JOINT ADVANCED MATERIALS & STRUCTURES CENTER OF EXCELLENCE

Crashworthiness - Certification by Analysis

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JAMS 2017 Technical Review
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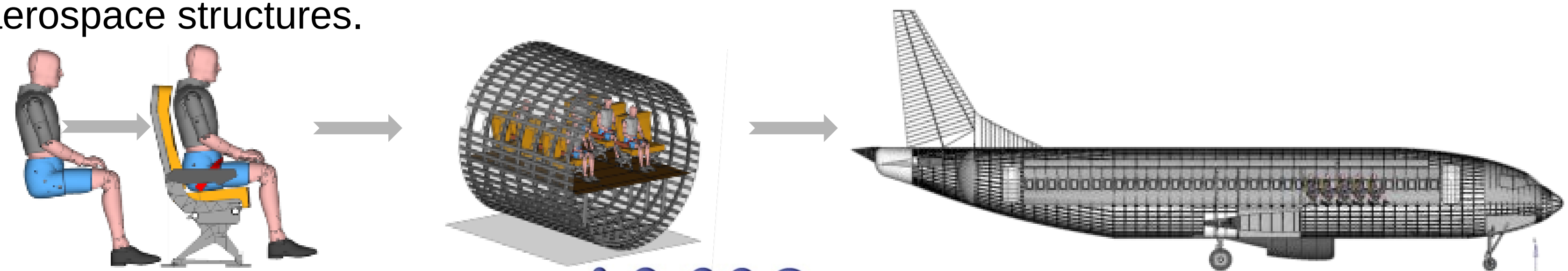
Wichita State University
National Institute for Aviation Research

Crashworthiness - Certification by Analysis

- 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.



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Crashworthiness - Certification by Analysis

- **Principal Investigators & Researchers**
  - **PI:** G. Olivares Ph.D.
  - **Researchers NIAR-WSU:** Chandresh Zinzuwadia , S. Keshavanarayana Ph.D. , Adrian Gomez , Nilesh Dhole, Luis Gomez, Hoa Ly, Armando Barriga
  - **8 Graduate and Undergraduate Students**
- **FAA Technical Monitor**
  - Allan Abramowitz
- **Other FAA Personnel Involved**
  - Joseph Pelletiere Ph.D.
- **Industry\Government Participation**
  - Gerard Elstak and Gerard Schakelaar – Dutch Air Police
  - ARAC Transport Airplane Crashworthiness and Ditching Working Group [FAA, EASA, NASA, Aircraft OEMs (Boeing, Embraer, Bombardier, Cessna, Mitsubishi, Gulfstream, Airbus), Academia]
  - Hiromitsu Miyaki , Japan Aerospace Exploration Agency, JAXA

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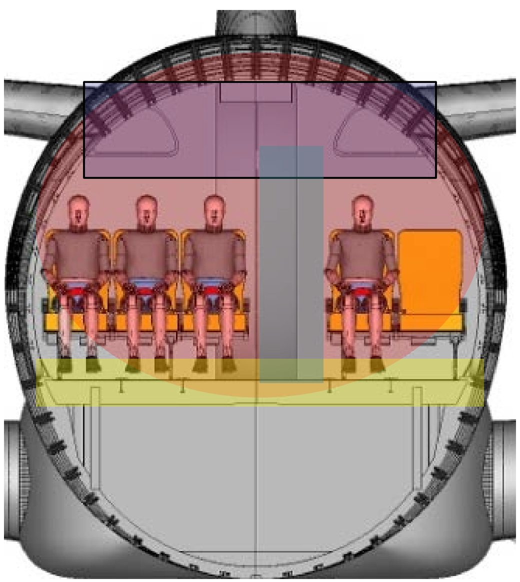
Aerospace Structural Crashworthiness

- **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:** Building Block Approach
    - **Experimental and Simulation**
      - Coupon Level to Full Scale
    - **Simulation**: Predictable modeling

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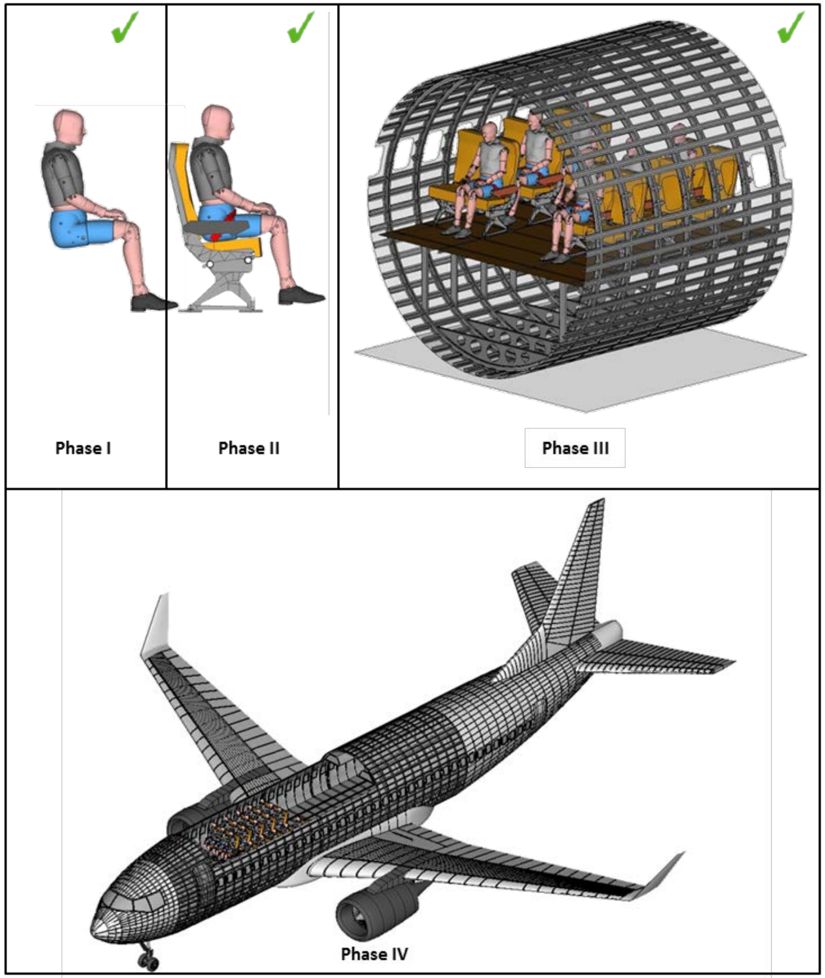
Crashworthiness CBA R&D Phases



