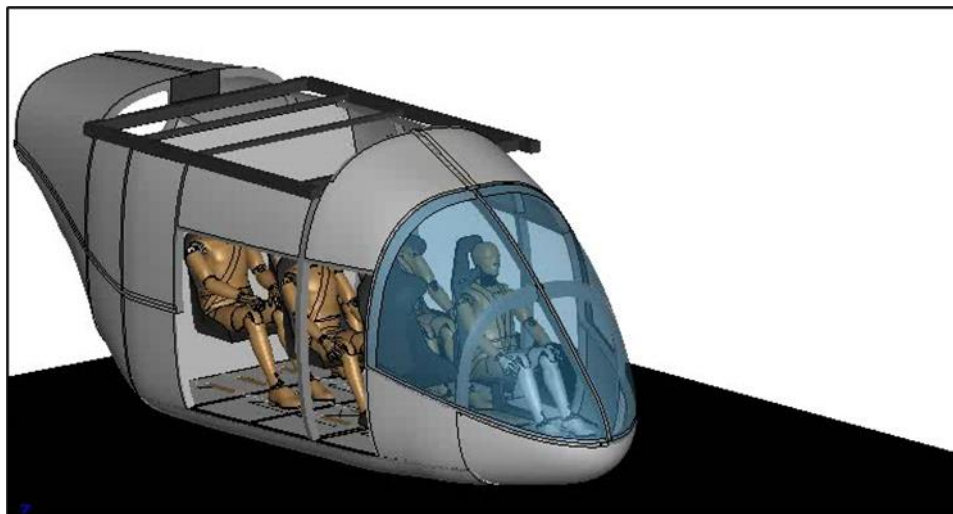


Component Characterization of an eVTOL Reference Model for Crashworthiness Studies

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Vehicle Test

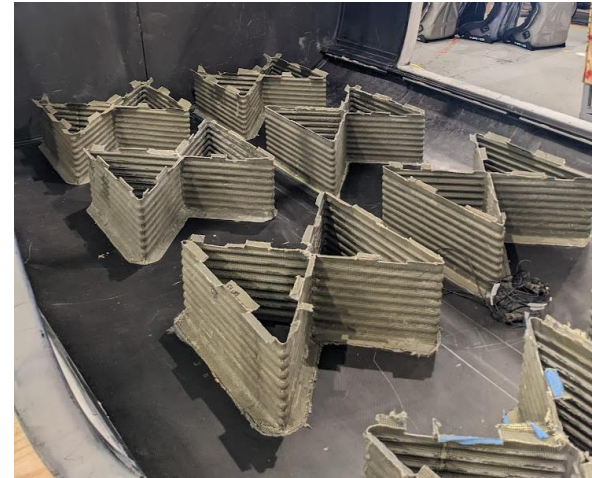


- Horizontal Velocity = 38.1 ft/s, Vertical Velocity = 31.4 ft/s
- Pitch 0.6 degrees nose down, 2 degrees yaw

Research Objectives



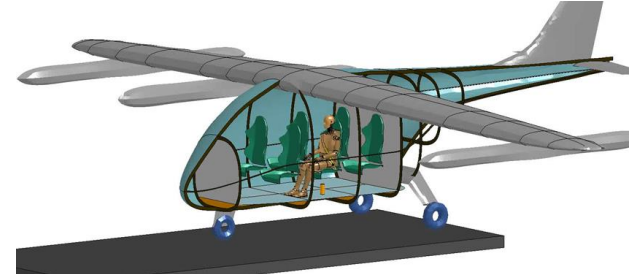
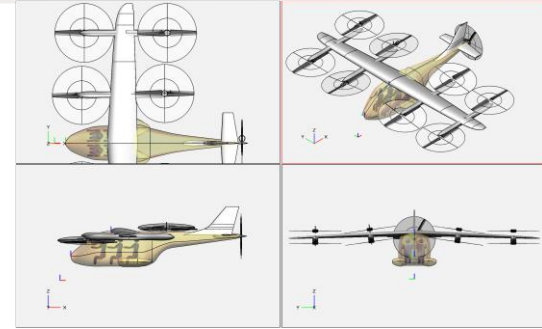
1. Generate data on generic electric Vertical Take-off and Landing (eVTOL) vehicle design under crash conditions to inform regulation development
2. **Generate data for the use in validation of computer modelling efforts**
3. Generate data from onboard Anthropomorphic Test Devices (ATD's, a.k.a. crash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



