The FAA's Center of Excellence for UAS Research

ASSURE

Alliance for System Safety of UAS through Research Excellence

2021 ANNUAL REPORT

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ASSURE-UAS

OVERVIEW

FOREWORD

Who would have believed we would still be fighting through the COVID-19 effects for almost two years now? But, as they say, "the show must go on" and so it did. Despite the virus and all the challenges it brought, ASSURE (the Alliance for System Safety of UAS through Research Excellence) was able to maintain pace in providing critical research to inform the Federal Aviation Administration (FAA), national policy, and industry standard groups on how to best integrate unmanned and manned systems into transportation infrastructure around the world. In turn, this work, will enable unmanned aircraft systems (UAS) conducting those dull, dirty, and dangerous missions to better serve societies through increases in commerce, public safety, and other public benefits.

With the help of the FAA and other stakeholders, ASSURE was able to work through some difficult financial challenges caused by the pandemic and long lead-times associated with a burdensome project approval process. The FAA Administrator approved critical cost-share waivers for FY20 and FY21 projects that significantly lowered match requirements easing the financial stress to universities underwriting large matching funds. This waiver enabled the team to continue to take on new projects despite unsure fiscal times. In addition, the FAA streamlined the project approval process allowing for more agile requirement development, proposal approvals, and steady execution of time-sensitive research that feeds the regulatory and standards processes.

While COVID-19 travel restrictions curtailed international expansion supporting the world's Civil Aviation Authorities and harmonization of unmanned aircraft research, standards, and regulations, ASSURE continued to conduct worldwide engagements virtually. As the pandemic and associated travel restrictions ease, ASSURE will once again hit the airways to develop the worldwide research network to support international standardization and conformity.

At the time of this writing, ASSURE researchers are engaged in forty-five different projects at various levels of completion from proposal to final reports and peer review; this is over a 10 percent increase over the substantial number of projects last year…in a pandemic! FAA-ASSURE level of effort in funding has remained strong and steady over the past 4 years.

The FAA has continued to conduct and add research into areas of increasing demand. Work continues to determine detect-and-avoid (DAA) performance standards and the means of compliance to enable beyond-visual-line-of-sight operations critical to the growth of unmanned operations. ASSURE is studying what is happening in the airspace below 400 feet above ground level, mid-air collision potential, and has developed a framework for establishing quantitative desired levels of safety for different operations and airspace. 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 is also studying 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 continued 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. ASSURE has also initiated studies supporting advanced materials and manufacturing, UAS detection and mitigation, a live engine ingest of a UAS, and work that will support UAS Traffic Management (UTM).

This Annual Report provides highlights of the work conducted in FY 2021. Please take a moment to review our work and contact us with any ideas, suggestions, or comments.

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

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MISSION:

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

WEBSITE:

http://www.assureuas.org/

ACKNOWLEDGMENTS

Another year of COVID-19 restrictions has passed with hardly a bump, all made possible due to a tremendous group of program managers, project managers, researchers, administrators, and sponsors.

The challenges continued: closures, shut-downs, different state rules, travel restrictions, and virtual meetings. But, in the second year of operations in the COVID-19 pandemic, we became more efficient and produced even more research. The FAA has been working remotely and has taken on the challenge of functioning and coordinating everything virtually. 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 pandemic normal. We would also like to welcome Mr. Darryl Groves as our new FAA Grants Officer and thank Dr. Patricia Watts for her years of support and wish her well in her new opportunities within the FAA.

I would like to take the long-overdue opportunity to thank Dr. Marty Fuller who has served as Director of Federal Relations for ASSURE's lead university, Mississippi State. He has been integral to the successful funding, organization, and direction of the ASSURE alliance. Dr. Fuller helped coordinate across the ASSURE team the Congressional response and assistance to the challenges created by the pandemic. His efforts along with his colleagues ensured that research could continue during this particularly challenging time.

I would also like to acknowledge the amazing team that ensures that ASSURE runs so smoothly. Billy Klauser, Deputy Director; Hannah Thach, Technical 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 team 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.

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 $53,968,876.34

	Award Amount	Expenditures	Remaining	Cost Share	Cost Share %
Program Office- Mississippi State University	**$7,061,593.78**	**$5,728,832.70**	**$1,332,761.08**	**$4,908,646.78**	**91%**
Core Schools	**$46,907,282.56**	**$20,888,986.52**	**$26,018,296.04**	**$18,498,045.05**	**89%**
Drexel University	$1,548,508.68	$894,610.10	$653,898.58	$725,406.63	82%
Embry-Riddle Aeronautical University	$4,593,369.13	$1,400,196.84	$3,193,172.29	$1,146,565.62	54%
Kansas State University	$3,383,705.00	$1,932,947.57	$1,450,757.43	$1,289,555.38	75%
Mississippi State University	$4,392,242.81	$1,952,660.48	$2,439,582.33	$1,409,803.55	61%
Montana State University	$709,062.28	$670,650.24	$38,412.04	$599,958.32	100%
New Mexico State University	$3,198,093.33	$1,565,999.06	$1,632,094.27	$1,565,999.06	89%
North Carolina State University	$1,052,140.39	$434,941.21	$617,199.18	$229,876.39	46%
Ohio State University	$4,511,139.21	$2,348,828.95	$2,162,310.26	$1,581,850.17	57%
Oregon State University	$2,769,736.00	$320,645.64	$2,449,090.36	$212,666.00	22%
University of Alabama-Huntsville	$5,139,172.43	$2,881,113.36	$2,258,059.07	$3,745,199.51	124%
University of Alaska-Fairbanks	$2,699,739.40	$349,019.25	$2,350,720.15	$430,759.49	40%
University of California-Davis	$111,920.97	$92,513.00	$19,407.97	$93,287.00	83%
University of Kansas	$1,904,173.86	$349,232.93	$1,554,940.93	$257,462.13	16%
University of North Dakota	$6,136,957.07	$2,869,836.05	$3,267,121.02	$2,328,463.96	77%
Wichita State University	$4,757,322.00	$2,825,791.84	$2,436,022.16	$2,881,191.84	61%
Totals	**$53,968,876.34**	**$26,617,819.22**	**$27,351,057.12**	**$23,406,691.83**	**69%**

SUMMARY BY PROJECT

Total Funding $53,968,876.34

	Award Amount	Expenditures	Remaining	Cost Share	Cost Share %
Program Management	**$7,379,115.97**	**$6,044,440.07**	**$1,334,675.90**	**$5,224,254.15**	**92%**
Projects	**$46,589,760.37**	**$19,681,703.04**	**$9,056,183.79**	**$18,182,437.68**	**68%**
A1: Unmanned Aircraft Integration: Certification Test to Validate sUAS Industry Consensus Standards	$299,996.00	$299,996.00	$0.00	$300,280.00	100%
A2: Small UAS Detect and Avoid Requirements Necessary for Limited Beyond Visual Line of Sight (BVLOS) Operations	$799,658.63	$799,658.63	$0.00	$799,944.34	100%

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SUMMARY BY PROJECT

Total Funding $53,968,876.34

	Award Amount	Expenditures	Remaining	Cost Share	Cost Share %
Program Management	**$7,379,115.97**	**$6,044,440.07**	**$1,334,675.90**	**$5,224,254.15**	**92%**
Projects	**$46,589,760.37**	**$19,681,703.04**	**$9,056,183.79**	**$18,182,437.68**	**68%**
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	$1,984,357.73	$219,020.06	$2,132,041.80	114%
A17: Airborne Collision Severity Evaluation - Engine Ingestion	$1,532,252.00	$1,330,857.00	$201,395.00	$1,223,225.81	127%
A18: Small UAS Detect and Avoid Requirements Necessary for Limited BVLOS Operations: Separation Requirements and Training	$1,207,574.00	$1,084,250.44	$123,323.56	$879,393.33	114%
A19: UAS Test Data Collection and Analysis	$431,785.89	$392,121.59	$39,664.30	$410,533.89	95%
A20: UAS Parameters, Exceedances, Recording Rates for ASIAS	$291,681.65	$283,842.10	$7,839.55	$396,319.22	140%

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SUMMARY BY PROJECT

Total Funding $53,968,876.34

	Award Amount	Expenditures	Remaining	Cost Share	Cost Share %
Program Management	**$7,379,115.97**	**$6,044,440.07**	**$1,334,675.90**	**$5,224,254.15**	**92%**
Projects	**$46,589,760.37**	**$19,681,703.04**	**$9,056,183.79**	**$18,182,437.68**	**68%**
A21: Integrating Expanded and Non-Segregated UAS Operations into the NAS: Impact on Traffic	$1,553,909.52	$1,253,451.23	$300,458.29	$412,008.12	79%
A23: Validation of Low-Altitude Detect and Avoid Standards- Safety Research Center	$1,500,000.00	$347,802.70	$1,152,197.30	$140,491.85	28%
A24: UAS Safety Case Development, Process Improvement, and Data Collection	$1,479,956.87	$386,137.74	$1,093,819.13	$345,725.95	70%
A25: Develop Risk-Based Training and Standard for Operational Approval and Issuance	$498,161.00	$271,798.89	$226,362.11	$100,000.00	60%
A26: Establish UAS Pilot Proficiency Requirements	$500,000.00	$314,593.33	$185,406.67	$166,666.00	100%
A27: Establish risk-based thresholds for approvals needed to certify UAS for safe operation	$500,037.00	$416,962.71	$83,074.29	$166,679.00	100%
A28: Disaster Preparedness and Response	$1,999,978.77	$913,482.19	$1,086,496.58	$747,553.77	112%
A29: STEM Outreach- UAS as a STEM Outreach Learning Platform for K-12 Students and Educators (STEM III)	$455,522.22	$272,787.70	$182,734.52	$120,893.99	93%
A31: Safety Risk and Mitigations for UAS Operations On and Around Airports	$1,481,814.00	$275,150.44	$1,206,663.56	$215,529.60	44%
A33: Science and Research Panel (SARP) Support	$70,383.00	$30,086.08	$40,296.92	$10,944.82	16%
A35: Identify Wake Turbelance and Flututer Testing Requirements for UAS	$1,498,921.00	$426,316.04	$1,072,604.96	$165,462.12	16%
A36: Urban Air Mobility (UAM): Safety Standards, Aircraft Certification and Impact on Market Feasibility and Growth Potentials	$1,199,922.00	$368,223.12	$831,698.88	$302,835.63	43%
A37: UAS Standards Tracking, Mapping, and Analysis	$499,900.00	$271,214.24	$228,685.76	$136,882.45	82%
A38: CyberSecurity and Safety Literature Review	$494,238.00	$275,243.47	$218,994.53	$161,103.75	62%
A40: Validation of American Society for Testing Materials (ASTM) Remote ID Standards- Safety Research Center	$750,000.00	$194,552.20	$555,447.80	$31,768.70	13%

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SUMMARY BY PROJECT

Total Funding $53,968,876.34

	Award Amount	Expenditures	Remaining	Cost Share	Cost Share %
Program Management	**$7,379,115.97**	**$6,044,440.07**	**$1,334,675.90**	**$5,224,254.15**	**92%**
Projects	**$46,589,760.37**	**$19,681,703.04**	**$9,056,183.79**	**$18,182,437.68**	**68%**
A41: Air Carrier Operations- Investigate and Identify the Key Differences Between Commercial Air Carrier Operations and Unmanned Transport Operations	$799,745.00	$105,304.48	$694,440.52	$9,377.50	4%
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	$104,721.11	$695,261.89	$7,672.50	3%
A43: High-Bypass UAS Engine Ingestion Test	$440,000.00	$1,878.54	$438,121.46	$1,878.54	1%
A44: Mitigating GPS and Automatic Dependent Surveillance- Broadcast (ADS-B) Risks for UAS	$830,000.00	$123,948.45	$706,051.55	$86,531.45	31%
A45: Shielded UAS Operations- Detect and Avoid (DAA)	$925,000.00	$158,991.45	$766,008.55	$199,998.98	65%
A46: Validation of Visual Operation Standards for Small UAS (sUAS)	$500,000.00	$57,420.23	$442,579.77	$80,442.08	33%
A47: Small UAS (sUAS) Mid-Air Collision (MAC) Likelihood	$1,059,000.00	$96,055.23	$962,944.77	$107,753.35	15%
A49: UAS Flight Data Research in support of Aviation Safety Information and Sharing (ASIAS)	$469,262.00	$83,315.58	$385,946.42	$44,681.30	29%
A50: Small Unmanned Aerial Systems (sUAS) Traffic Analysis	$2,326,501.00	$110,169.40	$2,216,331.60	$4,489.14	0%
A51: Best Engineering Practices for Automated Systems	$3,621,915.74	$49,871.64	$3,572,044.10	$16,989.51	1%
A52: Disaster Preparedness and Emergency Response Phase II	$3,278,651.80	$0.00	$3,278,651.80	$0.00	0%
A53: UAS Advanced Materials Investigation	$318,958.00	$0.00	$318,958.00	$0.00	0%
A54: Propose UAS Right-of-Way Rules for UAS Operations and Safety Recommendations (ERAU, KU, UND)	$1,393,767.00	$0.00	$1,393,767.00	$0.00	0%
A55: Identify Flight Recorder Requirements for UAS Integration into the NAS (ERAU, UND, WISU)	$1,089,090.00	$0.00	$1,089,090.00	$0.00	0%
Totals	**$53,968,876.34**	**$25,726,143.11**	**$10,390,859.69**	**$23,406,691.83**	**69%**

