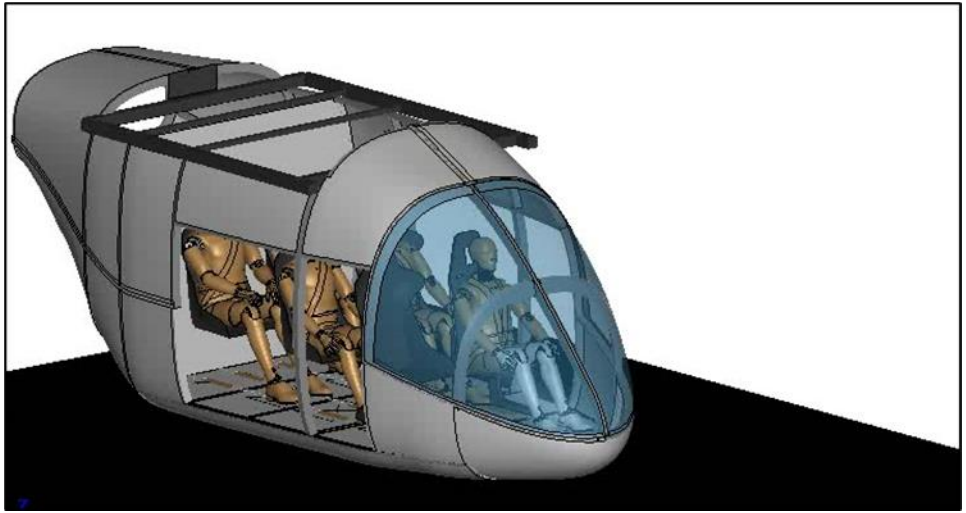
Simulation and Analysis of NASA Lift Plus Cruise eVTOL Crash Test

VFS 79th Annual Forum
West Palm Beach, FL,
May 18, 2023



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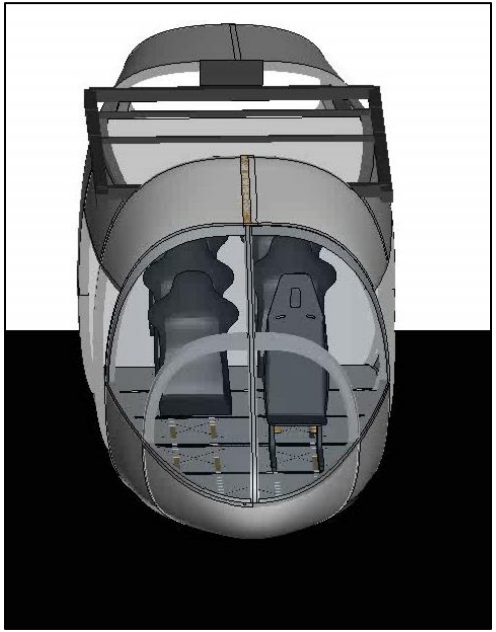
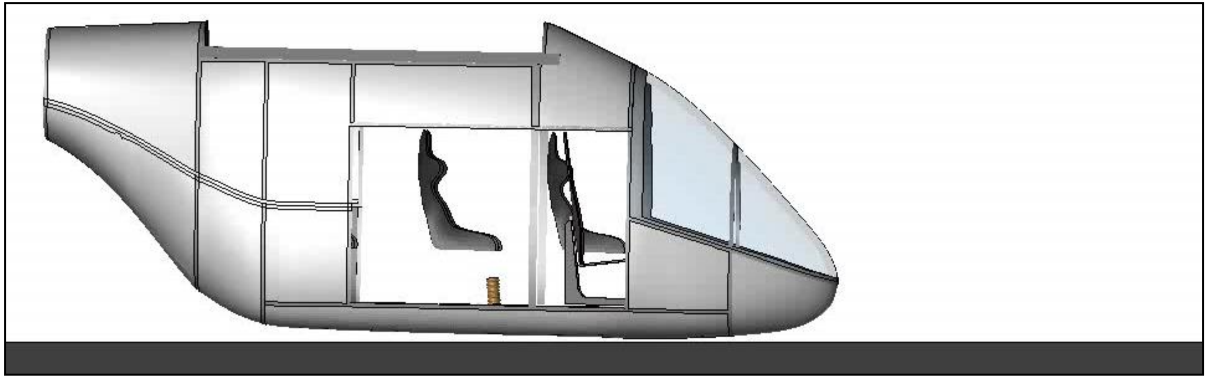
Test Video

