Urban Air Transport Crashworthiness - Integrated Safety Approach

NIAR Advanced Virtual Engineering and Testing Laboratories

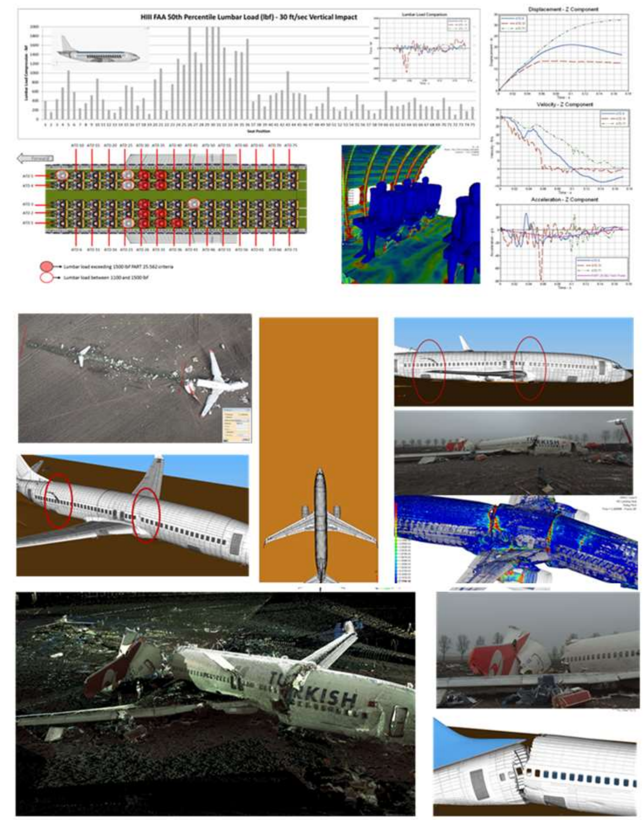
Gerardo Olivares Ph.D. | The Ninth Triennial International Fire & Cabin Safety Research Conference| October 28-31st 2019

NIAR WICHITA STATE UNIVERSITY
NATIONAL INSTITUTE FOR AVIATION RESEARCH

Aerospace Safety

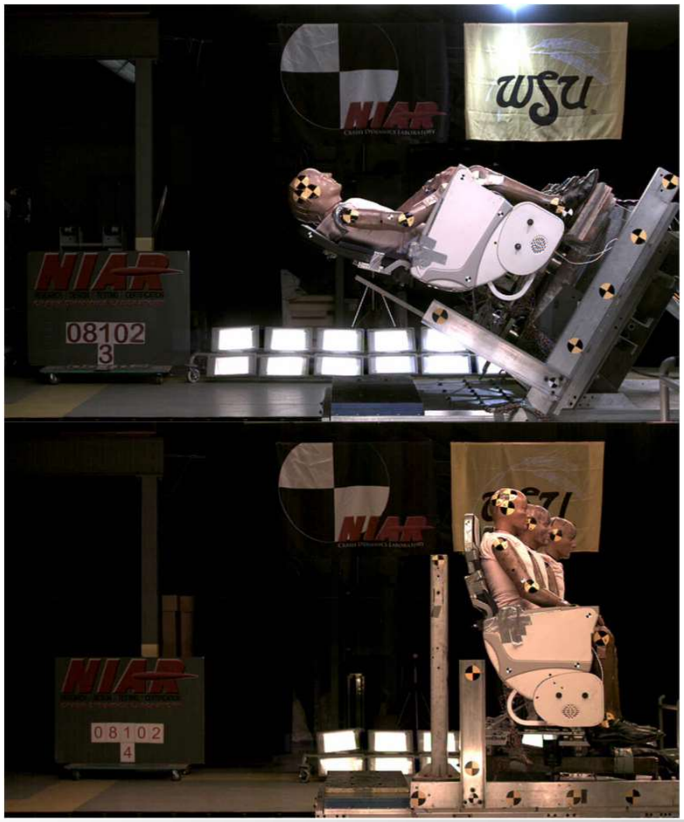
Non-Integrated vs. Integrated Safety

- Structural design for airplane safety combines airworthiness and crashworthiness design objectives to varying degrees.
- Airworthiness design objectives pertain to the ability of the airframe to withstand design loads, or to maintain safety of flight of the airplane relative to the operational environment.
- Crashworthiness design objectives pertain to safety of the occupants relative to the airplane.
- Occupant Safety must be an integral part of the overall technical and management processes associated with the design, development and operation of Urban Air Transport systems. Nowadays the crashworthiness design for aerospace applications under 14 CFR *.561 and *.562 only addresses the dynamic response of the seat and restraint system during emergency landing conditions. In order to improve the survivability rate of occupants an integrated safety approach is required.