COST SHARE SUMMARY BY CONTRIBUTORS

Adaptive Aerospace Group, Inc.	$5,897.34
Airbus	$459,228.00
AgentFly Software	$50,000.00
ARC	$41,355.58
Arlin's Aircraft	$3,000.00
AUVSI	$15,873.00
Boeing	$46,235.64
Consortium on Electromagnetics and Radio Frequencies	$2,675.00
DJI	$63,285.84
DJI Research, LLC	$48,522.80
Drexel University	$486,396.63
Embry-Riddle Aeronautical University	$960,171.50
General Electric	$145,930.48
GFK Flight	$17,050.00
GoPro	$29,925.60
GreenSight Agronomics, Inc.	$37,777.00
Honeywell	$30,275.78
Huntsville Airport	$199,592.80
Indemnis	$251,685.84
Intel	$113,101.60
K.I.M. Inc.	$51,200.00
Kansas Department of Commerce	$282,180.00
Kansas State University	$1,017,903.78
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	$2,136,319.59
Montana Aircraft	$6,000.00
Montana State University	$521,387.68
New Mexico State University	$1,565,999.06
North Carolina State University	$914,370.49
North Dakota Department of Commerce	$850,904.61
NUAIR	$20,923.02
Ohio State University	$511,194.19
Ohio/Indiana UAS Center (ODOT)	$298,188.75
Oregon State University	$137,666.00
R Cubed Engineering	$6,970.09
RFAL	$21,343.30
Rockwell Collins	$4,015.80
Sandia	$2,257.00
SenseFly	$471,131.36
Simlat Software	$147,260.00
Sinclair Community College	$929,819.40
State of Kansas	$91,604.83
Skyfire Consulting	$349,000.00
Technion Inc	$2,160,621.84
The Cirlot Agency	$116,824.90
University of Alabama in Huntsville	$1,931,661.03
University of Alaska Fairbanks	$430,759.49
University of California Davis	$93,287.00
University of Kansas Center for Research, Inc.	$257,462.13
University of North Dakota	$955,809.88
University of Vermont	$60,021.57
USRA, Inc	$65,800.00
Virginia Polytechnic Institute and State University	$450,580.65
Wichita State University	$2,471,698.84
Total	**$23,406,691.83**

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)
Cumulative Cost Share	**$23,406,691.83**

SUMMARY BY SOURCE

Universities	$15,832,508.91
State Contributions	$1,522,878.19
3rd Party Contributions	$6,051,304.73
Total	**$23,406,691.83**

RESEARCH STUDIES

AIRBORNE COLLISION SEVERITY EVALUATION - STRUCTURAL IMPACT

Wichita State University National Institute for Aviation Research | The University of Alabama in Huntsville | Montana State University | Embry-Riddle Aeronautical University

Lead: Wichita State University's National Institute of Aviation Research

Background:
Wichita State University's National Institute of Aviation Research (NIAR), University of Alabama, Huntsville (UAH), Montana State University (MtSU) and Embry-Riddle Aeronautical University (ERAU) make up the ASSURE COE research team. This follow-on study builds on our 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.

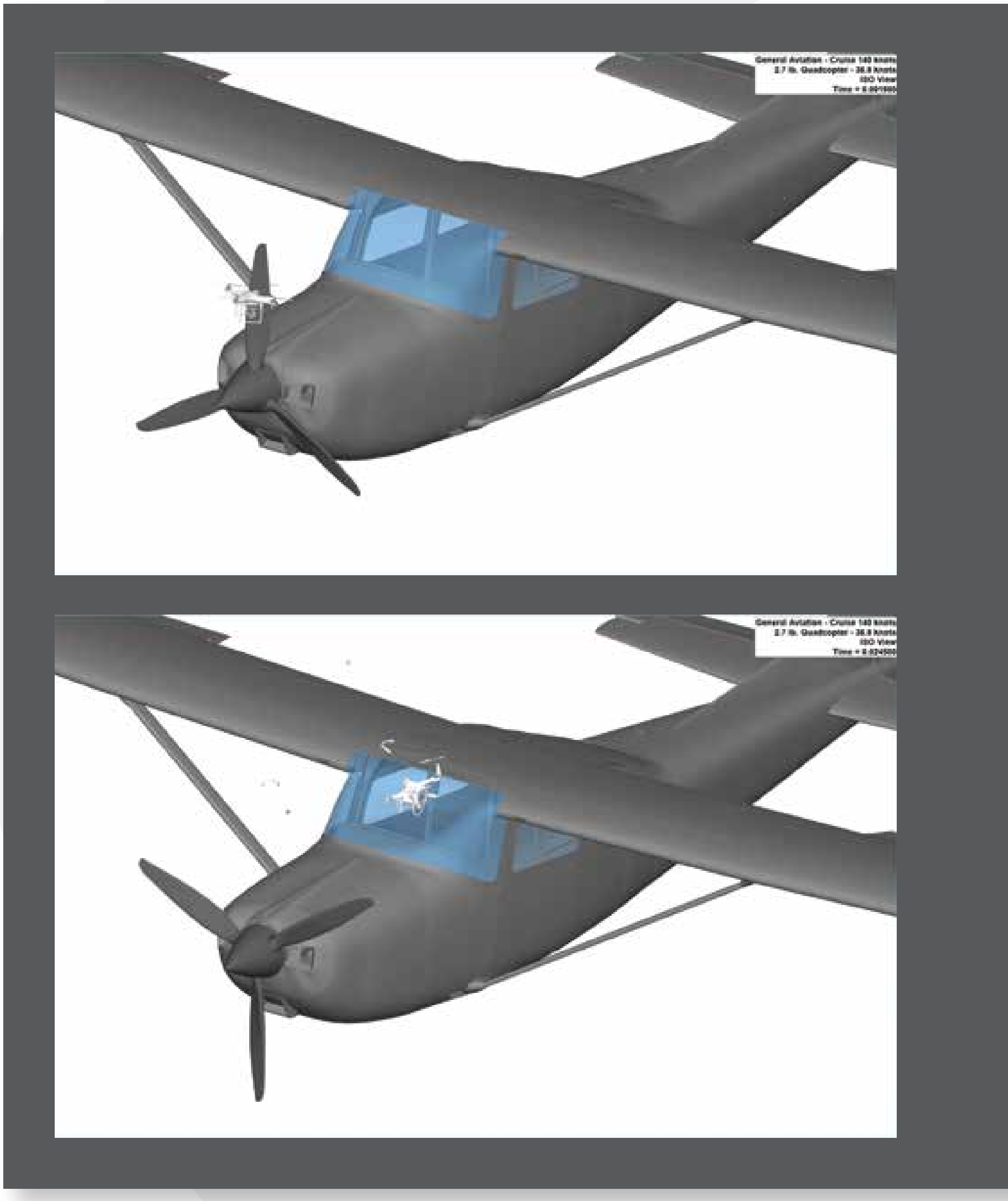
Approach:
The team is approximately two years into the research and plans to complete the project before the end of 2021. The study includes a peer review research task plan conducted just after the award and a review of the final report at the conclusion of the project.

Task 1 – Assessment of sUAS deflections due to aerodynamic Interaction with a commercial aircraft.
The research in Task 1 addresses the question of whether a sUAS could be deflected by the airflow around a large transport aircraft, prior to 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 will analyze 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 address 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 are studying sUAS collisions with rotorcraft airframes; specifically, rotors, blades, windshields, and tail structures. This research will help 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 will be developed. To further validate these models, UAH is conducting component level and full-scale testing. Once validated, the team will conduct crashworthiness structural FEA simulations and damage evaluation for mid-air collision between sUAS and rotorcraft.

Task 3 – Evaluate the severity of small 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 is studying sUAS collisions with GA airframes, specifically looking at propellers, windshields, and tail structures. This research will help identify the damage severity of sUAS-GA airborne collisions. Following NIAR's validated methodology a General Aviation Finite Element Model (FEM) will be developed. The research team will use the data generated by the low-velocity component level testing from Task 2 to validate the models. MtSU is conducting full-scale structural testing that will be used to further validated these models. Once validated, the team will conduct 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.

- Preliminary Task 3 results provide similar level of damage of those observed during the A3 project, with some impact conditions resulting in level 4 damage to the aircraft structure.

Name & Origin of All Research Personnel

Name	Origin
Gerardo Olivares (Lead PI) – WSU	United States
Luis Gomez (Research Manager) – WSU	United States
Rodrigo Marco (Research Engineer) – WSU	Spain
Hoa Ly (Research Engineer) – WSU	Vietnam
Nathaniel Baum (Research Engineer) – WSU	United States
Harsh Shah (Research Engineer) – WSU	India
Nidhi Sathyanarayana (Research Engineer) – WSU	India
Russel Baldridge (Research Engineer) – WSU	United States
Luis Castillo (Research Engineer) – WSU	Mexico
Akhil Bhasin (Research Engineer) – WSU	India
Aswini Kona Ravi (Research Engineer) – WSU	India
Ankit Gupta (Research Engineer) – WSU	India
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UAS AIRBORNE COLLISION SEVERITY EVALUATION – ENGINE INGESTION

The Ohio State University | Wichita State University | The University of Alabama in Huntsville

Lead: The Ohio State University

Background:
As the number of 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 ingest into an engine has been readily studied, the current tests and regulations cannot be transferred from birds to UASs. 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.

The ASSURE research team includes The Ohio State University (OSU), Wichita State University (WSU), and University of Alabama – Huntsville (UAH).

Approach:
The Ohio State University (OSU) is leading this effort working with Wichita State University – National Institute for Aviation Research (NIAR) and University of Alabama at Huntsville (UAH). The research is being carried out in close collaboration with engine industry manufacturers to create finite element (FE) models that will capture critical features of a fan UAV impact. The ingestion simulations will be carried out in LS-DYNA, a finite element 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 strain and impact energies for the nose cone and 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 strains and 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 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.

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

UND University of North Dakota · NM State University · UAF University of Alaska Fairbanks · Kansas State University · Mississippi State University · The Ohio State University

Lead: The University of North Dakota

Background:
A core rule of manned aviation is very concise--see and avoid. Unmanned Aircraft Systems (UAS) do not have the luxury of a pilot in the cockpit to see and safely avoid nearby traffic. The 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 follow-on work builds on our previous efforts to inform FAA regulations and industry standards addressing DAA and BVLOS operations. This ASSURE team:

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

The ASSURE research team includes the University of North Dakota (UND), New Mexico State University (NMSU), University of Alaska Fairbanks (UAF), Kansas State University Polytechnic (KSU), Mississippi State University (MSU), and The Ohio State University (OSU).

Approach:
The research focuses upon four primary tasks. In addition, the researchers have updated previous results, developed a test plan, and will submit 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 builds on our 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, explored framework expansion, and reviewed and revised the 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 is focused on how characteristics of the DAA system and the 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 is needed to validate separation framework simulations, evaluate DAA system capabilities, and evaluate the proposed testing plan. These are the foci of the flight tests. The flight tests also enable updates to the previous Safety Management System (SMS)/Safety Risk Management (SRM) analysis that the ASSURE team conducted.

The NMSU Flight Test Site (NMSU FTS), the Northern Plains UAS Test Site (NPUASTS), and the Alaska Center for Unmanned Aircraft Systems Integration (ACUASI) are conducting the flight tests. To date, six rounds of flight testing have been conducted.

Flight tests have informed the team of DAA system capabilities. They have also provided validation of the separation framework simulations and an opportunity to evaluate testing methodologies. The team has developed and evaluated a safe means for testing horizontal encounters, and has also extended methods to include descend-into and climb-into encounters.

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, there is a need to test encounters where the unmanned aircraft and/or intruder is climbing or descending. Test methods for when the intruder is climbing and descending have been developed.

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

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

The Ohio State University · Kansas State University · Embry-Riddle Aeronautical University · Drexel University · The University of Alabama in Huntsville · University of Alaska Fairbanks · NM State University · University of North Dakota · Virginia Tech

Lead: The Ohio State University and Kansas State University

Background:
This research will provide further insight into the safe integration of sUAS through forecasting of expanded and non-segregated sUAS operations. The ASSURE research team will collect data to inform the FAA on risk-based methodologies to develop and apply safety rules, regulations, and revised Safety Management System (SMS) protocols based on forecasted UAS operational needs and performance characteristics.

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)

As part of this research the ASSURE team will develop a quantitative framework for risk-based decision making and waiver approvals to meet the growing operational needs for OOP and BVLOS and the technological evolution of UAS.

Ohio State University (OSU) and Kansas State University (KSU) are leading this project, with help from Embry-Riddle Aeronautical University (ERAU), Drexel University (DU), University of Alabama-Huntsville (UAH), University of Alaska Fairbanks (UAF), New Mexico State University (NMSU), University of North Dakota (UND), and Virginia Tech (VT).

Approach:
This research is broken down into three phases. Each phase is broken down further into 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.

Phase 1 – Evaluation of data and establishment of quantitative impact of expanded operations
The Phase 1 outcome 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 aeroscope 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 – Establish scope of non-segregated operations
Building upon results from Phase 1, in Year 2 the researchers will project UAS traffic trends for the integration of expanded and non-segregated UAS operations into the NAS. The results will provide predictions regarding demand and an assessment of changes in demand

likely to occur. Phase 2 will also identify avionics equipage and procedure requirements necessary to facilitate expanded and non-segregated operations in the NAS.

