



A Summary of Test Results from a NASA Lift+Cruise eVTOL Crash Test

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Test Objectives



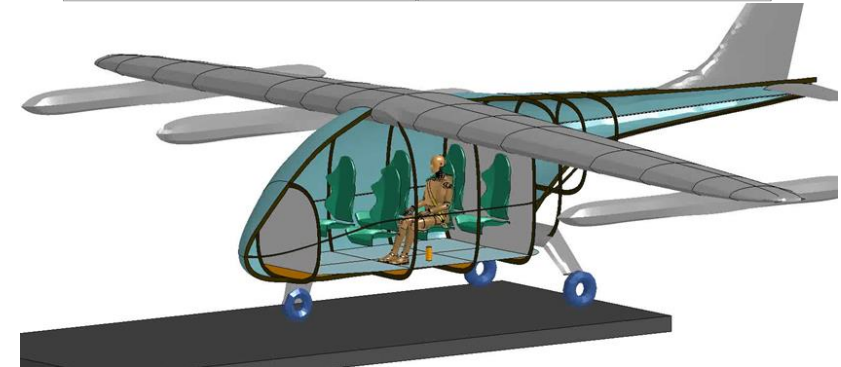
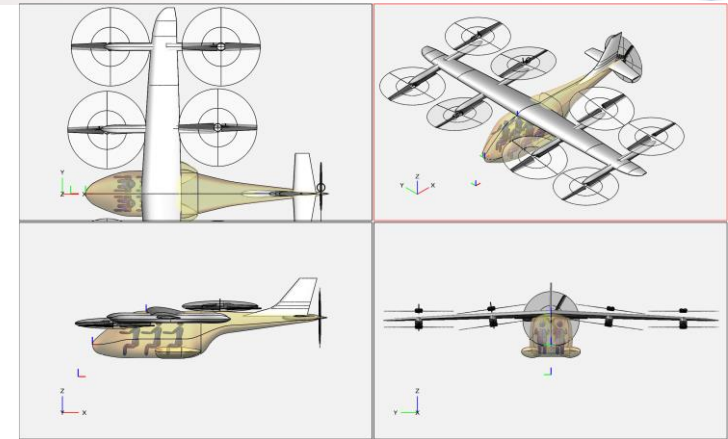
1. Generate data on generic electric Vertical Take-off and Landing (eVTOL) vehicle design under crash conditions to inform regulation development
2. Generate data for the use in validation of computer modelling efforts
3. Generate data from onboard Anthropomorphic Test Devices (ATD's, a.k.a. crash test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



Test Article – NASA Lift + Cruise Reference Vehicle

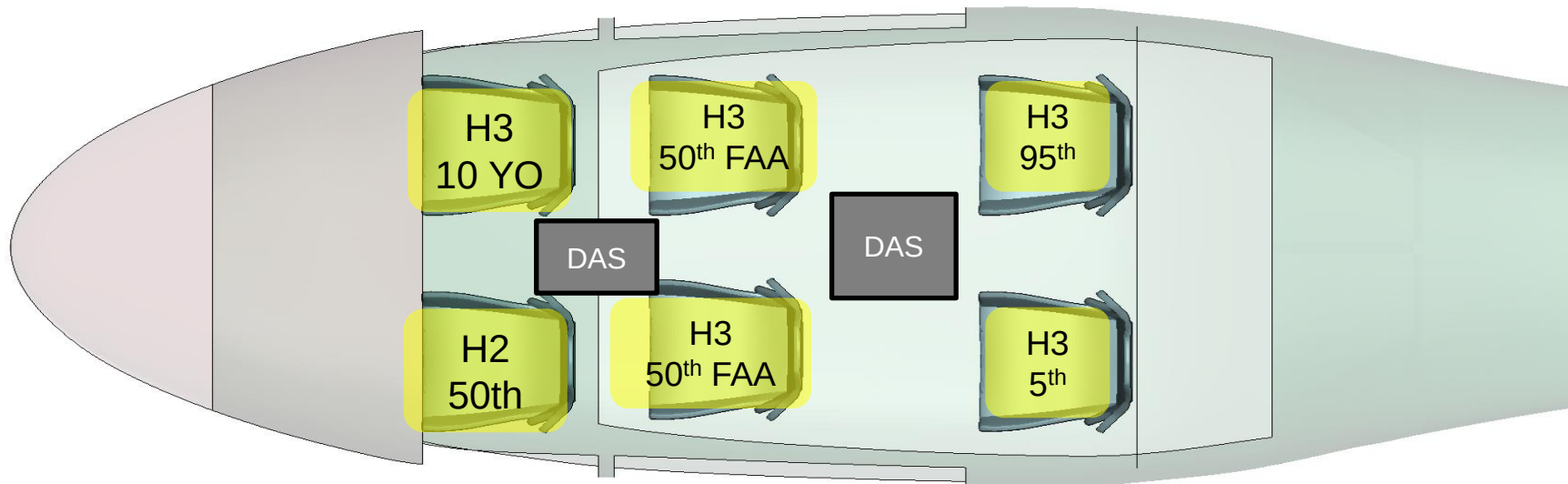


- Reference
 - Silva et al. *VTOL Urban Air Mobility Concept Vehicles for Technology Development*. 2018 Aviation Technology Integration and Operations Conference
- Test Article Specifications
 - Dimensions: 18 ft. x 6 ft. x 7 ft.
 - Total weight: 3450 lb.
 - Seats: 6 passenger
 - Wing Type: High wing
 - 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



ATD Layout

- Various size ATDs ranging from a 10 year old (YO) to a 95th percentile male seated in various configurations of seats
 - Mix of Hybrid II (H2) and Hybrid III (H3)
- Middle row experiment rigid to energy absorbing (EA) seat comparison
- Rear row experiment on ATD size