Test Article – NASA Lift Plus Cruise (LPC) Reference Vehicle



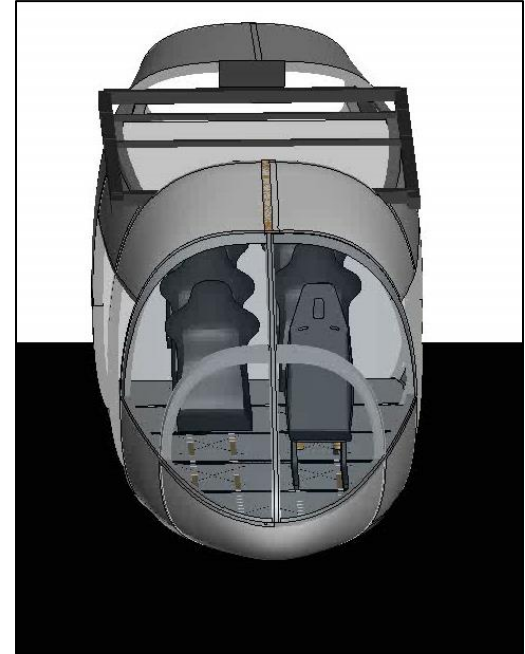
- Reference
 - Silva et al. *VTOL Urban Air Mobility Concept Vehicles for Technology Development*. 2018 Aviation Technology Integration and Operations Conference
- Test Article Specifications
 - Dimensions: 18 ft. x 6 ft. x 7 ft.
 - Total weight: 3450 lb.
 - Seats: 6 passenger
 - Wing Type: High wing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



Pre-Test Simulation Findings



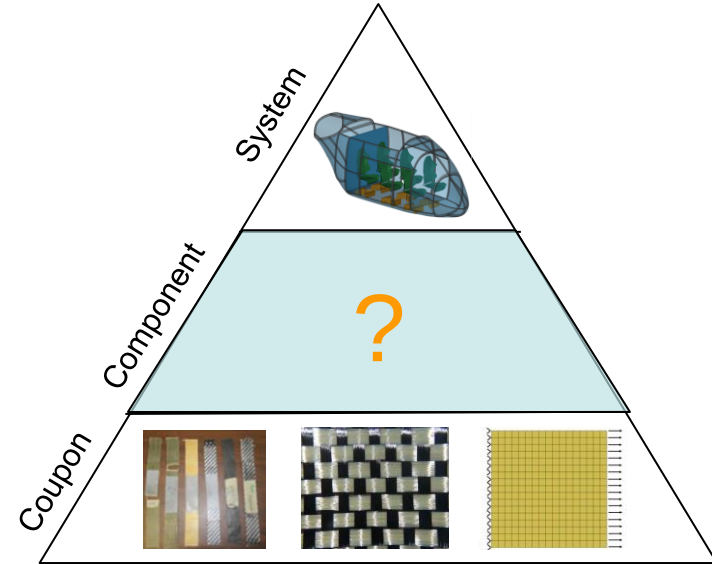
- LPC test article finite element model (FEM) developed using partial building block approach
 - External structural model developed from coupon test data
 - Subsystem testing conducted for internal EA components
 - System level integration conducted to match external structure assembly and internal component integration
- Pre-test FEM predicted structural response up until brittle composite failure
 - Structural material model limited in its prediction of cabin intrusion
- *Limitation: No subsystem testing of external structure conducted*



Overview of Component Characterization Study



- Component level testing was conducted on LPC subsystems to improve LPC FEM
- Airframe structure and seat environment subsystems tested to:
 - Assess modeling assumptions made during FEM development
 - Calibrate material models in representative dynamic loading conditions
 - Quantify predictive accuracy of occupant models in controlled impact environment

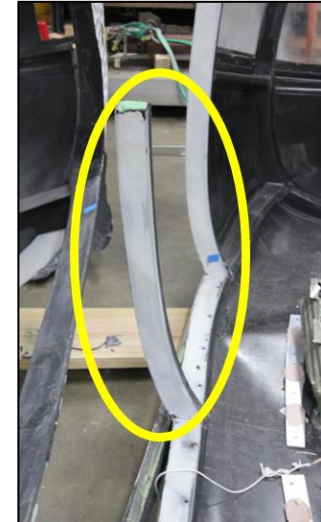


LPC Test Article: FEM Building Pyramid

Structural Test Specimens



- Structural test specimens gathered from LPC test article – post full-scale impact test
- Intact specimens of the LPC structural subsystems were cut from sections of LPC test article which showed no visible damage
 - Skin : behind C-pillar
 - Beams: B-pillar
 - Forming foam: lower center longeron