14CFR *.562 Dynamic Test Requirements

Non-Integrated vs. Integrated Safety



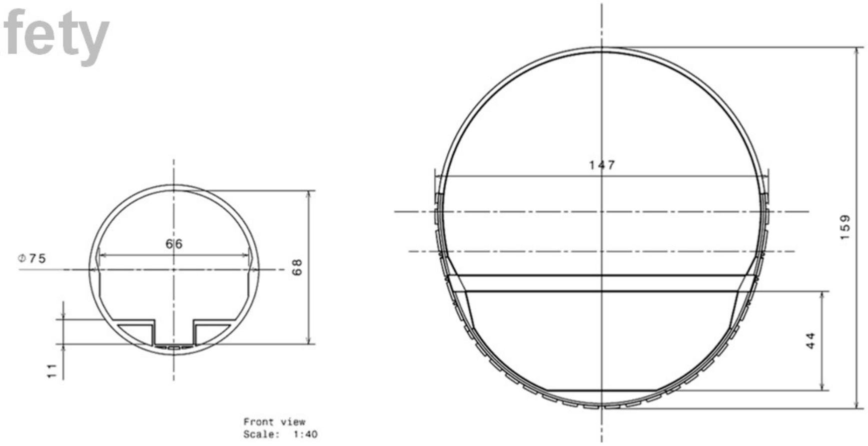
DYNAMIC TEST REQUIREMENTS	PART 23	PART 25	PART 27
TEST 1 Test Velocity – ft/sec Seat Pitch Angle – Degrees Seat Yaw Angle – Degrees Peak Deceleration – G's Time to Peak – sec Floor Deformation - Degrees	31 (9.5 m/sec) 60 0 19/15 0.05/0.06 None	35 (10.7 m/sec) 60 0 14 0.08 None	30 (9.2 m/sec) 60 0 30 0.031 10 Pitch/10 Roll
TEST 2 Test Velocity – ft/sec Seat Pitch Angle – Degrees Seat Yaw Angle – Degrees Peak Deceleration – G's Time to Peak – sec Floor Deformation - Degrees	42 (12.8 m/sec) 0 ±10 26/21 0.05/0.06 10 Pitch/10 Roll	44 (13.4 m/sec) 0 ±10 16 0.09 10 Pitch/10 Roll	42 (12.8 m/sec) 0 ±10 18.4 0.071 10 Pitch/10 Roll
COMPLIANCE CRITERIA HIC Lumbar Load – lbf Strap Loads – lbf Femur Loads – lbf	1000 1500 (6675 N) 1750[1]/2000[2] (7787N[1]/8900N[2]) N/A	1000 1500 (6675 N) 1750[1]/2000[2] (7787N[1]/8900N[2]) 2250	1000 1500 (6675 N) 1750[1]/2000[2] (7787N[1]/8900N[2]) N/A

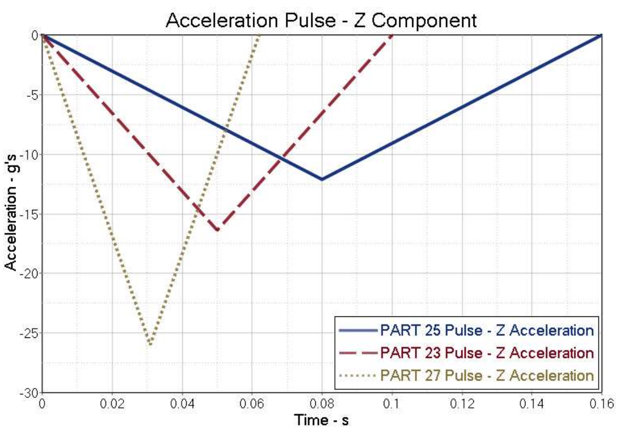
[1] – Passenger [2] - Pilot

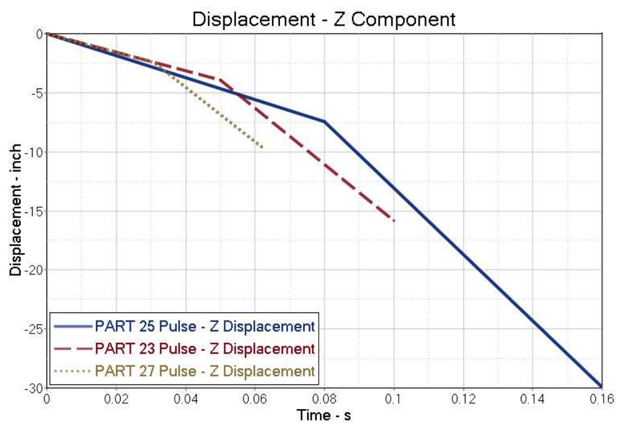
14 CFR *.562 Pulses Crush Requirements

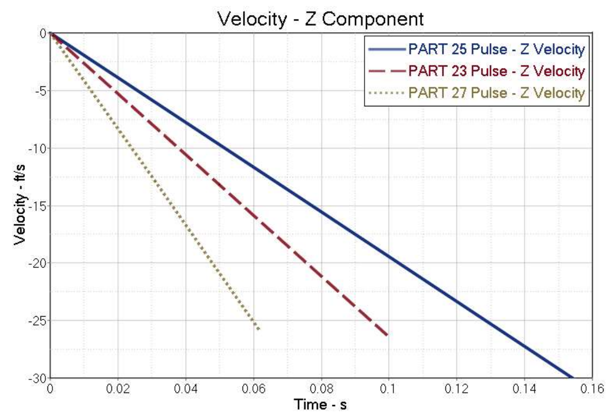
Non-Integrated vs. Integrated Safety

Test I	PART 25	PART 23	PART 27
Time to Peak (s)	0.08	0.05	0.031
Peak - Acceleration Pulse (g's)	14	19	30
Peak - Z Acceleration (g's)	12.1	16.4	26.0
Peak - Z Velocity (ft/s)	31.2	26.5	25.9
Peak - Z Displacement (inch)	30.3	16.2	9.6