- **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|

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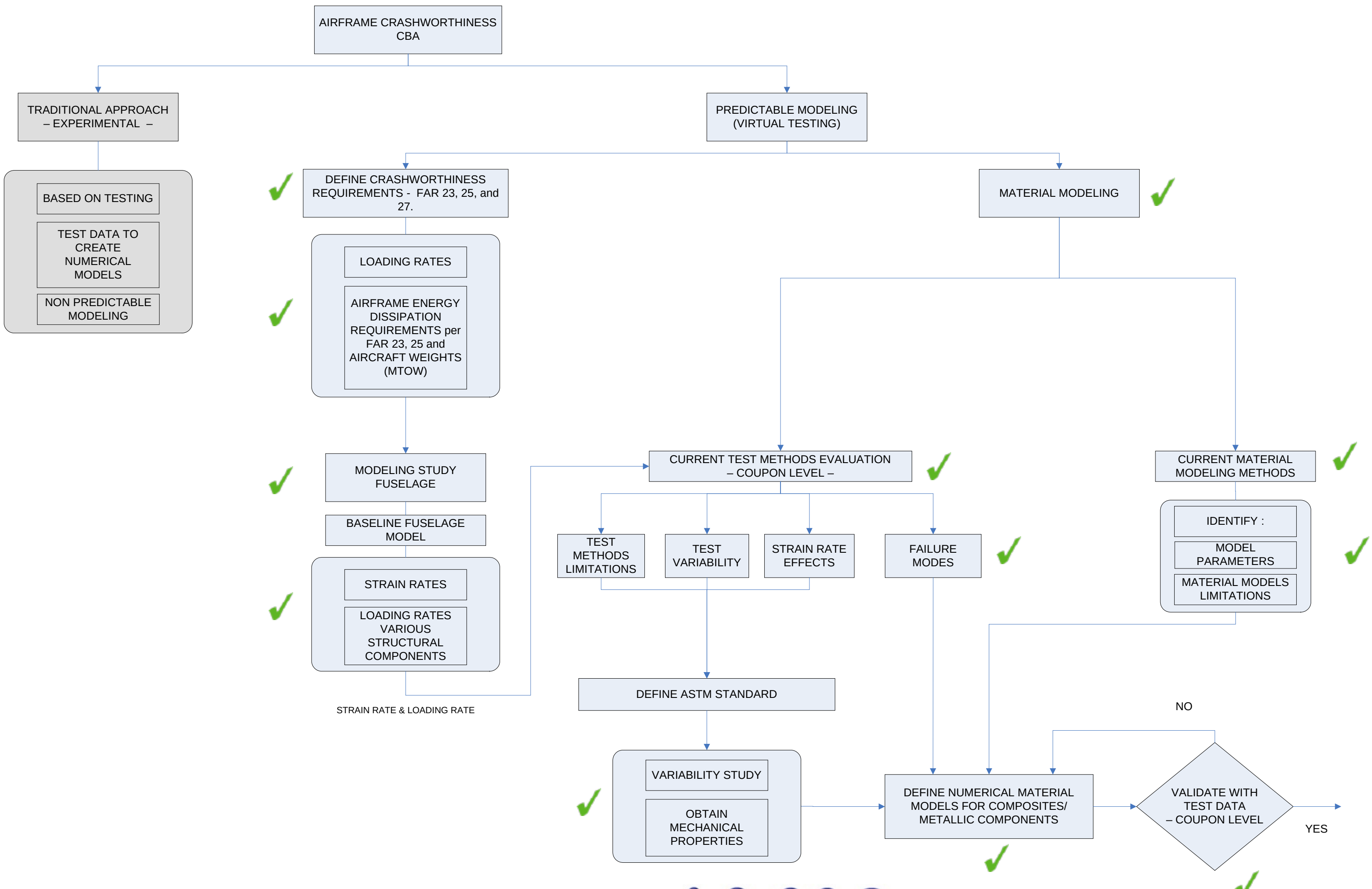
CBA: Composite Structures Crashworthiness