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

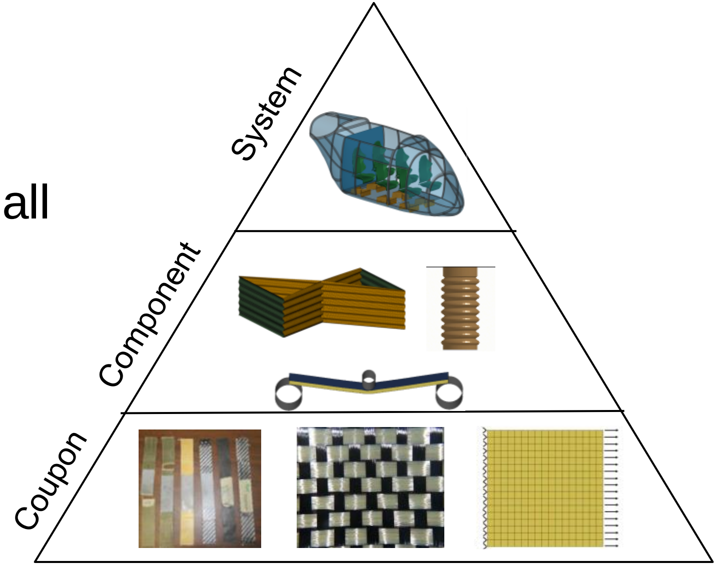
Pre-Test Prediction Simulation



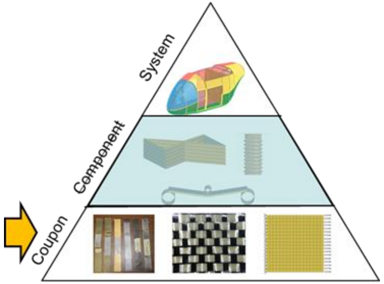


Vehicle Model development Overview

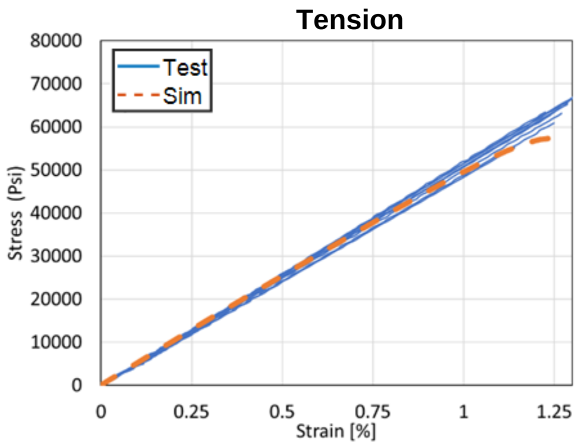
- Lift plus cruise (L+C) test article model developed using standard building block method
  - Single physics coupon testing conducted for all materials (external and internal structure)
  - Subsystem testing conducted for internal structural components
  - System level integration conducted to match external structure assembly and internal component integration
- *Limitation: No subsystem testing of external structure conducted*

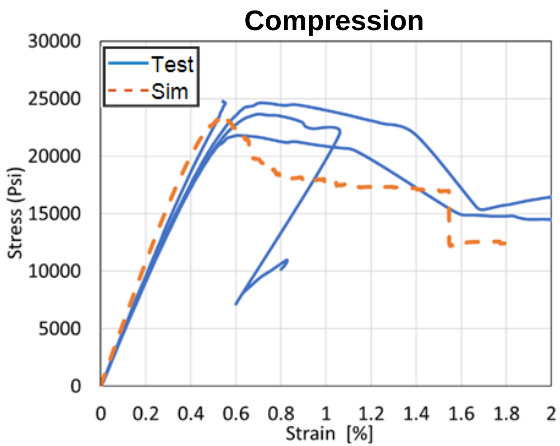


L+C Structural Model – Material Characterization

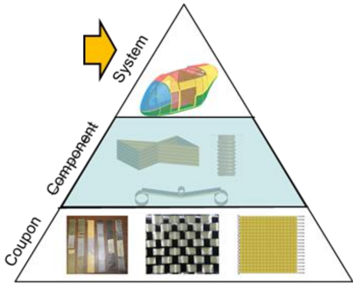


- Samples of Carbon Composite (C/C) material used in L+C external structure acquired
  - Samples included skin and frame layups which were fabricated using same curing methodology
- Laminated composite fabric material model generated from static tension and compression test data





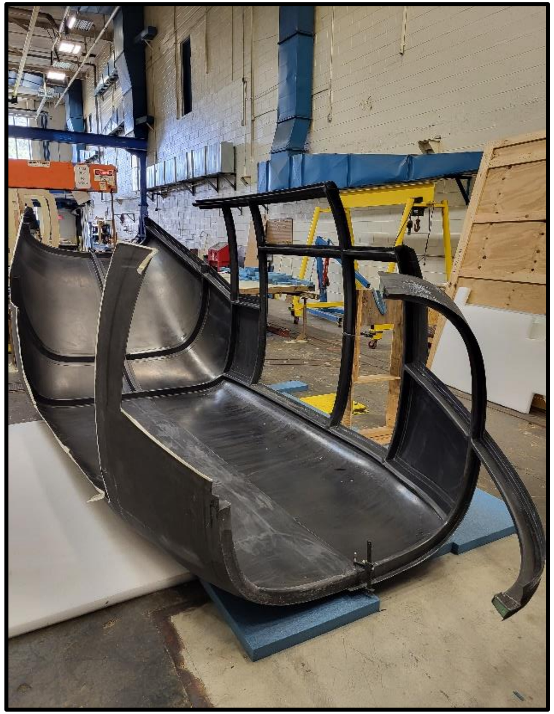
L+C Structural Model – Top level assembly



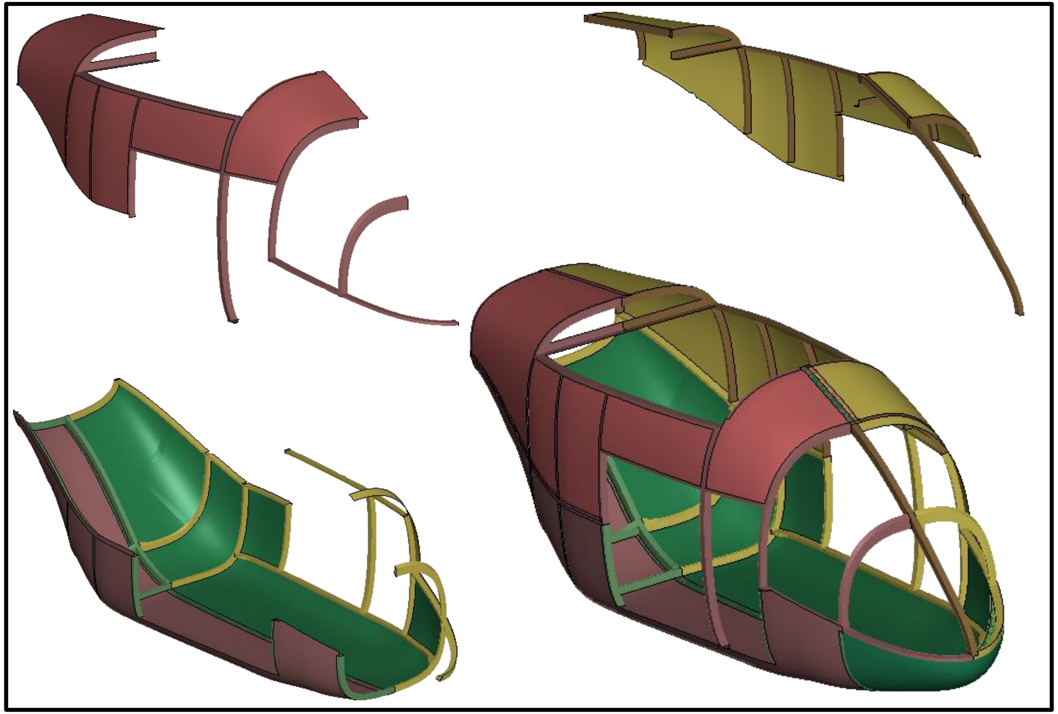
- Finite element model (FEM) generated to match geometry and assembly specifications of L+C test article
- Test article fabricated in four sections
  - Post-cure bonded together using lap joints with 4500 psi adhesive
- FEM parts generated to dimensions of each fabricated section
  - Lap joint bonds represented using tied contacts
- *Assumptions: Lap joint bond strength equal to adhesive specifications*

