



Lift + Cruise Crash Test to Improve Crashworthiness of eVTOL Aircraft

Jacob Putnam, Emilie Baker Ph.D., Justin Littell Ph.D.,
Nathaniel Gardner Ph.D.
Research Aerospace Engineer
NASA Langley Research Center
Structural Dynamics Branch (D322)

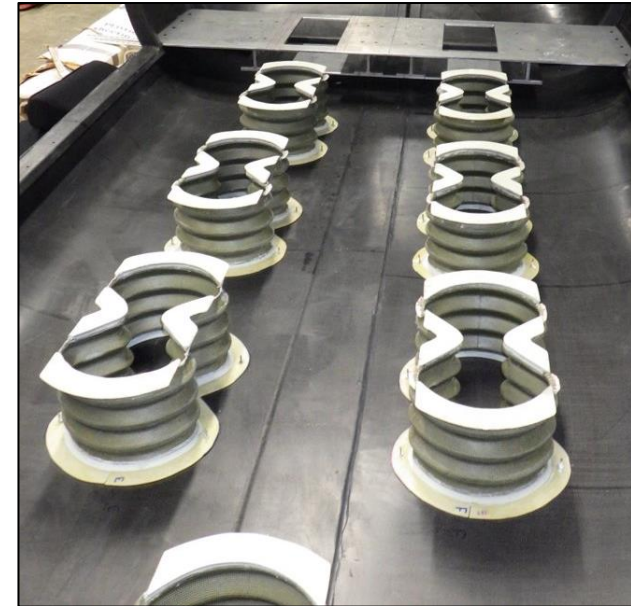
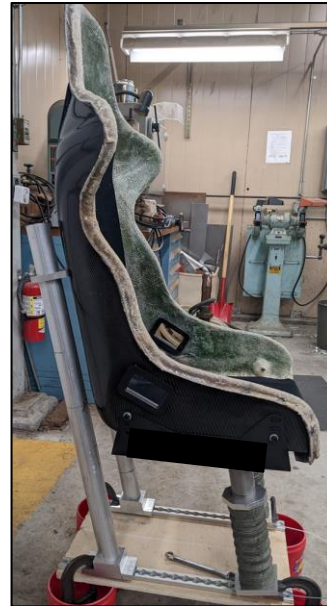


December 10, 2025

Test Objectives



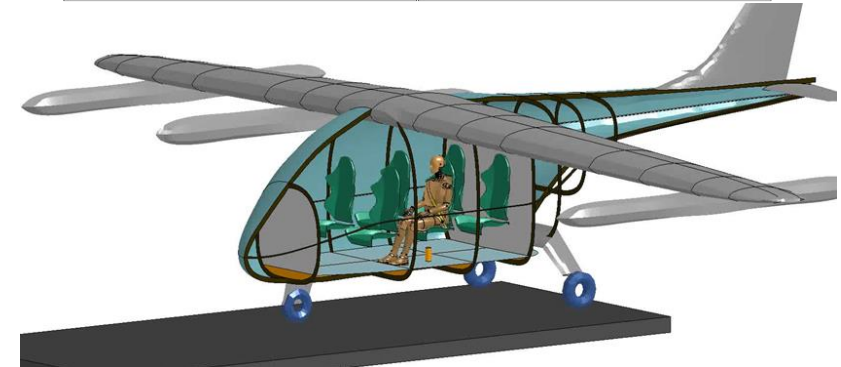
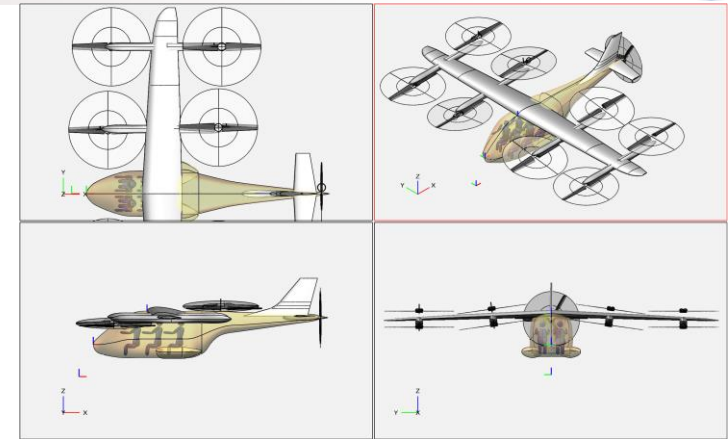
1. Generate data on generic electric Vertical Take-off and Landing (eVTOL) vehicle design under crash conditions to inform regulation development
2. Generate data for the use in validation of computer modelling efforts
3. Generate data from onboard Anthropomorphic Test Devices (ATD's, a.k.a. crash test dummies) for the evaluation of injury
4. Generate data on experimental energy absorbing component designs



Test Article – NASA Lift + Cruise Reference Vehicle



- Reference
 - Silva et al. *VTOL Urban Air Mobility Concept Vehicles for Technology Development*. 2018 Aviation Technology Integration and Operations Conference
- Test Article Specifications
 - Dimensions: 18 ft. x 6 ft. x 7 ft.
 - Total weight: 3450 lb.
 - Seats: 6 passenger
 - Wing Type: High wing
 - All composite design with skin and foam fill frame sections
- Structural components sized to maintain survivable volume under load
 - 12 g static vertical load
 - 30 ft/s dynamic vertical impact
 - Non-structural components replaced with mounted mass



Lift + Cruise Crash Test #1



- Horizontal Velocity = 38.1 ft/s, Vertical Velocity = 31.4 ft/s
- Pitch 0.6 degrees nose down, 2 degrees yaw



Lift + Cruise Crash Test #2 – Test Condition Changes

- Yaw component added to test #2 to induce combined horizontal/lateral loading on test article
 - Notional conditions: horizontal velocity – 42 ft/s, vertical velocity – 26 ft/s, 10° yaw.
- Overhead mass assumptions changed between test #1 and test #2
 - Test #1 (overhead mass - 1,080 lb)
 - Battery weight included in overhead mass
 - Rigid wing structure (no frangibility – worst case)
 - Test #2 (overhead mass - 394 lb)
 - Battery weight moved to floor
 - Some degree of frangibility/mass offloading allowed