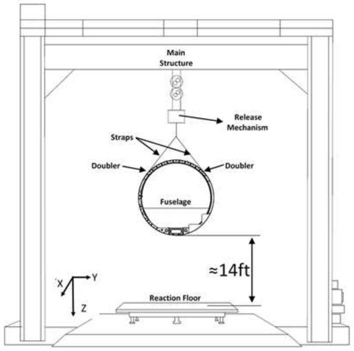


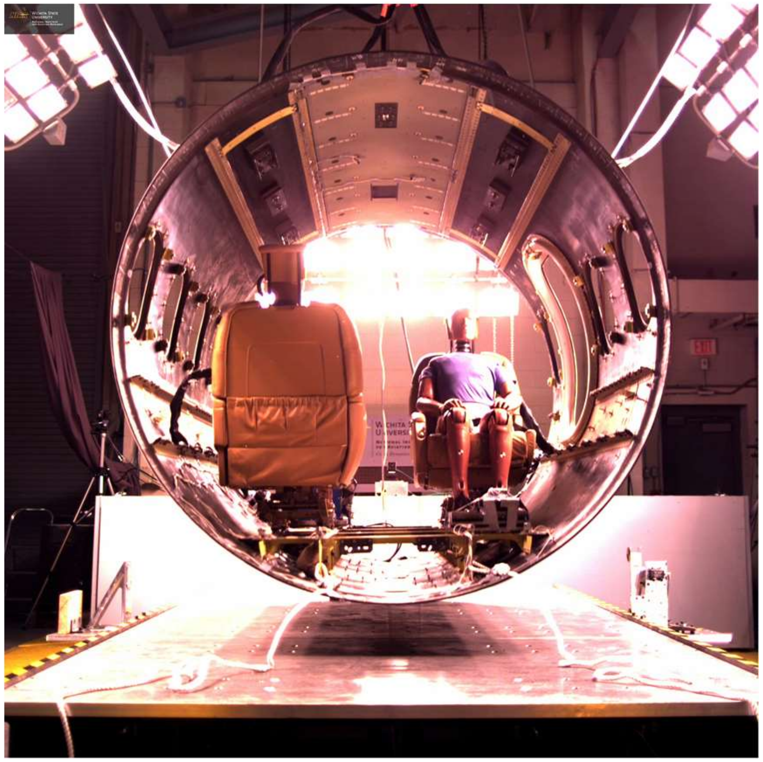


Non-Integrated vs. Integrated Safety

Example Aerospace Non-Integrated Safety Development

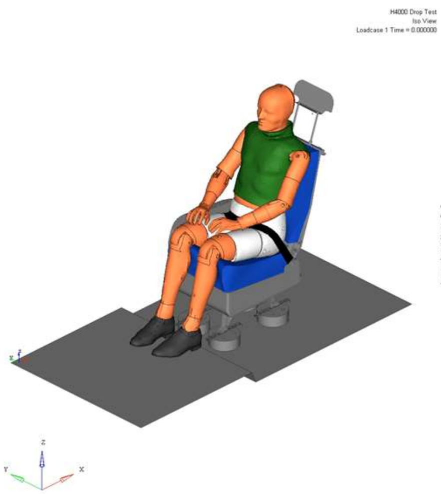
- Drop velocity: 30 ft./sec
- Composite Fuselage Certified under 14 CFR Part 25 - Airworthiness
- Dynamic Certified Seats per 14 CFR 25.561 and 562 – Emergency Landing Conditions

