Crashworthiness Certification by Analysis

Federal Aviation Administration

Presented by:

Luis Gomez

NIAR-WSU

Joint Centers of Excellence for Advanced Materials

JAMS Technical Review

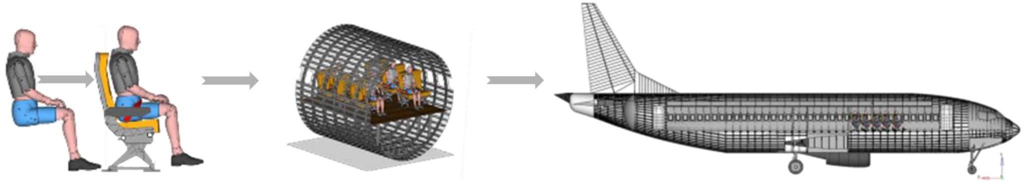
September 30, 2021

Introduction

- Provide a methodology and the tools required by industry to maintain or improve the level of safety of new composite aircraft when compared to current metallic aircraft during emergency landing conditions.
- Project Participants
  - PI: Gerardo Olivares Ph.D.
  - Researchers NIAR-WSU: Luis Gomez, Nilesh Dhole, Hoa Ly, Armando Barriga, Akhil Bhasin, Aswini Kona, Russel Baldridge, Nathaniel Baum, Vincent Robinson, Ankit Gupta, and Luis Castillo
  - Students: Gerardo Arboleda, Matt Torline, and Javier Martinez
- FAA Technical Monitor –Dave Stanley
- Other FAA Personnel – Joseph Pellettiere Ph.D.
- Industry Partnerships/Other Collaborations – ARAC Transport Airplane Crashworthiness and Ditching Working Group [FAA, EASA, Transport Canada, NASA, Aircraft OEMs (Boeing, Embraer, Bombardier, Cessna, Mitsubishi, Gulfstream, Airbus), DLR], Collins Aerospace, The Ohio State University, Hiromitsu Miyaki [Japan Aerospace Exploration Agency, JAXA]
- Matching contribution is additional NIAR/WSU technical resources

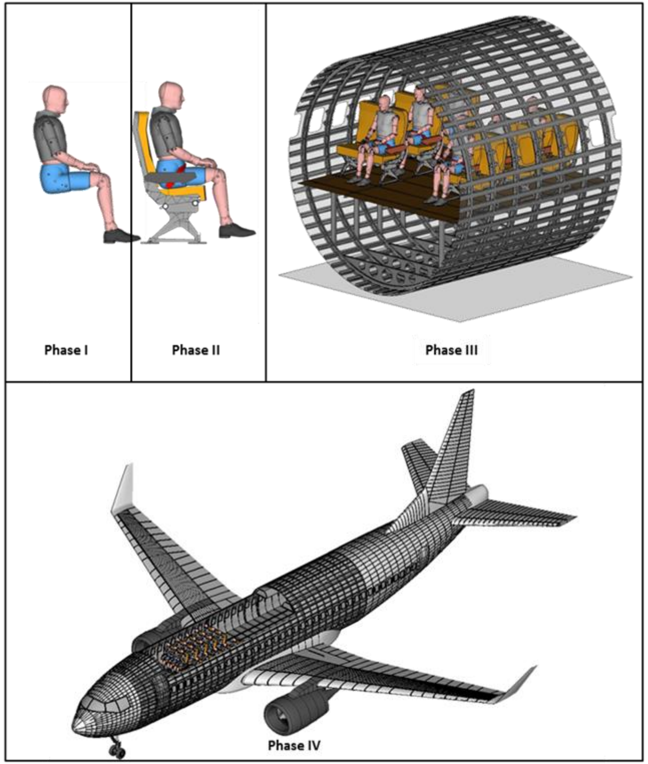
Background

- 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 and Scope
  - 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.



Project Status – Crashworthiness CBA

- **Phase 0:** Define Occupant Injury Limits | FAR *.562 | ✓
- **Phase I:** Develop and validate occupant ATD numerical models | SAE ARP 5765 | ✓
- **Phase II:** Define Modeling and Certification by Analysis Processes of Aerospace Seat Structures and Installations |AC 20-146|SAE ARP 5765 | Aircraft OEMS and Seat Suppliers Modeling and CBA Standards | ✓
- **Phase III:** Define Crashworthiness Building Block Approach for Aircraft Structures |CMH-17| ARAC Transport Airplane Crashworthiness and Ditching Working Group| Aircraft OEMS Methods| ✓
- **Phase IV:** Define Structural CBA Methodology |CMH-17| ARAC Transport Airplane Crashworthiness and Ditching Working Group| ✓



Experimental Work

Full Scale Testing Metallic Fuselage Section

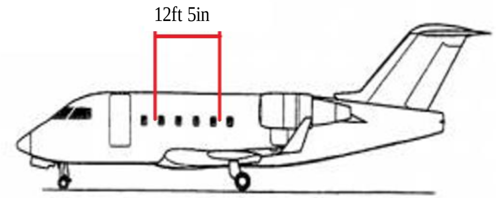
NIAR Fuselage Drop Tests

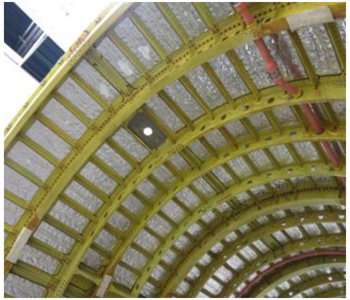
- **NIAR Crash Dynamics Laboratory**
- **Support ARAC for business jet size aircraft configurations**
- **Fuselage Section Drop Tests**
  - Support the development of airframe level crash requirements for business jet airplanes
  - Impact velocity 30 ft/s
  - Two tests will be conducted:
    - Composites Hawker 4000 - Completed August 2017
    - Metallic Challenger 601 (includes wingbox) – Scheduled End of October 2021
      - 2 FAA H3 50th ATDs
      - 3 PMHS

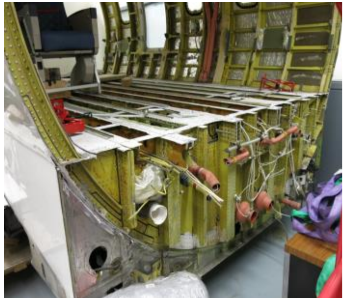
Test Article

- **Challenger 601 wingbox section, (FS) 409 to 559**
  - 12.5 ft long
  - 9 ft wide
  - Exit door on right fwd side
- **Same fuselage design as CRJ**

	Mass (lbs)
Fuselage Empty	2795
Rigid Seat (ATD)	443
Rigid Seat (PMHS)	440
Commercial Seat	437
Litter	370
DAQ and Mouting Plates	400
Ceiling Ballast	240
Floor Ballast	467
Total	5592