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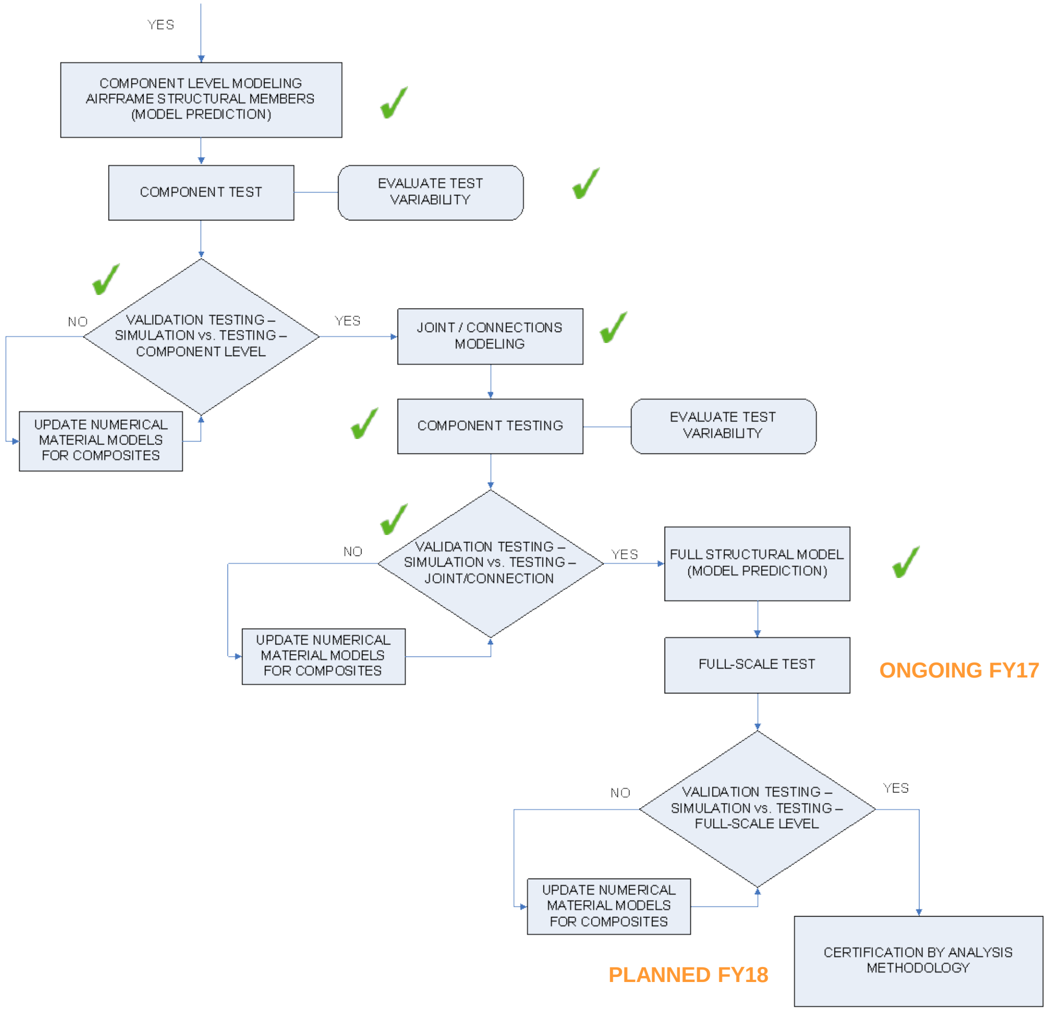
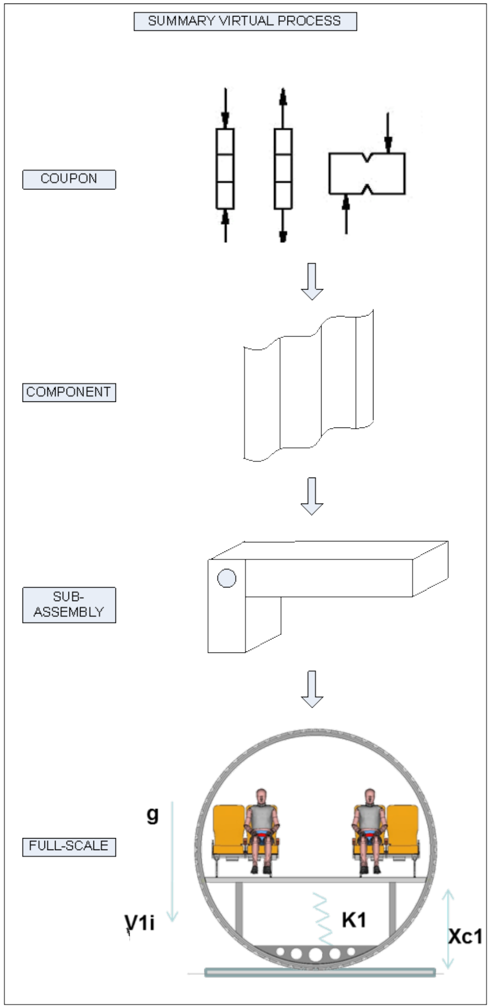
CBA Composite Structures Crashworthiness





