Crashworthiness by Analysis: Vertical Drop Test and Simulation of a Composite H4000 Fuselage Section

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The Ninth Triennial International Fire & Cabin Safety Research Conference| October 28-31st 2019

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NATIONAL INSTITUTE FOR AVIATION RESEARCH

Crashworthiness – Certification by Analysis

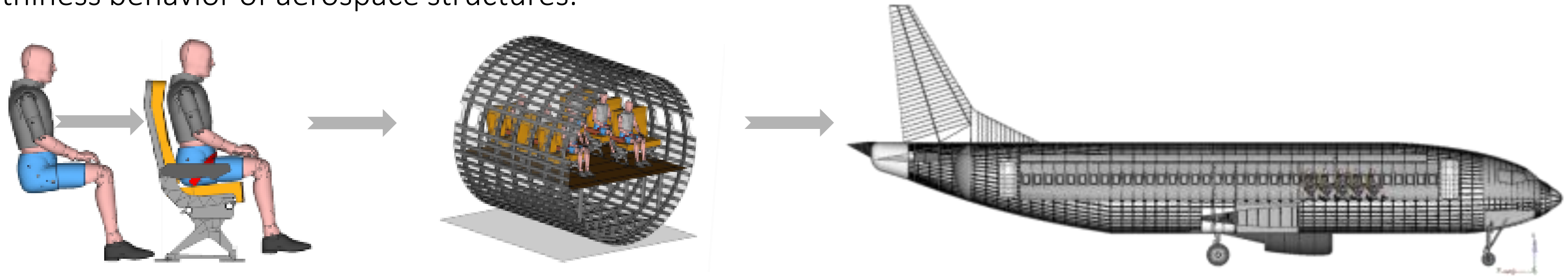
Acknowledgements

- FAA
  - Joseph Pelletiere Ph.D.
  - Allan Abramowitz
  - Funding the Drop Test Program
- KART – Spirit, Textron Aviation, Bombardier/Learjet, Airbus
  - Funding the Drop Test FE Analysis work
- Textron Aviation – Beechcraft, Cessna, Hawker
  - Providing Fuselage Section for testing
  - Providing CAD data and material information for H4000 Fuselage section
- Principal Investigators & Researchers
  - PI: G. Olivares Ph.D.
  - Researchers NIAR-WSU: Luis Gomez, Rob Huculak, Chandresh Zinzuwadia, Aswini Kona Ravi, Hoa Ly, Akhil Bhasin
  - NIAR Crash Dynamics Lab Staff
  - NIAR Virtual Engineering Lab Staff

Crashworthiness – Certification by Analysis

Introduction

- Motivation and Key Issues
  - The introduction of composite airframes warrants an assessment to evaluate that their crashworthiness dynamic structural response provides an equivalent or improved level of safety compared to conventional metallic structures. This assessment includes the evaluation of the survivable volume, retention of items of mass, deceleration loads experienced by the occupants, and occupant emergency egress paths.
  - Support FAA and ARAC Transport Airplane Crashworthiness and Ditching Working Group
- Objective
  - In order to design, evaluate and optimize the crashworthiness behavior of composite structures it is necessary to develop an evaluation methodology (experimental and numerical) and predictable computational tools.
- Approach
  - The advances in computational tools combined with the building block approach allows for a cost-effective approach to study in depth the crashworthiness behavior of aerospace structures.

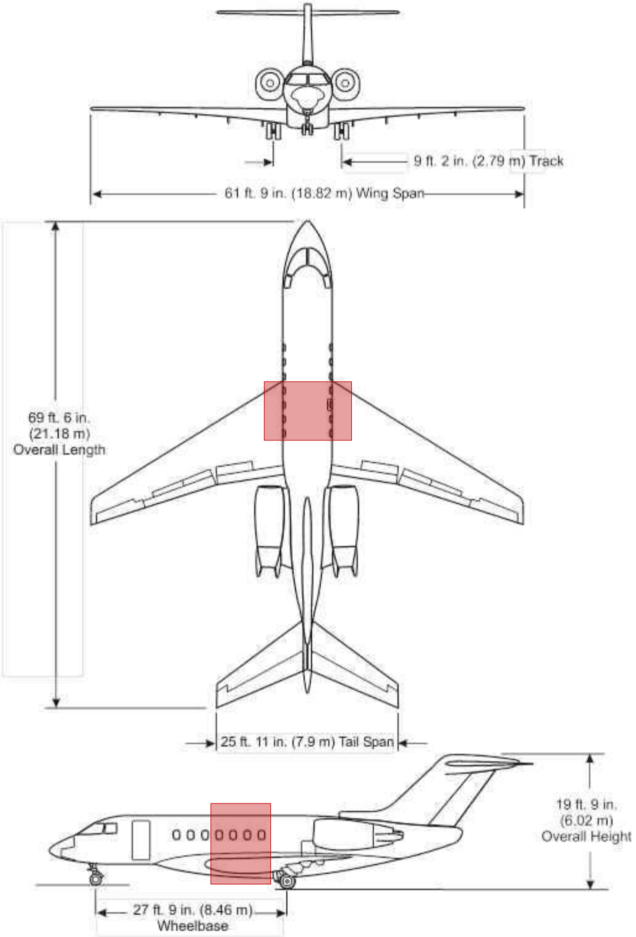


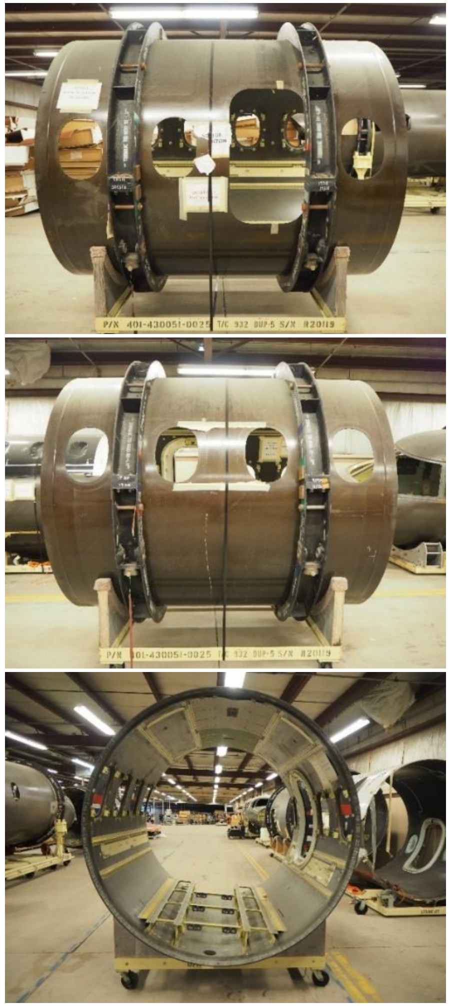
H4000 Drop Test

Test Setup and Results

H4000 Drop Test

Part 25 Aircraft



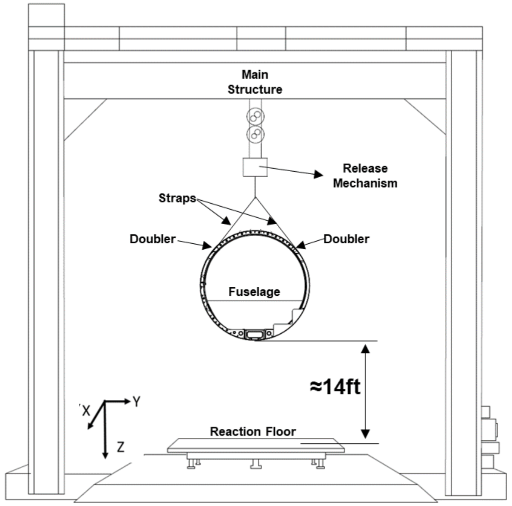


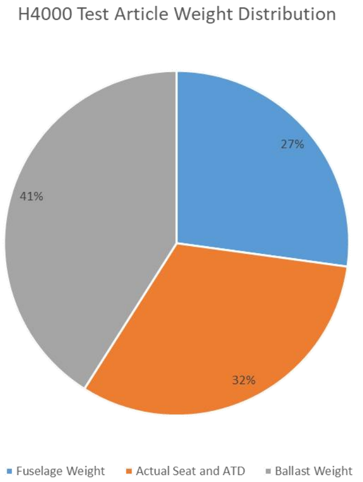
General Characteristics	
Seating	2+8/12
External Length	69 ft 6 in
External tail Height	19 ft 9 in
Wing Span	61ft 9 in
Empty Weight	23500 lb (10659 kg)
Gross Weight	26000 lb (11793 kg)
Performance	
Power	2 × Pratt & Whitney Canada PW308A turbofan 6,900 lbf/ ISA + 22 °C () each
Cruise Speed	Mach 0.84
Range	6075 km
Service Ceiling	45000 ft
Interior	
Cabin Height	6ft
Cabin Length	25 ft
Cabin Width	6 ft 6 in
Cabin Volume	762 ft^3

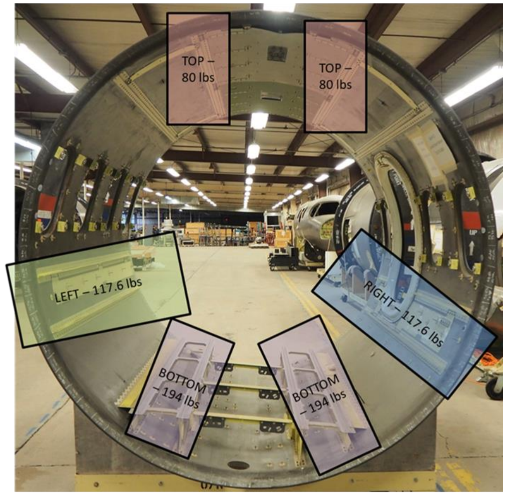
H4000 Drop Test

Test Setup

- Test Facility
  - NIAR Crash Dynamics Laboratory
  - 30 ft/s Drop Impact Velocity
- Test Article – H4000 Fuselage Section
  - Dimensions:
    - Length: ≈8 ft 2in
    - Diameter: ≈7 ft
  - One Exit Door Opening (Right Side)
  - Seven Window Openings:
    - 3 Right Side
    - 4 Left Side
  - Floor Structure with Seat tracks - Seat Track Width: 8' ¾"
  - No wing box structure
  - No upper panels/PSUs
  - Total Weight: 1499.77 lbs.
  - 4 Occupants:
    - 2 Seats: HII and FAA HII
    - 2 Seats: Ballast Weights representative of seats and occupants



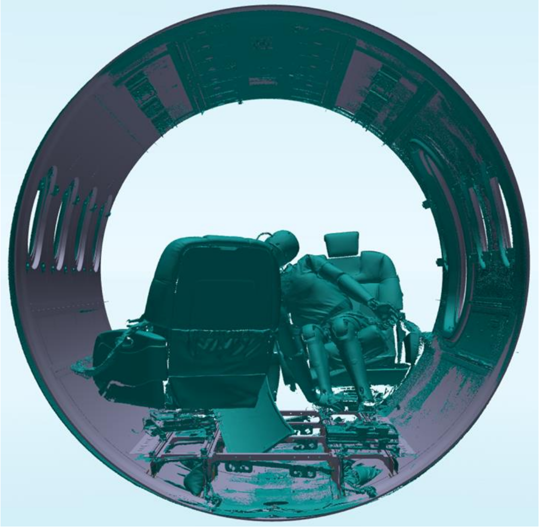


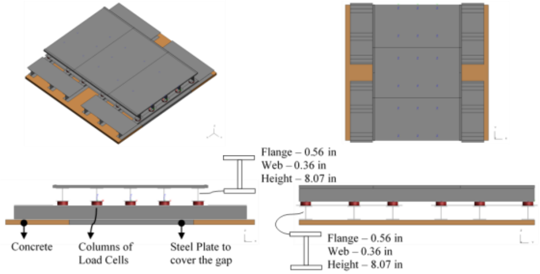


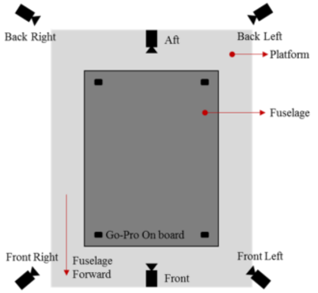
H4000 Drop Test

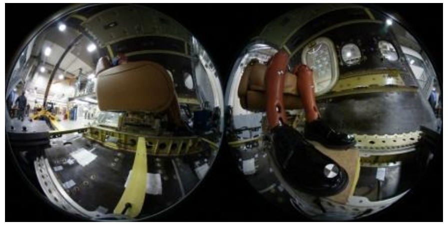
Instrumentation and DAQ

- Data Acquisition
  - DTS Slice Pro Data Acquisition System - 108 channels
    - ATDs (32 channels)
    - Accelerometers (36 channels)
    - Reaction Platform Load Cell (36 channels)
    - Strain Gages (4 channels)
  - 360 HD camera system - 4 GO-PROs
  - Six S-VIT AOS Tech. AG High Resolution Color (900 x 700 pixel) – 1000 fps
- Instrumentation
  - Accelerometers - Endevco 7264C accelerometers with measuring capability of 2000 g’s vertical and 500 g’s on the lateral axis will be used. The accelerometer data will be filtered using the SAE J211 CFC60 filter.
    - 4 triaxial accelerometers for the seat track corners.
    - 8 biaxial accelerometers on the seat tracks
    - 4 biaxial accelerometers will be used at the top center of the barrel section.
  - DIC – Digital Image Correlation - Capable to record 20,000 fps at a full resolution of 1024 x 1024 pixels.
    - A pair of monochrome Photron SA-Z 16 Gig RAM high speed cameras and
    - A pair of color Photron SA-Z 16 Gig RAM high speed cameras.
  - Four Strain Gages EP-08-250BF-350
  - HII and FAA HIII ATDs



