ASSURE UAS Research and Development Program Research Abstract
FAA Research Requirement: A11LUAS.7 UAS System Safety Criteria **UAS Research Focus Area:** Low Altitude Operations Safety
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ASSURE External Advisory Board Principle Investigator (if applicable): NA
Other ASSURE External Advisory Board (EAB) Performers: (if applicable): NA
Classified or Security Related Work: No

EXECUTIVE SUMMARY:

The research team consisting of UAH, ERAU, MSU and KU will address the research questions as defined in paragraph 3.2 below. The research will include literature search on related to human lethality thresholds to determine hazard definitions for ground collisions of UAS with people, review the methods of establishing severity classifications conducted by Georgia Institute of Technology and the University of North Dakota, evaluate the range of aircraft characteristics (kinetic energy, structure, shape, materials, etc.) from various UAS classes for comparison with similar characteristics for manned aircraft for which severity classification are already determined and conduct, as needed, modeling and analysis of UAS impacts with humans and manned vehicles/structures to determine severity of injuries when compared with lethality and injury thresholds when gaps are identified in the available data for determining hazard severity. The team shall analyze the results of models and literature searches to develop applicable operational and airworthiness standards as well as identify different or modified classes of UAS as the basis for modified airworthiness certification.

1.0 Background

UAS airworthiness considerations require an understanding of the hazard severity and likelihood of UAS operations in the NAS. Conventional 14 CFR system safety analyses include hazards to flight crew and occupants may not be applicable to unmanned aircraft. However, UAS operations may pose unique hazards to other aircraft and people on the ground. It is necessary to determine hazard severity thresholds for UAS using safety characteristic factors that affect the potential severity of UAS in collisions with other aircraft on the ground or in airborne encounters as well as collisions with people on the ground. These severity thresholds will help determine acceptable corresponding system failure levels in accordance with the applicable 14 CFR requirements (for example 14 CFR 23.1309 and 14 CFR 25.1309).

The following hazard risks must be considered in the determination of these thresholds:

1) Fatality potential with people on the ground due to impact by UAS with a lethal combination of kinetic energy, structure, shape, materials and or other significant hazards present upon collision.
2) Ground or airborne collision fatality potential due to impact with another aircraft by UAS with a lethal combination of kinetic energy, structure, shape, materials, etc. and or other hazards present upon collision.

Hazard severity threshold characteristics should be addressed for representative UAS to include:

a) traditional aluminum and various composite construction aircraft
b) fixed wing and rotary wing aircraft
c) tractor and pusher propulsion systems
d) flammable materials such as fuel
e) lethal kinetic energies based on combinations of mass and speed

FAAO 8900.1 defines the five-phase operational approval process and cautions the applicant to expect a very rigorous and involved effort to generate the necessary showings of compliance for new and novel operations. This FAA order also notes the need for all airworthiness approvals and operations requirements to be met before an operator can be authorized to conduct a particular operation. Comprehensive understanding of the lethality risk of the range of potential UAS is needed to address 8900.1 requirements.

FAA Order 8110.4C documents the FAA's processes for airworthiness approvals under a type certification or supplemental type certification. This order and related direction have processes to address certification of systems with new or novel design features for which appropriate safety standards may not exist.

Increased understanding of these operational and airworthiness compliance issues and the manner in which UAS and the pilots who operate them can demonstrate compliance is essential to the timely, safe, and efficient integration of UAS into the NAS.

There is no known research that has been completed in this area, but there is worldwide interest in coming to terms with system safety challenges such as this one for UAS. Research conducted or sponsored by other regulatory authorities will be leveraged to the maximum practical extent.

2.0 Scope

The research will address the following research questions and any related questions that are developed through the research process and agreed to with the FAA:

The main research questions being answered through this research are:

What are the hazard severity criteria for a UAS collision (weight, kinetic energy, etc)?
How can UAS be designed as to minimize the potential damage done during a collision?
What is the severity of a UAS collision with aircraft on the ground?
What is the severity of a UAS collision with property on the ground?
What is the severity of a UAS collision with a person on the ground?
What are the characteristics of a UAS where it will not be a risk to an aircraft or person/property on the ground?
Can the severity of a UAS collision with an aircraft or person/property on the ground be characterized into categories based on the UAS and what would those categories look like?

The research will include a thorough review of DO-344, DO-304 and DO-320 published by the RTCA Special Committee 203 (SC-203) system safety subgroup. The literature search will include review of FAA Order 8110.4C, FAA Order 8900.1 to address the airworthiness approval process for comparison of the different UAS aircraft classes to compare regulatory guidance in terms of hazard severity for ground collisions with vehicles with similar characteristics (weight, kinetic energy, structure, shape, materials, etc.) to adequately account for potential severity characteristics of UAS and provide for equivalent levels of safety for people, property and aircraft on the ground.