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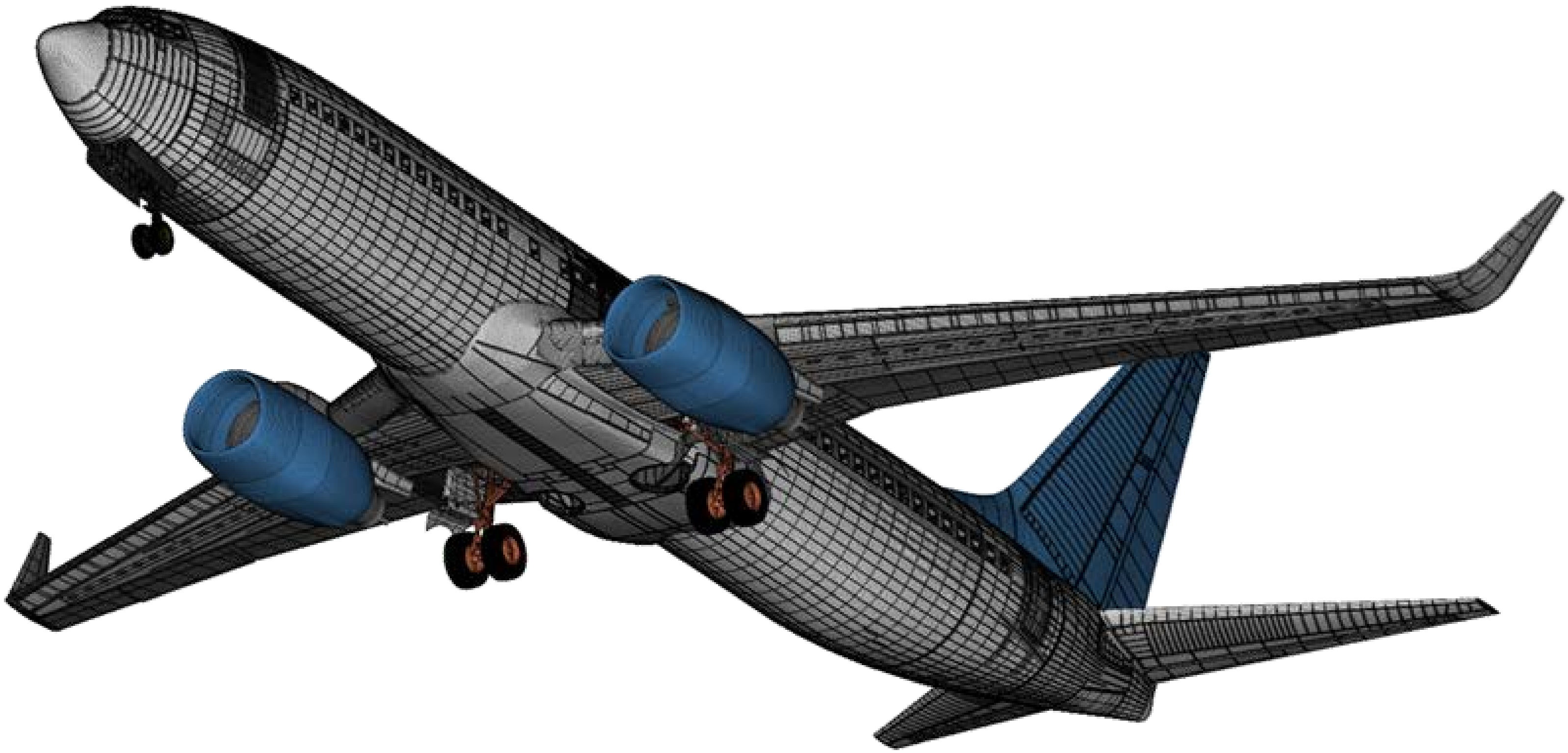
Ongoing Activities FY 16-17

- Full Scale Aircraft V&V Accident Reconstruction:
  - NLG and MLG updates with Kinematic Joints and Flexible Tire Models
  - Computational Fluid Dynamics Model Development
  - Initial Impact Position Studies
  - Full Aircraft Final Report
- ARAC Support Activities:
  - Full Narrow Body Transport Aircraft Survivable Impact Studies
  - Occupant Survivability Studies for Typical Coach Class and Business Jets Seats
  - Drop Tests Composite and Metallic Business Jets

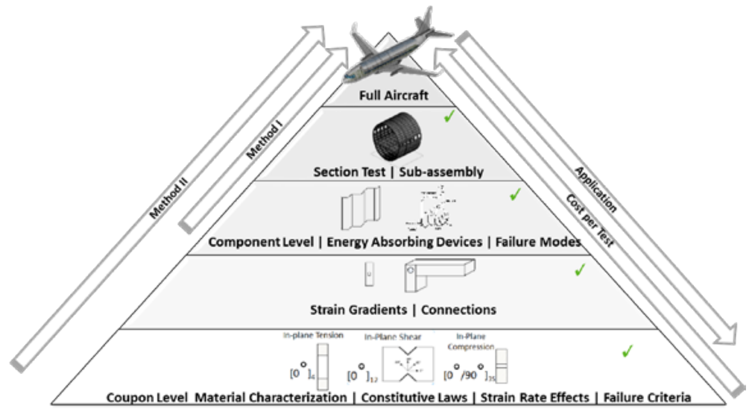


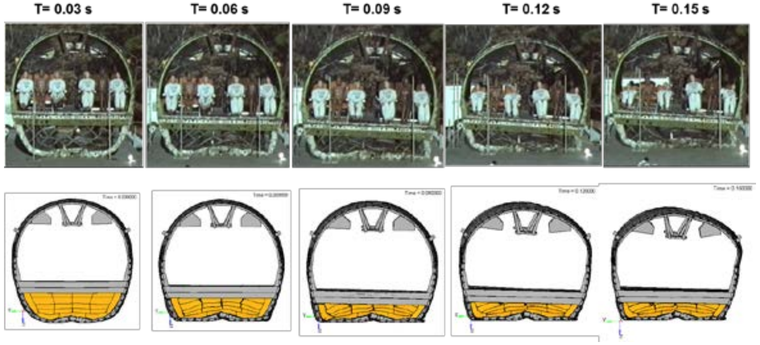
Crashworthiness Certification by Analysis