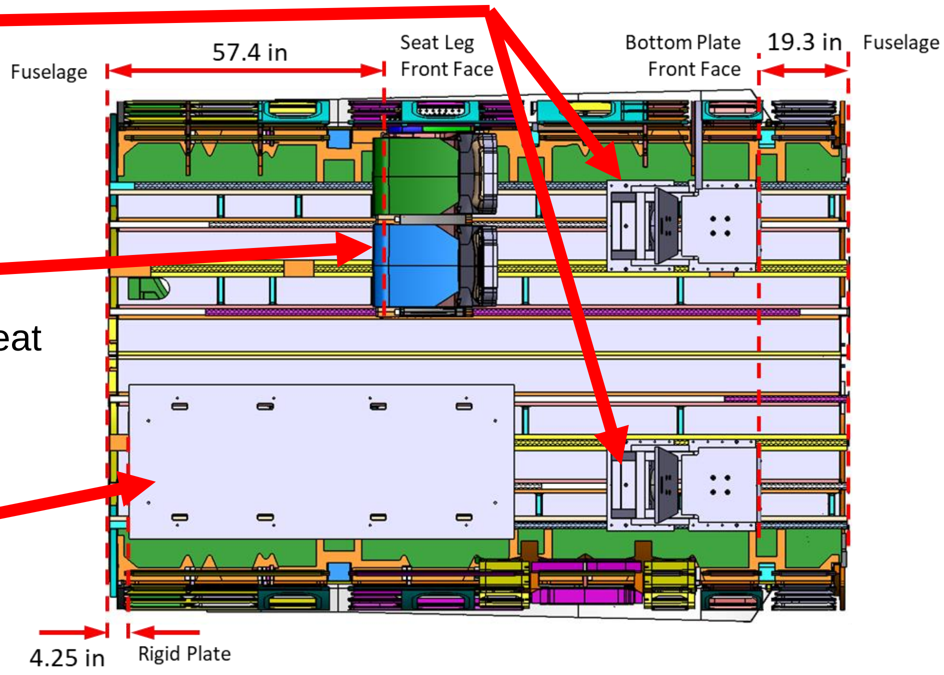






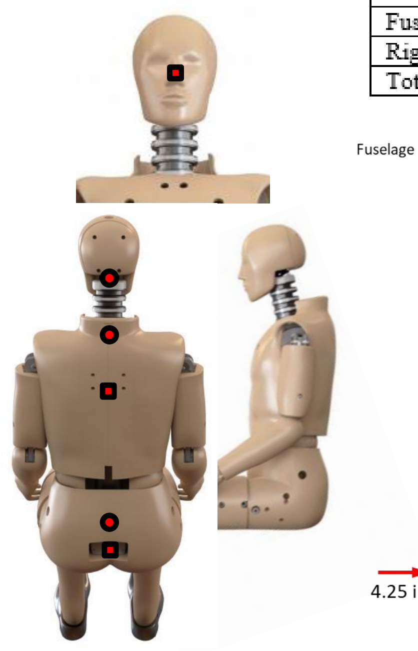
Interior Test Layout

- **2 Rigid Seats**
  - Side by side comparison
  - Symmetrical positions in fuselage
    - (1) FAA H3 50th ATD
    - (1) PMHS
- **1 Commercial Seat**
  - Typical regional jet double passenger seat
  - Side by side comparison
    - Slightly different positions (Inboard vs Outboard)
    - (1) FAA H3 50th ATD
    - (1) PMHS
- **1 Litter (Rigid Plate)**
  - (1) PMHS - Supine

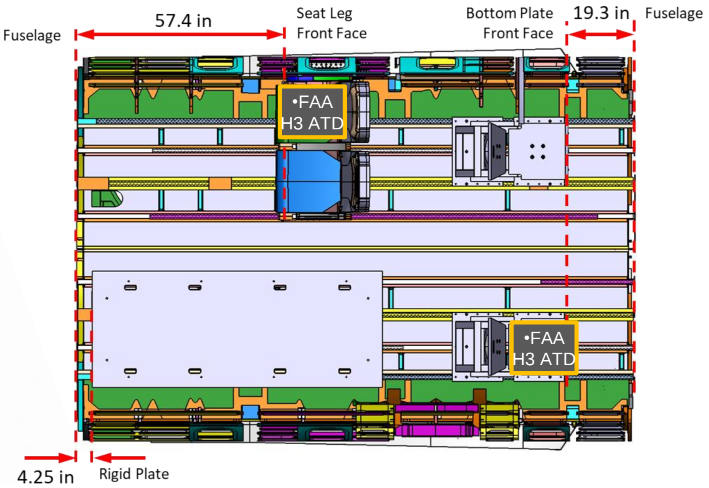


Instrumentation FAA HIII

- **Approximately 350 data channels**
- **Fuselage**
  - Floor and Ceiling accelerations
- **FAA H3 50th ATDs**
  - Head Accelerations and Angular Velocities
  - Upper and Lower Neck Forces and Moments
  - Chest and Pelvis Accelerations
  - Lumbar Forces and Moments

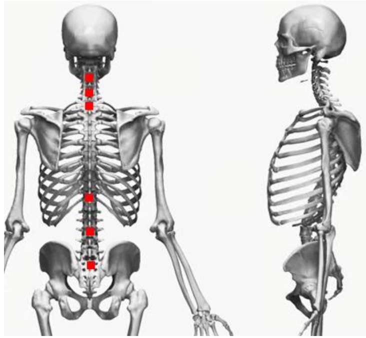


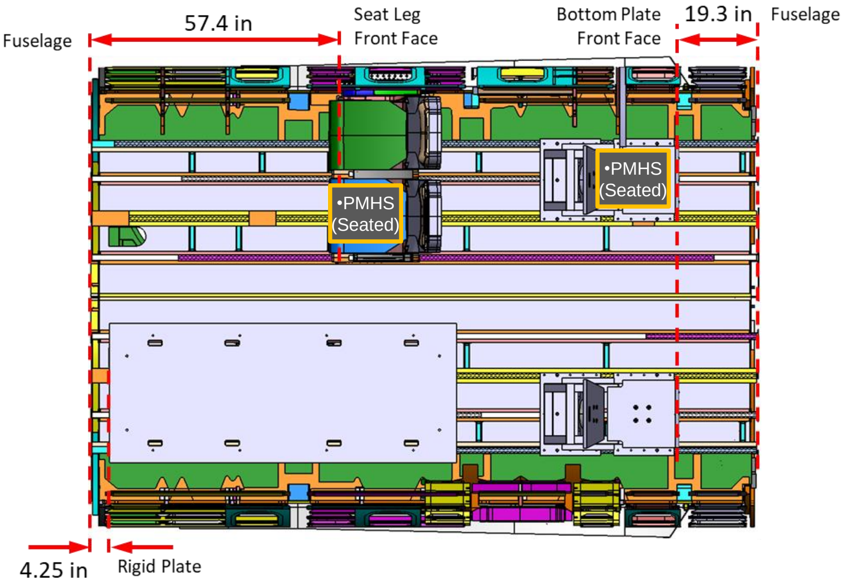
Sensor	Quantity
FAA HIII ATD (Two Occupants)	48
PMHS Seated (Two Occupants))	132
PHMS Supine	110
Fuselage Triaxial Accelerometer	12
Fuselage Biaxial Accelerometer	24
Rigid Seat (2)	12
Total	350



Instrumentation PMHS

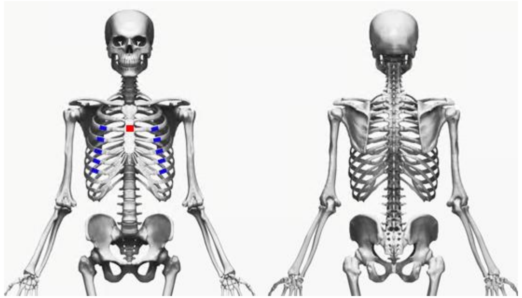
- **PMHS (Seated)**
  - Accelerations and Angular Velocities
    - Head
    - T1, T12, L3
    - Sacrum
    - Left Lateral Illiac
    - C3 and C5 Spine
    - Femur
  - Strain Gages
    - L3 and L5
    - Pubic Symphysis
    - Femur and Tibia
  - Pressure Sensor
    - L2/L3
    - L4/L5

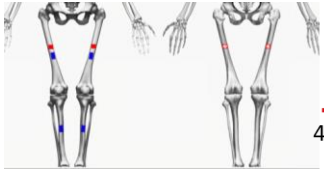


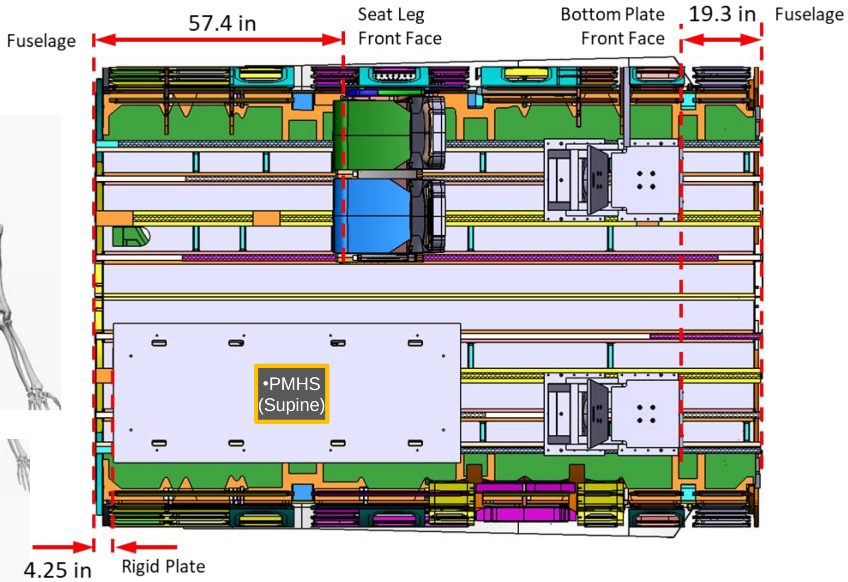


Instrumentation PMHS

- **PMHS (Supine)**
  - Accelerations and Angular Velocities
    - Head
    - T1
    - Sternum
    - Sacrum
    - C3 and C5 Spine
  - Strain Gages
    - Ribs 3-7
    - Sternum
    - Femur and Tibia
  - Chestband (59 channels)

