FAA UAS Research Results

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Research results can be found at assureuas.org

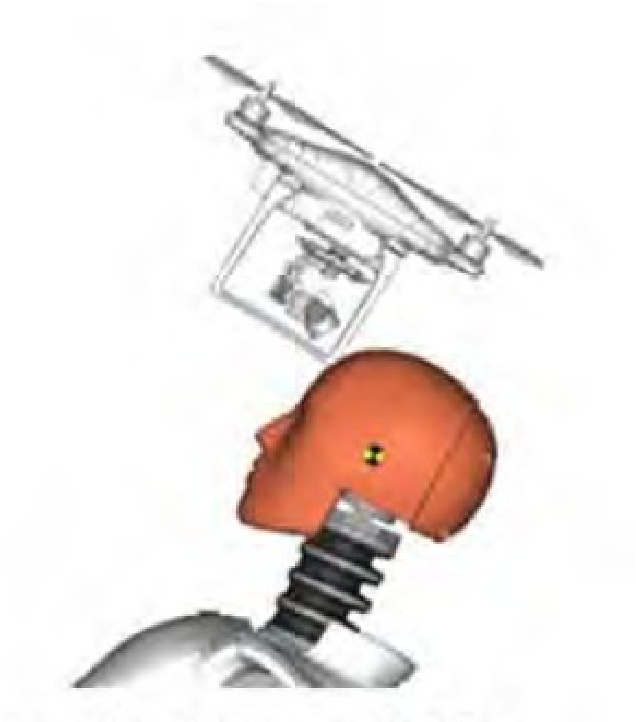
A4&A14: sUAS Ground Collision Hazard Study

Lead Principal Investigator:
Dave Arterburn, University Alabama-Huntsville

Also included: National Institute for Aviation Research (NIAR), Wichita State University (WSU), The Ohio State University (OSU), Mississippi State University (MSU) and Virginia Tech

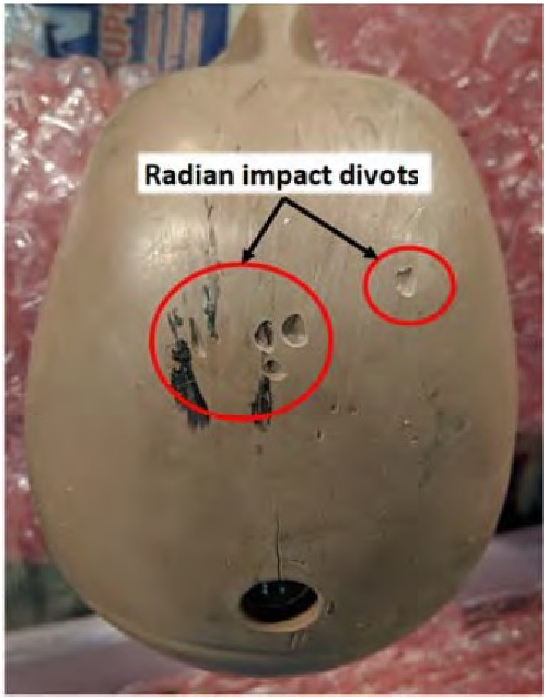
What risk/problem needs to be addressed for sUAS Operations Over People?

- **Inclusion of sUAS into the NAS may pose unique hazards to people on the ground**
  - It is necessary to determine the potential severity of sUAS ground collisions with people in order to define an acceptable level of safety
- **Airworthiness considerations require an understanding of the hazard severity and likelihood**



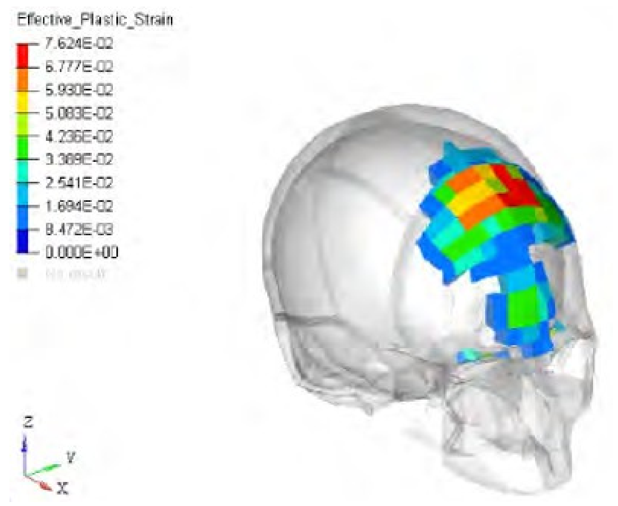
Research questions that address the risk/problem

- What are the hazard severity criteria for a UAS collision?
- What is the severity of a UAS collision with people on the ground?
- What are the design characteristics of a UAS that could minimize the potential injury during a ground collision?
- Can the severity of a UAS collision with a person be characterized into categories based on the UAS?