Structural Component Testing – Beam Structure



- Dynamic three-point bend testing conducted on beam structure specimens
- Low-speed: 10 ft/s
 - Specimen damage w/o failure
- High-speed: 15 ft/s
 - Specimen failure
- Impactor acceleration and surface strain recorded for model calibration



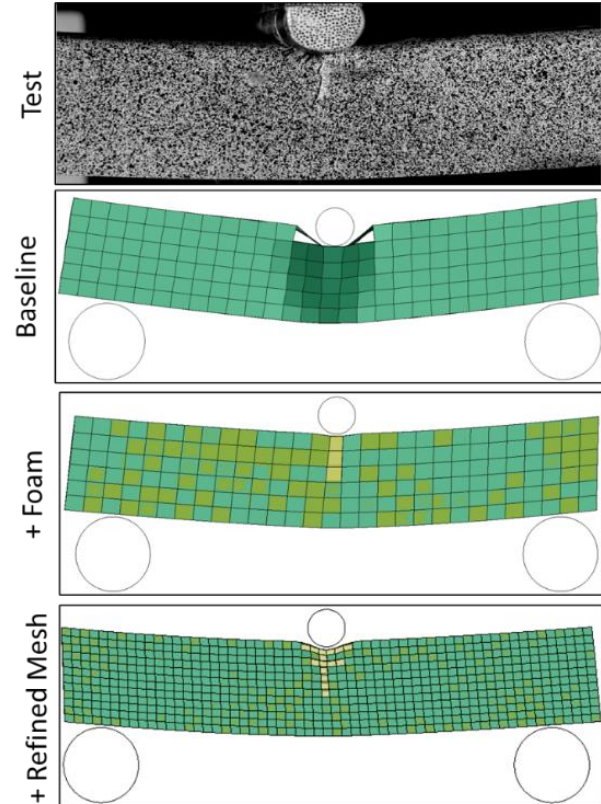
Specifications

Test fixture: 14 ft drop tower
Impacting mass: 115 lb
Indenter diameter: 1 in
Roller spacing: 1 ft

Structural Component Testing – Beam Structure (Analysis)



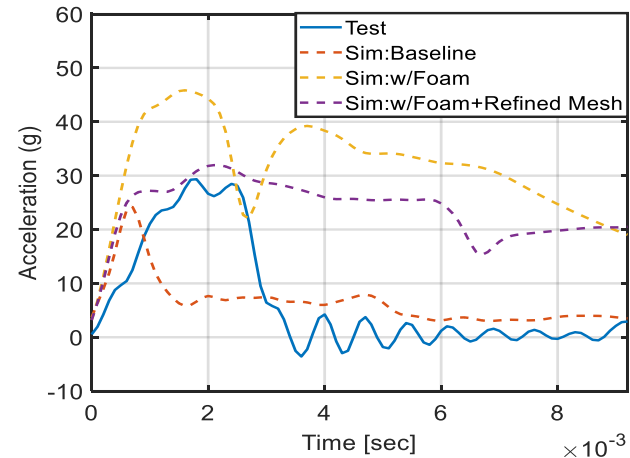
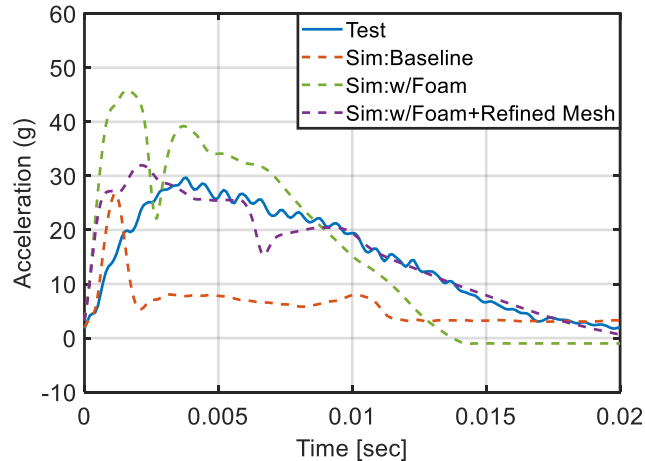
- Three-point bend testing used to evaluate mesh and beam structure simplifications used in original LPC vehicle FEM
- Three models generated:
 - Baseline: Representative beam section isolated from original LPC vehicle FEM
 - Foam: Added forming foam which was added during the fabrication process to shape the structural frames
 - Refined mesh: Mesh refined from 0.5 in to 0.25 in length



