
CERTIFIED PARTNER PARTICIPANT

BACKGROUND

This research will aggregate high quality Unmanned Aircraft Systems (UAS) flight data with commercial and general aviation flight data and surveillance data, to develop enhanced safety analyses for National Airspace System (NAS) stakeholders and to support UAS integration in the NAS.

The overarching purpose of this research is to enable safe integration of UAS in the NAS through building upon existing aviation database and data-sharing efforts encouraged and endorsed by participating government-industry entities. Through this research, a data architecture for unmanned air and ground vehicles and operations will be developed in

alignment with the FAA's Aviation Safety Information and Sharing (ASIAS) program.

This project will design and evaluate Flight Data Monitoring (FDM) for unmanned operations and integrate that data into the ASIAS system. In addition, this project will integrate the findings from ASSURE project A20 -UAS Parameters, Exceedances, and Recording Rates for ASIAS, which identified current UAS FDM capabilities and practices, including refresh/recording rate and robustness, and developed guidance for a UAS FDM standard. The team includes original members, University of North Dakota (UND), and Embry Riddle Aeronautical University (ERAU), who designed and deployed the National General Aviation Flight Information Database (NGAFID), which has successfully integrated and is data-sharing with ASIAS.

APPROACH

Task 1: Configure storage and formatting requirements of unmanned data.

The research team will configure storage and formatting requirements of unmanned data in the NGAFID database, or a database with the same look and underlying infrastructure.

Task 2: Configure and implement a prototype system to collect unmanned Flight Data Monitoring (FDM) records from industry and academic participants.

In this task the team will configure and implement a prototype system to collect unmanned Flight Data Monitoring records from industry and academic participants, preferably combined with ngafid.org, or at least an equivalent.

Task 3: Collect Unmanned Flight Data Monitoring records.

In Task 3, the researchers will collect at least 1000 flights of Unmanned Flight Data Monitoring records. Up to half of the flights may be simulated (FAA Tech Center and NASA offer to contribute), but representative of actual drone missions. The remaining flights must be actual flights over the US in the past two years. The flights will be diverse in duration (five to 90 minutes), weight (0.4 pound to 80 pounds), and configuration (transponder-equipped and not, quad-rotor and fixed wing), and will be published on a public website to display aggregate statistics and the diversity of the flights collected.

Task 4: Interface with unmanned communities and gather industry feedback.

The researchers will interface with unmanned communities such as UAST through conferences and symposia to determine their biggest concerns with aviation safety risk. They will evaluate industry recommendations for encouraging voluntary submission of Unmanned Flight Data Monitoring. The research will include prioritization by industry of specific safety risks that are best analyzed with Unmanned Flight Data Monitoring.

Task 5: Measure the risk of collision between unmanned and manned aircraft.

This research will measure the risk of collision between unmanned and manned aircraft. The risk will be calculated using the flights collected. At a minimum, the team will calculate and model the risk of collision with proximity and closure rate and measure how closely this model approximates the performance of TCAS, ACAS, or similar algorithms currently used in aviation.

Task 6: Measure a novel risk identified through the community outreach above.

The researchers will measure a novel risk identified through the community outreach, which will be displayed on the public webpage at an aggregate level.

Task 7: Create visualizations of collision risk and battery performance.

Within Task 7, the researchers will create visualizations of collision risk and battery performance. These visualizations will be available at an aggregate level on the website published above. The visualization will show locations and configurations with more than five incidents of high risk as calculated and at least ten locations, each with more than five incidents of high risk.

Task 8: Final Report.

All of the findings will be summarized into a Final Report, including recommendations for future research based on the gaps identified during the execution of this research.

KEY FINDINGS

This project has began in March 2021. Reports will be delivered throughout the 28-month period of performance, and the final report will be delivered to the FAA for peer review in 2023. Deliverable 1 was completed and delivered in July 2021, containing details on Task 1, which pertains to configuring storage and formatting of unmanned data in the NGAFID database. Specifically, the items in the deliverable report on the configuration and functionality of the database, with configuration files and example tables in spreadsheet format.

Deliverable 2 was delivered in November 2021, containing details on Task 2, which pertains to configuring and implementing a prototype system to collect unmanned Flight Data Monitoring records from industry and academic participants. This prototype system allows operators to upload their flight data files directly to the NGAFID database for further processing. Specifically, the items in the deliverable report on the configuration and functionality of the prototype system, including instructions on maintenance and use.

Deliverable 3 was delivered in March 2022, containing details on Task 3, which pertains to collecting at least 1000 flights of Unmanned Flight Data Monitoring records. For this task, all flights were actual flights over the US.in the past two years. The flights are diverse in duration (five to 90 minutes), weight (0.4 pound to 80 pounds), and configuration (transponder-equipped and not, quad-rotor and fixed wing). A page was created on the NGAFID website to display aggregate statistics, particular to each individual user of the system.

Deliverable 4 was delivered in August 2022, containing details on Task 4, which pertains to gathering the ideas of industry, government, and academia on prioritization of risk. This report includes lists of risks considered and recommendations for voluntary reporting. Additionally, qualitative feedback is included for recommendations and additional safety risks not directly considered by the survey.

The remaining deliverables pertaining to Tasks 5, 6, and 7 are due incrementally between the submission of this report and May 2023, with the Final Report due to the ASSURE project team in May 2023.

NAME & ORIGIN OF RESEARCH PERSONNEL

RYAN GUTHRIDGE - UND	UNITED STATES
JAMES HIGGINS - UND	UNITED STATES
BRANDON WILD - UND	UNITED STATES
MARK DUSENBURY - UND	UNITED STATES
TRAVIS DESELL - RIT	UNITED STATES
DAVID ESSER - ERAU	UNITED STATES

GRADUATION OF STUDENTS

SO HONG - RIT	2023
JEREMY COPENHAVER - ERAU	2024

sUAS TRAFFIC ANALYSIS

EMBRY-RIDDLE Aeronautical University
LEAD

KANSAS STATE UNIVERSITY

WICHITA STATE UNIVERSITY
NATIONAL INSTITUTE FOR AVIATION RESEARCH

BACKGROUND

A report by the National Academies of Science, Engineering, and Medicine (NASEM, 2018) suggests the Federal Aviation Administration (FAA) should expand on quantitative data collection to address risk as it pertains to Unmanned Aircraft Systems (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 (2018) 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

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” (NASEM, 2018, p. 41). 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. . .” (NASEM, 2018, p. 39).

In order 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 the integration of 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 placed across the country at various convenience sample locations across the NAS. The analysis of UAS traffic data will serve useful for monitoring the effectiveness of existing sUAS regulations and will provide useful 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, as well as 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, information useful for informing UAS Traffic Management (UTM) requirements, informing future 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 unmanned aircraft systems may operate safely in the national airspace system 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.
- Sec 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 carriage of property by small unmanned aircraft systems for compensation or hire. The FAA is to consider the unique characteristics of highly automated, small unmanned aircraft systems and include requirements for the safe operation of sUAS that addresses airworthiness.

  - sUAS 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 an important contributor in the development of policy and regulations for sUAS including effectiveness of Remote ID, sUAS detect 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 regulations and remote identification regulations.

PROPOSED APPROACH

The purpose of this project is to establish a framework for addressing the need to collect empirical data required to conduct sUAS traffic analysis in low-altitude airspace that will support the FAA's efforts in accurately forecasting sUAS growth, planning further sUAS airspace integration efforts, conducting risk assessments of proposed sUAS operations, and estimating compliance rates to existing and future regulations. The research team will purchase historical sUAS detection data from vendors providing sUAS detection services at locations throughout the United States. 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

- Assessing the frequency of sUAS encounters with manned aircraft
- Determining the state of sUAS operations and activity in proximity to aerodromes
- Providing findings and recommendations that may inform the development of Unmanned Traffic management (UTM) requirements and Urban Air Mobility (UAM) route design

Task A: Analysis Tool Development & Literature Review

The primary objectives of this task include developing the capabilities of Unmanned Systems Robotics Analysis (USRA), Inc. UAS and Counter-UAS Analytics Platform (UCAP) to store, format, integrate, database, process, analyze, display, and filter the various datasets to streamline the analysis process for the research team. Additionally, an extensive literature review will be conducted for this project to provide vital background information, explore prior related research on the scope of the research, and inform upon the proposed methodological approach.

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

The objective of this task is to provide a descriptive analysis of sUAS traffic trends from sample data. The research team will leverage UAS detection data to quantify operational trends.

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

The primary objective of this task is to provide an overview regarding the exceedance rates of various elements of Title 14 CFR, including Part 107 and Part 48.

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

The purpose of this task is to highlight potential risks to aviation operations as a result of sUAS flight around aerodromes and near manned air traffic. This section will also identify potential security challenges posed by sUAS operating in no fly zones and critical infrastructure.

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

The intent of this task is to leverage data gathered throughout the course of this project to inform upon industry growth, development, and further sUAS integration efforts.

Task F: Communicating Findings

During this project phase, the team will provide required written reports, briefings, and other deliverables as specified by the grant obligations. Additionally, the research team will make contact with applicable industry standards groups, industry stakeholders, and other interested parties to assess their interest in this research effort. The research team will engage with at least two industry standards groups annually. The research team will provide project update briefings to these bodies upon request and leverage these organizations to communicate project findings via the publication of articles, briefings, participation in panel discussions, or other related opportunities.