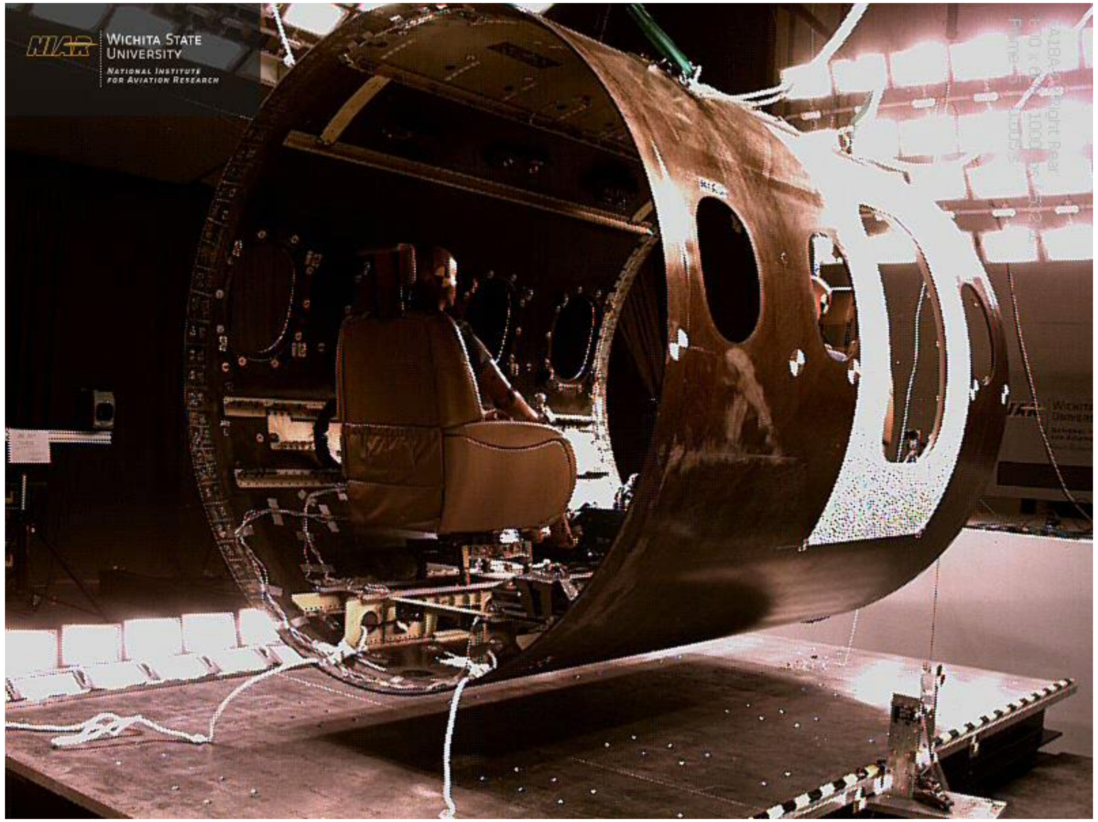


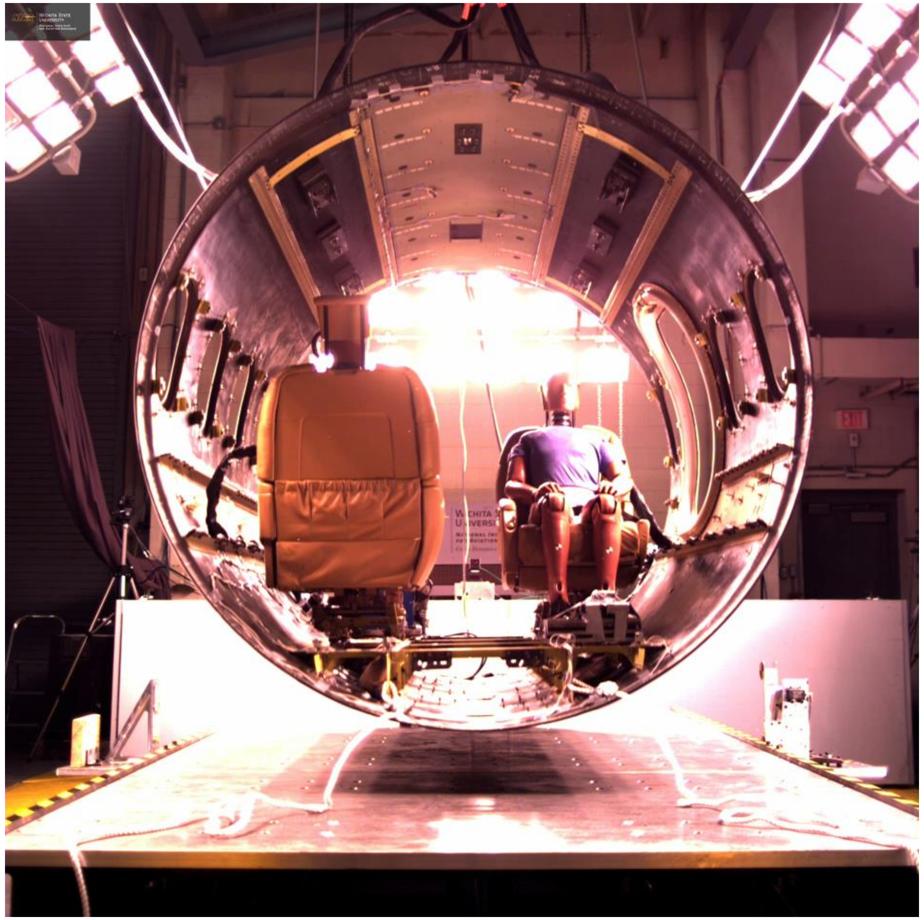




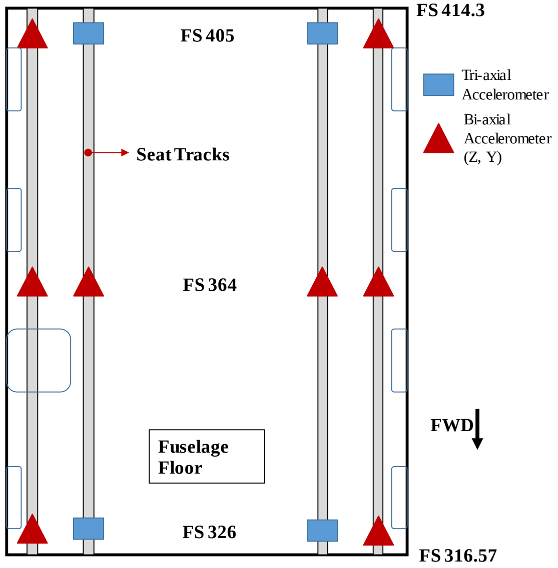
H4000 Drop Test

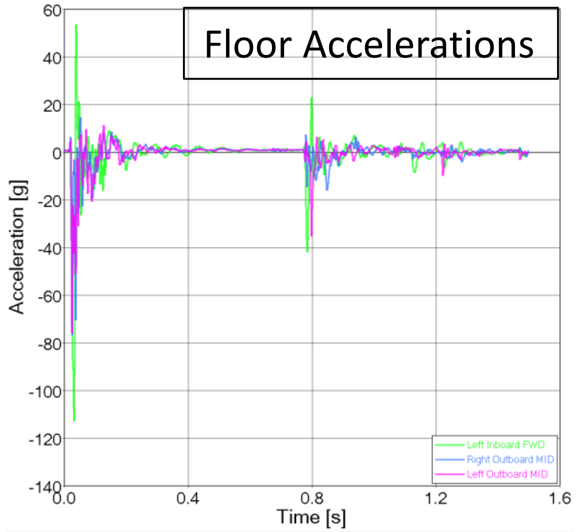
Test Results - Videos

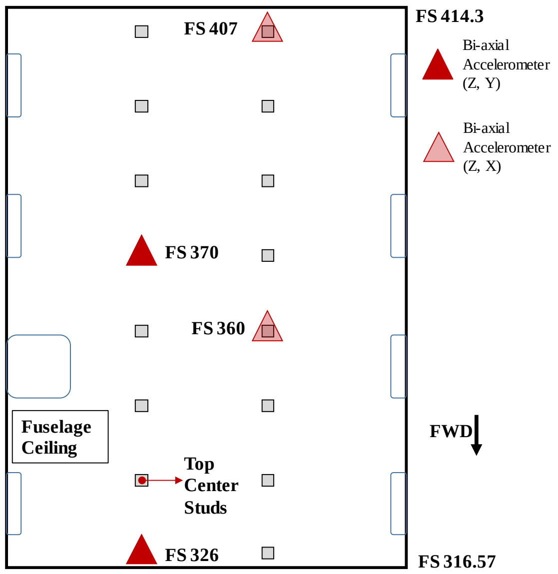


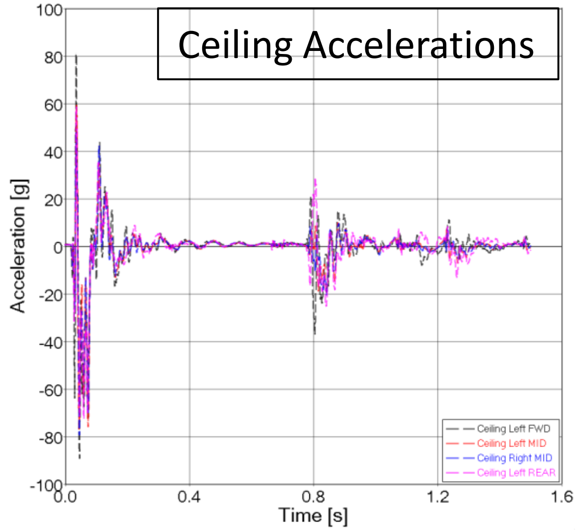


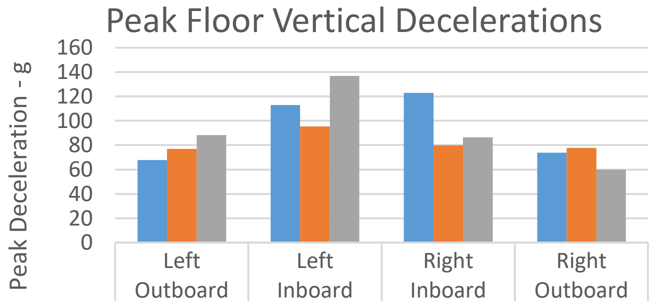
H4000 Drop Test



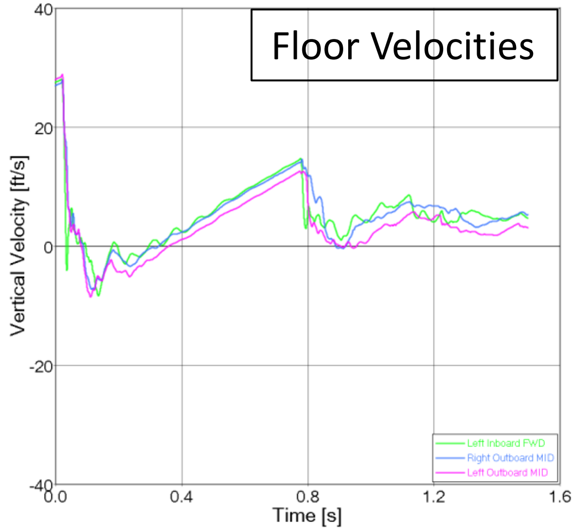


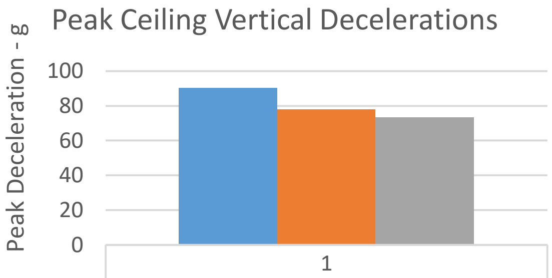




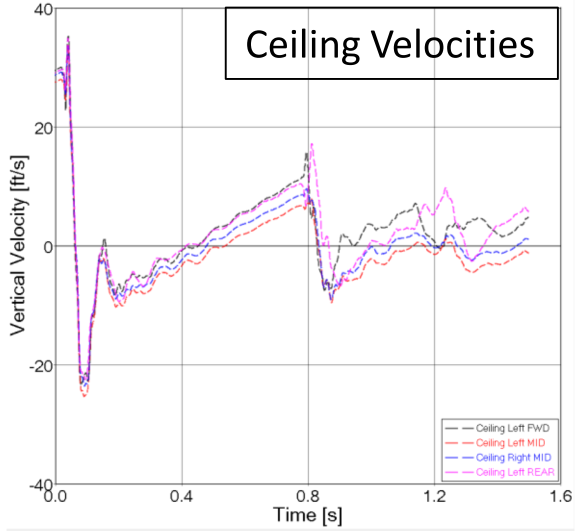


	Left Outboard	Left Inboard	Right Inboard	Right Outboard
FWD	67.68	113	123	73.72
MID	76.92	95.22	79.9	77.64
REAR	88.28	136.72	86.46	60