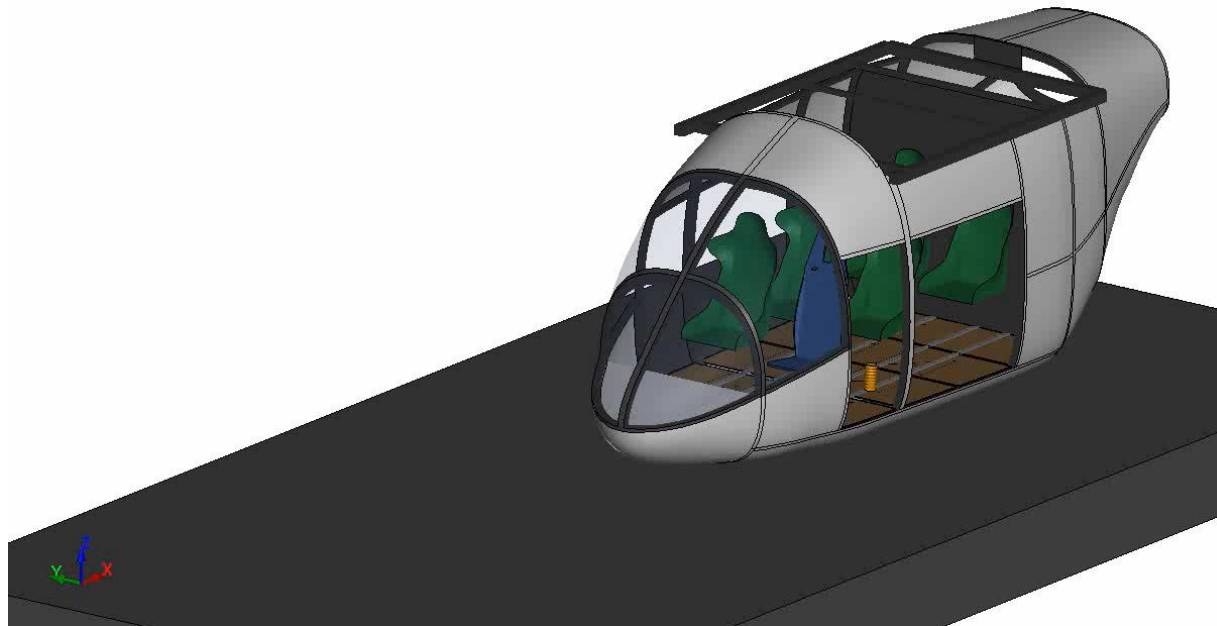


Pre-Test Predictions – Airframe Results

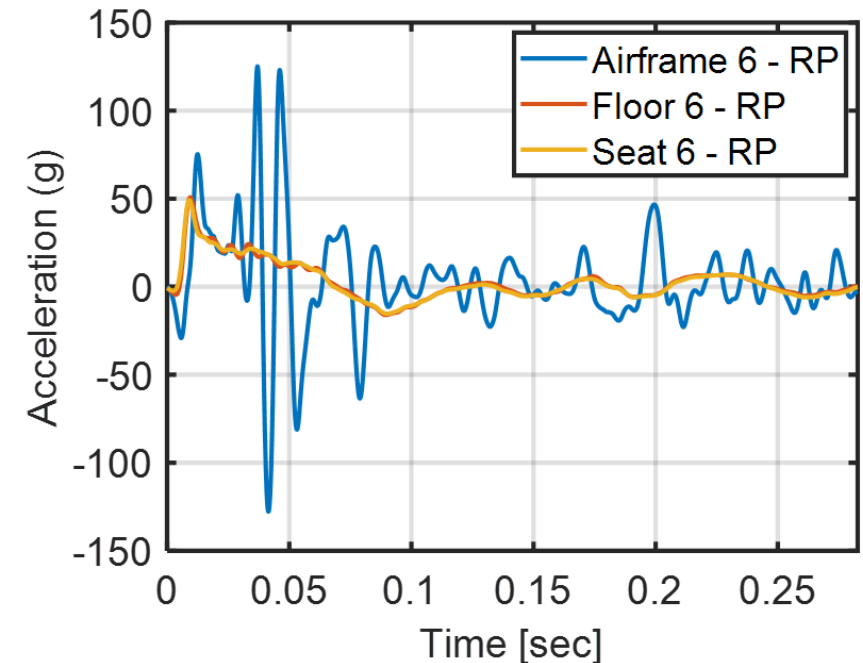


- Pre-Test simulation conducted to assess test article response to impact conditions
 - Cabin volume maintained
 - Sliding motion across concrete surface predicted w/ pitch up rotation

LS-DYNA keyword deck by LS-PrePost
Time = 0



Airframe and Seat base acceleration



Test Video



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

General Timeline of Events

Data Time	Impact (s)	Event
41.556	0	Impact
41.562	0.006	Subfloor begin crush
41.573	0.017	NASA energy absorbing seat begin stroke
41.590	0.034	Starboard B Pillar Break
41.592	0.036	Port B Pillar Break
41.605	0.049	Port C Pillar Break
41.612	0.056	NASA energy absorbing seat maximum stroke
41.642	0.086	Rear Starboard hardware sink start
41.761	0.205	Max hardware sink
44.205	2.649	Motion stop

- $t=0$ to $t+0.040-0.050$ s - primary time of energy absorbers crushing and start of cabin failures
- $t+0.050$ s to $t+0.200$ ms – collapse of the overhead structure

