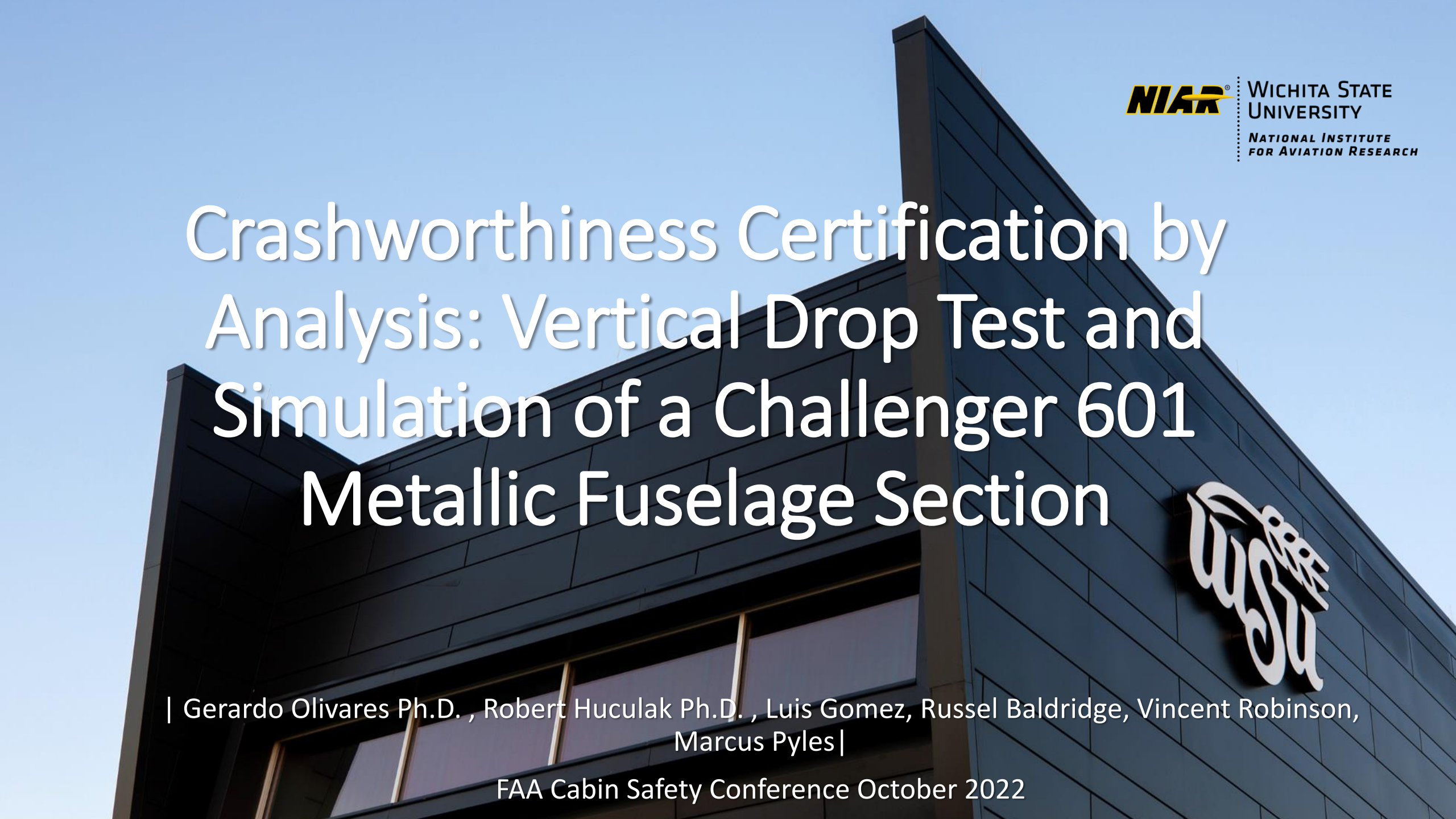


NIAR | Wichita State University
National Institute for Aviation Research

Crashworthiness Certification by Analysis: Vertical Drop Test and Simulation of a Challenger 601 Metallic Fuselage Section

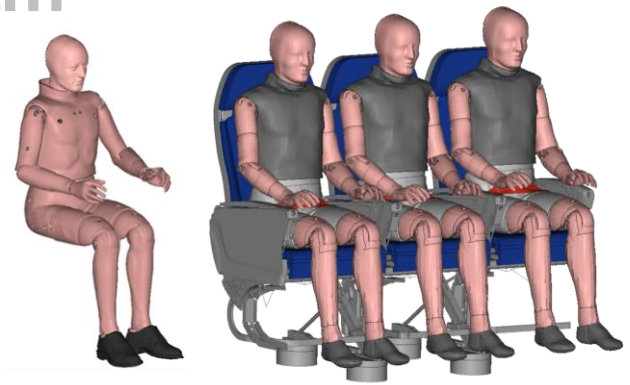
| Gerardo Olivares Ph.D. , Robert Huculak Ph.D. , Luis Gomez, Russel Baldridge, Vincent Robinson, Marcus Pyles|

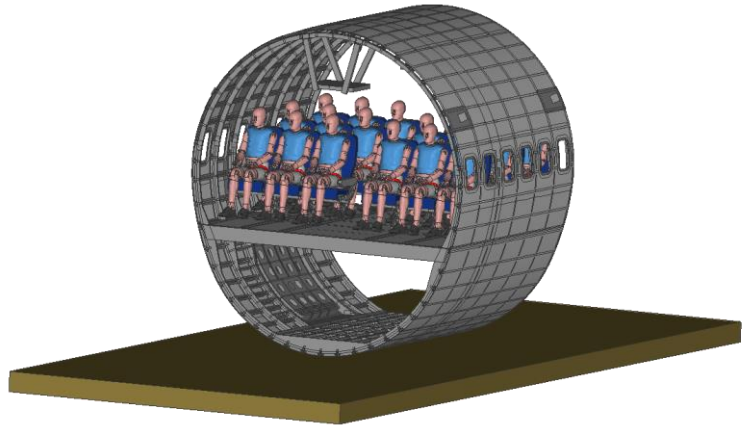
FAA Cabin Safety Conference October 2022

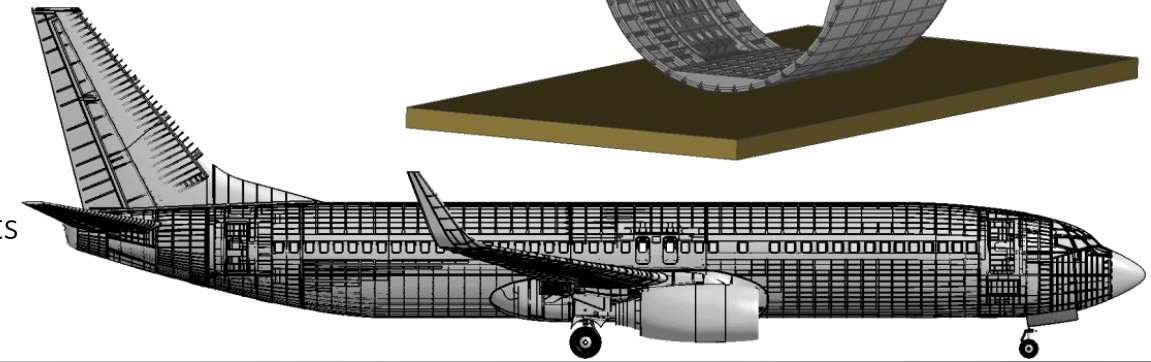
Airframe Crashworthiness

NIAR-FAA Certification by Analysis R&D Program

- 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.
- 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.
- Publications
  - AC 20-146 Aircraft Seat Certification and FAA Technical Reports.
  - ARAC – Aviation Rulemaking Advisory Committee.
    - Transport airplane ditching and crashworthiness requirements
  - SAE ARP 5765.
  - LSDyna Working Group – Cabin Interiors.



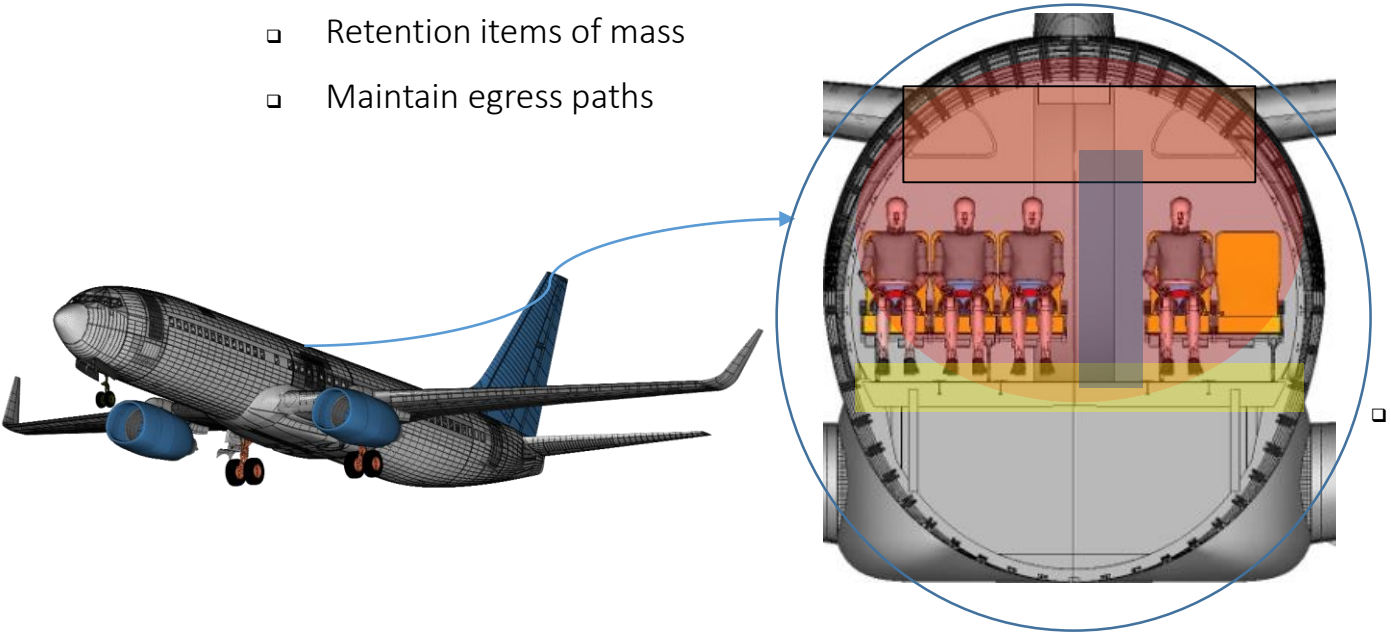




Airframe Crashworthiness - Certification

NIAR-FAA Certification by Analysis R&D Program

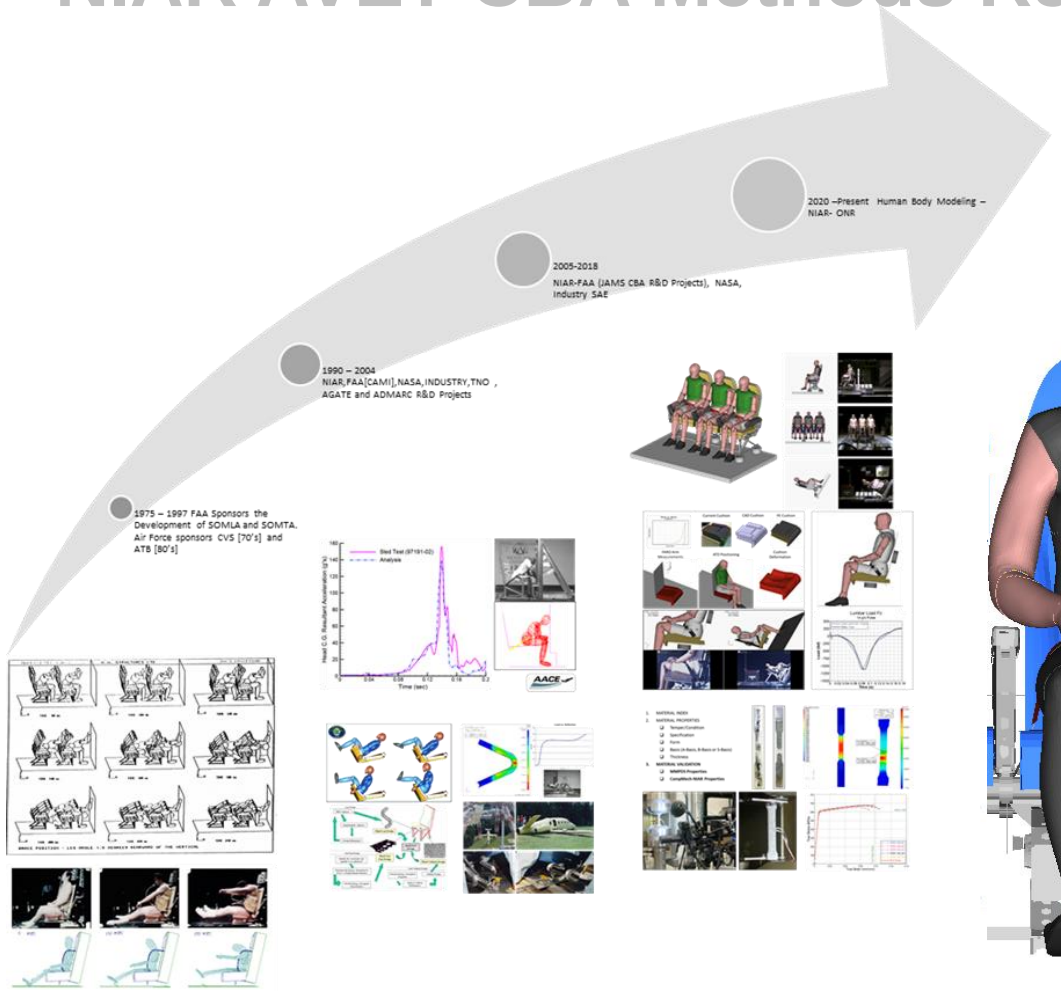
- Crashworthiness performance of composite structures to be equivalent or better than traditional metallic structures
- Crashworthiness design requirements:
  - Maintain survivable volume
  - Maintain deceleration loads to occupants
  - Retention items of mass
  - Maintain egress paths

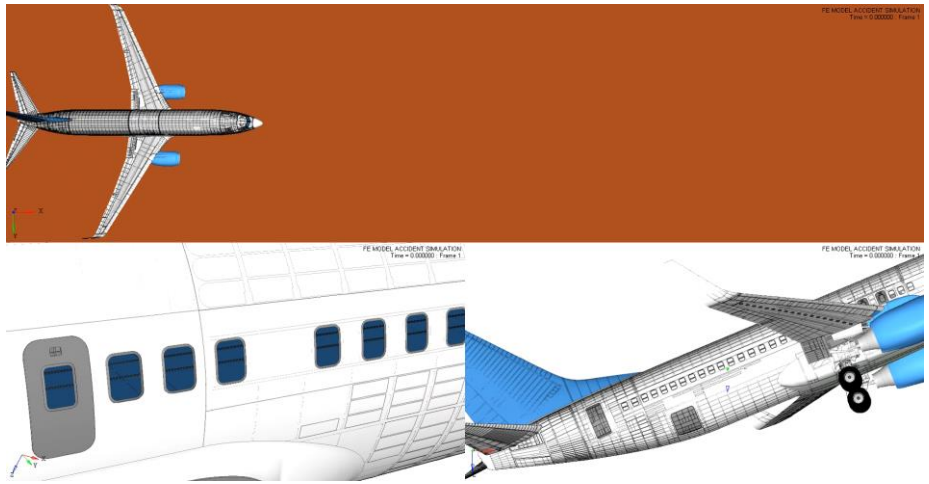


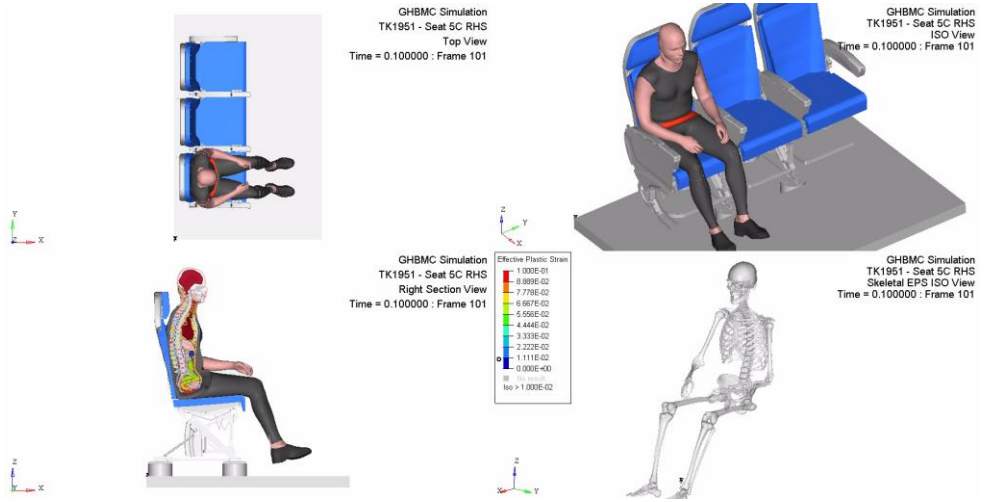
- Currently, there are two approaches that can be applied to analyze this special condition:
  - Method I: Large-Scale Test Article Approach
    - Experimental:
      - Large Scale Test Articles (Barrel Sections)
      - Component Level Testing of Energy Absorbing Devices
    - Simulation follows testing – Numerical models are **"tuned"** to match large test article/EA sub-assemblies results. Computational models are only predictable for the specific configurations that were tested during the experimental phase. For example, if there are changes to the loading conditions (i.e. impact location, velocity, ..etc.) and/or to the geometry, the model may or may not predict the crashworthiness behavior of the structure.
  - Method II: Simulation supported by the Building Block Approach
    - Experimental and Simulation
      - Coupon Level to Full Scale
    - Predictable modeling

Evolution Crashworthiness CBA

NIAR AVET CBA Methods R&D Program



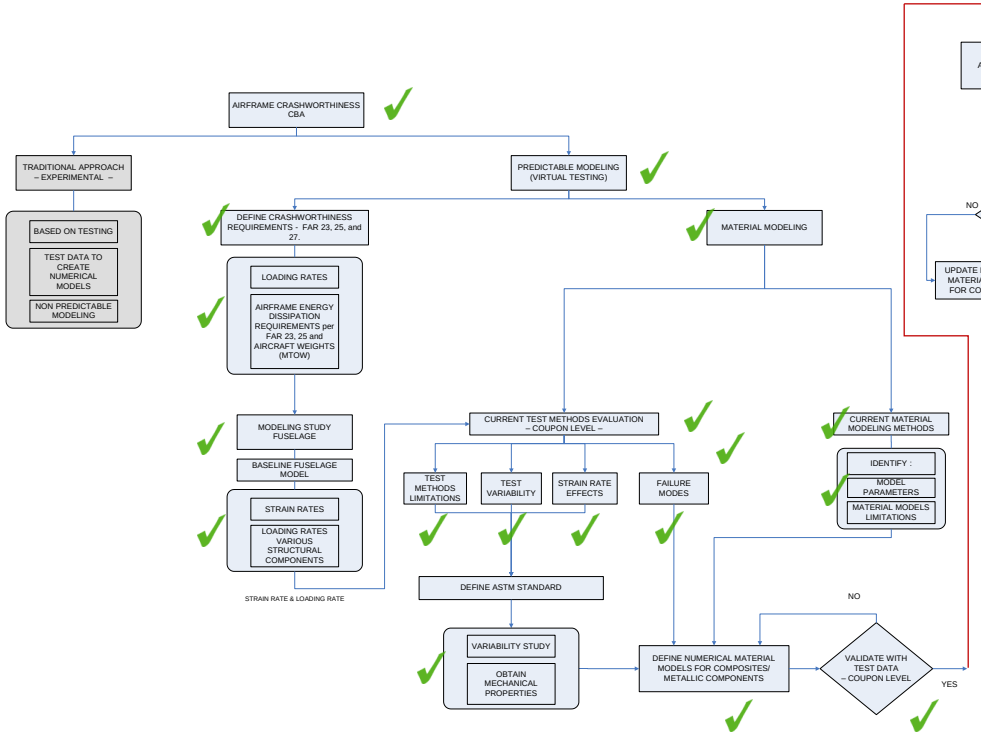


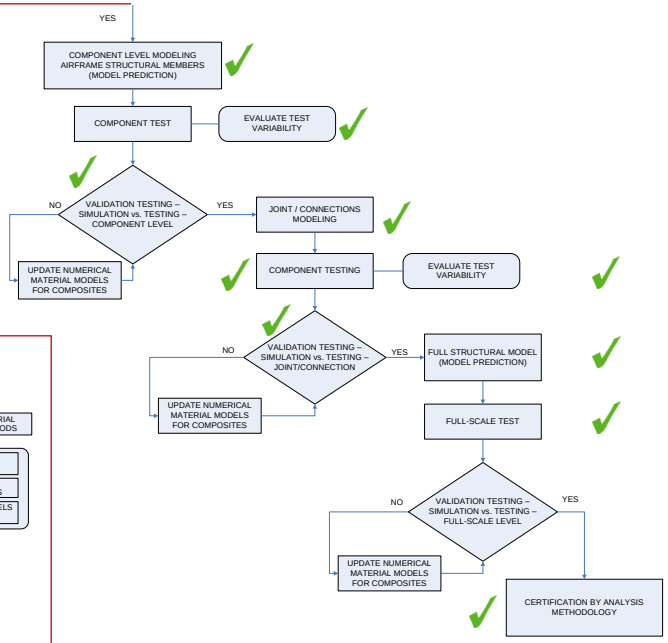


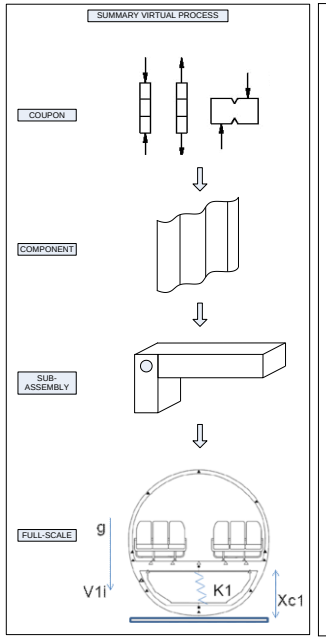
27 Years R&D Program: 1995 - Present

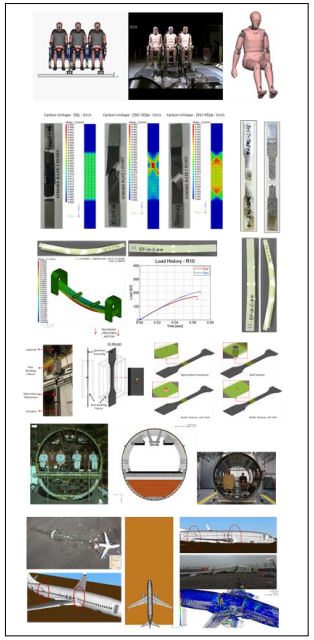
Airframe Crashworthiness R&D Roadmap

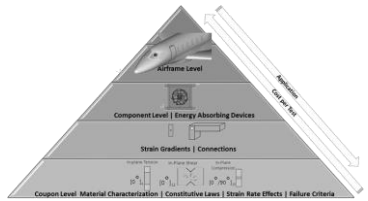
NIAR AVET Certification by Analysis R&D Program