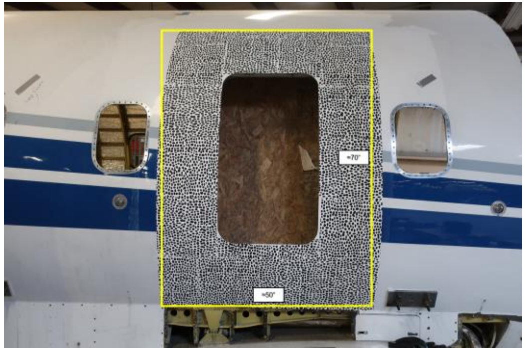


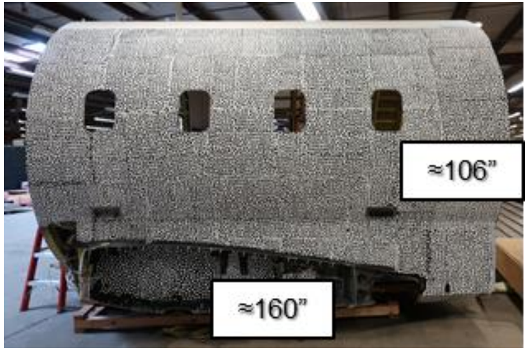


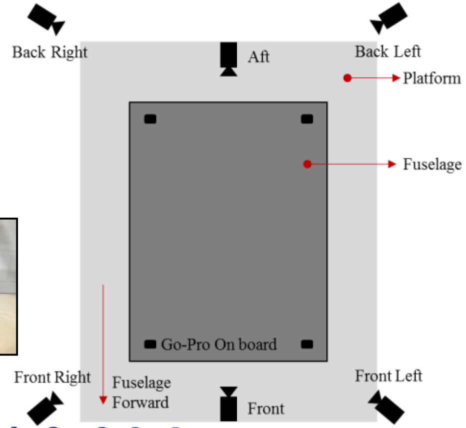


Instrumentation Fuselage

- **Fuselage Digital Image Correlation (DIC) to evaluate strain and deformations on the exterior surface**
  - Left side - Full side of fuselage
  - Right side - Exit door
- **12 High speed cameras**
  - (4) Photron SA-Z to support DIC
    - 1024x1024 resolution - Up to 20,000 frames/sec
  - (2) PCO dimax.CS4
    - 1920x1080 resolution - 2,000 frames/sec
  - (6) AOS
    - 800x600 resolution - 1,000 frames/sec
  - (4) GoPro Cameras
- **3D Scanners to capture pre-test setup, initial positions of occupants, and for comparison of fuselage deformations with post-test**
  - (4) Faro Focus S70 3D scanning suite
  - 1mm accuracy