L+C Structural Model – Top level assembly

Test Article Assembly

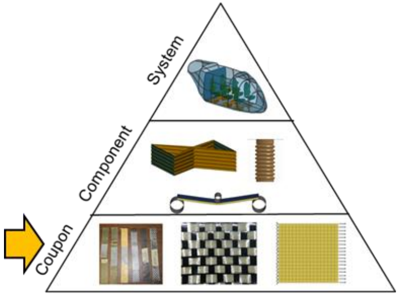


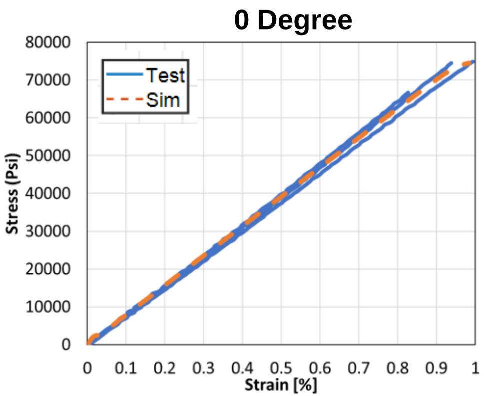
FEM Assembly

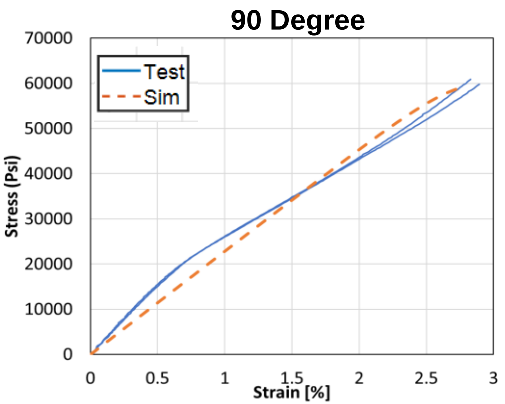


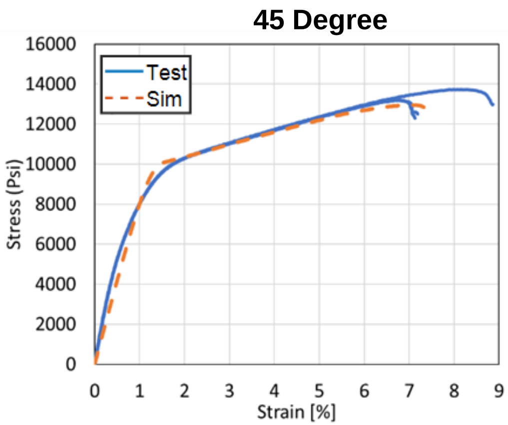
Internal Structure – Material Characterization

- Subfloor and energy absorbing (EA) seat components fabricated from Carbon Kevlar® (C/K) composite
  - Extensive coupon and component level characterization conducted previously using C/K fabric
- New resin system used in L+C component fabrication characterized through coupon tests



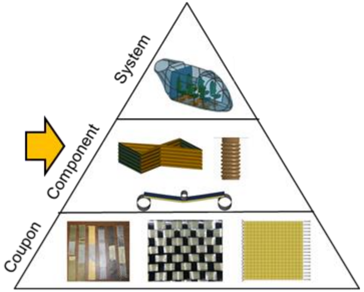




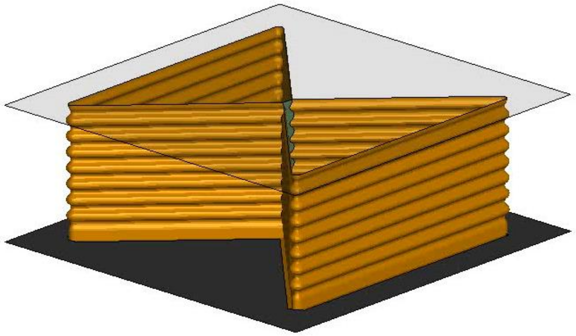


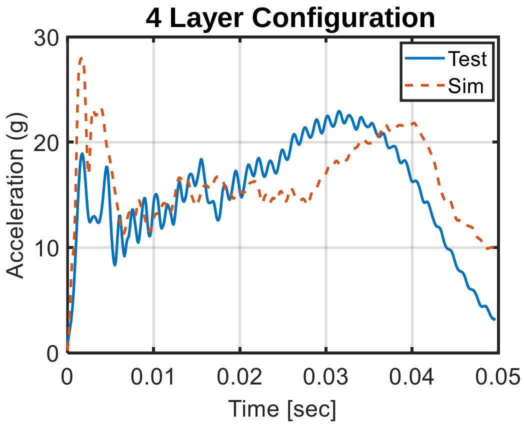
Internal Structure: Subfloor – Component Testing