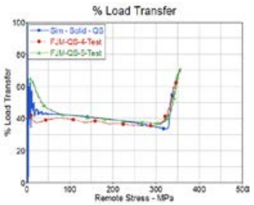
FULL AIRCRAFT CRASHWORTHINESS R&D

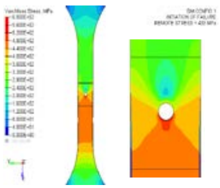
FEA N.B.T. Model Verification and Validation

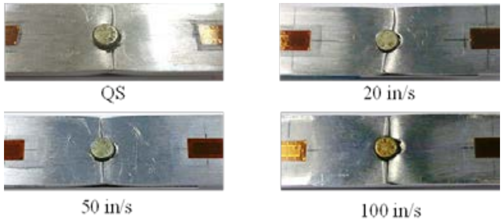
- Building Block Approach to define FEA Model
- Coupon to Section Test Validation:
  - Coupon Level Material Validation
  - Joints and Connections: Single and multiple fastener configurations. Quasi-static and Dynamic
  - Cargo validation with component level tests
  - Subassembly validation with 10 feet section test
- Full Scale Evaluation with Turkish Airlines Flight 1951
- Full aircraft model will be used to:
  - Identify the challenges involved in developing full aircraft models
  - Provide a better understanding of current state of the art airframe crashworthiness performance
  - Evaluate typical emergency landing scenarios to support ARAC activities
  - Future Diching Scenarios Evaluation