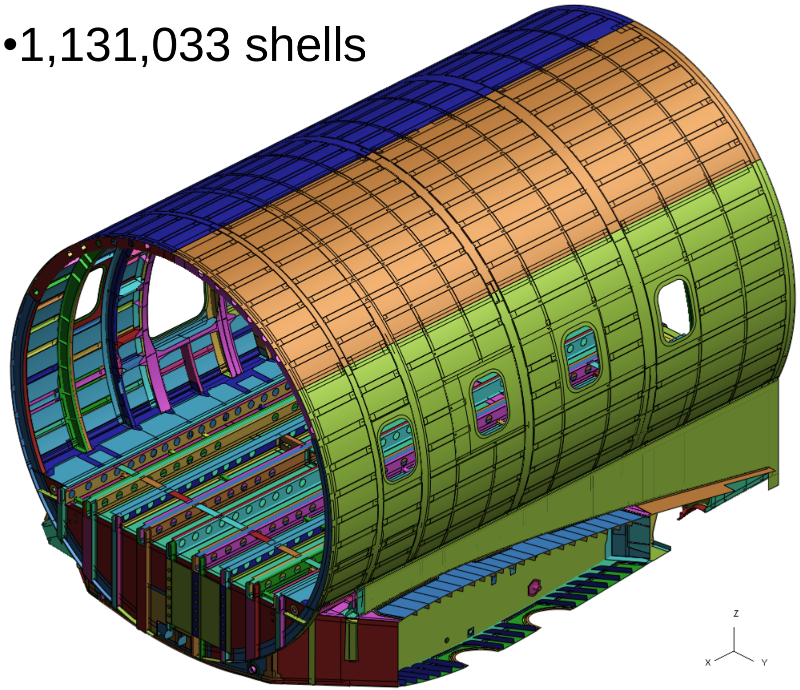




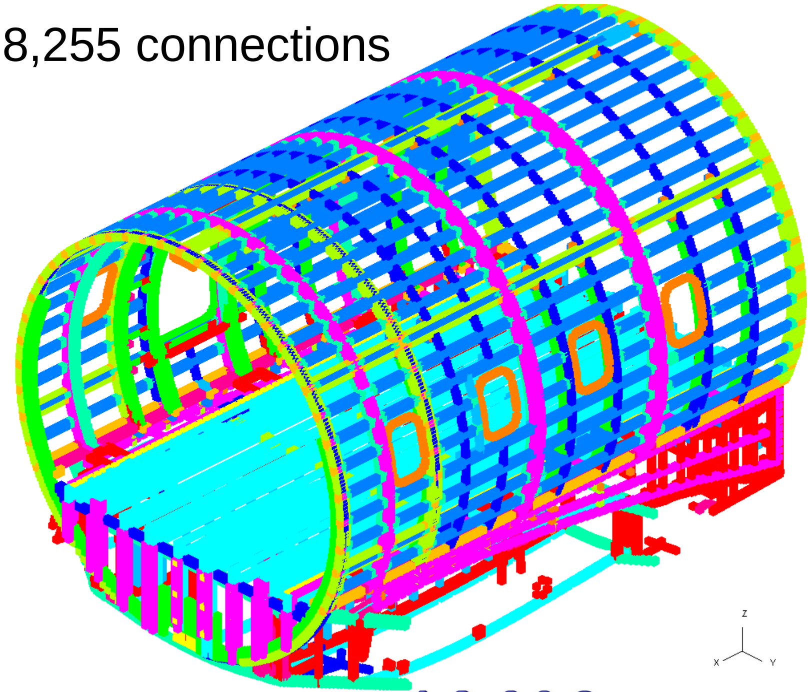


Fuselage FEM Details

- 1,131,033 shells

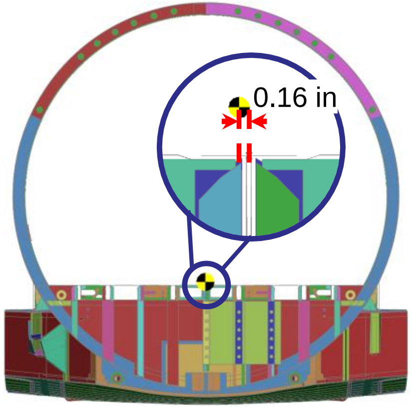


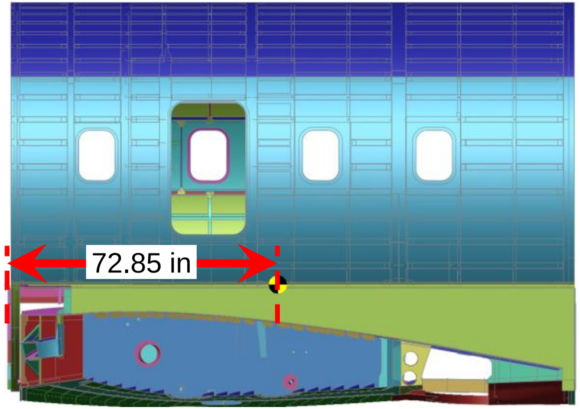
- 78,255 connections

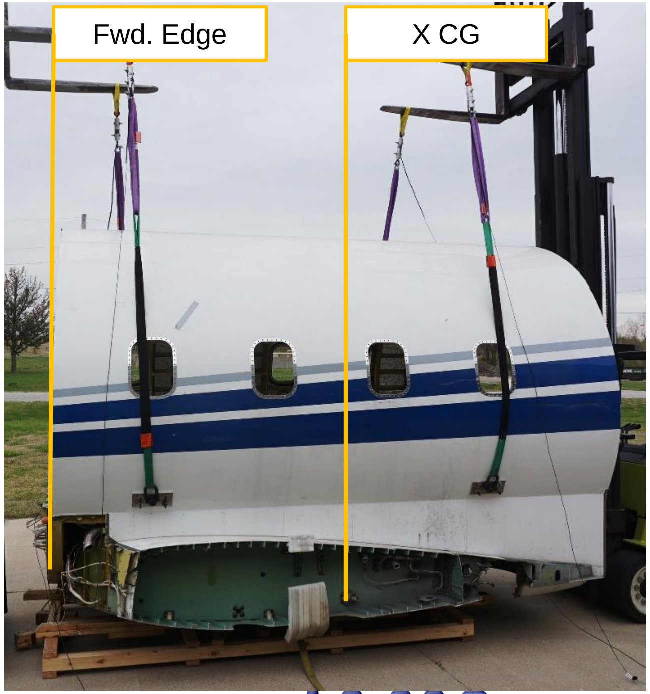


Fuselage Weight and CG

ITEM	Weight (lb)	CG X (in)	CG Y (in)
Test Article	2795	73.00	0.25
FEM	2795	72.85	0.16
Difference	0.00	0.15	0.09

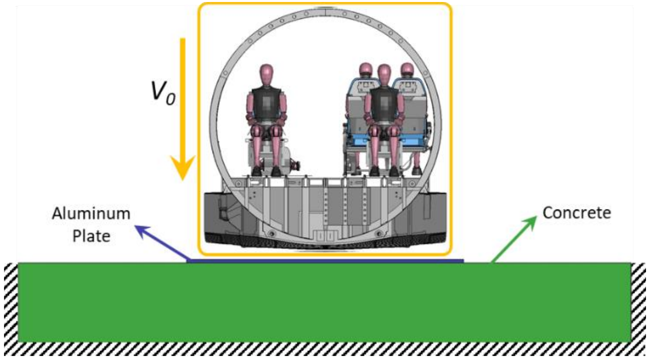


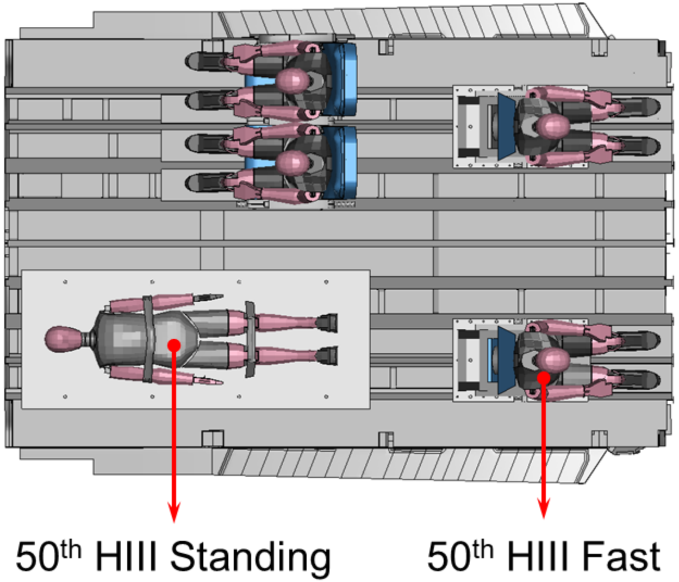




FEM Setup

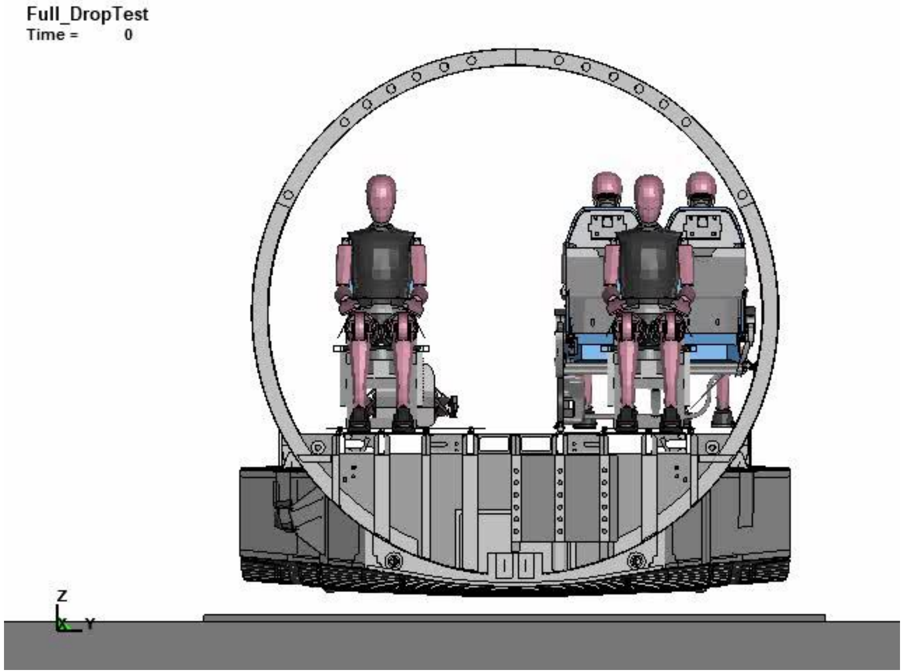
- **Preliminary analysis was performed using LSTC ATDs.**
  - Four of them were 50th HIII FAST ATDs
  - One was 50th HIII STANDING ATDs
- **Initial velocity (V_0) of 30 ft/s applied**
- **Fuselage impacts against four (4) aluminum plates, which are positioned on top of a concrete base**
- **Concrete base is fully constrained at the outside faces**