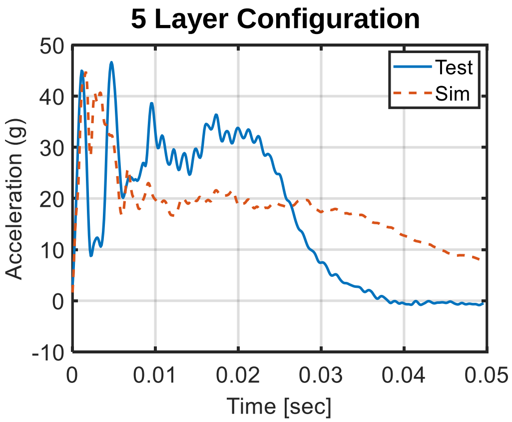
- Subfloor design: Self supported accordion cruciform
  - Proto-type design previously characterized (Putnam et al., 2022)
- Dynamic impact tests conducted to verify damage response prediction of component FEM



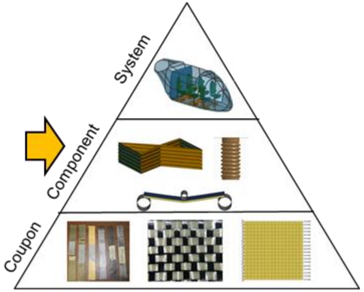
175 lb. mass: 22 ft/s impact





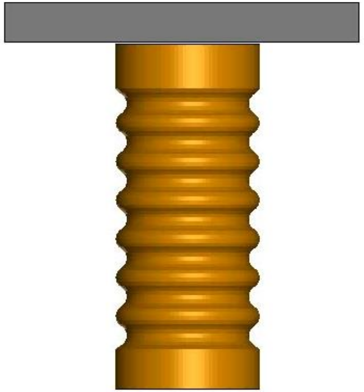


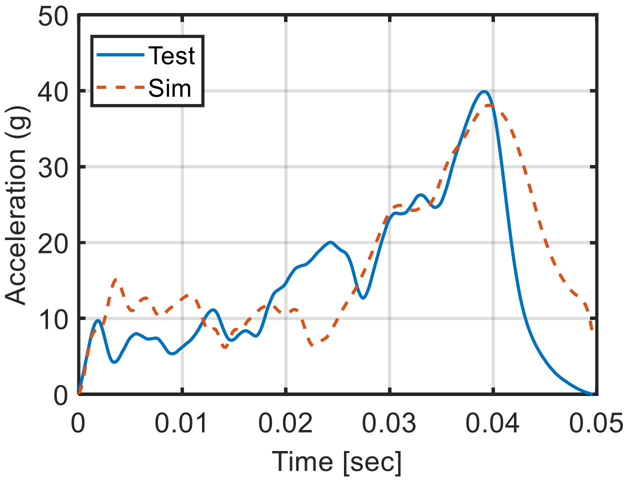
Internal Structure: Crush Tube – Component Testing



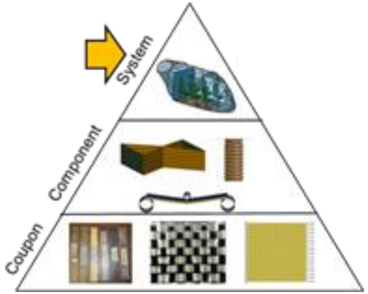
- Seat EA mechanism design: Accordion crush tube
  - Proto-type design previously characterized (Putnam et al., 2021)
- Dynamic impact tests conducted to verify damage response prediction of component FEM

<u>100 lb. mass: 22 ft/s impact</u>



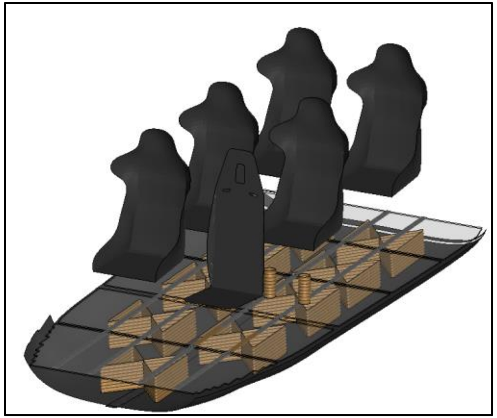


Internal Structure: Component Model Integration

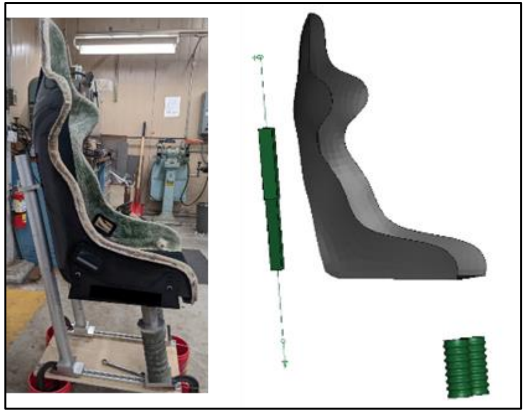


- Subfloor component models integrated into L+C structure matching test configuration
  - Tied contacts between subfloor floor and belly
- Crush tube model integrated into EA seat
  - Sliding joint used to approximate seat frame structure