Structural Component Testing – Beam Structure (Results)



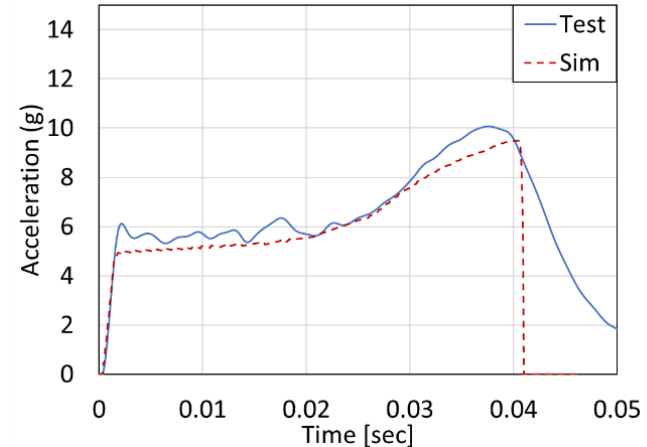
- Forming foam found to significantly alter beam structure response in three-point bend test configuration
- Refined mesh improved prediction of peak acceleration
- FEM did not predict specimen failure in high-speed test



Structural Component Testing – Forming Foam



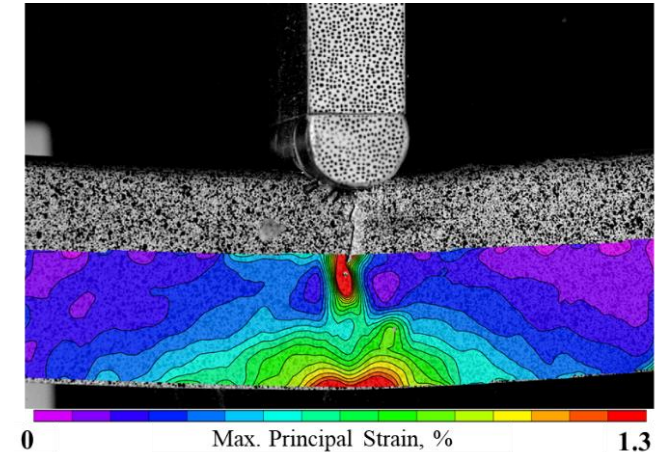
- Forming foam effect on beam section three-point bend response indicated need to include foam within FEM
 - Required improved material model characterization
- Material model generated using static compression testing
- Validated using dynamic impact compression test



Structural Component Testing – Beam Structure (Calibration)



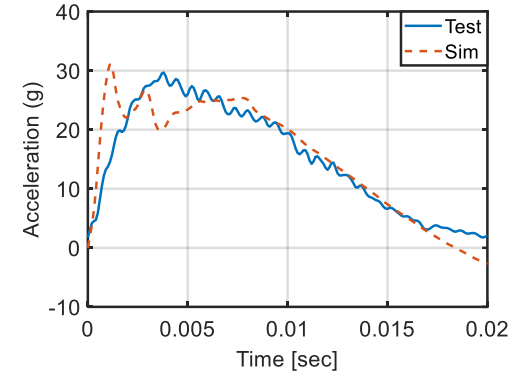
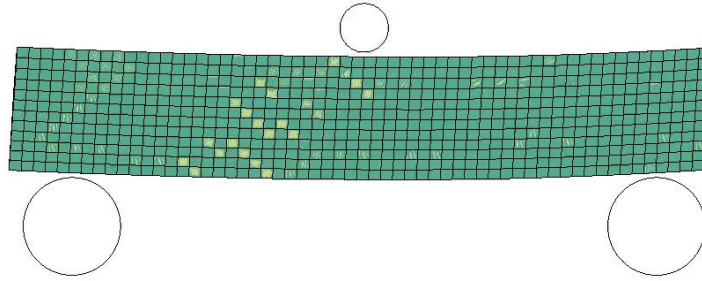
- Beam FEM with refined mesh and updated forming foam improved correlation but unable to replicate specimen failure
- Calibration of the element erosion parameters within the composite skin material was necessary
- Minimum strain limits for element erosion selected using three-dimensional digital image correlation (3D-DIC) data
- Erosion limits calibrated to produce crack propagation while minimizing energy loss through erosion