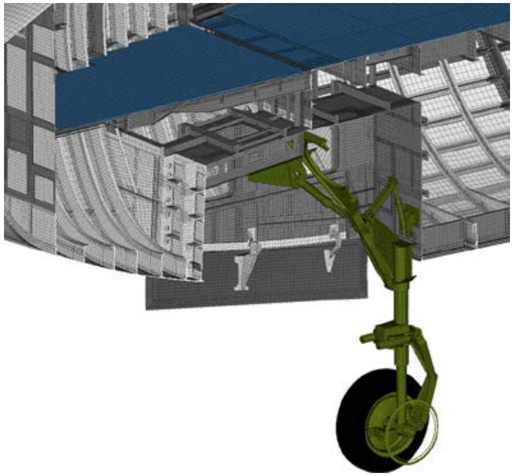


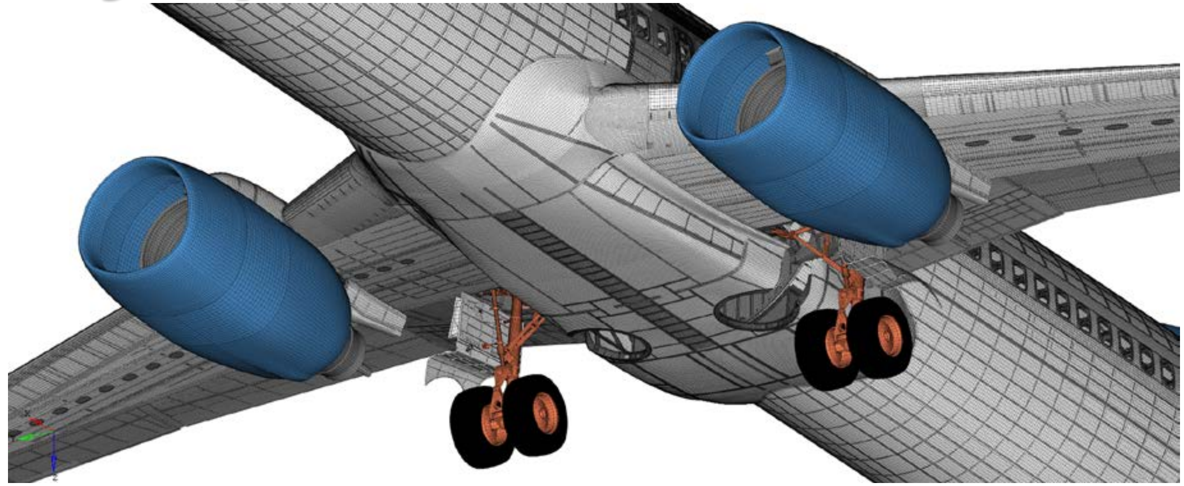




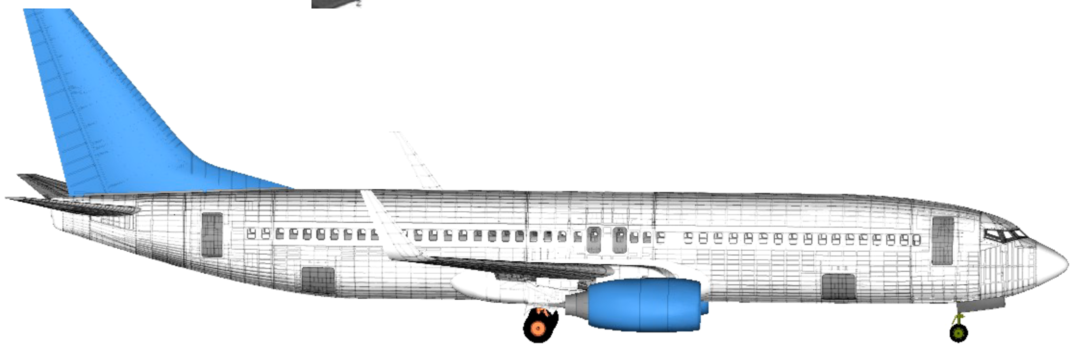


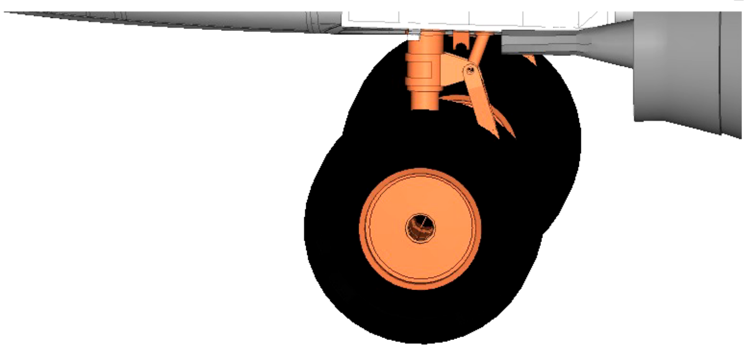
FEA Narrow Body Updates – NLG,MLG

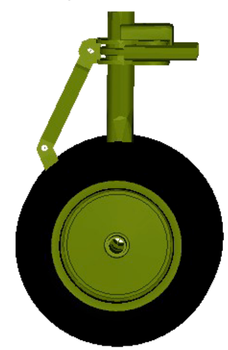




Landing Gear Check
Time = 0.000000 : Frame 1

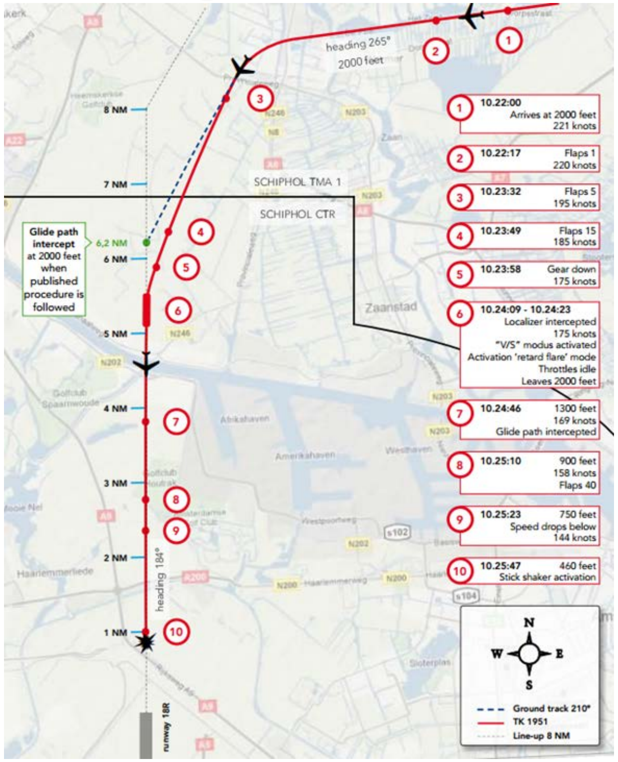






Accident Analysis – Event Description

- Turkish Airlines Flight 1951
- **Flight Route:** Istanbul to Amsterdam
- **Crash Date:** 25 February 2009 at 10.26 hours (local Dutch time)
- **Crash Location:** 1.5km (0.93 miles) from Polderbaan (18R) - Amsterdam Schiphol airport (EHAM)
- **Aircraft Type:** Boeing 737-800
- **Aircraft Orientation:** 22 deg. Pitch, 10 deg. roll to the left
- **Aircraft Speed:** Approx. 107 knots
- 128 Passengers + 7 crew
- **Overview of Crash Event:**
  - Aircraft entered Glide path late (almost one mile closer to runway)
  - Had to set low thrust to intercept path from above
  - Faulty left hand altimeter displayed -8 feet altitude (primary input for auto throttle)
  - Faulty input commanded the auto throttle to “RETARD Flare mode”
    - RETARD flare mode is selection normally applied during final landing phase below 27 feet
  - This reduced thrust to idle at an altitude and airspeed insufficient to reach the runway
  - The right hand altimeter displayed correct altitude
  - At 460 ft. altitude, aircraft warned of approaching stall and crew reacted by pushing throttle up to regain airspeed
  - Then captain took over and in response first officer relaxed his push on the throttle
  - Since autopilot was not deactivated, throttle went back to idle (RETARD mode)
  - Captain then deactivated auto throttle and increased thrust but it was too late
  - The aircraft stalled at 350 FT and speed of 105 knots



Data Source: Crashed during approach, Boeing 737-800, near Amsterdam Schiphol Airport, 25 February 2009. The Dutch Safety Board