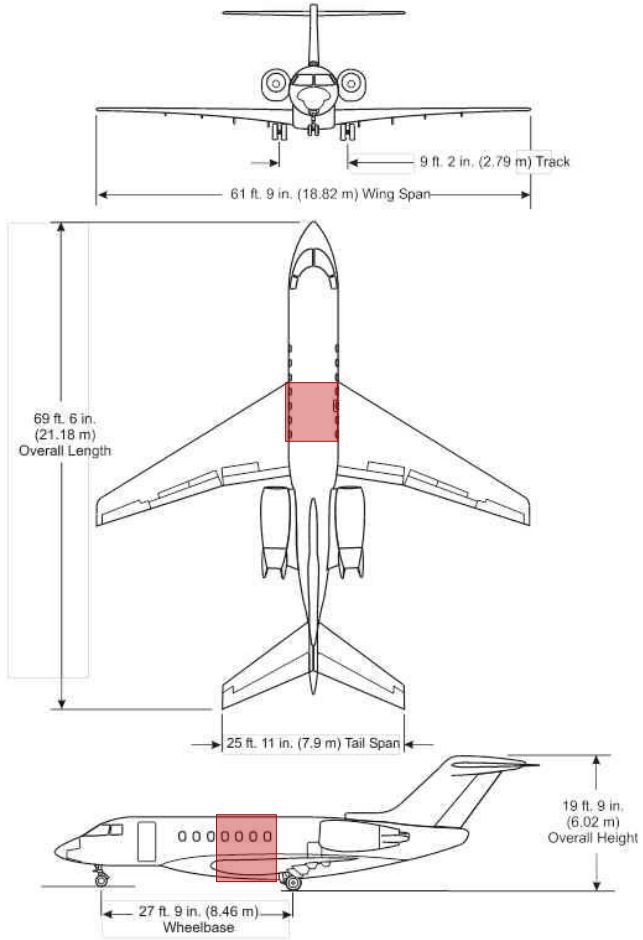
27 Year R&D Program: 1995 - Present

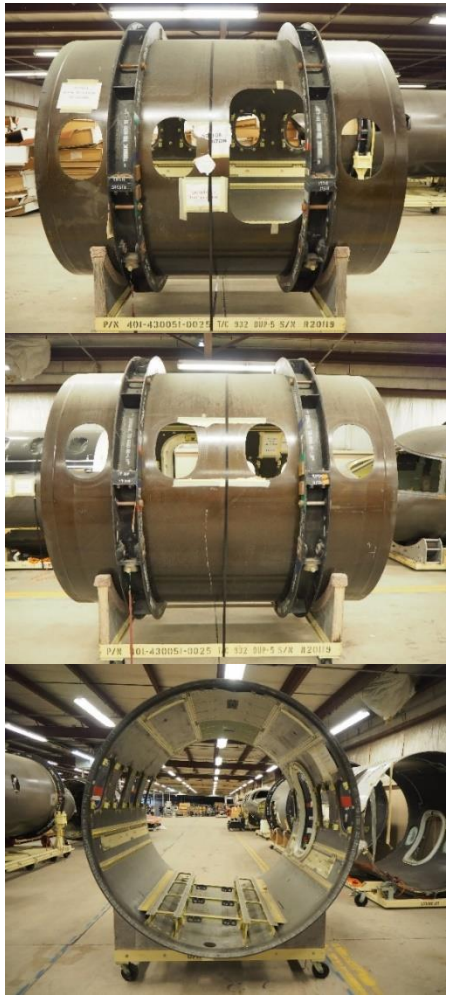
Full-Scale Test Program: Metallic and Composite 14 CFR 25 Airframes

Full Scale Fuselage Drop Test

H4000 Drop Test

14CFR Part 25 Aircraft

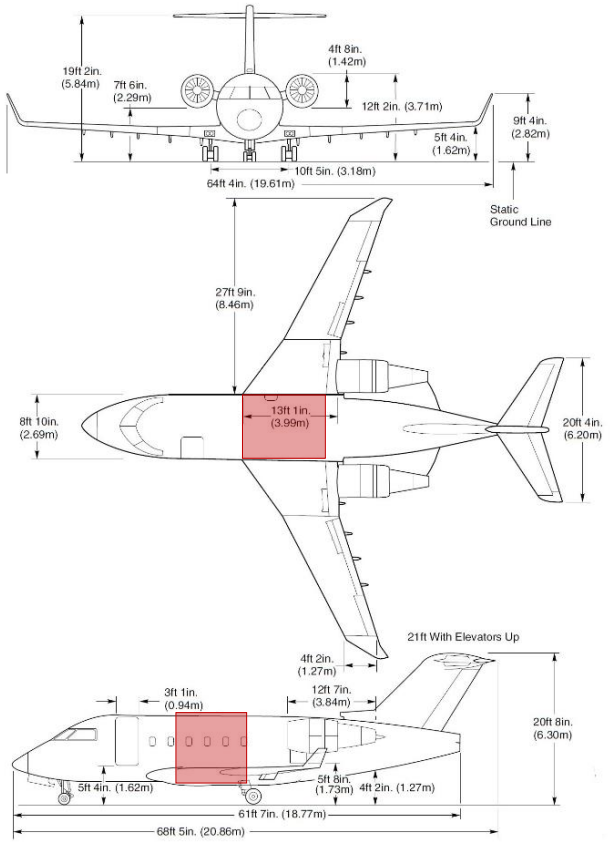




General Characteristics	
Seating	2+8/12
External Length	69 ft 6 in
External tail Height	19 ft 9 in
Wing Span	61ft 9 in
Empty Weight	23500 lb (10659 kg)
Gross Weight	26000 lb (11793 kg)
Performance	
Power	2 × Pratt & Whitney Canada PW308A turbofan 6,900 lbf/ ISA + 22 °C () each
Cruise Speed	Mach 0.84
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

CL601-3A (2B16) Drop Test

14CFR Part 25 Aircraft



General Characteristics	
Seating	2+11/19
External Length	68 ft 3 in
External tail Height	20 ft 7 in
Wing Span	64ft 3 in
Empty Weight	31000 lb
Gross Weight	43100 lb

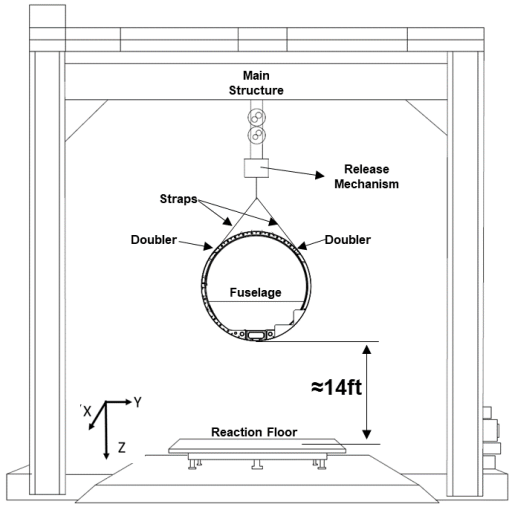
Performance	
Power	Engines: 2 Engine Mfg: General Electric Engine Model: CF34-3A
Cruise Speed	Mach 0.7
Range	3590 nm
Service Ceiling	41000 ft

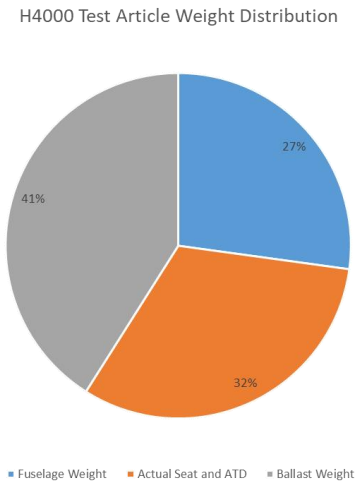
Interior	
Cabin Height	6.1 ft
Cabin Length	28.3 ft
Cabin Width	8 ft 2 in
Cabin Volume	1150 ft^3

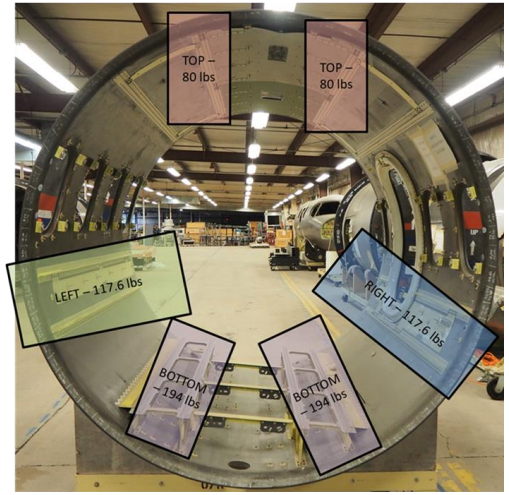
H4000 Drop Test

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



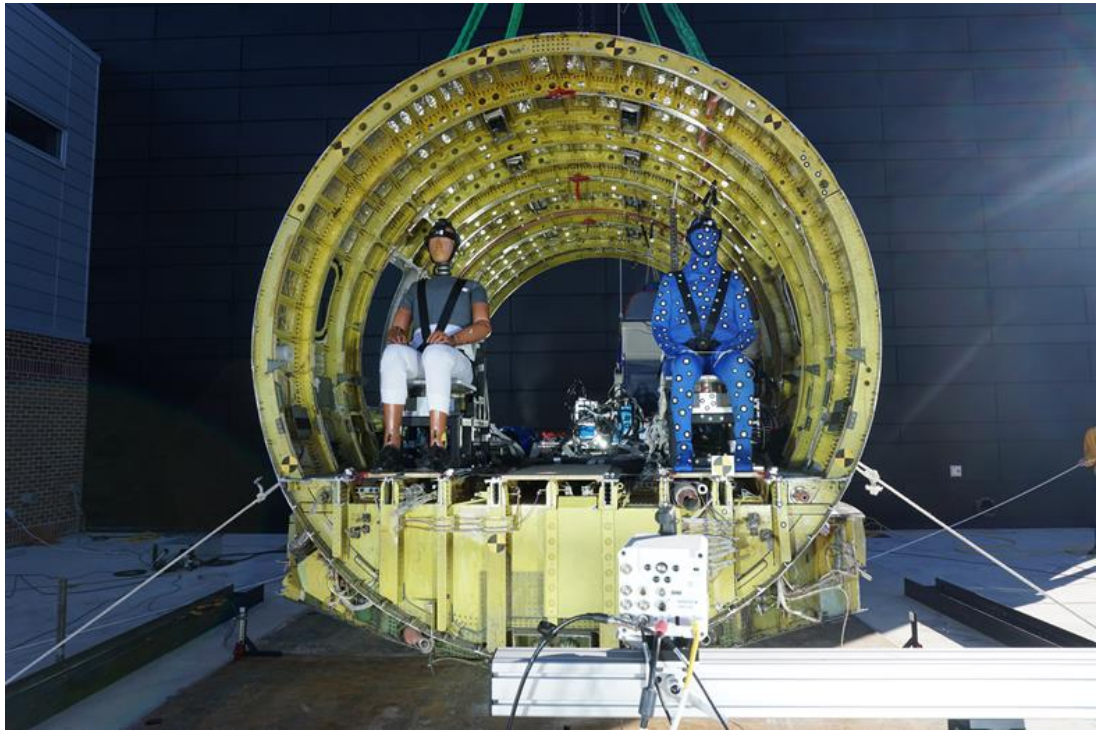


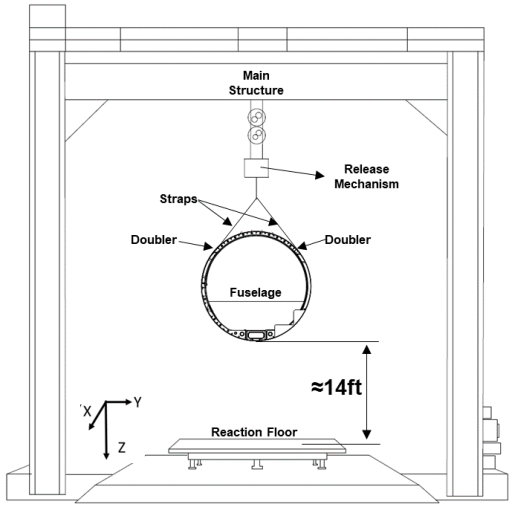


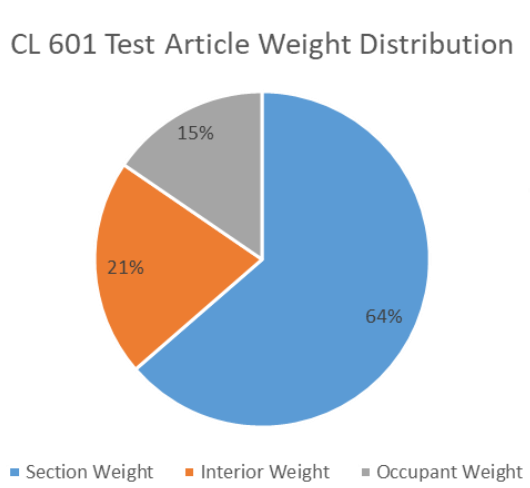
CL601-3A Drop Test

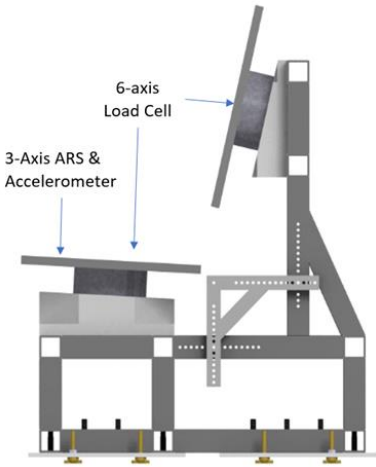
Test Setup

- Test Facility
  - NIAR AVET Full Scale Crash Facility
  - 30 ft/s Drop Impact Velocity
- Test Article – H4000 Fuselage Section
  - Dimensions:
    - Length: ≈12ft 5in
    - Diameter: ≈9 ft
  - One Exit Door Opening (Right Side)
  - Seven Window Openings:
    - 3 Right Side
    - 4 Left Side
  - Floor Structure; Floor Seat tracks and Wall Mounted
  - Wing box structure
  - No upper panels/PSUs
  - Total Weight: 5500 lbs.
  - 5 Occupants:
    - 2 Seats: PMHS and FAA HII
    - 2 Rigid Seats: PMHS and FAA HII
    - 1 PMHS Stretcher





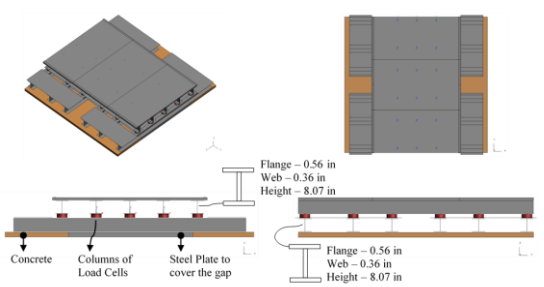


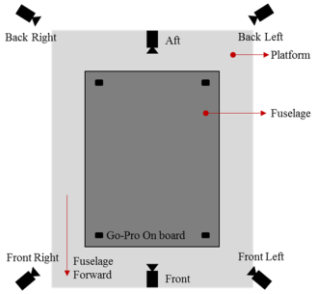


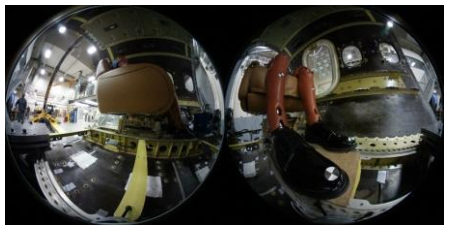
H4000 Drop Test

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.
  - HII and FAA HIII ATDs



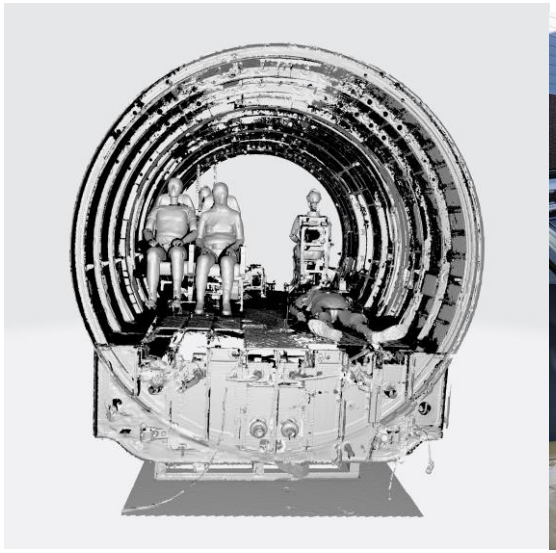


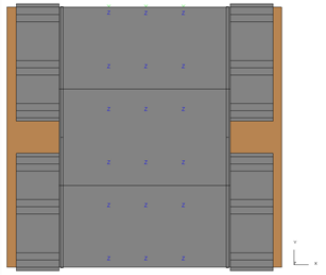


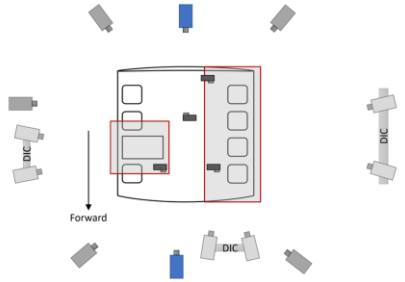
CL601-3A Drop Test

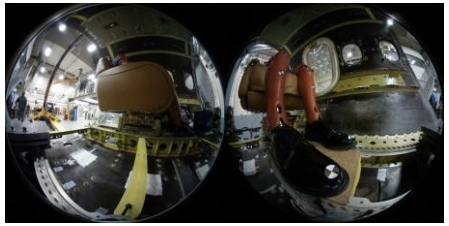
Instrumentation and DAQ

- Data Acquisition
  - DTS Slice Pro Data Acquisition System – 368 channels
    - ATDs (55 channels)
    - Accelerometers Structure (37 channels)
    - Accelerometers Seats (38 channels)
    - PMHS (240 Channels)
  - 360 HD camera system - 4 GO-PROs
  - Thirteen HSV Cameras – 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.
  - Two FAA HIII ATDs, and 3 PMHS
  - Rigid Floor Steel Plate