3.0 Research Framework

3.1 Research Requirement. The research requirement was established in A11LUAS.7 UAS System Safety Requirement as defined in the Statement of Work FAA COE Task: UAS Ground Collision Severity Evaluation. Research efforts are described in the mapping listed in paragraph 3.2.

3.2. Research Mapping.

The research is mapped to the research questions as defined below:

3.2.1 What are the hazard severity criteria for a UAS collision (weight, kinetic energy, etc.)?

The team will utilize a database developed by ERAU and UAH to outline the UAS characteristics for the existing classifications of UAS. The team will utilize research documents from the FAA including the RTCA SC-203 published documents DO-344, DO-320 and DO-304 to outline credible encounter scenarios from which to base hazard severity criteria. Furthermore, the team will research existing literature and data from the FAA Tech Center, DoD and NASA to develop a set of criteria for injury severity that can supplement the hazard severity definitions called found in AC 25.1309-1E. The injury severity definitions for personnel and property as well as the hazard severity for aircraft on the ground will be used as a basis for conducting modeling and further analysis among the various UAS platforms. Additionally, the research will compare the vehicle characteristics (weight, kinetic energy, structure, shape, materials, etc.) of UAS in the various categories and compare them with vehicle characteristics of manned aircraft for which there is existing regulatory guidance with airworthiness standards to identify commonality and gaps in the regulatory framework as it relates to airworthiness standards for the current UAS categories. The research will address whether additional subdivision of categories may be needed to address airworthiness standards.

3.2.2 What is the severity of a UAS collision with aircraft on the ground, property on the ground, a person on the ground under credible encounter scenarios?

The team will conduct a comparison of UAS characteristics from the various classes of UAS and conduct a comparison with manned aircraft for which there is a basis for comparison with existing hazard severity definitions in terms of the aircraft characteristics. A Global Hawk and a large transport aircraft of equivalent weight will have similar lethality characteristics to people and property on the ground and as such do not require new or creative hazard severity definitions and can apply similar airworthiness standards to those of transport category aircraft in terms of ground collision with people, property or aircraft on the ground. Small UAS platforms and perhaps larger UAS platforms made of unique materials then manned aircraft at the same or similar weight classes will be evaluated in terms of characteristics and their impact on lethality to determine whether additional distinction is required between the classes such as fixed wing versus rotary wing, gliders versus engine power aircraft, micro-UAS, etc.

As part of this work, the threat/risk posed by UAS collisions to humans on the ground will be assessed using two different modeling techniques of a small set of UAS collisions with persons on the ground. These simulations will be used to address the corner cases of the UAS ground collisions to assess the severity of the impacts to validate the assessment of existing standards or to validate gaps in the available data. The objectives of the human modeling are (1) to analyze the response and failure behavior of several typical UASs impact with human body on the ground; and (2) establish the damage threshold of UAS and its correlation with the key parameters in the crash accidents (e.g. shape, size and materials of UAS; impact energy and impulse etc.). To achieve this goal, advanced computational modeling techniques (e.g. finite element method/FEM) will be used to simulate the typical UAS/people impact scenarios. Three specific tasks will be carried out. Firstly, FE models of typical UASs will be constructed based on the CAD data and validated against the real world accidental data. Then, the validated UAS models will be integrated with an Anthropomorphic Test Device (ATD) and human body models to simulate the typical aircraft/people impact events. The injury of head and chest will be identified. Finally, a comprehensive parametric study will be performed to derive the damage criteria. Based on the results, a design guidance can be further suggested to improve the crashworthiness of UAS and safety of personnel on the ground. Finite element models of various UAS will also be used to address specific credible encounters with human subjects by modeling specific UAS characteristics of (weight, kinetic energy, structure, shape, materials, etc.) to address the gap areas and assess injury potential. Modeling will be utilized to address human injury where there are gaps in the amount of available data to address the research need.

3.2.3 What are the characteristics of a UAS where it will not be a risk to an aircraft or person/property on the ground under credible encounter scenarios?

The research described on item 3.2.2 above will address this research question. The boundaries of the definitions and analysis will be addressed through the review of available data for injury severity and UAS vehicle characteristics. A small number of corner points will be assessed using modeling and simulation to validate the boundaries. If additional modeling is required to address a larger number of gap areas in available injury severity data, then those gaps will be identified and additional funding requested to complete the data set.

3.2.4 How can UAS be designed as to minimize the potential damage done during a collision under credible encounter scenarios?

The research team will propose design methods based upon injury severity and UAS characteristics throughout the literature search and review of the UAS classes. No modeling of these new design features is proposed under this budget, but the evaluation of injury sources from various UAS characteristics and possible mitigations will be presented for future modeling and simulation as required.