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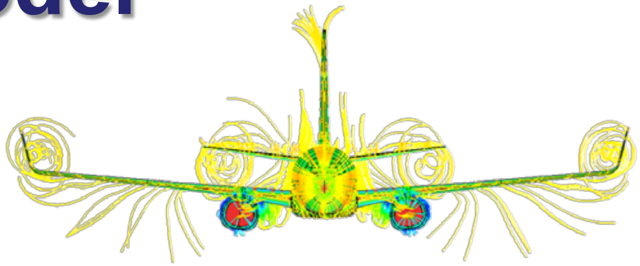
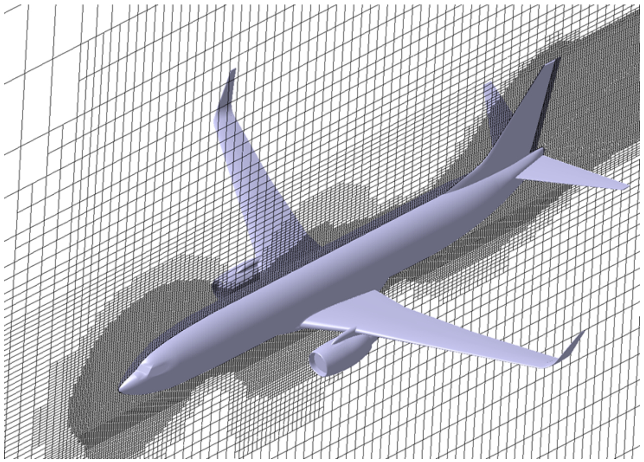
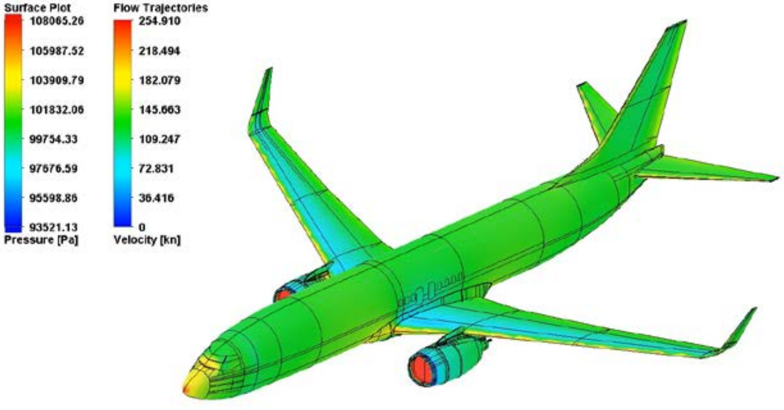
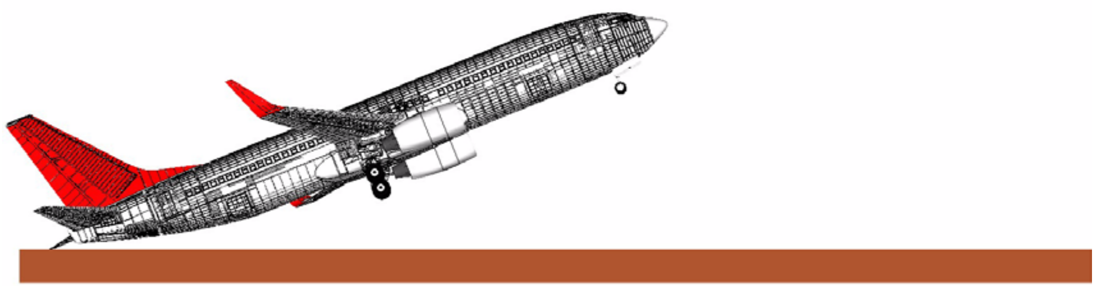
Aerodynamic Load CFD Model

- Preliminary evaluations were initially conducted without coupling of aerodynamic and propulsion loads.
- The failure mechanism did not correlate well with the real accident deformations.
- Additional work has been conducted to introduce aerodynamic and propulsion loads.