The Phase 2 outcome report will include the forecasted demand for expanded and non-segregated UAS operations, the distribution of UAS within the domain (including type, configuration, mission profiles, and equipage), the corresponding environments where the demand will occur, and a timeline which captures the expected pacing of and trends within the forecast.

Phase 3 – 'de minimis' risk likelihood and comparable framework
In Phase 3, the ASSURE team will define a predictable, repeatable, quantitative, risk-based framework for inclusion in the SMS process, including the use of sensitivity analyses to help decision makers consider the range of uncertainty associated with available data. This framework will provide a process for making risk-based decisions that applies across the varying levels of risk associated with the operation of different sUAS and that considers performance-based requirements to mitigate risk.

Key Findings:
Phase 1. 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.

In the Phase 1 report, the team further provides an analysis of Part 107 waiver approval letters. This analysis underscores the barrier that risk assessments associated with the use of DAA (Detect and Avoid) 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 Operations Over People that have been enabled by the use of parachutes. Interviews with FAA staff further indicated that rejections of Part 107 waivers are due primarily to a lack of supporting documentation critical to the development of a safety case in the areas of: operational context, system performance, and safety mitigations.

In Part 2 of the Phase 1 report, the analysis 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 Part 3 of this report, an analysis is 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 DJI 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. An initial assessment is presented in the draft report for Phase 1.

This effort is ongoing. The final report with findings from Phases 1-3 will be delivered to the FAA in January of 2022.

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VALIDATION OF LOW-ALTITUDE DETECT AND AVOID STANDARDS

Lead: Mississippi State University – Safety Research Facility

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 order to:

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

In order to meet the above needs, 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 in order 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.

Increases in UAS operations have also led to an increase 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 to measure pilot performance by MIT's Lincoln Laboratory in 1986-1991. 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 in order to develop recommendations for the validation and incorporation of Human Factors into specific UAS applications.

As the above 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 upon ensuring acceptable levels of safety for aviation stakeholders and the public at large. The secondary focus is to minimize any potential impacts upon 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).

Mississippi State University – Safety Research Facility (MSU) is leading this effort.

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 and will include applicable work, regulations, technical standard orders (TSO), 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
UASSRC 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 applicable 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 follow 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 accomplish 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 three fixed-wing general aviation aircraft. Each 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. Each 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 had the subject and intruder aircraft 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 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 aircrafts. 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:
This effort is ongoing. Reports will be delivered throughout the 24-month period of performance, and the final report will be delivered to the FAA in 2022.

Lessons learned and key findings to date have been qualitative and related to the execution of the flight test plan. Several flight tests have been executed at Starkville airport, and two different flight test methodologies were tested. The first involved a half-hour long flight across a ‘bow-tie’ or figure eight-like pattern. To increase the number of encounters and the variability of the encounter geometries, a second flight plan was tested. This flight plan involved the eastern half of the original figure-eight pattern and allowed the intruder aircraft to call out its position at one of over a dozen different stops along the half figure-eight. This allowed the intruder pilot and safety pilot onboard the ownship to clearly establish location throughout the flight test. Some changes to the intruder’s behavior at these loiter points will be made to account for more ‘realistic’ geometries, rather than loitering behaviors.

Name & Origin of All Research Personnel

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Graduation of Students

Name	Graduation Date
Jacob Butera	May 2021

UAS SAFETY CASE DEVELOPMENT, PROCESS IMPROVEMENT, AND DATA COLLECTION

Lead: University of North Dakota

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 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 the need 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. It will develop a system to capture test objectives and categorize them consistent with the FAA's UAS Integration Research Plan functional areas and research domains. The analysis of these data will inform the development of regulatory products (i.e., rules, standards, policy, etc.) needed to reach UAS integration milestones. Finally, it will facilitate the query and reporting of data in a consistent format across the Test Sites.

This research directly supports the 2018 Reauthorization Legislation, specifically, Section 343 (UAS Test Sites), and Section 345 (Small Unmanned Aircraft Safety Standards). Further, it includes collaboration with the UAS Integration Pilot Program (IPP), which is codified in Section 351.

The ASSURE research team includes the University of North Dakota (UND), the Northern Plains UAS Test Site (NPUASTS), Virginia Tech (VT), New Mexico State University (NMSU), University of Alaska Fairbanks (UAF), Kansas

State University Polytechnic (KSU), Mississippi State University (MSU), and The Ohio State University (OSU).

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, OOP NPRM, Other Rulemaking, and FAA 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 the TDCAS

Use an actual safety case to validate the TDCAS.

Key Findings:

This work is ongoing. Reports will be delivered during the 30-month period of performance, and the final report will be delivered to the FAA for peer review in Fall 2022.

"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."

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Graduation of Students

Name	Graduation Date
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Megan Patrick – MSU	May 2022

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

Kansas State University | University of Alaska Fairbanks | University of North Dakota

Lead: Kansas State University

Background:
Under the FAA Modernization and Reform Act of 2012, Congress tasked the FAA with integrating UAS into the National Airspace System (NAS). In order to comply with the Congressional mandate, the FAA established an 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. In order 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 is 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 theproposed system.

Approach:
The study includes a peer review of the research task plan and a review of the final report at the conclusion of the project. The study is broken down into two parts running in parallel.

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

These tasks are further broken down into subtasks.

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

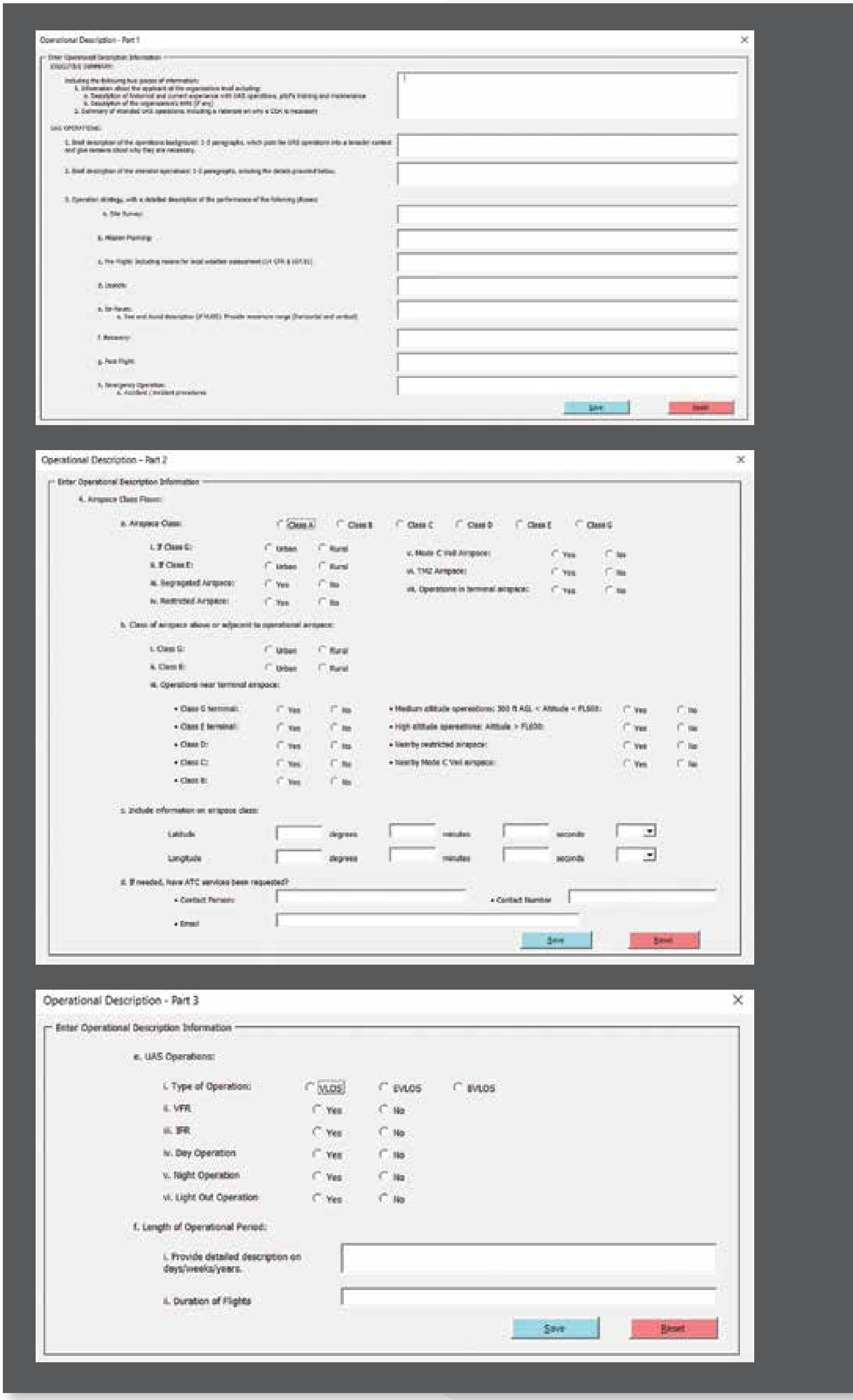
For this task, the research team used the information gathered from the literature review to develop a compliance-based risk framework for submitting and reviewing Part 107 waivers. This framework serves as a utility to establish a robust safety case and for the FAA to review Part 107 waivers in a repeatable 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 BVLOS with a Visual Observer (VO)

Perform a tabletop exercise with FAA stakeholders to explore this operational case and evaluate the risk-based framework throughout the waiver review process. Document gaps/shortfalls of the framework as they are identified. Identify lessons learned from the waiver review process and create a list of recommended changes to the risk-based framework.



This task affords 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 represents the least complex validation case, and it assesses the application of the framework to what could be considered 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 Visual Observer (VO)
Perform a tabletop exercise with FAA stakeholders to explore this operational case and evaluate the risk-based framework throughout the waiver review process. Document gaps/shortfalls of the framework as they are identified. Identify lessons learned from the waiver review process and create a list of recommended changes to the risk-based framework.

This task addresses a waiver application with an increased risk threshold from that of Task 2-1. Thus, this exercise enables researchers to evaluate the risk-based framework for a use case that requires more scrutiny on the part of FAA stakeholders. Specifically, the University of Alaska Fairbanks will conduct a tabletop exercise with FAA stakeholders to analyze a BVLOS waiver using the framework developed in Task 1-2. They will then document the details and outcomes of the tabletop exercise.

The tabletop results will help validate the Task 1-2 framework and serve as a feedback to fill in gaps if they are identified in the exercise.

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

Definitions for common SRA terminology 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 LOB. 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

- 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.
  - The framework uses the same "step-by-step" methodology as the COA form.
  - 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.

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Graduation of Students

Name	Graduation Date
Jacob Kimerer	November 2020

ESTABLISH PILOT PROFICIENCY REQUIREMENTS - MULTI-UAS COMPONENTS

Lead: Oregon State University

Background:
Several organizations have identified human factors issues unique to 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 will address 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 will help 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.

The ASSURE research team led by Oregon State University (OrSU), and includes Drexel University (Drexel), and Kansas State University Polytechnic (KSU).

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.

Tasks 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 identifies 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 generates a taxonomy of open problems and a report that captures the human factors limitations when monitoring multiple UAS. The researchers are:

- Identifying potential human factors limitations, including potential hazards, mitigations, and controls.
- Developing relevant operation scenarios and a task analysis that consider prior aircraft procedures. The operational scenarios include a loosely coupled domain (e.g., delivery) and a tightly coupled domain (e.g., wilderness disaster response).
- Reviewing the existing aptitude measurements and developing a taxonomy that informs gaps for single pilot multiple UAS deployments.

Task 4 – Assess Required Aptitude
This task focuses 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 will be used, specifically, the task analysis and use cases are directly informing the development of the computational user models. The computational models are focusing on the predominant human factors and training results developed during Tasks 1 and 3, but will also vary 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.
- Are developing the computational models, including their ability to provide a predictive analysis of human factors limitations. The base line loosely coupled task model has been developed and extensions are in progress to accommodate more complex aspects, such as unexpected events and supervisor distractions.

Key Findings:
The team's literature review identified 18 primary and a large number of lower-level gaps. The five primary 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.

"This research will address 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."

- *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 maneuverability, weather, and 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.

Based on the assessment of the human factors limitation when monitoring multiple UAS, the researchers identified the following gaps:

- Notional use case; lack of validated use cases for a wider range of loosely coupled tasks
- No industry standard for UAS and control station autonomy designs
- Aircraft configuration-specific methods for addressing each unscheduled event
- Limited research on task management strategies with and without autonomous support in multi-UAS package delivery contexts
- No data to inform which combination(s) of aptitudes are most important
- No single aptitude or measure can capture all of the human performance limitations related to multitasking with respect to supervising multiple UAS
- Need to develop measures that can be readily used in real-world operations
- Limited research on coordination and teamwork among multiple supervisors
- No data to inform the necessary levels of training and expertise required
- Lack of studies focused on the specific effects of vigilance and boredom in multi-UAS package delivery contexts

The researchers have developed a notional loosely coupled, delivery drone nominal use case and associated unexpected events based on feedback from industry-based subject matter experts. A computational model of the nominal use case has been implemented and can accommodate up to 100 UAS being supervised by a single human.