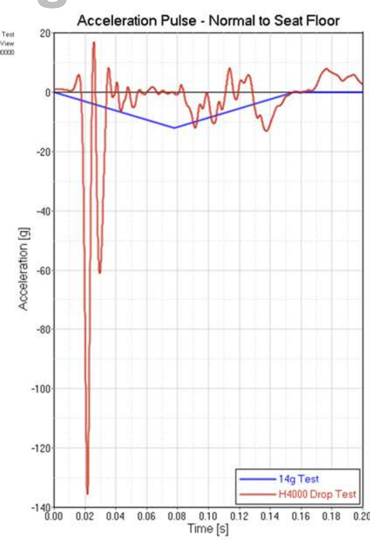


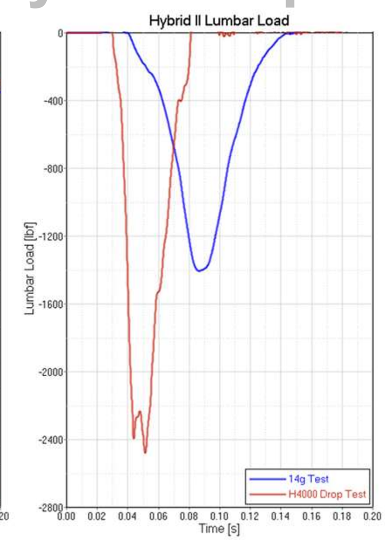


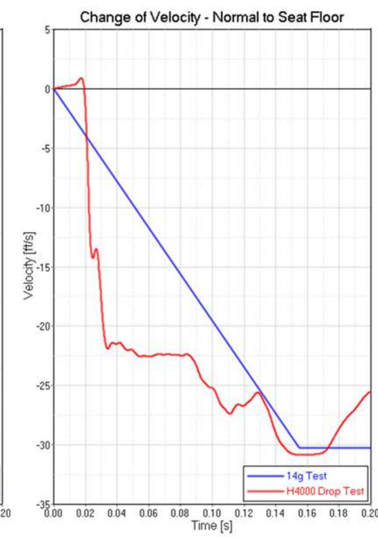
Non-Integrated vs. Integrated Safety

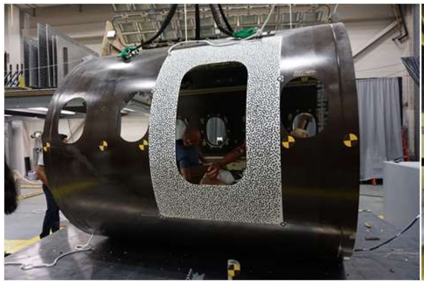
Example Aerospace Non-Integrated Safety Development







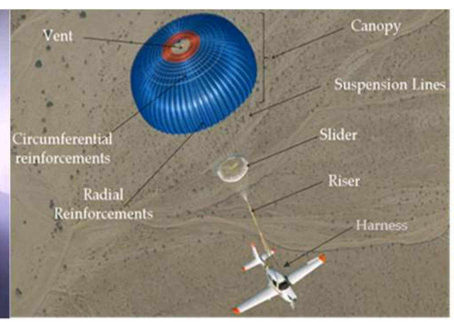




Aerospace Integrated Safety

Urban Air eVTOL Occupant Safety

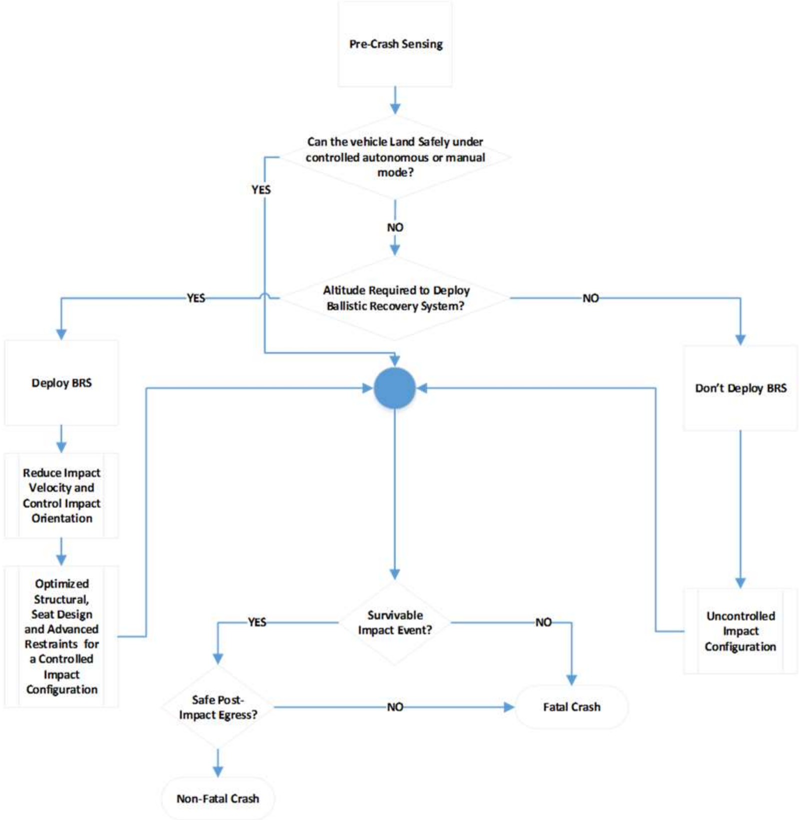
- The different elements that constitute the Integrated Safety concept approach are:
  - Pre-crash: Event Recognition.
  - Control Impact Velocity and Attitude: Distributed Propulsion System Redundancy, Parachute Ballistic Recovery Systems, Retro Rockets..Etc..
  - Integration of Landing Gear-Airframe Crashworthy Structure.
  - High-energy Absorbing Seats, and Advanced Restraints.
  - Post-crash: Battery Fire Suppression, and Egress.