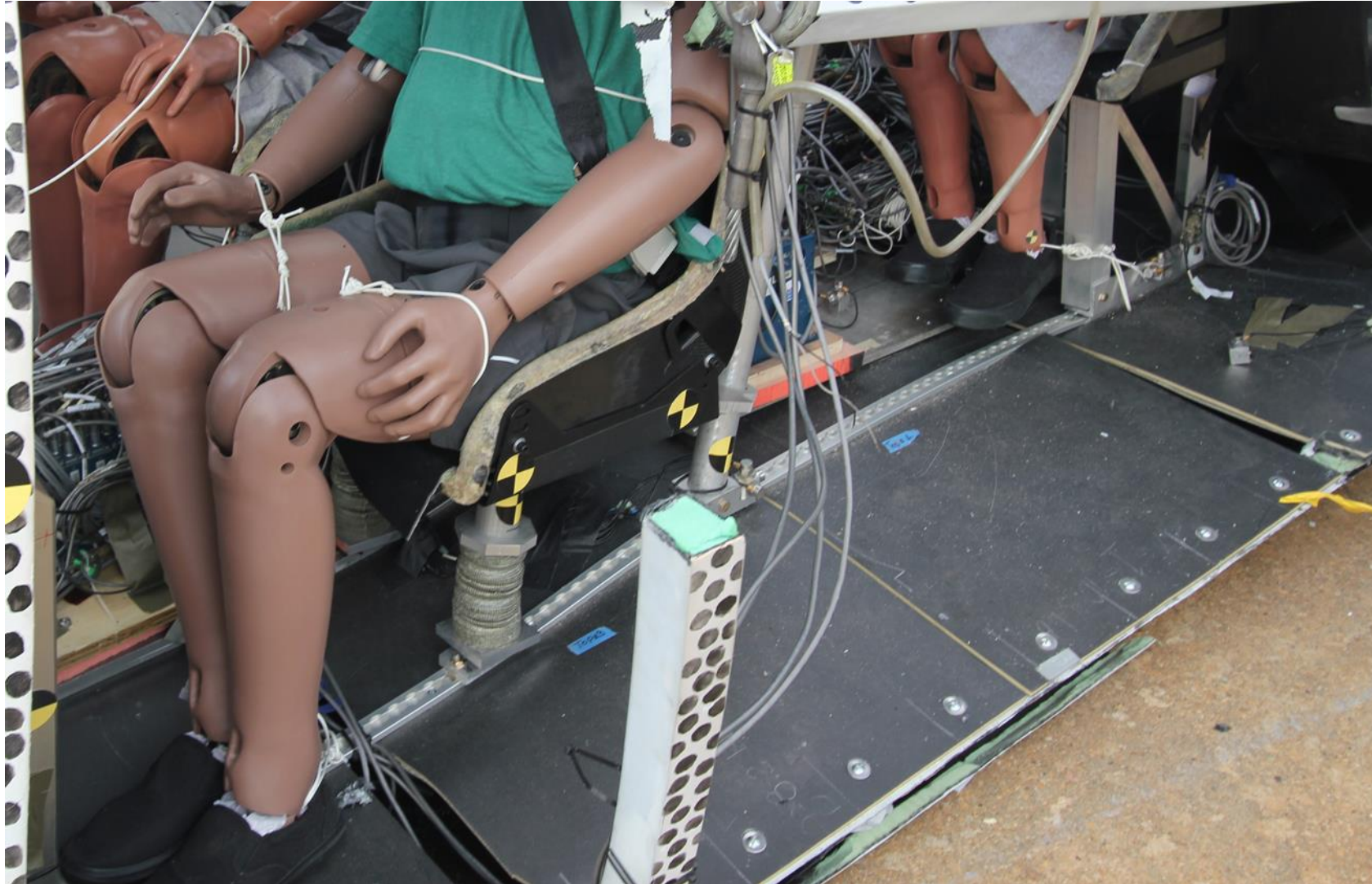
Video: $t=0$ to $t + 0.050$ s



Video: $t + 0.050$ s to $t + 0.200$ s



Post-test Pictures – NASA Energy Absorbing Seat

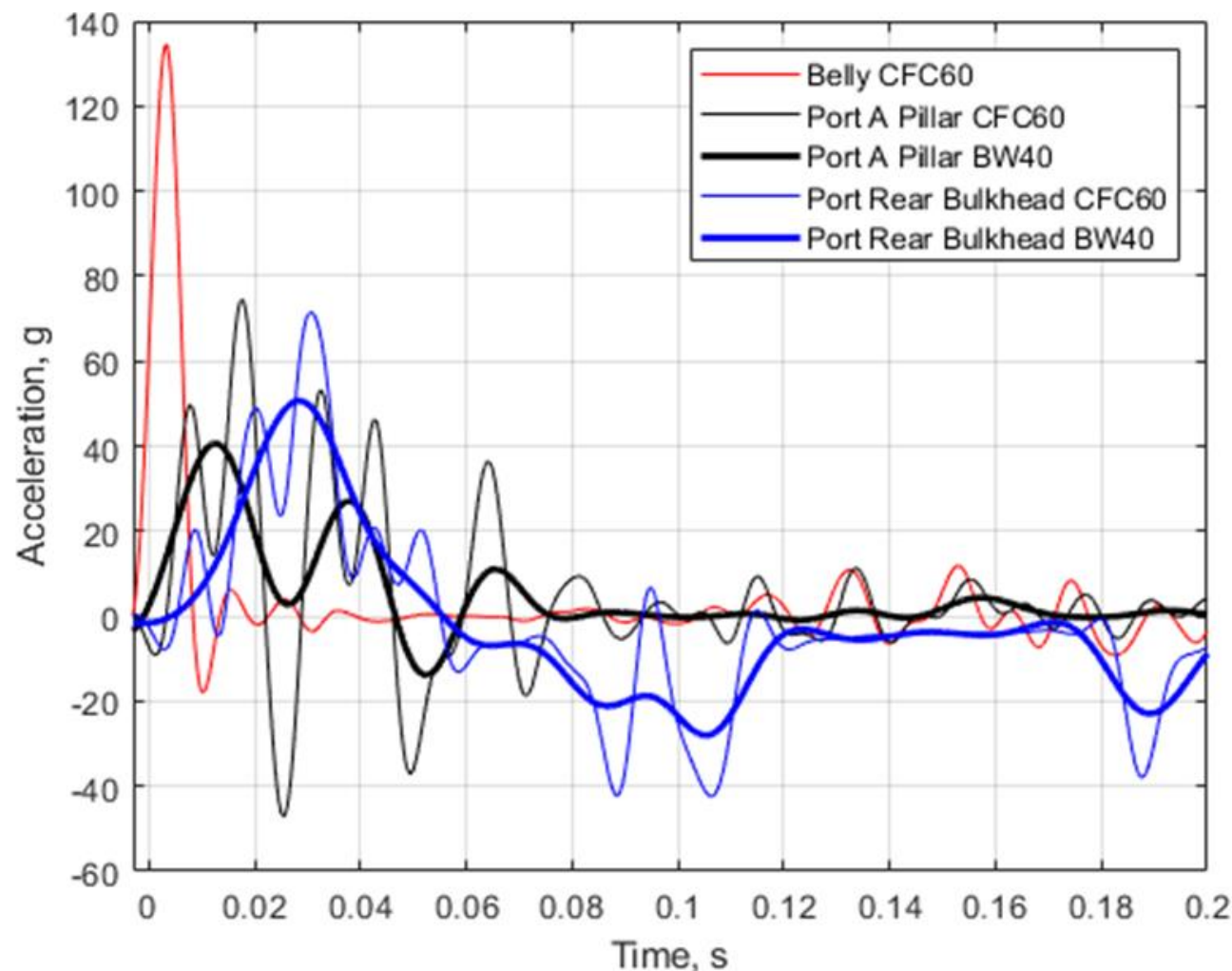


Post-Test Pictures Rear Two Rows



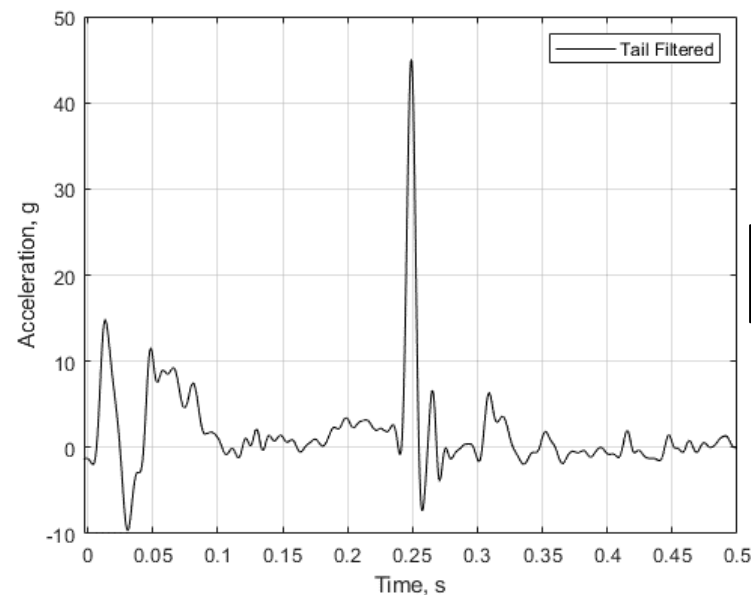
Floor Level Accelerations

- Belly impact resembles shock loading
- Significant amount of noise in the signal after SAE J211 filtering
- Attenuated to 41 g and 51 g for the A Pillar and Rear Bulkhead, respectively using lower 40 Hz lowpass filtering
- Pulse duration between 0.06 s and 0.08 s

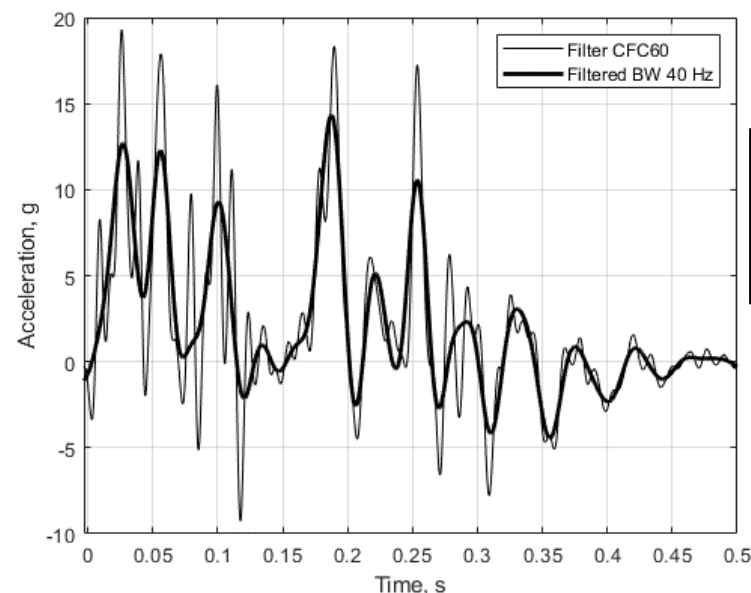


Other Airframe Accelerations

- Tail shows signs of initial acceleration and flexing
- Tail spike evident at 0.25 s after impact
- No additional loads measured