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Graduation of Students

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

Kansas State University · University of North Dakota · National UAS Training and Certification Center

Lead: Kansas State University

Background:
At present, 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 afford UAS operations in the same airspace as manned aircraft. Such operations will most likely involve interaction between UAS pilots, manned pilots, and air traffic controllers in a similar manner as aircraft operations are conducted today under instrument flight rules (IFR).

The ASSURE research team will focus on two elements of safety assurance. Research pertains to pilot training standards, informing standard(s) related to aircraft performance-based certification considerations across a range of operational approvals, and 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 will 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; and
- Participate in industry consensus standards groups to translate research into a standard that provides guidance to OEMs for the FAA's Durability and Reliability (D&R) type certification process.
- Document the FAA's D&R process via case study to provide feedback on the process and provide OEMs with initial guidance.

Kansas State University (KSU) is serving as the lead University driving this project in collaboration with University of North Dakota (UND) and Sinclair College (SC).

Approach:
To date, the research team has generated an RTP which currently serves as a living document to guide this research effort. One of the key objectives of this research is to transcribe the D&R process. Coordination with the Los Angeles Aircraft Certification Office (LA ACO) serves as a component of the peer review. 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 important 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 via use case scenarios. 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.

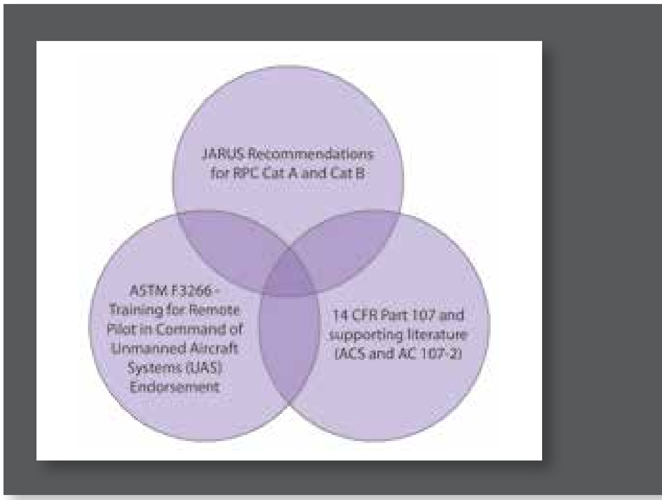
Task 2 – Durability and Reliability Type Certification Use Case Application
This task builds upon the literature review from Task 1 and exercises the Type Certification (TC) process for the purpose of establishing (1) establishing documented feedback for the FAA regarding the D&R TC process, and (2) providing guidance for OEMs who may wish to pursue a D&R type certification.

For this task, the research team will collaborate with the FAA's Aircraft Certification Service (AIR-694), the Los Angeles Aircraft Certification Office (LA ACO), and OEMs – e.g., senseFly and Telegrid, as they progress through the various phases of D&R.

This task also involves 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 relatively modest. The research team anticipates 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 Part 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 ascertain the need for a combination of both (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 research team accomplished the following regarding this task:
- Analyzed existing literature relating to UAS pilot qualifications and training.
- Constructed a framework of "go-to" knowledge, skills, and abilities (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 follows a "risk-based" approach, establishes a baseline, and affords the opportunity to allow flexibility for certain skillsets.
- The process includes classifying applicable requirements relating to their relevance of topical categories framed in JARUS RPC recommendations in addition to identifying parallels and gaps that may exist across differing training paradigms to identify commonalities and gaps.

Key Findings:
Task 1-1: Literature Review
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" (ALARP)

Under SMS, it is mandatory that risk is "as low as reasonably practicable," regardless of whether it was acceptable to be approved.

Task 2 Durability and Reliability Type Certification
This task is ongoing, and the list of observations is extensive. As such, this list identifies some of the most significant observations from the KSU research team as they follow both OEMs through the D&R TC process.
- UAS OEMS may require additional guidance even before starting the D&R TC process. Some of the initial documentation – e.g., CONOPs, Product Specific Certification Plan (PSCP), and Master Drawing List (MDL) may be challenging for OEMs that are new to aviation practices.
- OEMs may require additional spin-up on the nuances of 14 CFR Part 107 prior to beginning the TC process. Clarity regarding expectations for D&R flight demonstrations is a must.
- Processes for reviewing documents submitted by the OEM as part of the TC package can be slow when split across multiple FAA lines of business. This can lead to slowdowns and delays.
- Modifications to G-1 Issue Paper requirements and G-3 environmental testing requirements created significant slowdowns.
- Requirements for basic documents may not always be clear – e.g., maintenance manual content.
- Defining the maintenance manual to meet FAA content standards can be challenging for OEMs. For OEMs with limited familiarity with FAA maintenance manual content requirements, additional assistance may be required.
- Uncertainty regarding requirements for the MDL was observed in both applicants that the research team followed for this project.
- There is a lack of clarity regarding the FAA's shift in policy regarding how/where the GCS fits as part of the system and how it should be presented within accompanying manuals.

Task 3 Operational Training
Methodology
This task consisted of comparing remote pilot consensus standards to existing remote pilot certification standards and performing a side-by-side comparison across 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 11 recommendations for UAS remote pilot training requirements for (1) BVLOS, and (2) Operations over people. These recommendations are captured in the corresponding task reports.

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Graduation of Students

Name	Graduation Date
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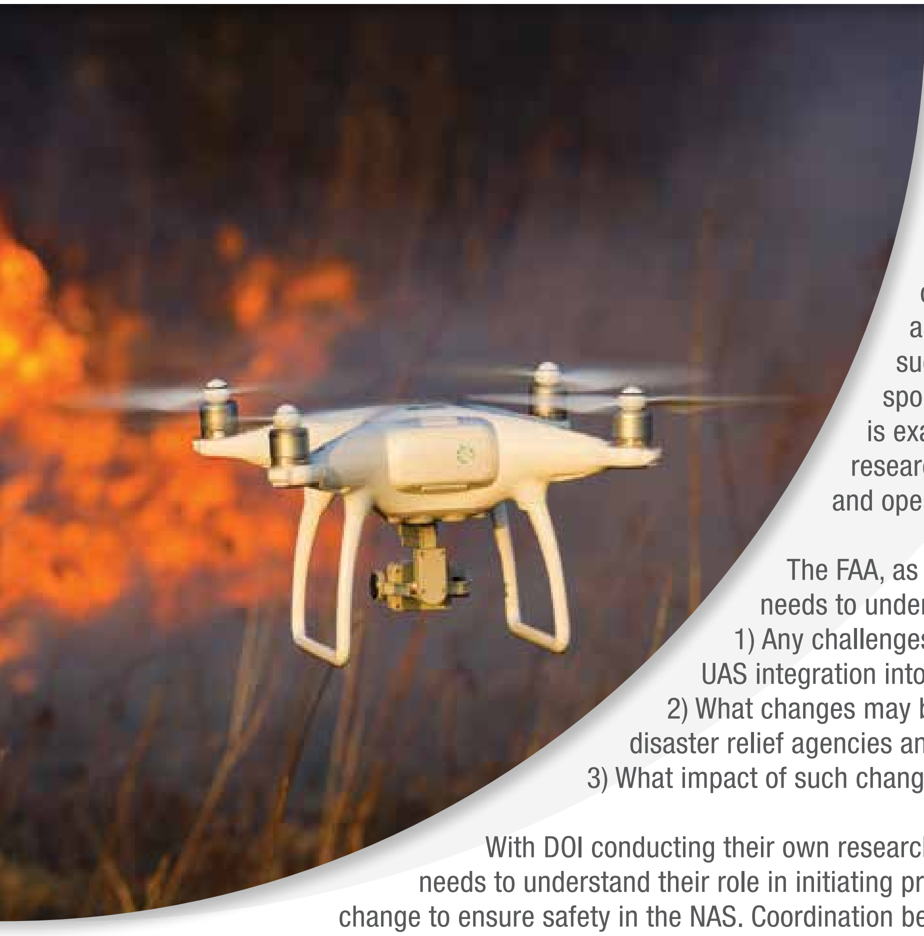
DISASTER PREPAREDNESS AND RESPONSE USING UAS – PHASE I



Lead: University of Alabama - Huntsville

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 NAS, needs to understand:

1) 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.

The ASSURE 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.

The University of Alabama – Huntsville (UAH) directs the overall project and work closely with University of Alaska-Fairbanks (UAF) and University of Vermont (UVM), New Mexico State University (NMSU), Oregon State University (OrSU), Mississippi State University (MSU), and North Carolina State University (NCSU).

Approach:
This research is broken into phases each with clear research questions and objectives. The ASSURE team is currently in Phase I, which is broken down into six tasks. 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 National Airspace System (NAS).

The effort focuses on procedures, policies and guidelines development to coordinate with FEMA/DOI/DHS, and other governmental agencies as well as local and state governments to ensure proper coordination during those emergencies.

Task 1. Survey of Experts for Disaster Preparedness and Response Use Case Development
The research team will survey government experts to find the use cases for emergency preparedness and response. They will include 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 will survey 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 will determine how local and state governments use manned aircraft to respond to disasters.

Task 3. Development of the CONOPS and ORA by Disaster
The researchers will develop Concepts of Operations (CONOPS) and Operations Risk Assessment (ORA) for some of the use cases that were reported on in Task 1. These CONOPS will 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 will take the CONOPS and ORA's 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 will determine 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:
This effort is ongoing. After completing the second peer review, program adjustments were made to bound the research. The team has held national and regional symposiums to engage industry, government, and academia.

The researchers have developed and conducted surveys using online systems and computer-based processes and analytics. Interviews have been completed with key personnel across several agencies, including NOAA, FEMA, DOI, NASA, US Forest Service, USGS, National Weather Service, Civil Air Patrol, FIRSTNET.Gov, and CAL FIRE. Preliminary results from the surveys and interview show the following results:

- More national exercises and training are requested.
- Funding is one of the primary issues.
- Coordination with the FAA is a necessity.
- Enhanced guidance for Part 107 is valuable.

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Graduation of Students

Name	Graduation Date
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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 | THE UNIVERSITY OF ALABAMA IN HUNTSVILLE | UAF UNIVERSITY OF ALASKA FAIRBANKS | UC DAVIS | THE OHIO STATE UNIVERSITY | National UAS Training and Certification Center

Lead: New Mexico State University

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".

New Mexico State University (NMSU) is leading the ASSURE team in cooperation with University of Alabama in Huntsville (UAH), University of Alaska Fairbanks (UAF), University of California at Davis (UCD), The Ohio State University (OSU), and Sinclair College (SC). 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.

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 and the outreach activities completed followed the overall plan until early in 2020. All of the in-process activities for the STEM Outreach events were basically halted due to Covid. It was impossible to do the planned in person outreach activities, camps, and instruction when schools closed, and states restricted student interaction. It is simple to say, these STEM efforts were turned upside down, and each school started the process to readjust the offerings. Through 2021, 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.

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 again their existing outreach activities like the UAS Roadshows and UAS Summer Camps. Restrictions related to Covid pushed out plans, but adjustments were made. Demographic focus continues to be on middle school students who are primarily Hispanic and Native American.

Key highlights included STEM program presented to FAA's Aerospace Human Factors Research Division (AHFRD). This was coupled with a presentation by FAA's Chris Sharp (FAA STEM AVSED). ASSURE and FAA PMs attended. The NMSU STEM Outreach Center offered "Drone Camps" with a limit of 10 students per session (Covid protocols in place including masks). July 12-16, 2021 was "Drones 1 – Drones for Beginners (AM and PM sessions)"; and July 19-23, 2021 had "Drones 1 – Drones for Beginners (AM session)", and "Drones 2 – Drones for Advanced Flyers (PM session)". In total, 30 middle school grade students attended the camps. Campers explored the basics of flight. With this foundational knowledge, they explored piloting through the flight simulators. Finally, campers tested out their skills with driving drones through obstacle courses. Finally, The NM UAS FTS team supported the "Wings 'n Wheels Fest 21" at the Las Cruces International Airport on September 25, 2021 (8 to 4 PM) with display and hands on activities. The NMSU team had an Aerostar and helicopter on display along with flight simulators and ground bots for hands on activities. Approximately 2,900 people attended the event (had many children come by to "play" and "fly"). A B-25 was on display and gave flights to the public, 34 airplanes on display at the show, 59 show cars, 4 motorcycles, 6 big trucks, and one jet boat too!