Lift + Cruise Crash Test #2 – Internal Structure

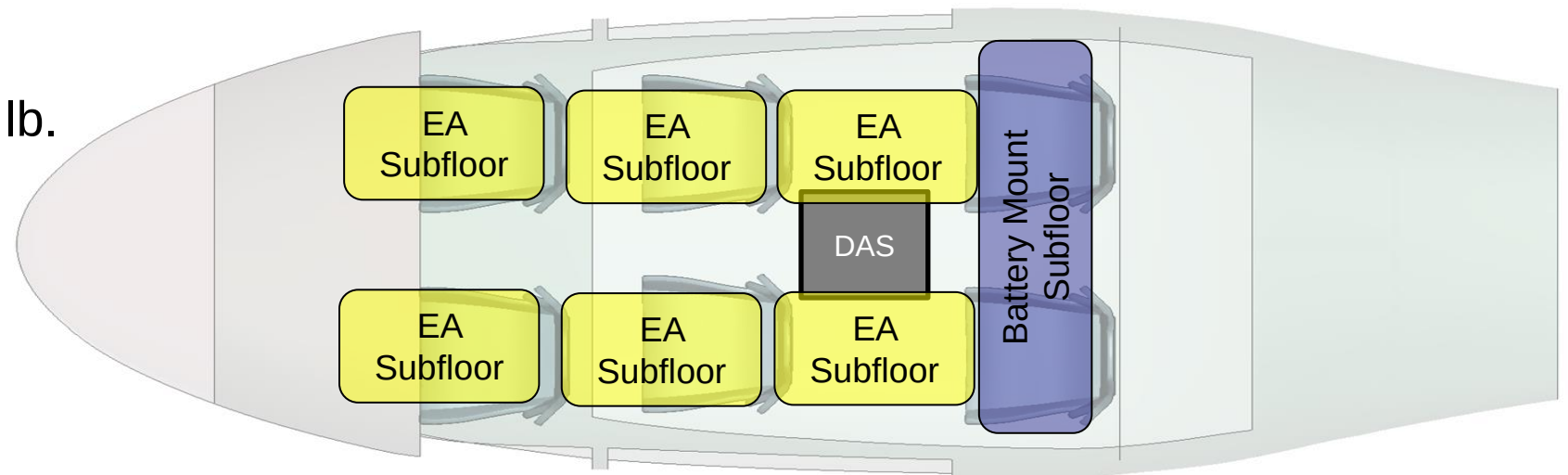


- NASA designed EA Subfloor integrated between floor and belly under most seats
 - Carbon/Kevlar material w/ absorption achieved through wall folding
 - Self supporting structure, robust to horizontal/lateral loading
- Underfloor mounted battery configuration used in rear seats
 - Aluminum structure
 - Rigid battery mass: 200 lb.

NASA EA Subfloor



Aluminum Battery Mount Subfloor



Lift + Cruise Crash Test #2 – Seats



- Various unique seat designs evaluated within test article
 - Generic seat buckets with rigid frame attachment (Rigid)
 - Generic seat buckets with NASA designed EA (NASA EA)
 - Commercial off the shelf (COTS) design