- Overhead mass exhibits noisy response which peaks under 20 g if using the CFC* filters and 12 g if using a lower-pass filter
- Noise is the structure collapsing and the overhead mass sinking into the cabin



Tail



Overhead mass

Photogrammetry Analysis

- Plotting Sigma which is pixel deviation from reference.
 - High Sigma values indicate failure locations
- Video goes through the first 0.150 seconds



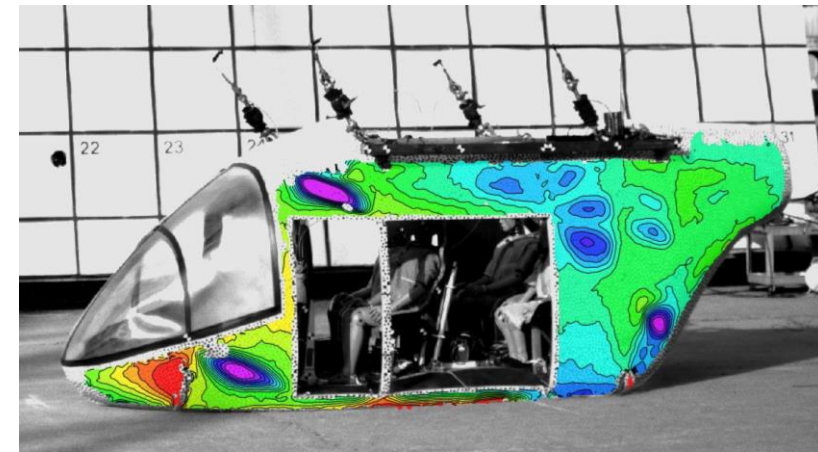
Photogrammetry Analysis (cont.)

- Plotting vertical deformation to determine items such as cabin intrusion
 - Data shows deformation from reference, which needs to be proceeded to determine the delta between ceiling and floor
- Plotting lateral (out of plane) deformation to determine skin buckling and additional failure locations
 - Data will be used for computational modelling



5.4" 33.6"

$t + 0.150$ seconds



0.8" -1.0"