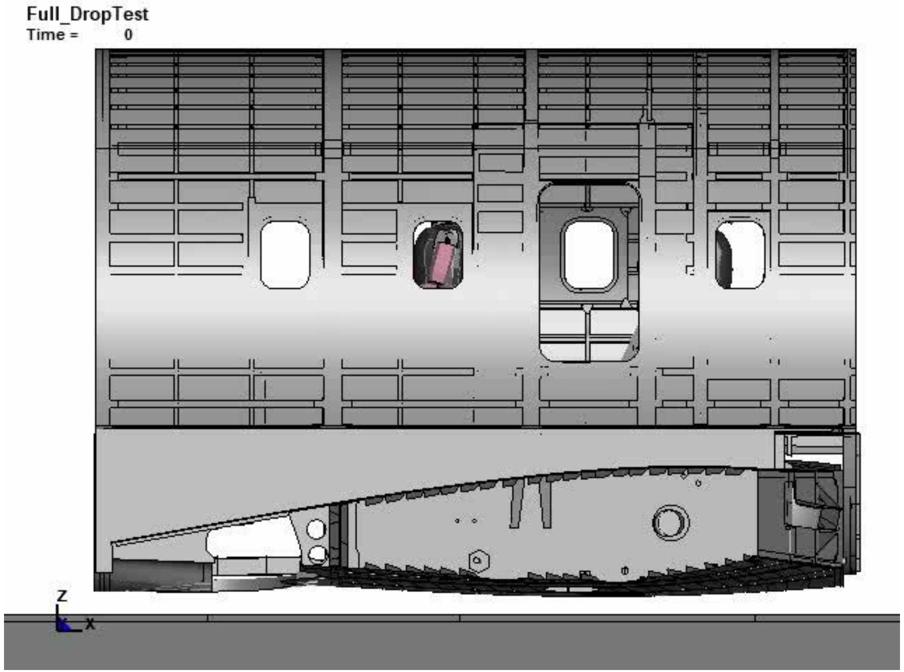




CL601 Drop Test Simulation

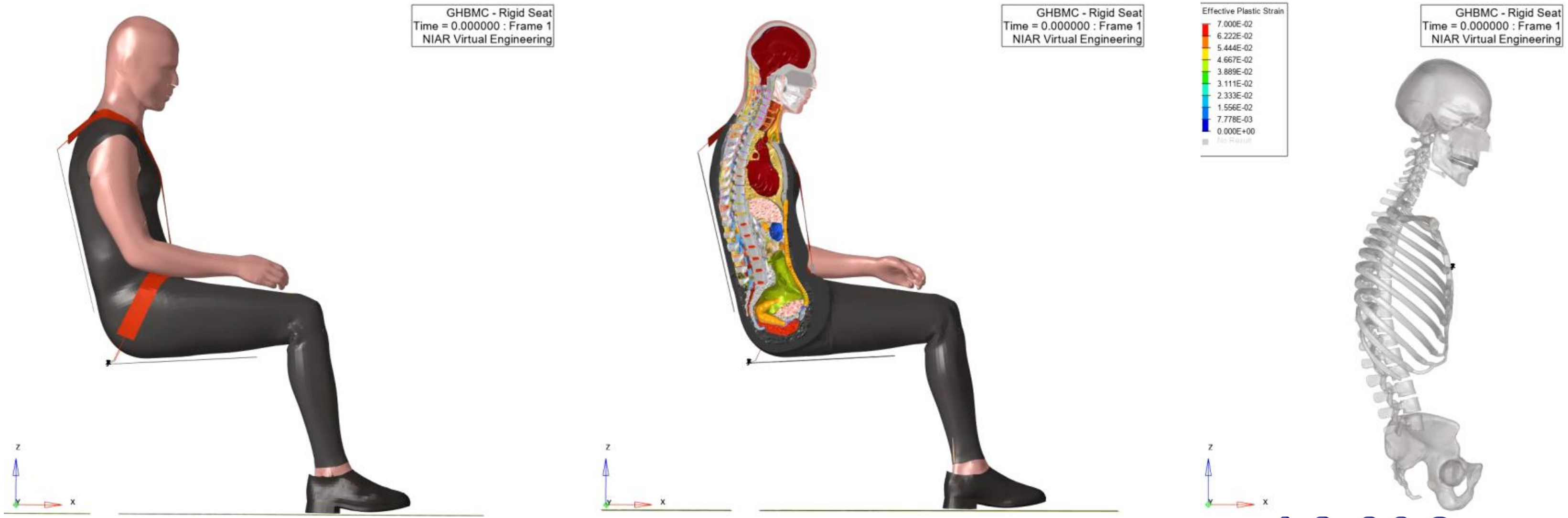
- **Preliminary Model Kinematics**





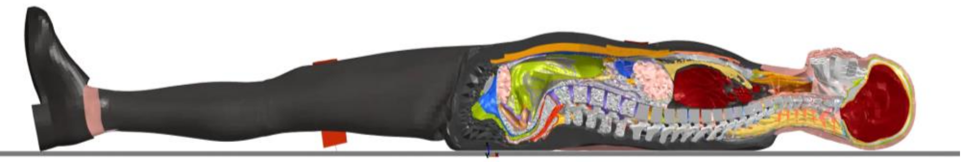
PMHS Instrumentation Support Analysis

- Motion of the Rigid Seat was extracted from full scale analysis and used as a boundary condition on a subassembly model with just a rigid seat and the GHMBC 50th
- Results will be used to identify areas of interest and define instrumentation requirements.



PMHS Instrumentation Support Analysis

- **Motion of the Rigid Litter was extracted from full scale analysis and used as a boundary condition on a subassembly model with just a rigid seat and the GHMBC 50th**
- **Results will be used to identify areas of interest and define instrumentation requirements.**



Next Steps

- Test schedule for October 28th
- Results presentation and findings will be available End of November.
- Final report Q1 2022

Certification by Analysis

Full Aircraft Ditching R&D

Phase I – Modeling Approach

- **Four methods were evaluated and reviewed:**
  - Mesh-Based Lagrangian
  - Coupled Eulerian-Lagrangian
  - Arbitrary Lagrangian-Eulerian (ALE)
  - Meshless Lagrangian (SPH)
- **SPH selected for this work:**
  - Large fluid deformations do not result in numerical instabilities
  - Extensive research data available [2,9,11,12,13,14]
  - Optimum particle spacing requires some trial and error
  - Computational techniques such as particle deactivation and adaptive mesh can be used to improve computational efficiency
  - Water pressure is hard to extract
  - Air-water interaction is hard to model
    - Hydrodynamic effects are limited (suction, cavitation)

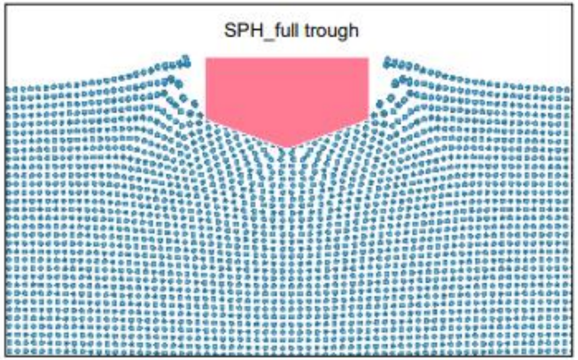
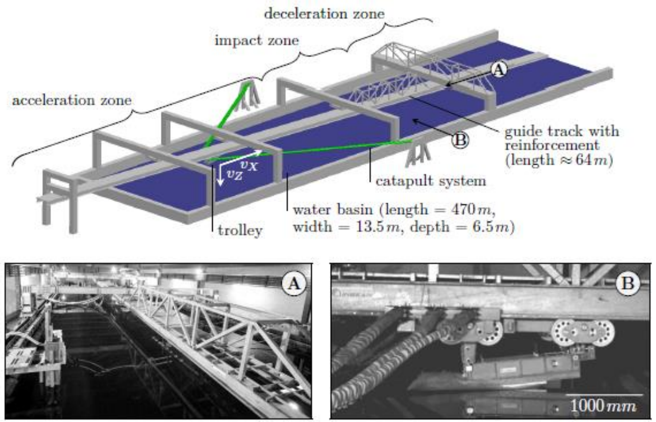


Figure from [11]

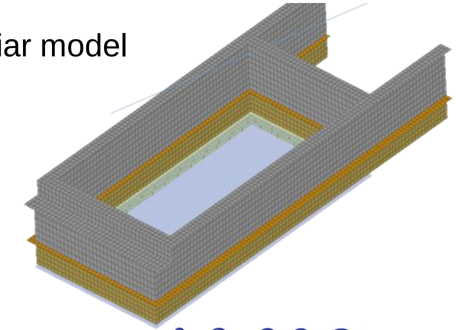
Phase I – Modeling Approach Validation

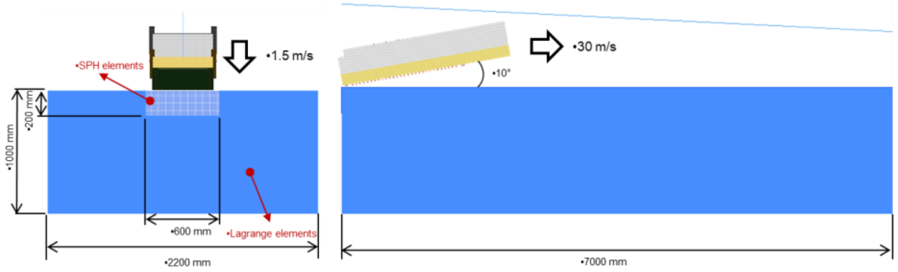
- **Test campaign conducted as part of the research project SMAES at CNR-INSEAN test facility in Rome [4]**
- **Tests comprised 65 tests with varying conditions:**
  - 1.5 m/s [4.92 ft/s] vertical velocity and 30 to 45 m/s [98.4-147.6 ft/s] - horizontal velocity
  - 3 aluminum panels of varying thickness (0.8mm, 3mm, and 15mm) and 1 composite panel
  - Flat, convex, and concave plate shapes
  - 4,6, and 10 deg pitch angles
- **NIAR's modeling approach was validated against:**
  - 15mm, 3mm, and 0.8mm AL plate at 10 deg pitch



Test Structure: Model and Experimental Setup. Figure from [2]