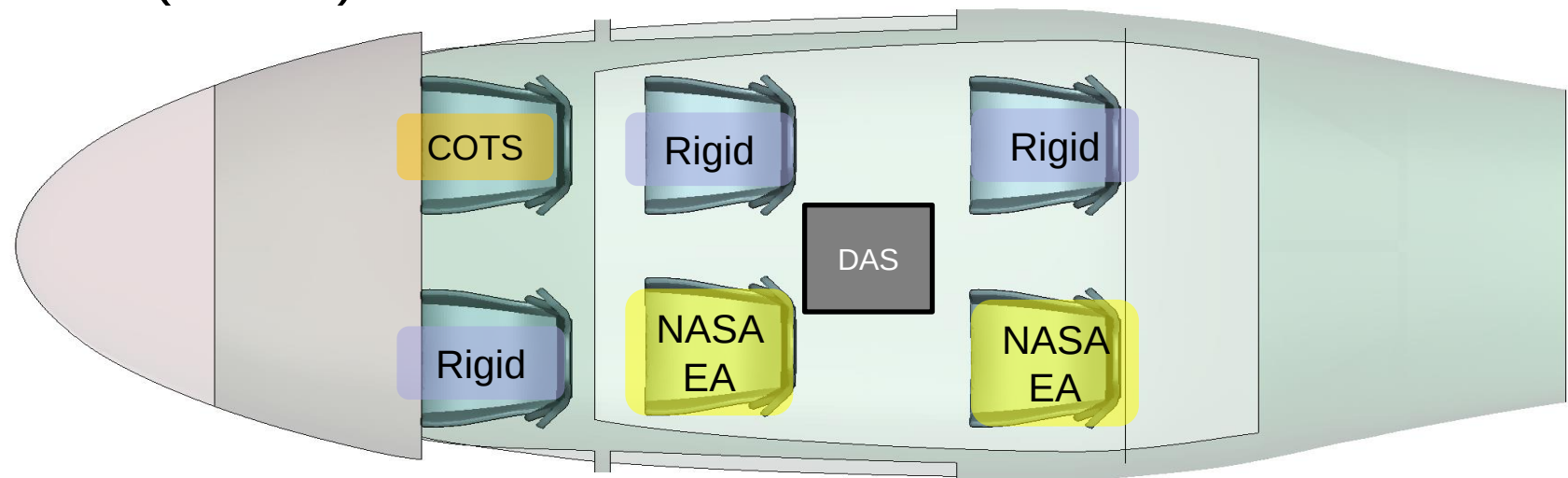
Composite Bucket
– Rigid Frame



Composite Bucket
– NASA EA Frame

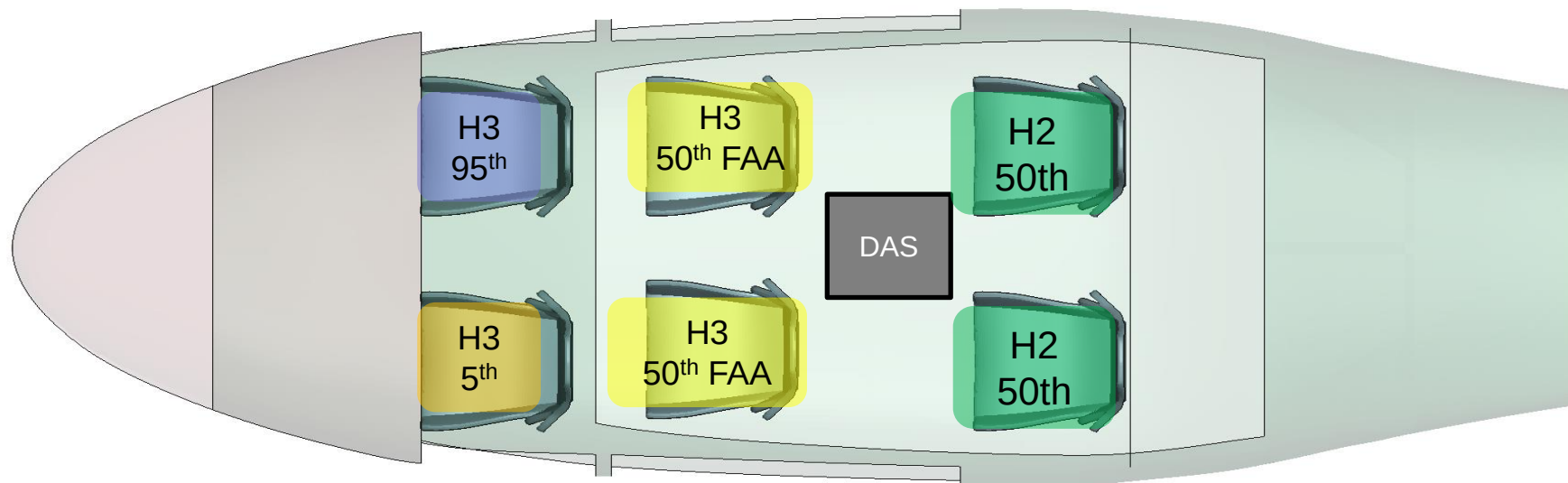


COTS



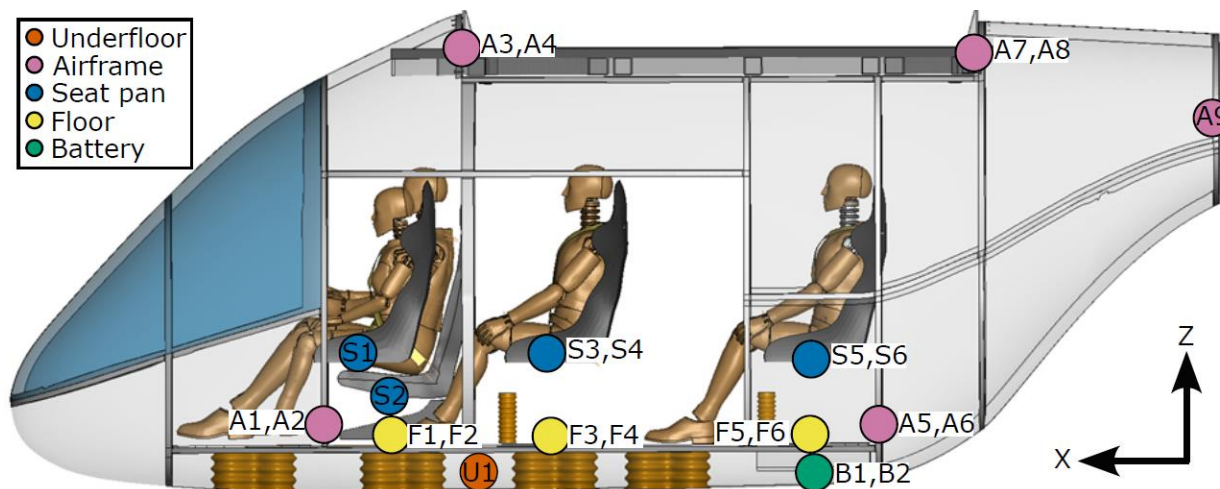
Lift + Cruise Crash Test #2 – Occupant Experiments

- Hybrid III ATDs ranging from 5th female to a 95th male seated in various configurations of seats
 - Mix of Hybrid II (H2) and Hybrid III (H3)
- Front row: ATD size comparison
- Middle row: rigid to EA seat comparison
- Rear row: EA seat comparison over rigid battery subfloor



Lift + Cruise Crash Test #2 – Instrumentation

- Instrumentation included throughout test article to track accelerative loading through structure
 - Belly, airframe structure, floor, battery masses, and seats
- Each ATD fully instrumented
 - Head (HIC), neck (N_{ij}), and spine (lumbar load) injury metrics calculated



Pre-Test Predictions



- Pre-Test simulation conducted to assess test article response to impact conditions
 - Cabin volume maintained
 - Sliding motion across concrete surface predicted w/ pitch up rotation



Test Video



- Horizontal Velocity = 38.1 ft/s, Vertical Velocity = 28.4 ft/s
- Pitch=0.1° nose down, Roll=2.7° starboard, Yaw= 16.7 ° portside

General Timeline of Events

Impact (s)	Event
0	Impact – Front
0.006	Subfloor Crush Begins
0.012	Impact - Rear
0.022	Seat 6 Stroke Begins
0.032	Seat 1 Stroke Begins
0.043	Maximum Subfloor Crush
0.049	Seat 6 Stroke Ends
0.052	Seat 1 Stroke Ends
0.077	Nose Begins Rebound from Ground
3.042	Motion stop

- $t=0$ to $t+0.040-0.050$ s - Crushing of energy absorbing structures
- $t+0.050$ s to $t+0.200$ ms – Rebound of airframe structure