$t + 0.020$ seconds

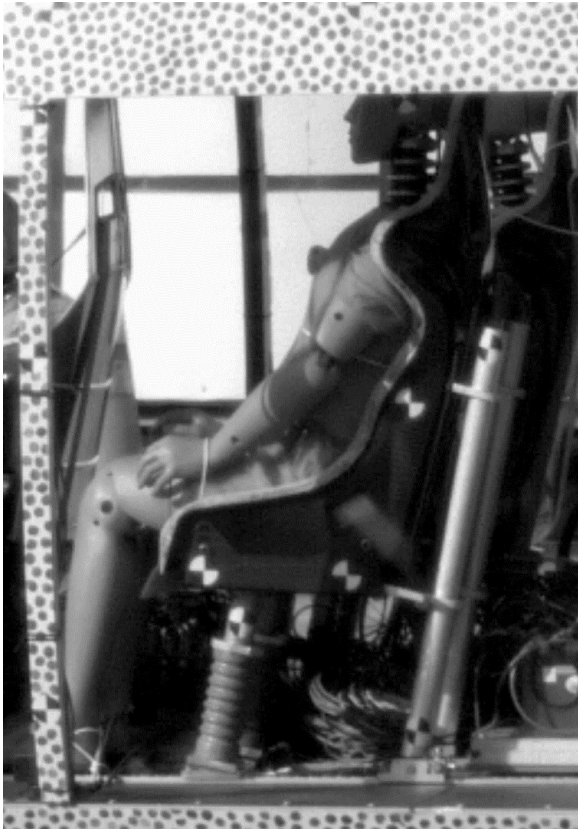


Lumbar Load Injury Metrics

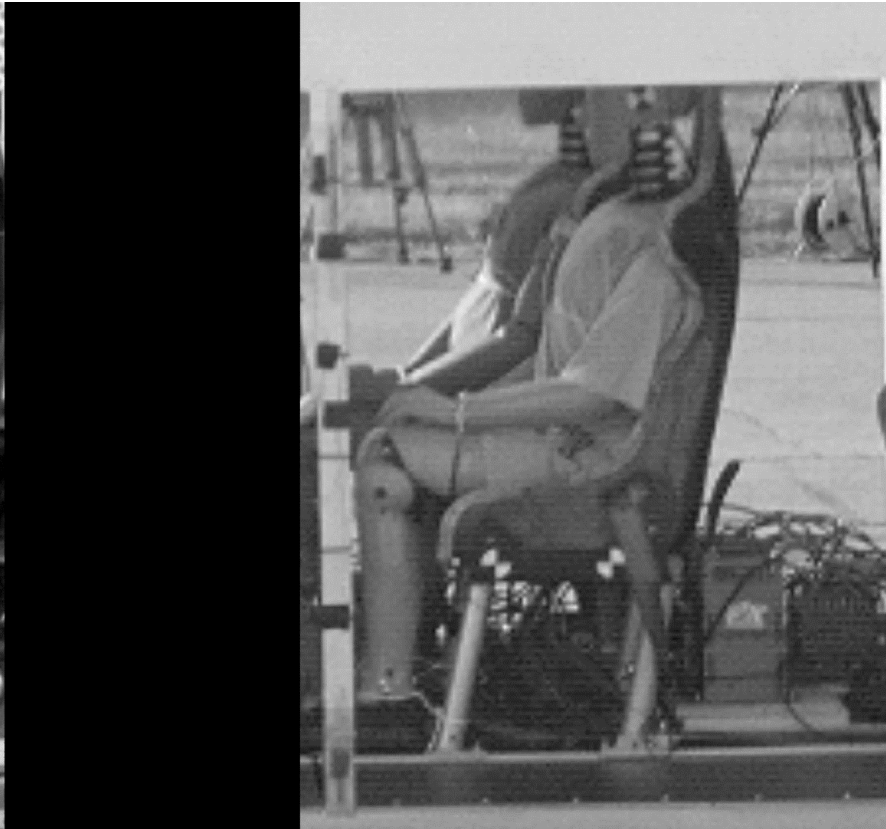
- Lumbar loads both over and under regulatory limits
- EA seats produced lumbar loads below limits
- Rigid seat above limits
- Non-standard ATDs evaluated against Full Spectrum Crashworthiness Criteria
 - 95th limit 1757 lb – 1.1 normalized value
 - 5th limit 933 lb – 2.3 normalized value

ATD	Lumbar Load (lb.)
1 – HIII 10 YO - Front Stbd	862.4
2 – HII 50 th - Font Port	1216.9
3 – FAA HIII 50 th - Middle Stbd	2499.7
4 – FAA HIII 50 th - Middle Port	1347.1
5 – HIII 95 th - Rear Stbd	1864.7
6 – HIII 5 th - Rear Port	2173.0

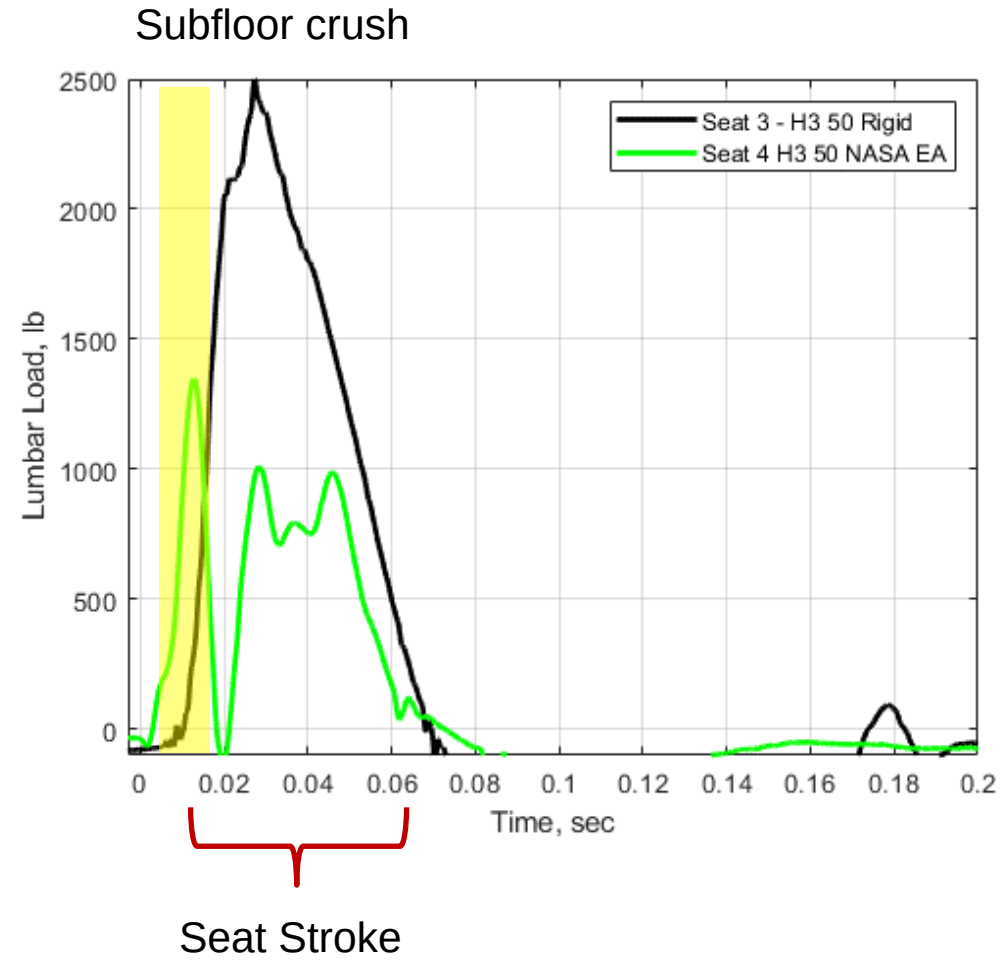
Middle Row Experiment: EA Seat to Non-EA Seat