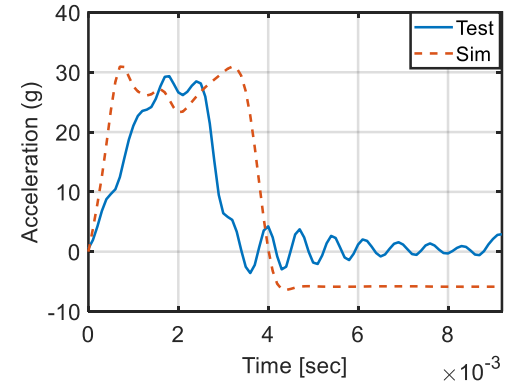
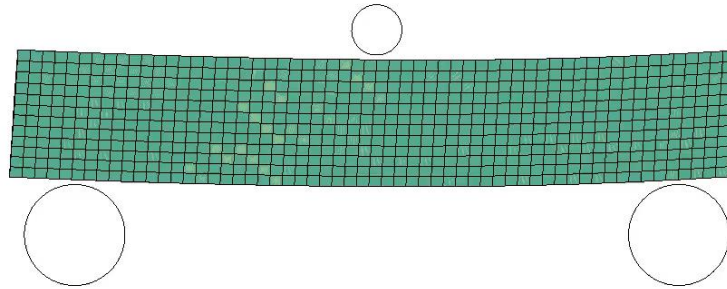
Structural Component Testing – Results



Low Speed, 10 ft/s



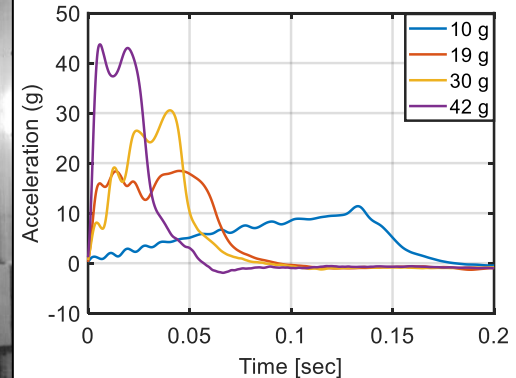
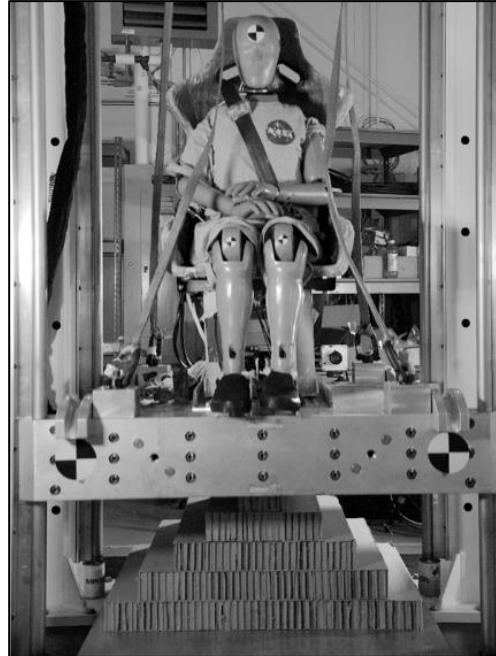
High Speed, 15 ft/s



Seat Component Characterization



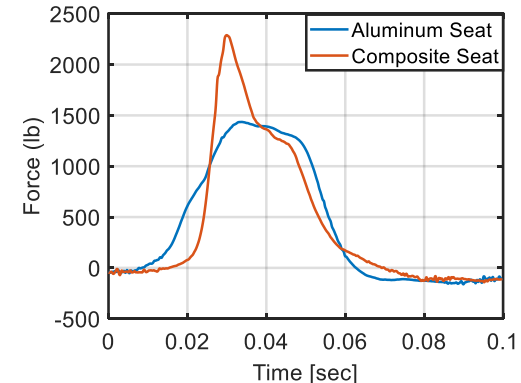
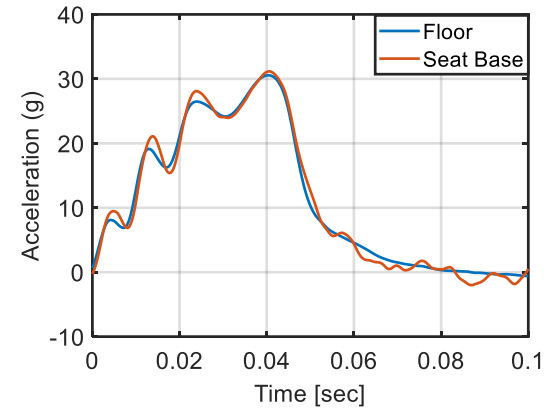
- Seat level vertical impact tests conducted using 30 ft drop tower facility
 - Seats: combination of generic, commercial, and NASA developed
 - Conditions: 10 g – 45 g peak impact acceleration
 - ATDs: Hybrid III 5th, 50th, 95th