Video: $t=0$ to $t + 0.050$ s



Video: $t + 0.050$ s



Post-Test Pictures – Airframe Structure



Port



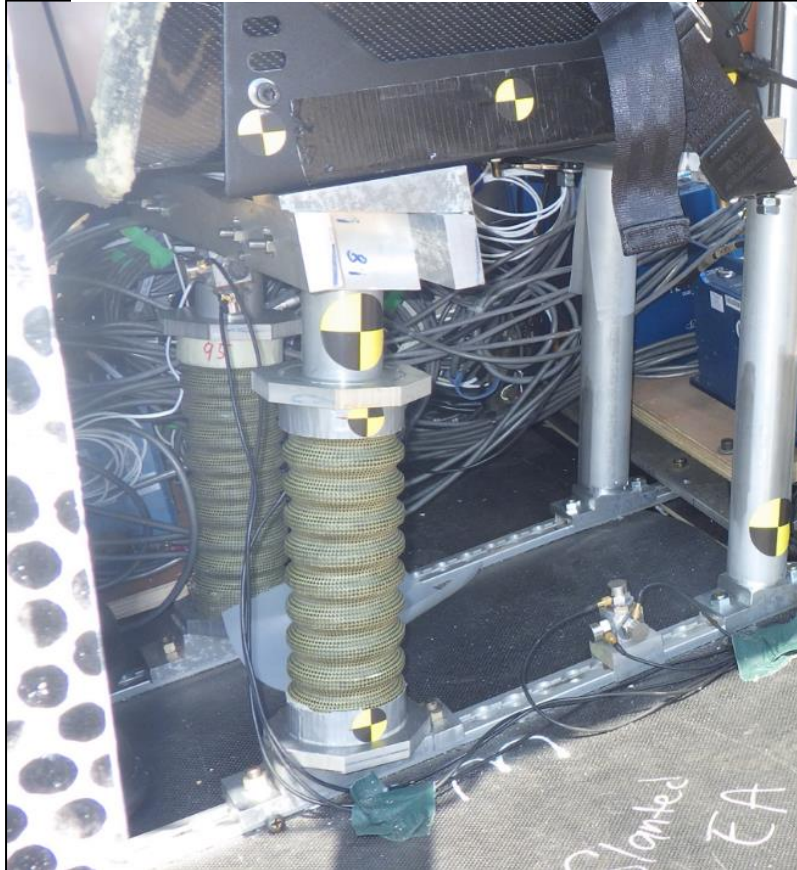
Starboard



Post-test Pictures – NASA Energy Absorbing Seats



Seat 4 – Middle Portside

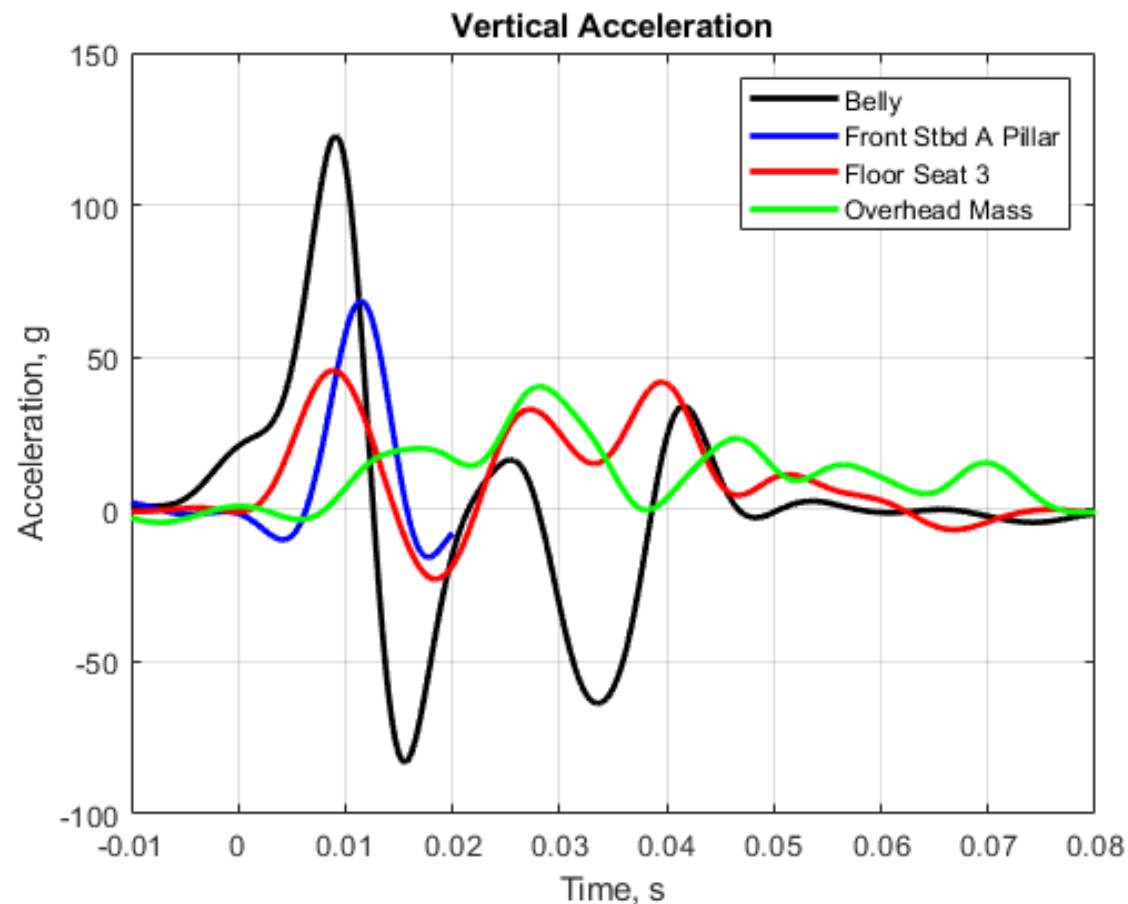


Seat 6 – Rear Portside



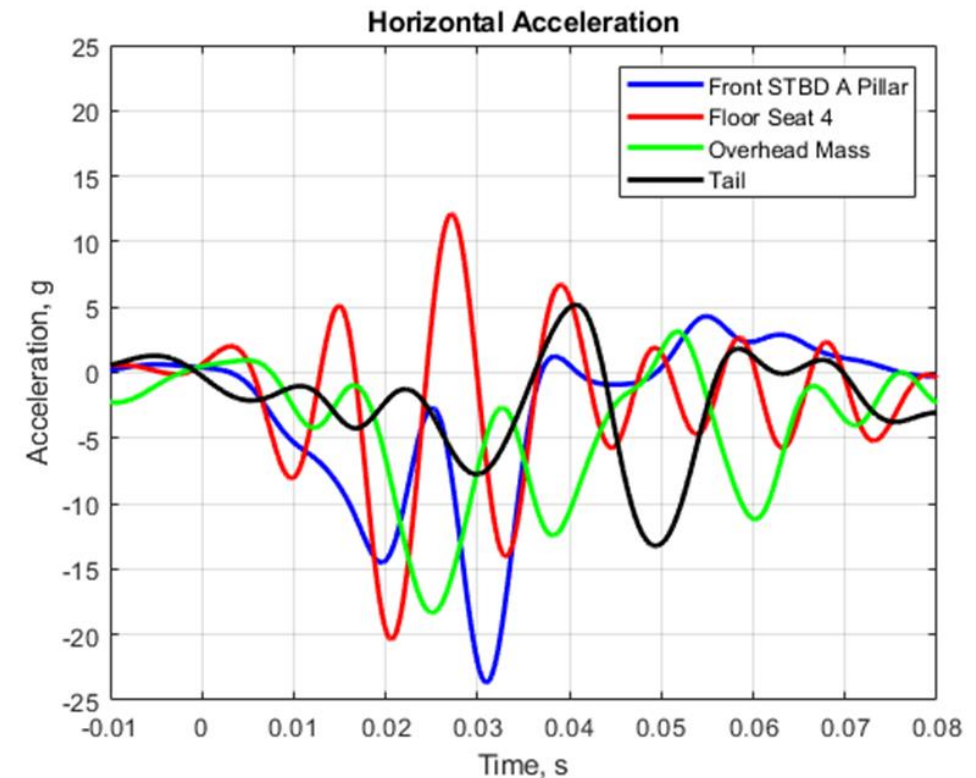
Airframe Acceleration - Vertical

- Belly impact resembles shock loading with a peak ~ 120 g and 5ms rise time
- Peak acceleration attenuated as it progresses through the airframe structure
- Triangular acceleration pulse with peak of ~ 40 and rise time of 25ms measured in overhead mass



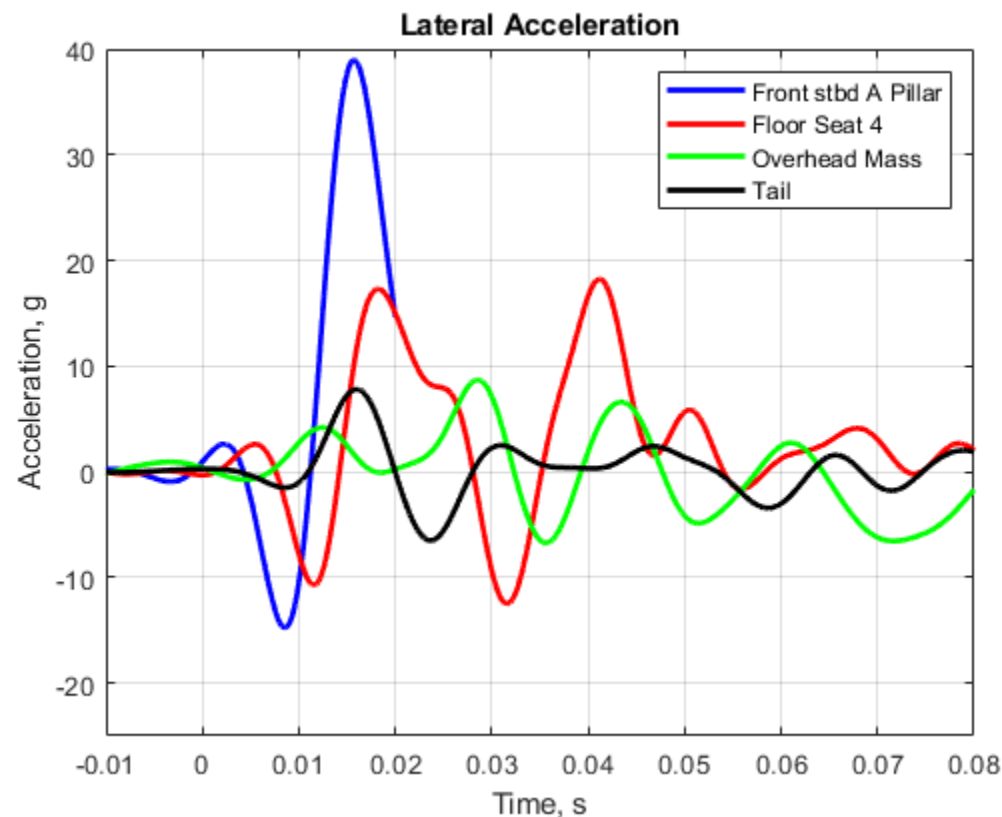
Airframe Acceleration - Horizontal

- Peak horizontal acceleration low
– consistent with expectations of impact with rigid concrete surface
- Acceleration generally consistent through airframe structure
- Acceleration pulse highly oscillatory as impact shock propagated through structure