EA Seat



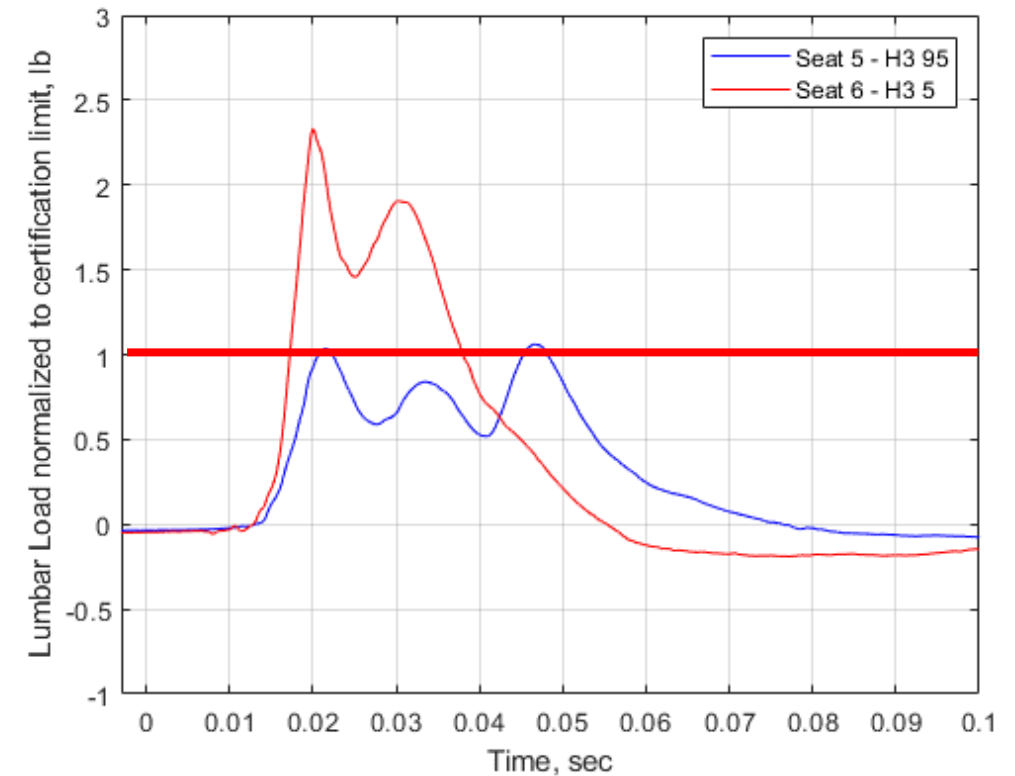
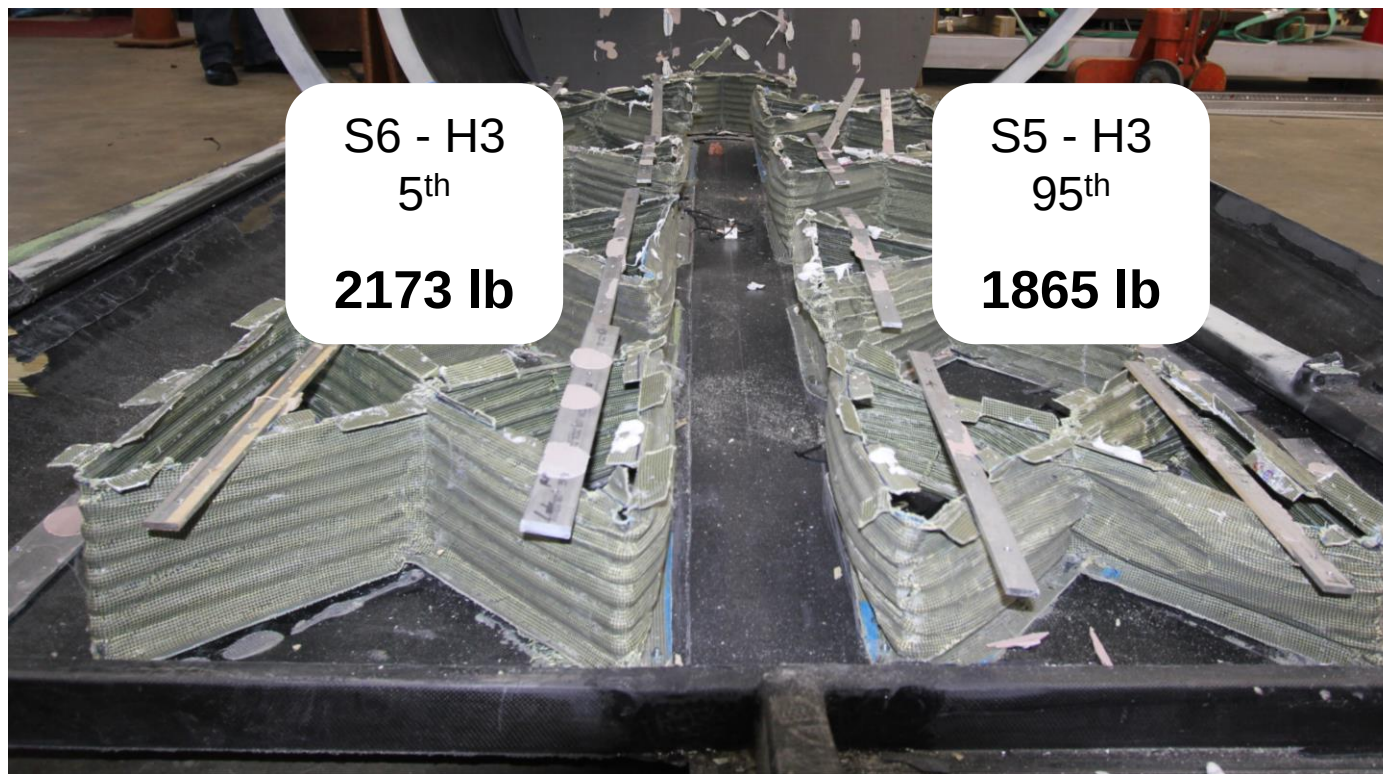
Non-EA Seat