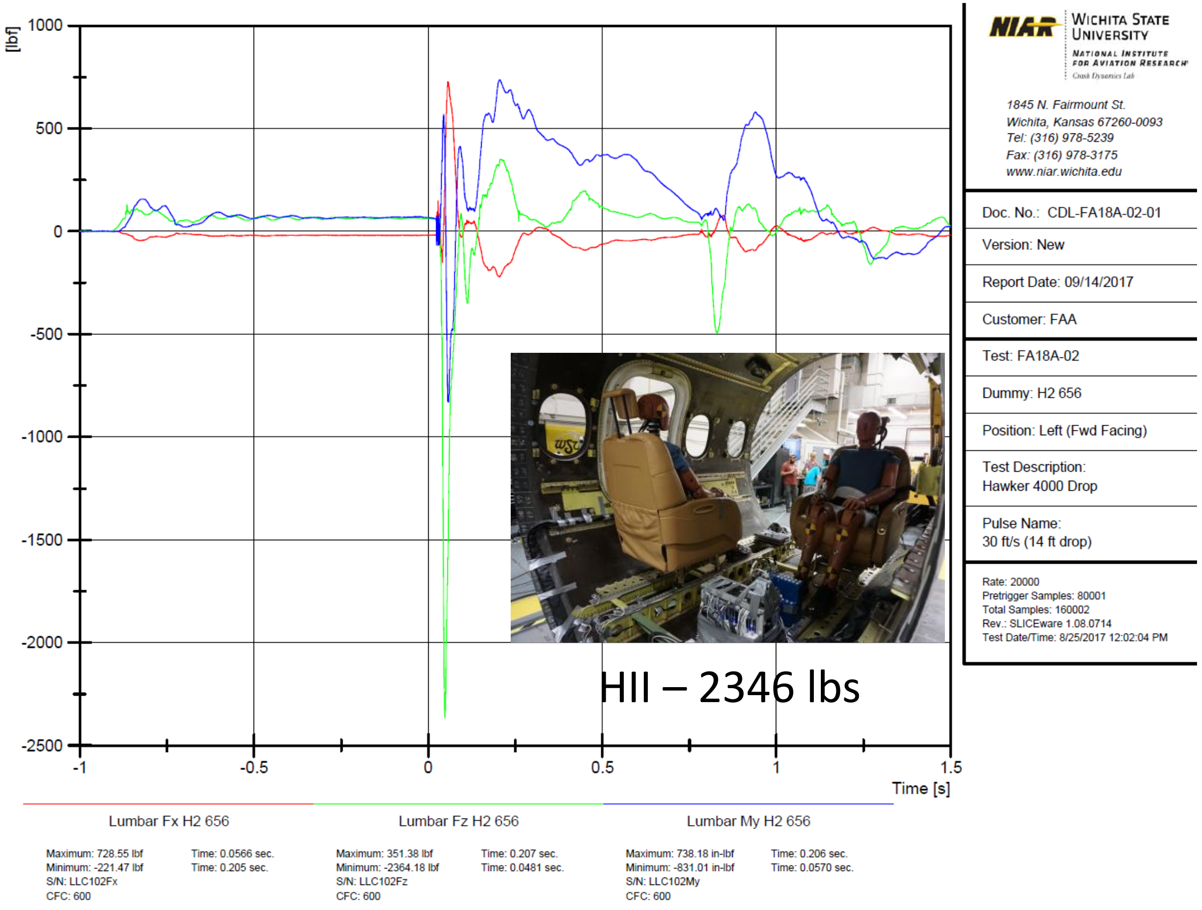


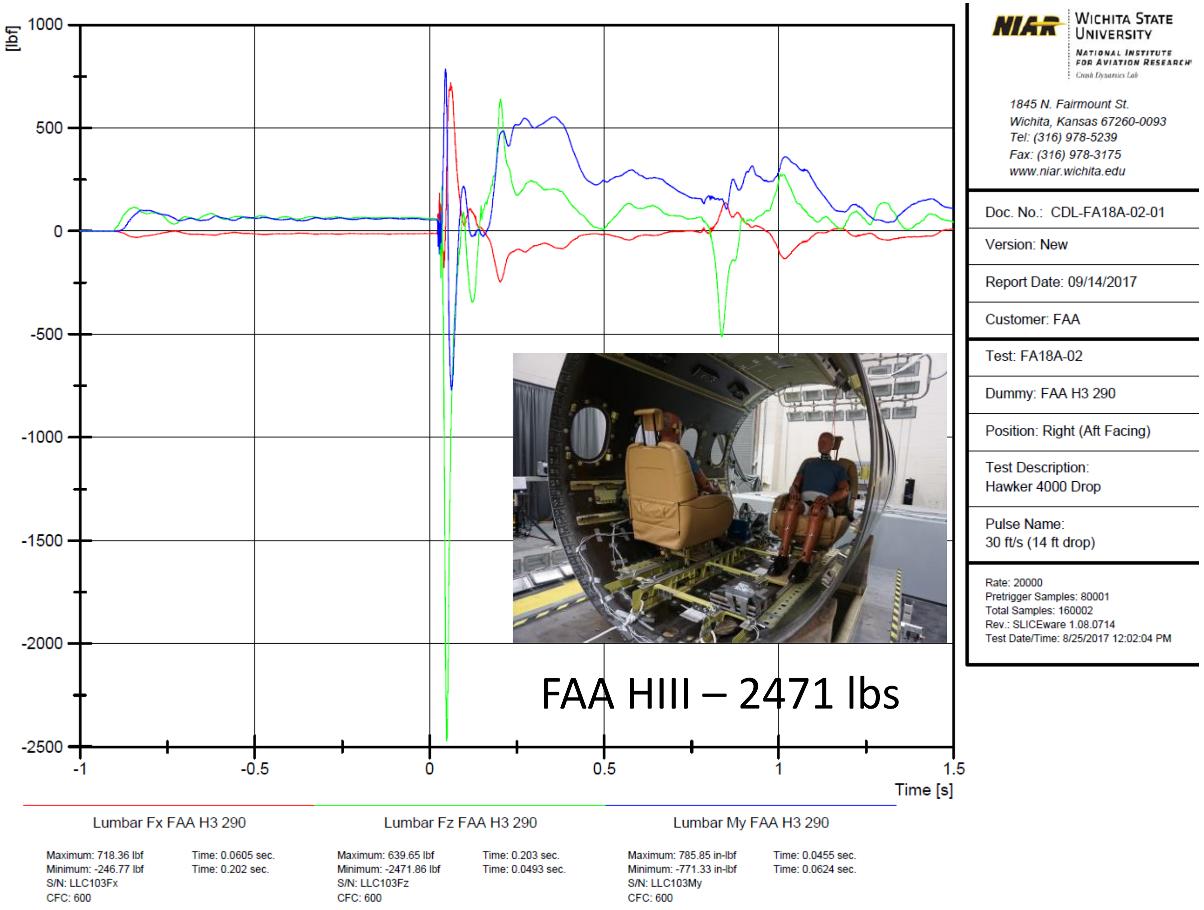
	1
FWD	90.19
MID	77.88
REAR	73.41



H4000 Drop Test

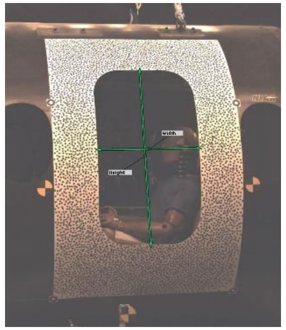
ATD Lumbar Loads

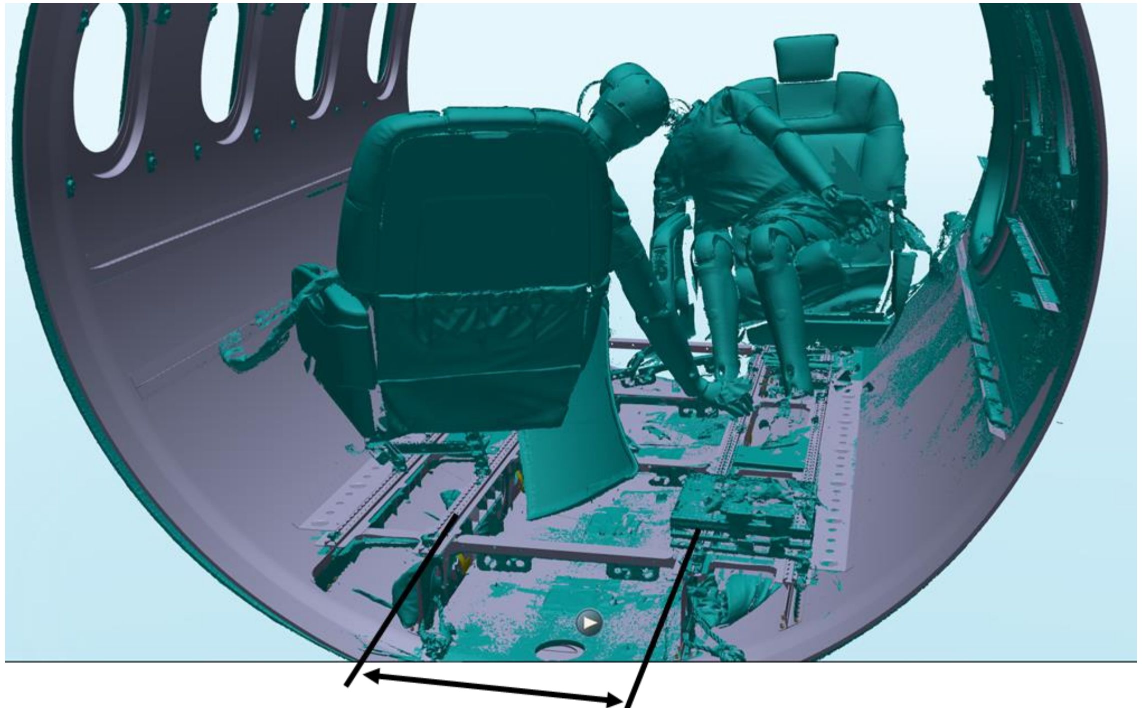




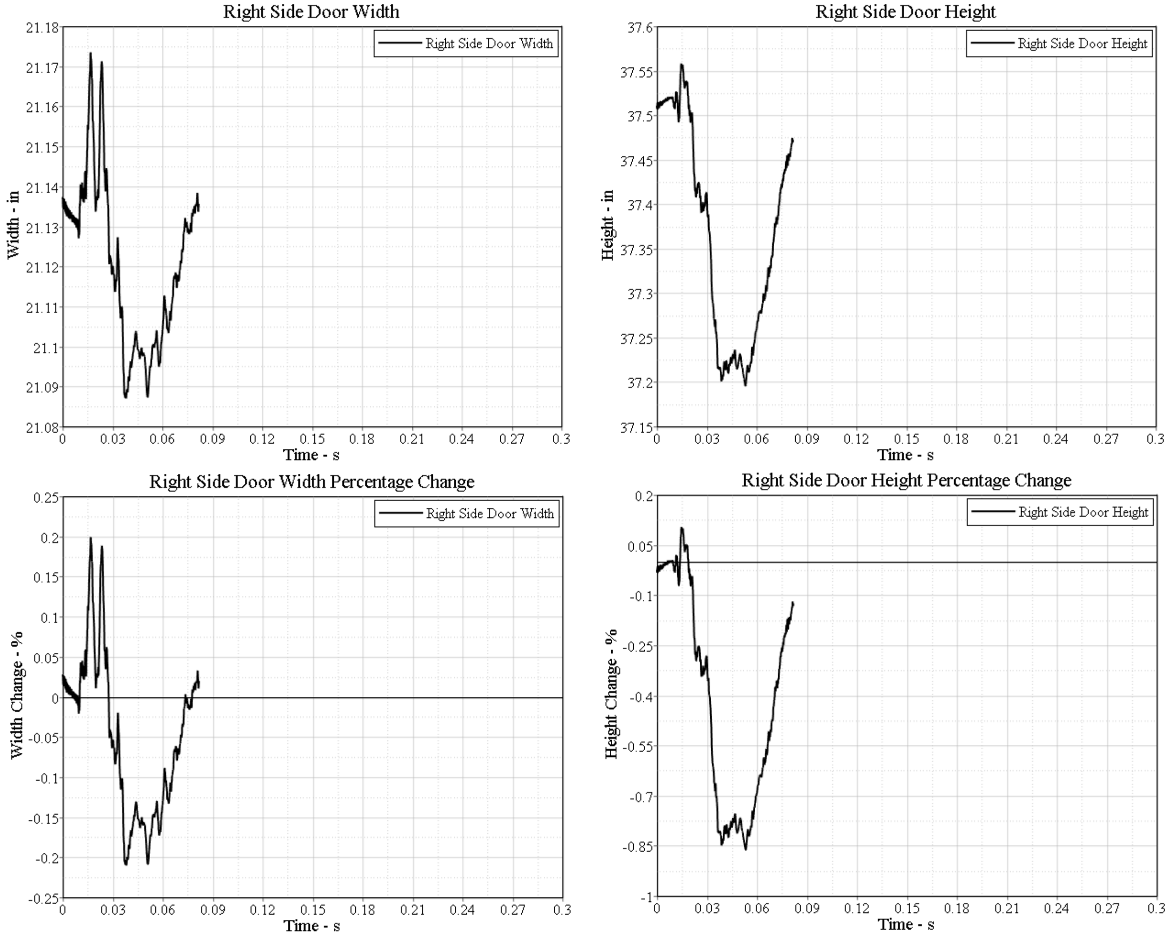
H4000 Drop Test

Egress Evaluation





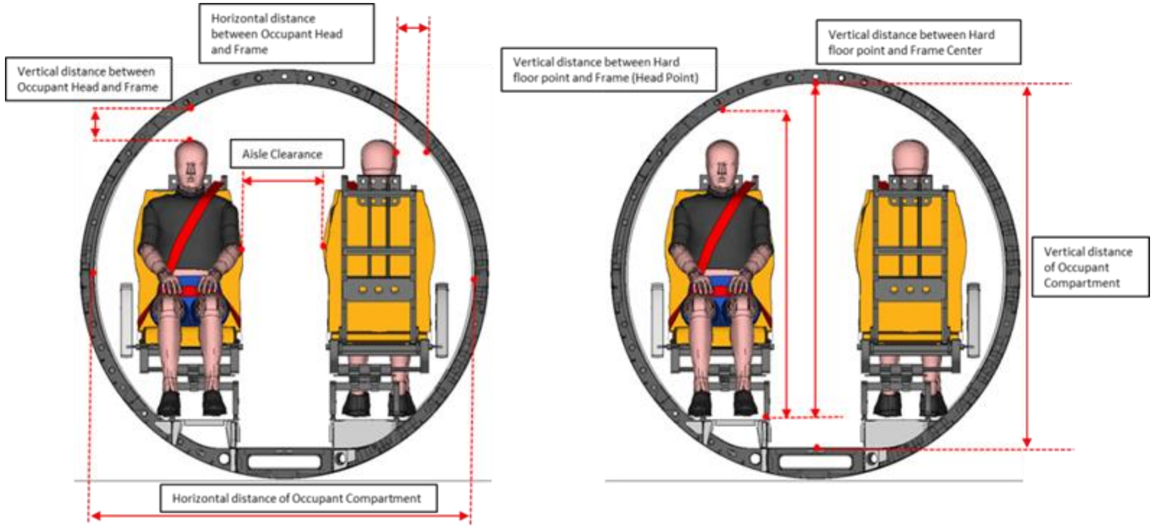
0.25” Difference



H4000 Drop Test

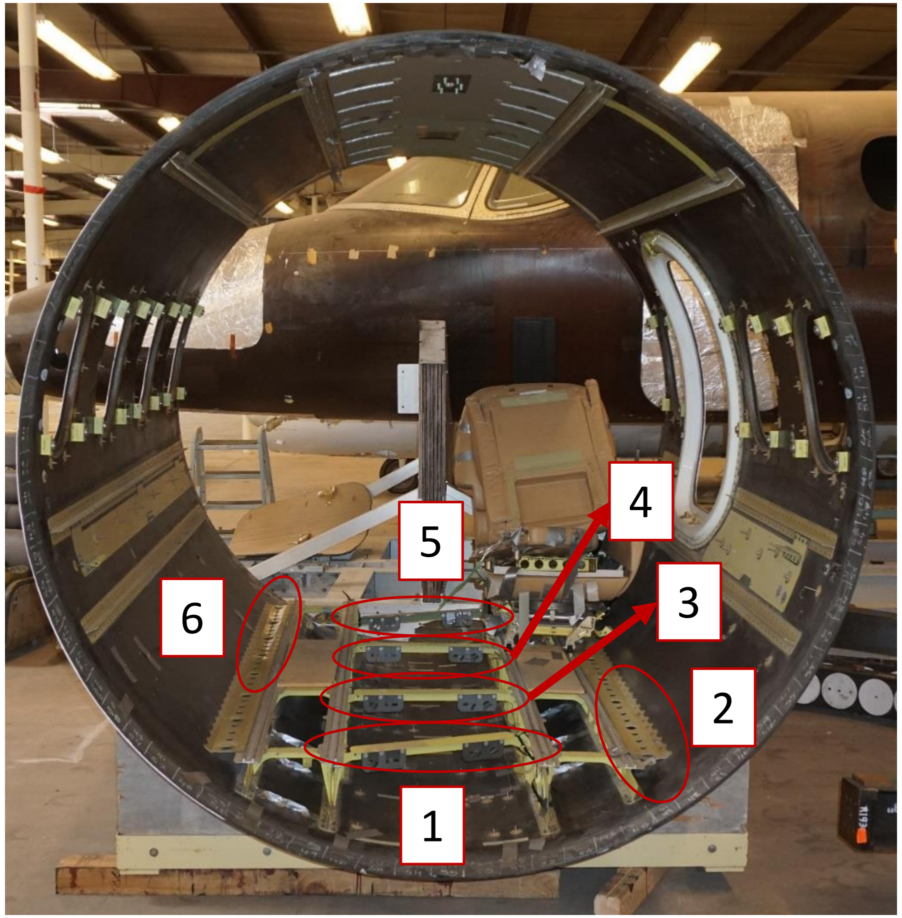
Crashworthiness Evaluation Criteria

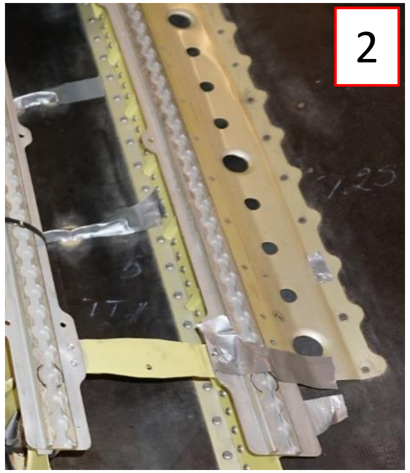
- Maintain Survivable Volume ✓
  - Overall Survivable Space Dimensional Check (Peak during Dynamic Event and Post Test Deformations) ✓
  - Avoid Occupant to Interior Structure Contacts during impact ✓
- Maintain Deceleration Loads to Occupants
  - Injury Criteria Limits per 14 CFR 25.562) : ✗
    - 1500 lbf, HIC 1000, Shoulder Strap Loads….
- Retention Items of Mass
  - No items of mass such as overhead bins ✓
  - Occupants and Seat Structures supported throughout the crash event (14 CFR 25.562) ✓
- Maintain Egress Paths
  - Maintain Aisle Distance (Min 12-15 inches per 14 CFR 25.815 and 25.807(d)(4)) ✓
  - Evaluate Plastic deformations of the supporting structure near the exit door ✓
  - Floor Warping
  - Floor Beam Failures – Reduced Strength to support passenger weight