Airframe Acceleration - Lateral

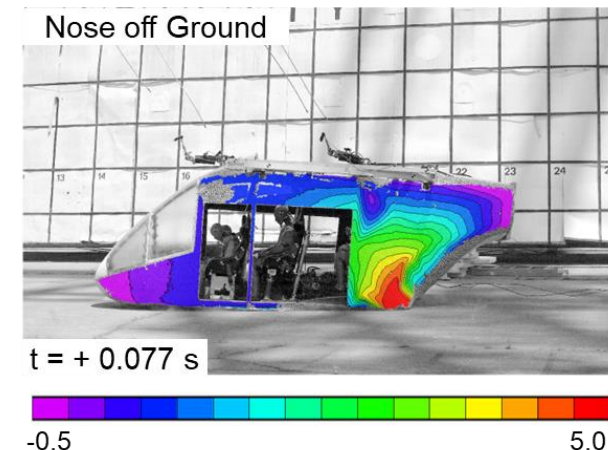
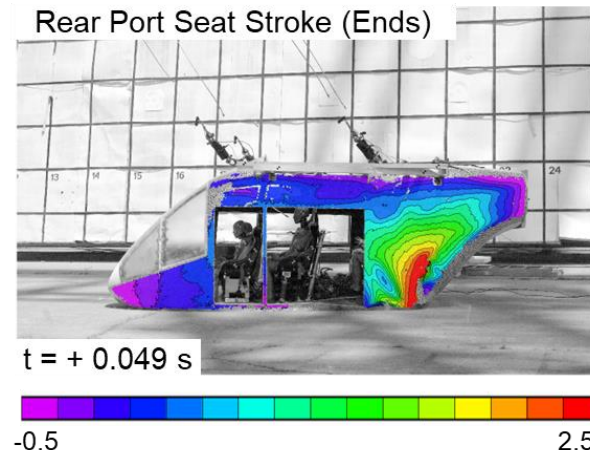
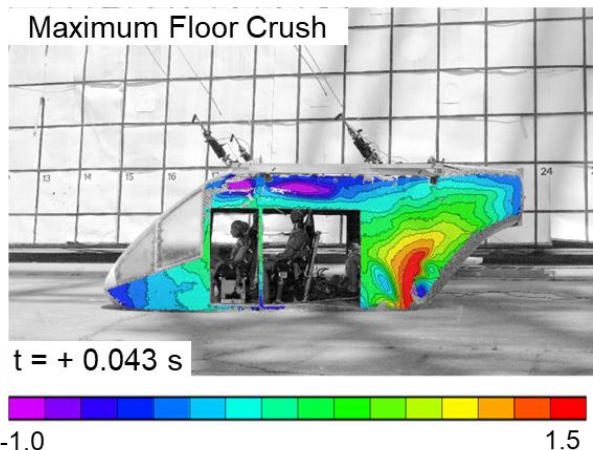
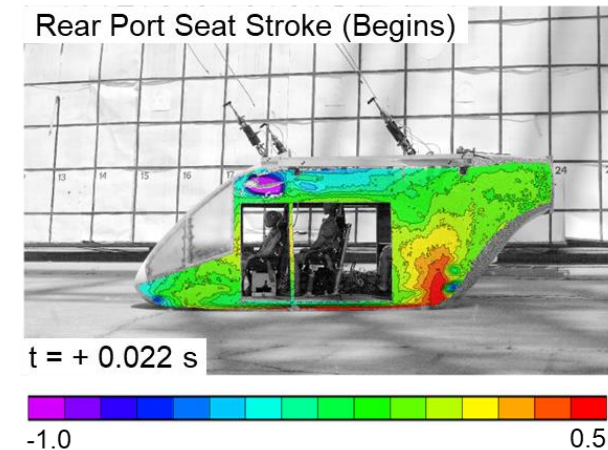
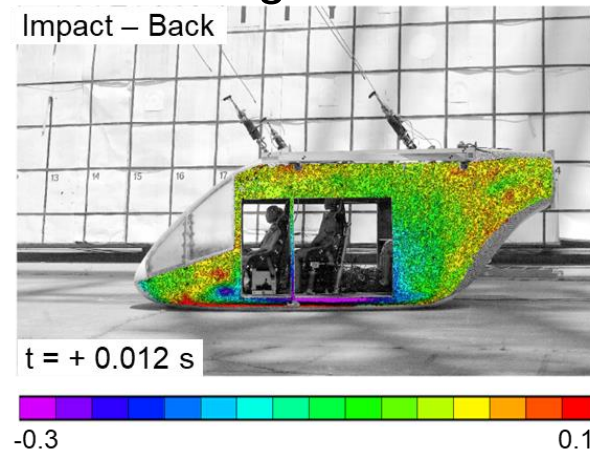
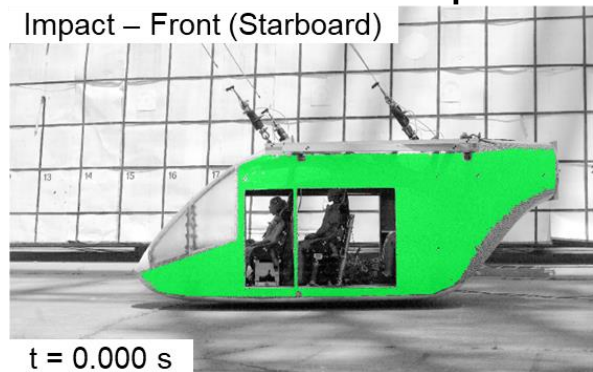
- Large localized accelerations occur at the point of impact
 - Front starboard side
- Acceleration attenuates through the aircraft structure, but significant events are present
 - Floor at seat 4
- Event last approximately 50 ms