<u>3.3 Research Review.</u> The research will include a review of Embry Riddle and UAH data on small UAS platforms.

<u>3.4 Research Approach.</u>

Task	Proposed Outcomes	Date Due	ASSURE Performer
1. Literature Search	White Paper outlining UAS Characteristics across UAS Classes including comparison of UAS platforms to manned aircraft in terms of lethality characteristics	T+6 months	UAH ERAU KU MSU
	Development of injury severity definitions for human modeling efforts		
2. Development of initial Human Modeling and UAS modeling to complete initial	The objectives of the human modeling are (1) to analyze the response and failure behavior of several typical UASs impact with human	T+9 months	ERAU MSU KU

gaps in available data on injury severity and validate UAS Characteristics under 1-2 credible encounter scenarios	body on the ground; and (2) establish the damage threshold of UAS and its correlation with the key parameters in the crash accidents (e.g. shape, size and materials of UAS; impact energy and impulse etc.).		
	Development of UAS Modeling to verify UAS characteristics in various failure modes to validate characteristics		
3. Final Report	FY16 Final report, detailing key safety characteristics and there thresholds for levels of safety operating in the NAS. Includes recommendations for additional modeling efforts that cannot be completed in 12 months.	T+12 months	UAH ERAU KU MSU
4. Technical Interchange Meetings (TIMs)	Meeting notes capturing the discussions and action items from each TIM. The budget for this task also covers travel expenses. Two, 2 day meetings proposed.	Submit 3 days after the TIM	UAH ERAU KU MSU
5. Quarterly Status Reports	The report will provide the status of the research desired products, schedule, budget and risks.	Quarterly	UAH ERAU KU MSU
6. Additional Human and UAS interaction modeling	Expand human and UAS modeling to additional encounter scenarios to complete injury severity analysis	T+18 months	ERAU MSU KU UAH
7. Update Final Report	Requirements Validation & Report	T+21 months	UAH ERAU MSU KU

T=Date of Award

4 Government Furnished Information

The government will furnish the following information to the performer:

a) Technical Research/Data describing data that is considered.

5 Period of Performance/Projected Schedule

The technical period of performance for this task order is from the Date of Award (listed in table as T) for 21 months.

Task	FY16				FY17		
	4Q CY15	1Q CY16	2Q CY16	3Q CY16	4Q CY16	1Q CY17	2QCY17
1. Literature Search	■	■					
2. Development of initial Human Modeling and UAS modeling to complete initial gaps in available data on injury severity and validate UAS Characteristics under 1-2 credible encounter scenarios		■	■				
3. Final Report				■			
4. Technical Interchange Meetings (TIMs)							
5. Quarterly Status Reports							
6. Additional Human and UAS interaction modeling					■	■	
7. Update Final Report					■	■	■

6 Matching

Matching of funds will come from cost sharing for labor and in kind contributions for modeling activities and use of existing research as well as equipment and software purchases for the modeling effort.

7 Proposed Outcomes

This section includes the schedule and a list of desired products. This needs to include:

- Dependencies. Availability of FAA Tech Center data and completion of the literature search and review of UAS characteristics database will determine the scope and size of the modeling efforts planned under this effort. The team will utilize data collected under the testing efforts for the Airborne Collision testing where appropriate to fill in additional data sets for ground collision with aircraft or ground collision with similar property and vehicles.
- Timeline. See paragraph 3.4
- Anticipated follow-on proposals. Additional proposals from this effort will include future human injury versus UAS characteristics modeling that are beyond the scope of the funding available for this effort.

8 List of Universities and Individuals Involved in the Project

David Arterburn, Director, RSESC, University of Alabama in Huntsville
Ratan Jha, Director, RASPET Flight Laboratory, Mississippi State University,
Dr. Mark Ewing, Associate Professor and Director of the Flight Research Laboratory, Kansas University
Dr. Eduardo Divo, Associate Chair, Mechanical Engineering Department, Embry-Riddle Aeronautical University,
Dr. Zhu Feng, Assistant Professor, Embry-Riddle Aeronautical University,

9 Estimated Level of Effort and Associated Costs

Performer: University of Alabama in Huntsville		
Year	**Performance Period**	**Tasks**
FY16	12 months	Task 1,3,4,5
FY17	9 months	Task 6,7
Total	**21 months**	
Performer: Mississippi State University		
Year	**Performance Period**	
FY16	12 months	Task 1,2,3,4,5
FY17	9 months	Task 6,7
Total	**21 months**	
Year	**Performance Period**	
FY16	12 months	Task 1,2,3,4,5
FY17	9 months	Task 6,7
Total	**21 months**	
Performer: Kansas University		
Year	**Performance Period**	
FY16	12 months	Task 1,2,3,4,5
FY17	9 months	Task 6,7
Total	**21 months**	