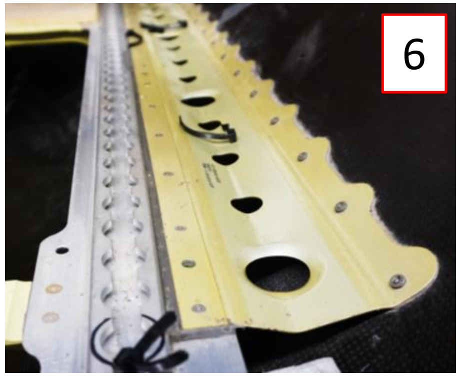


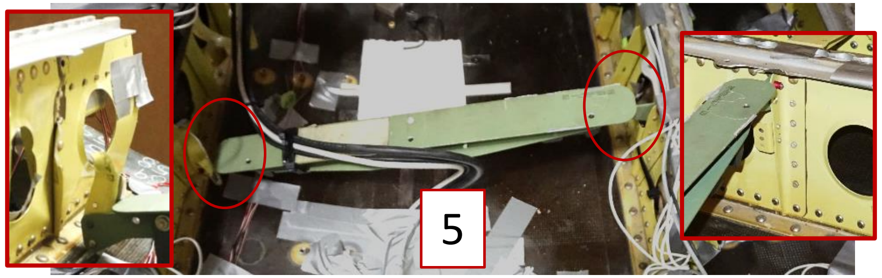
H4000 Drop Test

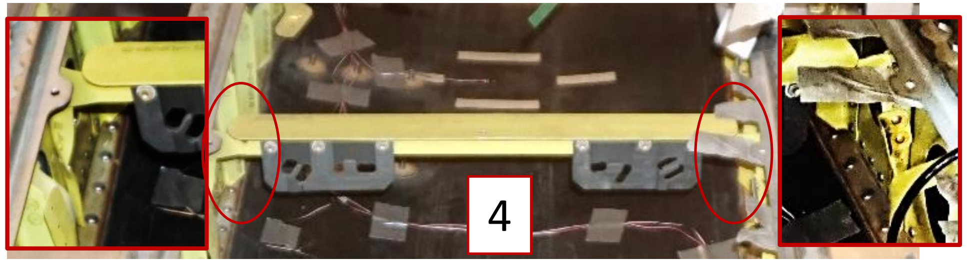
Metallic Damage Evaluation

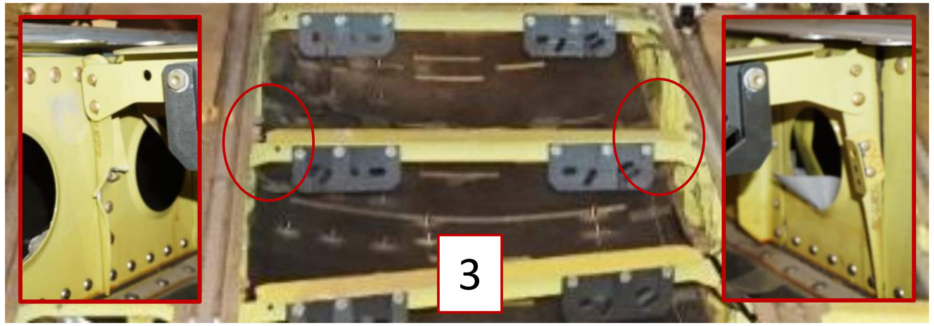


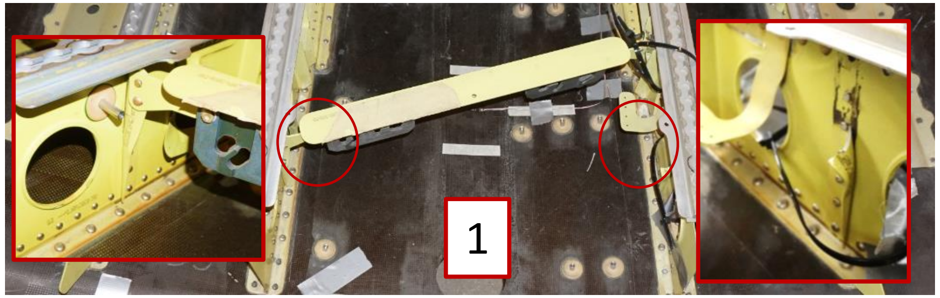






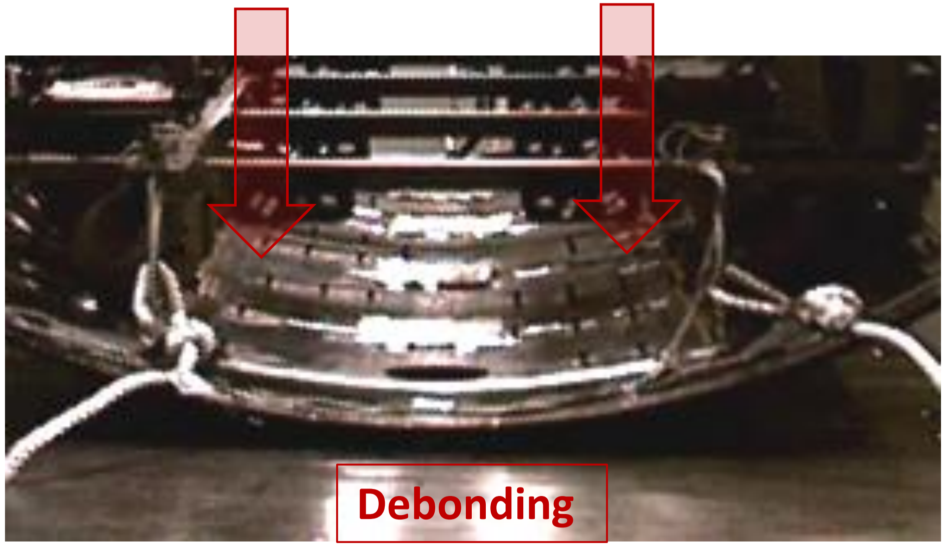


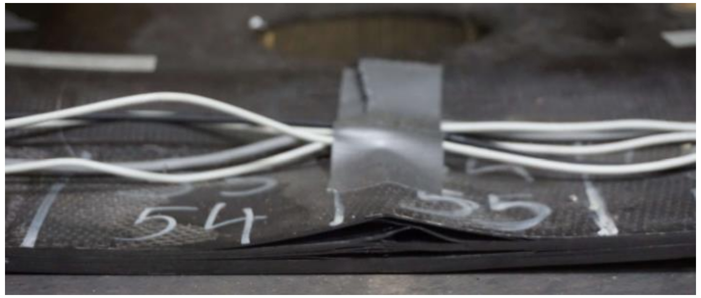


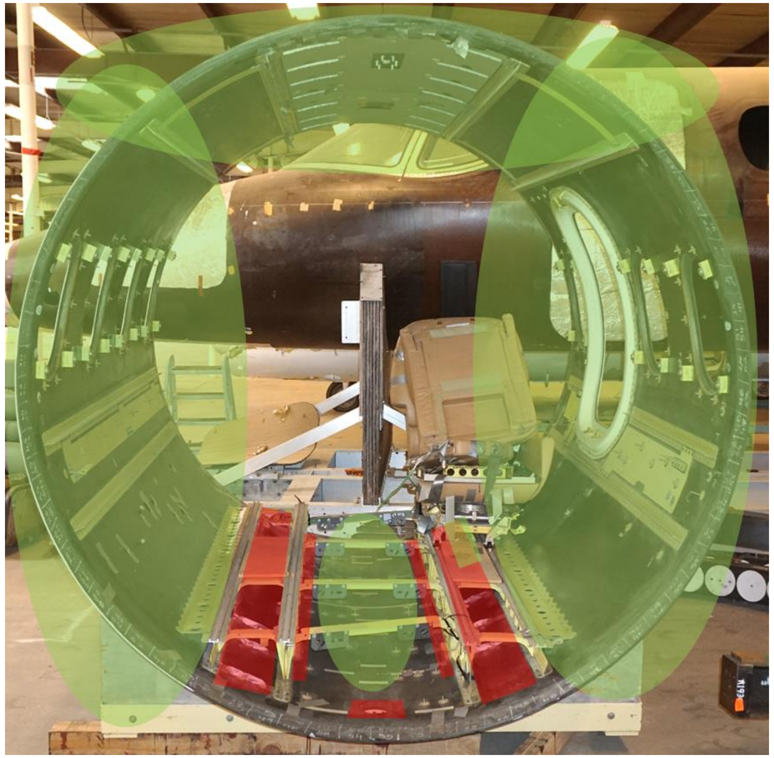


H4000 Drop Test

Composite Damage Evaluation





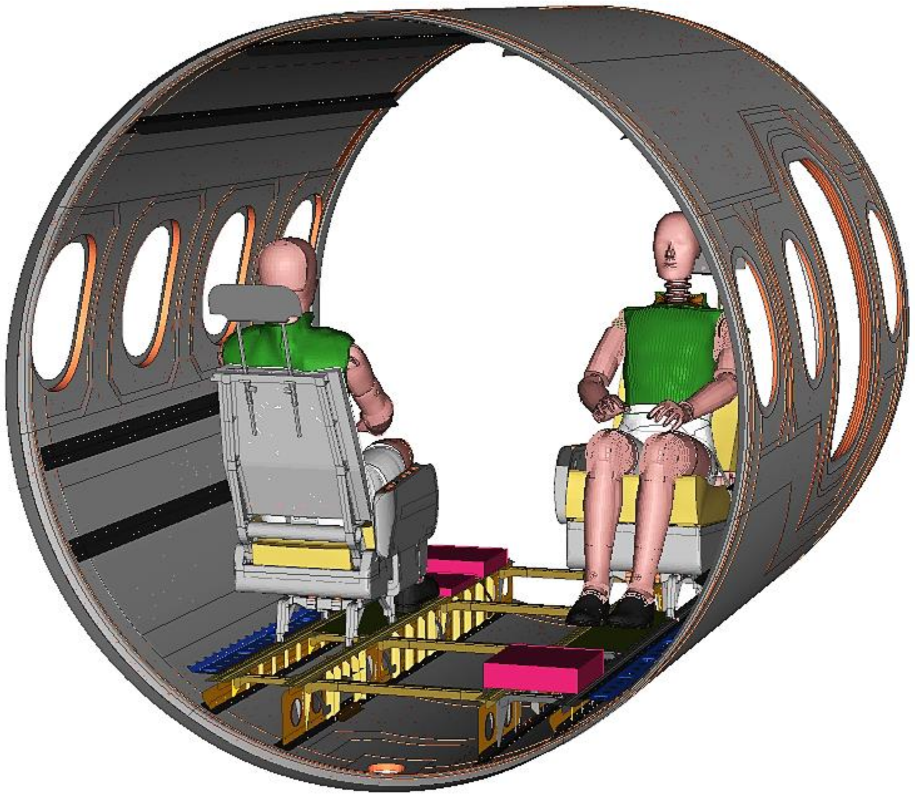


H4000 Drop Simulation

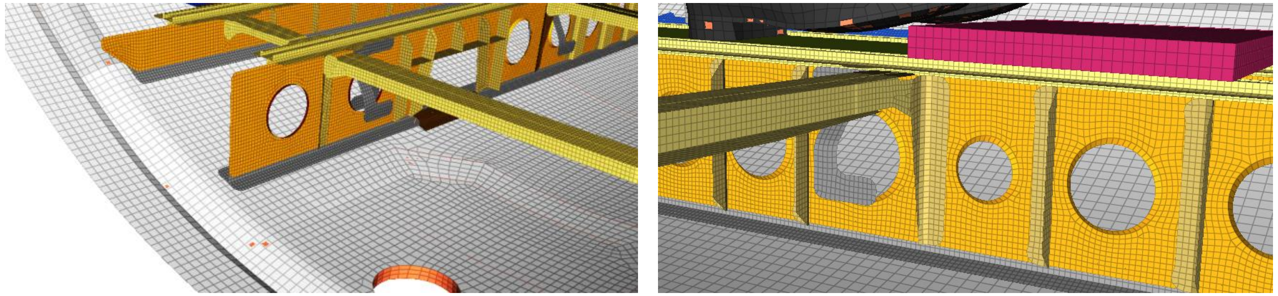
Comparison of Composite Modeling Techniques

H4000 Drop Simulation

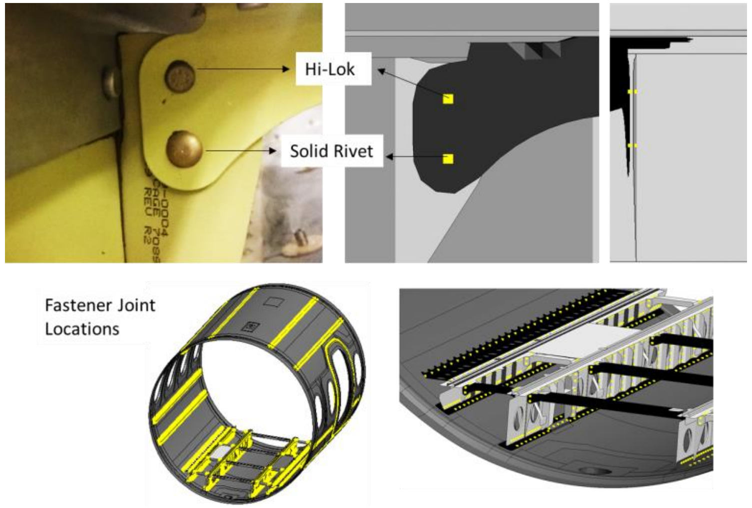
FE Model



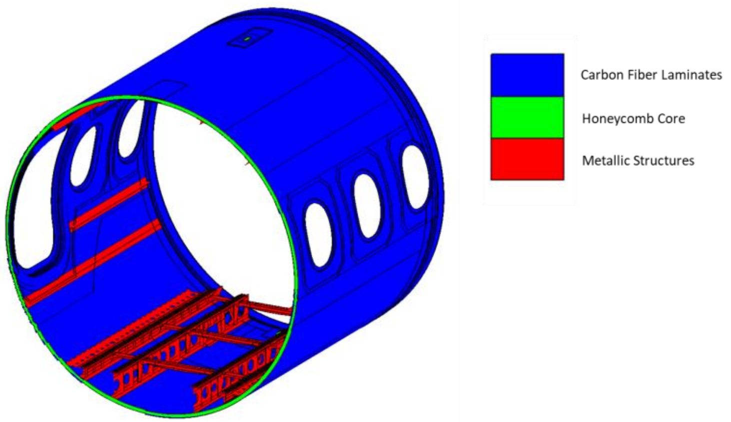
Mesh



Fasteners



Materials

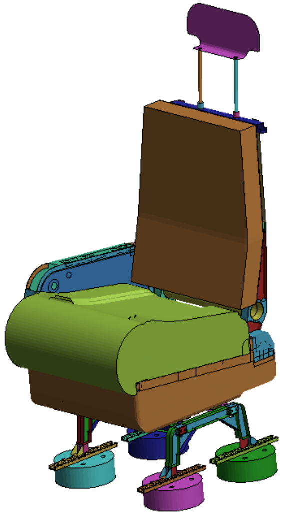


NOTE: Material specifications for metallic parts and composite material data was provided by Textron

H4000 Drop Simulation

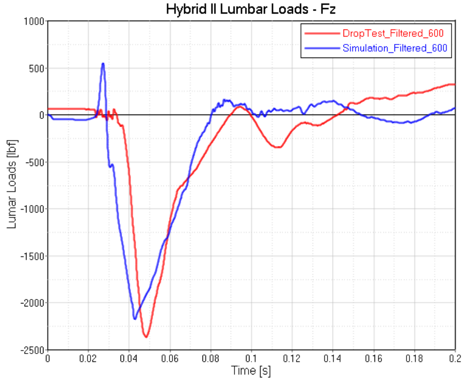
FE Model of Seats

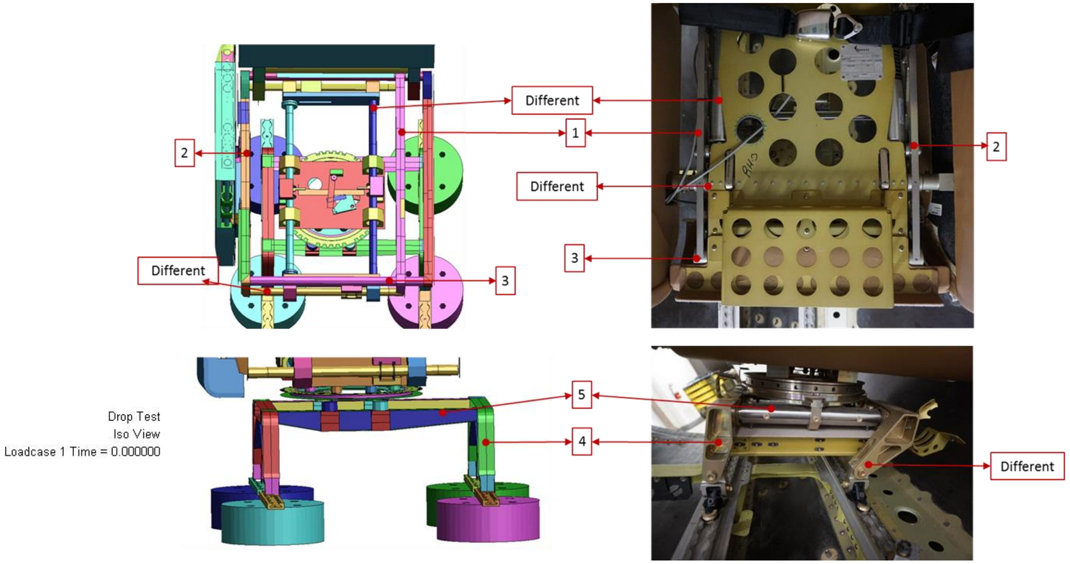
- Available model of Part 23 seat was modified to fit the H4000 fuselage section
- Seat model response was verified using acceleration pulse from test