Photogrammetry Analysis

- Out-of-Plane Deformation

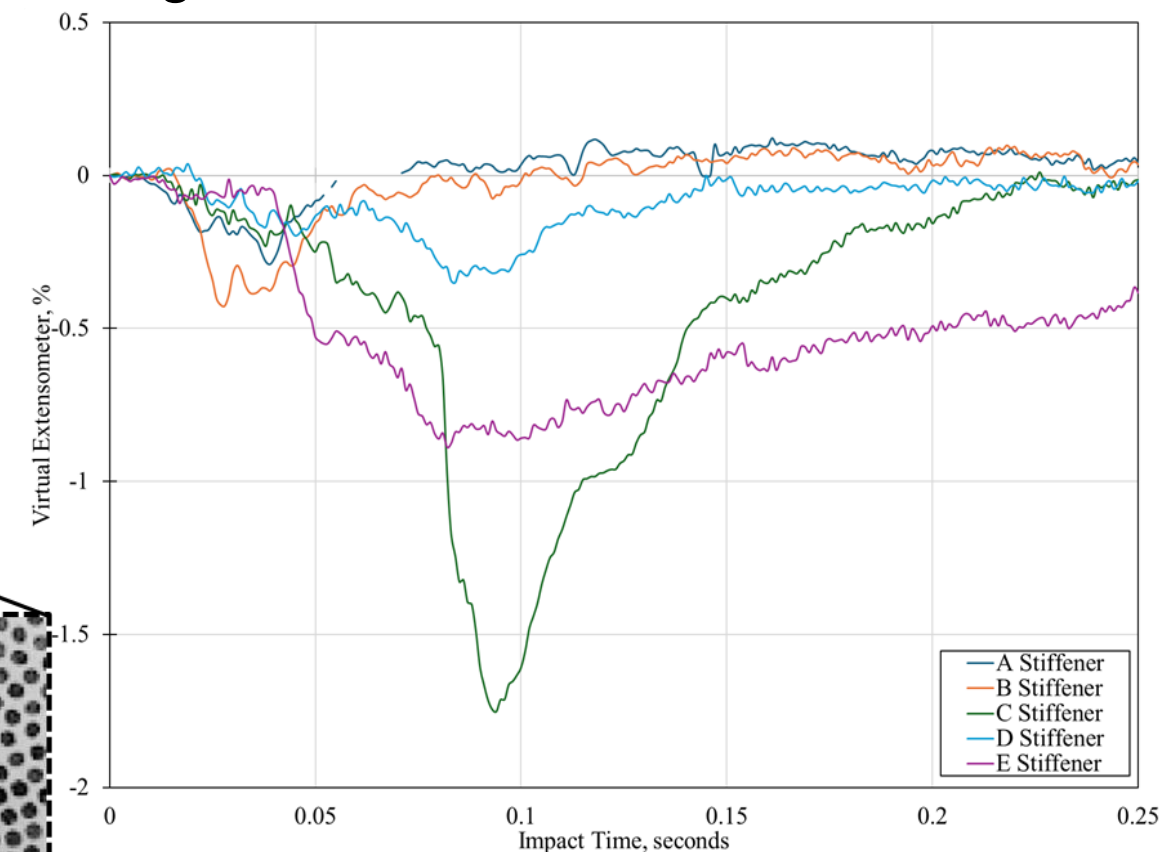
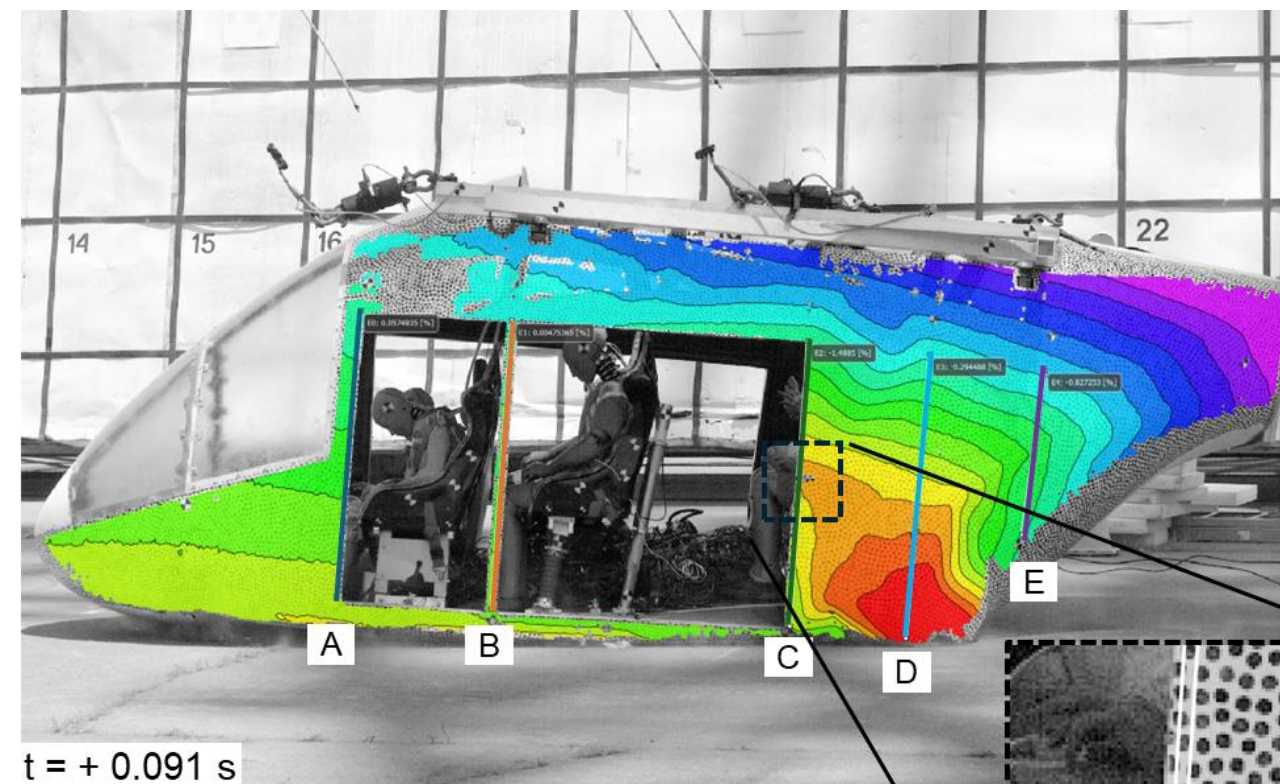
- Determine skin buckling and additional failure locations
- Data will be used for computational modelling



Out-of-Plane Deformation, inches

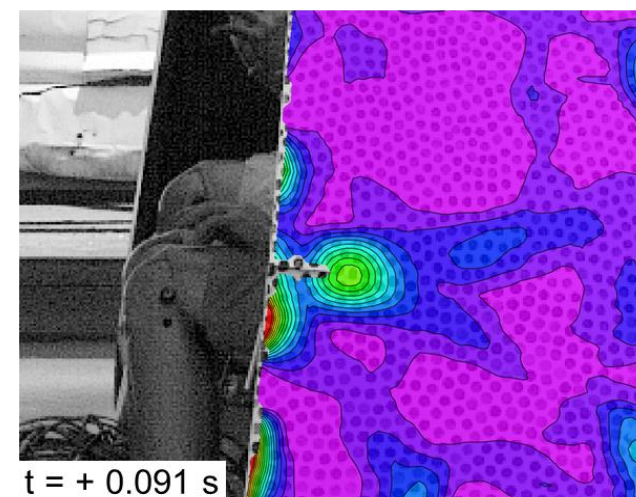
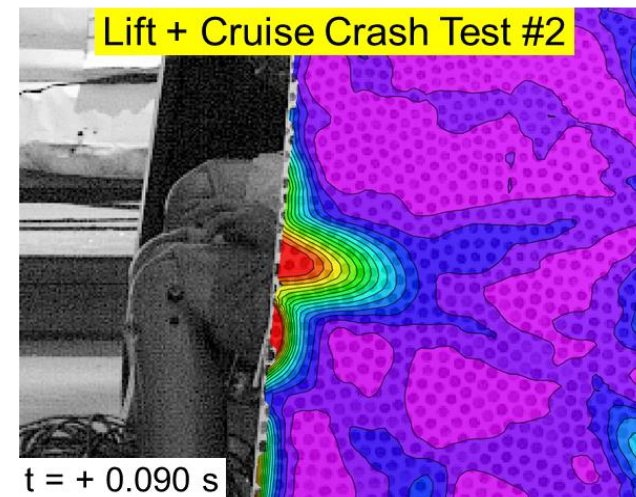
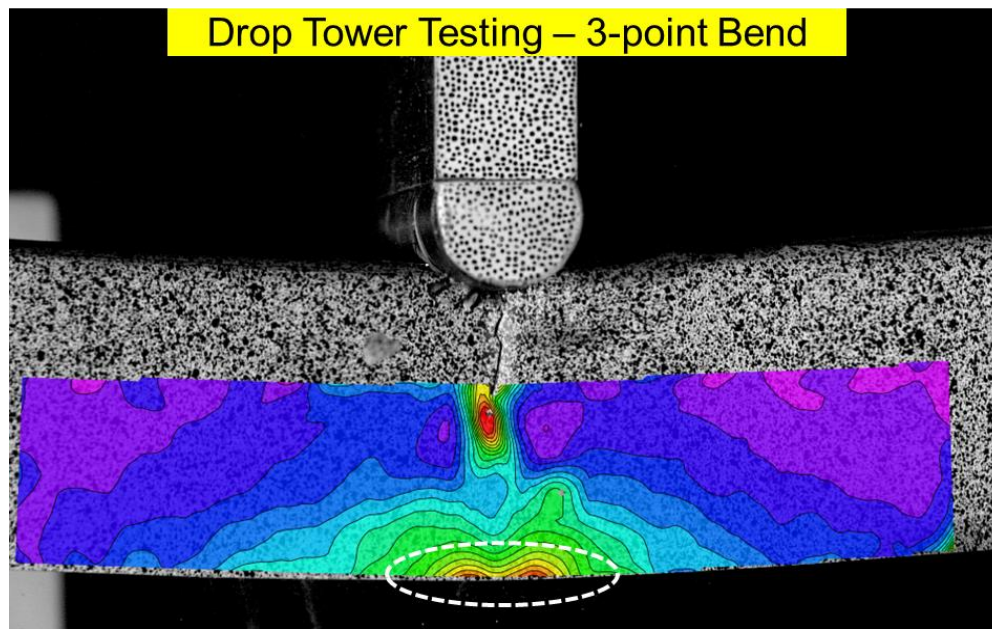
Photogrammetry Analysis (cont.)