KEY FINDINGS

The research team recently concluded the first year of project performance. Data was collected from July 2021 through January 2022 from an array of 166 sensors positioned at 64 geographically-diverse locations around the United States. Nearly 471,000 sUAS flights were identified from among a population of more than 116,000 platforms. Small UAS flights show utilization trending towards smaller, newer platforms. The preponderance of operations occurred in dense population centers. A large number of sUAS operations occurred during selected holidays. The results indicate emerging patterns in the data, such as seasonality and time of day variations. Generally, UAS operations peak during midday local time, with slightly higher utilization rates on weekend days. About a quarter of all flights were carried out during local nighttime hours. A majority of sUAS flights lasted just a few minutes. Most detected sUAS flew at relatively slow speeds, with about a third of detected flights flying at walking speed. The data showed high utilization of Class G airspace. Extensive use of Low Altitude Authorization & Notification Capability (LAANC) areas were also noted, particularly in 400-foot grids. A large number of sUAS flights took place within proximity to heliports, highlighting a potential risk for low-altitude rotorcraft encounters. Generally, most sUAS flights were carried out within proximity of their operators; however, even at close range, visibility may be lost due to the relatively small size and visual footprint of newer drones. As the project moves into its second year of performance, the research team will address other challenges, including evaluating UAS flights near critical infrastructure, UAS hotspots near aerodromes, and encounters with manned aircraft. Additional details about these findings are provided in the ASSURE A50 Initial Annual Report, which is scheduled for publication in late 2022.

NAME & ORIGIN OF RESEARCH PERSONNEL

RYAN WALLACE - ERAU	UNITED STATES
STEPHEN RICE - ERAU	UNITED STATES
DOTHANG TRUONG - ERAU	UNITED STATES
RICHARD STANSBURY - ERAU	UNITED STATES
BRENT TERWILLIGER - ERAU	UNITED STATES
SCOTT BURGESS - ERAU	UNITED STATES
KRISTINE KIERNAN - ERAU	UNITED STATES
TYLER SPENCE - ERAU	UNITED STATES
FLAVIO MENDONCA - ERAU	BRAZIL
CAROLINA ANDERSON - ERAU	UNITED STATES
SCOTT WINTER- ERAU	UNITED STATES
DAVID KOVAR - URSA	UNITED STATES
TOM HARITOS - KSU	UNITED STATES
KURT CARRAWAY - KSU	UNITED STATES
KATIE SILAS - KSU	UNITED STATES
TIMOTHY BRUNER - KSU	UNITED STATES
LUIS GOMEZ - NIAR	UNITED STATES
ARMANDO DEABREU - NIAR	PORTUGAL
HARSH SHAH - NIAR	INDIA
GERARDO ARBOLEDA - NIAR	ECUADOR
DEEPAK SINGH	NEPAL

GRADUATION OF STUDENTS

SANG-A LEE	MAY 2026

BEST ENGINEERING PRACTICES FOR AUTOMATED SYSTEMS

LEAD

BACKGROUND

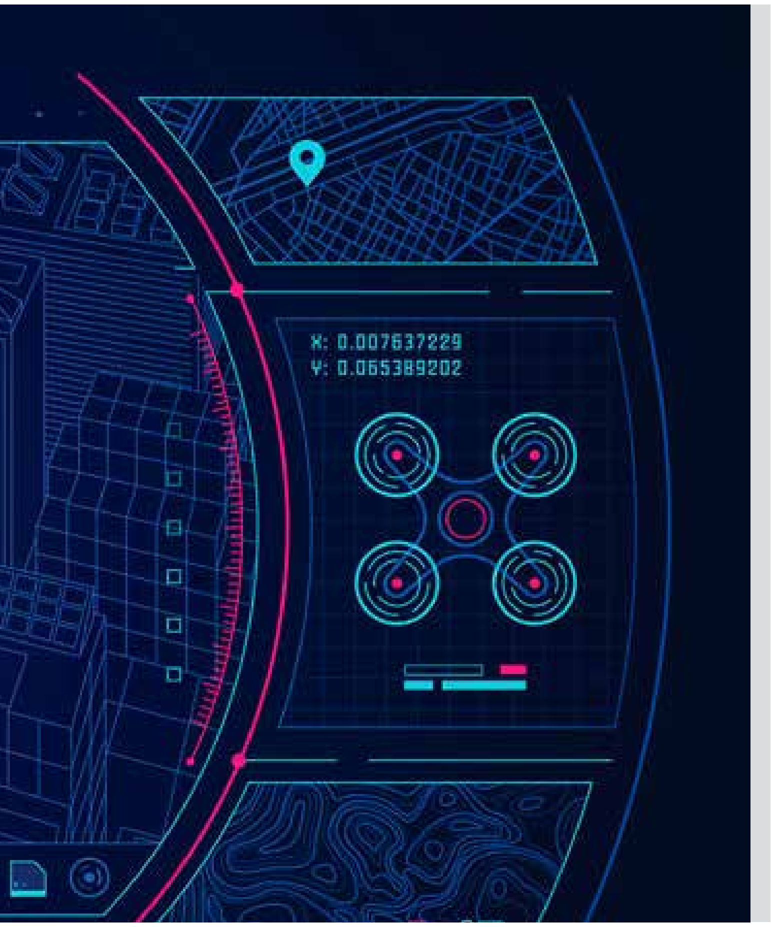
Advances in aviation are evolving towards a wider range of fully automated functions, all the way from perception (translating raw sensor data into actionable information) to control. Many of these advances are occurring with UAS (regardless of size), in which the trend is towards assigning the human over-the-loop control and allowing the 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 what potential risks and benefits there may be with 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 will perform a broad literature review of automation failures affecting UAS, and other highly automated aviation functions that are reused or reusable in UAS. The literature review will identify root causes of automation failures for UAS operations, and other aviation systems that are relevant to UAS. A significant portion of the literature review will focus on UAS automation failures. The team will create an annotated bibliography that briefly summarizes each of the identified automation failures, the outcomes, and the root causes. The annotated bibliography is expected to include hundreds of references. The team will complement 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 will determine 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 will also develop appropriate risk assessment methods in light of these findings.
The principle investigators, and structured interviews with SMEs serving as consultants on the project, will identify 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

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 has just completed Task 1 and delivered a report summarizing the results from 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 significant cross-area research needs identified in this report are listed below.

1. The Perception survey has pointed to the difficulties of navigating dense airspace with less-than-great perception performance. Any motion planning algorithm must be demonstrably capable of meeting these difficulties. Right-of-way rules that might be proposed must also make a rigorous argument, backed by simulation or real flight, that they can ensure safety of air traffic under these perception conditions, and under these projected densities.
2. The environmental modeling review has identified that “Onboard weather sensors can help with flight correction and with understanding of the limitations of UAS to fly under specific weather conditions”. This is directly relevant to the design of on-board runtime verification algorithms, and requires paying attention to the overhead of runtime monitors in terms of computational resources
3. There is a need to develop distributed runtime verification algorithms for monitoring the global behavior of interacting UAS, and the environmental conditions that are a major cause of failure of UAS operations. This runtime verification must account for time drifts: that is, communication delays, measurement delays, and drifting UAS clocks. It must be resilient to a certain amount of UAS non-cooperation (whether due to failure or an attack).
4. The Flight Testing survey has highlighted that Machine Learning (ML)-based controllers can outperform more traditional controllers in certain settings. However, there isn’t yet rigorous validation and verification of AI-based flight controllers, whether in design-time mathematical analysis, automated (formal methods-based) verification, or in flight tests. This is a dangerous gap, since ML-based controllers are much less predictable than more traditional controllers. This research would aim at filling this gap, to establish a baseline of what is achievable before developing corresponding guidance.
5. The Robust Inference survey noted that most mitigations do not consider the possibility of adversarial sensor data falsification even though many sensing modalities are known to be prone to it with cheap hardware. There is a need to develop mitigations that account for data falsification, guided by the known vulnerabilities identified by the security survey and by the practical possibilities supported by UAS builds.
6. The probabilistic risk assessment survey has observed that most risk analysis work in UAS is qualitative in nature, and lacks a rigorous mathematical framework. This is untenable if regulation and guidance are risk-based, where

"less risky" conops get fewer a priori restrictions placed on them. This risk-based approach was advocated for by some of the expert interviewees. While this approach makes sense broadly speaking, it cannot be actually implemented unless there's a way to quantify risk. This research would aim at developing a quantitative framework and demonstrating in a concrete application: assessing the risk reduction of using certain formal verification techniques at design time.

NAME & ORIGIN OF RESEARCH PERSONNEL

DAVID HAN	UNITED STATES
AMIRREZA ROUHI	IRAN
ADHINANDA DUTTA	INDIA
HARIHARAN NARAYANAN	INDIA
SADIA AFRIN ANANNA	BANGLADESH
STEVEN WEBER	UNITED STATES
MATTHEW MCCRINK	UNITED STATES
PHILIP SMITH	UNITED STATES
LINDSAY WILLS	UNITED STATES
HOUSSAM ABBAS	LEBANON
KHUSHAL BRAHMBHATT	INDIA
SAHIR GILL	INDIA
CHARLES KOLL	UNITED STATES
MAHSA SAEIDI	IRAN
RAKESH BOBBA	INDIA
GABRIEL RITTER	UNITED STATES
JINHONG CHOI	REPUBLIC OF KOREA
YEONG JIN JANG	REPUBLIC OF KOREA
JINSUB KIM	REPUBLIC OF KOREA
GALPOTTAGE DILAN SENARATNE	SRI LANKA
CHANCE CHARLES	UNITED STATES
KHUSHAL BRAHMBHATT	INDIA
SAHIR GILL	INDIA
CHARLES KOLL	UNITED STATES
MAHSA SAEIDI	IRAN
RAKESH BOBBA	INDIA
GABRIEL RITTER	UNITED STATES
JINHONG CHOI	REPUBLIC OF KOREA
YEONG JIN JANG	REPUBLIC OF KOREA
JINSUB KIM	REPUBLIC OF KOREA
GALPOTTAGE DILAN SENARATNE	SRI LANKA
CHANCE CHARLES	UNITED STATES

DISASTER PREPAREDNESS AND EMERGENCY RESPONSE - PHASE II

LEAD

BACKGROUND

This research ties directly to the M-17-30 OMB Memo in that it addresses the RE&D priority practice to maximize interagency coordination by ensuring that the COE works with federal agencies such as DOI, and DHS, as well as regional, state, and local organizations to study the use of UAS by each agency during emergency and disaster responses. This will help research coordination and avoid duplicative efforts across the government. This requirement will be a continuation of the A28 Disaster Preparedness and Response effort.