Research Approach (Phases 1 & 2: 2015-2019)

- **Over 512 impact tests and simulations were conducted**
  - 16 different fixed-wing and multi-rotor UAS, as well as various objects and payloads (**wood blocks – NPRM rigid object**, batteries, etc.) with weights ranging from 0.71 lbs. to 13.2 lbs at a range of low to terminal velocities
  - Evaluated heavier sUAS using mitigations, such as sUAS with parachutes



  - Initially utilized crash test dummies to review and determine thresholds of serious but non-lethal injury utilizing Abbreviated Injury Scale (AIS)
  - Increased the fidelity of the injury modeling and testing by utilizing Post Mortem Human Subjects (PMHS)
  - Developed a test methodology for assessing the level of risk of sUAS to persons on the ground in the event of a collision
  - Compared the thresholds for serious, but non-lethal injury established using the crash test dummies with the injury thresholds yielded from PMHS testing

Comparison of Steel & Wood with Phantom 3

UAS

Test Weight: 2.69 lbs.
Impact Velocity: 49-50 fps
Impact Energy: 100-103 ft-lbs.

Motor Vehicle Standards
- Prob. of neck injury: 11-13%
- Prob. of head injury: 0.01-0.03%

Range Commanders Council Standards
- Probability of fatality from…
  - Head impact: 98-99%
  - Chest impact: 98-99%
  - Body/limb impact: 54-57%

Wood

Test Weight: 2.69 lbs.
Impact Velocity: 52-54 fps
Impact Energy: 116-120 ft-lbs.

Motor Vehicle Standards
- Prob. of neck injury: 63-69%
- Prob. of head injury: 99-100%

Range Commanders Council Standards
- Probability of fatality from…
  - Head impact: 99-100%
  - Chest impact: 99-100%
  - Body/limb impact: 67-70%

Steel

Test Weight: 2.7 lbs.
Impact Velocity: 52-53 fps
Impact Energy: 114-121 ft-lbs.

Motor Vehicle Standards
- Prob. of neck injury: 61-72%
- Prob. of head injury: 99-100%

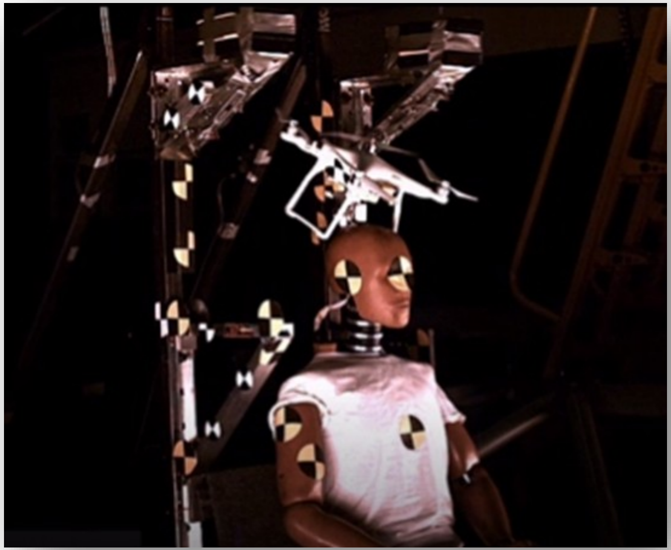
Range Commanders Council Standards
- Probability of fatality from…
  - Head impact: 99-100%
  - Chest impact: 99-100%
  - Body/limb impact: 65-71%

Key Findings:
Ground Collision Severity Report

- **Collision Dynamics of sUAS is not the same as being hit by a rock**
  - Multi-rotor UAS fall slower than metal debris of the same mass due to higher drag on the drone
  - sUAS are flexible during collision and retain significant energy during impact
  - Wood and metal debris do not deform and transfer most of their energy
- **Three dominant injury metrics applicable to sUAS**
  - Blunt force trauma injury – Most significant contributor to fatalities
  - Lacerations – Blade guards required for flight over people
  - Penetration injury – Hard to apply consistently as a standard
- **Payloads can be more hazardous due to reduced drag and stiffer materials**
- **Lithium Polymer Batteries need a unique standard suitable for sUAS to ensure safety**