- Plotting out-of-plane deformation at time that crack initiates in C-Stiffener
- Plotting Virtual Extensometer time-history data to investigate stiffener strain during deformation



Photogrammetry Analysis (cont.)

- Plotting Maximum Principal Strain, ϵ_1 , to compare with dynamic drop test data of stiffeners



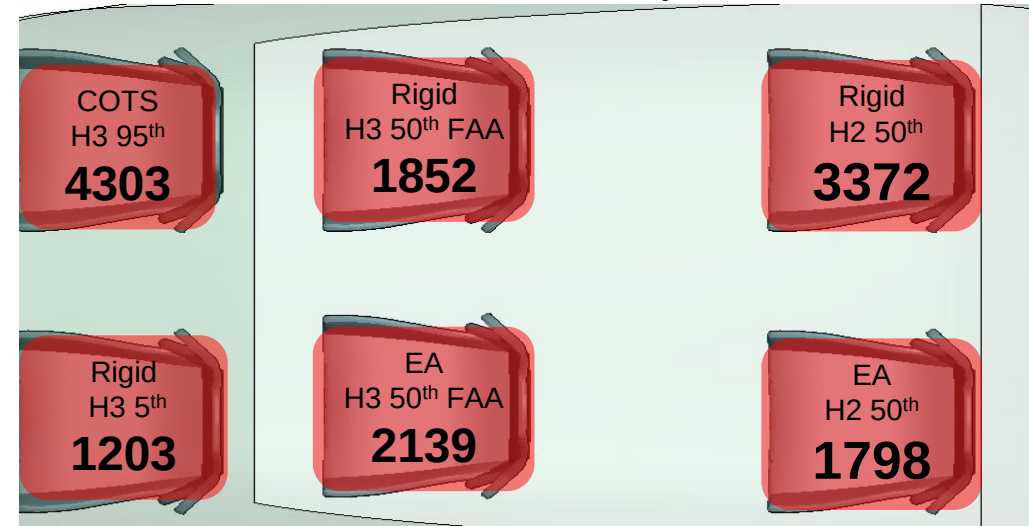
Injury Metric Summary

- All injury criteria utilized are summarized here with maximum values
 - Green – under limits
 - Red – over limit
 - White – no data

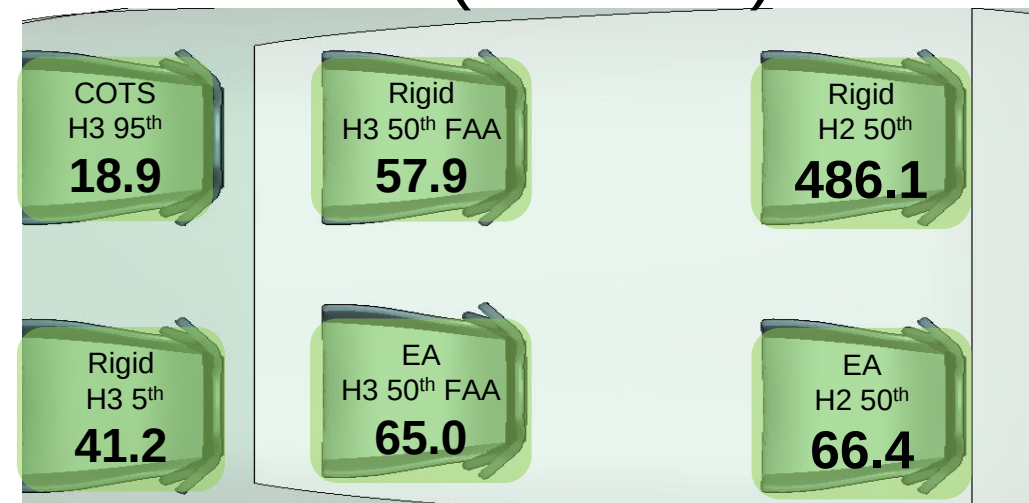
N_{ij} (limit = 0.5)



Lumbar Load, lb.



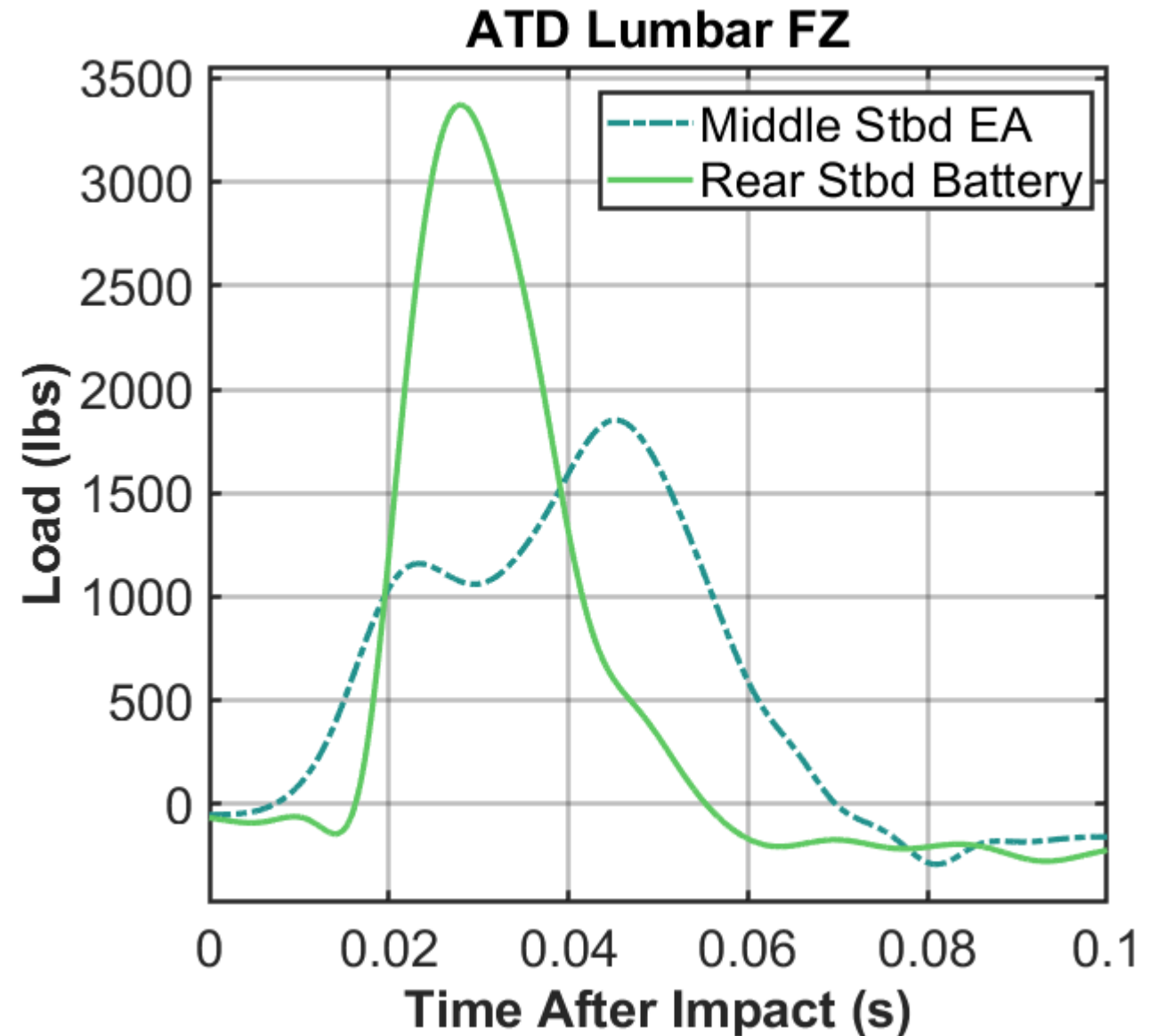
HIC36 (limit 700)