Seat Component Characterization – Modeling Assumptions



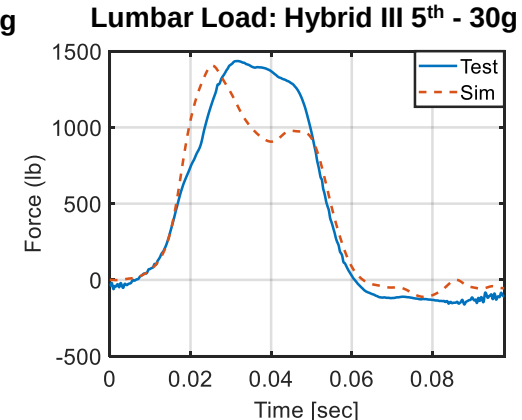
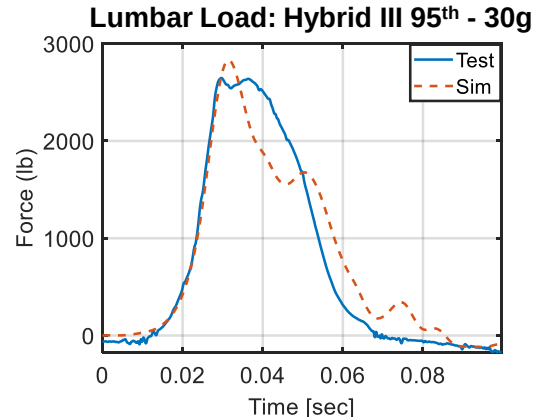
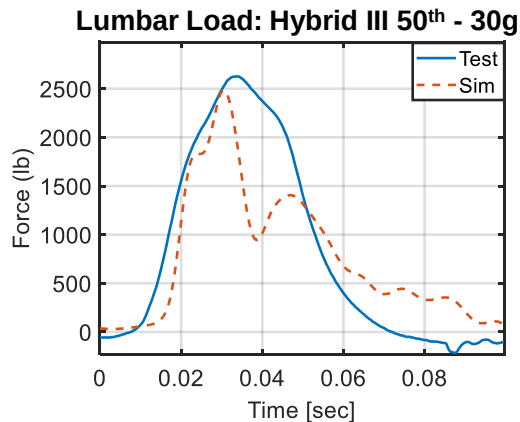
- Seat component testing used to evaluate modeling assumptions made in LPC seat FEMs
- *Assumption 1*: Aluminum seat frames effectively rigid
 - Validated by matched floor and seat base acceleration results
- *Assumption 2*: Seat bucket effectively rigid
 - Invalidated by ATD response sensitivity to seat bucket material
- Seat FEMs were updated to include representative seat bucket material models



Seat Component Characterization – Model Correlation



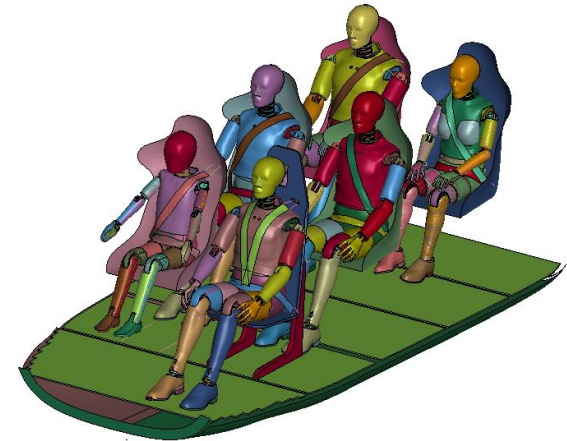
- Hybrid III 5th, 50th, and 95th FEMs simulated in each tested condition (12 tests)
- Compressive lumbar load prediction compared to test to quantify correlation
- All peak loads predicted within 10%
 - 10/12 predicted within 5%