Internal Floor/Seat Setup

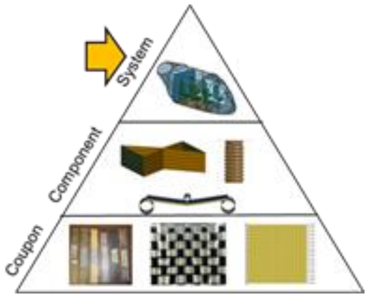


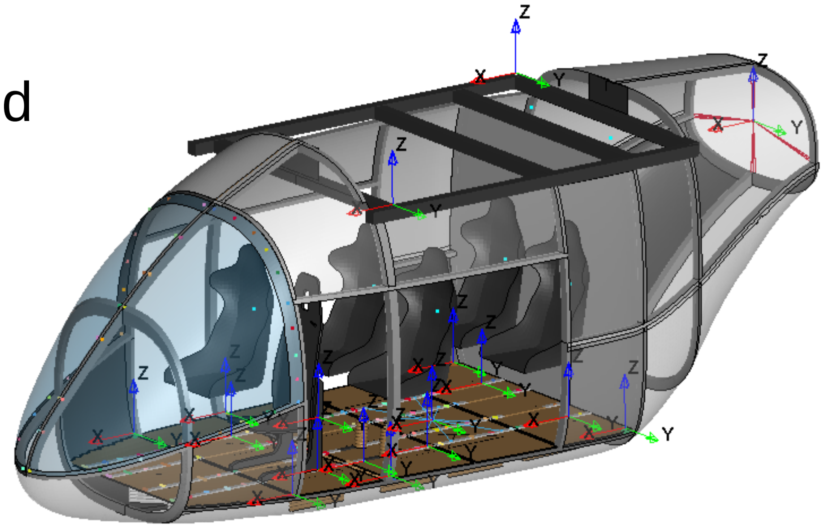
NASA EA Seat



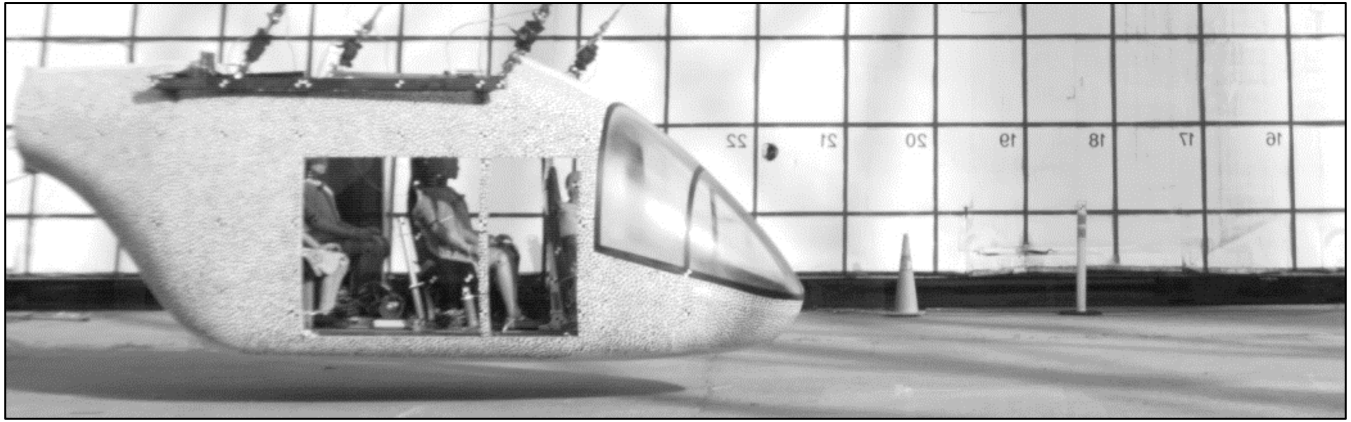
Complete L+C Test Article FEM

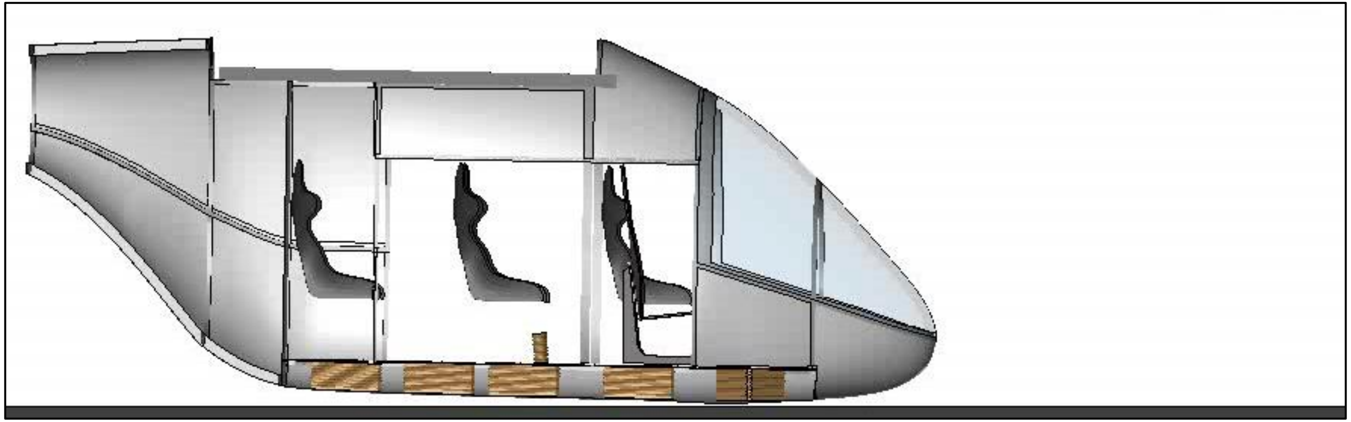
- Seats rigidly fixed to floor seat tracks
- Anthropomorphic test devices (ATDs) used in test represented as point masses
  - Occupant breakout simulations originally intended to simplify analysis
- Lifting hardware and mass integrated
- Accelerometer outputs included on structure, floor, and seats