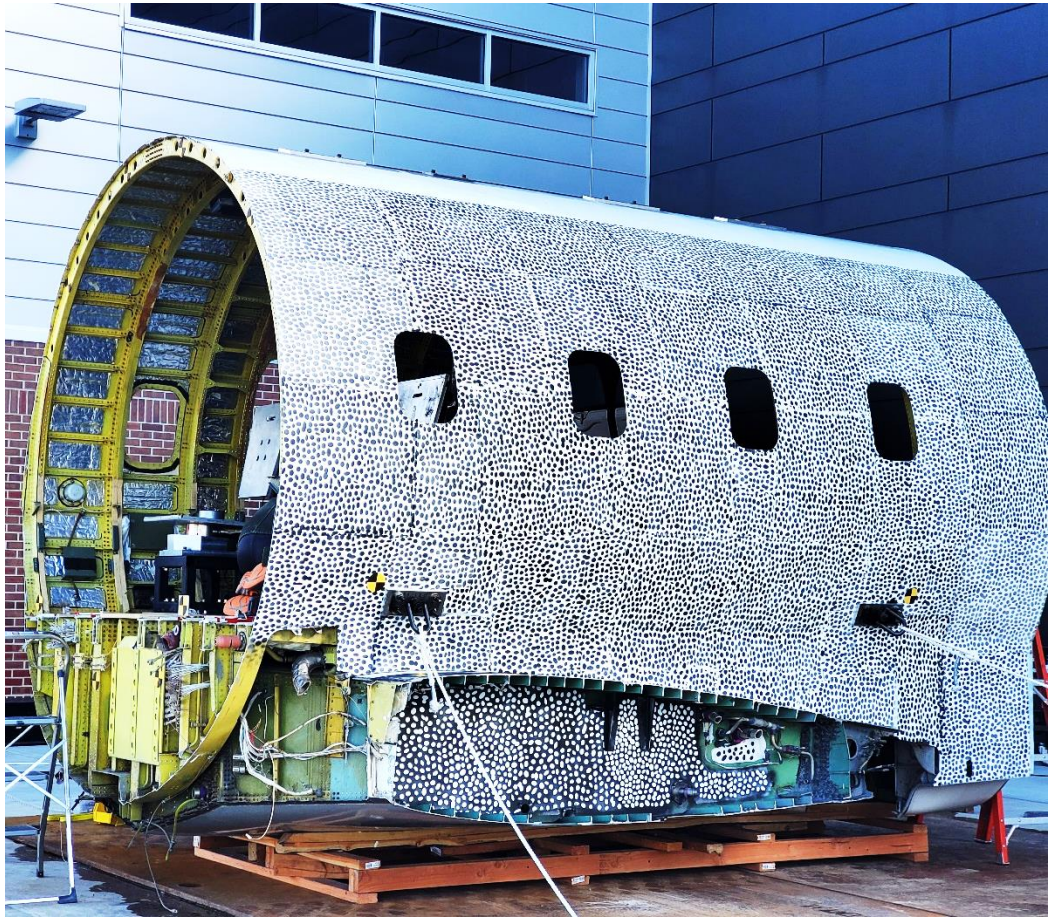


CL601 – 30ft/s Drop Test

Pre-Test

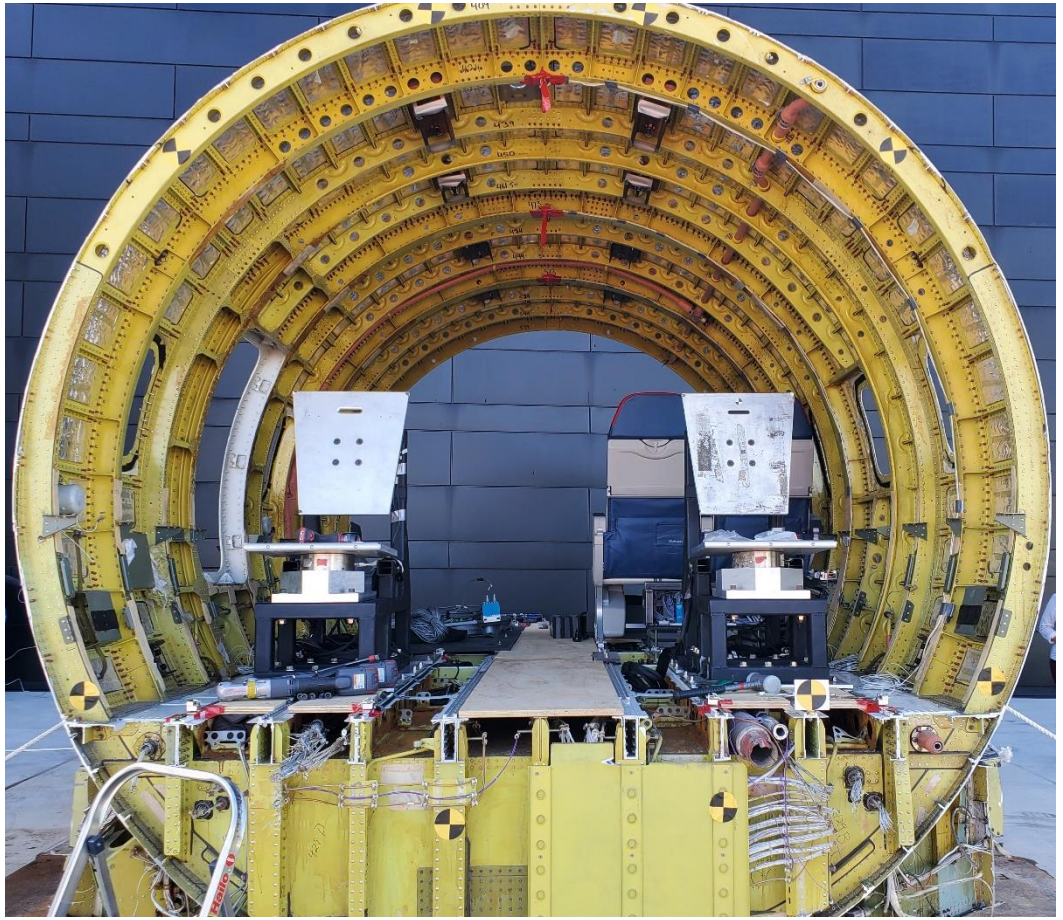
Test Article Details

CL601-3A Drop Test



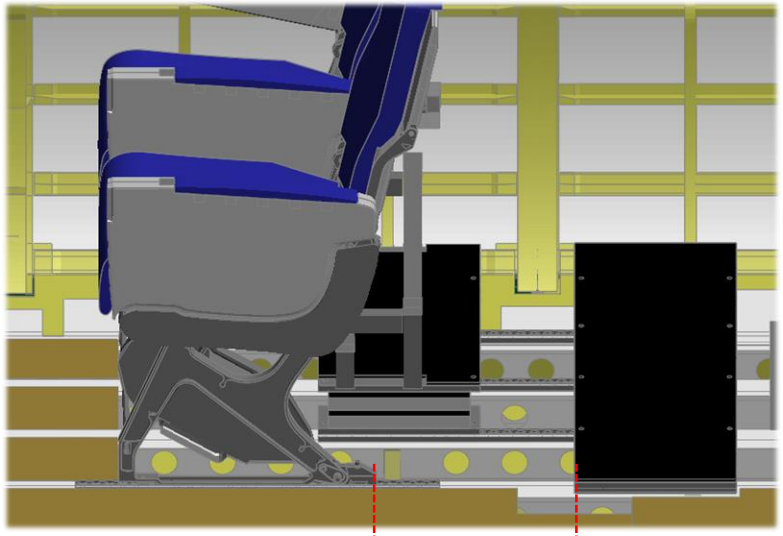
Test Article Details

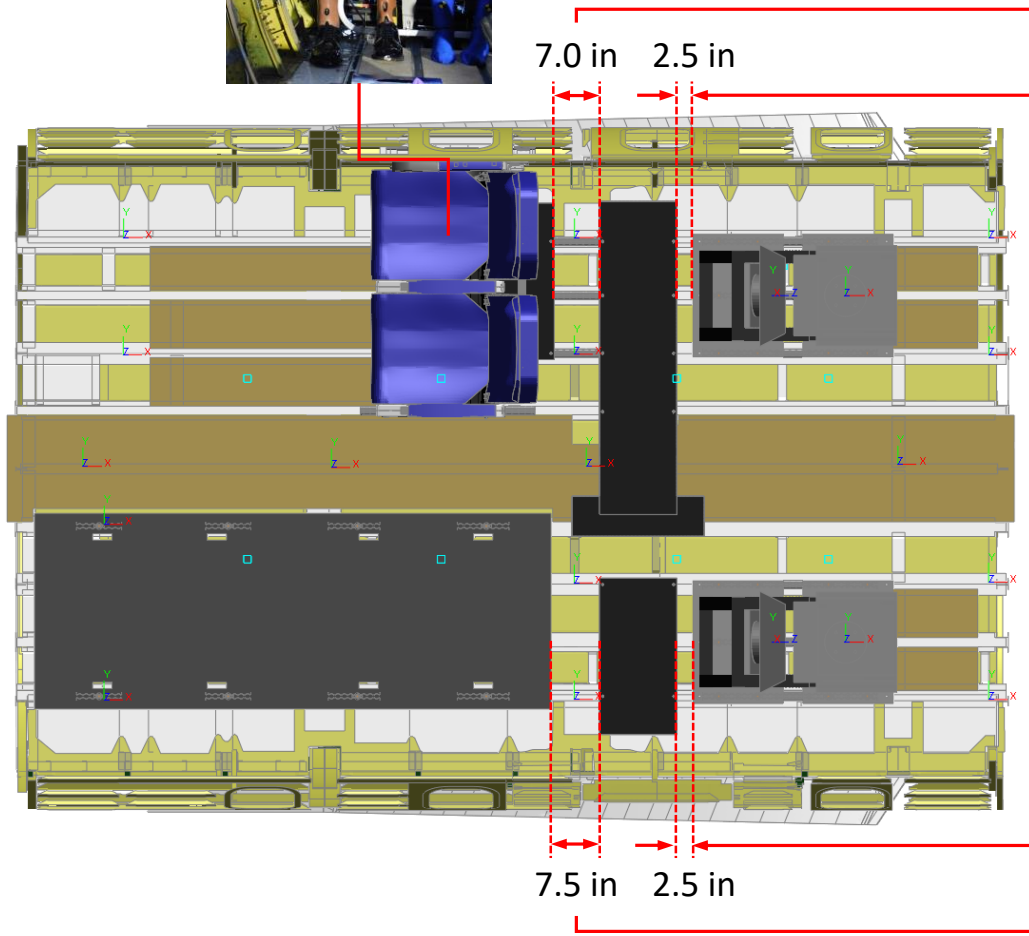
CL601-3A Drop Test

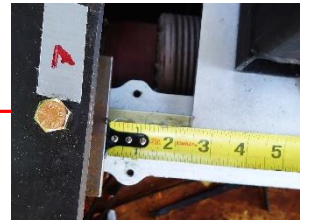


Seating Layout

CL601-3A Drop Test

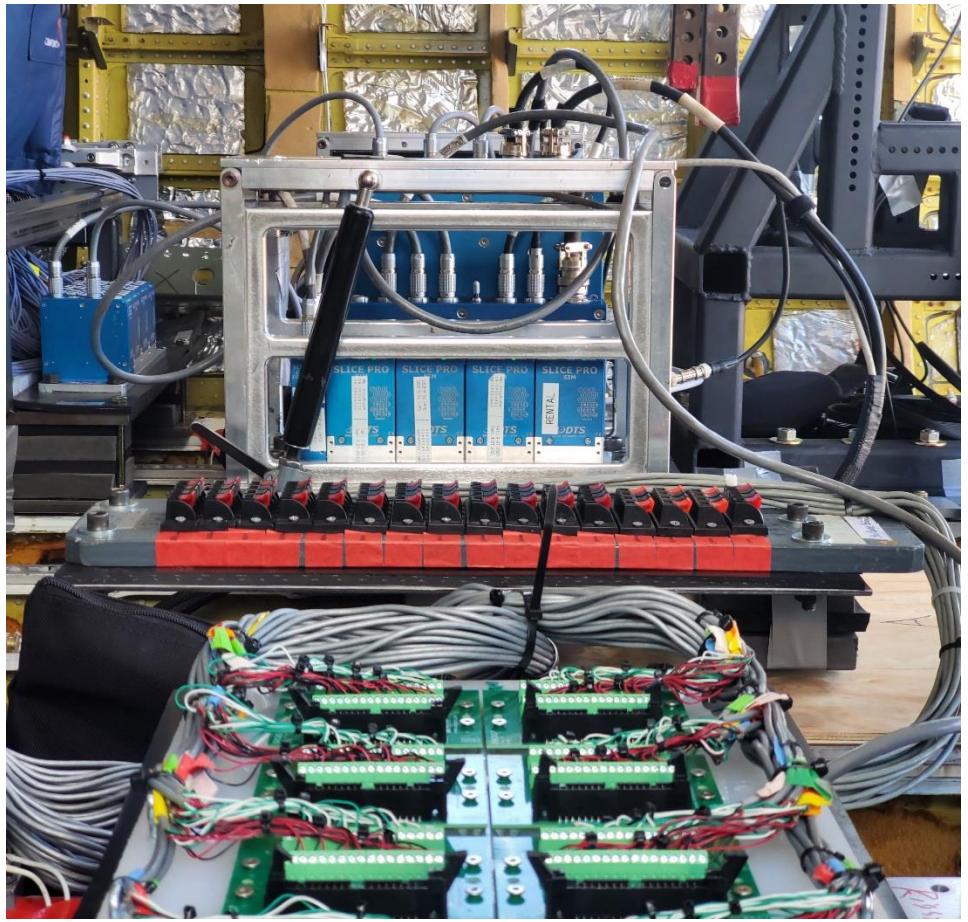






Test Article Details

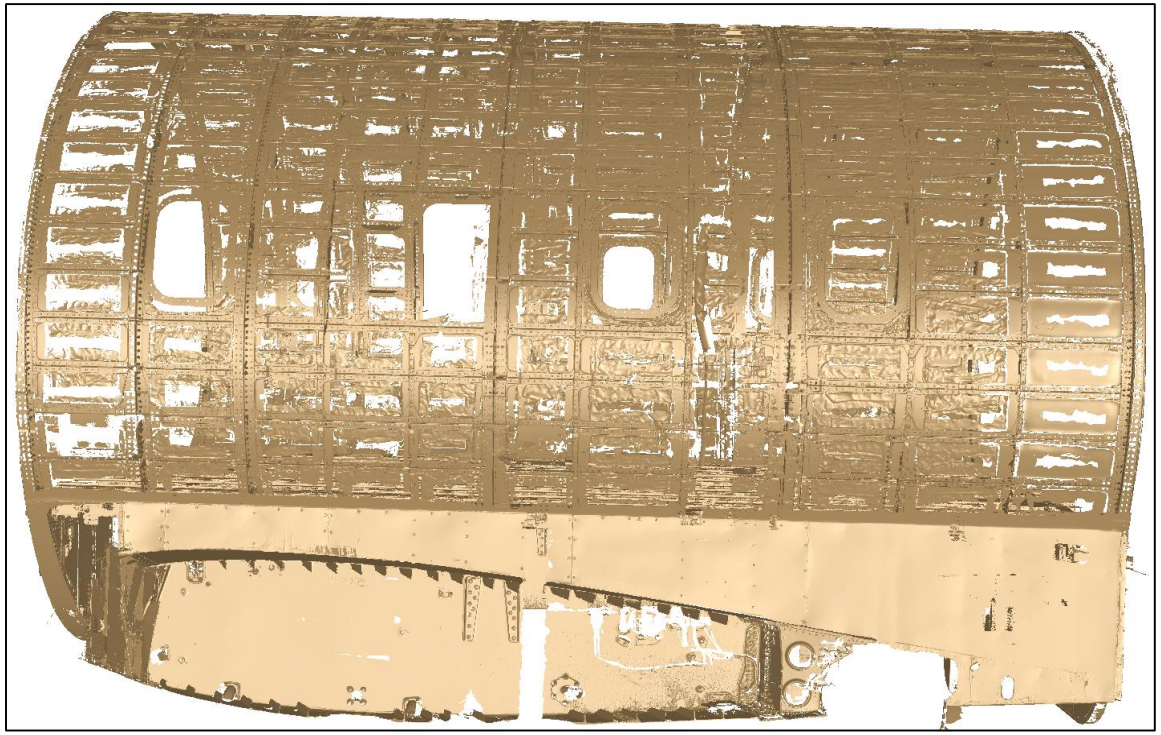
CL601-3A Drop Test



Challenger 601 Drop Test Scan

Reverse Engineering CL601

Challenger 601 Model

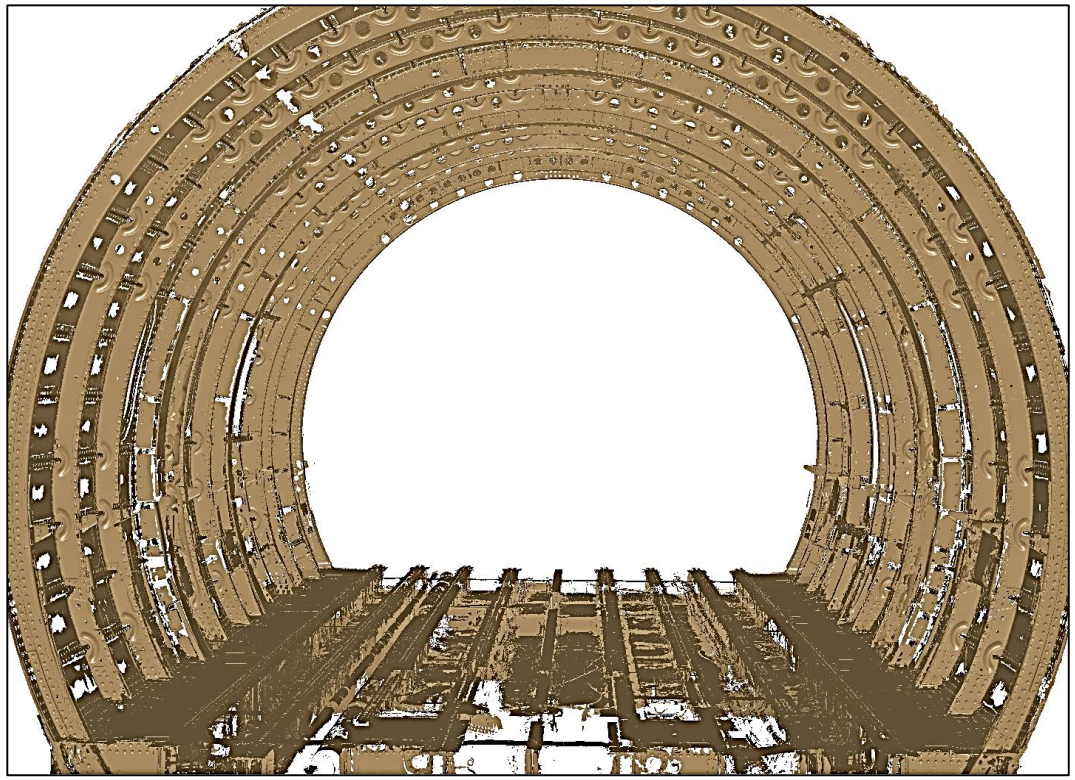


Challenger 601 Scan

Challenger 601 Drop Test Scan

Pre Test - Scans vs Pictures

Challenger 601 Model

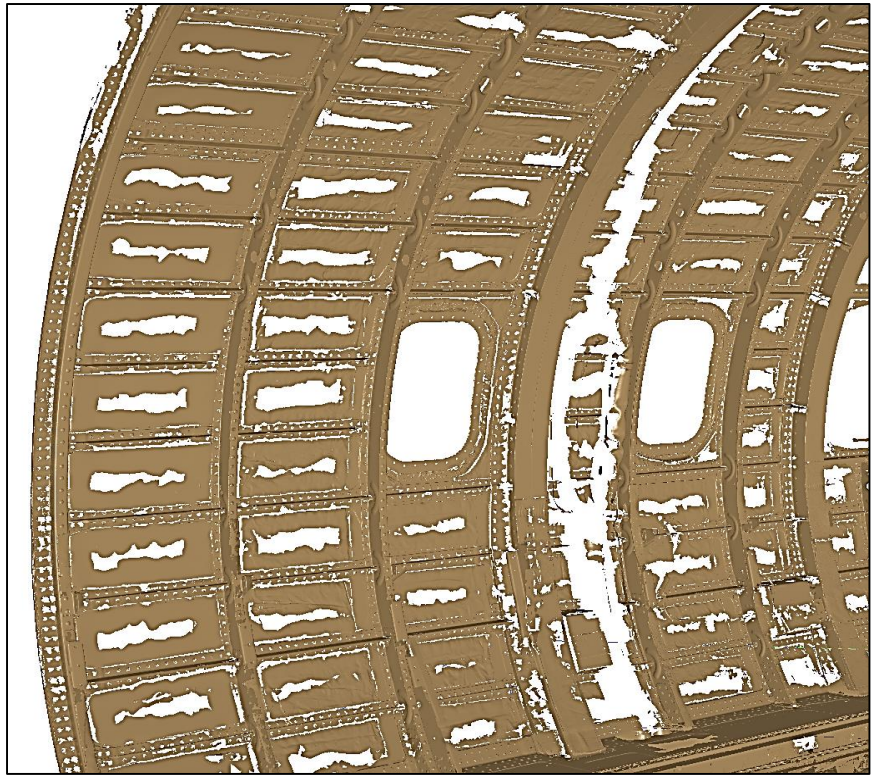


Challenger 601 Scan

Challenger 601 Drop Test Scan

Pre Test - Scans vs Pictures

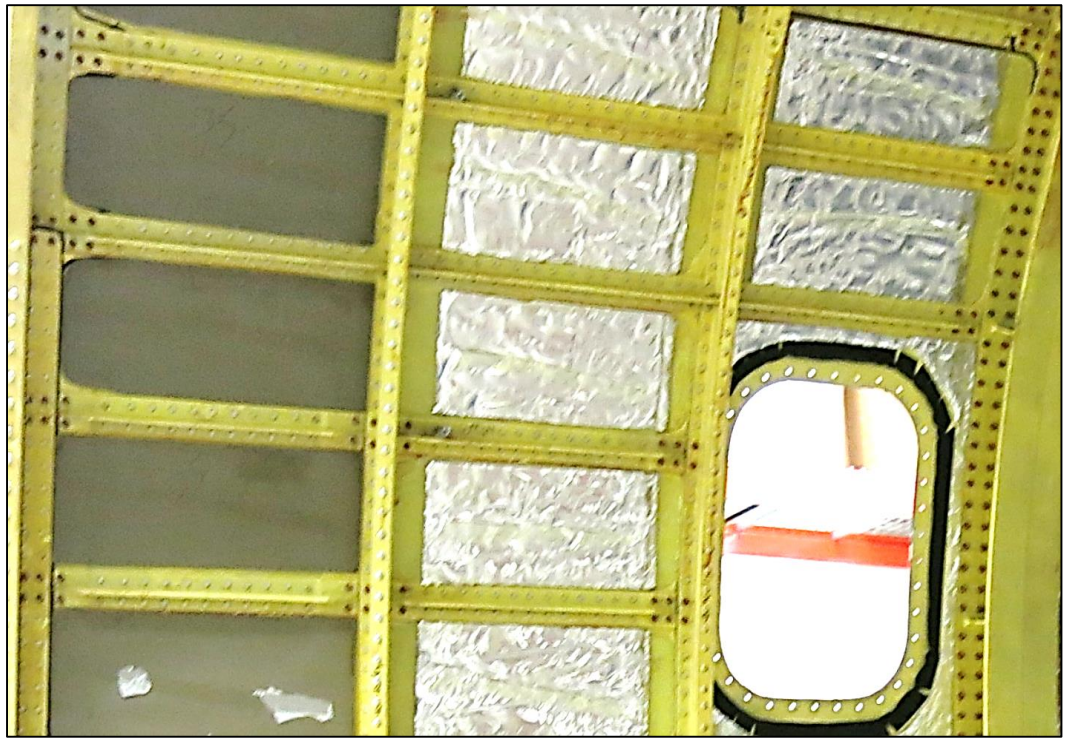
Challenger 601 Model



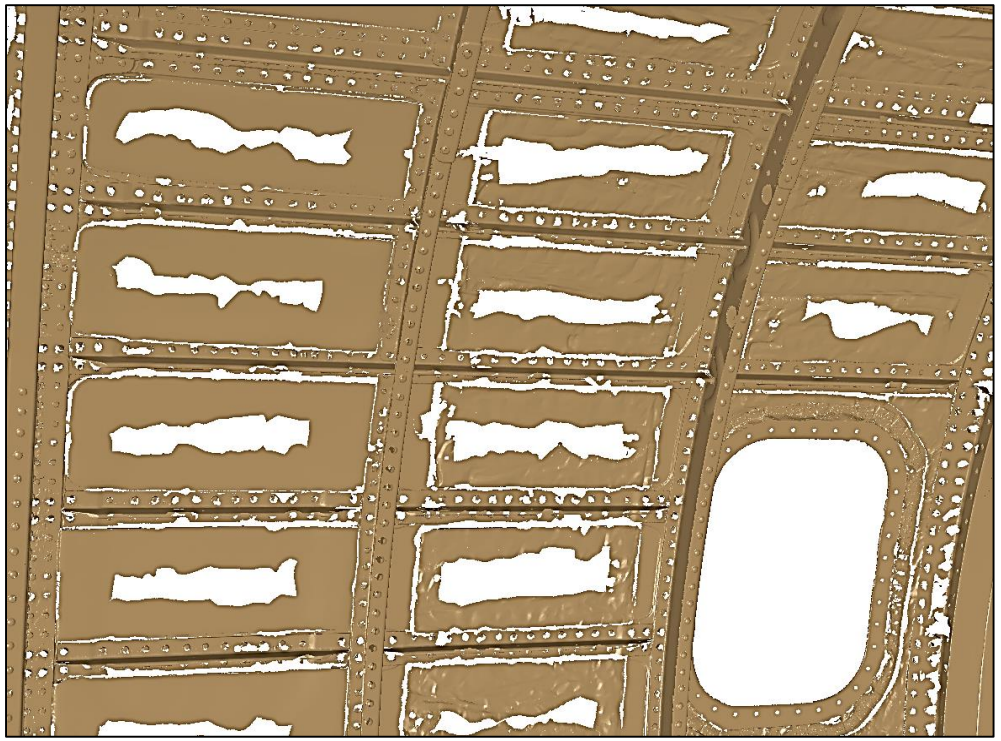
Challenger 601 Scan

Challenger 601 Drop Test Scan

Scans vs Pictures



Challenger 601 Model

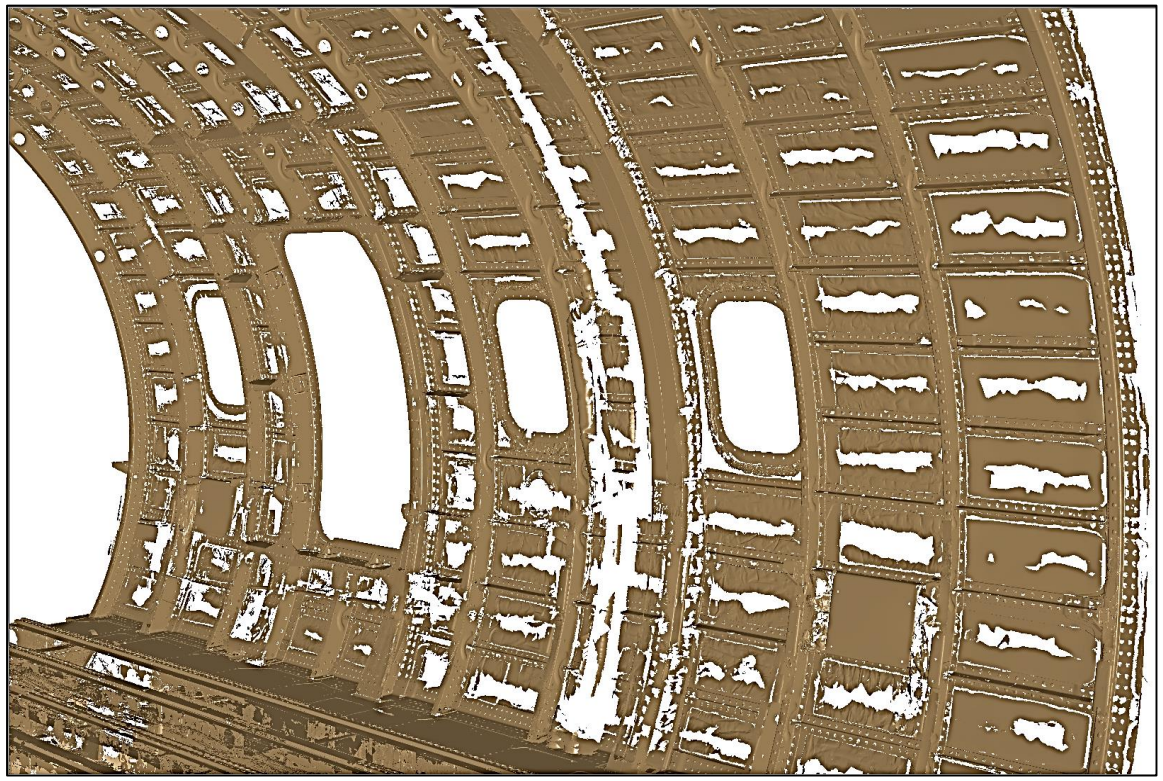


Challenger 601 Scan

Challenger 601 Drop Test Scan