Energy Absorbing Subfloor for Non-Standardized ATD Sizes



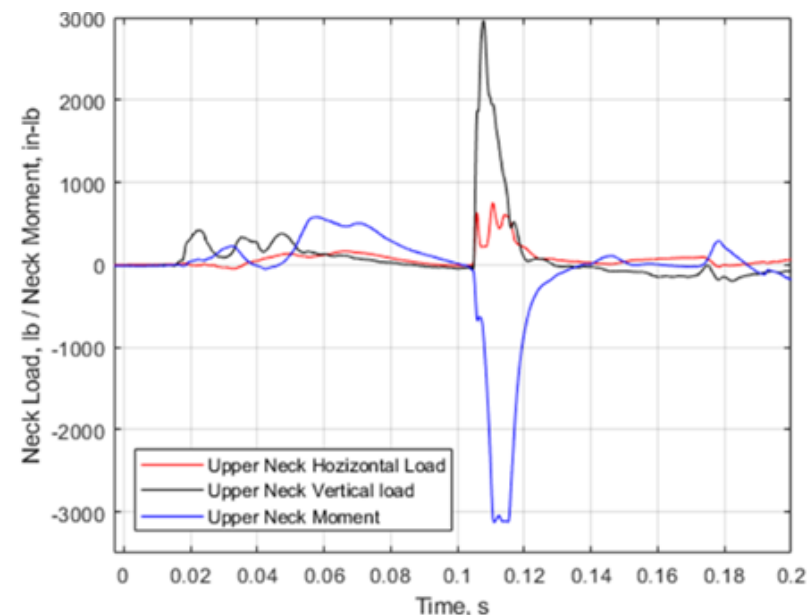
- Examining the subfloors in row 3 of seats, which contained the 5th and 95th percentile ATDs



Head and Neck Injury Metrics

- All measured locations showed below injury limit values for the Head Injury Criteria (HIC) using a 36 millisecond window
 - Using a limit of 1000
- 95th ATD neck injury criteria (Nij) fell out of family with the others and it is suspected that the overhead mass impacted this ATD head
 - Using a limit of 1

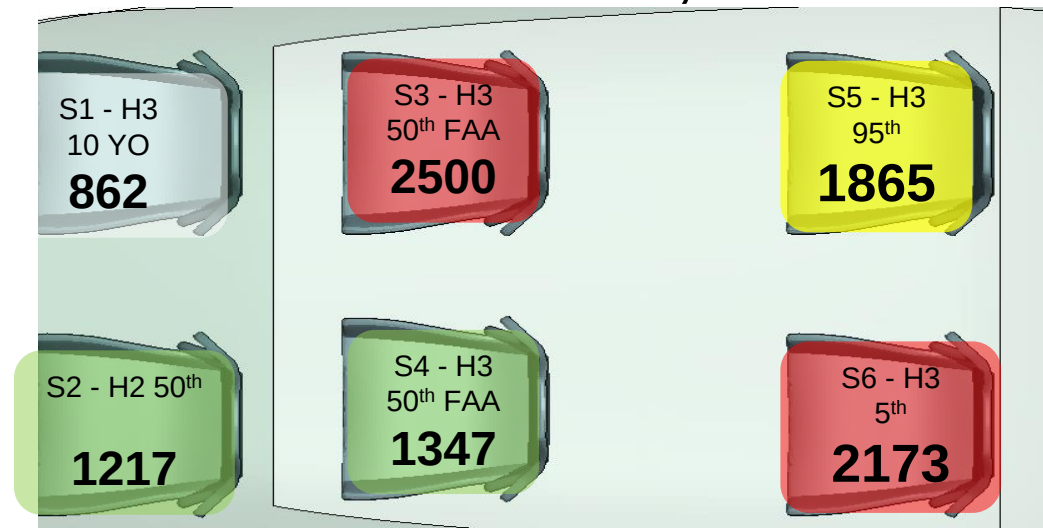
ATD	HIC36 Value	Nij Value
1 – HIII 10 YO - Front Stbd	Not Calculated	Not Calculated
2 – HII 50 th - Font Port	Not Available	Not Calculated
3 – FAA HIII 50 th - Middle Stbd	140	0.66
4 – FAA HIII 50 th - Middle Port	98	0.33
5 – HIII 95 th - Rear Stbd	Not Available	3.36
6 – HIII 5 th - Rear Port	202	0.73