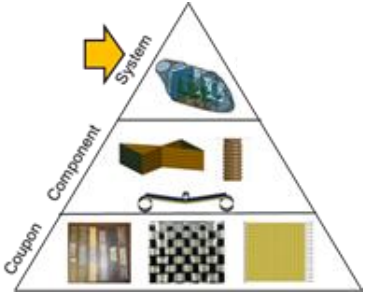
Occupant Compartment Loading vs Structural Failure

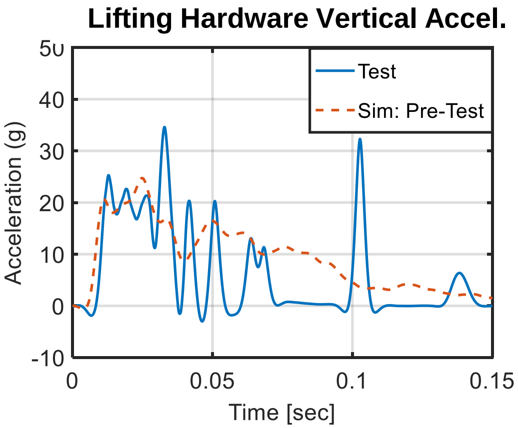


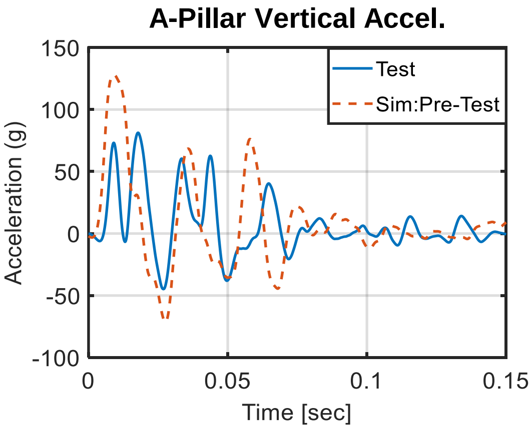


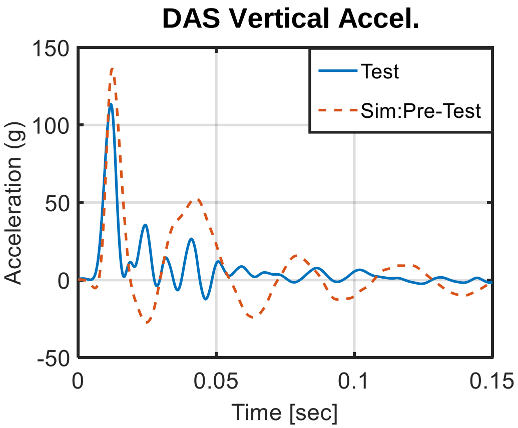
Structural Acceleration Predictions

- Although composite structure failure was not captured, the accelerative load measured in structure was generally predicted by the test article FEM
  - Primary acceleration load occurred before composite failure progression

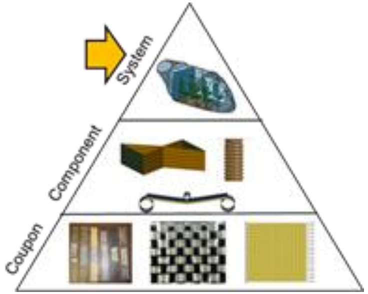








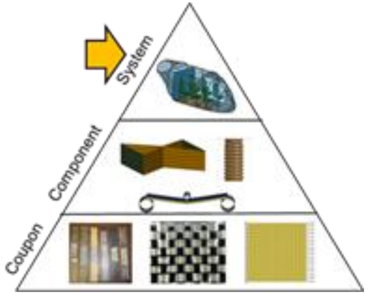
Post-Test Model Calibration

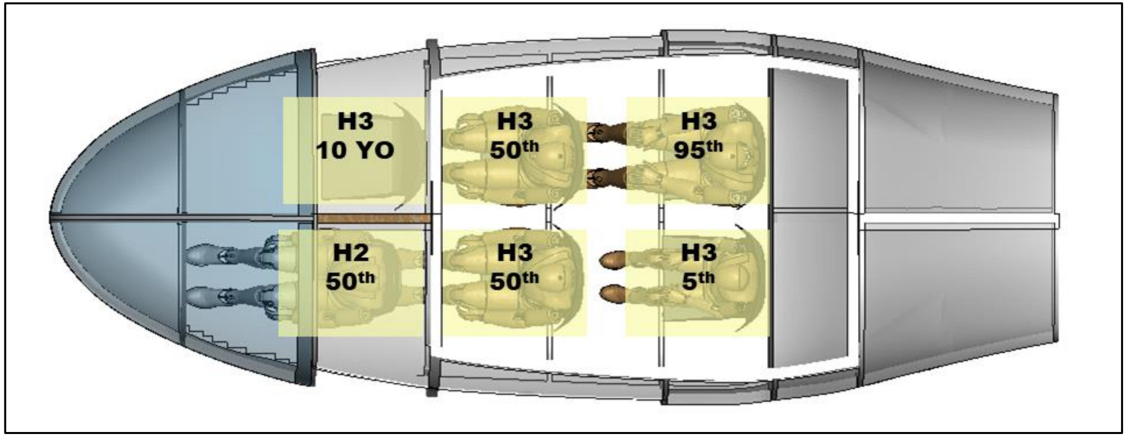


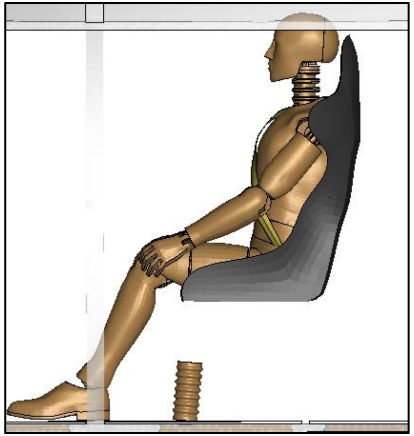
- L+C model was calibrated to improve test correlation
- Tuned parameters which defined damage and failure within the C/C structure material model
  - Element erosion strain limit (ERODS): 0.5 to 0.15
  - Material strength degradation after stress limit (SLIMS): 0.8 to 0.5
- ATD models were included in the vehicle simulation
  - De-coupling of occupant mass from seat found to have effect on accelerations predicted within occupant compartment
  - EA components in seat and subfloor sensitive to timing of seat/occupant mass interaction