Currently in the National Airspace System (NAS), during emergencies, UAS have created

incursions that have hampered those emergency responses. With a coordinated response, UAS have shown to be extremely helpful and useful to first responders. With DOI doing their own research into how to help respond to natural disasters, the FAA has an opportunity to determine coordination procedures to ensure safety in the NAS.

The 2018, 2019, and 2020 Omnibus Budget appropriations also directs the FAA to support the expanded role of the UAS Center of Excellence (COE). This also directs the COE to "expand the Center's role in transportation disaster preparedness and response."

Through continuation of ongoing efforts, the FAA will ensure that the Center of Excellence expands its role into these areas while also helping to meet the FAA's overall goal of safe UAS integration into the NAS.

APPROACH

Task 1. Review of Phase 1

Researchers will conduct an extensive review of Phase 1, including conduct of an in-depth Peer Review with the FAA focused mostly on Use Cases, CONOPS and ORAs.

Task 2. Mock Event Demonstrations

This task is to exercise the products of Phase 1 in a real disaster scenario. This includes all coordination and working through FEMA/DOI/DHS and determine what role local and state governments play in this area.

Task 3. Lesson Learned

This task is for the documentation and assessment of lesson learned from the exercises and demonstrations from Task 2. The lessons learned will be documented via the exercises with assessment via After Action Review with event participants, leadership and first responders including operational pilots, regulatory agents and the entire group that makes UAS response during disasters possible. In parallel with lessons learned, training conduct will be assessed looking at task, conditions and standards for the future of first responder credentialing and training using the Task 4 developed products.

Task 4. Procedures and Guidelines

Provide the final policies, procedures and guidelines for UAS flight coordination and use in a disaster to assure effective and efficient use of UAS in local, state and federal responses.

KEY FINDINGS

- The CONOPS for disaster scenarios developed in Phase I are directly translatable to the events planned for this effort.The level of detail, approach, operational plans, use of specified personnel, and timelines are at a sufficient level of detail to translate into the scripts for the these events.
- The events being planned for the this effort have been defined to be seminars, workshops/tabletop exercises, drills, and functional exercises. These have been defined as follows:
  - Seminar – discussion-based training to develop a common framework of understanding of a specific disaster type.
  - Workshop with Tabletop Exercise – train policies and procedures relating to a particular disaster type.
  - Drill – field exercise, repetitive in nature, to demonstrate a specific function and gain proficiency relating to a specific disaster type.
  - Functional Exercise – multi-day field exercise presenting situations demanding decisions across multiple entities. These decisions and their consequences are then discussed and scored in accordance with a prepared rubric.
- The processes to be followed in preparing for these events has been defined.
- The types of events to be conducted for specific disaster types has been finalized as follows:
  - Oil Spill: Spill from Terminal onto Land & Ocean (Seminar, Workshop/Tabletop)
  - Wildland Fire: Prescribed Burn (Seminar, Full-Scale Exercise)
  - Wildland Fire: New Fire in Satellite Data (Seminar, Workshop/Tabletop)
  - Hurricane/Tornado/Flooding: Hurricane w/ Associated Tornadoes (Seminar, Workshop/Tabletop, Full-Scale Exercise)
  - Earthquake w/ Tsunami: Large EQ followed by Tsunami Warning (Seminar, Workshop/Tabletop, Drill)
  - Volcanic Eruption: Volcanic Summit Activity w/ Plume (Seminar, Workshop/Tabletop)
  - Airport Terrorism: Ground Impact & Hostile Airborne Assets (Seminar, Drill)
  - Train Derailment: At Terminal w/ Local Impacted Infrastructure (Seminar, Workshop/Tabletop, Full-Scale Exercise)
  - Pandemic: Medical Delivery Between Rural Communities, (Seminar, Full-Scale Exercise)
  - Pandemic: Medical Delivery Between Major Hub and Rural Community, (Seminar, Full-Scale Exercise)
- The events are currently scheduled to take place between 9 November 2022 and early June, 2023.

NAME & ORIGIN OF RESEARCH PERSONNEL

JERRY HENDRIX - UAH	UNITED STATES
ROBERT MEAD - UAH	UNITED STATES
CASEY CALAMAIO - UAH	UNITED STATES
NISHARNTH GOLI - UAH	INDIA
STEPHEN WARR - UAH	UNITED STATES
BENJAMIN NOEL - UAH	UNITED STATES
ALEXANDER MCGOWAN - UAH	UNITED STATES
JARLATH O'NEIL-DUNNE - UVM	UNITED STATES
DAVID ROSOWSKY - UVM	UNITED STATES
MANDAR DEWOOLKAR - UVM	UNITED STATES
DAVID NOVAK - UVM	UNITED STATES
JAMES SULLIVAN - UVM	UNITED STATES
MOLLY MYERS - UVM	UNITED STATES
ADAM ZYLKA - UVM	UNITED STATES
MADDY ZIMMERMAN - UVM	UNITED STATES
CATHY CAHILL - UVM	UNITED STATES
PETER WEBLEY - UAF	UNITED KINGDOM
NICK ADKINS - UAF	UNITED STATES
THOMAS ELMER - UAF	UNITED STATES
JESSICA LARSEN - UAF	UNITED STATES
WILLIAM REMMERT - UAF	UNITED STATES
HENRY CATHEY - NMSU	UNITED STATES
JOSEPH MILETTE - NMSU	UNITED STATES
TIM LOWER - NMSU	UNITED STATES
ANDRE DENNEY - NMSU	UNITED STATES
ROSS PALMER - NMSU	UNITED STATES
GARY LENZO - NMSU	UNITED STATES
ROBERT MCCOY - NMSU	UNITED STATES
JULIE A ADAMS - OrSU	UNITED STATES
MICHAEL OLSEN - OrSU	UNITED STATES
ERICA FISCHER - OrSU	UNITED STATES
DAE DUNG KANG - OrSU	REPUBLIC OF KOREA
JUNFENG-MA - MSU	CHINA
MICHAEL THOMPSON - MSU	UNITED STATES
EVAN ARNOLD - NCSU	UNITED STATES
DANIEL FINDLEY - NCSU	UNITED STATES
MICHAEL PICINICH - NCSU	UNITED STATES
THOMAS ZAJKOWSKI - NCSU	UNITED STATES
KURT CARRAWAY - KU	UNITED STATES

GRADUATION OF STUDENTS

REBECCA GARCIA - MSU	MAY 2023

ADVANCED MATERIEALS AND PROCESSES SURVEY FOR AAM AND UAS AIRCRAFT

LEAD

BACKGROUND

Advanced Air Mobility (AAM) and Unmanned Aircraft Systems (UAS) platforms are rapidly growing markets with promising advancements that could potentially change the landscape of air transportation in the future. This innovative and dynamic growth in the aviation industry also introduces the need for regulation to maintain the safety and security of the National Airspace System (NAS). The Federal Aviation Administration (FAA) has organized its regulatory efforts around five areas of activity – aircraft, airspace, operations, infrastructure, and community. The focus of this research project pertained specifically to the aspects of advanced materials and related

related processes. This research aimed to achieve the following key aspects of the AAM and UAS industries:

- Identify the novel advanced material systems and processes in use and being considered for advanced air mobility and unmanned aircraft systems designs.
- Understand the major differences between the future advanced materials and currently available traditional materials for which the FAA has already published policy and guidance for certification purposes.
- Identify potential limitations of current policy and guidance and propose future activities to support UAS and AAM certification.

APPROACH

This research project was divided into three working packages. Under the first working package, the research questions that need to be addressed in this study are defined. Under the second working package, a literature review and an industry-based survey were conducted to address the research questions defined in the first working package. The third working package consisted of a peer-reviewed final report. A detailed breakdown of these working packages is presented below:

Working Package 1 – Research Questions

In this working package, the WSU and MSU research teams along with the FAA leadership identified the primary research questions to be addressed in this project:

Research Question - 1: Novel Advanced Material Systems and Processes

This research question focused on identifying any new or unique composite or other advanced material systems and processes in use or planned for future use on AAM and UAS aircraft but are currently not in use on traditional aircraft or rotorcraft. This question aims to identify all the composite materials, additively manufactured, and components manufactured through other advanced manufacturing applications.

Research Question - 2: Applications of Existing Advanced Material Systems

This research question focused on identifying new or unique applications of existing composite materials in AAM and/or UAS aircraft. Additional areas of focus are:

- To identify if advanced materials such as thermoplastics, ceramic matrix composites, and hybrid structures are in use in AAM and/or aircraft.
- To identify and document the joining methods and repair and inspection criteria.

Research Question – 3: Public Material Databases – Critical Material Characteristics for AAM and UAS

This research question focused on identifying material characteristics uniquely critical to the AAM and UAS that are not included in the material databases developed for traditional aviation applications, such as Composite Materials Handbook-17, National Center for Advanced Materials Performance, or Metallic Materials Properties Development and Standardization.

Working Package 2 – Literature Review and Industry Survey

A literature review and industry-wide survey were conducted to address the research questions described in Working Package 1. The industry survey was conducted using New Product Blueprinting, a commercially available market survey software. A total of 33 interviews were conducted with leading raw material suppliers, AAM and UAS original equipment manufacturers, tier-one suppliers, and subject matter experts from industry and academia. The objective was to conduct a broad set of interviews to obtain diverse and wide-ranging data from various divisions of the AAM and UAS industries.

Working Package 3 – Peer-Reviewed Final Report

The final report consisting of findings from the course of this research project was peer-reviewed and published.