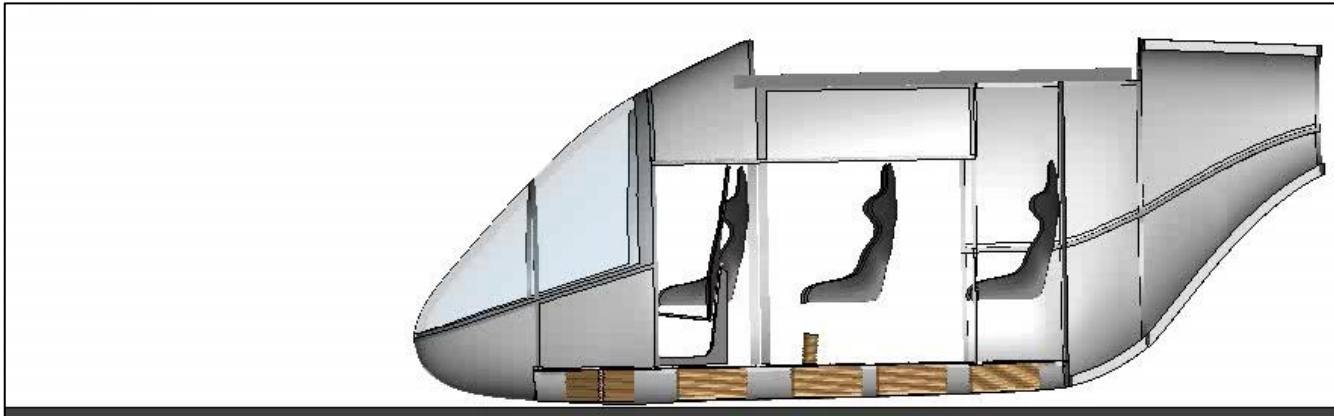
Updated LPC Test Article FEM



- Findings from structural component and seat subsystem testing integrated into LPC test article FEM
- Structural FEM updates:
 - Element mesh length refined: 0.25 in
 - Forming foam model added
 - Calibrated composite material model
- Seat subsystem updates:
 - Updated seat bucket material models
 - Addition of Hybrid III 10-year-old FEM

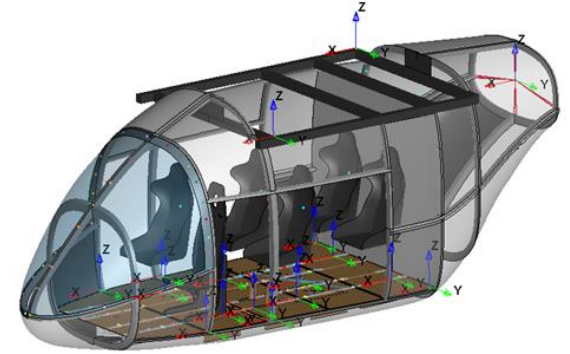


Calibrated LPC Test Article FEM Correlation – Kinematics

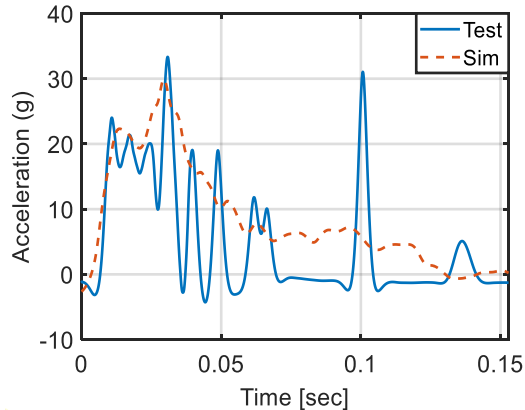


Calibrated LPC Test Article FEM Correlation – Structural Accel.