Aerospace Integrated Safety

Urban Air eVTOL Occupant Safety

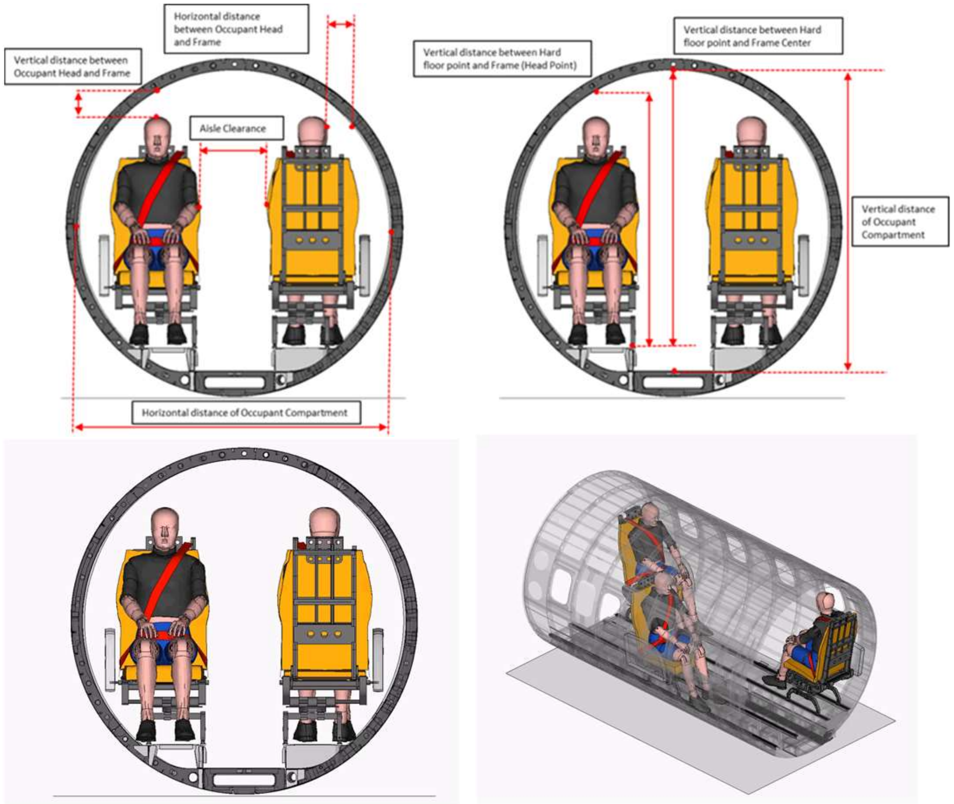
- Occupant safety must be an integral part of the overall technical and management processes associated with the design, development and operation of eVTOL Urban Air Transport systems.
- The different elements that constitute the integrated safety concept approach are:
  - Pre-crash: Event Recognition.
  - Control Impact Velocity and Attitude: Distributed Propulsion System Redundancy, Parachute Ballistic Recovery Systems, Retro Rockets ..Etc..
  - Integration of Landing Gear-Airframe Crashworthy Structure.
  - High-energy Absorbing Seats, and Advanced Restraints.
  - Post-crash: Battery Fire Suppression, and Egress
- Energy Absorbing Landing/Take off Sites
- The implementation of Pre-Crash, Active Safety Systems can prevent or mitigate the outcome of eVTOL crashes. The autonomous nature of eVTOL Urban Air Transport systems could potentially provide a significant effect in the reduction of fatalities caused by human error (75 % of the cases for GA fixed wing aircraft).



Aerospace Integrated Safety Criteria

Urban Air eVTOL Occupant Safety

- Maintain Survivable Volume
  - Overall Survivable Space Dimensional Check (Peak during Dynamic Event and Post Test Deformations)
  - Avoid Occupant to Interior Structure Contacts during impact
- Maintain Deceleration Loads to Occupants
  - Injury Criteria Limits per 14 CFR *.562 :
    - 1500 lbf, HIC 1000, Shoulder Strap Loads….
- Retention Items of Mass
  - Interior items of mass per 14 CFR *.561
  - Occupants and Seat Structures supported throughout the crash event (14 CFR 23.562)
- Maintain Egress Paths
  - Maintain Aisle Distance
  - Evaluate Plastic deformations of the supporting structure near the exit door
  - Floor Warping
  - Floor Beam Failures – Reduced Strength to support passenger weight