Key Findings:

- A majority of the first-generation AAM aircraft is to use legacy traditional aerospace materials and manufacturing processes. This is expected to change in the second-generation vehicles as higher volume manufacturing will drive automation and novel material systems selection.
- Some of the advanced materials currently in use and planned for future use in AAM aircraft are traditional thermoset materials, snap cure thermosets, and thermoplastics.
- Some of the fabrication processes currently in use and planned for future use are hand layup, autoclave cure, automated fiber placement, automated tape layup, resin transfer molding, stamp forming, and continuous compression molding.
- With regards to the small UAS industry (under 55 lbs. 14 CFR 107), some of the advanced material systems currently being used are carbon fiber, glass fiber composite materials, aluminum, magnesium-based alloys, and core materials such as honeycomb, expanded polypropylene, and polyvinyl chloride foams.
- Some of the manufacturing processes being used are molding processes such as injection molding, over-molding, compression molding, and additive manufacturing technologies.
- The non-small UAS industry (over 55 lbs.) is interested in adopting materials and

processes followed by the automotive industry and reduce the costs associated with traditional aerospace applications. The material systems of interest are rapid-cure thermosets and thermoplastics.

NAME & ORIGIN OF RESEARCH PERSONNEL

GERARDO OLIVARES - WSU	UNITED STATES
LUIS GOMEZ - WSU	UNITED STATES
ASWINI KONA RAVI - WSU	INDIA
AKHILL BHASIN - WSU	INDIA
HOOLOOMANN RAMDIAL - WSU	MAURITIUS
MATTHEW ROBERSON - MSU	UNITED STATES
WAYNE HUBERTY - MSU	UNITED STATES
CHRISTOPHER BOUNDS - MSU	UNITED STATES

GRADUATION OF STUDENTS

HOOLOOMANN RAMDIAL	DECEMBER 2021

PROPOSE UAS RIGHT-OF-WAY RULES FOR UNMANNED AIRCRAFT SYSTEMS (UAS)OPERATIONS AND SAFETY RECOMMENDATIONS

LEAD

BACKGROUND

Right-of-Way rules govern the interactions between non-cooperative aircraft in order to maintain safe interactions. Right-of-Way rules were derived in part from the See-and-Be-Seen safety concept, the maneuverability limitations of aircraft types to give way, and other safety considerations.

The research effort is to develop safety-based recommendations to the FAA for UAS right-of-way rules in order to better accommodate UAS integration into the National Airspace System (NAS). The research effort will also benefit UAS standards (e.g. 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
  - Examples include: UAS waiver assessments, policy development, rulemaking, etc.
- UAS industry standards development
  - Examples include: design standards, training standards, operations and procedure standards, etc.

APPROACH

Task 1: Background Report

The performer has performed 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 to include 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 was necessary to support right-of-way rules. The performer identified potential gaps in 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 to include 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 AAM/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 leads 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 on research tasks, and to be used as a reference for safety recommendations developed by the project. The report was peer reviewed by the ASSURE performers, appropriate subject matter experts determined by the FAA, and comments were adjudicated.

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, ability for the researchers to providing 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 will prioritize research to be conducted in follow-on tasks based on available resources, project schedule, industry need, safety considerations, and other applicable criteria that is needed to address the gaps in UAS right-of-way rules. Based on the research prioritization the performers will create a simulation plan and 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 will include:
- Visual Conspicuity Flight Test Plans (Task 4) to answer research questions needed to form new right-of-way rule recommendations.
- Selection of appropriate/expected DAA architectures/equipment and sensors for simulations and demonstration flights in Task 3 and Task 4. Simulations in Task 3 will include both single and multiple-UAS interactions.
- Simulations to validate proposed

right-of-way rules using physics-based simulations of UAS and crewed aircraft maneuvering, including expected computational decision-making and communication latencies and automation failures.

- Demonstration flights (Task 4) to validate proposed right-of-way rules

The performer must identify the necessary tools and techniques to precisely capture the test conditions; the data to be collected; how the data will be analyzed; lessons learned; images, video, or recordings that can be referenced for safety discussions; and so forth.

Task 4: Flight Test

Based on the outcomes from previous tasks, the research team will develop flight test plans and execute flight tests of UAS and crewed aircraft encounters for the predetermined use cases. The intent of testing and demonstrations is to refine and validate initial recommendations. The research team will plan, schedule, and execute aircraft encounters with static obstacles and with other (intruder) aircraft. Encounters will be evaluated for test safety and will maintain adequate vertical and/or horizontal separation. Encounters will be structured to facilitate the collection of data to address FAA knowledge gaps and support final recommendations. The research team will utilize the available aircraft, aircrews, and equipment for testing. Due to the cost of technology and availability of technology, multiple UAS (such as swarm flights or multi-robot systems) will be conducted during simulations. If needed, flights to simulate multiple UAS will be accomplished by KU using 2-3 multiple UAS systems. Reports will interpret the significance of test outcomes and the degree to which results refine and validate prior assumptions, understandings, and recommendations. Reports should interpret whether the prior recommendations were supported by the research activities or if those recommendations need to be refined. Reports will document whether research test methods were appropriate for answering the research questions or if changes to test plans are recommended.

Task 5: Final Briefing and Final Report

The performer will summarize and aggregate all of the previous papers and reports (into a final report package for the overall project. The package for the overall project. The final report should answer the knowledge gaps and include research findings from the project tasking. The report should provide clear recommendations to the FAA and UAS standards development organizations. The report should include newly proposed UAS right-of-way rules with safety justification, metrics, thresholds, and other information to support proposals. The report should also highlight areas of future research needed to address remaining gaps in right-of-way rules. The report should discuss how project outcomes can be used to inform policy, regulations, advisory circulars, and industry consensus standards.

KEY FINDINGS

Thus far, the team has completed Task 2 UAS Gap Prioritization, UAS Safety Hierarchy, and identified various right-of-way scenarios for testing and initial right-of-way rules.

NAME & ORIGIN OF RESEARCH PERSONNEL

PAUL SNYDER - UND	UNITED STATES
DR SREEJITH VIDHYADHARAN - UND	INDIA
JOE VACEK - UND	UNITED STATES
JAMES MOE- UND	UNITED STATES
DAN MYLES - UND	UNITED STATES
MICHAEL MULLINS - UND	UNITED STATES
EVAN BOLLINGER - NPUAST	UNITED STATES
JOSEPH REILLY - NPUAST	UNITED STATES
BRAD GENGLER - NPUAST	UNITED STATES
DR M ILHAN AKBAS - ERAU	TURKEY
DR SCOTT BURGESS - ERAU	UNITED STATES
DR KRISTY KIERNAN - ERAU	UNITED STATES
DR MARK EWING - KU	UNITED STATES
DR SHAWN KESHMIRI - KU	IRAN
DR HEECHUL YUN - KU	REPUBLIC OF KOREA
COOPER MCCOY	UNITED STATES
BRAD SCHROEDER - KU	UNITED STATES

GRADUATION OF STUDENTS

KYLE FOERSTER	AUGUST 2023
VIVEK SAINI	MAY 2022
QITAO WENG	MAY 2023
JUSTIN CLOUGH	MAY 2024

IDENTIFY FLIGHT RECORDER REQUIREMENTS FOR UNMANNED AIRCRAFT SYSTEMS (UAS) INTEGRATION INTO THE NATIONAL AIRSPACE SYSTEM (NAS)

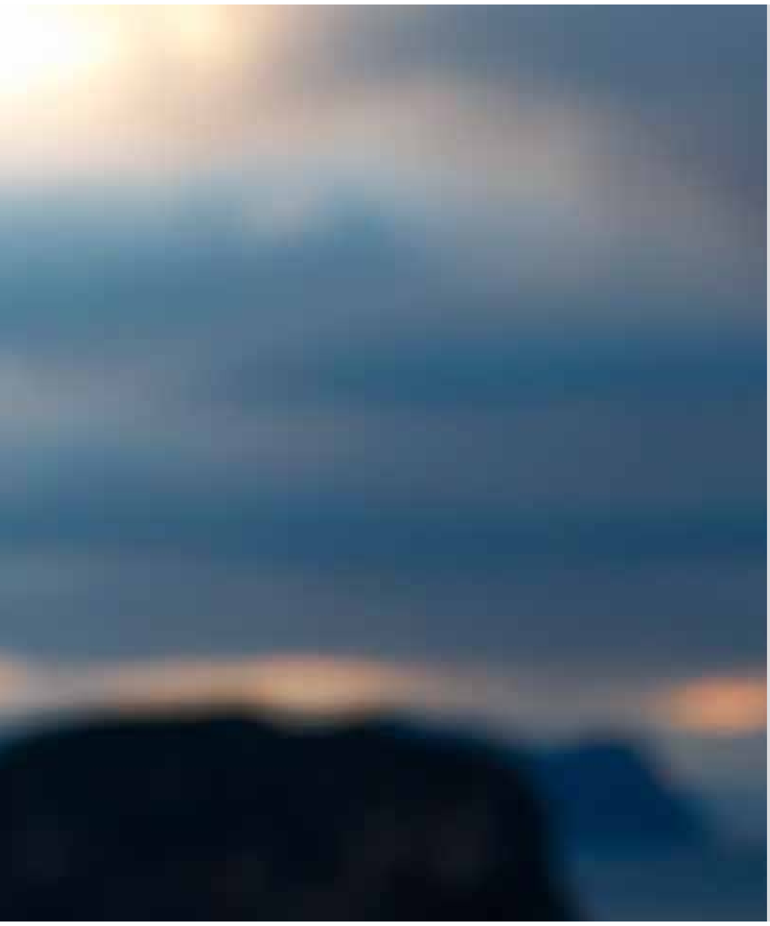
UNIVERSITY OF NORTH DAKOTA
LEAD
WICHITA STATE UNIVERSITY
NATIONAL INSTITUTE FOR AVIATION RESEARCH
EMBRY-RIDDLE
Aeronautical University

BACKGROUND

Unmanned Aircraft System (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. In order 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 FDR, which collects aircraft state and performance data. The second technology is the 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 (ANSI) Unmanned Aircraft Systems Standardization Collaborative (UASSC) 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 Federal Aviation Administration (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 that 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. (Completed)

The team performed a literature review on data recorders that includes 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 shall provide 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 standard, regulation, order, policy, report, 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
- Test methods or metrics on evaluating the data recorder survivability

Task 2: Assess and Develop Proposed Data Recorder Requirements (Ongoing)

Based on Task 1, researchers will evaluate any standards or proposed data recorder requirements from EUROCAE and ASTM for sUAS, medium sized UAS, large UAS, and UAM aircraft. Researchers will evaluate proposals for safety benefit and whether the proposal adequately addresses the data needs 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 benefit, the researchers will also consider cost, size, weight, power, and ease of implementation for the various proposals and standards. The researchers will also develop and propose their own data recorder requirements if industry standards or proposals do not exist or if they feel that proposals did not adequately consider safety benefit, cost, size, weight, power, and ease of implementation for different types of UAS and UAM aircraft.