Scans vs Pictures

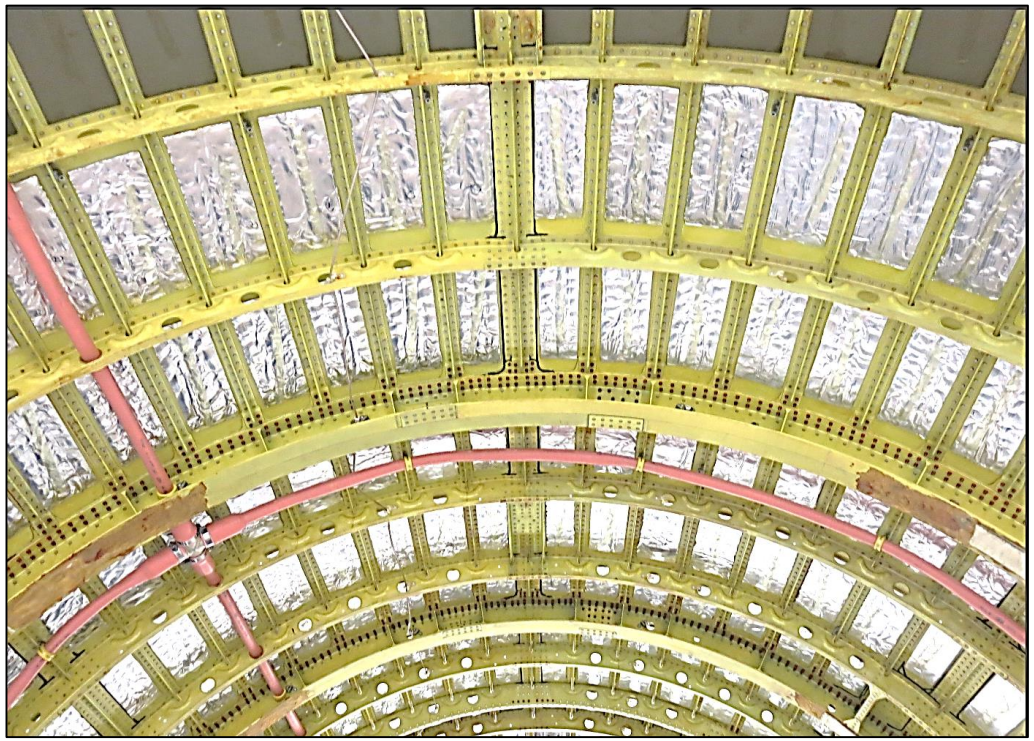
Challenger 601 Model



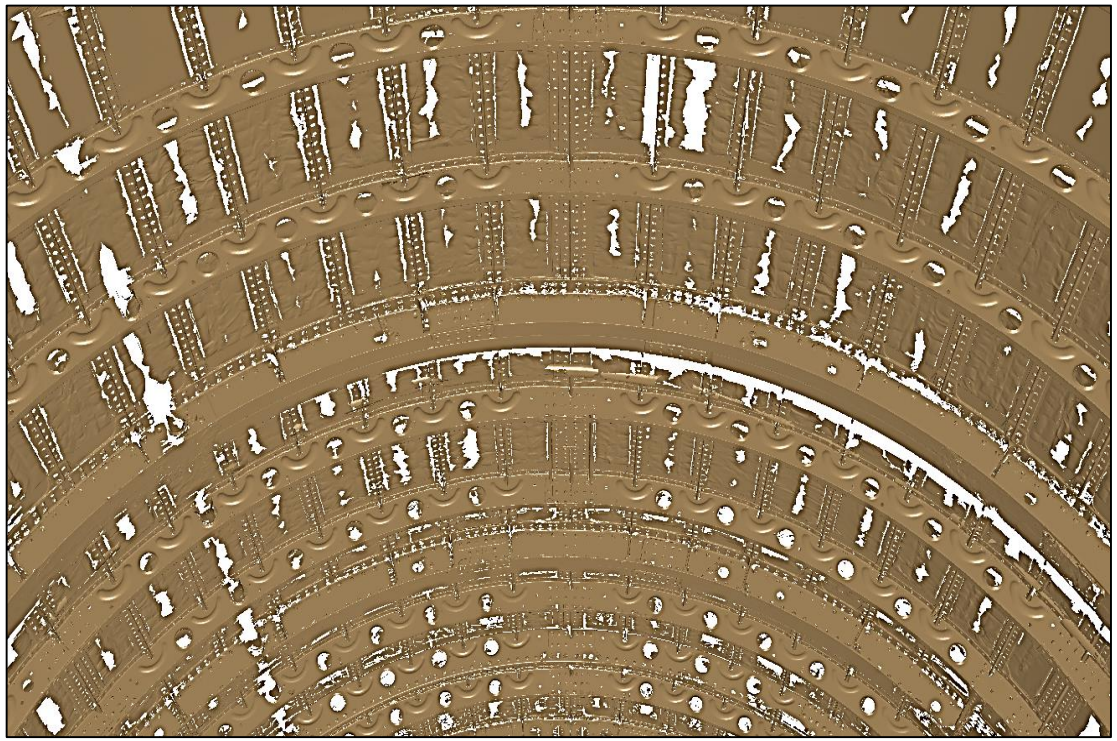
Challenger 601 Scan

Challenger 601 Drop Test Scan

Scans vs Pictures



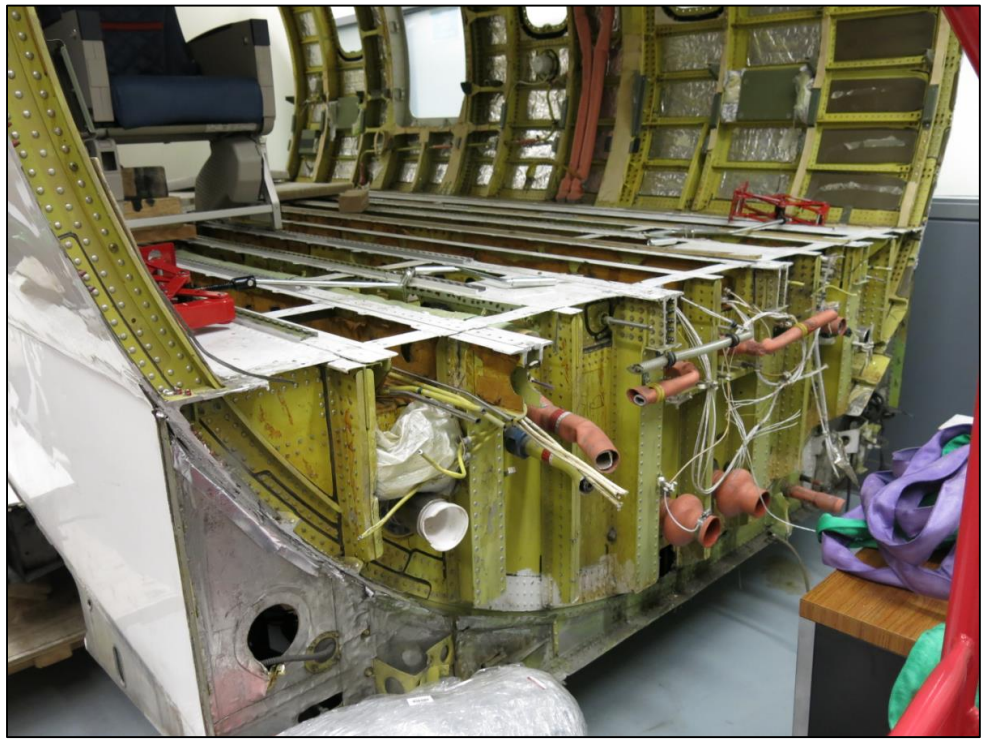
Challenger 601 Model



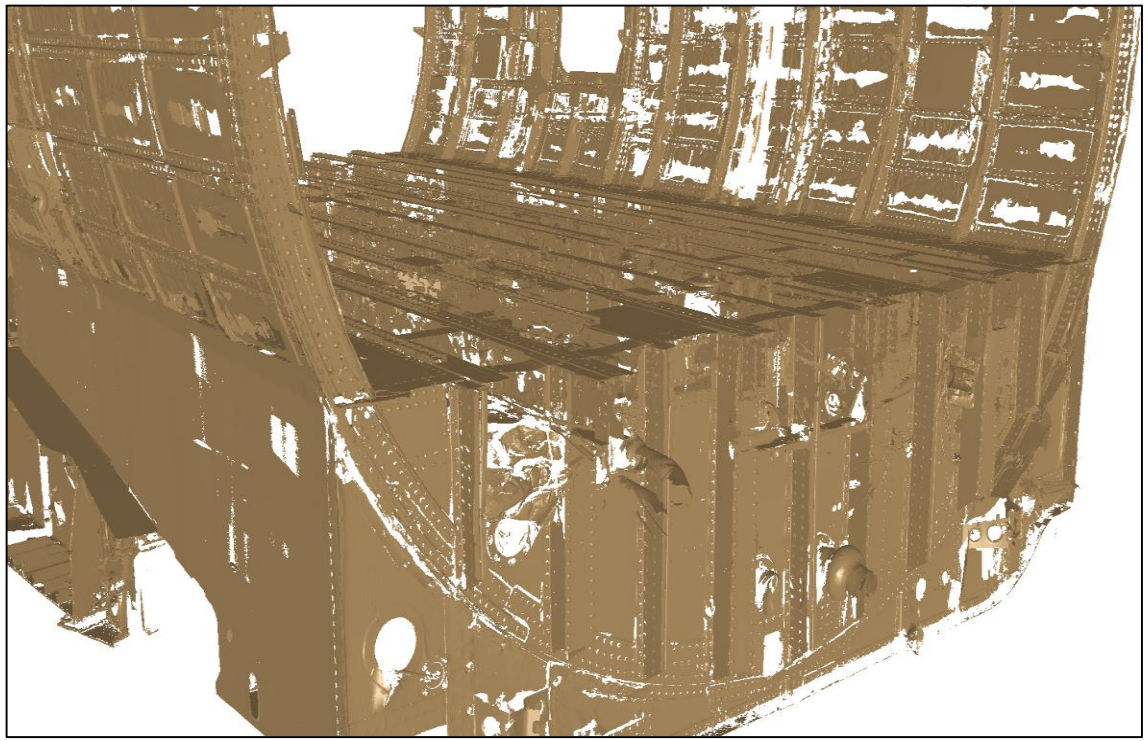
Challenger 601 Scan

Challenger 601 Drop Test Scan

Scans vs Pictures



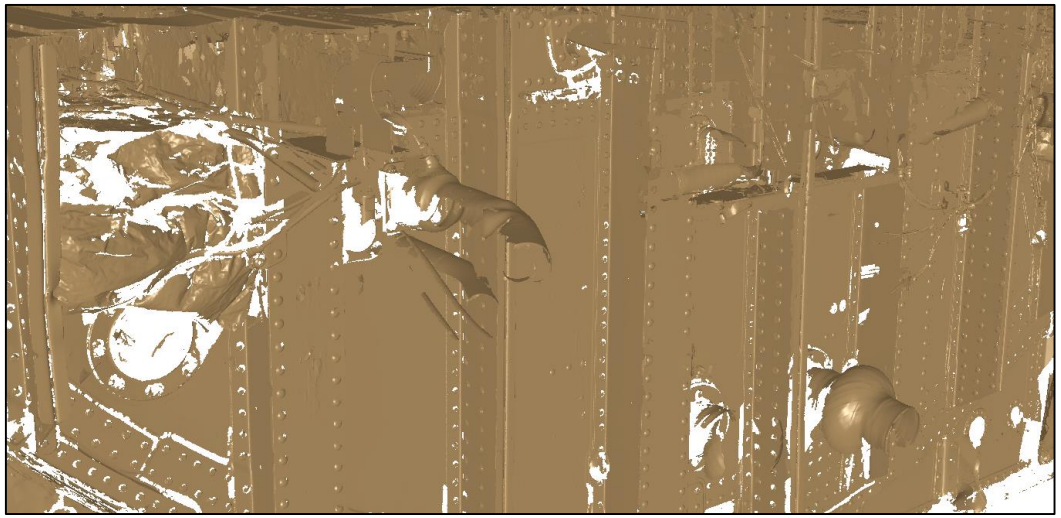
Challenger 601 Model



Challenger 601 Scan

Challenger 601 Drop Test Scan

Scans vs Pictures



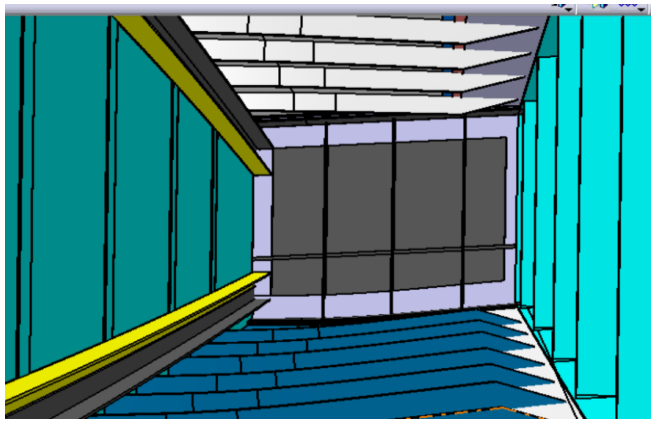
Challenger 601 Model

Challenger 601 Scan

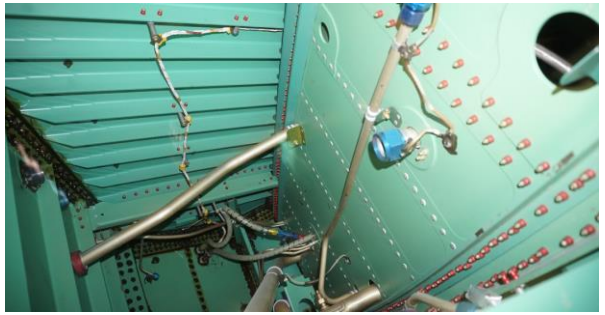
CL601 Wing-box Reverse Engineering

CAD Model

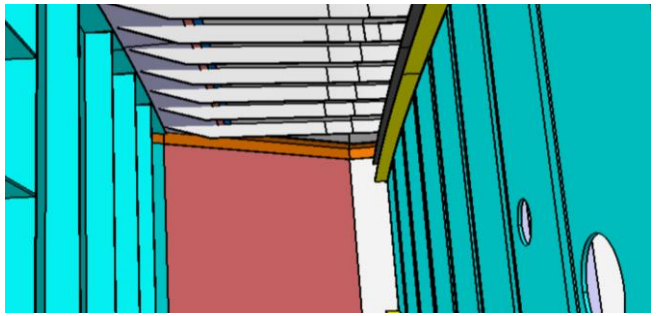
Wingbox- Looking Aft



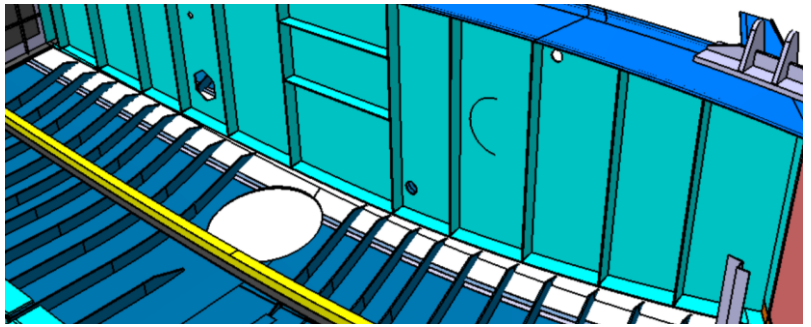
Wingbox- Looking Aft



Wingbox- Looking Forward



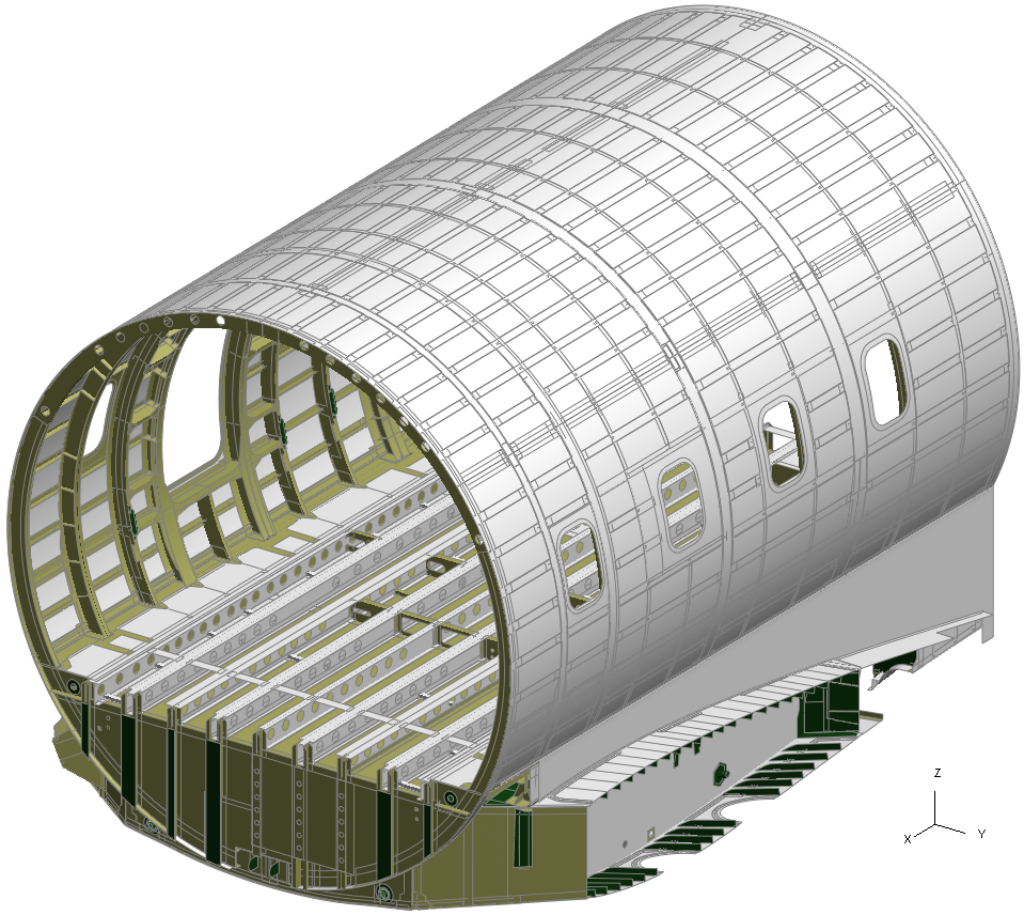
Wingbox- Looking Forward



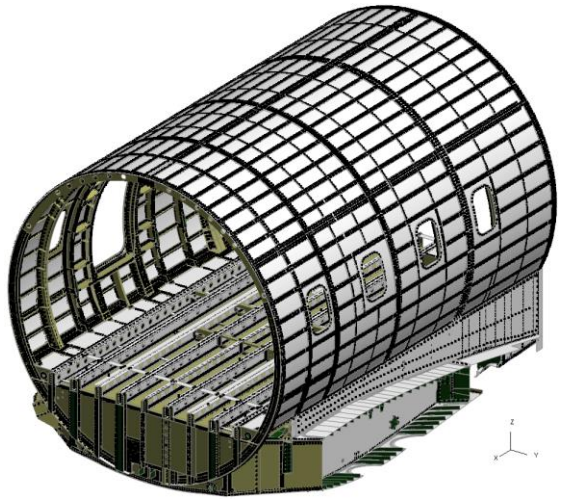
Outermost Rib

Challenger 601 – CAD and FEM

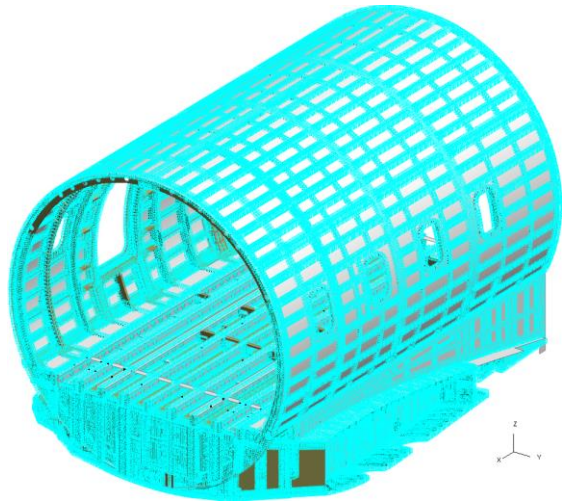
Pre-Test Simulations



1,131,033 shells



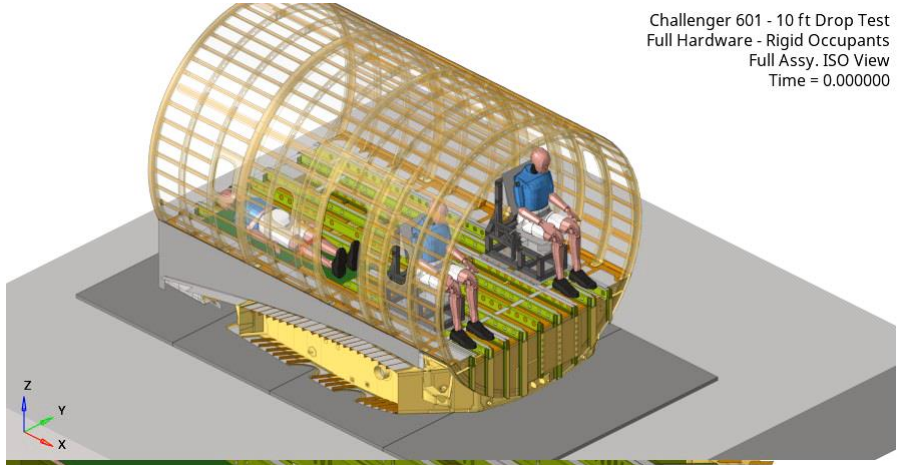