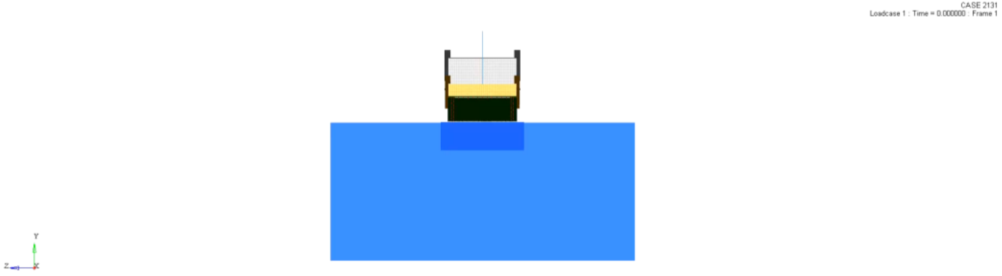
Niar model

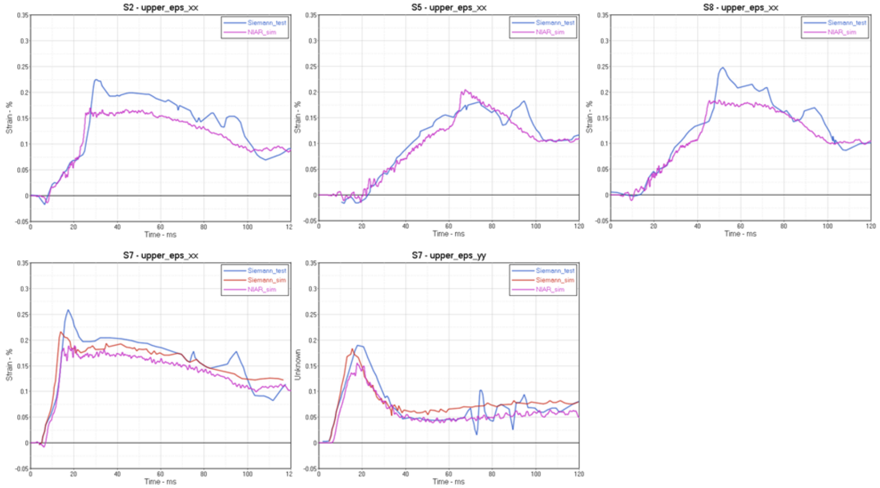


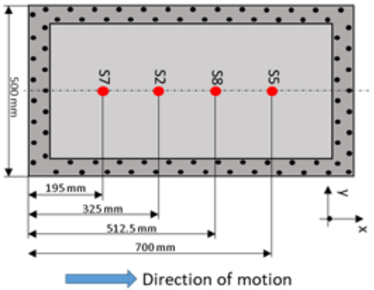


Phase I – Modeling Approach Validation

- **Modeling Method Validation Results - 3mm Flat Al Panel**



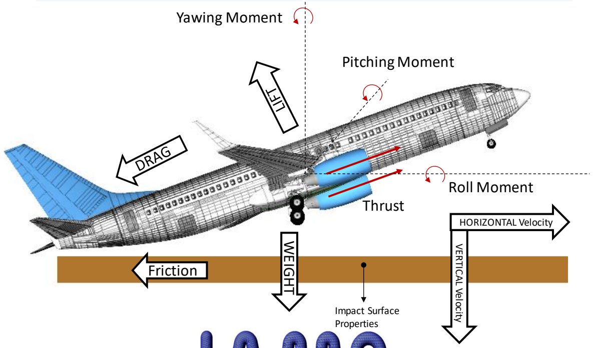




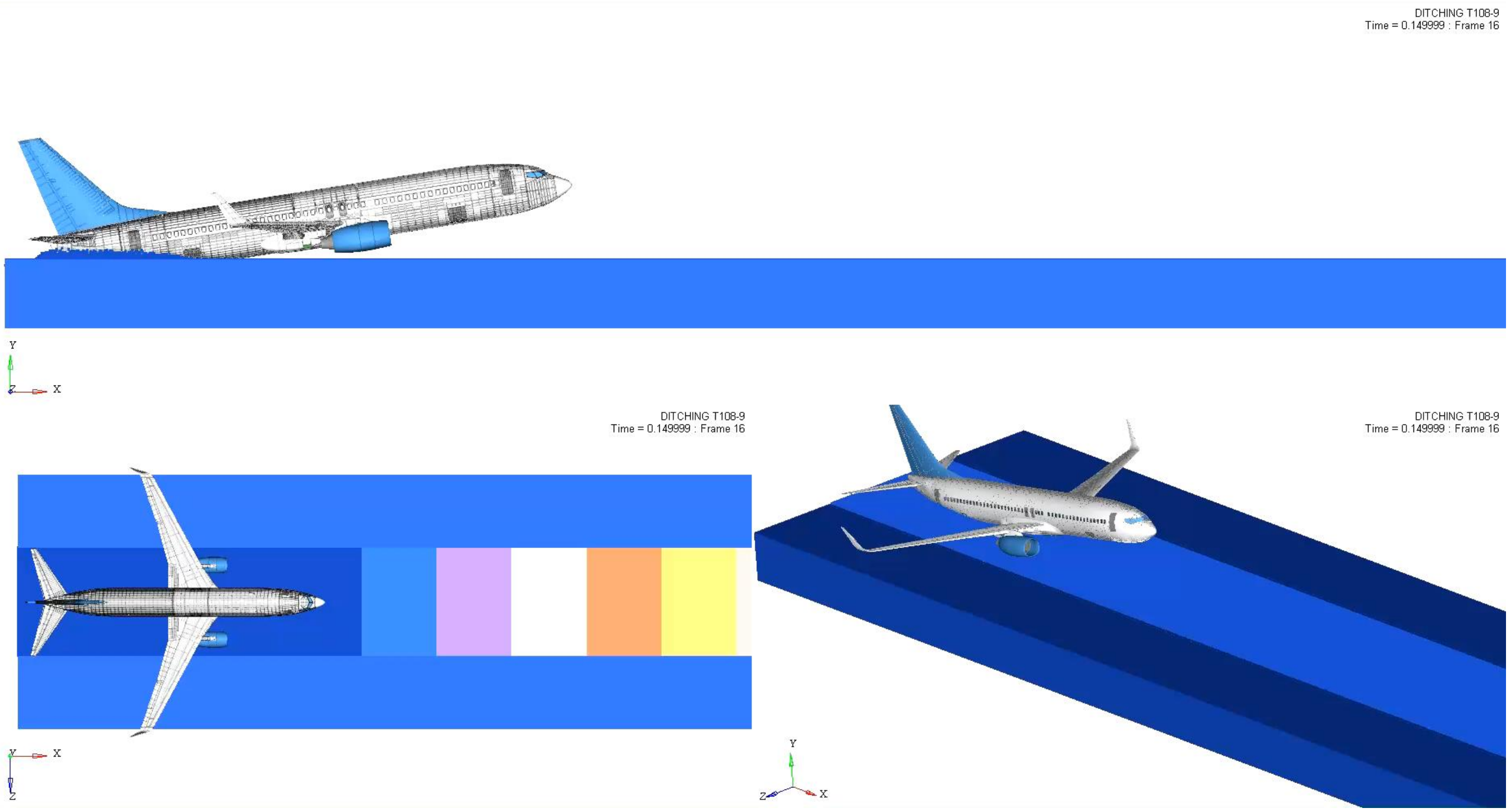
Phase II – Hudson River Ditching

- **Load Case Description – Hudson NTSB report**
  - This is a planned ditching event that includes pilot input and water flow
  - NIAR simulation only includes the boundary conditions identified in the NTSB report and motionless water
- **FEA Assumptions**
  - Motionless water and no air modeled
  - Aerodynamic forces based on last data point from FDR*
  - No pilot inputs during ditching event
  - No ambient pressure
  - NIAR Single aisle FEM (Representative aircraft) Not the same as in Hudson ditching (A320-214)
  - Deformations are expected to be similar but not the same as in the Hudson case