Leveraging previous work conducted by National Institute for Aviation Research (NIAR) at Wichita State University (WSU) on incident/accident reconstructions to support National Transportation Safety Board (NTSB) investigations, researchers will develop and propose a minimum set of data channels and sampling rates required to conduct future UAS accident/incident investigations. Researchers will also develop an accident reconstruction demonstration example using NIAR's methods to support an accident investigation process. The purpose of this demonstration will be 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 will follow existing test procedures or propose a set of novel test procedures to evaluate the survivability of flight data recorders for sUAS and medium sized UAS. In this task, researchers will identify 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 conduct 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 update previous data recorder assessments and proposed requirements.

Task 5: Final Briefing and Final Report

The team will summarize and aggregate all papers and reports into a final package.

NAME & ORIGIN OF RESEARCH PERSONNEL

DR JAMES HIGGINS	UNITED STATES
DR ZACH WALLER	UNITED STATES
DR RYAN GUTHRIDGE	UNITED STATES
DR BRANDON WILD	UNITED STATES
DR MARK DUSNBURY	UNITED STATES
DR GERARDO OLIVARES	UNITED STATES
LUIS GOMES	UNITED STATES
HARSH SHAW	UNITED STATES
RODRIGO MARCO CARRILLO	UNITED STATES
ARMANDO BARRIGA DE ABREU	UNITED STATES
HOA LY	UNITED STATES
DR HOUBING SONG	UNITED STATES
RICHARD STANSBURY	UNITED STATES
CARLOS ALBERTO CASTRO	UNITED STATES
CHENGTAO XU	UNITED STATES

EVALUATE UAS ELECTROMAGNETIC COMPATIBILITY (EMC)

LEAD

BACKGROUND

This research is focused on small UAS (sUAS) and medium sized UAS that are smaller than a typical light sport aircraft. The term, "UAS" is intended to cover both of these UAS categories within this requirement.

UAS operations that encounter Electromagnetic Interference (EMI), Magnetic Fields, or Electric Fields may experience:

- Loss of Control
  - Sudden unpredictable runaway unmanned aircraft maneuvers and loss of control
  - Unexpected maneuvers into terrain, flight obstacles, and across airspace boundaries

- Loss of safety confidence in the system
  - o Decreased trust in automated and semi-automated UAS operations
  - o Remote Pilot frustration and workload saturation from an inability to control the unmanned aircraft
- Adverse behavior for ATC and Airport Operations
  - o For larger UAS, unnecessary deviations from directions given by ATC, disruption of air traffic flow management, frustrated separation services
  - o Unnecessary deviations from flight paths and airport patterns

RESEARCH QUESTIONS

Research is needed to enable the FAA to better understand these risks and answer the following research questions with respect to EMI, H fields, and E fields that a UAS may encounter.

- What are the safety risks? How many reported events are occurring worldwide? What can we learn from those events? What risks are unique to UAS vs other aviation systems?
- What are the expected RF fields encountered at typical RF emitter sites that a UAS may encounter? (e.g. radar, radio, tv, etc.)
- How susceptible are UAS to EMI, H fields, and E fields? What UAS components are most susceptible? (not just the radio, but also includes the aircraft and ground components of the UAS)
- How susceptible are UAS to operations near power lines? (leverage ASSURE Shielded DAA Operations research to the extent possible)
- How susceptible are UAS to static magnetic fields such as steel structures and ground based fields such as electromagnetics?
- What are the appropriate component and system metrics for describing the degree of susceptibility?
- What are recommended safety thresholds?
- What low cost test methods can be used to evaluate UAS for susceptibility?
- What low cost mitigations can be incorporated into UAS design to mitigate the various risks? (e.g. methods to increase immunity, methods of detection, etc.)
- What operational procedures are recommended to mitigate the various risks? (e.g. minimum distance from power lines,

methods to verify operational status before takeoff, awareness of local transmitters and how to know if they are a problem, information on what platforms an aircraft should not take off from or fly next to, etc.)

APPROACH

Task 1: Literature Review and Risk Identification

The performers will conduct a literature review to determine if there are existing answers to the research questions. Leveraging the literature review, the team will identify potential risks and vulnerabilities for UAS operations. The performers will propose risk metrics for the subject matter. They will also make recommendations for future areas of study. The literature review is broken down into 3 sub-tasks to cover 1) impacts of radio frequency emissions, 2) trust methods in automated and semi-automated operations, and 3) effects of static magnetic fields.

Task 2: Research Planning

The performers will hold a scoping peer review with the FAA in order to prioritize the work that would be most beneficial for answering the research questions and meeting project objectives. The performers will develop plans to conduct that work. This could include test plans, simulation plans, analysis plans, and/or validation demonstrations that show the effectiveness of low-cost testing methodologies or show the benefits of proposed low-cost mitigations.

Task 3: Plan Execution

The performers will integrate the Report and Validation Results of Task 2 into a single report. This report will include 1) the impacts of power lines on UAVs and quantify the electromagnetic field strength. Lab-based experimental results will validate the field strength and also provide the impact to UAVs; 2) effect of EMI on UAS components such as GPS/sensor that may lead to loss of control or safety; and 3) baseline wireless performance of UAS autopilot operations.

The team will conduct the agreed to tests, analyses, simulations, and/or demonstrations from approved plans and document what was done along with any unexpected outcomes, challenges, and lessons learned. Reports will interpret the significance of outcomes and the degree to which results refine and validate prior assumptions, understandings, and recommendations.

Task 4: Final Report

The team will summarize and aggregate all of the previous papers and reports into a final report package for the overall project. The Final Report should answer the research questions and provide clear recommendations to the FAA and industry standards. The final report will also make recommendations for future research.

KEY FINDINGS

University of Kansas:

Front-door effects on UAS C2 Links:

1. Front-door ISR thresholds for stable and unstable C2 link connection and disconnection
2. Potential WiFi RFI effects and safety distances to WiFi access points
3. Potential adjacent 4G LTE/5G RFI effects

and safety distances to transmit tower

Backdoor RFI effects on UAS sensors (accelerometers, gyros, compass, LiDAR, barometers) and autopilot

1. Conservative safety distance to cellphone towers
2. Conservative safety distance to airport ASR antennas

University of North Dakota:

- No significant magnetic field was measured across multiple transmission lines from the data captured using several UAS.
- The electric and magnetic fields are large enough to cause adverse impacts to UAS battery and subsequently motor current in drones near antenna locations on microwave towers.
- The rate of battery degradation was faster near 230kV line than other power transmission lines.

Drexel University:

Drexel characterized the influence from 60 Hz transmission line magnetic fields to UAS onboard sensors (magnetometer, gyroscope, and GPS).

NAME & ORIGIN OF RESEARCH PERSONNEL

GARY FRIEDMAN - DU	UKRAINE
FEI LU - DU	CHINA
AMR MOSTAFA - DU	UNITED STATES
SHERVIN SALEHI RAD - DU	IRAN
SHUYAN ZHAO - DU	CHINA
JAMAL ALHOURANI - DU	JORDAN
RITUPARNA GOSH - DU	INDIA
RYAN ADAMS - UND	UNITED STATES
PRAKASH RANAGANATHAN - UND	INDIA
NIROOP SUGUNARAJ - UND	INDIA
ZAKARIA EL MRABET - UND	MOROCCO
JAYA PREETHI MOHAN - UND	INDIA
AKSHAY RAM RAMACHANDRA - UND	INDIA
BARATHWAJA SUBASH CHANDAR - UND	INDIA
ANTON SKURDAL - UND	UNITED STATES
JILU LI - KU	CHINA
FERNANDO RODRIGUES-MORALES - KU	UNITED STATES
CARL LEUSCHEN - KU	UNITED STATES
MARK EWING - KU	UNITED STATES
SHAWN KESHMIRI - KU	UNITED STATES
AARON PADEN - KU	UNITED STATES
DANIEL GOMEZ -GARCIA - KU	BOLIVIA
AARON MCKINNIS - KU	UNITED STATES
DEEGODAGAMAGE MIHINDU SUMANASEKARA - KU	SRI LANKA

GRADUATION OF STUDENTS

AMR MOSTAFA - DU	DECEMBER 2023
SHERVIN SALEHI RAD - DU	DECEMBER 2025
SHUYAN ZHAO - DU	DECEMBER 2024
JAMAL ALHOURANI - DU	DECEMBER 2025
RITUPARNA GOSH - DU	DECEMBER 2025
NIROOP SUGUNARAJ - UND	DECEMBER 2025
ZAKARIA EL MRABET - UND	MAY 2022
JAYA PREETHI MOHAN - UND	MAY 2023
AKSHAY RAM RAMACHANDRA - UND	MAY 2024
BARATHWAJA SUBASH CHANDAR - UND	DECEMBER 2023
ANTON SKURDAL -UND	DECEMBER 2024
AARON MCKINNIS - KU	MAY 2023
DEEGODA GAMAGE MIHINDU SAMANASEKARA - KU	MAY 2025

INVESTIGATE DETECT AND AVOID (DAA)TRACK CLASSIFICATION AND FILTERING

THE OHIO STATE UNIVERSITY
LEAD
EMBRY-RIDDLE Aeronautical University
MISSISSIPPI STATE UNIVERSITY
UNIVERSITY OF NORTH DAKOTA
CAL ANALYTICS

BACKGROUND

Developing robust Detect and Avoid (DAA) systems is a key requirement for enabling routine Beyond Visual Line of Sight (BVLOS) missions in the National Airspace System (NAS). A hurdle to their widespread adoption is a lack of track classification performance requirements related to 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 the development of 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 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 from 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 will conduct 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 will be used to assign a likelihood and severity of the risks identified in Task 1. These metrics will be 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 a functional hazard analysis, failure modes, effects, criticality analysis, or fault trees may be used. Additionally, categorization and identification of the impact of misleading information on overall system risk will be investigated.