78,255 Fasteners

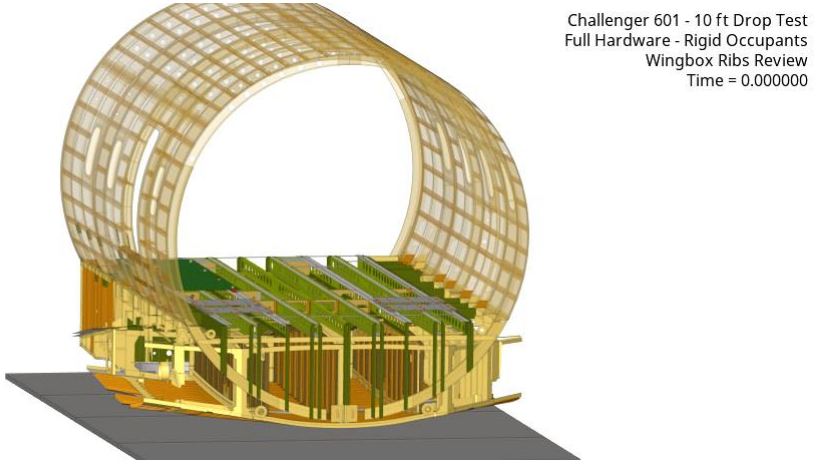


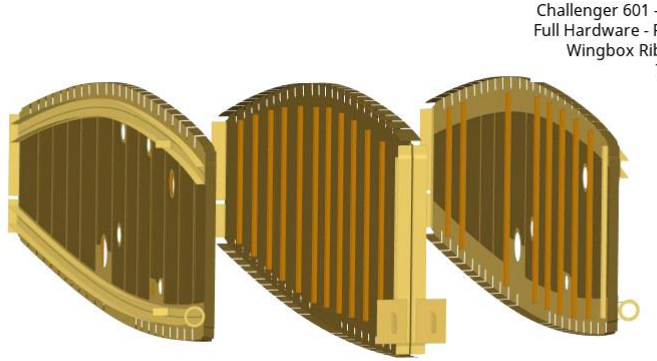
- Fuselage Empty:
  - TA: 2795.00 lb
  - Model: 2795.02 lb
    - Seat tracks included on fuselage weight. *ELEMENT_MASS readjusted.

Pre-Test Simulation

Pre-Test Simulations CL601 – 30ft/s Drop Test

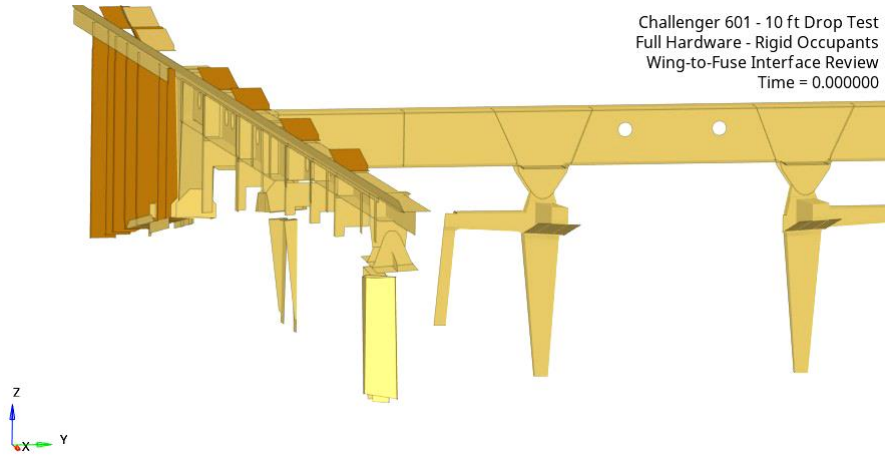


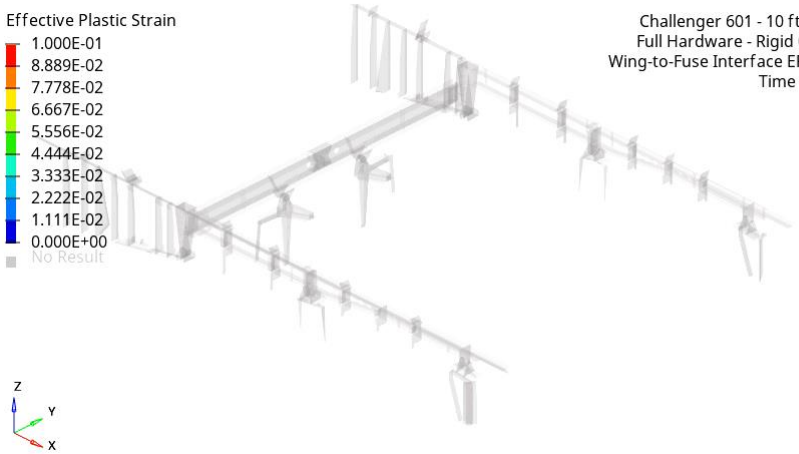


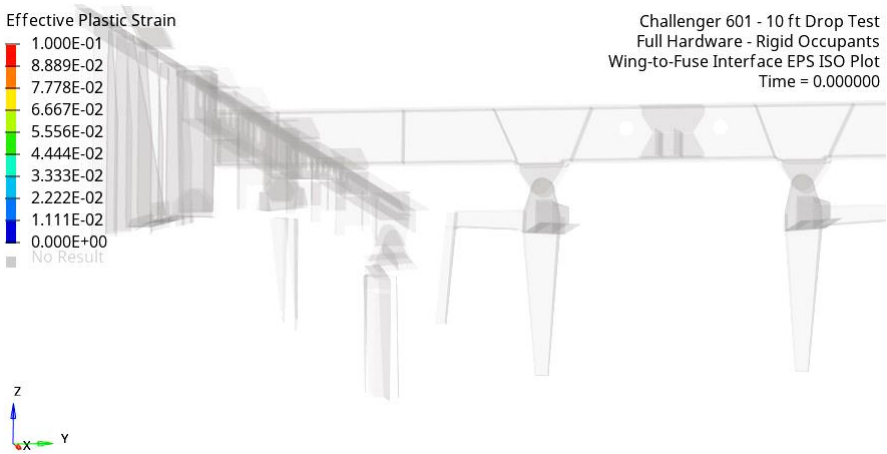


Pre-Test Simulation

Pre-Test Simulations



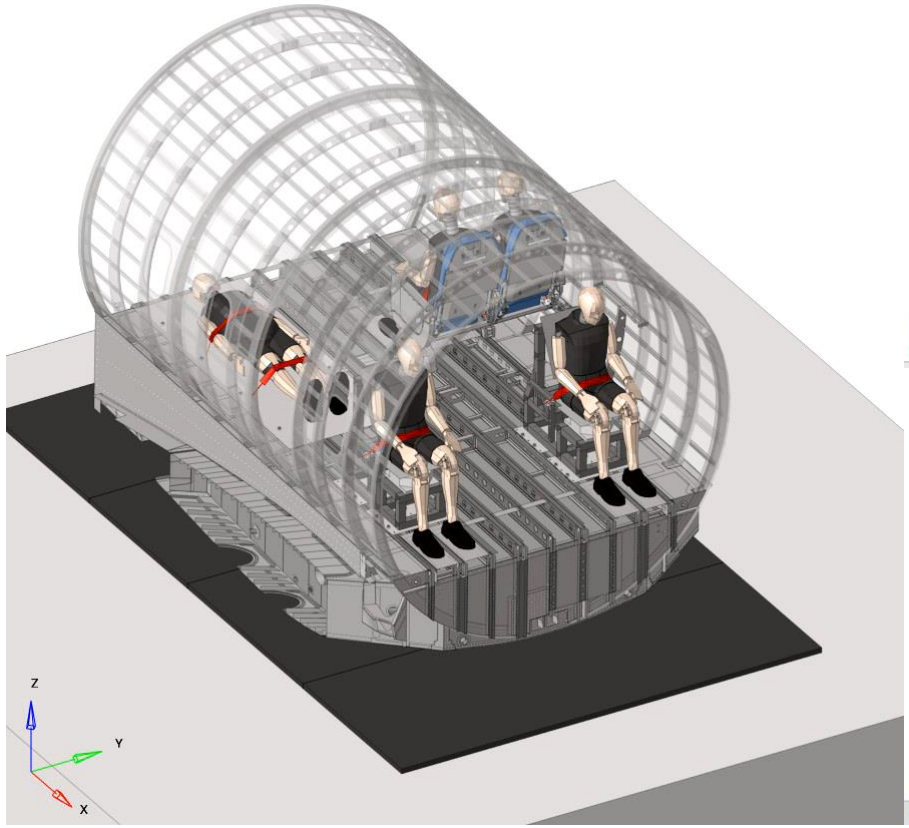




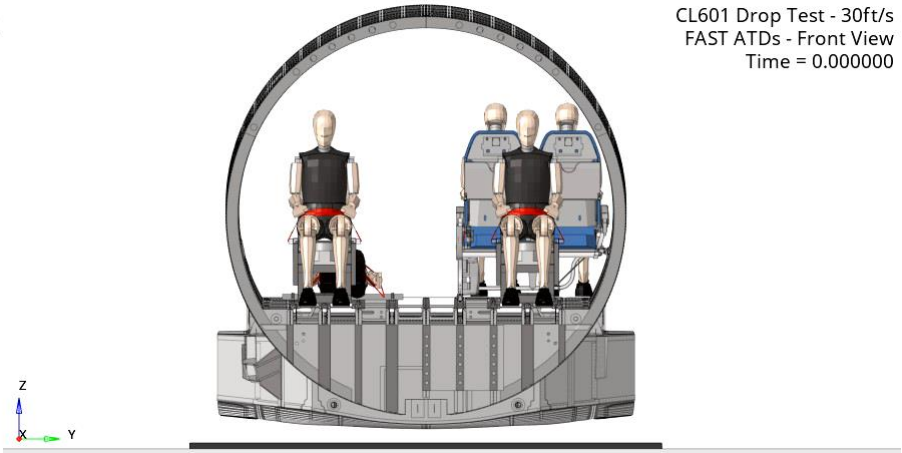
Fuselage and ATD Response

Pre-Test Simulations

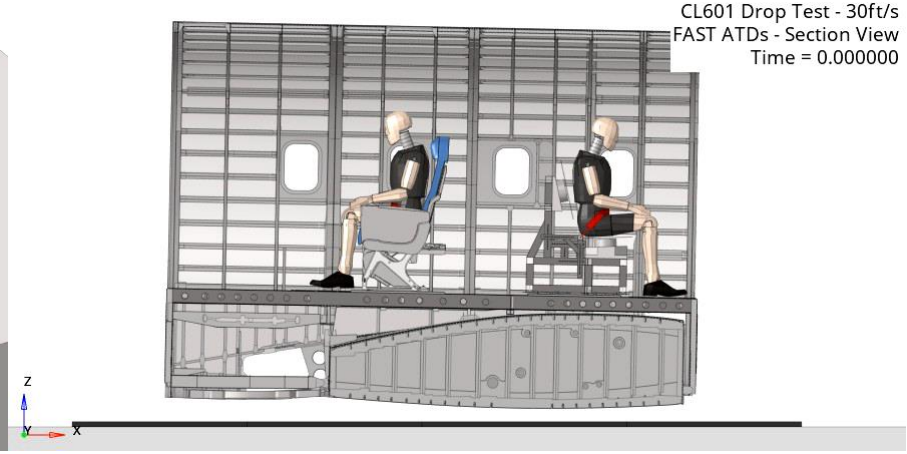
CL601 Drop Test - 30ft/s
FAST ATDs - ISO View
Time = 0.000000



CL601 Drop Test - 30ft/s
FAST ATDs - Front View
Time = 0.000000



CL601 Drop Test - 30ft/s
FAST ATDs - Section View
Time = 0.000000



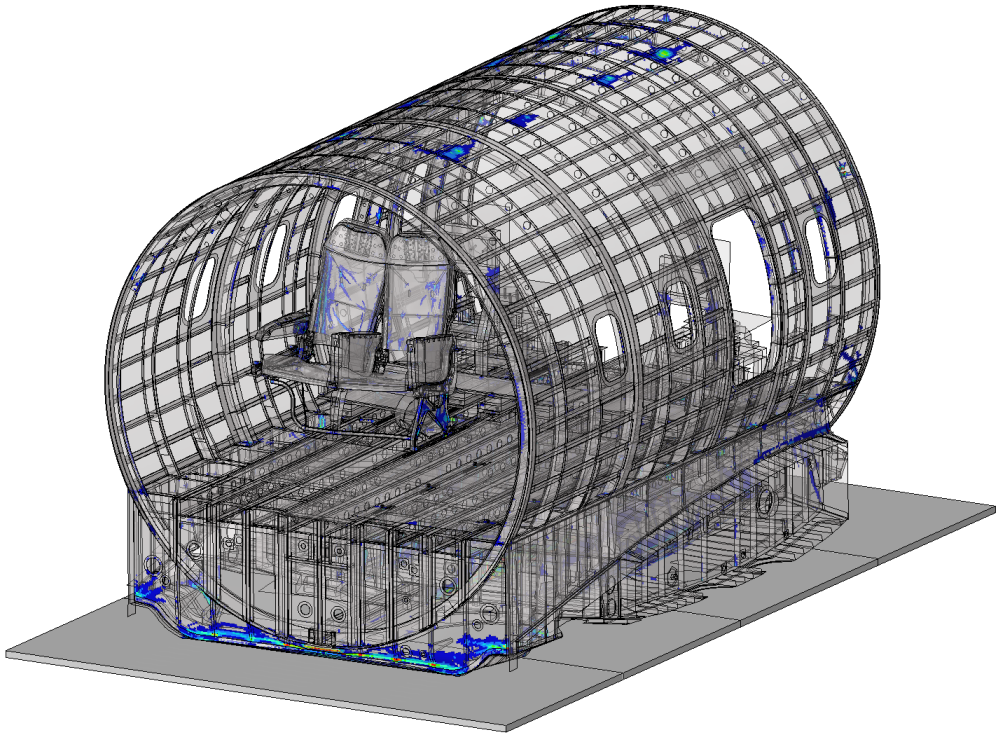
Effective Plastic Strains

Pre-Test Simulations

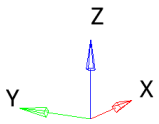
Plastic strain(vonMises, Max)

1.042E-01
9.262E-02
8.104E-02
6.947E-02
5.789E-02
4.631E-02
3.473E-02
2.316E-02
1.158E-02
0.000E+00
No Result