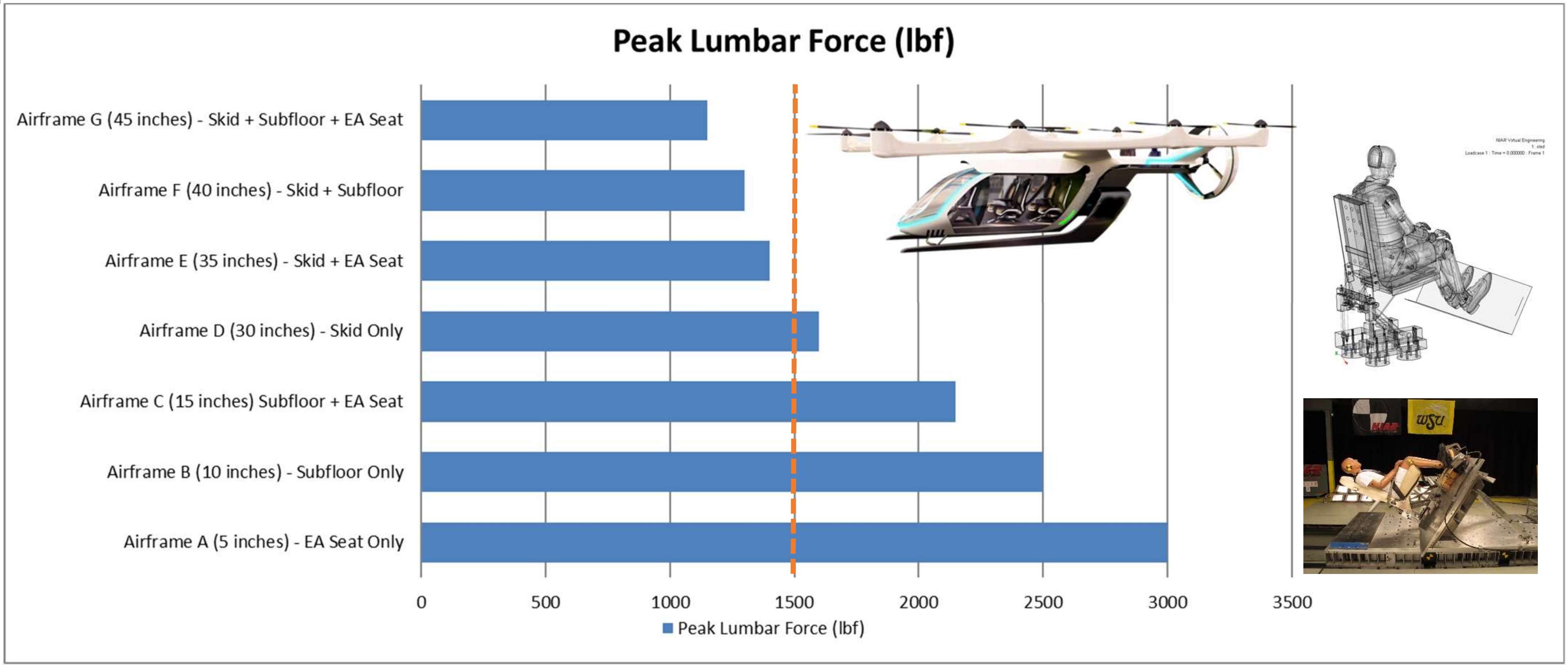
Example Urban Air Integrated Safety

Aerospace Integrated Safety

- **MTOW:** 3500 lbs.
- **Energy Absorbing Seat Stroke:** 5 inches.
- **Maximum Subfloor Crushable Space:** 10 inches.
- **Skid Structure Maximum Crushable Space:** 30 inches.
- **50 % Energy Absorbing Structural Efficiency.**
- **Ballistic Recovery System** that can reduce the Vertical Impact Velocity to 30 ft./sec and control the impact orientation.
- **Conceptual Design:** Initial Sizing Energy Methods.

Example Urban Air Integrated Safety

Aerospace Integrated Safety



Engineering and Certification Methods

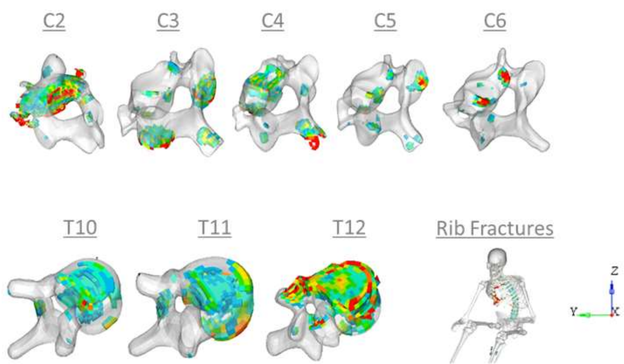
Urban Air eVTOL Integrated Occupant Safety

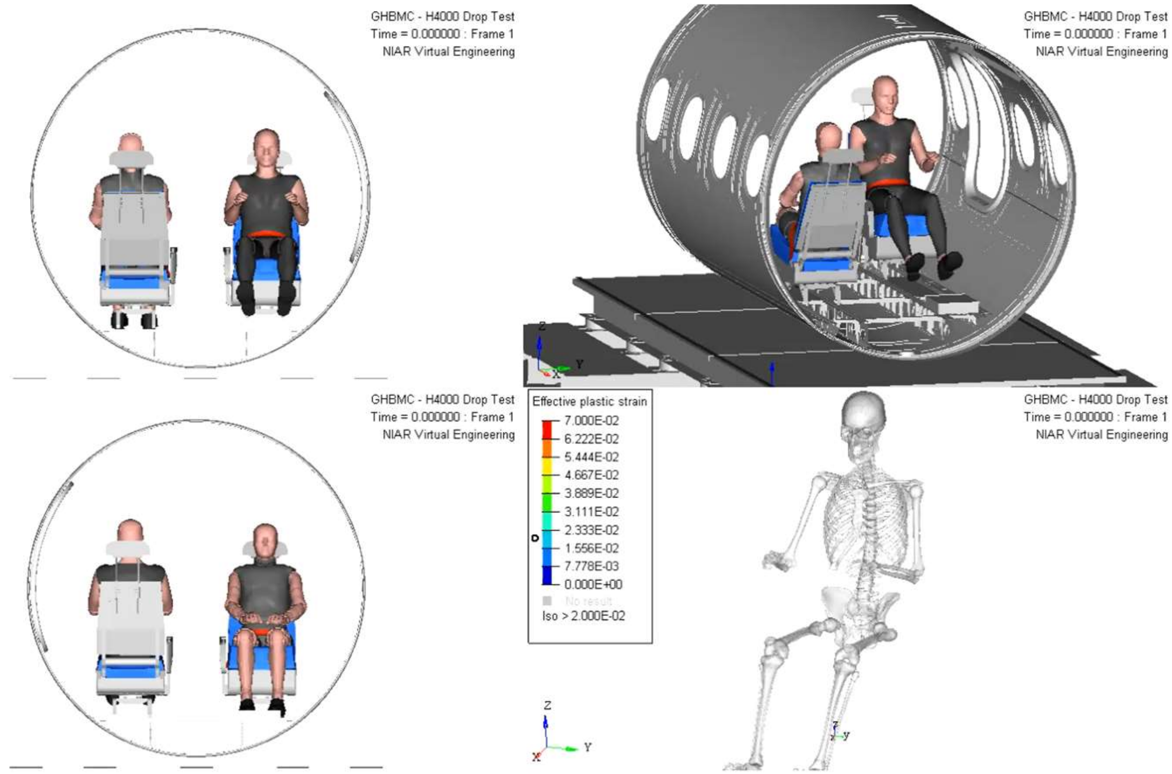
- 1 – Experimental – with physical ATDs:
  - High Cost and Time.
  - Difficulties optimizing the system through physical prototypes.
  - Hard/Impossible to quantify the Energy Absorbing capabilities of the individual crashworthy design features.
  - Deterministic approach: Reduced to one single impact configuration.
  - Current ATD’s (HII and FAA HIII) will not capture real world eVTOL occupants injury mechanisms.
- 2 - Computational supported by the building block approach - with Virtual ATDs:
  - High Cost of entry: validated methods and tools.
  - Reduced development and Certification cycles.
  - Non-deterministic approach: Optimized solutions for multiple impact conditions and occupant sizes. Robust Design.
  - Virtual ATD’s (HII and FAA HIII) will not capture real world eVTOL occupants injury mechanisms.