University of Alabama in Huntsville (UAH) – Alabama Unmanned Systems Operations Mastery for Educators (AUSOME)
The Alabama Unmanned Systems Operations Mastery for Educators (AUSOME) Program has continued outreach for educators in numerous forms. A "Science Never Stops" Video Interview was completed on 25 January 2021. The USSRC "DRONE" Exhibition with AUSOME Demonstrations/Guest Lectures took place in March through September 2021. United States Space and Rocket Center Crew Chief Part 107 Training and Skydio 2 Flight Training was completed. The summer of 2021 there were the AUSOME Demos for Space Camp for Educators and Elite Space Academy. Significant Educator group outreach and training was completed. The groups, dates, and number of teachers included the following:

- USSRC Space Camp for Educators, 11 Teachers – 11 June 2021
- Alabama Educator Professional Development Group One, 30 Teachers – 18 June 2021
- Alabama Educator Professional Development Group Two, 25 Teachers – 25 June 2021
- State Teachers of the Year 2020, 50 Teachers – 16 July 202
- State Teachers of the Year 2021, 35 Teachers – 23 July 2021

The UAH/AUSOME team has also been coordinating with the Alabama State Department of Education's STEM division known as the Alabama Math, Science, and Technology Initiative (AMSTI) on providing inputs for the state Digital Literacy Curriculum program and educator professional development training. The AUSOME and AMSTI partnership have a goal to jointly develop UAS STEM kits locations across Alabama where educators can be instructed on how to use UAS in the classroom. These STEM kits will include a collection of lesson plans, UAS, and example code for introducing high school level to UAS a tool for data collection, introductory computer science, and aerospace education.

University of Alaska Fairbanks (UAF) – The Alaska UAS Airshow
Due to the remote nature of the state of Alaska, the Airshow will provide UAF an opportunity to fly experts from the University of Alaska Fairbanks's Alaska Center for UAS Integration (ACUASI) to schools across the state. These experts will teach students about UAS safety, rules, regulations, aerodynamics, and potential careers using UAS. The ACUASI team will take flight simulators and small first-person-view UAS for the students to use during the event.

In addition to interacting with Alaska Native middle school students, the experts will work with law enforcement, school officials, and the community as a whole because of the small size of these towns and villages. The Airshow is a follow-on from the successful Roadshows conducted under the previous ASSURE STEM projects and will use the materials developed, acquired, and used during that effort. Covid has presented a challenge since access to the remote communities was closed. The UAF conducted several STEM outreach events including July 13 – Camp Fire Alaska – Cooper Landing, Alaska (2 hours south of Anchorage). The State of Alaska Department of Transportation and Public Facilities UAS Program Coordinator participated. August 9-13, "Summer Sessions 'Drone Camp'" was 1 week long, 3 hours per day course on the UAF campus. The team conducted an airshow at Galena, Alaska, Sept 23-25. There were approximately 100 kids from many different villages (~60% Alaska Native). Students were talked to about TRUST, airspace, challenges like cell phone coverage so poor that getting LAANC approvals is difficult at best. A solution is going to help the instructor, who is a CFI, get a Dronezone waiver to be able to fly at appropriate places around town. Ongoing efforts include continuing Zoom type talks and interaction 'when the internet allows'. An upcoming outreach is planned at Tok, Alaska. Due to COVID-19 Delta Variant concerns, many remote communities are now limiting access to outsiders again. This may limit UAF's ability to connect with rural communities to conduct the official 'Alaskan UAS Airshow '.

University of California at Davis (UCD) – STEM Summer Drone Academy
UCD targets schools with student populations from rural and inner city, minority, low income, non-English first language, and no university experience in family. UCD partners with Nathan Metzler, CITRIS, and the Banatao Institute at UCD; he has led the classes for our STEM program. UCD partnered with the campus Early Academic Opportunity Program, EAOP, in 2018 because they have more than 1500 STEM eligible students in their database. Building on the highly successful 2018 Summer Drone Academy and the 2020 in-person weekend High School Drone Build Camp, UCD offered the UC Davis 4th Annual Drone Academy in August 2021. FAA and CITRIS jointly sponsored in-person on-campus STEM and Drone Academy for minority and under-represented 9th -12th grade students. It was a 5 day-all day, in person program, including meals. Students from 9 regional schools, rural and inner city attended. (about 50:50 participation of women and men in the enrollment. Summer camp was 55% female.) Students are part of long term education program to bring them into advanced education after high school (AEOP at UC Davis). Unpiloted Aircraft Systems (UAS) used as a learning platform. Enrichment, guest speakers, trips to campus museums, research labs, and engineering manufacturing labs were included.

The Ohio State University (OSU) – Translating Engineering to Kindergarten Through 8th graders (TEK8) with a Focus on UAS Research
The OSU TEK8 program will continue to recruit and mentor academically talented undergraduate engineering students in the Primary Investigator's (PI) research labs. The students in the PI's labs will support research focused on UAS development and integration into the National Airspace System (NAS). The students will take a course in the fall with in-service teachers pursuing graduate coursework. The undergraduate researchers will team with the teachers to transform their research experience into several engineering design challenges appropriate for grades K-8, and then take the project into underserved K-8 classrooms.

The TEK8 program works with Metro Middle School (a diverse semi-public, non-charter, privately funded school). The goal of this program is three-fold:

- Encourage undergraduate research and underrepresented minority participation in engineering;
- Introduce teachers to project-based learning strategies and educate them in engineering practice and the design process; and
- Refine the engineering design challenges and document them in a web-hosted university extension.
- Projects completed this past year included UAS Engine ingestion studies that incorporated structural analysis of the systems, running bird ingest studies, and assessment of fan damage. Another project focused on development of a test stand for a next generation Mars flight vehicle, circuit board design, and flight performance testing.

Sinclair College National UAS Training and Certification Center – Interactive Middle School UAS Introduction and Simulation Experience
The original purpose of the effort related to Sinclair was to provide presentations highlighting UAS applications, careers, and technologies, as well as selected ASSURE projects, coupled with interactive hands-on simulation leveraging RealFlight simulators operated in the Sinclair Tactical Ground Control Station (T-GCS) or Mobile Ground Control Station (M-GCS) deployed to 6th grade classes around the state of Ohio. Early success was achieved from January to early March 2020 before Covid impacted all outreach. To adjust, Sinclair sought and received approval for an alternative approach to continue the outreach goals of the project while following best practices for social distancing, wearing masks, and cleaning equipment. This included continued pursuit of middle school classroom outreach when possible,

but added support of UAS focused camps, engagement at remote control and traditional aviation flying events, and deployments to aviation and history related museums. For each outreach day, the T-GCS or M-GCS were still deployed outside of the facilities but desktop simulators were employed with social distancing and sanitation protocols. This modified approach has allowed Sinclair to continue outreach until conditions permit middle school programs again. The Sinclair team has completed over 107 days at 31 locations totaling 6,045 individuals. Many more days are scheduled to complete this outreach.

Key Findings:

University of Alabama Huntsville:

- Teacher training materials have matured and are effective at fostering UAS excitement with educators.
- Multiple outreach events and activities have generated additional requests for UAH STEM support.
- The USSRC Camp and Education Programs will introduce UAS in their robotics and space camp activities with the support of AUSOME.

University of Alaska Fairbanks

- The UAF team's ability to conduct its planned outreach to remote, fly-in, predominantly Alaska Native communities in Alaska as a part of the 'The Alaska UAS Airshow' has been severely disrupted by the COVID-19 pandemic. The remoteness of those communities and their lack of health infrastructure has resulted in travel to the communities by outsiders being prohibited, and the lack of bandwidth in these villages has limited the UAF team's ability to conduct real-time distance delivery of content to the schools.
- The UAF team developed new materials and methods for delivering the content to the villages without video-streaming material.
- The team was able to hold summer camps as well as some outreach events with Covid protocols in place.

The Ohio State University

- Two more students completed the TEK-8 program supporting UAS research

University of California at Davis

- Camps showed nearly equal numbers of female and male students, multiracial students, and a good balance of rural and urban students

Sinclair College

- From the start of program outreach on January 6, 2020 through September 30, 2021, the following metrics were achieved:
  - 107 outreach days at 11 locations in Ohio including the Dayton, Cincinnati, Columbus, Cleveland, and other regions in Ohio.
  - Supported SOFWOLF Camp in Provo, UT.
  - Engaged 6,045 individuals in sixth grade middle school classrooms and the broader public at approved alternate camp and museum outreach events.
  - Established agreements with alternate venues to conduct outreach.

New Mexico State University

Successful summer camps were completed based on previously prepared materials with new elements added, and additional outreach events completed to reach the broader community.

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SAFETY RISKS AND MITIGATIONS FOR UAS OPERATIONS ON AND AROUND AIRPORTS

Lead: University of Alaska Fairbanks

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 ATO SMS Manual indicates safety analyses are performed in response to NAS changes or existing safety issues.

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

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

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

This safety and risk analysis 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 Air Traffic (AT) 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

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

Task 2: Propose other potential areas of research beyond what is outlined in the task. Coordinate and prioritize the research to be conducted. Develop a Research Task Plan with potential increased/decreased scoping based on findings. Hold a scoping peer review with the FAA and other parties determined by the FAA to discuss the Research Task Plan and determine the appropriate scope level. The sponsor, based on other areas identified, will select research that meets the FAA's immediate needs based on the cost estimate.

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

Define the overall concept and specific use cases for conducting operations on the airport surface. This includes but is not limited to:

- UAS airport inspections
- Perimeter security
- Foreign Object Debris (FOD) inspections
- Runway inspections
- Emergency response
- Wake Turbulence Separation
- Large UAS takeoff and recovery

Consider the airspace class (B, C, D, E, G), towered/non-towered etc. for each use case.

Task 4: Using the FAA's ATO Safety Management System (SMS) process, identify the hazards and mitigations of the use cases. Consider 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.

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

Task 6: Flight Testing – Propose flight testing and analysis with exit criteria for three use cases to validate the proposed mitigations. According to the Request for Proposals, this task can be completed in parallel with other tasks; however, the intent is to test the use cases that have undergone the SMS review in Task 5.

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 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.

Key Findings:
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 Code of Federal Regulations (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 literature available 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.

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IDENTIFY WAKE TURBULENCE AND FLUTTER TESTING REQUIREMENTS FOR UAS

Lead: University of Kansas

Background:
The research team consisting of the University of Kansas (KU) and The Ohio State University will work together to support the FAA effort to establish rules for:

- mitigation of risks due to sUAS upset caused by wake vortex encounters
- flutter flight testing of 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 airspace including at or around airports, ranging from big passenger UASs (e.g., Kitty Hawk Cora UAS, ~4,000 lbs) to small package delivery UASs (less than 50 lbs).

Approach:
The research effort will include:

- Literature review in the area of UAS response to wake turbulence.
- Determination of research shortfalls and development of case studies to address shortfall areas.
- Analysis and assessment of representative UAS responses to encountering wake vortices with varying strengths using:
  - Physics-based simulation of wake encounters.
  - sUAS flights through simulated as well as actual wake velocity fields to validate simulations.
- Conduct of likelihood-based assessment of unfavorable UAS responses and provide safety analysis considerations for FAA policy, guidance, and procedures for wake turbulence mitigation for UAS.
- Quantitative flight test support for assessing the gust response and flutter margins of existing and future UAS winged vehicles.
  - High-fidelity gust load measurement in wake vortex encounter.
  - Flexible damping to demonstrate new flutter prediction algorithms.
- Simulation of wake encounters and flutter onset for a range of to allow extrapolation of methods to a wider range of UAS, including UAM vehicles

Task 1: Literature Review
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

"New detailed separation rules and guidance to UAS/airport operators are needed to guide safe UAS operations in controlled or uncontrolled airspace including at or around airports."

- 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 within 30 days of the final report delivery.

Task 6: Program Management. ASSURE program management of the research project and performers.

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 and the research task plan (RTP).

Wake vortex modelling

The team identified the existing wake vortex velocity field theories and mathematical models. For the evolution of wakes, NASA's AVOSS (Aircraft Vortex Spacing System) 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 upset due to wake encounter

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.

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URBAN AIR MOBILITY: SAFETY STANDARDS, AIRCRAFT CERTIFICATION AND IMPACT ON MARKET FEASIBILITY AND GROWTH POTENTIALS

Wichita State University | Mississippi State University | NC State University | Embry-Riddle Aeronautical University

Lead: Wichita State University's National Institute of Aviation Research

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). In order 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 [Secy. Mulvaney memo, August 17, 2017], 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 at 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 (e.g. regular business commuters, ad hoc travelers, etc.) for UAM viability;
- Characteristics of population density, traffic patterns including congestions, 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 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 to identify barriers for additional demands on the NAS. While some of the existing constraints have been documented [see Thipphavong, et. al. (2018)], detailed analyses are presently unavailable and the implications on UAM emergence and its penetration are not clear. For example, it is not evident how UAM:

- May impose demand on additional Air Traffic Control (ATC) infrastructure including airspace and workload on controllers?
- May require new paradigm to integrate with UAS Traffic Management (UTM) and/or Advance Traffic Management (ATM)?
- May impose demand on regulatory requirements including standards for airworthiness, certifications for design, maintenance and operations for vehicle-level and system-level safety and security?
- Will be resilient to a wide range of disruptions including weather and localized sub-system failures such as GPS?
- Will 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 (NAICS) 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 its applicability to UAM aircraft certification

Safety is a fundamental condition in order for urban air mobility 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 wide spectrum of vehicle architectures 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.
- Vertiport: Multimodal interface are a critical infrastructure for UAM.

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UAS CYBER SECURITY AND SAFETY LITERATURE REVIEW

Lead: Oregon State University

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

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 with 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 with 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 UAVs / 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. A Research Task Plan (RTP) with potential increased/decreased scoping based on findings and review will be developed and delivered.

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. We 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 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.