Min = 0.000E+00



Commercial Seat with Occupants
Time = 0.050000

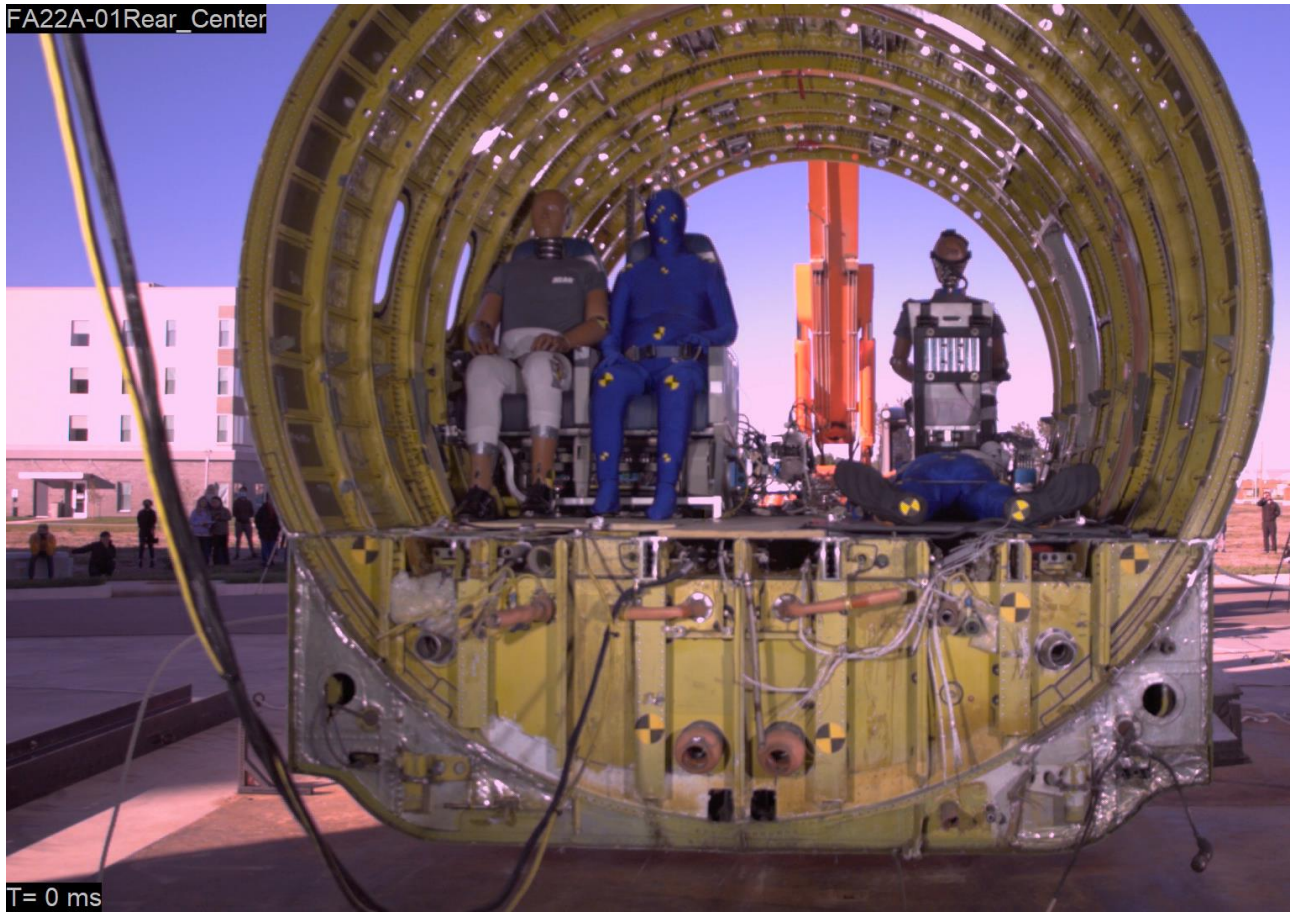


H4000 and CL601 – 30ft/s Drop Test

Fuselage and Occupant Injury Data Comparison: Metallic vs Composite

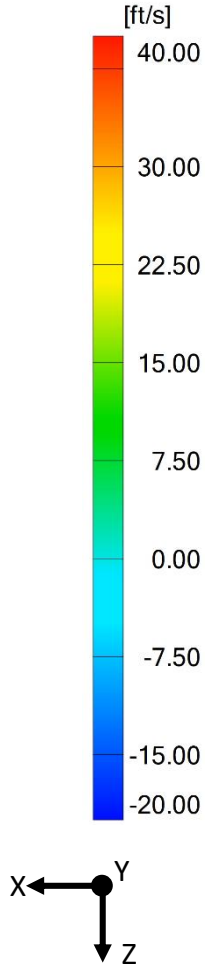
CL601-3A Drop Test

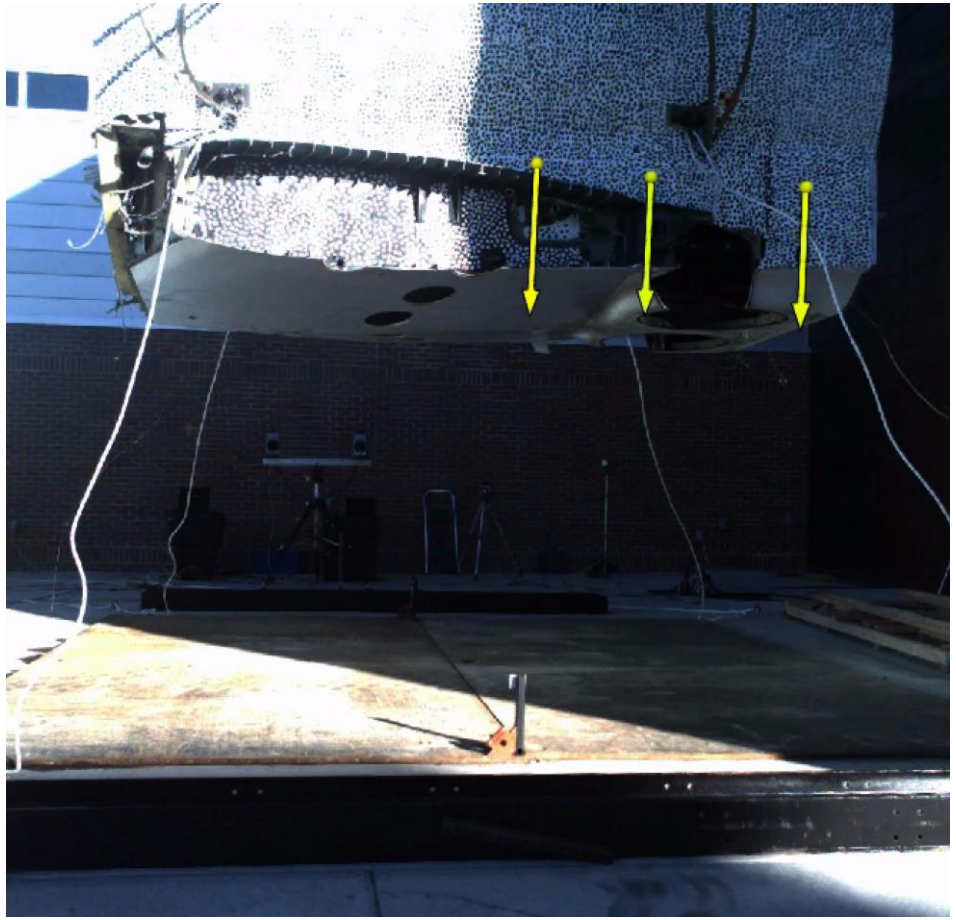
Test Results – High Speed Videos

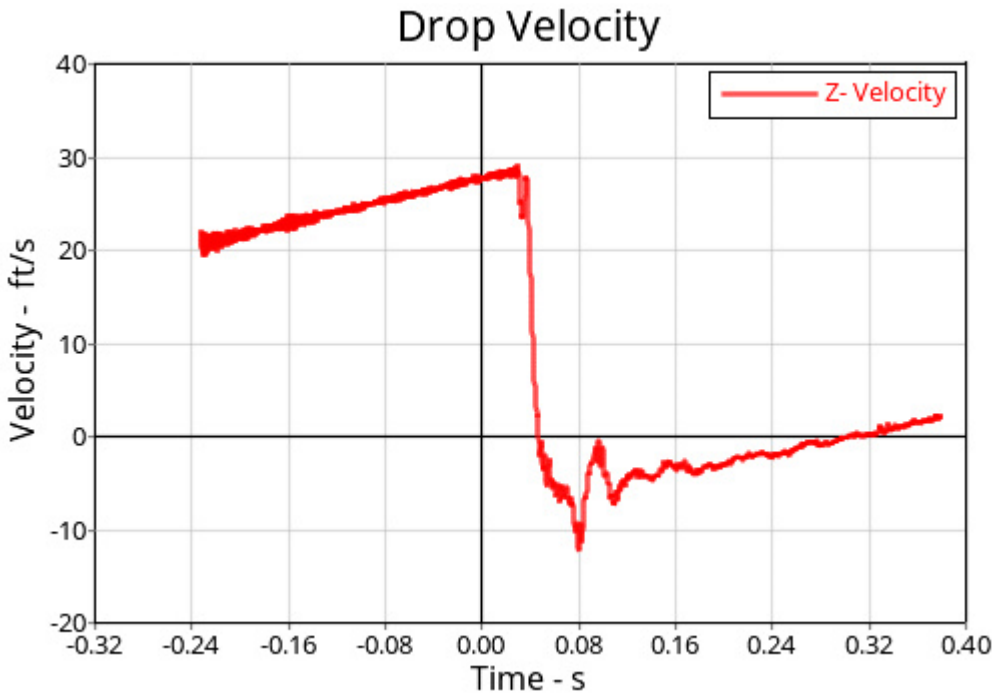


Fuselage Vertical Velocity Change

CL601 – 30ft/s Drop Test

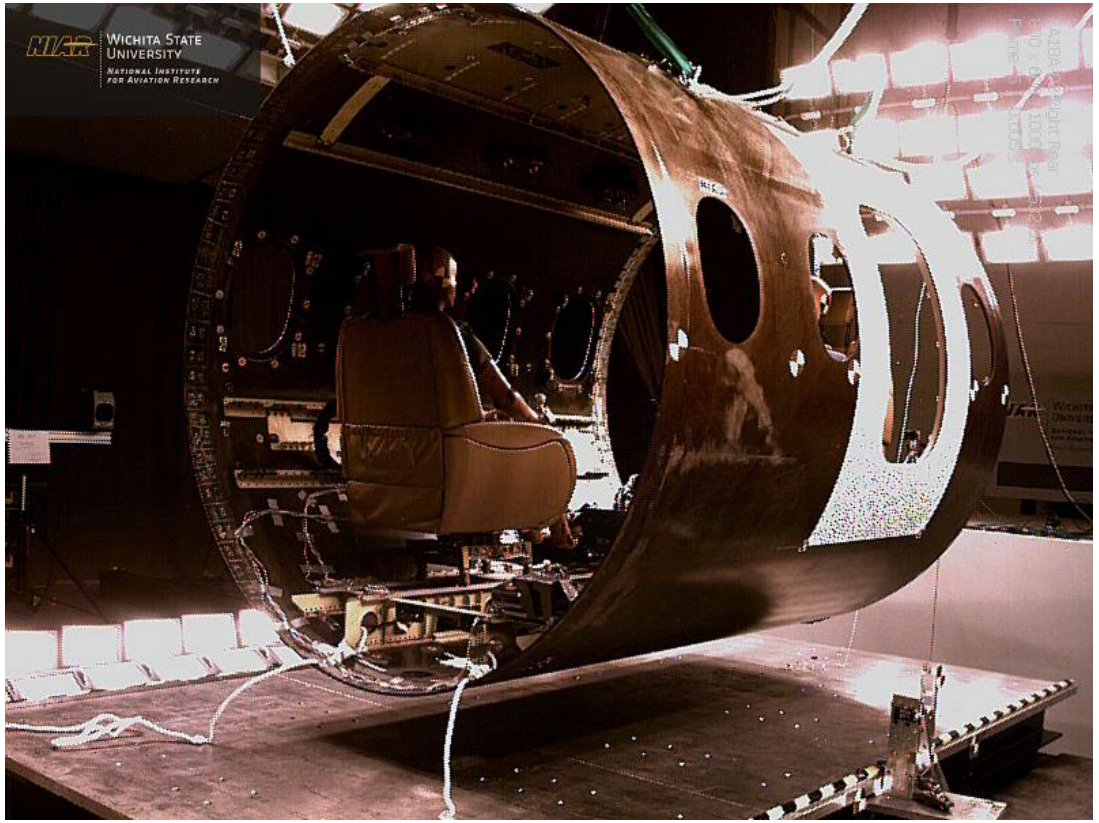


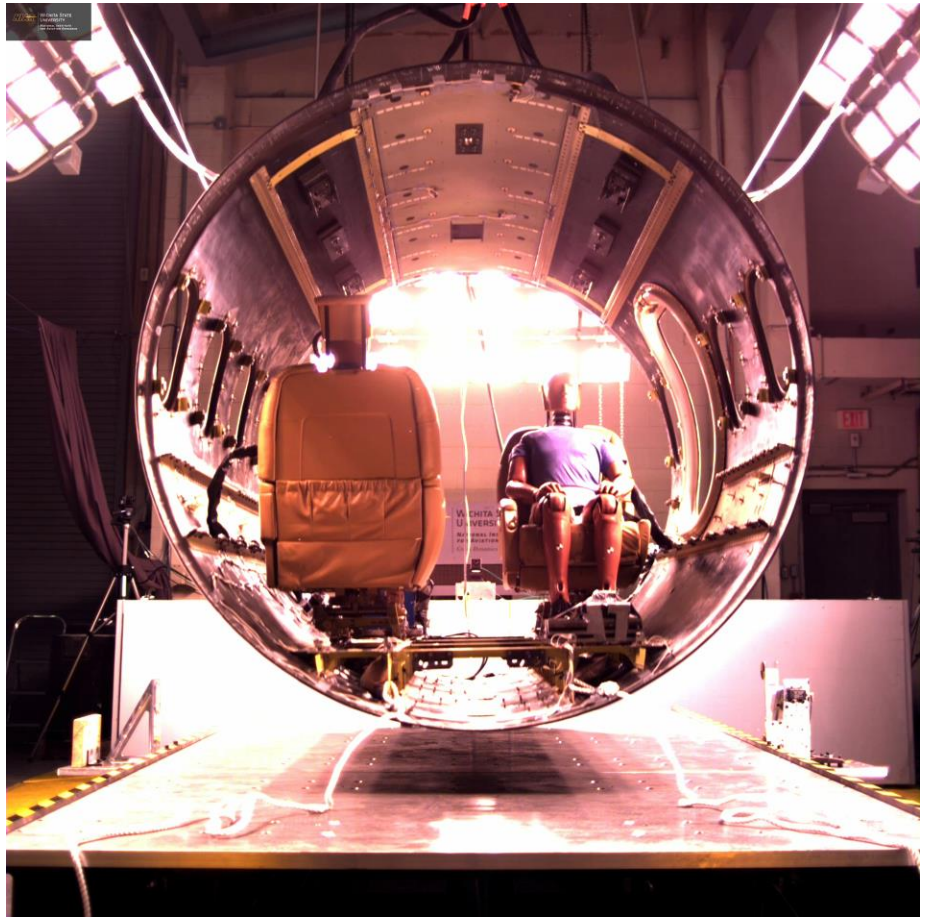




H4000 Drop Test

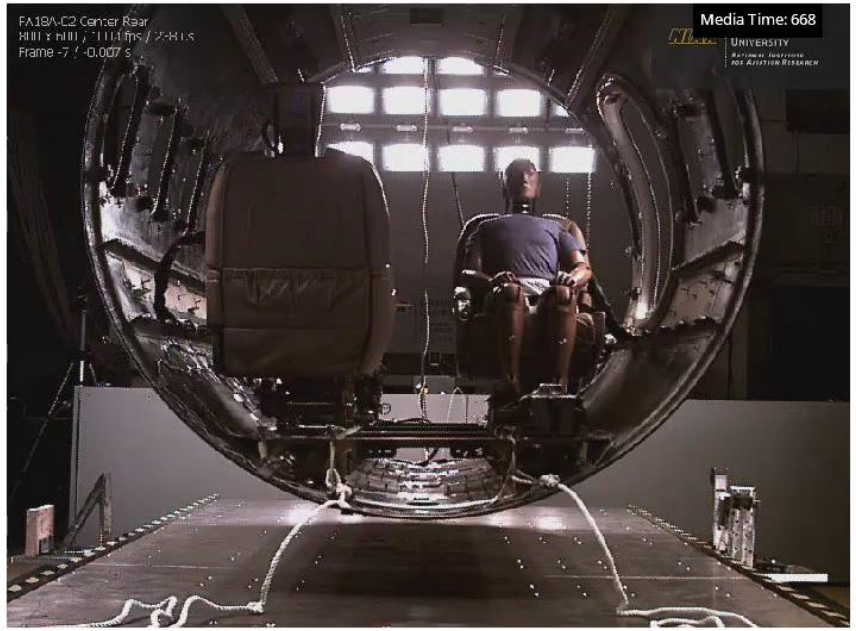
Test Results – High Speed Videos





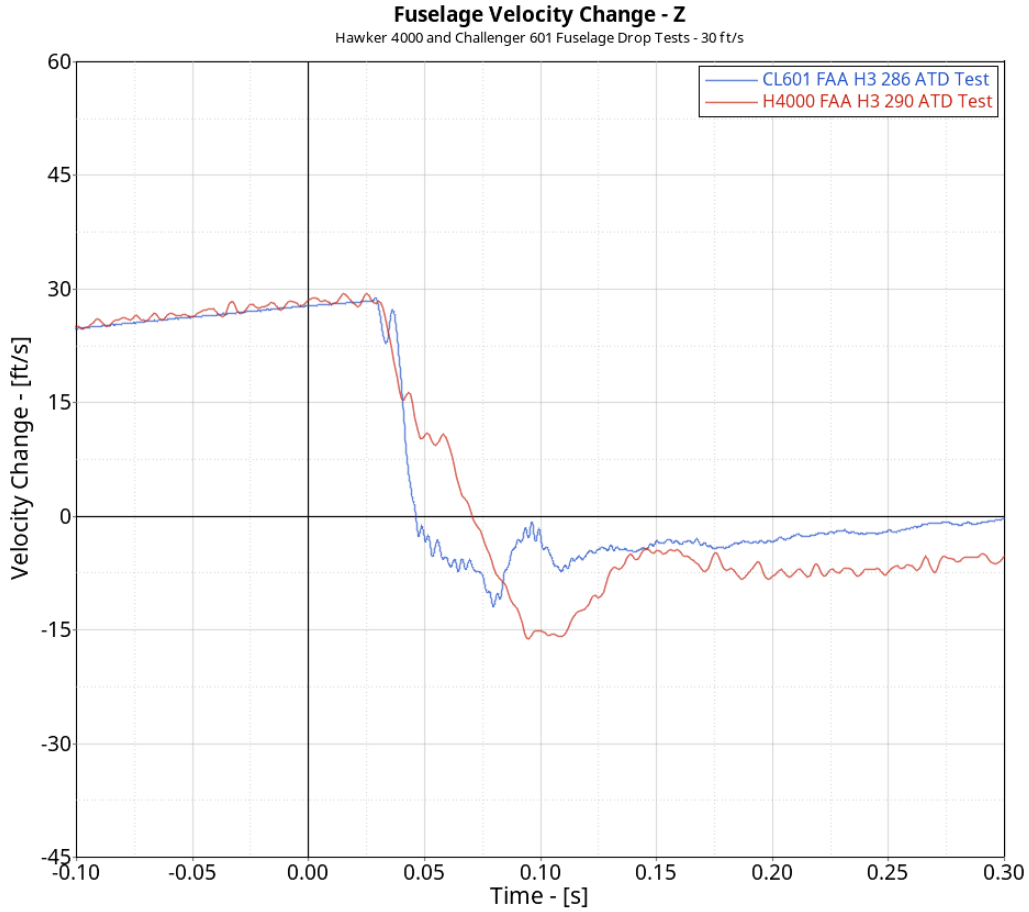
Center Rear View HSV

H4000 and CL601 – 30ft/s Drop Test



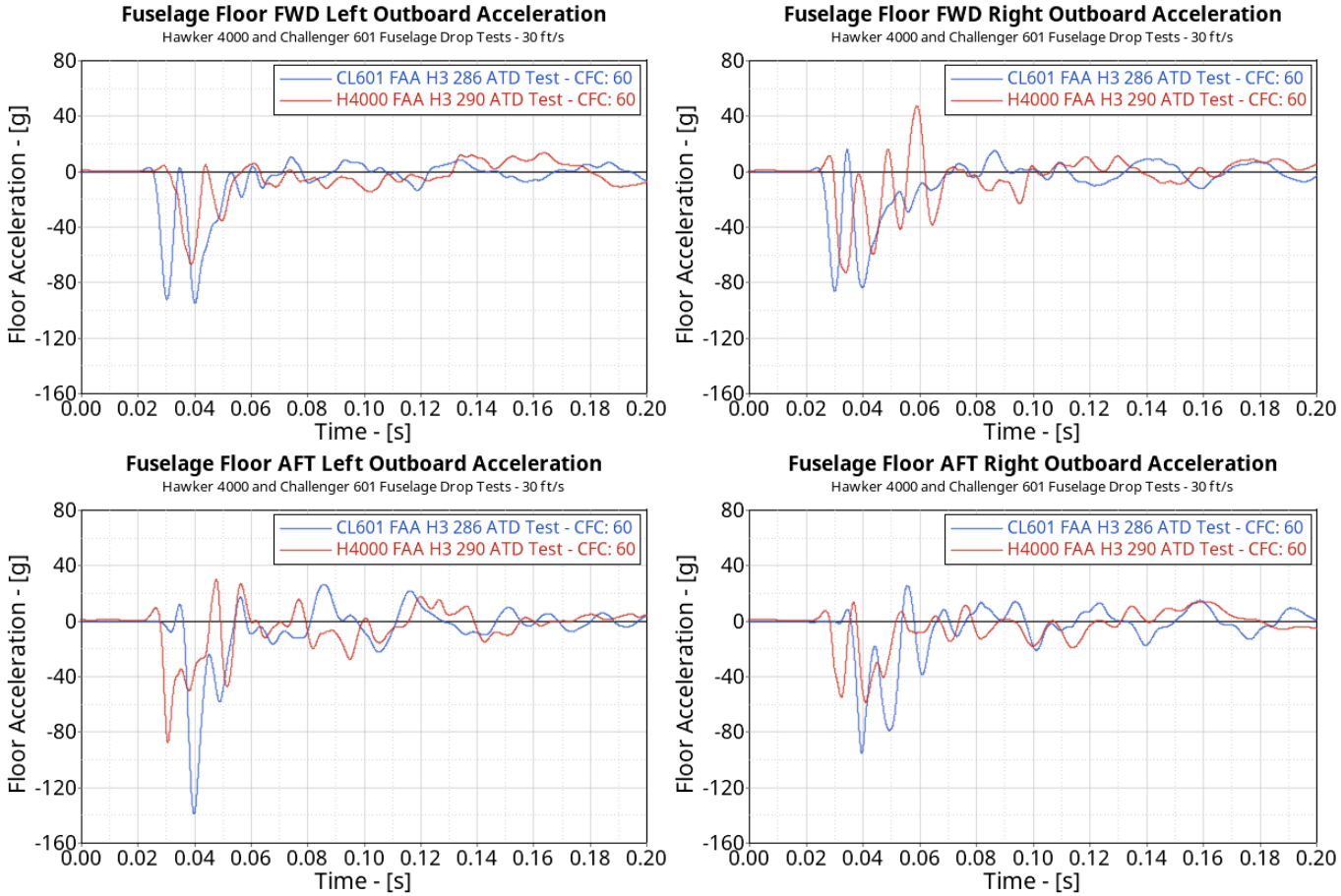
Fuselage Vertical Velocity Change

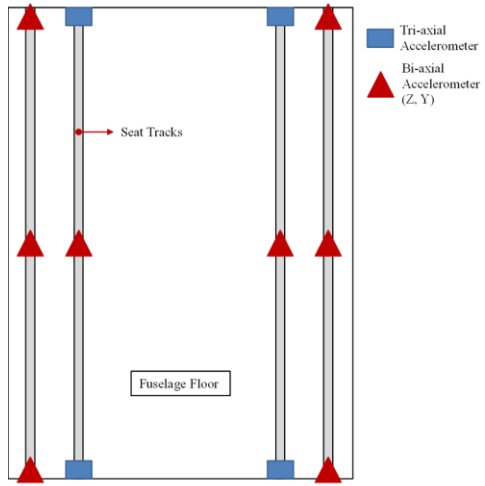
H4000 and CL601 – 30ft/s Drop Test



Fuselage Floor Accelerations

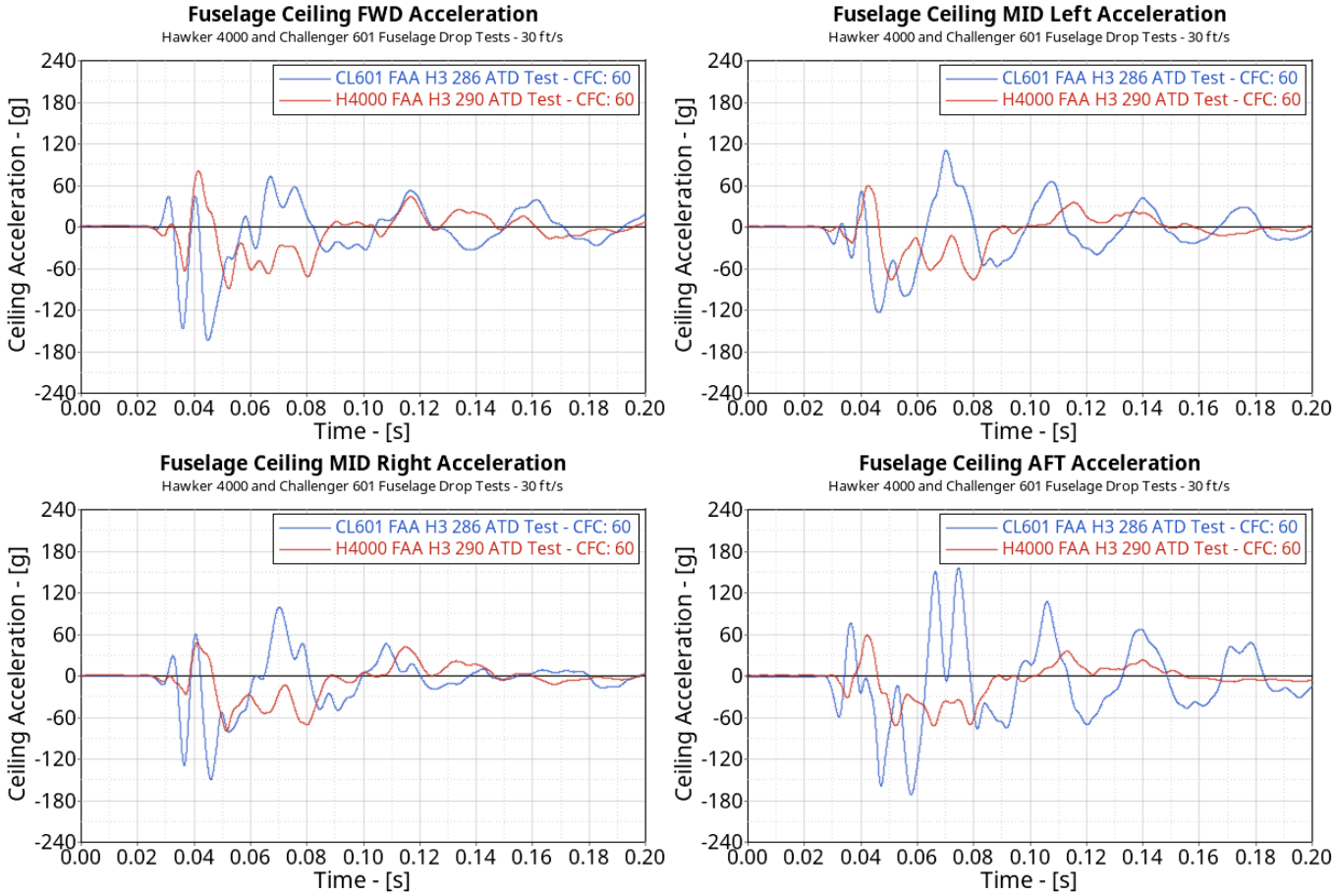