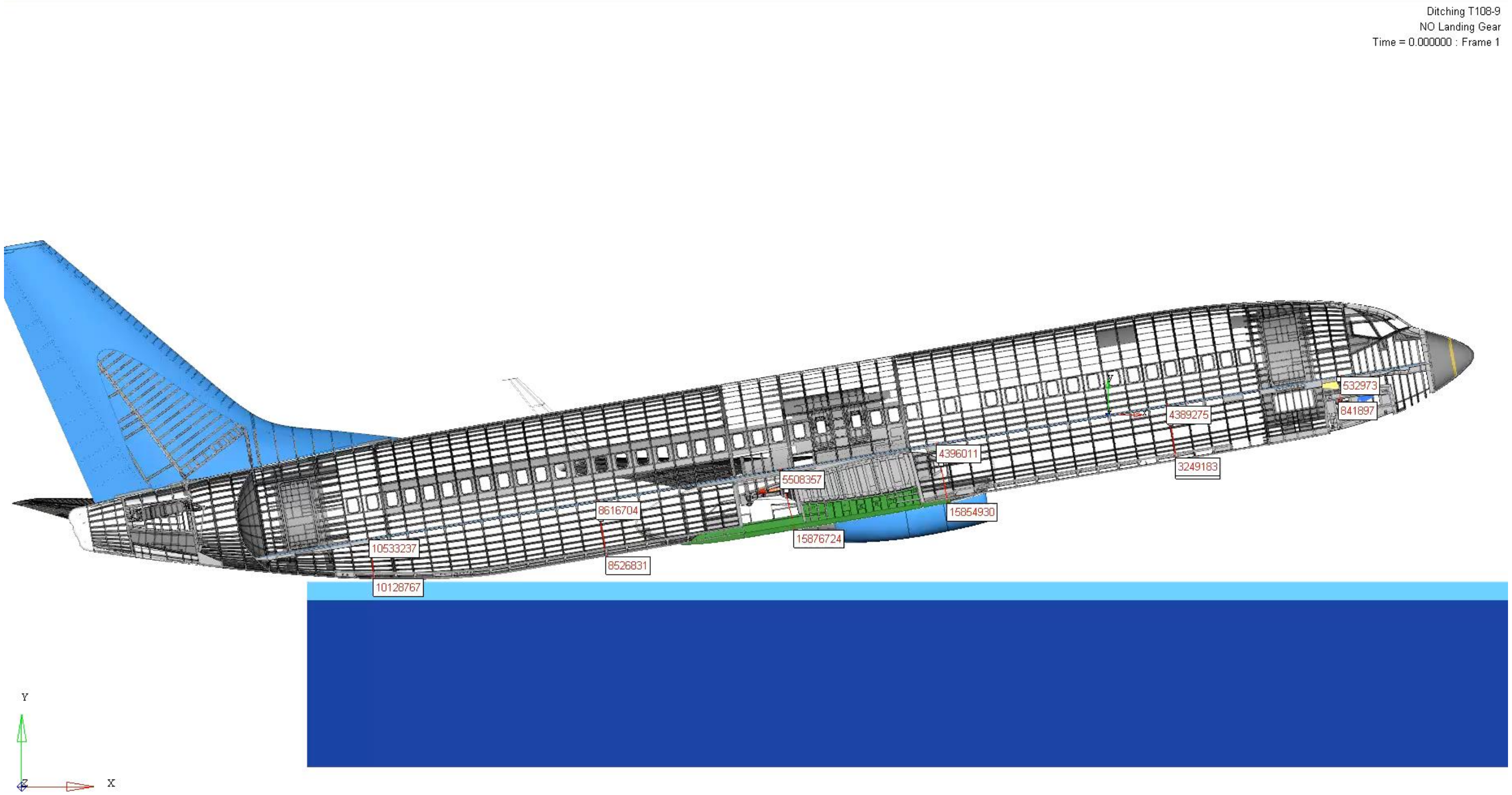
Parameter	Ditching Analysis
Horizontal Velocity	64.31 m/s [211 ft/s]
Vertical Velocity	3.81 m/s [12.5 ft/s]
Pitch Angle	9.5 deg
Main Landing Gear	NO
Nose Landing Gear	NO
Thrust R Engine	0%
Thrust L Engine	0%
Aerodynamic Loads	Lift
Gravity	Yes
Impact Surface	Water



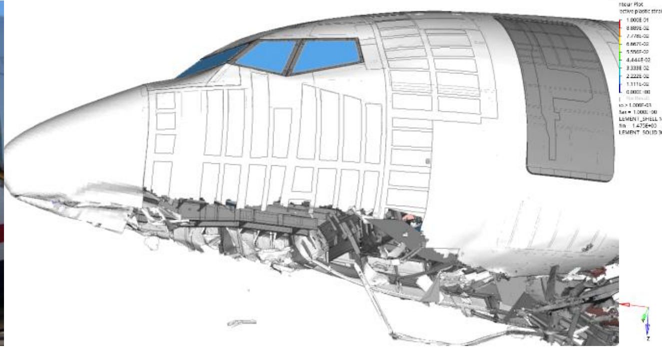
Phase II – Hudson River Ditching Kinematics

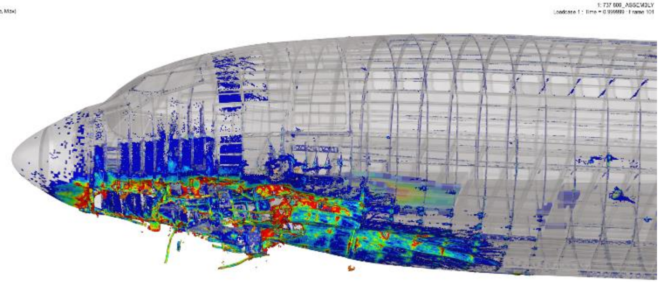


Phase II – Hudson River Ditching Kinematics

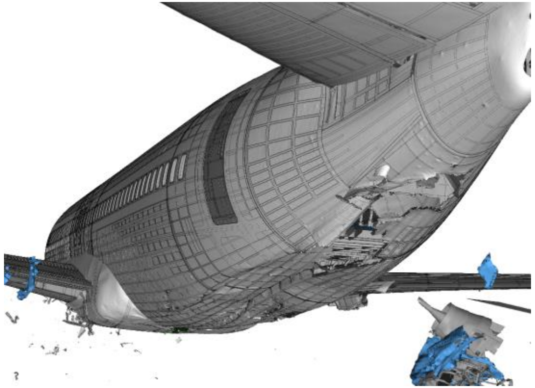


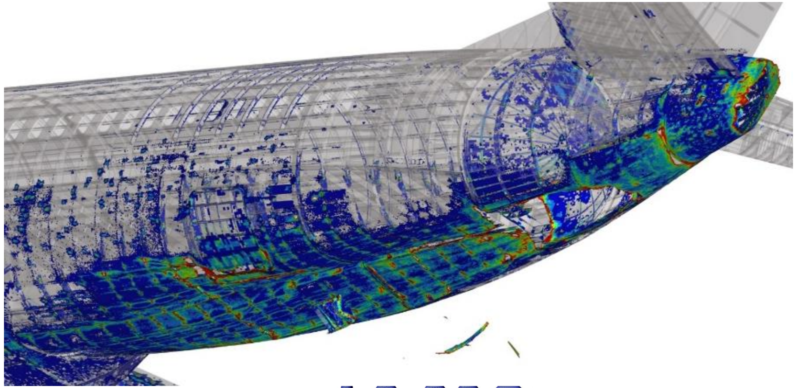
Phase II – Hudson River Ditching Results



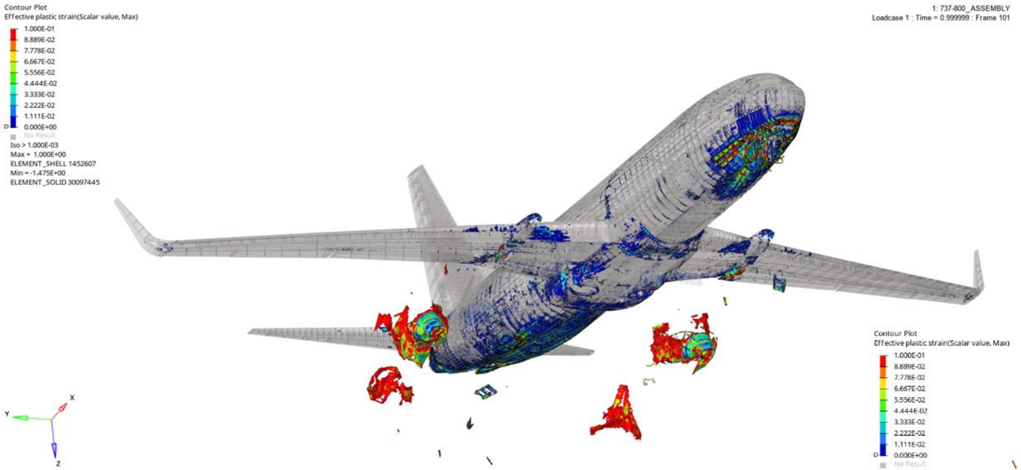


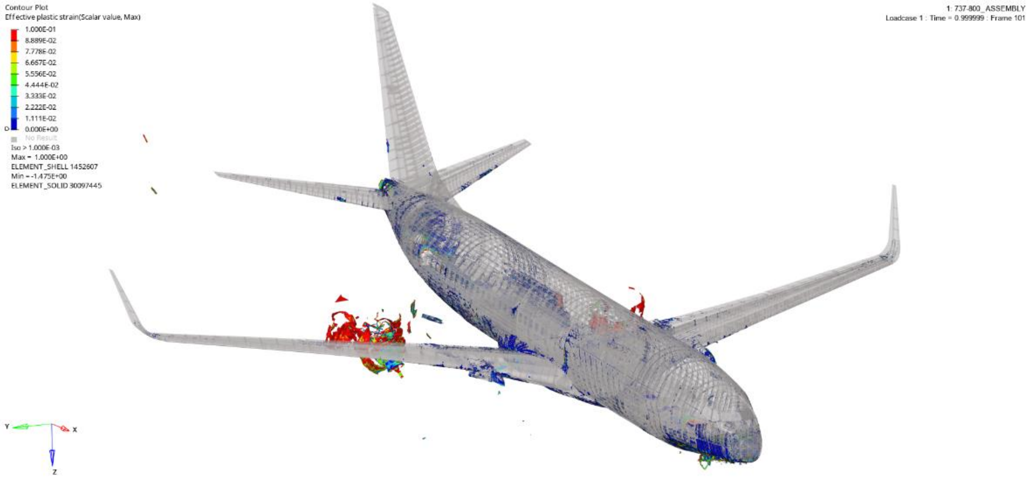
Numerical model nose slams the water due to lack of pilot input. Actual ditching event had a controlled pitch rate.