ATD Model Integration

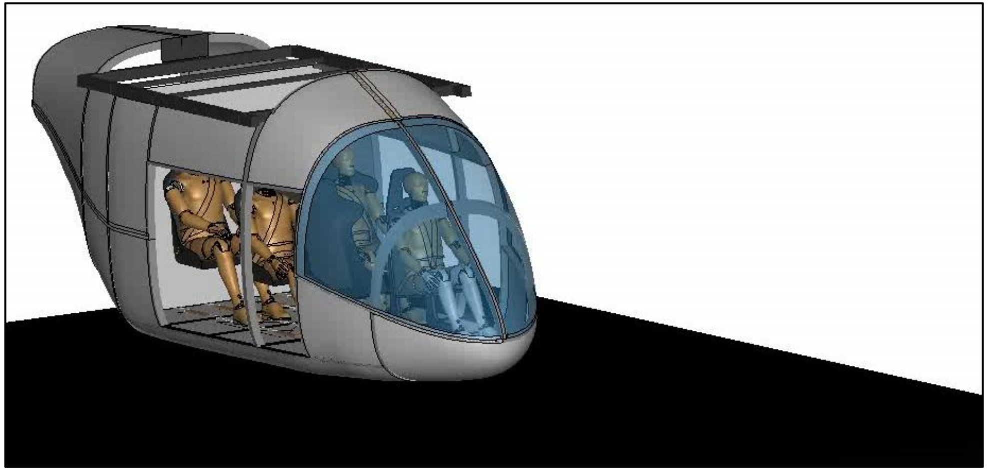
- LSTC H3 5th, 50th, 95th FEMs integrated into vehicle seat configurations
  - H3 10 YO ATD left as rigid mass due to lack of available FEM
- Pre-loading phase added to simulation fit under gravity and tension belts (0.10 s)