H4000 and CL601 – 30ft/s Drop Test

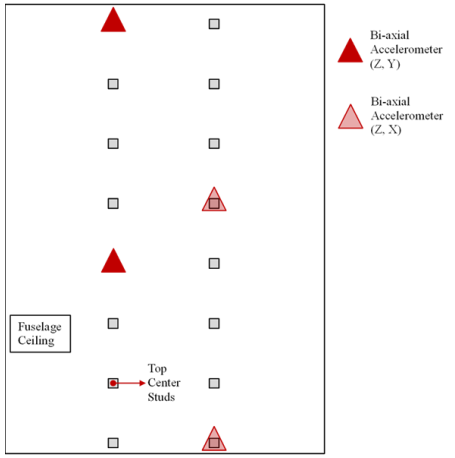




Fuselage Ceiling Accelerations

H4000 and CL601 – 30ft/s Drop Test



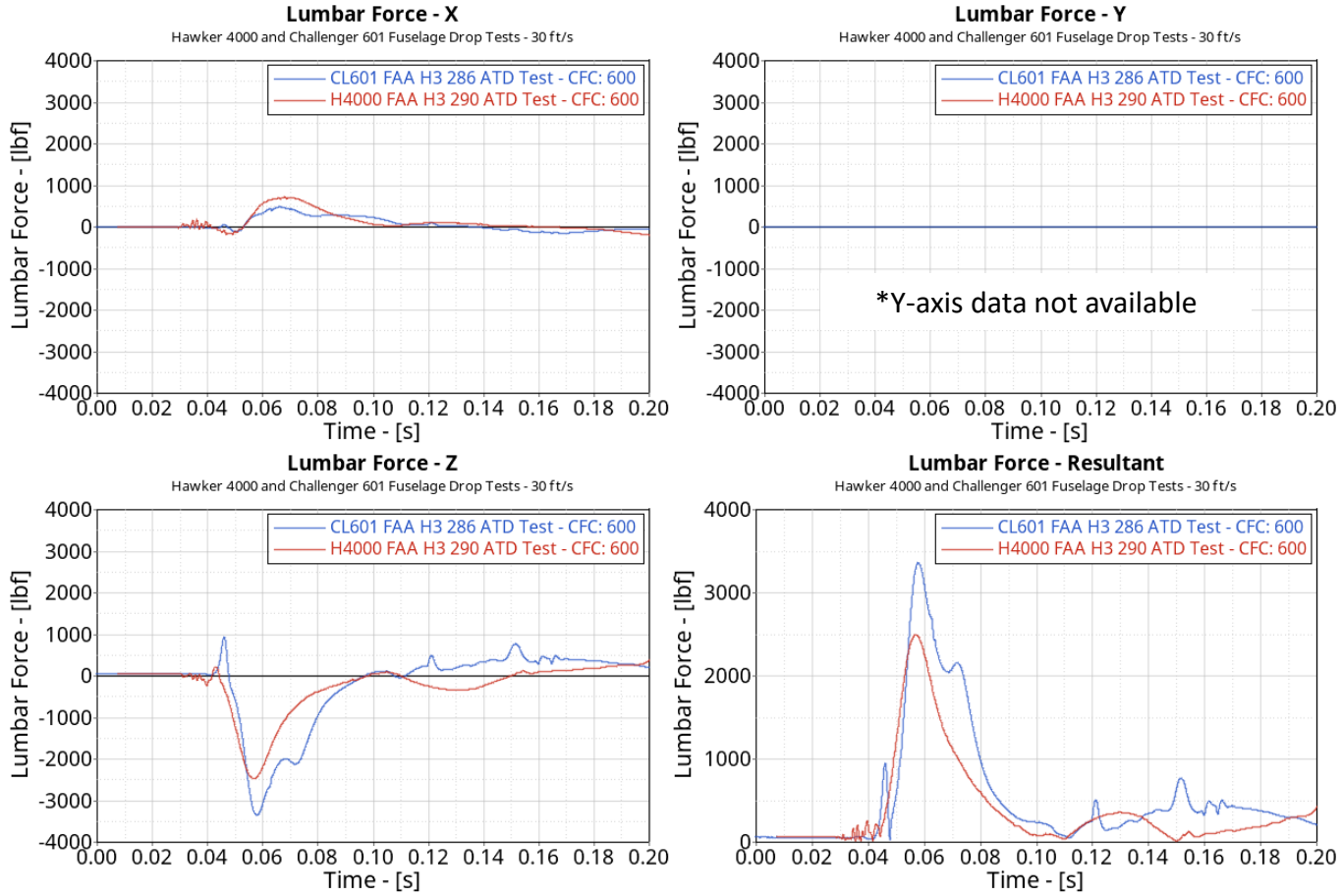


H4000 and CL601 – 30ft/s Drop Test

ATD Data Comparison

FAA HIII 50th – Lumbar Forces

H4000 and CL601 – 30ft/s Drop Test



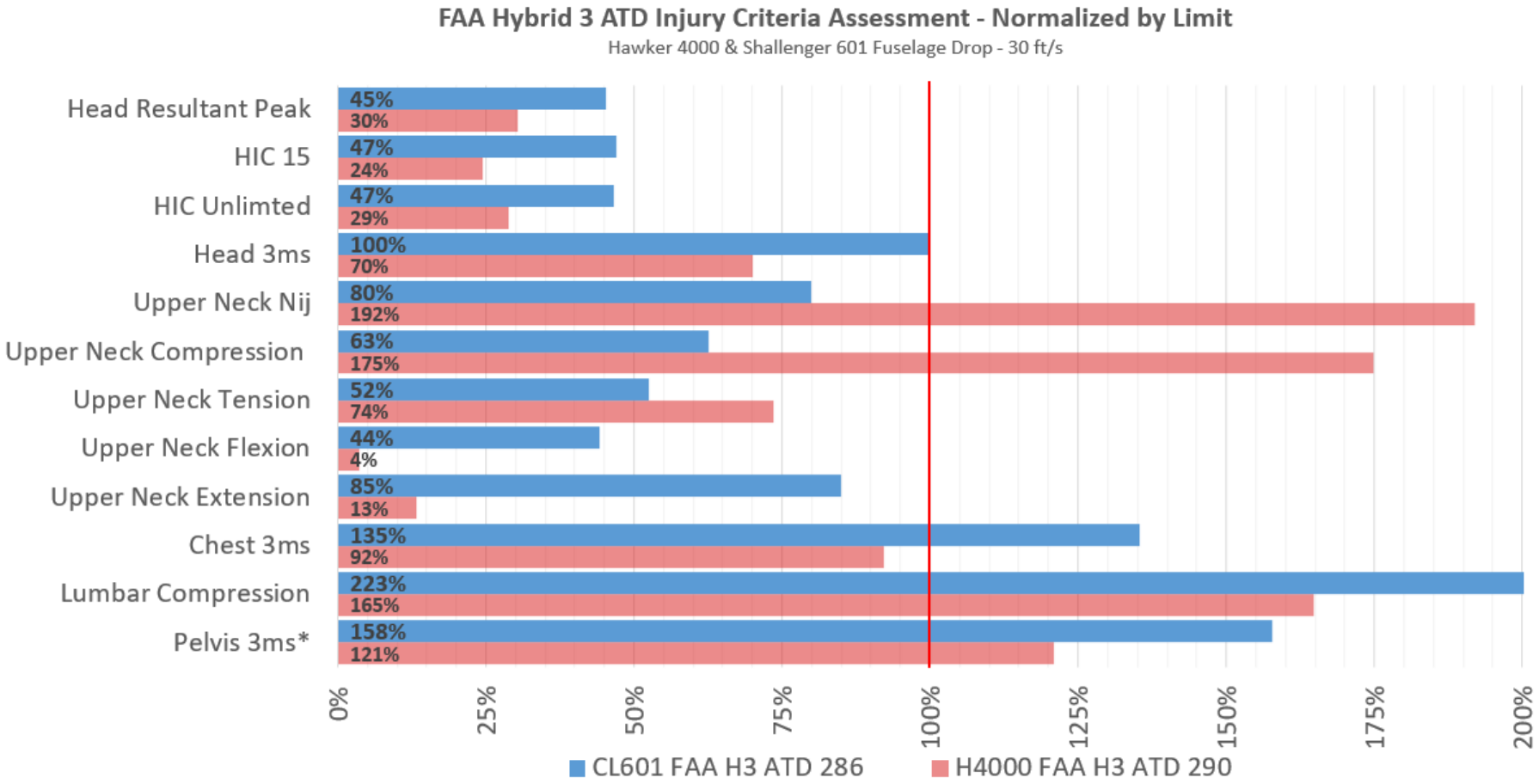
ATD Data Comparison

H4000 and CL601 – 30ft/s Drop Test

		Occupant Injury Metric Summary		
		Limit Value	CL601 FAA H3 286	H4000 FAA H3 290
Injury Metric	Head Resultant Peak (g)	200	90.76	60.9
	HIC 15	700	328.5	171
	HIC Unlimted	1000	466.93	289.2
	Head 3ms (g)	80	79.94	56.04
	Upper Neck Nij	1	0.8	1.92
	Upper Neck Compression (lbf)	1384.8	866.56	2421.26
	Upper Neck Tension (lbf)	1530.0	802.49	1124.73
	Upper Neck Flexion (ft-lbf)	140	61.81	5.18
	Upper Neck Extension (ft-lbf)	-42	-35.70	-5.58
	Chest 3ms (g)	60	81.17	55.36
	Lumbar Compression (lbf)	1500	3352.29	2471.86
	Pelvis 3ms (g)	60	94.66	72.51