Mitigations to the prioritized risks will be developed. The risk mitigations may be operational, or material in nature. The mitigations will be sorted into categories like the risks and assessed for feasibility, utility, and effectiveness at a qualitative level. This task will be reinforced via the literature research and industry survey.

The risk prioritization and mitigation development tasks will heavily inform requirements and metrics development. Specifically, the team will develop requirements/metrics to guide air picture cleanliness, classification performance requirements, data filtering, and human factors for DAA systems. These requirements/metrics will be 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 will be provided with key recommendations regarding prioritization, mitigation, and requirements outlined. This report will form the basis for test planning in Task 3.

Task 3: DAA System Performance and Test Planning

A test plan will be developed focused on air picture modeling. Scenarios will be 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 will be used to characterize DAA system performance and help evaluate the developed air cleanliness, classification performance, and data filtering requirements.

Specific modeling constraints for incorporating pilot-in-the-loop simulations will be identified to assess overall task loading based on airspace density and the number of UAS under control by the PIC. This framework will be incorporated into the modeling and simulation framework adopted in Phase 2 testing.

A final report for Task 3 will be developed to recommend testing to be conducted in Phase 2 of the research with specific recommendations for model development to enable the accurate assessment of air picture cleanliness.

Task 4: Peer Review / Feedback from Standards Bodies

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

Task 5: Scenario and Subsystem Model Refinement

Phase 1 of this project culminates with FAA and industry review of developed and prioritized risks, risk mitigations, and requirements /

metrics accordingly. The team will coordinate updates with the FAA to ensure their buy-in before finalization.

After the team has developed mature risks/metrics for DAA system and associated performance, the team will develop encounter scenarios to fully understand and exercise the interaction of developed performance requirements/metrics and risks to DAA systems. The encounter scenarios will be tailored to align with the prioritization of risks, risk mitigations, and requirements/metrics. Encounter scenarios will cover 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 will be exercised in a variety of airspace densities (sparse to dense) and misleading surveillance information rates (low to high) to understand the impact to 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 will be used to develop representative sensor models for ground and airborne DAA systems. These will be 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 will be collected from representative DAA systems currently emplaced to assess clutter performance, track classification and filtering performance, and to provide repeatable test scenarios for evaluation in the modeling and simulation framework. These clutter representations will be 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 will be 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 will be generated. The results will 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 started development of risk models which 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 begun developing granular clutter models based on specific sensor interfaces and failure modes, which include such physical sources as random stochastic noise, and colored sources such as returns from non-aircraft targets moving or stationary targets. Embry Riddle Aeronautical University has begun the development of a unified simulation engine which will allow for incorporation of 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.

NAME & ORIGIN OF RESEARCH PERSONNEL

MATTHEW MCCRINK - OSU	UNITED STATES
DHUREE SETH - OSU	INDIA
CHRISTA MSKELVEY - OSU	UNITED STATES
RICHARD PRAZENICA - ERAU	UNITED STATES
KYLE RYKER - MSU	UNITED STATES
BOUTINA DRIOUCHE - MSU	UNITED STATES
BRYAN FARRELL - MSU	UNITED STATES
JEREMIAH NEUBERT - UND	UNITED STATES
MARK ASKELSON - UND	UNITED STATES
SEAN CALHOUN - CAL ANALYTICS	UNITED STATES

ILLUSTRATE THE NEED FOR UAS CYBERSECURITY OVERSIGHT AND RISK MANAGEMENT

KU
LEAD

The Ohio State University

Drexel University

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 gaps in Cybersecurity. This research requirement will address the need for Unmanned Aircraft Systems (UAS) Cybersecurity Oversight and Risk Management as it pertains to the relationship to the National Airspace System (NAS) and Federal Aviation Administration (FAA) systems.

APPROACH

Task 1: Literature Review and Industry Engagement

Researchers will review all publicly available information concerning the IG, GAO, and other reports that delineate Risk Management Assessments elements, concerns, and best practices. Example: In GAO-19-105, the Executive Summary highlighted 5 Core Security functions that Federal Agencies were evaluated on (Identify, Protect, Detect, Respond and Recover). Researchers will work from the GAO-19-105 and an initial with additional emphasis on cyberphysical issues common in UAS environments. Researchers will continue to work with industry partners 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 performers will map static analysis, simulation, and cyber-physical system analysis to UAS specific cybersecurity tasks. The resulting framework will provide an initial roadmap for applying a framework to an operational system.

Task 3: Test Cybersecurity Oversight Tool or Process

Researchers will test the UAS Cybersecurity Oversight and Risk Management Tool or Process created in Task 2. They 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 will select a common platform and apply the framework and associated tool to that platform. Both simulation and flight testing will be employed. Furthermore, the researchers intend to involve student "hacking clubs" from participating institutions in demonstrating attacks as a way to broadly disseminate this approach while educating next-generation professionals.

Task 4: Peer Reviewed Final Report and Final Briefing

The performers will write a final report documenting:

1. The Cybersecurity Oversight Tool or Process
2. The process and results of testing the Cybersecurity Oversight Tool or Process
3. Areas of need and future research

KEY FINDINGS

As anticipated, existing cybersecurity frameworks are too general for effective application in the UAS domain. The GAO-19-105 report documents five canonical cybersecurity functions - Identify, Protect, Detect, Respond and Recover – that do apply, but must be specialized for UAS application and operational environments. Discussions with industrial partners confirm this finding.

The researchers have begun mapping specific mechanisms to functions defined by more general frameworks. The team has seen application of NLP to malware discovery and will see application of model finding to discover where an adversary may work around an executing protocol. These studies exemplify this approach of mapping techniques to abstract cybersecurity functions. Specifically, the team is examining static analysis, dynamic analysis, and cyberphysical system analysis techniques within the GAO-19-105 framework. This examination provides guidance to engineers as well as demonstrating the need for a specific UAS cybersecurity framework.

Several important decisions made this far involve selection of an experimental platform. This approach will use the same framework across all research activities. The team has identified ArduPilot as the primary flight control system for exploring system attacks. ArduPilot is widely used and has accompanying simulation software that supports simulation during testing without requiring a physical aircraft. The team has identified UxAS as a user-space application for exploring application specific attacks. UxAS was developed by AFRL for the purpose of providing an experimental platform for the kinds of experiments we are performing.

NAME & ORIGIN OF RESEARCH PERSONNEL

PERRY ALEXANDER	UNITED STATES
RAKESH BOBBA	UNITED STATES (INDIA)
STEVEN WEBER	UNITED STATES
ADAM PETZ	UNITED STATES
GARRETT MILLS	UNITED STATES
DREW DAVIDSON	UNITED STATES
MARK EWING	UNITED STATES
HOUSSAM ABBAS	UNITED STATES (LEBANON)
YEONGJIN JANG	REPUBLIC OF KOREA
AKSHITH GUNASEKARAN	UNITED STATES
GABRIEL RITTER	UNITED STATES
KAPIL DANDEKAR	UNITED STATES
SPRIOS MANCORIDIS	UNITED STATES
MALVIN NKOMO	ZIMBABWE
SADIA ANNANA	BANGLADESH
ABHINANDA DUTTA	INDIA
HARIHARAN NARAYANAN	INDIA
JOHN CARTER	UNITED STATES

EVALUATION OF UNMANNED AIRCRAFT SYSTEMS (UAS) INTEGRATION SAFETY AND SECURITY TECHNOLOGIES IN THE NATIONAL AIRSPACE SYSTEM (NAS) PROGRAM

LEAD

BACKGROUND

After years of close coordination, the FAA and "federal security partners" Departments of Defense, Energy, Justice, and Homeland Security obtained the authority to test, operate, and evaluate systems and technologies that help ensure the safe and secure integration of UAS into the National Airspace System (NAS). The National Defense Authorization Act (NDAA) of 2017 granted the DOD and DOE authorities to safeguard the NAS. The NDAA act of 2018 expanded the DOD's authorities by increasing the types of facilities and assets that could be covered by these technologies. The FAA Reauthorization Act of 2018 provided the DHS and DOJ similar authorities to those

of DOD and DOE for specific mission sets. The FAA was also granted authority in the FAA Reauthorization Act of 2018 to employ these technologies for testing, research & development activities, and to support plans for standards derivations.

UAS technology offers tremendous benefits to our national economy and society. The limitless versatility of UAS also presents unique safety and security challenges. Technologies and processes for the detection, tracking, and identification of UAS cannot be truly effective without a means for differentiating legitimate, safe, and secure operations from those that may be unauthorized. The interdependency of these technologies, systems, processes, and procedures requires a holistic solution set that is suitably proven and interoperable. Any proposed solution must take into consideration a wide array of potential for misuses, maintain the security posture of interagency partners, provide a means for compliance with permissible operations, and support enforcement actions when necessary.