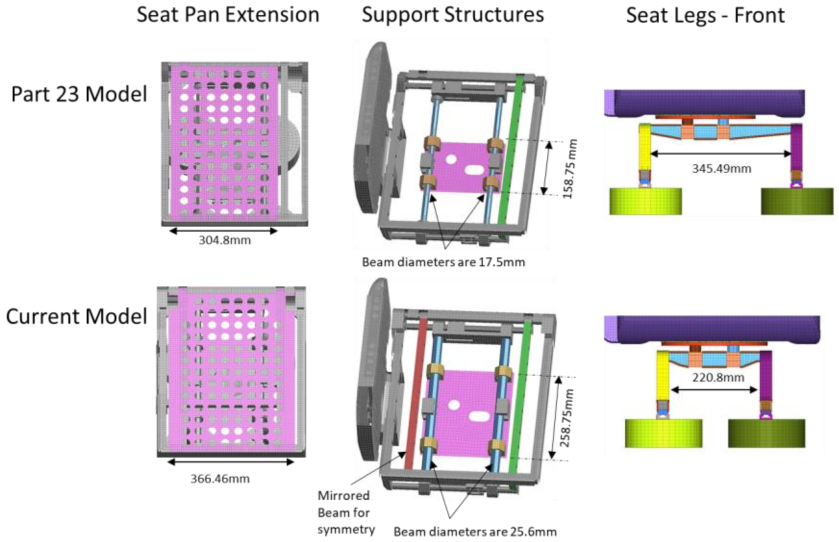


- Part 23
- Passenger Seat

- H4000 (Part 25) Seat
- IPECO Seat

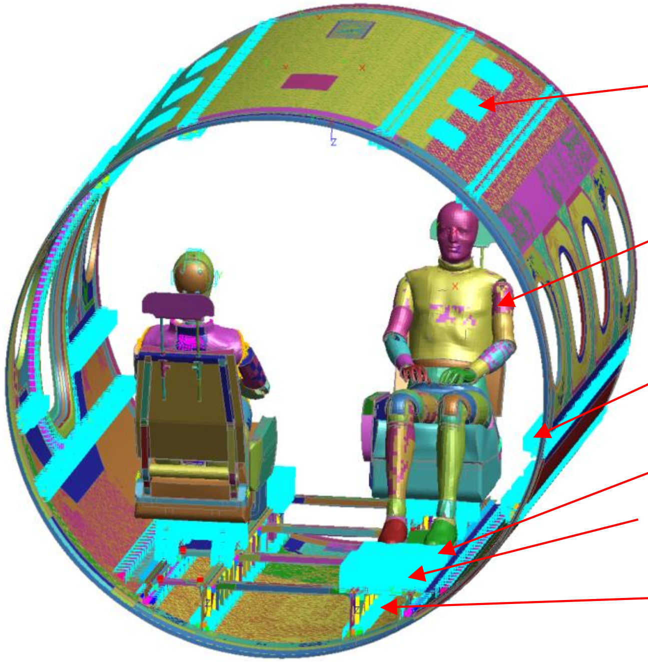






H4000 Drop Simulation

FE Model Weight and Balance

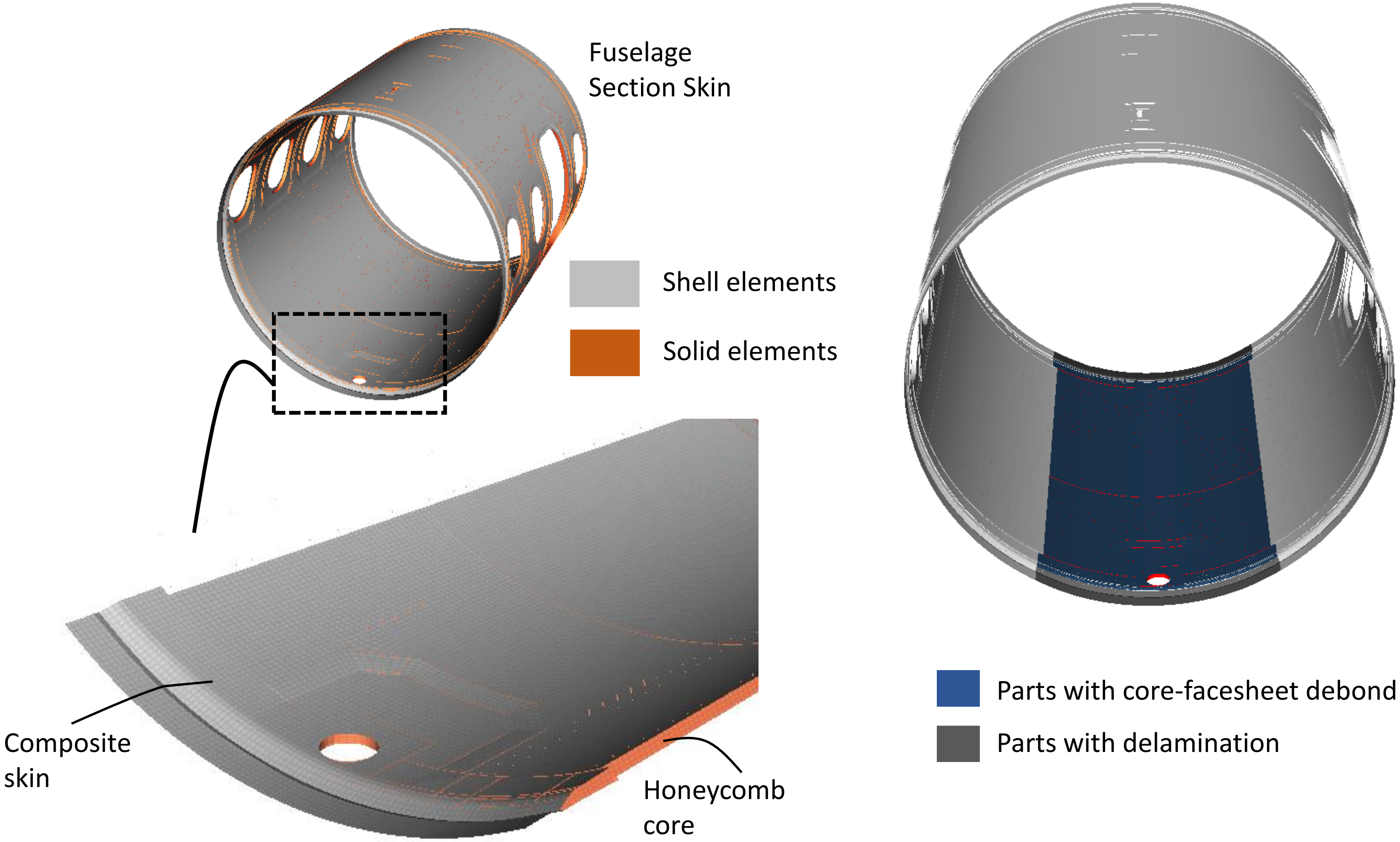


	Test Articles	FE Models
Forward	Mass (lbs)	Mass (lbs)
Fuselage Weight	417.17	417.17
Seat Ballast/DAQ	75.2	75.2
Battery	41.6	41.6
Seat [Aft Facing]	73	73
ATD [FAA H3 50th]	170	179.6
Ceiling Fwd Left [A]	18	18
Ceiling Fwd Right [D]	18	18
Center		
Ceiling Center Left [E]	22.9	22.9
Ceiling Center Right [F]	22.4	22.4
Side Ballast Left [Windows]	20.5	20.5
Side Ballast Right [Windows/Door]	20.5	20.5
Aft		
Seat Ballast	98.8	98.8
Seat [Fwd Facing]	75.5	75.5
ATD [H2 50th]	170	166.1
Ceiling Aft Left [B]	18	18
Ceiling Aft Right [C]	17.9	17.9
Floor		
Floor Left 1 [Fwd]	20.1	20.1
Floor Left 2	9.9	9.9
Floor Left 3	20.1	20.1
Floor Left 4	20.1	20.1
Floor Left 5	20	20
Floor Left 6 [Aft]	19.9	19.9
Floor Right 1 [Fwd]	20.2	20.2
Floor Right 2	9.9	9.9
Floor Right 3	20.1	20.1
Floor Right 4	20.1	20.1
Floor Right 5	20	20
Floor Right 6 [Aft]	19.9	19.9
Total Weight	**1499.77 lbs**	**1505.47 lbs**

H4000 Drop Simulation

Modeling Methodologies Compared

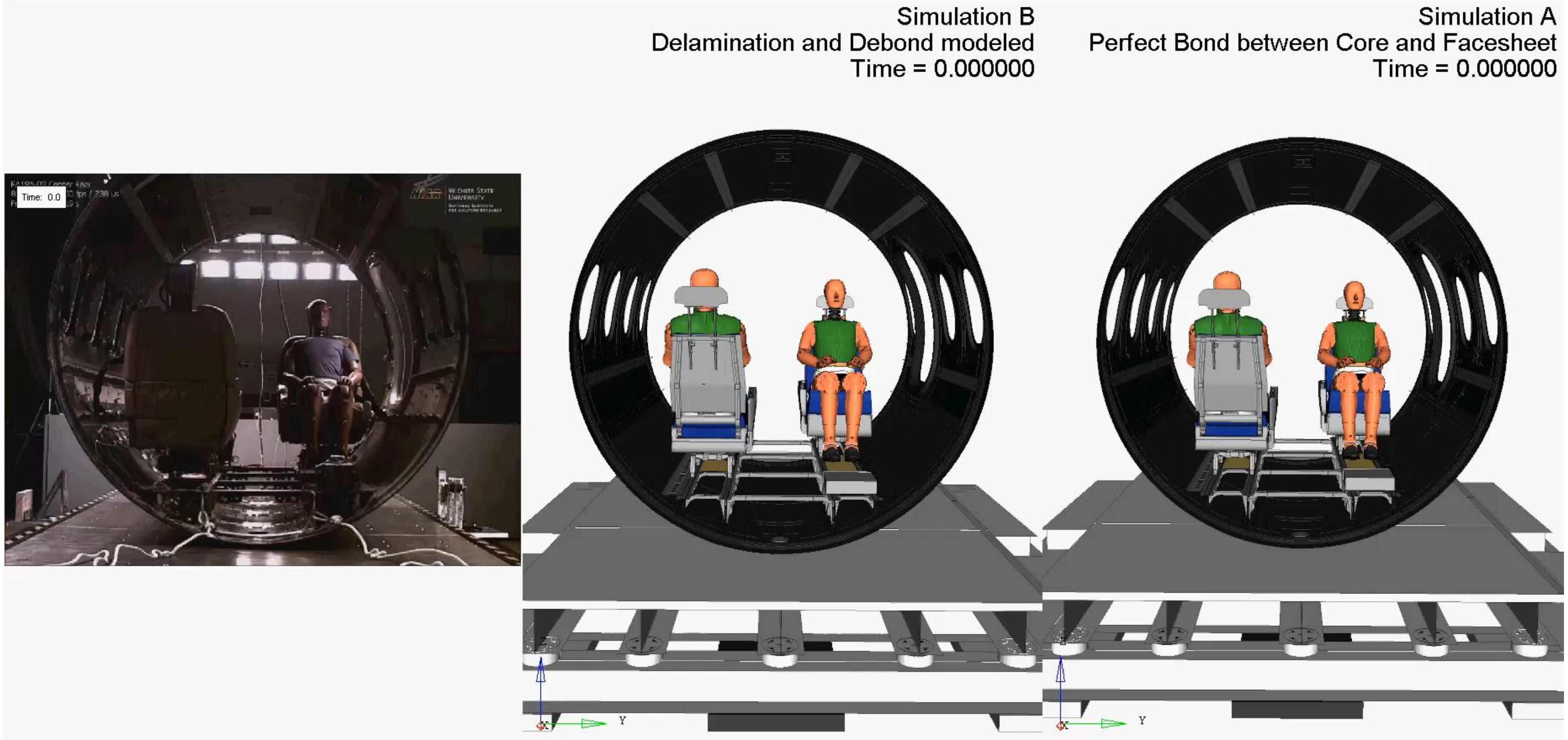
- Two modeling methodologies compared:
  - Nodal connectivity of core and facesheet
    - Refer as SIM A
  - Debond and Delamination modeling using Tie break Contacts
    - Refer as SIM B
    - Tiebreak contacts parameters defined based on [1] and NIAR internal research.