ATD Data Comparison

H4000 and CL601 – 30ft/s Drop Test



CL601 – 30ft/s Drop Test

Post Test Damage Evaluation

Seat Post Test – CL601

H4000 and CL601 – 30ft/s Drop Test

Seat Post Test – CL601

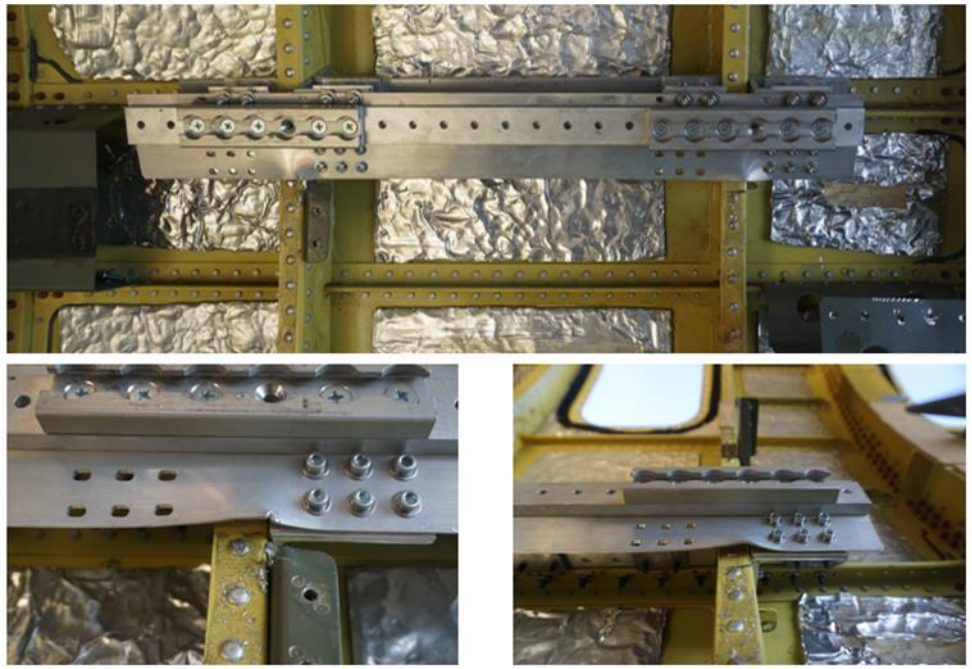
H4000 and CL601 – 30ft/s Drop Test

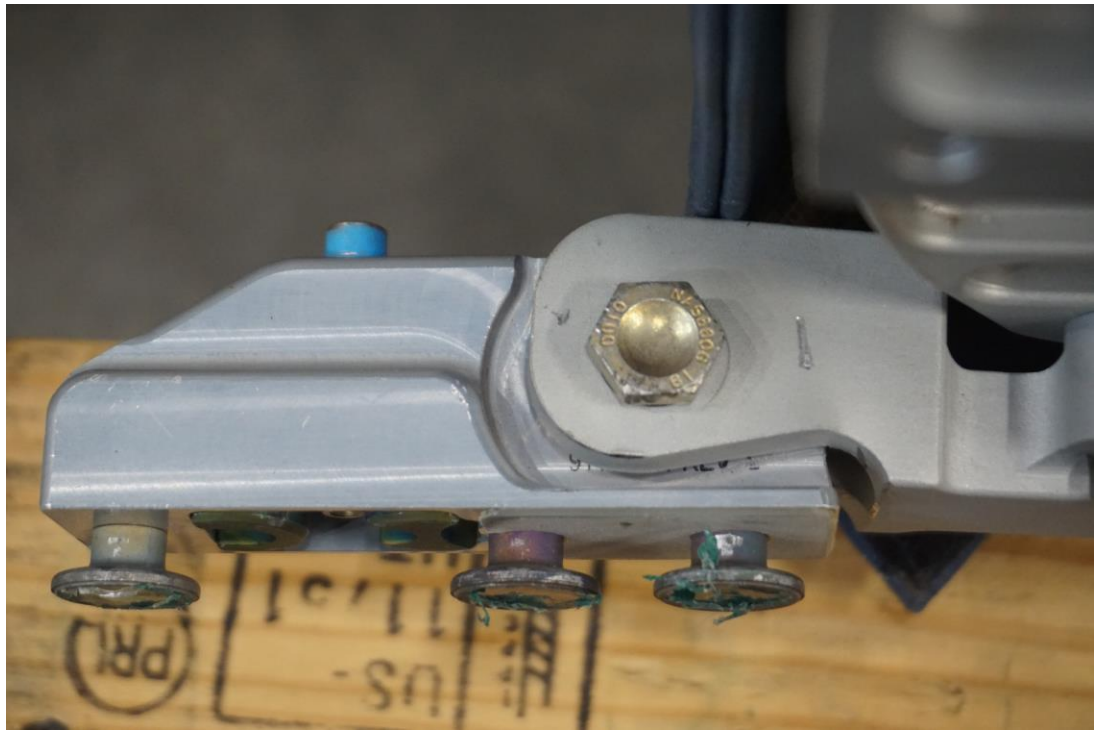
Seat Post Test – CL601

H4000 and CL601 – 30ft/s Drop Test

Seat Post Test – CL601

H4000 and CL601 – 30ft/s Drop Test





Seat Post Test – CL601

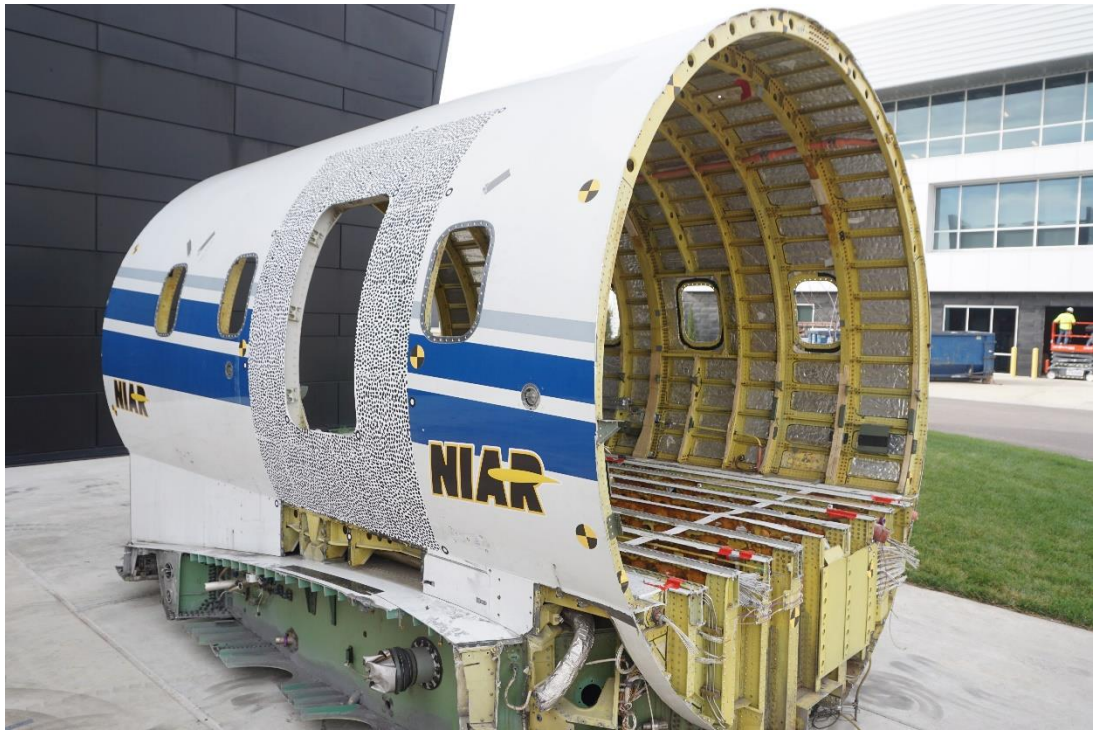
H4000 and CL601 – 30ft/s Drop Test

Seat Post Test – CL601

H4000 and CL601 – 30ft/s Drop Test

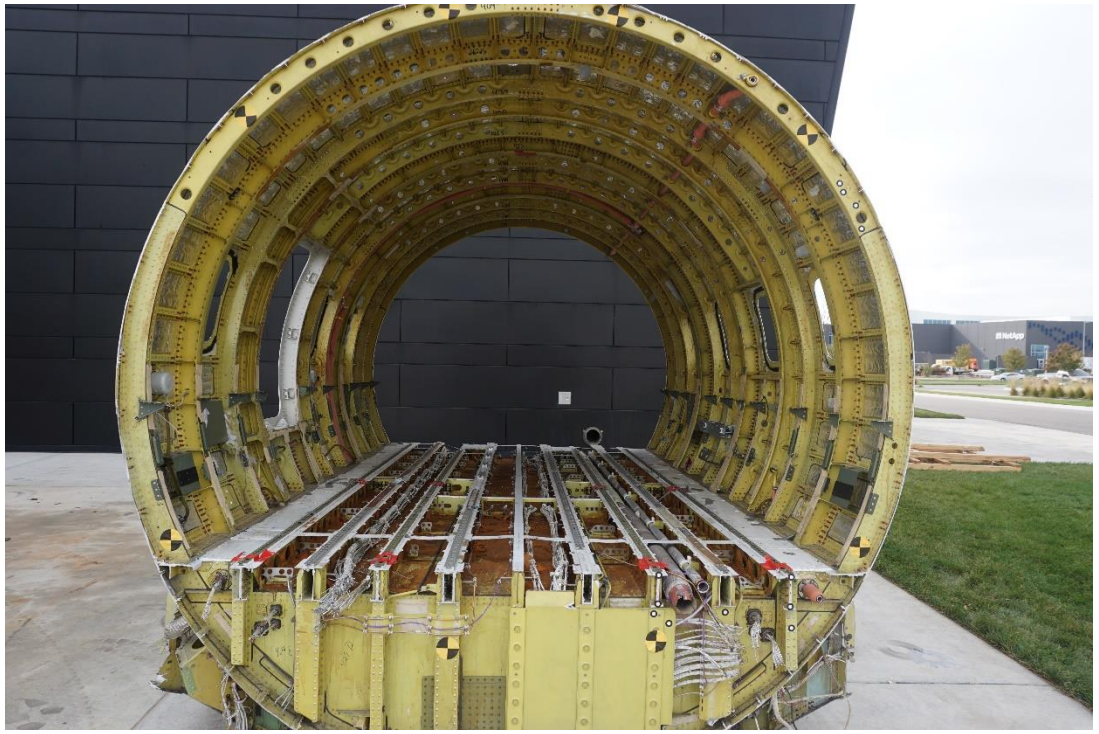
Seat Post Test – CL601

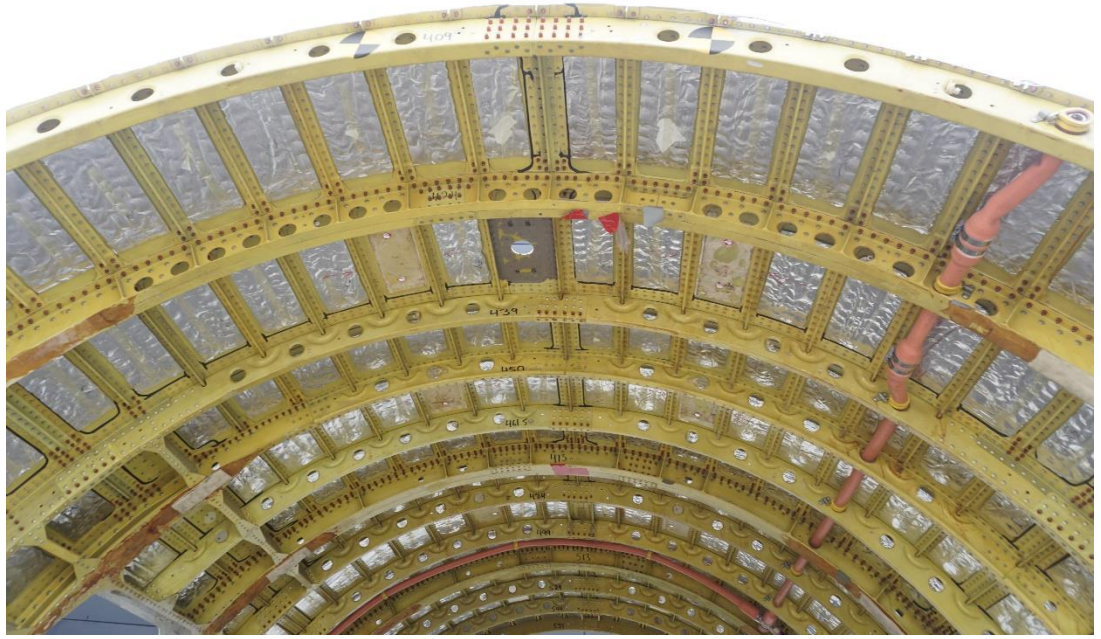
H4000 and CL601 – 30ft/s Drop Test



Seat Post Test – CL601

H4000 and CL601 – 30ft/s Drop Test





Seat Post Test – CL601

H4000 and CL601 – 30ft/s Drop Test

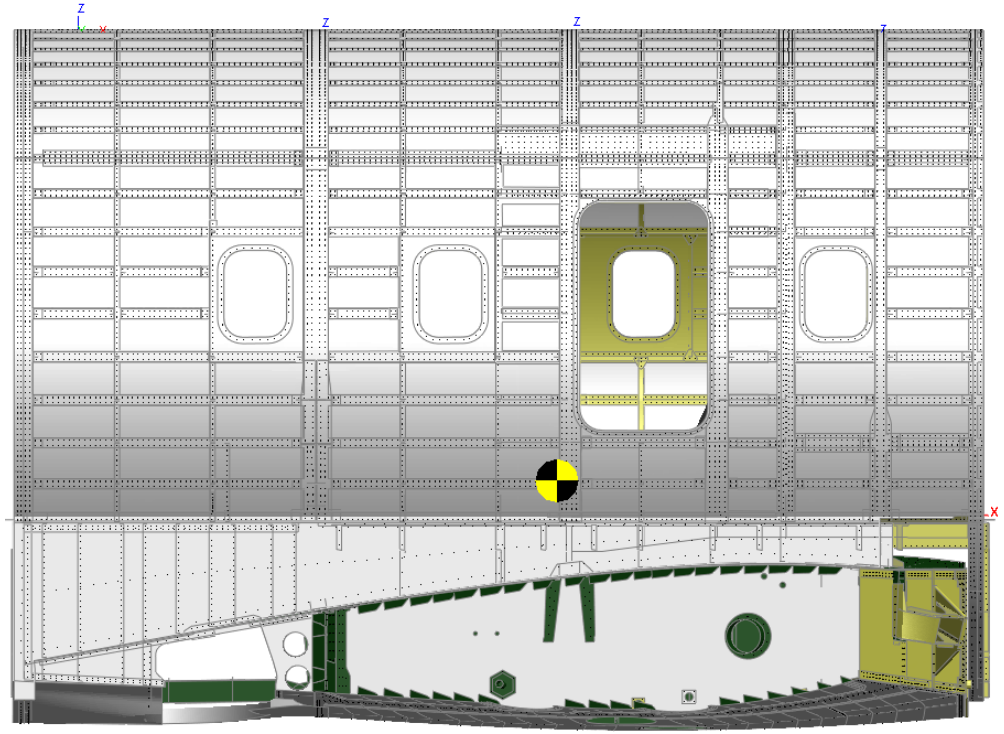
CL601 – 30ft/s Drop Test

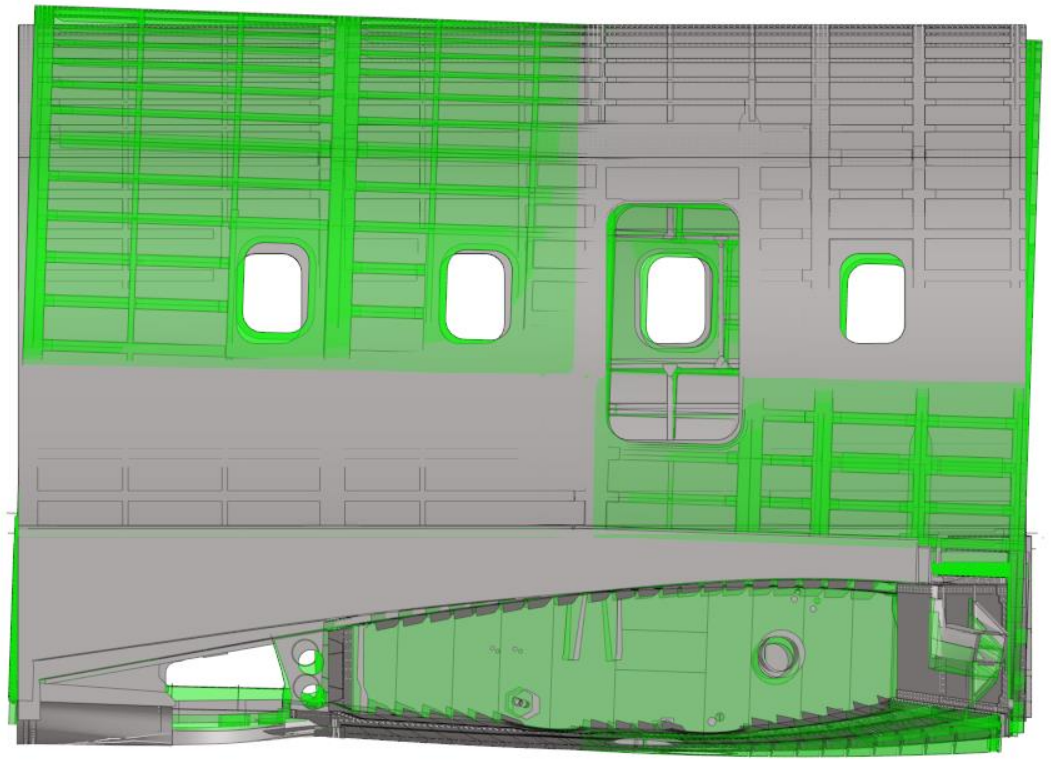
Certification by Analysis Modeling Methods Validation

Adjustments per Test Initial Conditions

Certification by Analysis

- Whole fuselage was rotated by 2 deg. before impact. Only the initial Position and impact velocity were adjusted.



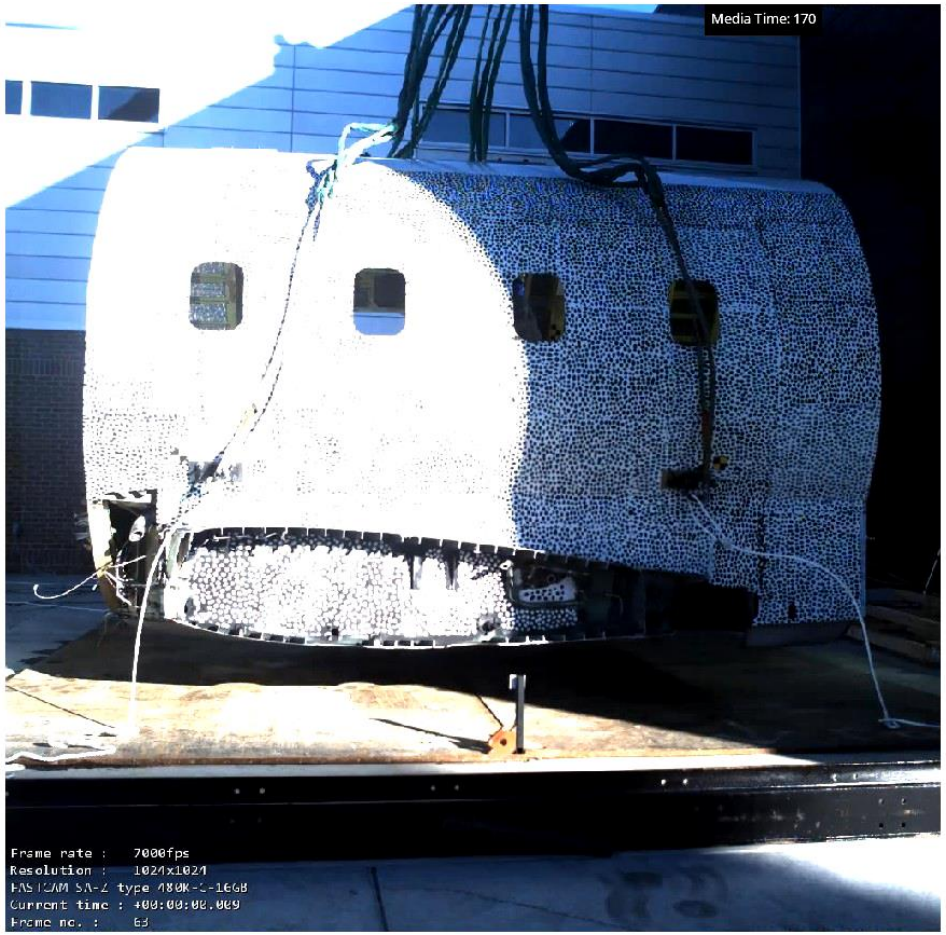


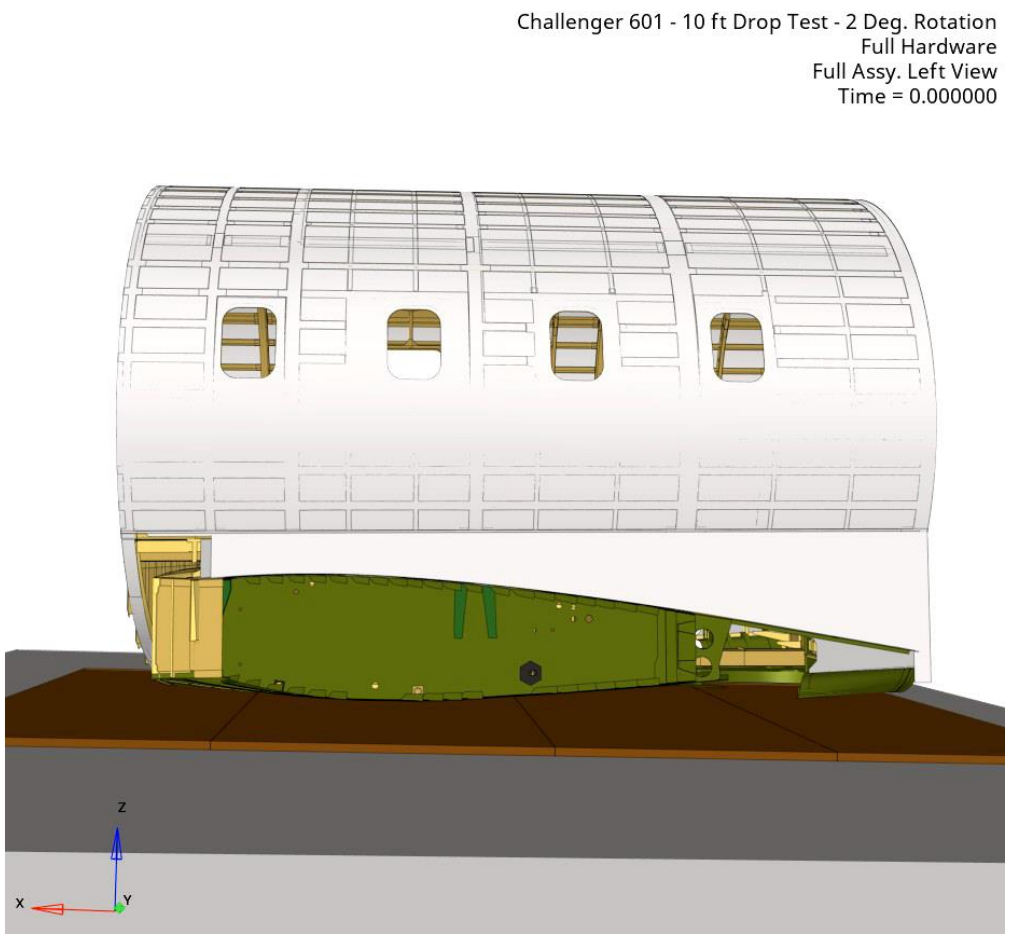
Baseline

Rotated from FEM CG

Challenger 601 – Kinematics Prediction

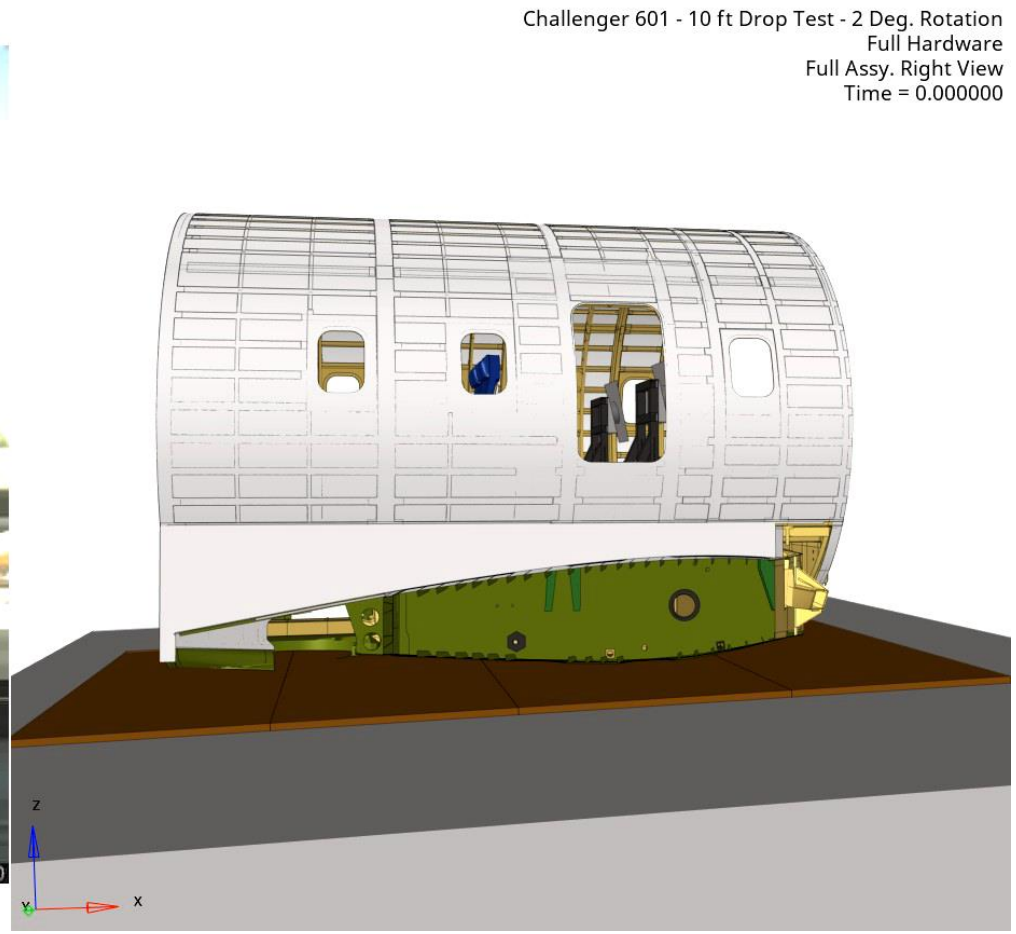
Certification by Analysis





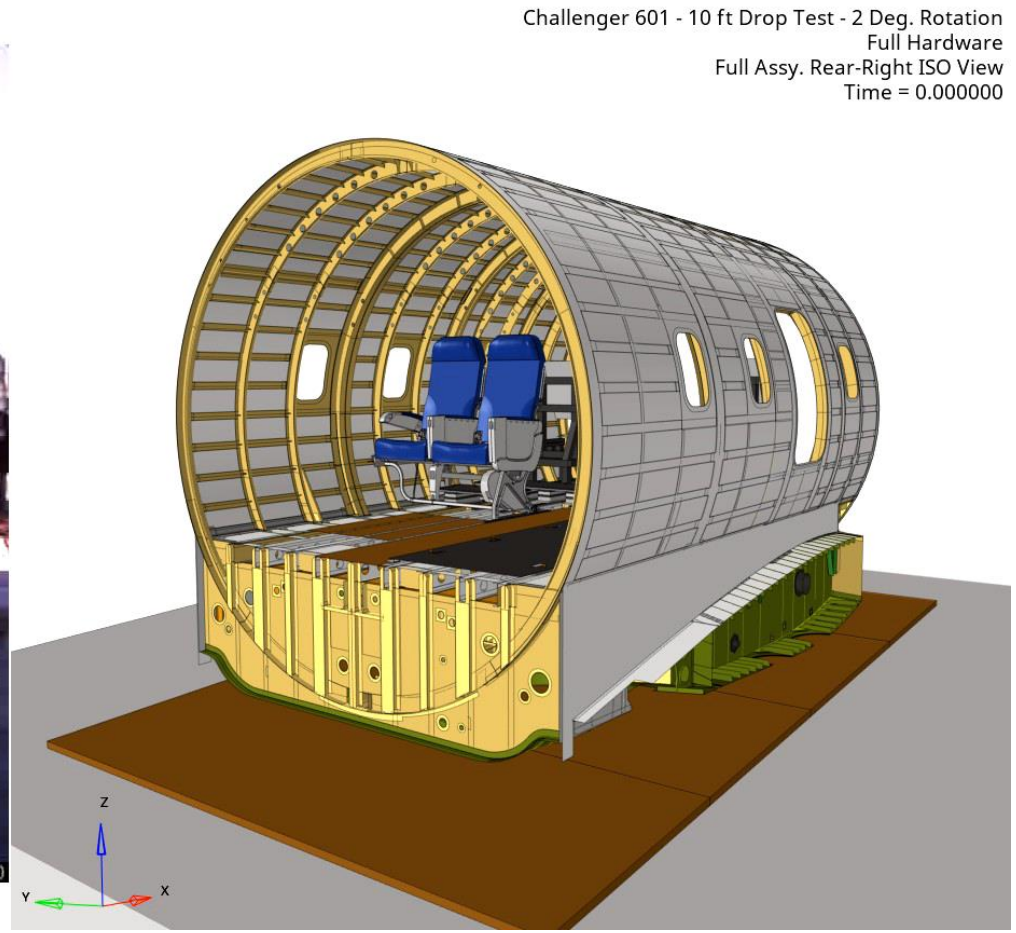
Challenger 601 – Kinematics Prediction

Certification by Analysis



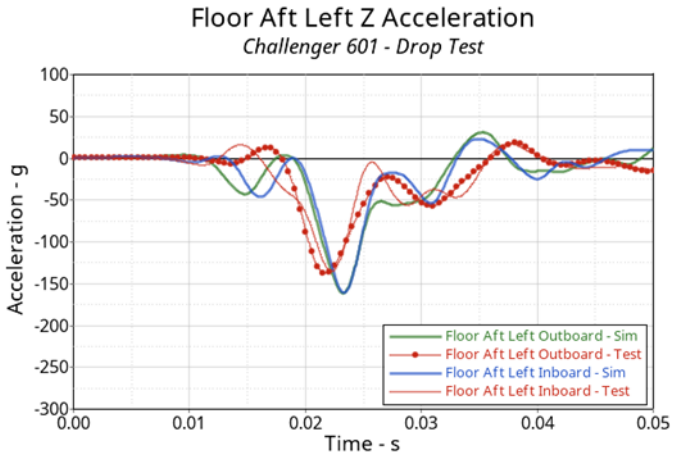
Challenger 601 – Kinematics Prediction

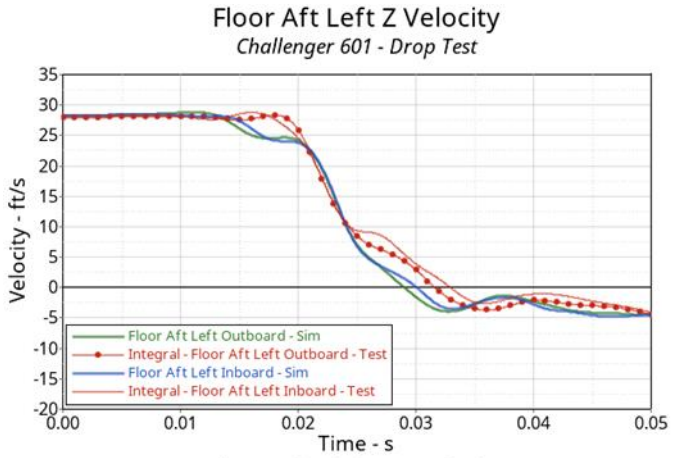
Certification by Analysis

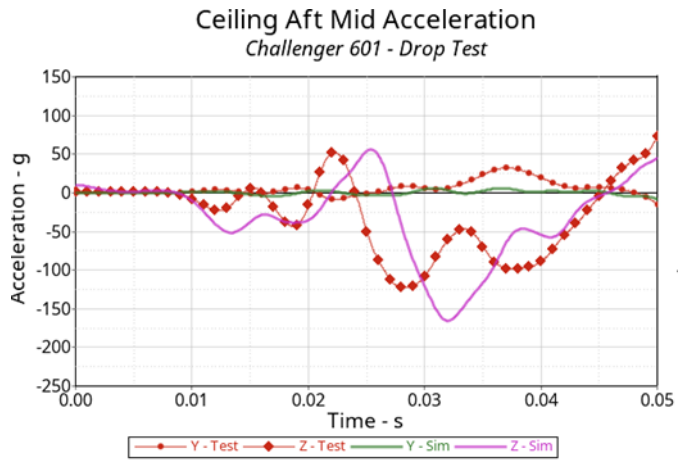


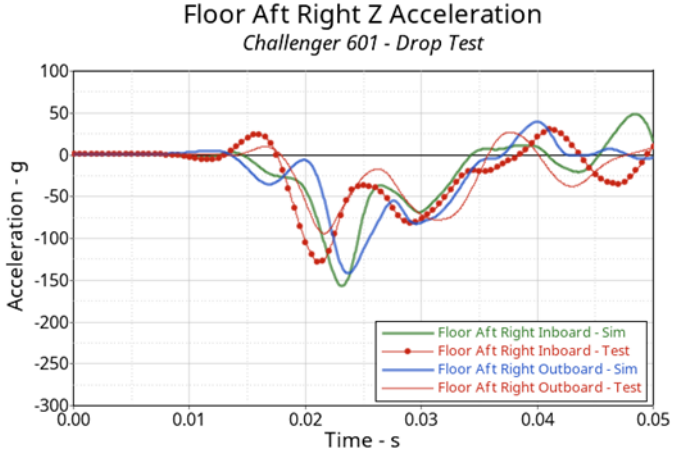
Challenger 601 Accelerometers Prediction

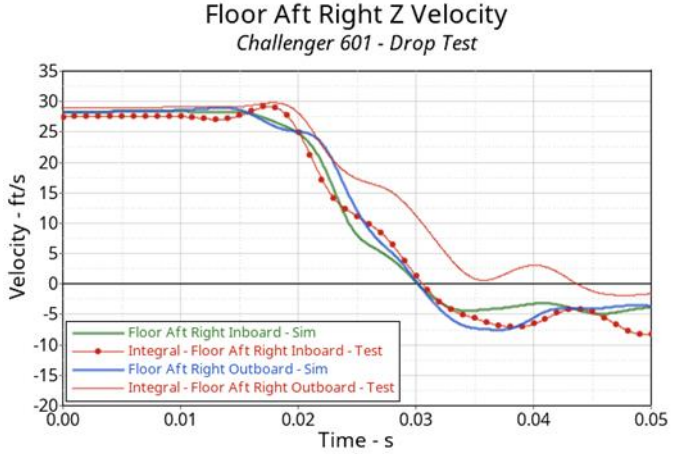
Certification by Analysis

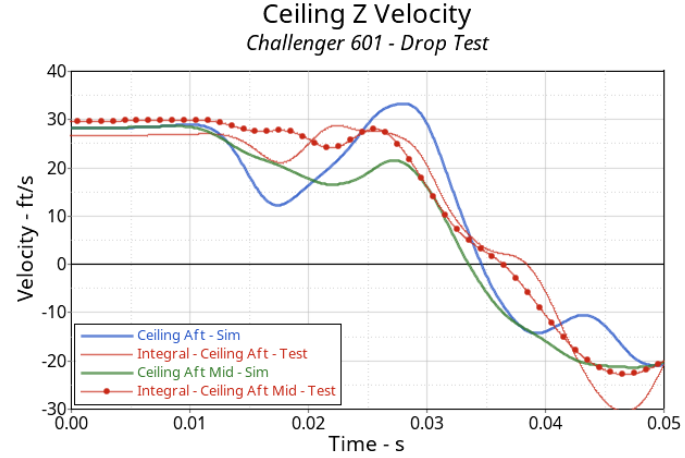












Conclusions and Recommendations

Certification by Analysis

- The Composite and Metallic fuselage sections tested provide a similar level of safety under vertical loading conditions.
- Both designs meet all the crashworthiness requirements except the lumbar load criteria due to the reduced airframe subfloor crushable space available.
- The composite structure tested in this program stored more elastic energy due to the initial ground impact, resulting in higher secondary impact velocities.
- Simulation methods are capable of predicting the structural and occupant responses when used in conjunction with the building block approach.
- CBA methods will be crucial for the implementation of an Integrated Safety approach for future novel commercial and advanced air mobility aircraft applications [Airframe and Seats].

Thank you for your attention.

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