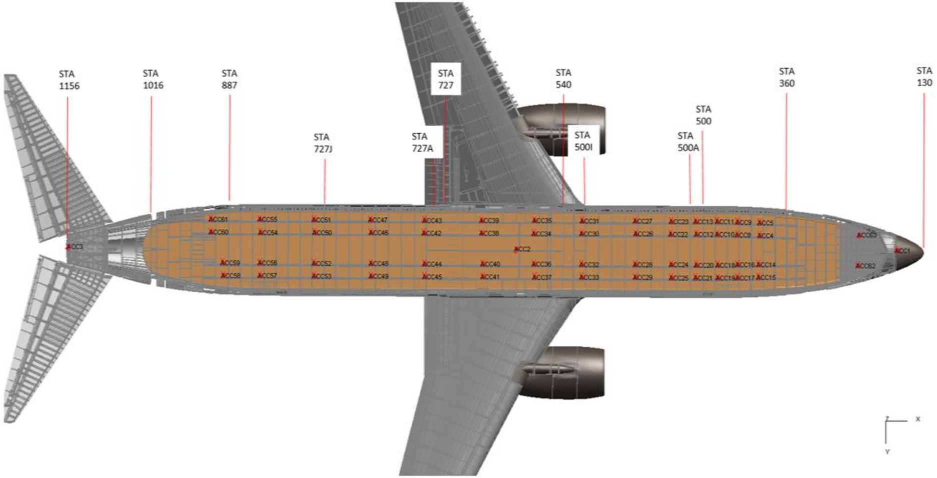
Phase II – Hudson River Ditching Results

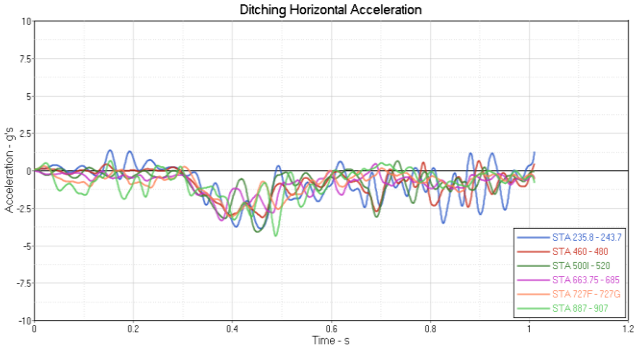


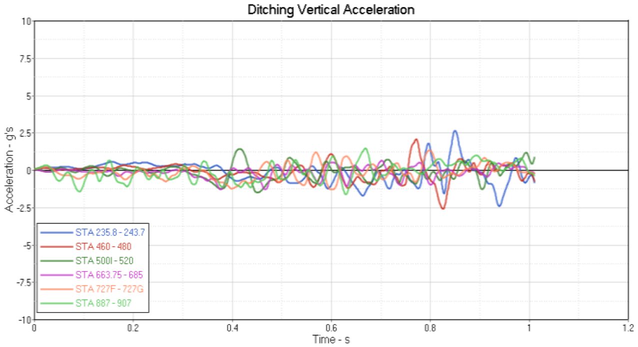


Phase II – Hudson River Ditching Results

- **Selected Seat Location Accelerations**







Phase II – Hudson River Ditching Findings

- **Damage/deformations in the aft fuselage were similar to the Hudson ditching event**
- **Extensive nose damage was observed in the FEA while the Hudson ditching event did not have significant damage**
  - This is most likely attributed to the observed pitch down kinematics in the FEA
    - As the literature review indicated, this behavior is due to the lack of suction forces.
    - Pilot input could also change the aircraft attitude during the event.
  - Trying to incorporate pilot input and/or suction effects requires a significant amount of research and guesswork
    - Adding air particles or switching to ALE will result in severe computational slowdown. Debugging/validating the modeling approach will take considerable time as well.
    - Pilot input will be based on estimations, since the FDR data does not show data during the ditching event.
- **Vertical accelerations in the selected seat locations do not exceed 2.5 g's**
- **With the current modeling approach, it is possible to simulate the first stages of the ditching event for roughly 50ms (impact)**
  - Subsequent events are not represented appropriately due to the reasons listed previously
- **Future Recommendations**
  - Add air/ambient pressure to account for suction forces
    - Adding air particles (SPH or DEM) or switching to ALE
    - Debugging/validating the modeling approach will require considerable time
  - Pilot input might influence the behavior of aircraft during the ditching event
    - Pilot input will be based on estimations, since the FDR data does not show data during the ditching event
  - Explore the effects of water flow direction and turbulent conditions

Questions?

References

- [1] J. Gomes, “Numerical Simulation of Aircraft Ditching of a Generic Transport Aircraft” [Ms Thesis], Tecnico Lisboa, Nov 2015
- [2] M. Siemann, “Numerical and Experimental Investigation of the structural Behavior during Aircraft Emergency Landing on Water” [PhD Diss], 2016
- [3] V. Shigunov and H. Soding, “Planned Ditching Simulation of a Transport Airplane”. KRASH users’ seminar, Jan 2001
- [4] T. Mai, D. Greaves, and A. Raby, “Aeration Effects on Impact: Drop Test of a Flat Plate”, in Twenty-fourth International Ocean and Polar Engineering Conference, Busan, Korea, 2014.
- [5] A. G. Smith, et al, “Investigations of the behaviour of aircraft when making a forced landing on water (ditching)”. Ministry of Supply Aeronautical Research Council Reports and Memoranda, London, 1957
- [6] Wagner H.“Über Stoß- und Gleitvorgänge an der Oberfläche von Flüssigkeiten“. In Zeitschrift für angewandte Mathematik und Mechanik, 1932.
- [7] L. Benítez Montañés, H. Climent Máñez, M. Siemann, and D. Kohlgrueber. “Ditching Numerical Simulations: Recent Steps in Industrial Applications” , in Aerospace Structural Impact Dynamics International Conference, Wichita, USA, 2012.
- [8] McBride E.E. and Fisher L.J. “Experimental investigation of the effect of rear-fuselage shape on ditching behavior”, NACA Technical Note 2929, Washington, April 1953
- [9] N. Toso. “Contribution to the Modelling and Simulation of Aircraft Structures Impacting on Water” [Phd Diss]. University of Stuttgart, 2009.
- [10] T. Zhang, S. Li, and H. Dai. “The suction force effect analysis of large civil aircraft ditching”. Science China Technological Sciences 55, 2012.
- [11] S. Shah. “Water Impact Investigations For Aircrat Ditching analysis” [Ms Thesis]. RMIT University, 2010
- [12] J. Pelfrene. “Study of the SPH method for simulation or regular and breaking waves” [thesis]. Universiteit Gent 2010
- [13] C. Bisagni and M.S. Pigazzini. “Modelling Strategies for numerical simulation of aircraft ditching”. In International Journal of Crashworthiness, 2017
- [14] K. Jackson and Y. Fuchs. “Comparison of ALE and SPH Simulations of vertical drop tests of a composite fuselage section into water”. In 10th international LS-DYNA users conference, 2008
- [15] M. Siemann and B. Langrand. “Coupled fluid-structure computational methods for aircraft ditching simulations: Comparison of ALE-FE and SPH-FE approaches”. In Computers & structures, 2017