[1] Mode I Fracture Toughness of Composite Sandwich Structures for use in Damage Tolerance and Analysis: Vol. I Static Testing Including Effects of Fluid Ingression, DOT/FAA/TC-16/23, September 2017

H4000 Drop Simulation

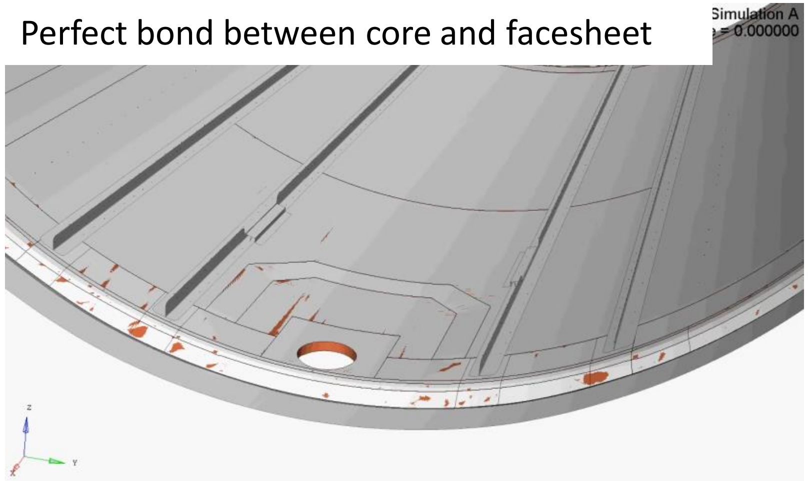
Simulation Results



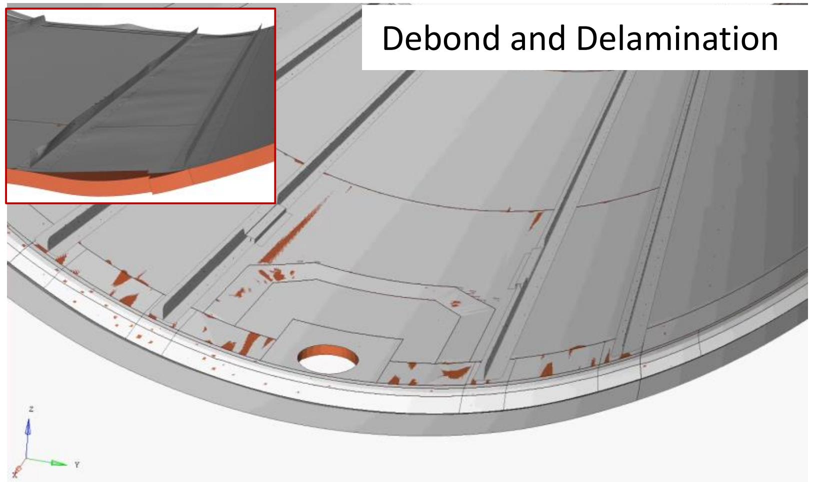
H4000 Drop Simulation

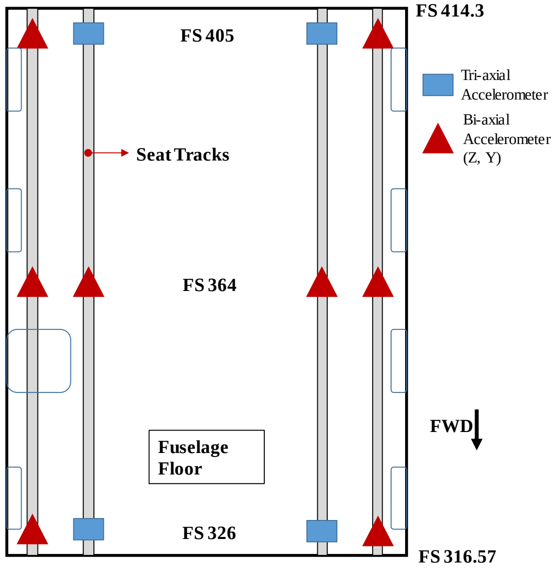
Simulation Results

Perfect bond between core and facesheet

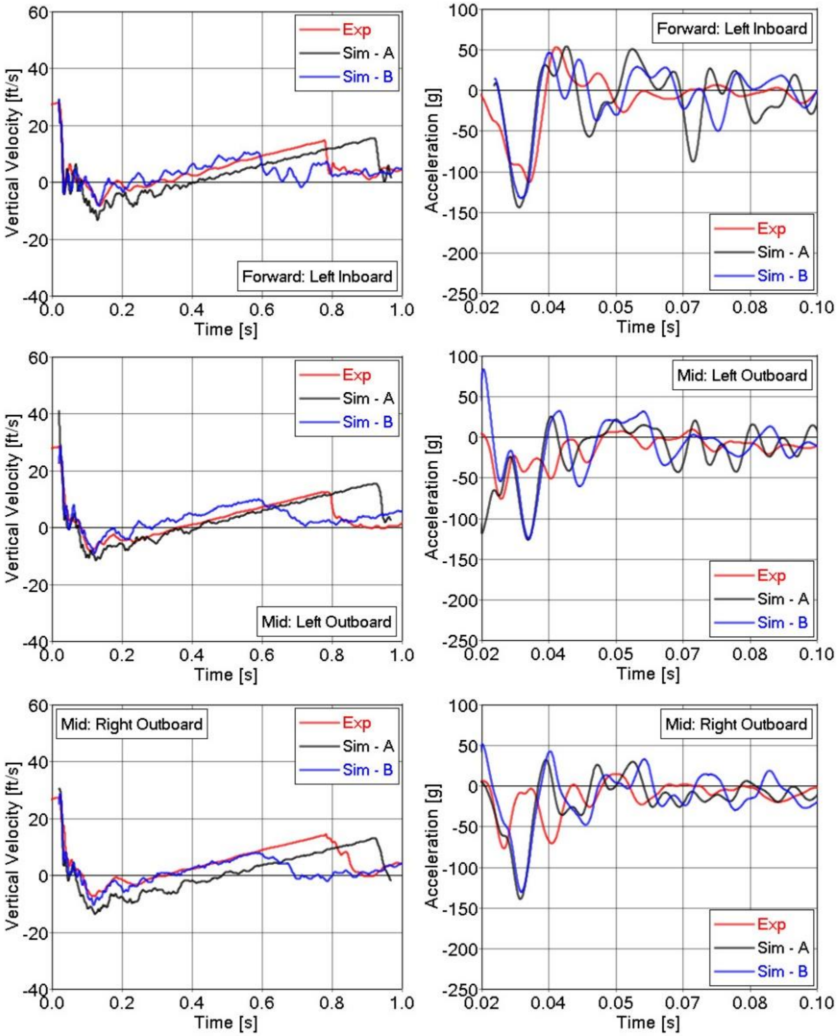


Debond and Delamination





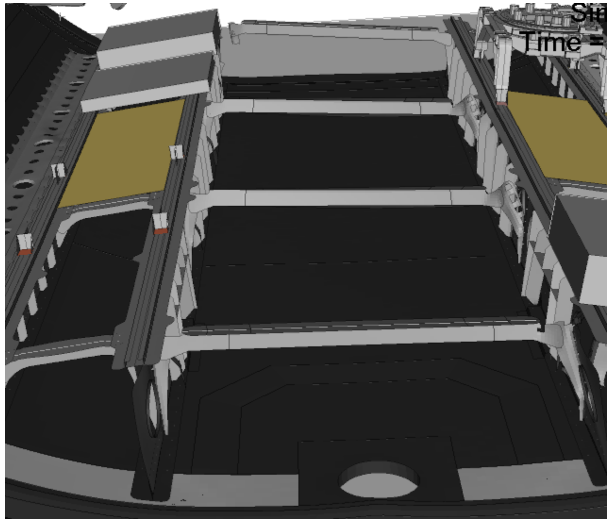
Sim A – Core and facesheet with nodal connectivity
Sim B – Delamination and Debond modeled using Tiebreak contacts