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, 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 (COP) and UAS Traffic Management (UTM) 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 qill support development aimed at solutions for critical national security problems affiliated with the hazardous and malicious operation of UAS. This development of solution 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, Communications, Navigation, and Surveillance (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.

APPROACH

Task 1: UAS Flight Operations

The Performer will conduct UAS flight operations demonstrating the various flight characteristics and scenarios developed to assess the counter-UAS system's 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.

Task 2: Analysis and Recommendations for UAS Integration Safety and Security Technologies

The FAA's UAS integration effort and associated legislation has increasingly focused on ensuring the safety and security of UAS operations. The results of this effort will directly inform safety and security policy development and legislative requirements for:

- Ensuring that technologies or systems that are developed, tested, or deployed by Federal departments and agencies to detect and mitigate potential risks posed by errant or hostile UAS operations do not adversely impact or interfere with safe airport operations, navigation, air traffic services, or the safe and efficient operation of the national airspace system.
- Developing UAS integration safety and security systems to detect and mitigate unauthorized UAS that interfere with firefighting efforts in our nation.
- Developing UAS integration safety and security systems to detect, identify, and reduce the severity and impact of unauthorized UAS that interfere with approved manned and unmanned aircraft operations.

UAS and supporting technologies, sensors for differentiating between different types of aircraft, COP and UTM systems, performance standards, policies and procedures, and many other technologies and processes for ensuring the safety and security of UAS operations are evolving rapidly. Therefore, the analyses and recommendations developed during this task will be reported in multiple steps to provide the sponsors with the most up to date information as the technologies, procedures, and understanding develop during the course this effort. The analyses and recommendations will be divided into the following reports:

1) Technologies, Sensors, and Systems Report

2) Safety, Efficacy, and Interoperability Report
3) Certification, Detection, Tracking, Identification, and Hazards Report
4) UAS Integration Safety and Security Interference Report
5) Development of Minimum Performance Standards Report
6) UAS Integration Ontology

KEY FINDINGS

The FAA and DHS have a variety of complementary testing needs. Identifying what tests at specific locations within specified timeframes will maximize the use of this project's, FAA's, and DHS's resources and collect the data required to answer the research questions has been challenging.

In response to a Request for Information, vendors offered diversity of safety and security systems, including both hand-held and stationary, radiofrequency jamming and command and control spoofing, warhead intercept, high-powered microwave, and high-powered laser systems for conductingmitigation activities, for participation in flight campaigns. They also offered a wide variety of detection, tracking, and identification techniques including passive radiofrequency monitoring, acoustic monitoring, remote identification monitoring, and radar detection.

The team, in consultation with program sponsors, identified a diversity of Group 1 and Group 2 aircraft (~30 types) with a variety of control links and protocols and flight characteristics (e.g. multicopter vs. fixed-wing) to challenge the various counter-drone systems during the test events.

NAME & ORIGIN OF RESEARCH PERSONNEL

CATHERINE CAHILL - UAF	UNITED STATES
NICK ADKINS - UAF	UNITED STATES
GREGORY FOSTER - UAF	UNITED STATES
BEMNER NICKISCH - UAF	UNITED STATES
LEVI PURDY - UAF	UNITED STATES
MATTHEW WESTHOFF - UAF	UNITED STATES
JASON WILLIAMS - UAF	UNITED STATES
RONALD WINNINGHAM - UAF	UNITED STATES
WILLIAM REMMERT - UAF	UNITED STATES
ZACH BARNES - UAF	UNITED STATES
REBECCA GARCIA - MSU	UNITED STATES
SAMEE KHAN - MSU	UNITED STATES
SHAWN MCNUTT - MSU	UNITED STATES
JENNIFER BJORAKER - NMSU	UNITED STATES
HENRY CATHEY - NMSU	UNITED STATES
JOSEPH MILLETTE - NMSU	UNITED STATES
MITCHELL MATHEISON - NMSU	UNITED STATES
JERRY HENDRIX - UAH	UNITED STATES
HENRY CATHEY - NMSU	UNITED STATES
JOSEPH MILLETTE - NMSU	UNITED STATES
MITCHELL MATHEISON - NMSU	UNITED STATES
JERRY HENDRIX - UAH	UNITED STATES

CONDUCT SCIENCE TECHNOLOGY ENGINEERING AND MATH (STEM) OUTREACH TO MINORITY K-12 STUDENTS USING UNMANNED AIRCRAFT SYSTEMS (UAS) AS A LEARNING PLATFORM (STEM IV)

LEAD

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 Unmanned Aircraft Systems (UAS) field, the FAA UAS Center of Excellence (COE)/ASSURE is conducting STEM activities using UASs 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.

In FY17 and FY18, New Mexico State University and Tuskegee University performed Phase II of the Minority Outreach project, which consisted of two UAV Roadshows per university (conducted September to November 2018) and summer camps (held in June and July 2018). The target audiences for these events were Grades 5 -12 students. The Roadshows focused on Physics of Flight, Subsystems of a UAV and UAS, how UASs are used, how the FAA is interfacing with UAS and past ASSURE research including dynamics of airborne collision, UAS traffic forecasting and Detect and Avoid (DAA). The summer camps focused on physics of flight, flight simulator exercises, wind tunnel demonstrations, hands on projects, and a team research project (encompassing programming and data collection and analysis).

All materials that were used by the roadshows and summer camps were provided to ASSURE and consist of building blocks that can be mixed and matched to be tailored for future STEM programs and can be replicated by other groups.

For Phase III of the Minority Outreach Project (in FY18 and FY19), two additional ASSURE Universities, The Ohio State University and Sinclair College, used the materials created in Phase I to conduct STEM programs and tailored their approaches to the specific underrepresented communities in their geographic areas. In the FY21 follow-on, new COE Universities expanded the reach of the program further by building upon the previous phases of this project. FY22 will further expand on previous work.

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. This effort, Phase IV, has just kicked off.

APPROACH

NCSU: NC State is already active in K12 STEM education through myriad on and off campus programs. This funding allows for increased capacity and a greater focus on UAS and aviation subjects within the broader STEM initiatives. In addition, many NC State programs already support the FAA's focus on minority and under-resourced communities with respect to diversity in STEM fields.

KSU: 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 proposes a mix of virtual and face-to-face engagements with middle school students from underrepresented communities in the state of Kansas. Specifically, we will focus on areas with large percentages of Hispanic and Black students. KSU will primarily focus on Kansas City, Topeka, and Wichita.

To motivate the next generation of UAS pilots and aviation leaders by exposing students to UAS recreational and career options. Student learning outcomes will include: comprehend fundamentals of safe flight operations; understand delineation between hobbyist and commercial operations; successfully complete FAA Recreational UAS Safety Test to become recreational flyer; explore recreational flyer and modeler community-based organizations in their local area; given a kit, build a multirotor UAS; explore basic flight fundamentals on a multirotor UAS

Sinclair: Sinclair College, enabled through its National UAS Training and Certification Center, is very active in UAS related STEM education. This has been partially supported through the ASSURE A29 STEM III project, as well as participation in many separate college hosted events or off-campus camps and hands-on activities. Additional support through this project will enable Sinclair to expand efforts reaching diverse students through directly hosted events and collaborations with partnering organizations.

NAME & ORIGIN OF RESEARCH PERSONNEL

EVAN ARNOLD	UNITED STATES
DANIEL FINDLEY	UNITED STATES
JOY DAVIS	UNITED STATES
KURT CARRAWAY	UNITED STATES
SPENCE SCHRADER	UNITED STATES
SHANNA WALKER	UNITED STATES
JACOB KIMERER	UNITED STATES
ANDREW SHEPHERD	UNITED STATES
DOUGLAS HAMMON	UNITED STATES
SETH SCHWARTZ	UNITED STATES
JOSHUA BOHUN	UNITED STATES
BRADLEY MACLEOD	UNITED STATES
BRANDON JACOB	UNITED STATES
BRENDON MOSS	UNITED STATES
AMANDA WARREN	UNITED STATES
TRISTIAN GIARDULLO	UNITED STATES

Disaster Preparedness and Emergency Response – Phase III

THE UNIVERSITY OF ALABAMA IN HUNTSVILLE
LEAD

NM STATE UNIVERSITY

The University of Vermont

NC STATE UNIVERSITY

KANSAS STATE UNIVERSITY

BACKGROUND

This research ties directly to the M-17-30 OMB Memo in that it addresses the RE&D priority practice to maximize interagency coordination by ensuring that the COE works with federal agencies such as DOI, and DHS, as well as regional, state, and local organizations to study the use of UAS by each agency during emergency and disaster responses. This will help research coordination and avoid duplicative efforts across the government. This effort will be a continuation of the A28 Disaster Preparedness and Response effort.

Currently in the National Airspace System, during emergencies, unmanned aircraft

systems have created incursions that have hampered those emergency responses. With a coordinated response, UAS have shown to be extremely helpful and useful to first responders. With DOI doing their own research into how to help respond to natural disasters, the FAA has an opportunity to determine coordination procedures to ensure safety in the NAS.

The 2018, 2019, and 2020 Omnibus Budget appropriations also directs the FAA to support the expanded role of the UAS Center of Excellence (COE). This also directs the COE to "expand the Center's role in transportation disaster preparedness and response."

Through contrinuation of ongoing efforts, the FAA will ensure that the Center of Excellence expands its role into these areas while also helping to meet the FAA's overall goal of safe UAS integration into the NAS.

APPROACH

This work is Phase III of UAS Disaster Preparedness and Emergency Response Research. It will build off of the results, findings, and lessons learned from Phase I and Phase II. The requirement is intended to be a long-term research effort that may address the following 6 research areas and subsequent research questions, as well as any additional related questions that arise during the research process.