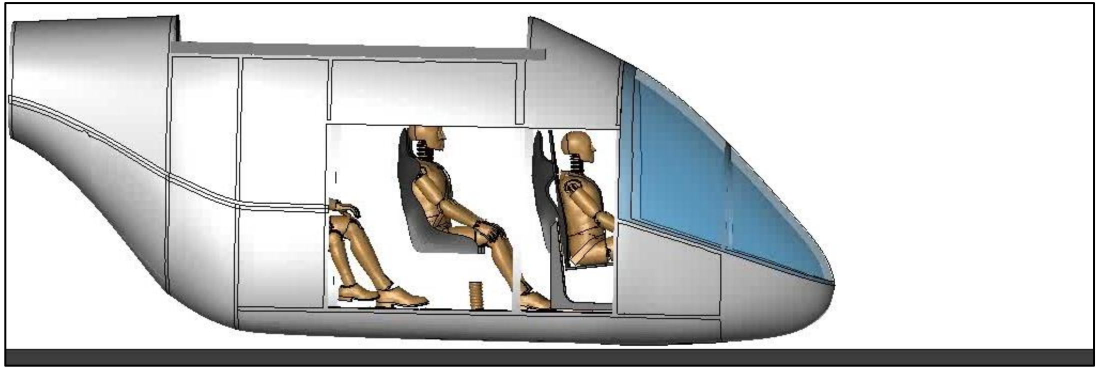


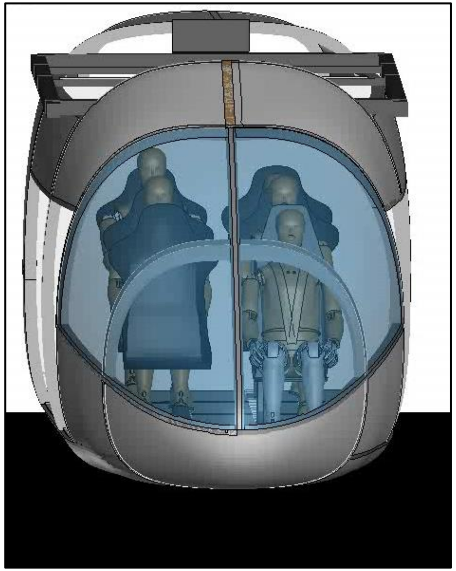




Post-Test Model Simulation

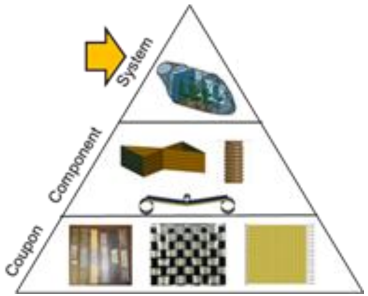


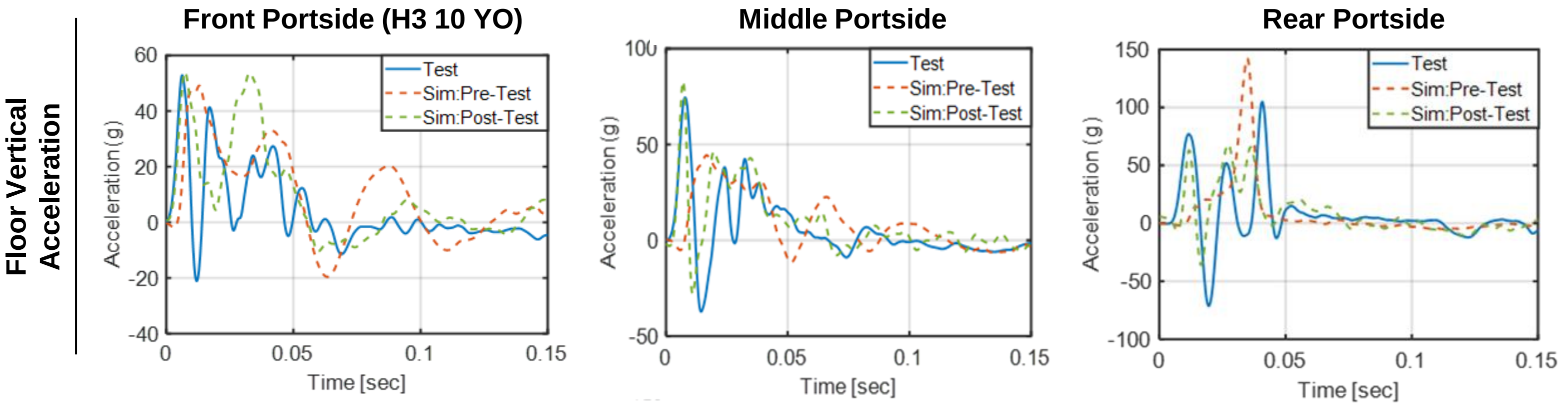




Post-Test Model Simulation – Acceleration Predictions

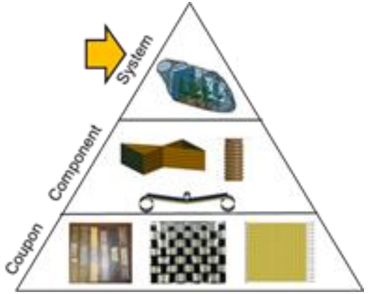
- Prediction of occupant compartment acceleration time history improved with inclusion of ATD models
  - Initial peak acceleration and oscillations in acceleration shape better captured
- Prediction improvement marginal at seat location which retained rigid mass representation of H3 10 YO ATD

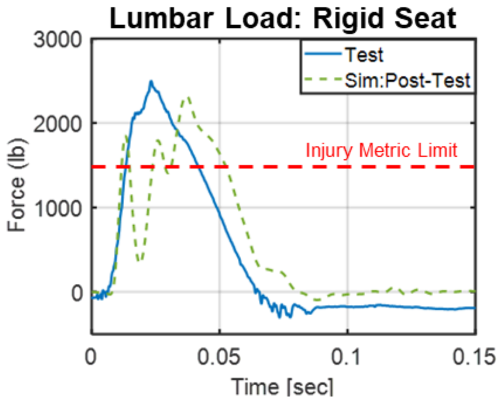


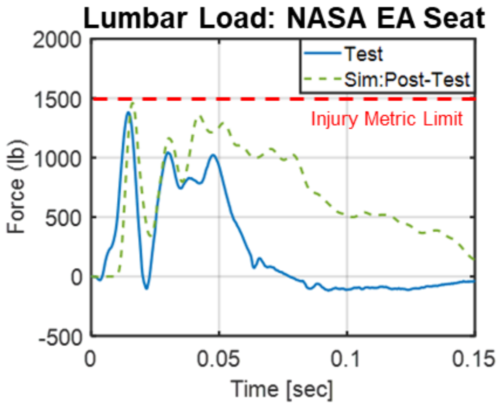


Post-Test Simulation – ATD Injury Metric Prediction

- 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



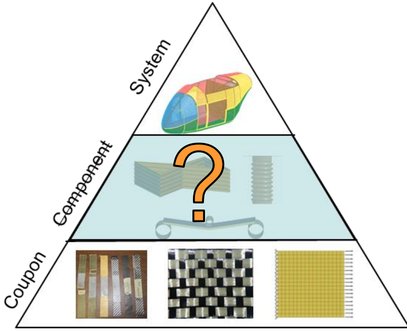




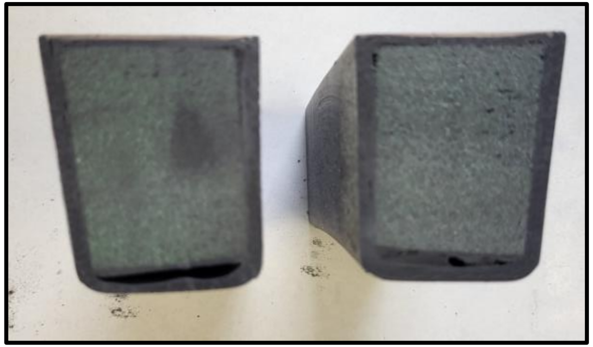
Conclusions

- Damage and failure properties of C/C material models require calibration under representative loading conditions to accurately predict vehicle structural response to dynamic impact loading
  - Coupon testing of C/C material not sufficient to develop material model which predicted failure observed in test
- Component level model calibration of internal structures led to accurate prediction of acceleration measured in the vehicle cabin
- Rigid mass representation of occupants not always valid in vehicle level analysis
  - Deformable structures are sensitive to coupling between occupant mass and vehicle

Next Steps – Component Testing of Fuselage Specimens



- Tuning material model parameters improved prediction of vehicle structural response but did it do so for the right reason?
- Currently conducting component tests of structural specimens gathered from the L+C test article (post test)
- *Goal:* quantify L+C structural material characteristics under dynamic load
  - Assess possible effects of fabrication defects



Next Steps – Full Scale Verification Test

- Second L+C test article fabricated
  - In the process of defining upcoming test conditions
- Verification of tuned L+C model
  - Extensibility of model outside tuned conditions
- Verification of final EA Mechanism design
  - Optimized using tuned L+C model
- Additional assessment of composite structural response variability between builds

Questions?

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