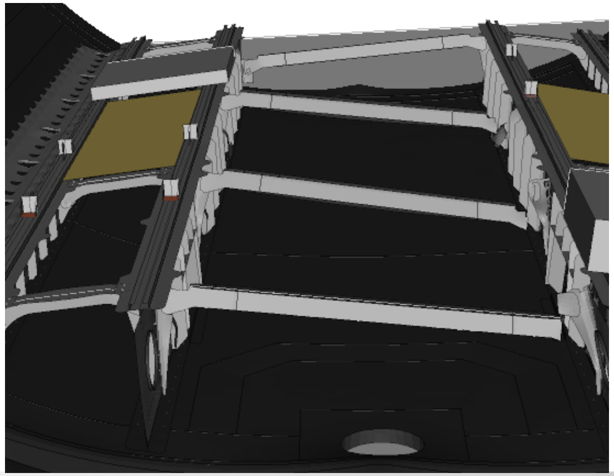
H4000 Drop Simulation

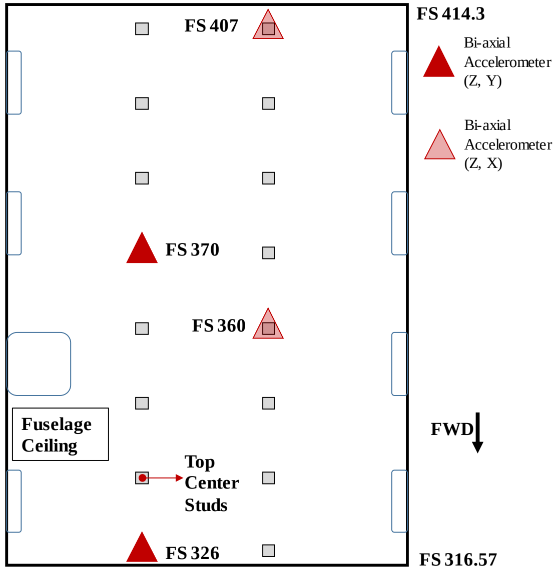
Simulation Results

SIM A

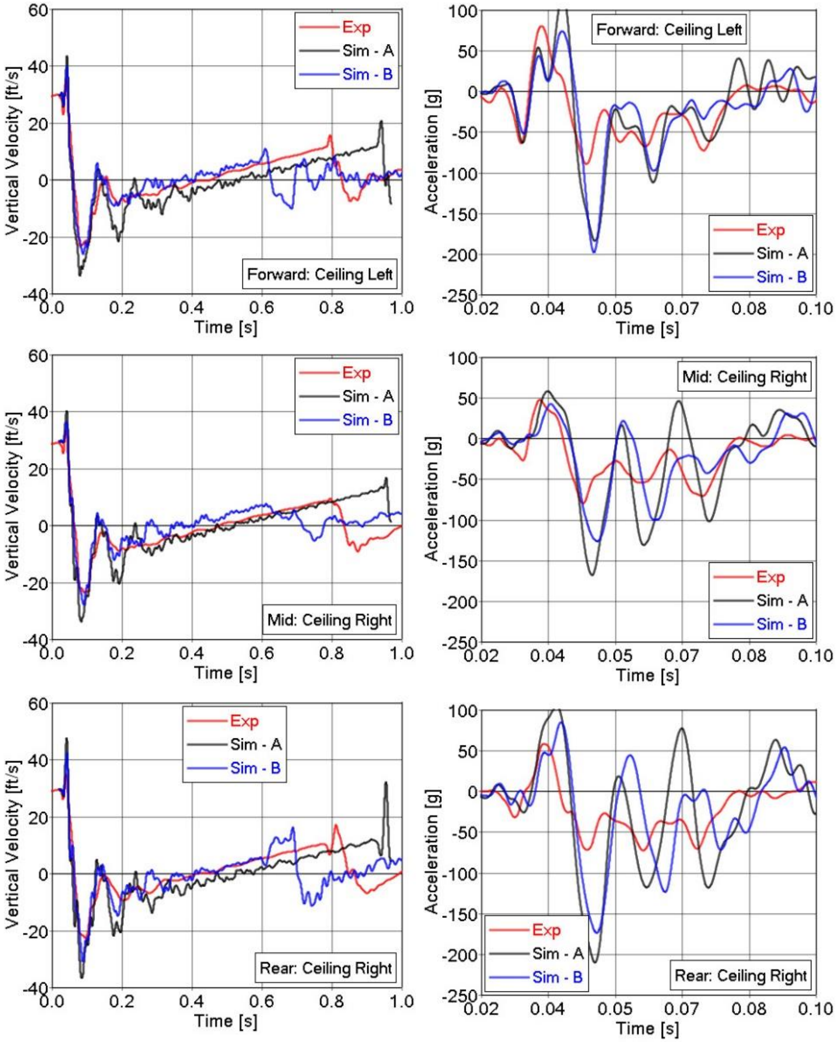


SIM B



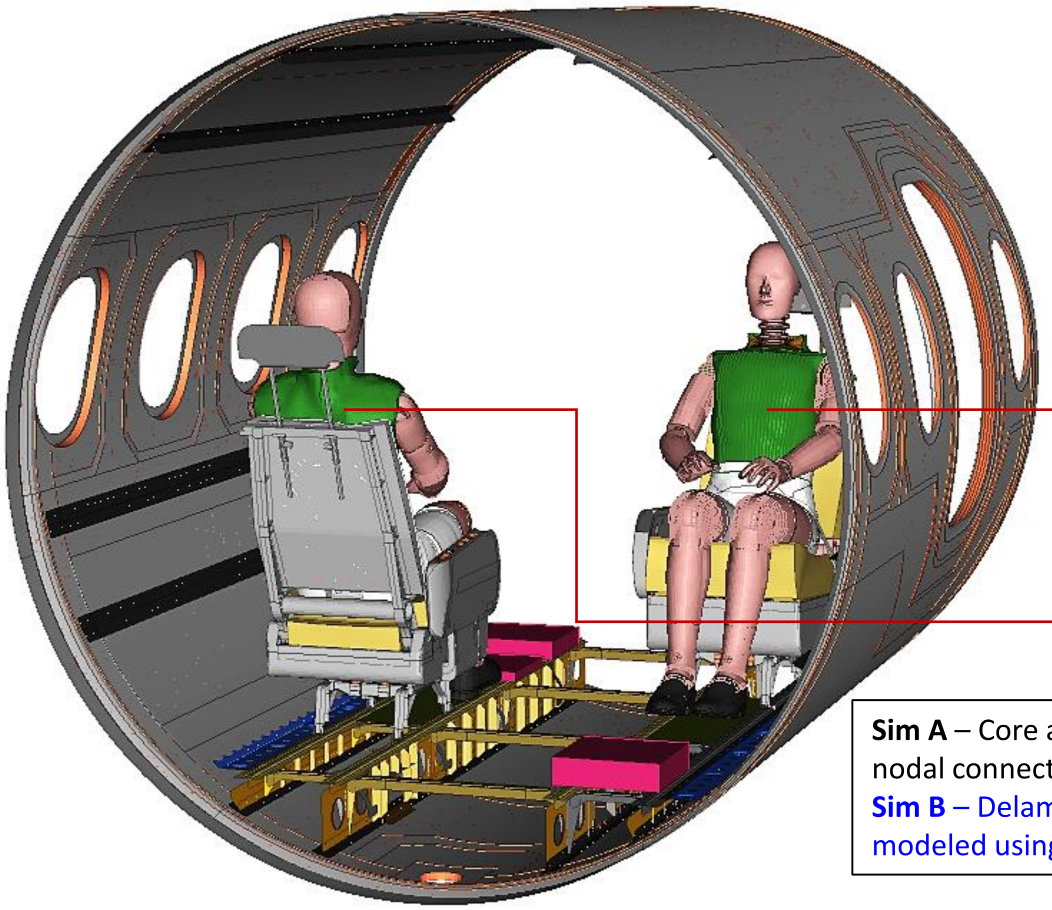


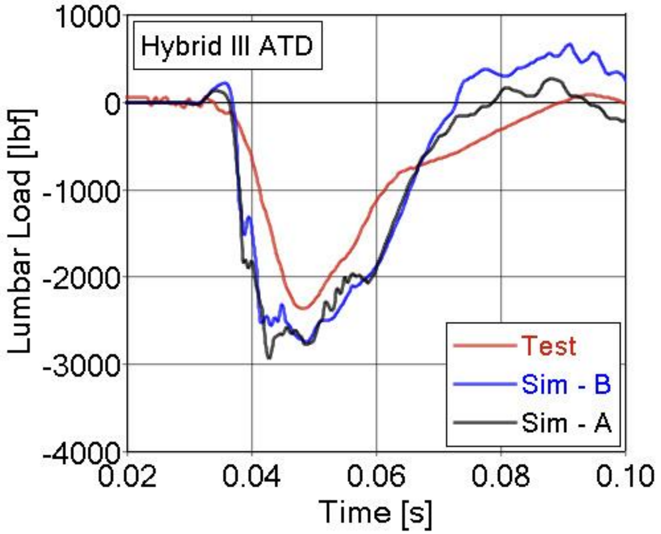
Sim A – Core and facesheet with nodal connectivity
Sim B – Delamination and Debond modeled using Tiebreak contacts

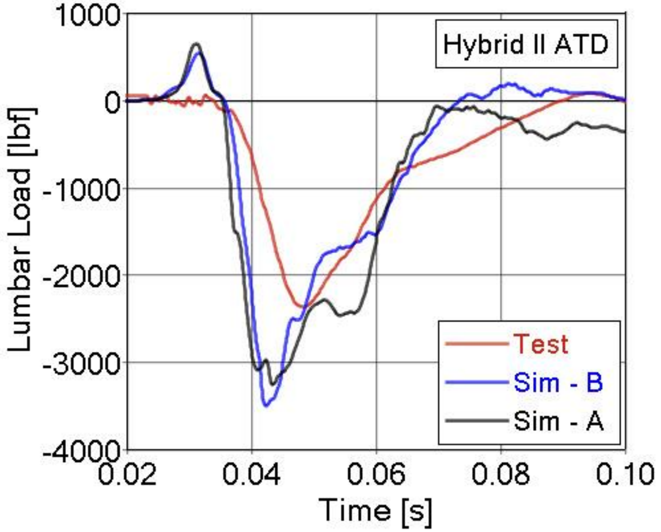


H4000 Drop Simulation

ATD Lumbar Loads



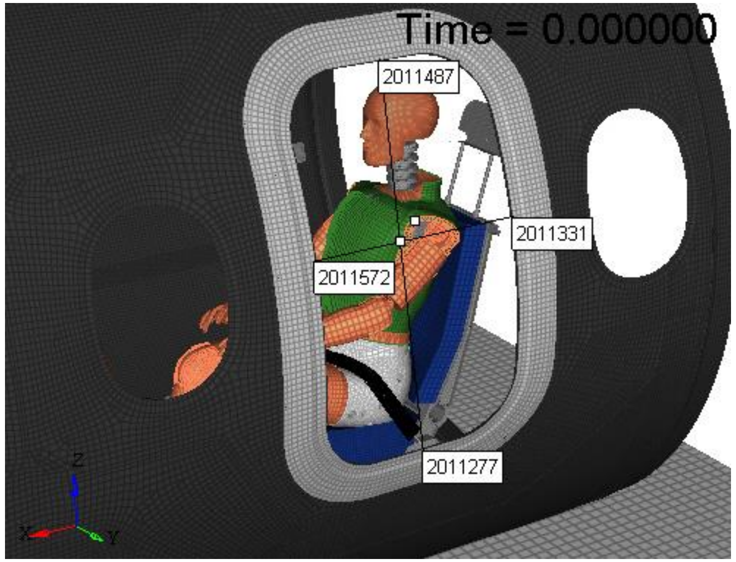




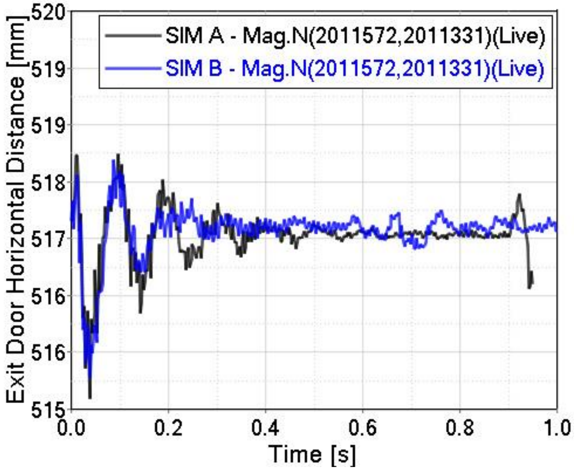
Sim A – Core and facesheet with nodal connectivity
Sim B – Delamination and Debond modeled using Tiebreak contacts

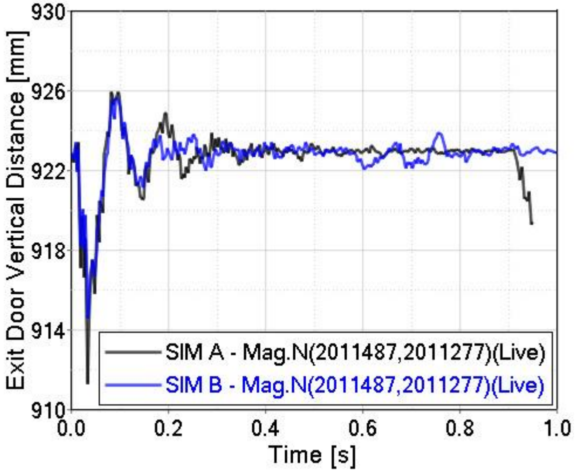
H4000 Drop Simulation

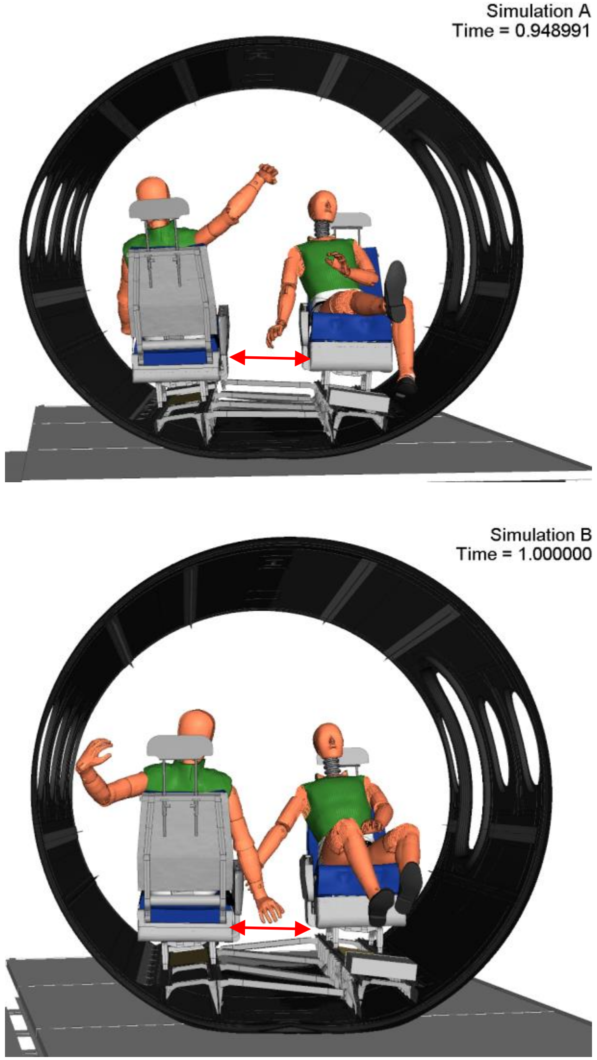
Egress Evaluation



Sim A – Core and facesheet with nodal connectivity
Sim B – Delamination and Debond modeled using Tiebreak contacts



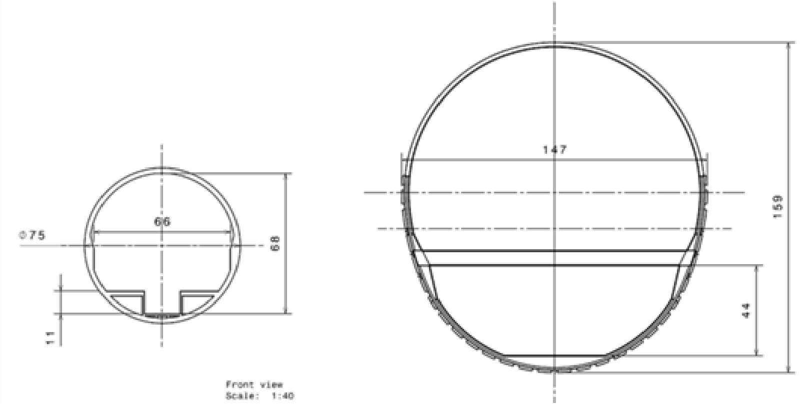


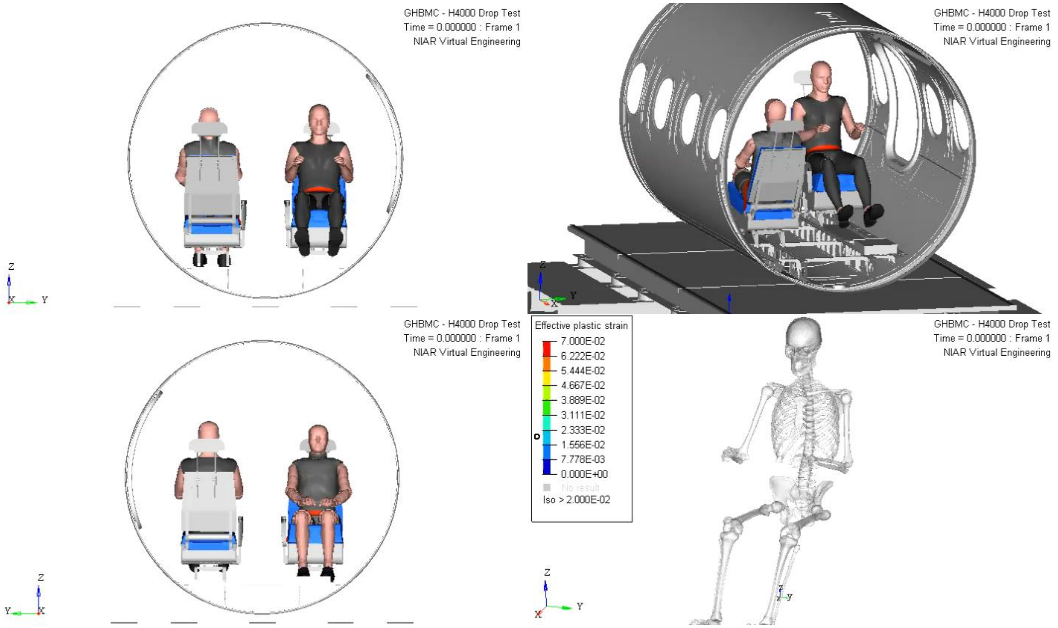


Conclusions and Future Work

H4000 Drop Test and Simulation

- The two composite modeling approaches resulted in different kinematics and velocity profile
- The acceleration profiles and ATD response was similar in both cases
- The damage of the metallic components was slightly more on model with Delamination and De-bonding but mostly similar
- The ATD response can be improved if the actual seat is modeled
- Composite delamination and debond can be captured using tiebreak contacts with correct parameter definitions. In this case, the damage does not seem to affect the initial acceleration response in the simulation but the later response changes
- As presented in the past, this test confirms that structures with limited subfloor space will not manage to meet the requirements for impact velocities in the range of 30 ft./sec [They will be in the range of 18ft./sec]
- NIAR recommends to define the vertical impact velocity based on effective subfloor space, instead of only MTOW.
- Work on improving FE models
- Use Section drop to evaluate human body models and compare injury levels





Thank you for your attention.

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