Figure 1: UAS Operational Phases

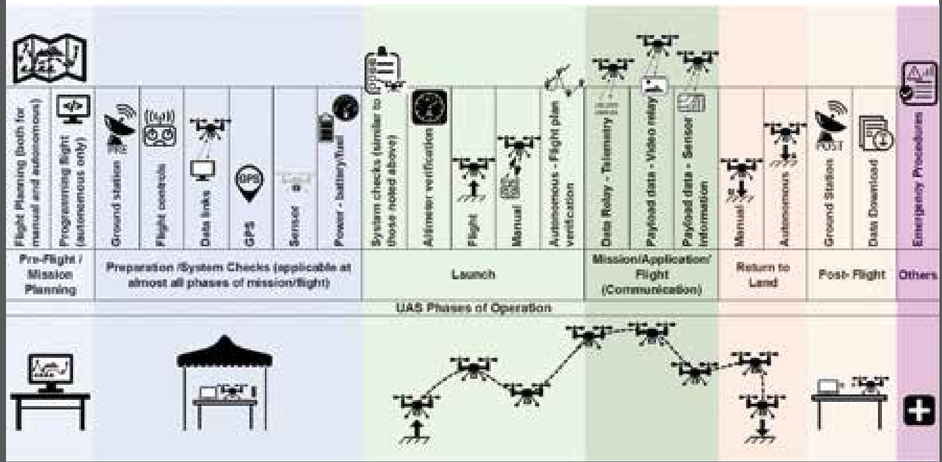


Figure 2: UAS Components

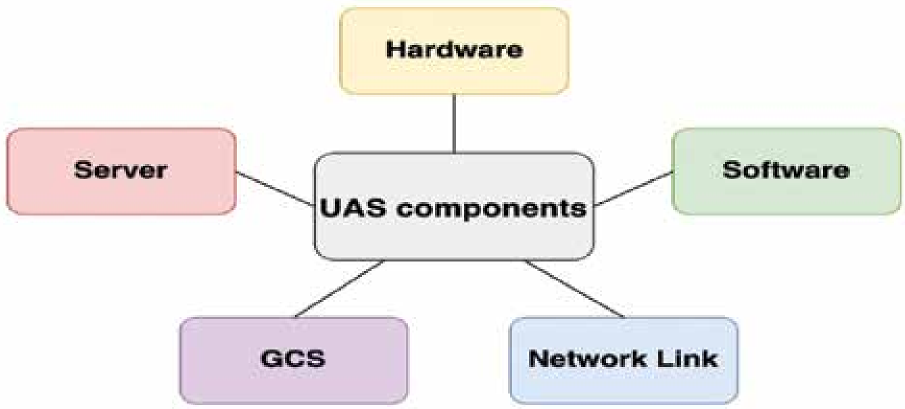


Figure 3: Defense Strategies for UAS

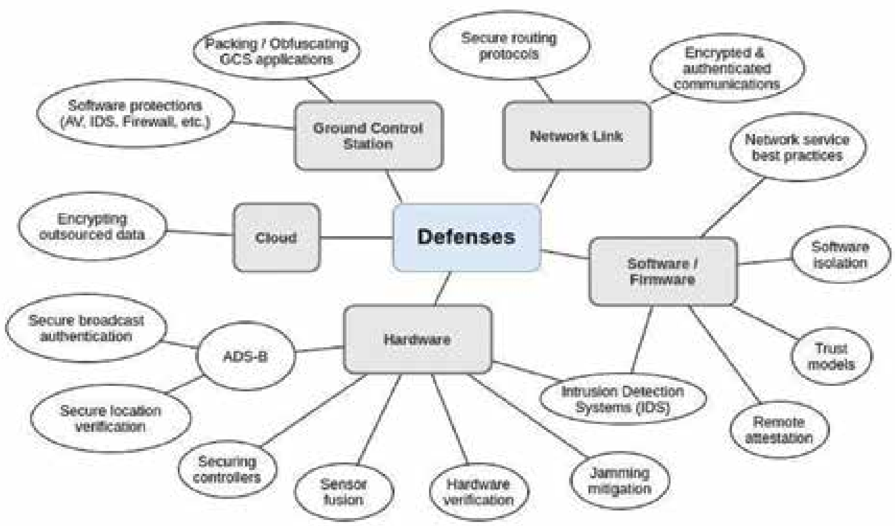
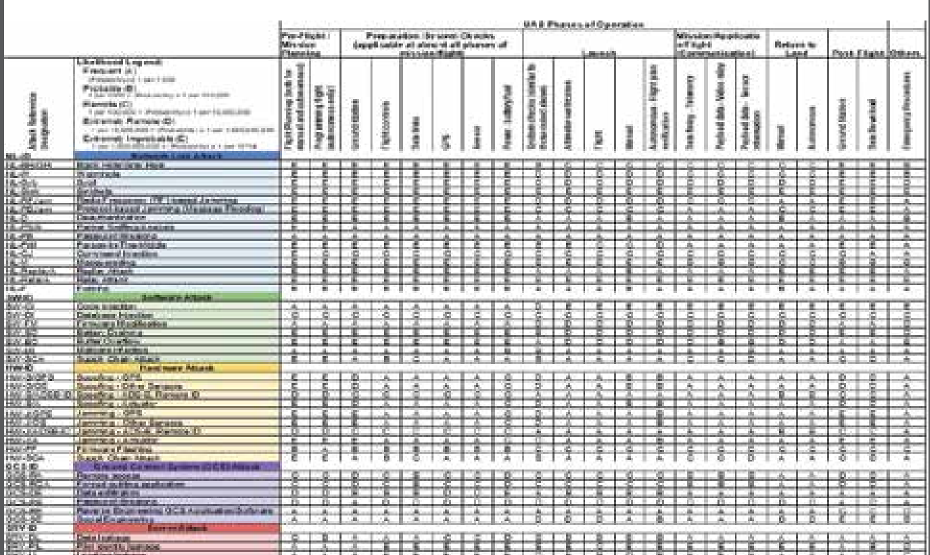


Figure 4: Preliminary Cyber Threat Likelihood for UAs Operational Phases



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.

Literature Review: The team gathered a corpus of 1294 papers from key technical databases (IEEE, ACM, AIAA) 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 547 papers in stage 3 within the project time constraints.

The team is currently documenting and organizing the identified threats and attack vectors using i) UAS components (see Figure 2) and ii) UAS Operational Phases (see Figure 1). The team is also creating a preliminary Cyber Threat Likelihood and Cyber Threat Risk profiles for UAS Operational phases (see Figure 4 for a sample). The team has also investigated potential mitigation and defense strategies (see Figure 3).

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VALIDATION OF ASTM REMOTE IDENTIFICATION STANDARDS

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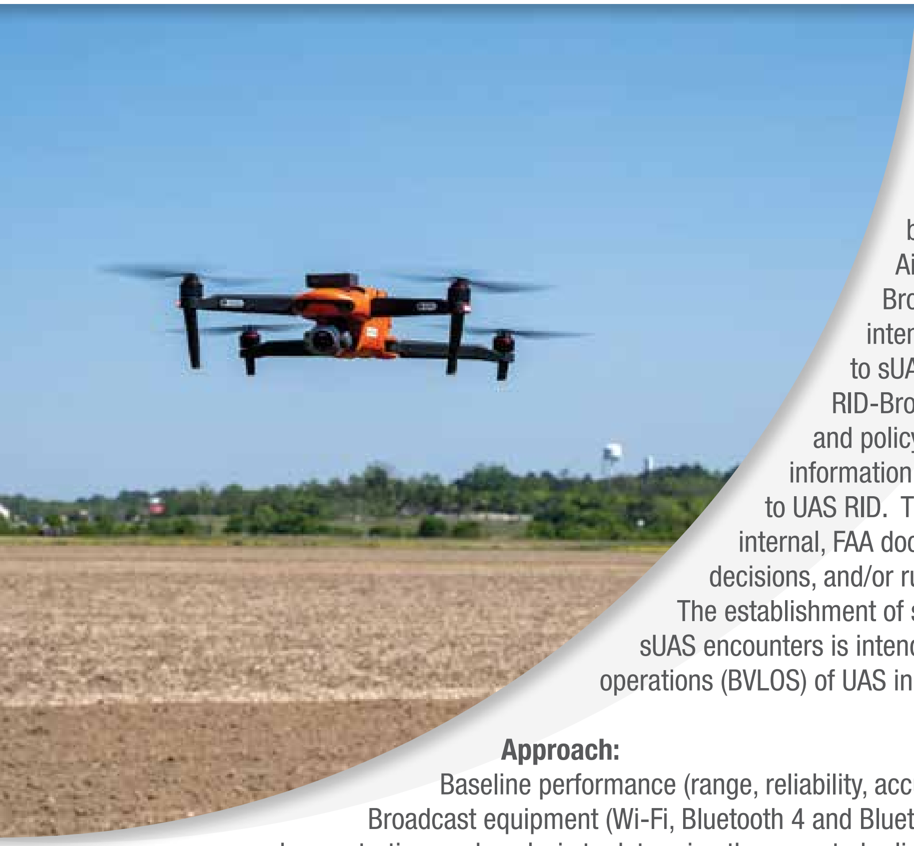

Lead: Mississippi State University

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 operations (BVLOS) of UAS in the NAS.

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 effort to ensure all tasks are in alignment with the tasks detailed in this proposal. 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. The UASSRF understands that product outcomes are intended to support FAA needs with respect to FAA rulemaking, policy decisions, safety analysis, and acceptance of standards, and will work with the FAA toward those objectives.

Task 2: Literature Review

The UASSRF will conduct 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 will identify and document RID stakeholders and their associated needs from RID broadcasts and may also identify potential expanded uses of RID-Broadcast technologies and their stakeholders not listed in the NPRM/RID Rule. A draft interim report will be provided to prioritize FAA analysis needs.

Task 3: Simulation, Demonstration, and Analysis Plan

- 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: Simulation, Demonstration, and Analysis Plan Execution

- Comprehensive reports from simulation, assessments, testing, demonstrations, and analysis.

Task 5: Final Report Package and Briefing

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 is still conducting validation testing, so currently available results are preliminary. At this time two prototype systems have been tested at a variety of broadcast periodicities – a UAS with integrated Wi-Fi NaN RID capabilities and a standalone Bluetooth 4 and 5 based RID module. An Android-based cell phone was used as the receiver of the RID messages from the two platforms in this test. Current range testing has been conducted in a rural environment with a noise floor between –107 and –112 dBm. During testing, it was found that there was potential destructive interference when range testing the Bluetooth RID module (this was noted at range of 500 m away from the receiver). It was hypothesized that high tension transmission lines between the receiver location and the broadcast device was the source of Fresnel interference – interference due to obstacles in or near the path of a radiofrequency beam. Results from a validation test suggested that there was potential constructive interference occurring. Due to these results, it was determined that future testing should be conducted in a manner as to avoid expected interference sources when interference is not a desired input into testing. In general, the current results collected from the available RID units show that broadcasting at a higher periodicity increases the range at which detection of packets occurs.

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

Lead: Kansas State University

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. Larger UAS 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. While some of these departments require certificates of authorizations (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 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. These forecasts are used throughout the agency for safety and investment analysis along with workload planning.

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

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

- Understand key differences with existing commercial air carrier and charter operators and likely trends in large UAS, particularly with a focus 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;

In order to address these issues, an approach to predicting the larger (>55lb) commercial aircraft growth into the higher non-segregated altitudes (e.g., above 400ft AGL) is needed, with special emphasis on the use of these UAS in 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, the Task Order 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 literature reviews for this effort and the A42 effort were linked and combined into a single document. This was done to ensure that there was no duplication of effort and to identify distinct similarities and differences between unmanned air transport and unmanned air cargo. As such, a single combined literature review document was submitted for both projects.

Task 2: Use Case Development

Using outputs from the literature review and market analysis, the research team is determining the scope of use cases such that they (1) are representative of applicable market and technical trends for UAM, and (2) allow for research tasks to be completed within the allotted period of performance. This task also enables the research team to focus the scope on specific topics of interest that arise from the literature review and/or market analysis.

Task 3: Experiment Plan

The development of an experiment plan as part of this task informs research activities carried out in Task 4. The experimental 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. The performers will coordinate with the sponsor and selected subject matter experts (SMEs) to ensure that the experiments address the research questions identified for each use case. The experiment plan developed as part of this task must be appropriately scoped within the context of Task 2 and resulting use cases(s).

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 UAM and unmanned passenger transport. 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 UAM and unmanned passenger transport.

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 – Changes will be required regarding traffic management.
- Regulatory considerations – The current regulatory framework will likely require updates to accommodate new technologies, practices, and airworthiness/certification considerations to accommodate unmanned air transport aircraft.
- Automation – The shift to automation will begin by phasing out the pilot, starting with simplified vehicle operation (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. Note that UAM has the potential to adversely affect existing public transportation networks.
  - To achieve large scale usage, UAM infrastructure will need a significant expansion: more access points (vertiports) and electric grid upgrades to handle charging the vehicles. Access point operational efficiency will be important to maintaining low costs and significant time savings for the users.
  - Regulations will also play a key role 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.