Engineering and Certification Methods

Urban Air eVTOL Integrated Occupant Safety

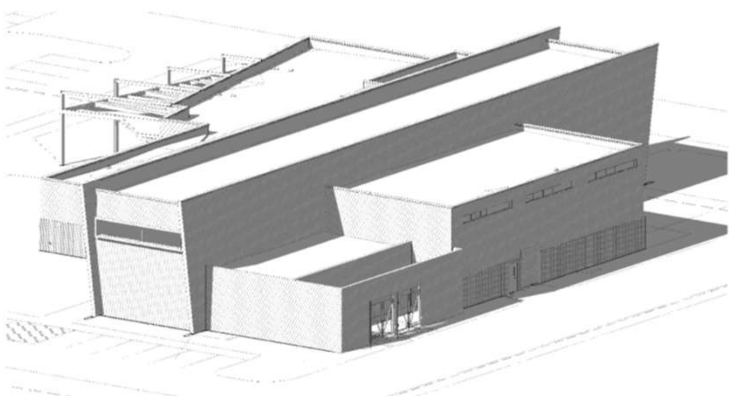
- 3 - Computational supported by the building block approach - with Virtual Human Body Models:
  - High Cost of entry: validated methods and tools.
  - Reduced development and Certification cycles.
  - Non-deterministic approach: Optimized solutions for multiple impact conditions and occupant sizes. Robust Design.
  - Virtual Human Body models will capture real world eVTOL occupants injury mechanisms. Further V&V research is required to evaluate Human body models for non-conventional seating arrangements and aerospace loading applications