This project will define and document data exchange requirements with logical models and a data dictionary to support small UAS (sUAS) capabilities and pilot proficiency data. Data must include the necessary performance measures, metrics, and evaluation data provided by (medical, police, fire) that will be captured for each flight event and data elements to be exchanged. This document will continue to evolve and require updates as additional scenarios and use cases are developed under operation sites.

Phase I and Phase II of the UAS Disaster Preparedness and Emergency Response Research uncovered research areas for Phase III. Those are:

- Technological Solutions to Enable Expanded Operations

- Additional Use Cases and Operational Characteristics
- Legislation, Policies, Procedures, and Standards
- Data Sharing and Storage Considerations
- Outreach (Domestic and International)
- Data collector and database for the flight events

Task 1: Review of Phase I and Phase II Findings, Recommendations, and Lessons Learned

The team will conduct an in-depth analysis of the results, findings, recommendations, and lessons learned during Phase I and Phase II.

Task 2: Identification and Analysis of Technological Solutions to Enable Expanded Operations

The team will research technological solutions to enable expanded UAS operations supporting disaster and emergency response and recovery missions.

Task 3: Identification and Analysis of Additional Use Cases and Operational Characteristics

The team will research additional use cases and operational characteristics of UAS supporting disaster and emergency response and recovery missions.

Task 4: Analysis of Legislation, Policies, Procedures, and Standards

The team will research the impact of new legislation on UAS disaster and emergency response and recovery operations, as well as develop draft policies, procedures, and standards for UAS supporting disaster and emergency missions.

Task 5: Investigation of Data Sharing and Storage Considerations

The team will research and evaluate mechanisms needed to address the data needs of the disaster and emergency response and recovery community.

Task 6: Conduct Domestic and International Outreach

The team will research how to expand and streamline outreach within the disaster and emergency response and recovery community, both domestically and abroad. The team will continue to expand involvement in disaster and emergency response and recovery outreach activities, to increase awareness of research and conduct outreach activities. Various types of permitted activities include active participation in related standards activities, conducting outreach at conferences and events approved by sponsor, hosting workshops and working groups to review and assess project findings and recommendations, and flight-testing events.

Task 7: UAS Flight Testing Events and Scenarios

The team will conduct mock (or real) UAS flights at UAS Testing Sites to illustrate the use of UAS during or after different types of disasters and emergencies. These flight events should

should inform the following: the technological solutions identified enable expanded UAS disaster and emergency response and recovery operations, assess the optimal type of UAS to be used during specific disasters and emergencies, the proper coordination procedures needed at the local/state/federal levels, identification of UAS metrics, how to enhance/standardize the collection and sharing of data transmitted during these missions, and any additional findings.

Task 8: Development of Required Documentation

The team should delegate responsibility to various teams to develop the deliverables in addition to the development of the recommended draft policies, procedures, and guidelines for UAS supporting disaster and emergency response and recovery missions. This documentation should be approved by appropriate stakeholders and made publicly available to standards bodies and experts in the disaster and emergency response and recovery domain.

Task 9: Data Collector and Database Development

In this task, the team will develop the data governance, management, and system architecture needed to develop the Data Collector and Database. Data captured by the data collector will be used for flight events, post-event analysis, and other evaluation and analysis efforts. Data collected during the project will be analyzed to produce various key performance measures and metrics that characterize how overall pilot proficiency in a flight environment.

KEY FINDINGS

This project is just starting and key finding are starting to evolve.

NAME & ORIGIN OF RESEARCH PERSONNEL

JERRY HENDRIX - UAH	UNITED STATES
ROBERT MEAD - UAH	UNITED STATES
CASEY CALAMAIO - UAH	UNITED STATES
STEPHEN WARR - UAH	UNITED STATES
BENJAMIN NOEL - UAH	UNITED STATES
ALEXANDER MCGOWAN - UAH	UNITED STATES
JARLATH O'NEIL-DUNNE - UVM	UNITED STATES
DAVID ROSOWSKY - UVM	UNITED STATES
MANDAR DEWOOLKAR - UVM	UNITED STATES
DAVID NOVAK - UVM	UNITED STATES
JAMES SULLIVAN - UVM	UNITED STATES
MOLLY MYERS - UVM	UNITED STATES
ADAM ZYLKA - UVM	UNITED STATES
MADDY ZIMMERMAN - UVM	UNITED STATES
HENRY CATHEY - NMSU	UNITED STATES
JOSEPH MILETTE - NMSU	UNITED STATES
TIM LOWER - NMSU	UNITED STATES
ANDREW DENNEY - NMSU	UNITED STATES
ROSS PALMER - NMSU	UNITED STATES
GARY LENZO - NMSU	UNITED STATES
JUNFENG-MA - MSU	CHINA
ALAN MARTINEZ - MSU	UNITED STATES
EVAN ARNOLD - NCSU	UNITED STATES
DANIEL FINDLEY - NCSU	UNITED STATES
MICHAEL PICINICH - NCSU	UNITED STATES
THOMAS ZAJKOWSKI - NCSU	UNITED STATES
KURT CARRAWAY - KSU	UNITED STATES

PROCEEDINGS & FUTURE RESEARCH

UPCOMING RESEARCH

2022

- Identify Models for Advanced Air Mobility/Urban Air Mobility Safe Automation
- Detect and Avoid Risk Ratio Validation
- Determine The Collision Severity Of Small Unmanned Aircraft Systems (SUAS) In Flight Critical Zones Of Manned Helicopter
- Validate sUAS Well Clear Requirements
- Disaster Preparedness and Emergency Response Phase III

2023

- Develop Models to Inform the Integration of Advanced Air Mobility (AAM) into the National Air Space System (NAS)
- Conduct Safety Risk Management Analysis On Small Unmanned Aircraft Detect And Avoid Systems
- Evaluate Unmanned Aircraft Systems (UAS) Pilot Training and Certification for all UAS Operational Capabilities
- Conduct Science Technology Engineering and Math (STEM) Outreach to Minority K-12 Students Using Unmanned Aircraft Systems (UAS) as a Learning Platform
- Increase Small Unmanned Aircraft Systems Conspicuity in Terminal Environments
- Identify Weather Research and Knowledge Gaps in the Boundary Layer for UAS
- Identify Weather Hazards for Unmanned Aircraft Systems
- Assess the Vulnerabilities of Packaging and Package Containment Systems

JOURNAL ARTICLES & CONFERENCE PROCEEDINGS

Rahmani, S K, Wang, Z J, Matt, J, Chao, H, Zheng, Z, Keshmiri, S and Ewing, M, “Comparison of Low- and High-Fidelity CFD Based Estimates of Forces, Moments, and Aerodynamic Coefficients with UAS Flight Test Data”, 2022 AIAA Aviation and Aeronautics Forum and Exposition 27 June-1 July

Lin, Z, Matt, J J, Chao, H, Zheng, Z and Ewing, M, “Vortex Encounter Modeling and Simulation for Small Fixed-Wing UAS with Inner Loop Attitude Controller”, 2022 AIAA Aviation and Aeronautics Forum and Exposition 27 June-1 July

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
ASSURE FAA Program Management Review, Virtual Web Event	October 2020
Disaster Preparedness and Recovery Peer Review, Virtual Web Event	November 2020
FAA International Roundtable Meeting, Virtual Web Event	January 2021
Safety Case Development, Process Improvement & Data Collection Research Stakeholder Focus Group Meeting, Virtual Web Event	February 2021
AMUSE 2021, Virtual Web Event	February 2021
ASSURE FAA Program Management Review, Virtual Web Event	March 2021
UAM Safety Standards, Aircraft Certification and Impact on Market Feasibility and Growth Potentials Research Peer Review, Virtual Web Event	March 2021
FAA International Roundtable Meeting, Virtual Web Event	March 2021
Waiver Review Research Stakeholder Focus Group Meeting, Virtual Web Event	April 2021
Multi UAS Control Research Stakeholder Focus Group Meeting, Virtual Web Event	May 2021
FAA International Roundtable Meeting, Virtual Web Event	May 2021
FAA UAS Symposium, Virtual Web Event	June 2021
ASSURE Membership for FAA BVLOS ARC	June 2021 - February 2022
FAA International Roundtable Meeting, Virtual Web Event	July 2021
ASSURE Present @ AUVSI Xponential, Atlanta GA	August 2021
Integrating Expanded & Non-Segregated Ops briefing to BVLOS ARC, Virtual Web Event	August 2021
Wake Turbulence Research Focus Group Review, Virtual Web Event	August 2021
Disaster Preparedness and Recovery Peer Review, Virtual Web Event	September 2021
Disaster Preparedness and Recovery Peer Review, Virtual Web Event	September 2021
FAA International UAS/AAM Integration Research Roundtable, Virtual Web Event	September 2021
Shielded UAS Operations Stakeholder Focus Group, Virtual Web Event	September 2021
Program Management Review - Virtual	October 2021
Program Management Review - Virtual	March 2022
Xponential AUVSI	April 2022
FAA symposium	April 2022
Final Peer Review: Integrating Expanded and Non-Segregated UAS Operations into the NAS: Impact on Traffic Trends and Safety	June 2022
Final Peer Review: Advanced Materials Investigation: Composite Material Analysis for UAS & AAM	July 2022
Testified before the Subcommittee: FAA Reauthorization: Integrating New Entrants into the National Airspace System	September 2022
Program Management Review – Alaska	September 2022

PROGRAM MANAGEMENT REVIEW

The entire ASSURE team would like to thank the University of Alaska, Fairbanks, for hosting the September 2022 Program Management Review. The Spring 2023 PMR is to be hosted by Wichita State University National Institute of Aviation Research.

THE ASSURE UNIVERSITY COALITION

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UNIVERSITY

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National UAS
Training and Certification Center

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The FAA's Center of Excellence for UAS Research
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