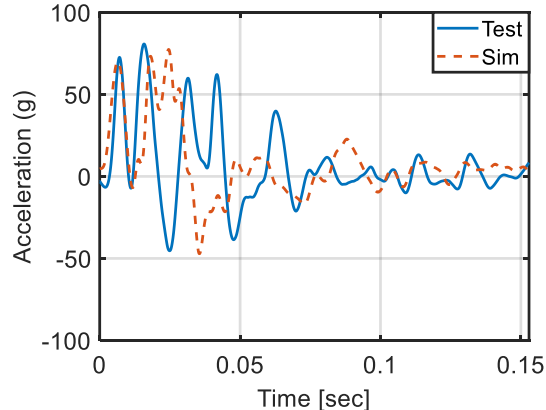
- Accelerations measured throughout the LPC test article structure closely replicated by updated FEM
 - Indication that the structural stiffness effectively characterized within the vehicle FEM



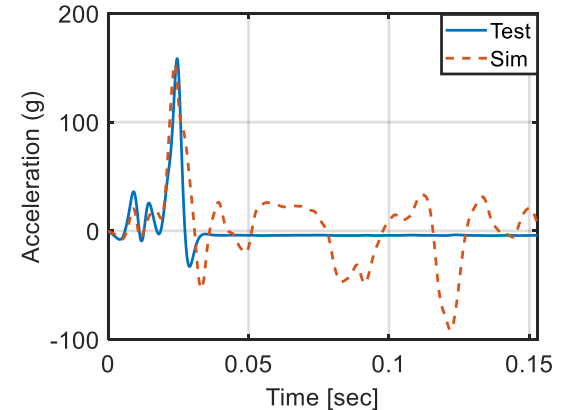
Lifting Hardware Vertical Accel.



A-Pillar Vertical Accel.



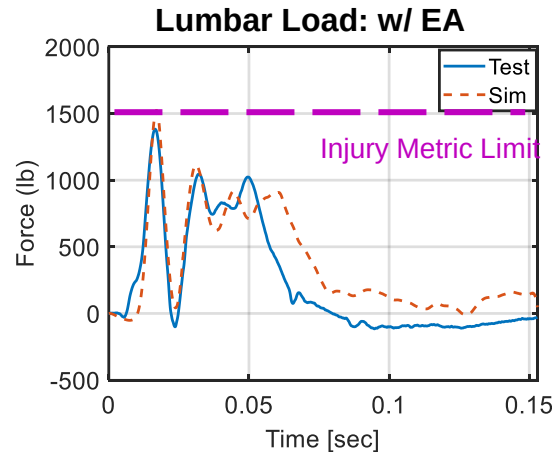
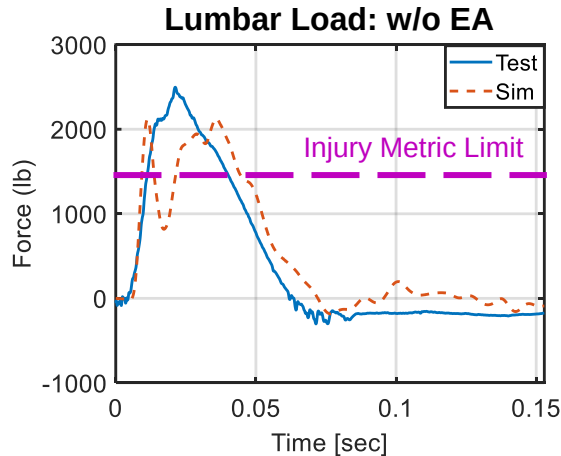
C-Pillar Vertical Accel.



Calibrated LPC Test Article FEM Correlation – ATD Response



- Post-test model simulation accurately identified capability of EA components to reduce occupant injury risk
 - Lumbar load ATD response closely predicted in rigid and NASA EA seat configurations
- Results provide confidence in using model to predict EA mechanism capability for future design optimization



Conclusions



- Pre-test prediction of the LPC full-scale impact test demonstrated the need for subsystem calibration at relevant dynamic loading conditions
- Structural component and seat subsystem testing was conducted to improve FEM characterization
 - Resulted in: Mesh refinement, inclusion of fabrication material elements, calibrated strain-based erosion limits for composite structural model, and application of updated seat material models
- Component level characterization led to updated LPC test article FEM which closely replicated test results
 - Structural kinematics driven by brittle composite failure
 - Accelerative loads within structure
 - ATD responses

Next Steps



- Second LPC test article fabricated, test planned for FY25
 - Evaluation of structural response under different loading environment
 - Evaluation of overhead mass effects – frangible wing assessment
 - Validation of calibrated LPC FEM
 - Validation of updated EA mechanism designs
- Future work:
 - Utilize LPC FEM to study expanded range of impact environments
 - Study occupant surrogate models within relevant eVTOL environments (advanced ATD and human body models)



Questions?

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