Middle vs Rear Row: EA Subfloor vs Battery Compartment

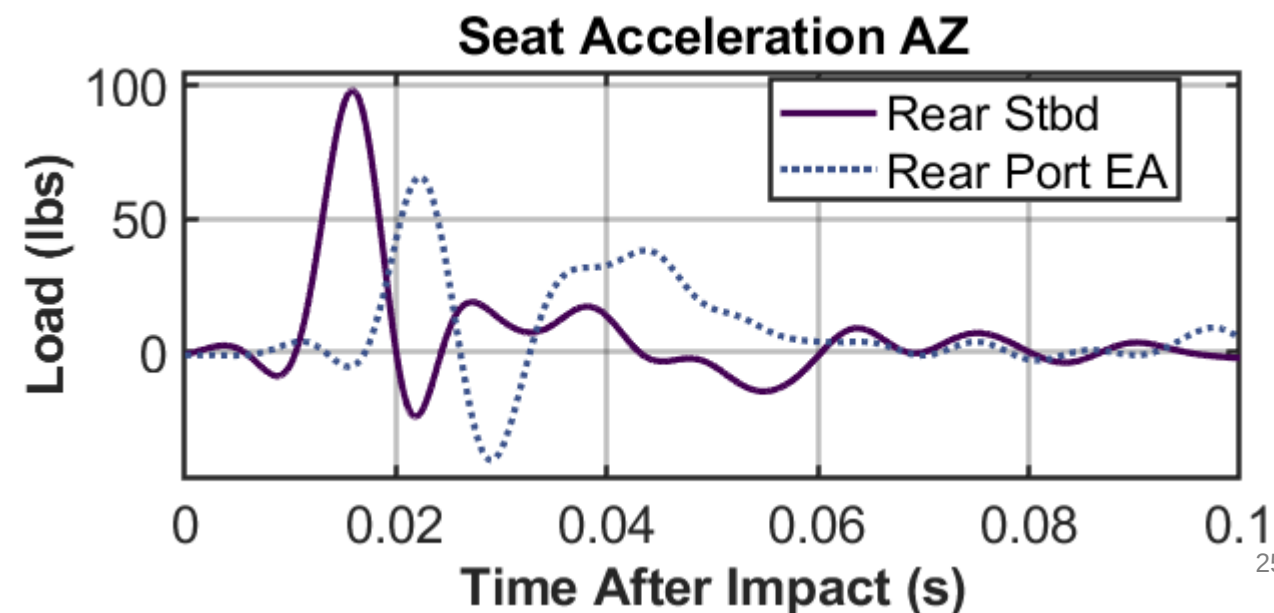
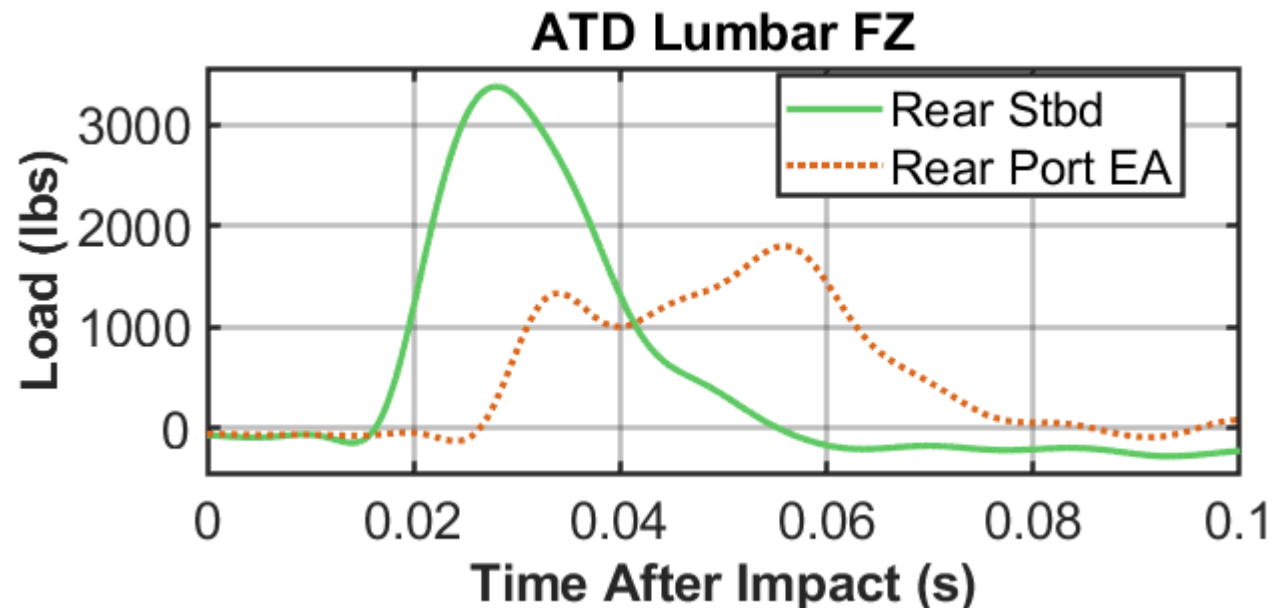


- Peak lumbar load of Rear starboard ATD 3372 lb.
- Peak lumbar load of Middle starboard ATD 1852 lb.
- Significant reduction in lumbar load when EA is used in the subfloor as compared to a rigid subfloor.



Rear Row: EA Seat to Non-EA Seat

- Peak lumbar load of rear starboard ATD is significantly larger (3372lb) compared to the rear port ATD (1798lb) which had EA tubes.
- Peak acceleration 98g (no EA tubes) vs 65g (EA tubes)
- Significant reduction in lumbar load and acceleration when EA tubes are used in the chair design.



Summary



- Test was conducted to successfully to satisfy four objectives
 - Generate generic eVTOL vehicle in crash environment, evaluate EA designs, evaluate ATD response, validate of computational models
- Generic eVTOL vehicle tested in full-scale multi-axis crash environment
 - Overhead mass assumptions updated from previous test to effects on retainment of cabin volume in crash environment
- EA subfloor and seat designs shown to reduce occupant loads
- ATDs demonstrated sensitivity to vehicle structural variations within eVTOL crash environment
- Computational model validation to be discussed in future presentations