Name & Origin of All Research Personnel

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Graduation of Students

Name	Graduation Date
Michael Kerr	2025

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

University of Alaska Fairbanks · Kansas State University · NC State University · The Ohio State University · The University of Alabama in Huntsville · University of North Dakota

Lead: University of Alaska Fairbanks

Background:

According to FAA rules, UAS weighing 55 pounds or greater must be registered using the existing aircraft registration process. Many of these aircraft are presently flown within the NAS by federal agencies, including the Departments of Defense (DoD), Homeland Security (DHS), Interior (DOI), Energy (DOE), Agriculture, NASA, and some state and local governments, and academia. In 2018, these Agencies had flown 3,784 flights (by 42 Reapers or 90 ops per aircraft per year); 494 flights (by 23 Shadows or 21 ops per aircraft per year); 362 flights (by 13 Predator A or 28 ops per aircraft per year); and 290 flights (by 3 Global Hawks and Tritons or 97 ops per aircraft per year). While some of these organizations require certification of authorizations (COAs) lasting two years, others have their own self-certification for authorizations, e.g., DoD, Customs and Border Patrol (CBP).

While defense and civilian agencies are already using large UAS in the NAS, it is anticipated that these UAS may also be used for commercial purposes (e.g., agricultural spraying, commercial real estate, pipeline inspections, communication relay, etc.) in the near future. One of the uses could potentially be transportation of air cargo. Continued safe integration of UAS is essential, and the FAA is taking a proactive approach in understanding trends, identifying new markets, and forecasting large UAS in the NAS. These forecasts are used throughout the agency for safety and investment analysis along with workload planning.

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

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 Sept. 27, 2019 it flew medical supplies at WakeMed's hospital campus in Raleigh, North Carolina. 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 (i.e., large UAS, 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. We also anticipate that large UAS will be used to facilitate cargo delivery. New and additional procedures, airspace rules, and equipment standards, including 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. For instance, under what circumstances, can these large UAS fly within the Mode-C veils?
- Understand separation requirements and/or rules for integration (i.e., communication, navigation, surveillance, informational - CNSI rules in particular) into these airspaces.
- Understand requirements for type design, airworthiness and production approvals (e.g., type certificates, airworthiness certificates and production certificates); also understand how changes in these may facilitate regulatory initiatives such as MOSAIC.
- Understand safety risk management requirements for these integrations.
- Provide projection of workforce associated with these anticipated changes and implications on airspace requirements including procedures and regulations.
- Provide an understanding of physical infrastructure required to facilitate large UAS delivering cargo incrementally in the NAS. For example, redesigning of airport including ramps, delivery points, and etcetera.

In order 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 operations. 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-and-current-aircraft-based cargo deliveries, along with 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 (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 (PoP) 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 experimental plan will identify the key issues that need to be addressed in each use case identified in Task 2, as well as design experiments that are tailored to quantify the effects of those factors on the specific use case. 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 with 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. The performers will coordinate with the sponsor and selected subject matter experts (SMEs) to ensure that the experiments address the research questions identified for each use case. The experiment plan developed as part of this task must be appropriately scoped within the context of Task 2 and resulting use cases.

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:
In 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 UAS with cargo capacity 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 for UAS with cargo capacity 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 (UTM)
    - 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.

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HIGH-BYPASS TURBOFAN UAS ENGINE INGESTION TEST

Lead:
The Ohio State University

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 in order to define an Equivalent Level of Safety to manned aviation.

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

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

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

The team includes The University of Ohio (OSU) and Wichita State University (WSU).

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 test plan 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.

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 UAV 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:

This project has just begun. Reports will be delivered throughout the 33-month period of performance, and the final report will be delivered to the FAA for peer review in 2024.

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Hoa Ly (Research Engineer)	Vietnam
Luis Castillo (Research Engineer)	Mexico
Akhil Bhasin (Research Engineer)	India

MITIGATING GPS AND ADS-B RISKS FOR UAS

Lead: University of North Dakota

Background: Unvalidated or unavailable GPS and "ADS-B In" data poses security and safety risks to automated UAS navigation and to Detect and Avoid 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 Detect and Avoid, 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 Detect and Avoid 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.

The team includes the University of North Dakota (UND), Kansas State University (KSU), Embry Riddle Aeronautical University (ERAU), University of Alaska Fairbanks (UAF), and Oregon State University (OrSU).

> "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."

Approach:

Task 0: Program Management

The performer will manage this effort to ensure all tasks are in alignment with the tasks detailed. The performer will coordinate with the FAA 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: 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. (RTCA 228)

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

- 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: Test, Analysis, and Demonstration Report(s)
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. Reports will be proofread by a technical writer and the appropriate subject matter experts. The FAA will be given an opportunity to review draft reports.

Task 5: Final Briefing and Final Report
Summarize and aggregate all of the previous papers and reports (excluding meeting notes) 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 Detect and Avoid standards.

Task 6: Peer Review
Plan and budget for a peer review of the final report to ensure public availability of the research within 30 days of the final report delivery.

The research requirement is intended to assess the safety and security risks of unvalidated GPS and ADS-B In data used to support a variety of UAS operations to include sUAS operations, unmanned cargo transport, and remotely piloted passenger transport operations. For sUAS operations, particular emphasis will be on low cost and easy to implement mitigations commensurate with their safety and security risks.

The research requirement is intended to assess the safety and security risks of unvalidated GPS and ADS-B In data used to support a variety of UAS operations with a focus on sUAS operations. For sUAS operations, particular emphasis will be on low cost and easy to implement mitigations commensurate with their safety and security risks.

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.

Task 1 – Literature Review and Risk Assessment Key Findings: The team conducted 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. The report also includes a safety and security risk assessment of potential UAS operations that rely on GPS and ADS-B data.

As expected, the analysis found that the only low risk situations occur with operations in the Part 107 conditions, the medium risk category contains the BVLOS and urban area conditions, and the high risk category contains only urban and near airport operations, which require significant mitigation schemes to reduce the risk to an acceptable level.

Going forward, based on the risk assessment in Task 1, the research team will conduct a market survey of market solutions to mitigate loss of GPS and loss of ADS-B data as part of Task 2. The work will focus on reducing the level of risk for medium risk operations, while also considering solutions for high risk operations. The market solutions to mitigate unvalidated GPS and unvalidated ADS-B In data and will include estimated costs, ease of implementation, and a preliminary assessment of their effectiveness. The research team will explore and propose potential solutions for GPS mitigation strategies for denied and/or jammed environments, in addition to cybersecurity and counterintelligence measures. Finally, the team will examine the recorded ABS-B data to expose potential risks and provide guidance on mitigation schemes.

Name & Origin of All Research Personnel

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Graduation of Students

Name	Graduation Date
Niroop Sugunaraj	December 2021

SHIELDED UAS OPERATIONS: DETECT AND AVOID (DAA)

Lead: University of North Dakota

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 manned 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.

The team includes the University of North Dakota (UND), the Northern Plains UAS Test Site (NPUASTS), New Mexico State University (NMSU), Kansas State University (KSU), Embry Riddle Aeronautical University (ERAU), and North Carolina State University (NCSU).

Approach:
Task 1: Literature Review and Risk Identification
The research team will identify potential risks for shielded operations and conduct a large comprehensive literature review of shielding research, of identified risks associated with shielding 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 mitigations and prioritize each.

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 manned 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 those efforts by informing those efforts of 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:
To date, the literature review has been the primary focus of this research effort. Overall, the amount of literature that directly addresses shielded UAS

operations is scarce. However, significant research has been conducted in related areas, such as aircraft operations at low altitudes, and the impact of structures/objects on supporting systems (e.g., GPS).

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

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

The team is continuing to work on all of these issues. In addition, it is exploring challenges regarding terminology used with shielded operations and related legal questions.

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Graduation of Students

Name	Graduation Date
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Tatiana Gutierrez – ERAU	May 2024
Eduardo Morillo – ERAU	December 2022

VALIDATION OF VISUAL OPERATION STANDARDS FOR SMALL UAS (SUAS)

Lead: Kansas State University

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, to include relevant literature provided by the sponsor. The performer will review literature pertaining to requirements for visual observers, to include literature on their roles/functions and limitations. The literature review performed in this task will inform future tasks and assist in scoping this research.

Task 2: Updated Research Task Plan

The research team will update the Research Task Plan (RTP) based upon findings from the literature review in Task 1 and revise the project scope accordingly. The updated research task plan will reflect findings that steer goals/objectives of this research for Tasks 3 – 7.

Task 3: Initial Test and Analysis

Task 3 consists of the development and execution of test plans that are guided by research findings from the literature review in Task 1 and scoped per Task 2. As part of this task, the research team will develop, review, and execute a test plan that seeks to answer key research questions. For the peer review element(s) of this task, subject matter experts (SMEs) with knowledge in testing, human factors, design of experiments, and visual detection will be used. A list of these SMEs will be included in project deliverables.

The team will develop Flight Test Plans (FTPs) for demonstrating visual limitations, environmental constraints, and potentially demonstrating visual illusions, to quantify the safety of Visual Line of Sight (VLOS) and Extended Visual Line of Sight (EVLOS) operations.

- FTPs will include 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 may include unmanned aircraft operations in proximity to static obstacles. Data will be collected with the intent to address FAA knowledge gaps and inform safe standoff ranges and/or operational procedures from static obstacles when conducting a VLOS operation. Test variables will include different ranges from the visual observer to the static obstacle. Visual observers will estimate unmanned aircraft altitudes and distances between the unmanned aircraft and the static obstacle. VO estimates will be compared with measured distances. For both static object and aircraft encounters, VOs will assess the need to initiate avoidance or evasion maneuvers.

FTPs will include:

1. Flight course design: Determine flight paths, altitudes, and timing. Develop safety mitigations that support safe flight testing.
2. Pilot Recruitment: Identify, recruit, and schedule manned and unmanned pilots with adequate ranges of qualifications and experience.
3. Encounters: Plan, schedule, and execute unmanned aircraft encounters with static obstacles and with other aircraft. Encounters will be evaluated for test safety and will maintain adequate vertical and/or horizontal separation. Encounters must be structured to facilitate the collection of data to address FAA knowledge gaps. Utilize the necessary aircraft, aircrews, and equipment for testing.
4. Data Collection: Identify the necessary tools and techniques to precisely capture at minimum:
    a. Images and videos that can be referenced for safety discussions about VLOS operations.
    b. The test conditions and measurements that are important for quantifying VLOS safety performance
    c. The encounter parameters of the UA and aircraft for encounters. Examples include:
        I. The encounter geometries, altitudes, and the closing rate between UA and aircraft
        II. Vertical and lateral separation between UA and aircraft at closest point of approach (CPA) during the encounter
    d. The encounter parameters of unmanned aircraft with respect to static obstacles. Examples include:
        I. The encounter geometries, altitudes, and distances between the unmanned aircraft and the obstacle
        II. Vertical and lateral separation between the unmanned aircraft and the obstacle at the CPA during the encounter.

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

The research team will hold 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, will select components of the FTP and data analysis plan that meets the FAA immediate needs and is appropriate to the project scope. This task will consist 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 will implement the FTP to gather requisite data to answer research questions. These initial flight tests are precursors to follow-on testing that occurs in Task 4. As such, initial flight tests are aimed at validating methodology and further refinement of plans to ensure useful, valid data collection.

Task 4: Flight Tests
Flight tests for data collection and analysis that is in alignment with finalized flight test and data analysis plans. Flight tests for this task seek to answer key research questions through data collection and analysis.

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.

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, 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 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.

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Graduation of Students

Name	Graduation Date
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SMALL UAS (SUAS) MID-AIR COLLISION (MAC) LIKELIHOOD

WICHITA STATE UNIVERSITY NATIONAL INSTITUTE FOR AVIATION RESEARCH · KANSAS STATE UNIVERSITY · EMBRY-RIDDLE Aeronautical University · KU

Lead: Wichita State University's National Institute of Aviation Research

Background:

The primary goal of regulating Unmanned Air Systems (UAS) operations in the National Airspace System (NAS) is to assure an appropriate level of safety. This goal is quantified by national aviation agencies as an "Equivalent Level of Safety" (ELOS) with that of manned aviation. There are major 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 Unmanned Air Systems. These differences could introduce new failure modes, and, as a result, and increased perceived risk that needs to be evaluated. Any UAS operation or test must show a level of risk to human life no greater 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 operated 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...) in order to assess the damage severity to manned aircraft. The objective of the research is to evaluate the severity of a typical quad and fixed wing sUAS airborne collision with a manned aircraft. Mitigated and unmitigated results can be evaluated to understand the performance of the DAA on decreasing the likelihood of a MAC as well as 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 appropriate Equivalent Level of Safety criteria.

Approach:

Task 1: Literature Review

The research team will identify relevant research and documentation in the areas of Unmanned Aircraft Systems (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 a sUAS and a manned aircraft. DAIDALUS and ACAS sXu are

"Any UAS operation or test must show a level of risk to human life no greater 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."

potential DAA algorithms under consideration 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 a sUAS vs. a bird strike of similar weight in terms of severity and frequency. The research will estimate economic impact if enough information is available.

Key Findings:
The literature review is in progress at this time. Development of encounter sets with MITLL encounter models and based on operational sUAS characteristics is in progress as well. 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 2022.

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Name	Origin
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Graduation of Students

Name	Graduation Date
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Aaron McKinnis	May 2023

UAS FLIGHT DATA RESEARCH IN SUPPORT OF ASIAS

Lead: University of North Dakota

Background:
This research will aggregate high quality Unmanned Aircraft Systems (UAS) flight data with commercial and general aviation flight data and surveillance data, in order 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 Aviation Safety Information Analysis and Sharing (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 United States 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 above. 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 above, 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 above 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 just begun, as of 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.