Research Benefits

- **The ASSURE results show that injury caused by a rigid object at kinetic energy levels (Cat 2/Cat 3) in the OOP NPRM is equivalent to the injury caused by a sUAS at a higher kinetic energy**
  - This indicates that a sUAS can exert much higher kinetic energy than a rigid object and stay within the parameters of the NPRM



- **ASSURE developed simplified test methods that operators can utilize to yield results that could provide an alternate means of compliance for the Operations Over People NPRM/rule**
  - The ASSURE test methods are currently being used to inform the development of the ASTM F38 Standard for Impact Test Methods for Operating sUAS Over People

A3: sUAS Air-to-Air Collision Severity Study

Lead Principal Investigator:
Gerardo Olivares, Ph.D., Wichita State Univ.

Also included: The Ohio State University (OSU), Mississippi State University (MSU) and Montana State University

What risk/problem needs to be addressed for sUAS Operations in the NAS?

- **Inclusion of sUAS into the NAS may pose hazards other aircraft**
  - It is necessary to determine the potential severity of sUAS airborne collisions with manned aircraft in order to define an acceptable level of safety

- **Airworthiness considerations require an understanding of the hazard severity and likelihood**

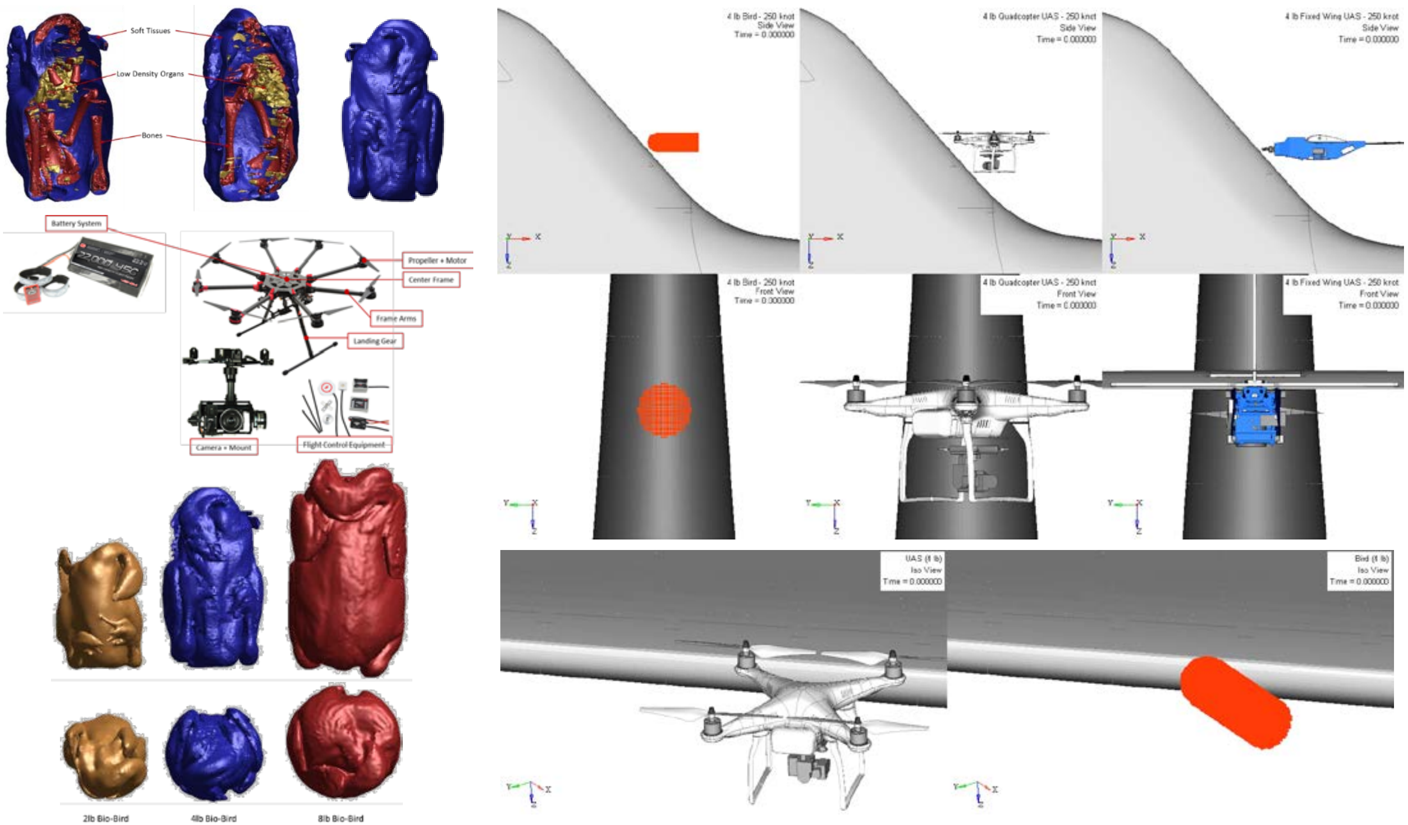
Research questions that address the risk/problem