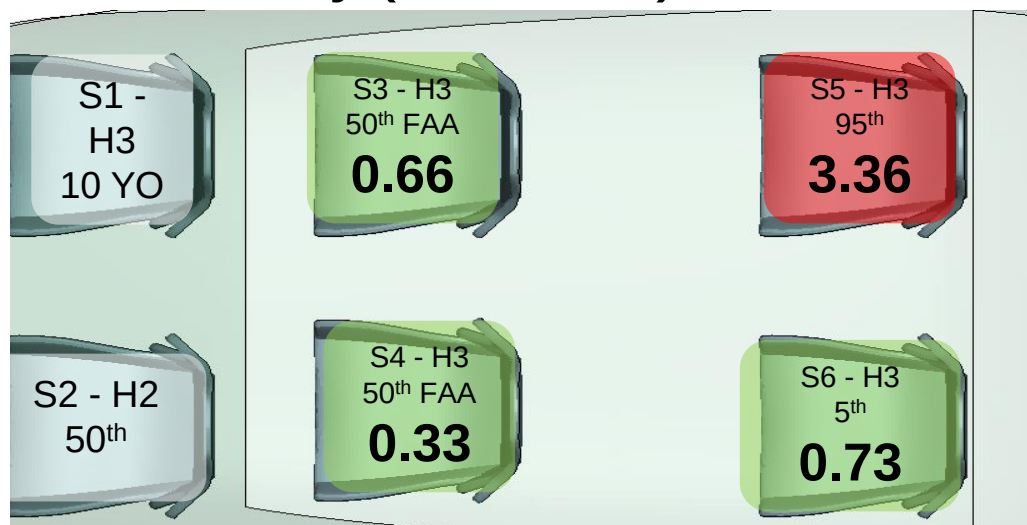
Injury Metric Summary

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

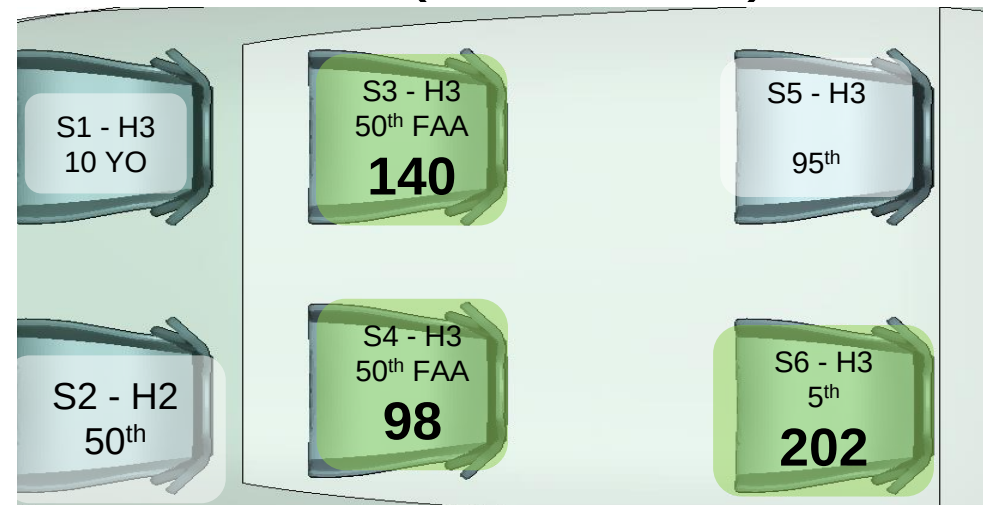
Lumbar Load, lb.



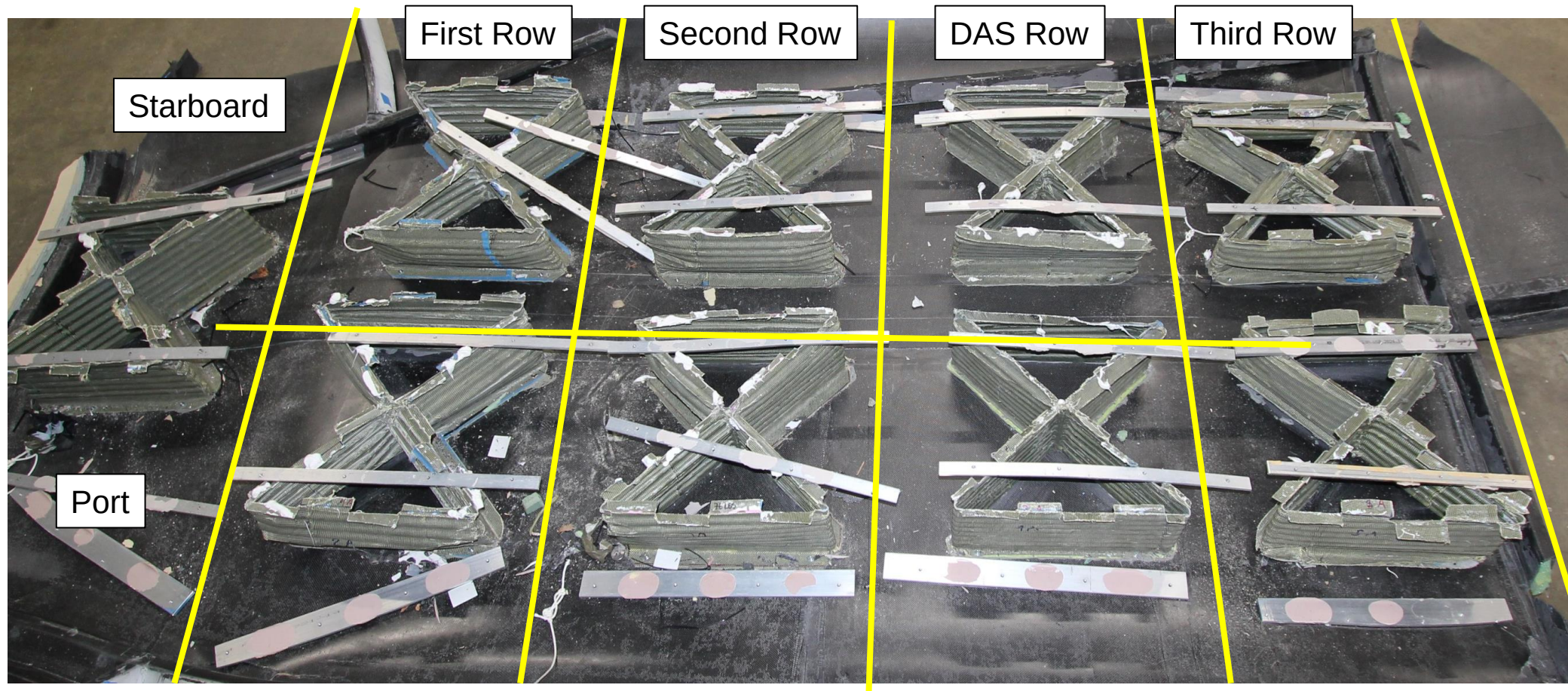
Nij (limit = 1)



HIC36 (limit 1000)



All Subfloor Energy Absorber Post-Test Crush



- All energy absorbers exhibited post-test crush of non-zero value
- Energy absorbers seemed to be sized for the heavier components
- Influence from the continuous seat rail affected the response

Summary



- Test was conducted to satisfy four objectives
- Test article was primarily designed through the use of computational simulations
 - Sizing
 - Layout
 - Impact conditions
- Two primary events occurred
 - Energy absorbing structures crushed
 - Structural failures leading to overhead mass collapse
- Stroking seats limited lumbar loads
- 95th ATD seated in rear was likely affected by overhead mass collapse



Conclusion and Discussion

- All four objectives satisfied
- Energy absorbers limited loads in the occupants, however interactions between occupants/seats likely affected response
- Roof structure was assumed to be all overhead. This is a single point design and there are other concepts that do not have these same features
- ATD injury varied depending on ATD size and seated location
- Second Lift+Cruise test article currently at NASA Langley Research Center. Analyses ongoing to determine test conditions