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SUAS TRAFFIC ANALYSIS

EMBRY-RIDDLE Aeronautical University | KANSAS STATE UNIVERSITY | WICHITA STATE UNIVERSITY NATIONAL INSTITUTE FOR AVIATION RESEARCH

Lead: Embry Riddle Aeronautical University

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 DJI Aeroscope 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 in and will support the FAA in forecasting, planning, risk assessments, 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 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.
- Section 376, where Congress tasked the FAA to assess the use of UTM services including, "the potential for UTM services to manage unmanned aircraft systems carrying either cargo, payload, or passengers, weighing more than 55 pounds, and operating at altitudes higher than 400 feet above ground level"
    - sUAS traffic data will help inform the amount of traffic that UTM will need to manage
- Section 44808 directs the FAA to plan for 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 two companies providing sUAS detection services at more than 100 locations across the United States. Specific emphasis is placed on the following objectives:

- Assessing the effectiveness of existing regulations under 14 Part 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 1: Analysis Tool Development & Literature Review

The primary objectives of this task include developing the capabilities of URSA's UAS and Counter-UAS Analytics platform 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 2 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 Aeroscope sUAS detection data to quantify operational trends.

Task 3: 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 4: 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 5: 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 6: 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:
This project has just begun. Reports will be delivered throughout the 39-month period of performance, and the final report will be delivered to the FAA for peer review in 2024.

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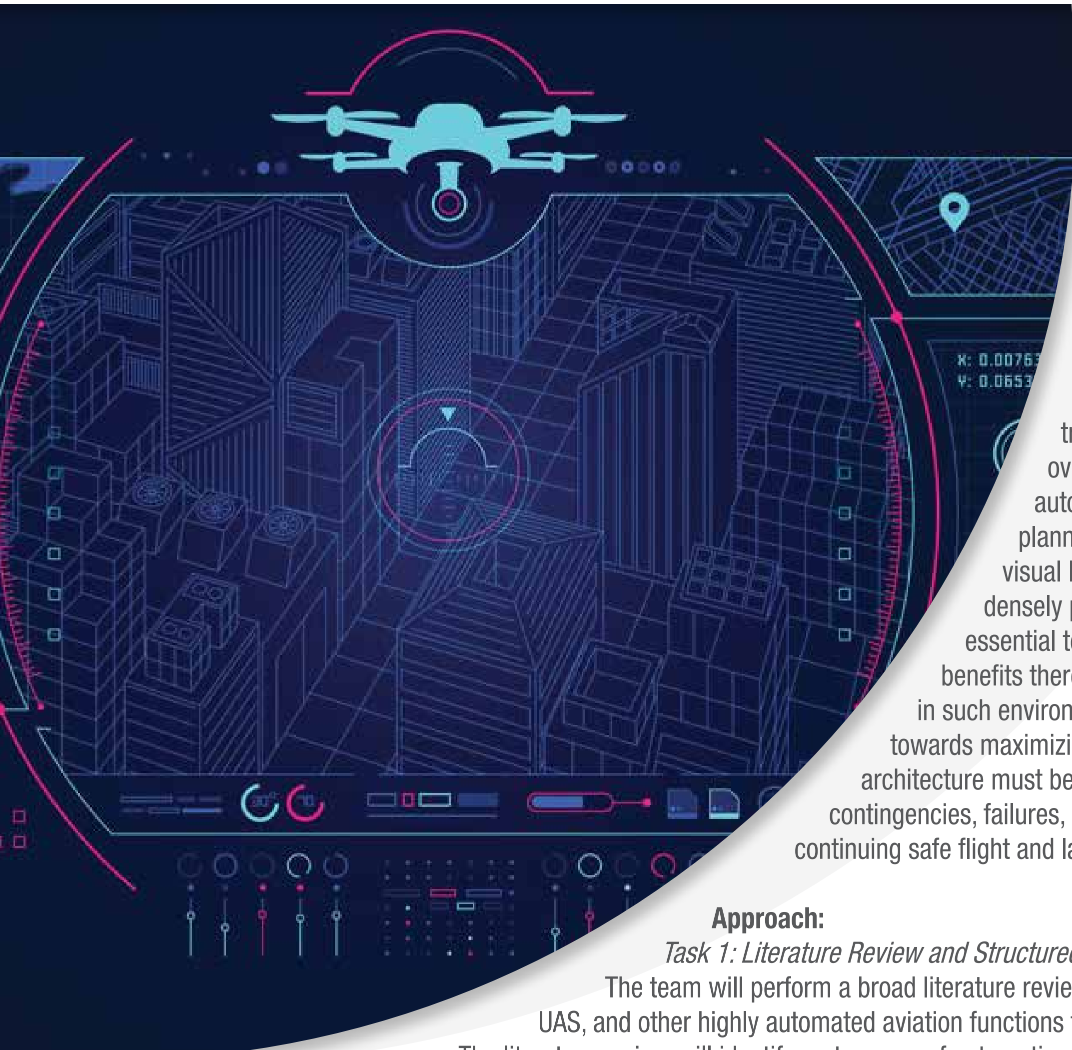
BEST ENGINEERING PRACTICES FOR AUTOMATED SYSTEMS



Lead: Oregon State University

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 re-usable 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 PIs, 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 UAS and 2) put into practice new guidance for specific automated functions of UAS.

Task 4: Validation of Design Guidance
This task will validate the methods developed in Task 3 and apply the risk assessment methods developed in Task 2, in simulation, limited flight testing, and by expert review.

Key Findings:
This project has just begun. Reports will be delivered throughout the 42-month period of performance, and the final report will be delivered to the FAA for peer review in 2025.

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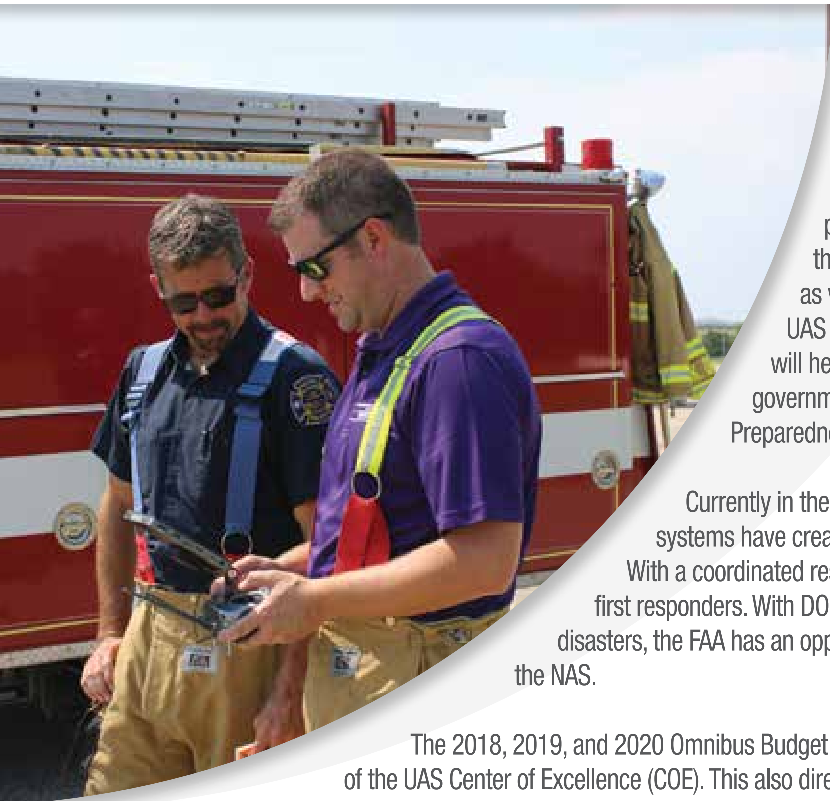
Abbas, Houssam	Lebanon
Askleson, Mark	United States
Bobba, Rakesh	India
Bowes, Robert	United States
Byrd, Anastasia	United States & Russia (Dual citizen)
Choi, Jinhong	Republic of Korea
Chowdhury, Mozammal Hosain	Bangladesh
Chrit, Mounir	Morocco
Dania, Paul Omeiza	Nigeria
Dutta, Abhinanda	India
Ewing, Mark Stephan	United States
Han, David	United States
Jang, Yeong Jin	Republic of Korea
Keshmiri, Shawn	United States
Kim, Jinsub	Republic of Korea
Majdi, Marwa	Tunisia
McCrink, Matthew	United States
Narayanan, Hariharan	India
Natarajan, Arun	United States
Rouhi, Amirreza	Iran
Smith, Philip	United States
Weber, Steven	United States
Wills, Lindsay	United States
Woldegiorgis, Yonatan Asmerom	Ethiopia

DISASTER PREPAREDNESS AND EMERGENCY RESPONSE – PHASE II



Lead: University of Alabama – Huntsville

Background:

The requirement is intended to be long-term research. It 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, driven by the FY18 Omnibus.

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 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 0. Project Management and Research Task Plan Development.

The performer will hold a kickoff meeting to review sponsor needs, review the Research Task Plan, clarify any issues with scope, and to discuss the technical approach and methodology.

Task 1. Review of Phase 1

Task 1 will be to conduct an extensive review of Phase 1 of the A28 program 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 to determine what role local and state governments play in this area.

Task 3. Lesson Learned

This task is for the documentation and assessment of lessons learned from the exercises and demonstrations from Task 2. The lessons learned will be documented via the exercises with assessment via After Action Review (AAR) 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 tasks, 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:
This effort is ongoing. 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 2022.

Name & Origin of All Research Personnel

Name	Origin
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	United States
Mandar Dewoolkar	United States
David Novak	United States
James Sullivan	United States
Molly Myers	United States
Adam Zylka	United States
Maddy Zimmerman	United States
Cathy Cahill - UAF	United States
Peter Webley - UAF	Great Britain
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

Name & Origin of All Research Personnel

Name	Origin
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	South Korea
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

Graduation of Students

Name	Graduation Date
Rebecca Garcia - MSU	May 2023

PROCEEDINGS & FUTURE RESEARCH

UPCOMING RESEARCH

Below are the areas of research the FAA has funded or has expressed interest in funding, considering its limited resources. The 2021 upcoming work was proposed at the end of the fiscal year and is awaiting official award. The 2022 upcoming work is ASSURE's best guess for future research based on FAA priorities for supporting the mission to safely integrate UAS into the National Airspace System and are subject to change.

2021 Research

- UAS Electromagnetic Compatibility
- DAA Track Classification
- UAS Cybersecurity Oversight
- Safety and Security Technologies
- STEM IV
- Disaster Preparedness & Recovery for UAS Phase III
- SARP Support

2022 Research

- DAA Risk Ratio Validation
- AAM Modeling to Inform UAS Integration
- Collision Severity of sUAS in Flight Critical Zones of Manned Helicopter
- AAM / UAM Safe Automation Modeling

JOURNAL ARTICLES & CONFERENCE PROCEEDINGS

- Schwartz, E., Todd, C., & Wallace, R.J. (2021). Unmanned Vehicles for Emergency Management and Hurricane Response (Panel Session). 2021 Florida Automated Vehicles (FAV) Summit, Orlando, Florida. https://favsummit.com/
- Wallace, R.J., Truong, D., Stansbury, R.S., & Engstrom, J. (2021, March 17). SUAS Operational Trends: A Multi-Year Detection Study in Controlled Airspace. Presented at International Virtual Conference on Air Mobility with Unmanned Systems and Engineering (AMUSE), Nanyang Technical University, Singapore. Retrieved from https://atmri.ntu.edu.sg/amuse/Pages/Programme.aspx
- Development of a Simulation Environment for Validation and Verification of Small UAS Operations, GNC-02/IS-02, Guidance and Control Architectures for Autonomous Systems I , AIAA SciTech Conference, January, 2022. San Diego, Ca.

SIGNIFICANT EVENTS

Significant Events	Date
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
ASSURE Present in Spain for Spanish Gov't, Academia, and Industry	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

The ASSURE University Coalition

Assure has the knowledge of a 25 Member University Coalition

MISSISSIPPI STATE UNIVERSITY

UAF UNIVERSITY OF ALASKA FAIRBANKS

THE OHIO STATE UNIVERSITY

UCDAVIS UNIVERSITY OF CALIFORNIA

KU

UAH THE UNIVERSITY OF ALABAMA IN HUNTSVILLE

EMBRY-RIDDLE Aeronautical University.

NM STATE UNIVERSITY

KANSAS STATE UNIVERSITY

WSU WICHITA STATE UNIVERSITY

OSU Oregon State University

NC STATE UNIVERSITY

MONTANA STATE UNIVERSITY

AUBURN UNIVERSITY

UND UNIVERSITY OF NORTH DAKOTA.

Drexel UNIVERSITY

Concordia UNIVERSITÉ UNIVERSITY

TUSKEGEE UNIVERSITY

National UAS Training and Certification Center

Indiana State University

LOUISIANA TECH UNIVERSITY.

TECHNION Israel Institute of Technology

UNIVERSITY OF Southampton

The University of Vermont

NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

LED BY MISSISSIPPI STATE UNIVERSITY

The FAA's Center of Excellence for UAS Research

ASSURE

Alliance for System Safety of UAS through Research Excellence

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