- **What are the hazard severity criteria for a UAS collision with a manned aircraft?**
- **What is the severity of a UAS mid-air collision?**
- **How can the design of a UAS minimize potential damage during a mid-air collision?**
- **What are the design characteristics of a UAS that could minimize the potential injury during a mid-air collision?**
- **Can the severity of a UAS collision with a manned aircraft be characterized into categories based on the UAS?**
- **Can a sUAS Impact be Classified Similar to a Bird Strike?**

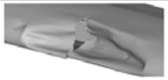
Air-to-Air Collision Severity Study: Scope

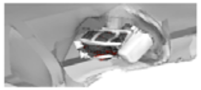
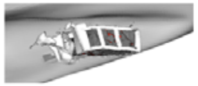
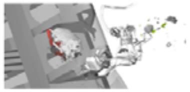
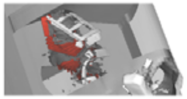
- **Study of Severity of perfect strike (Physical Damage & Fire Risk)**
  - Targets:
    - Narrow-body commercial transport (B737 / A320 Class)
    - Business Jet (Learjet 31A Class)
  - Projectile (UAs)
    - Quadcopter (DJI Phantom III)
    - Fixed-Wing (Precision Hawk Lancaster)

Can a sUAS Impact be Classified Similar to a Bird Strike?



Severity Level and Risk of Post Impact Battery Fire Classification

Severity Level	Description	Example
Level 1	• Undamaged. • Small deformation.	
Level 2	• Extensive permanent deformation on external surfaces. • Some internal structure deformed. • No failure of skin.	
Level 3	• Skin fracture. • Penetration of at least one component.	
Level 4	• Penetration of UAS into airframe. • Failure of primary structure.	

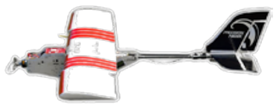
Fire Risk	Description	Example (UAS Visible)	Example (UAS Hidden)
Yes	• UAS (including the battery) penetrates the airframe. • Battery deforms but stays undamaged. • Validation tests showed that partly damaged batteries created heat and sparks.		
No	• The UAS does not penetrate the airframe.		
No	• UAS (including the battery) penetrates the airframe. • The battery sustains great damage, destroying its cells. • Validation tests showed that completely damaged batteries did not create heat or sparks.		

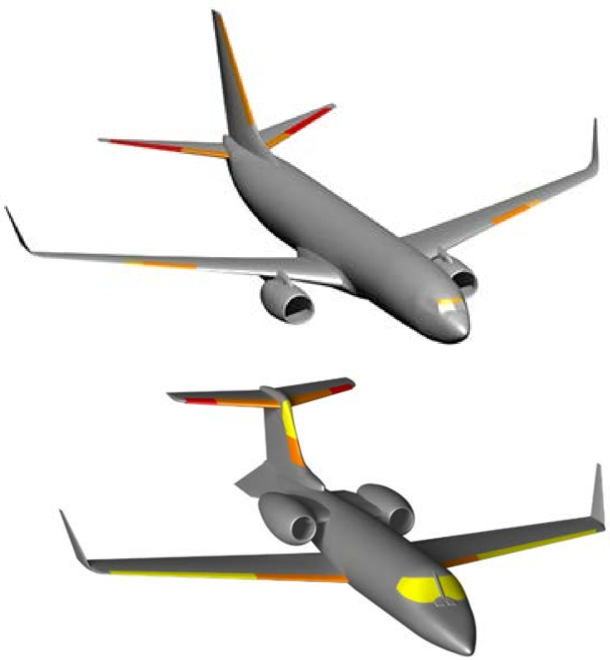
Note: These risk levels are specific to this project and not related to any FAA standard

What is the Severity of a sUAS Midair Collision with a Jet Aircraft?