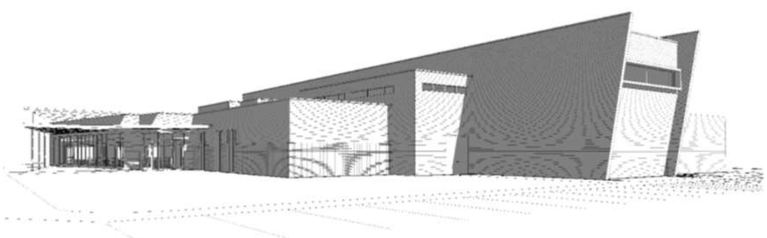


NIAR AVET Laboratories – October 2019

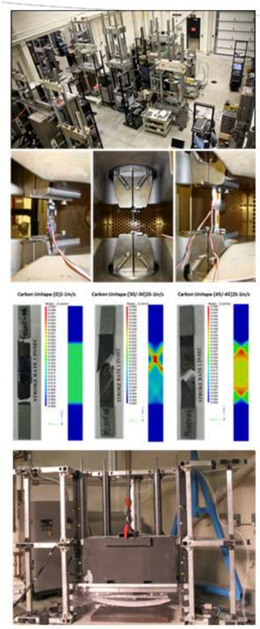
NIAR 4.0 and vNIAR 5.0

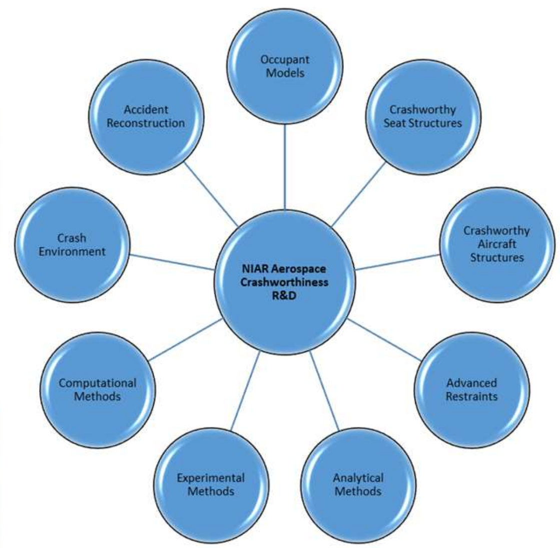


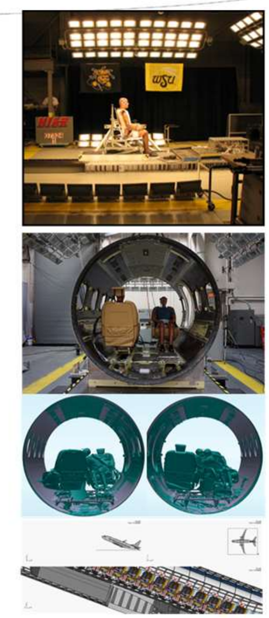
1 NORTHEAST PERSPECTIVE



2 SOUTHEAST PERSPECTIVE

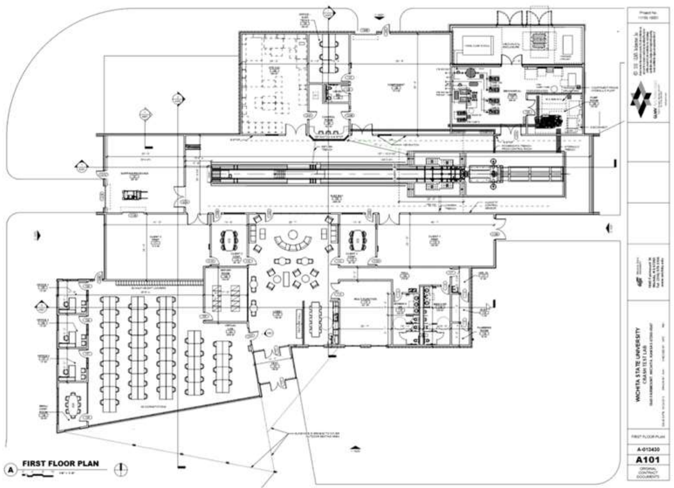




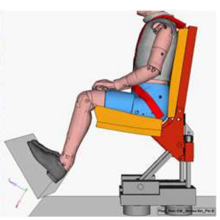


NIAR AVET Laboratories - Crashworthiness

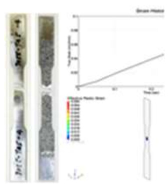
NIAR 4.0 and vNIAR 5.0



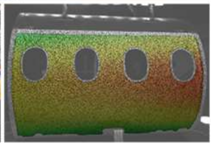
- Center of Excellence to support the research and development of new aerospace crashworthiness standards for manned and unmanned aerospace applications:
  - COE JAMS 2005-Present [FAA, ARAC, SAE, Industry]
  - COE ASSURE 2015-Present [FAA, ASTM, Industry]
- Future Center of Excellence for Urban Air Transport Integrated Safety. Industry partnerships.
- Human Body Modeling for Military and Aerospace Applications – [ONR]
- Methods and New Safety Concepts Development: 25 years of experience
- Support from Conceptual Design to Certification
- Coupon to Full Scale Testing Capabilities – Virtual and Physical Testing







Conclusions

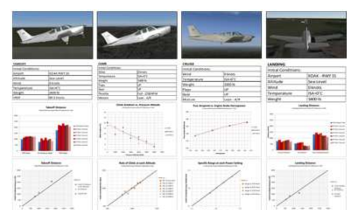
Aerospace Integrated Safety

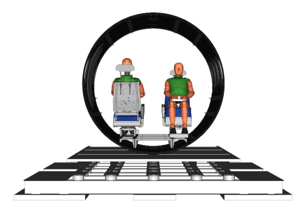
- In order to successfully operate eVTOL vehicles, occupant safety must be an integral part of the overall technical and management processes associated with the design, development and operation of eVTOL Urban Air Transport systems.
- Current emergency landing conditions requirements specified in 14 CFR *.561 and *.562 do not provide the level of safety required for eVTOL vehicles.
- A successful implementation of the eVTOL market will require the development of Emergency Landing Standards and means of compliance (FAA, EASA, ASTM.. etc.) that address real world safety expectations.
- Emergency landing standards will need to be defined for eVTOL vehicles taking into consideration their unique design features and operation:
  - New and Novel Electric Distributed Propulsion Systems
  - New and Novel Vehicle Architectures
  - Non-conventional seating arrangements
  - Complex Urban environment operations (sharing airspace with other aircraft, sUAS, building infrastructure, people on the ground..etc..)
  - Mixed Modes of Transportation (Air and Ground)
  - Landing Sites crashworthiness design
  - Battery System Protection and post impact fire risk assessment
- Crashworthiness design needs to be implemented from the conceptual design stage of the vehicle, since the crashworthiness optimization of the various structural elements cannot be implemented once the design has been driven only by airworthiness requirements.

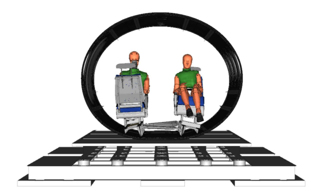
Conclusions

Aerospace Integrated Safety

- Virtual Development and Certification methods will enable innovation and enhance vehicle safety.
- Further research is required to evaluate Non-Conventional Seating Arrangements – support development and validation of Human Body Models for Aerospace applications
- Proven technologies exist today that will enable the design of real world safe vehicle crashworthiness designs.
- With eVTOL vehicles we have an opportunity to introduce a new culture of integrated safety in the aerospace industry. This concept of integrated safety could also improve the survivability rates for General Aviation.
- NIAR has the experience and facilities required to help regulators and industry solve the new crashworthiness challenges presented by the eVTOL applications.







Thank you for your attention.

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