2.7 lb. Quadcopter

4 lb. Fixed Wing





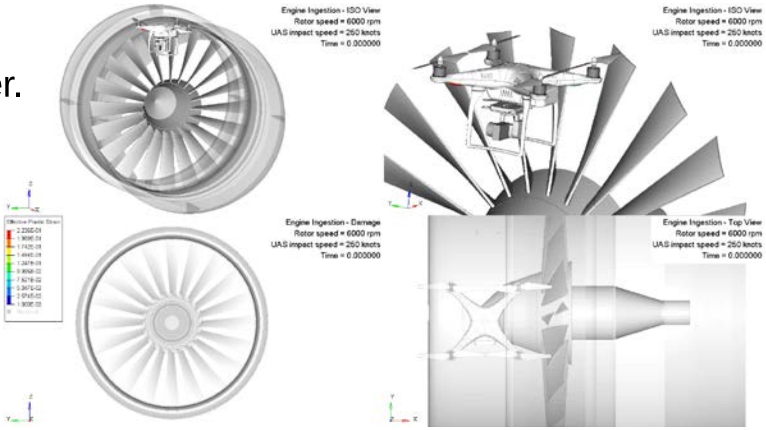
Level 1	
Level 2	
Level 3	
Level 4	

Conclusions Airframe – sUAS Impact R&D

- **Comparison to Bird Strikes**
  - sUAS collisions caused greater structural damage than bird strikes for equivalent impact energy levels
- **Velocity and Mass (kinetic energy)**
  - Physical damage noted for velocities above landing speeds for masses equal to or above 2.6lbs (1.2 kg)
  - Damage severity increases with increased mass and velocity
- **Stiffness of Components**
  - Component level testing demonstrated that stiff components such as motors can produce severe damage.
  - Full-scale sUAS simulations confirm: most damage produced by stiffer components (battery, motor, payload)
- **Distribution and Connection of Masses**
  - Distribution of mass and stiffness in the design of the sUAS is critical to the energy transfer
  - With concentrated or aligned masses the probability of critical damage increases.
- **Energy Absorption Capability**
  - sUAS designs which incorporate energy absorbing components (materials and/or structural features) could reduce the damage to the target aircraft

Engine Ingestion – Summary Results

- Quick look study using FAA Fan-Blade-Out Model
- Simulations focus on damage to fan, nacelle, and nosecone only
- Similar findings as structural research
- Fixed wing introduced more damage than the quadcopter.



- Stiffer components such as motors, cameras and batteries do the most damage to the fan.
- Location of impact along fan is a key parameter--More damage as the impact occurs closer to the blade tip.
- Takeoff scenario is the worst case because of high fan speeds.

Questions?

ANG-C21 Research Projects (Active)

Control Account Number	Research Project	Program Manager
A11L.UAS.7 (COE-A34)	Safety Case Methodology	Richard Lin
A11L.UAS.22 (COE-A18)	BVLOS – Seperation Requirements and Testing	Michael Reininger
A11L.UAS.23	C2 Link	Melanie Flavin
A11L.UAS.31	High Visual Contrast	Melanie Flavin
A11L.UAS.38	UAS Fuel Cells	Michael Reininger
A11L.UAS.39	UAS Lithium Batteries	Michael Reininger

ANG-C21 Research Projects (Active)

Control Account Number	Research Project	Program Manager
A11L.UAS.44	UAS Air Carrier Ops	Richard Lin
	Flight Path Display	Melanie Flavin
	Flight Test Data Collection	
	Safety Case Development	
	eCommerce	

ANG-C21 Research Projects (Active)

Control Account Number	Research Project	Program Manager
A11L.UAS.56	SARP Well Clear Research	Michael Reininger
	Airborne Collision: Engine Ingestion	Melanie Flavin
A11L.UAS.60 (COE – A16)	Airborne Collision: Structural Impact	Melanie Flavin
A11L.UAS.61 (COE – A??)	Automation and Autonomy	Phillip Maloney
A11L.UAS.68 (COE – A28)	Disaster Prep	Michael Reininger

ANG-C21 Research Projects (Active)

Control Account Number	Research Project	Program Manager
A11L.UAS.71 (COE – A27)	Risk-Based Thresholds	Richard Lin
	Risks Around Airports	Richard Lin
	Waiver Case Study Review	
	Pilot Proficiency Requirements	
	Wake Turbulence	

ANG-C21 Research Projects (Active)

Control Account Number	Research Project	Program Manager
A11L.UAS.78 (COE – A38)	UAS Cyber Security and Safety Lit Review	Richard Lin
	Section 383 UAS Detection at Airports	
	ATO Large UAS Collision	