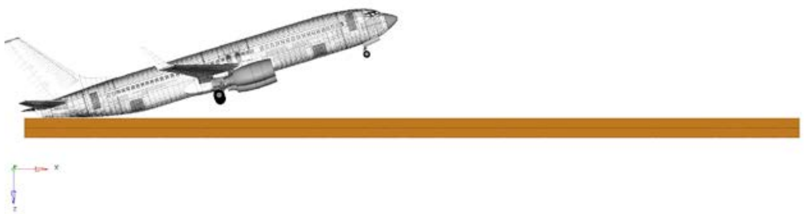


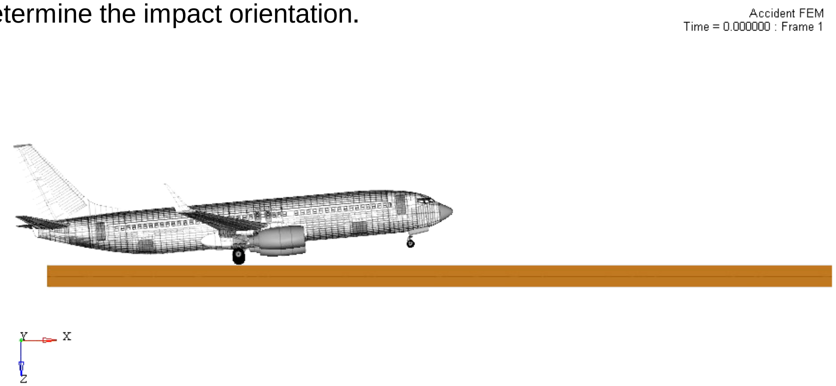


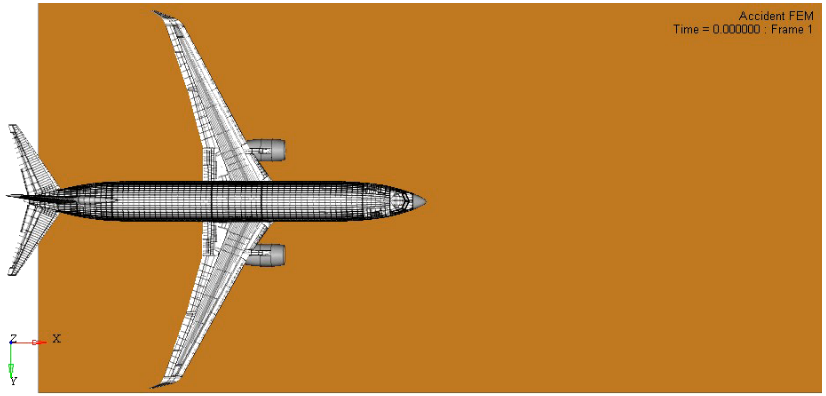


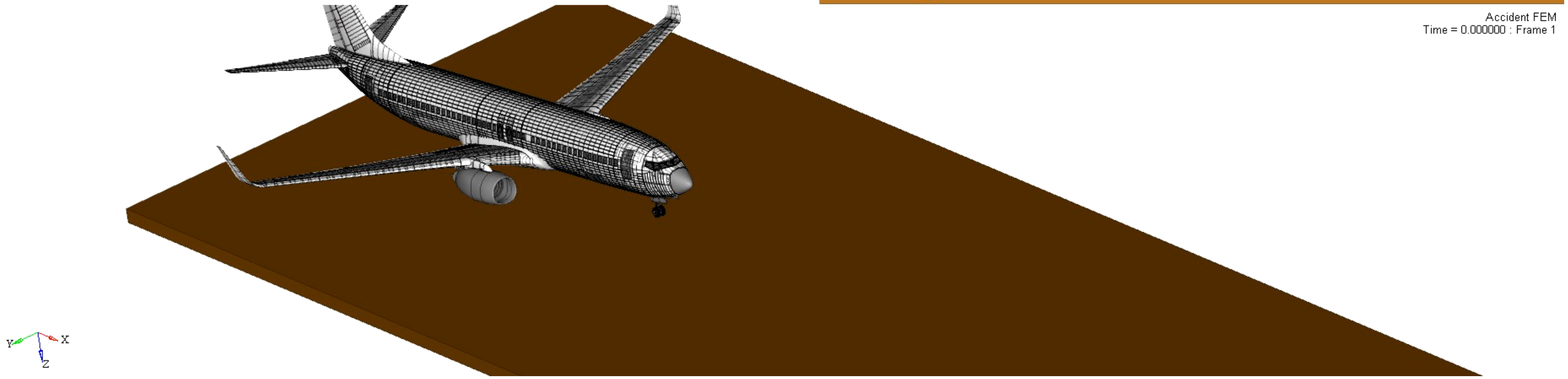
Pre-Impact Orientation Studies

- Initial evaluations were conducted with the impact orientation described in the official accident report:
  - From the Flight Data recorder the aircraft position was 22 degrees above the horizon and banked 10 degrees to the left. The altitude at this last reading was 140 ft..
- Additional ongoing work:
  - Extrapolating data from flight data recorder.
  - Using the ground markings from the fuselage, and landing gear to determine the impact orientation.

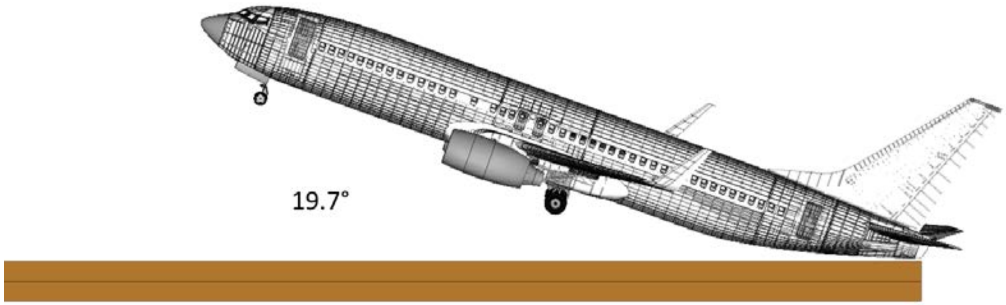


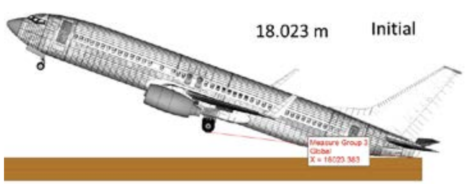


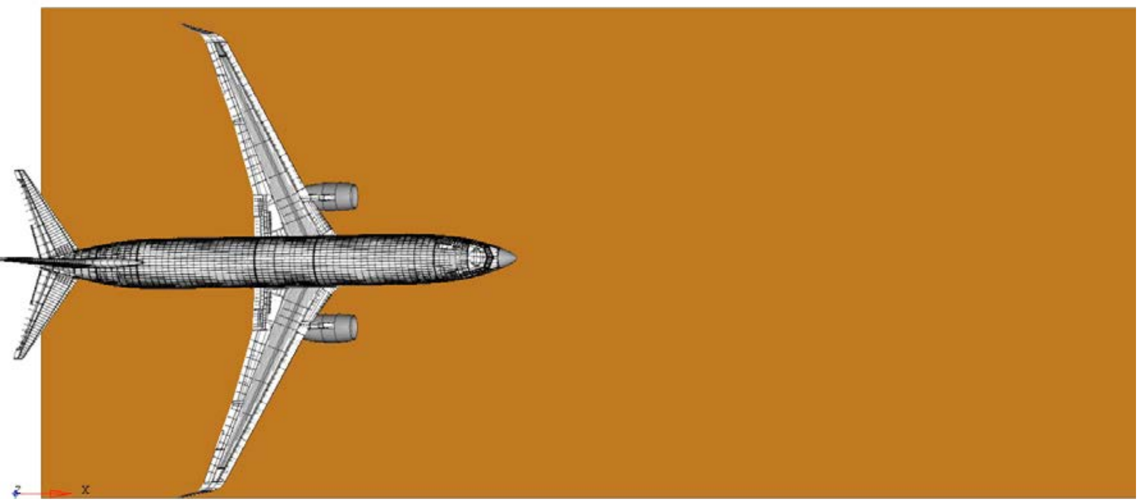


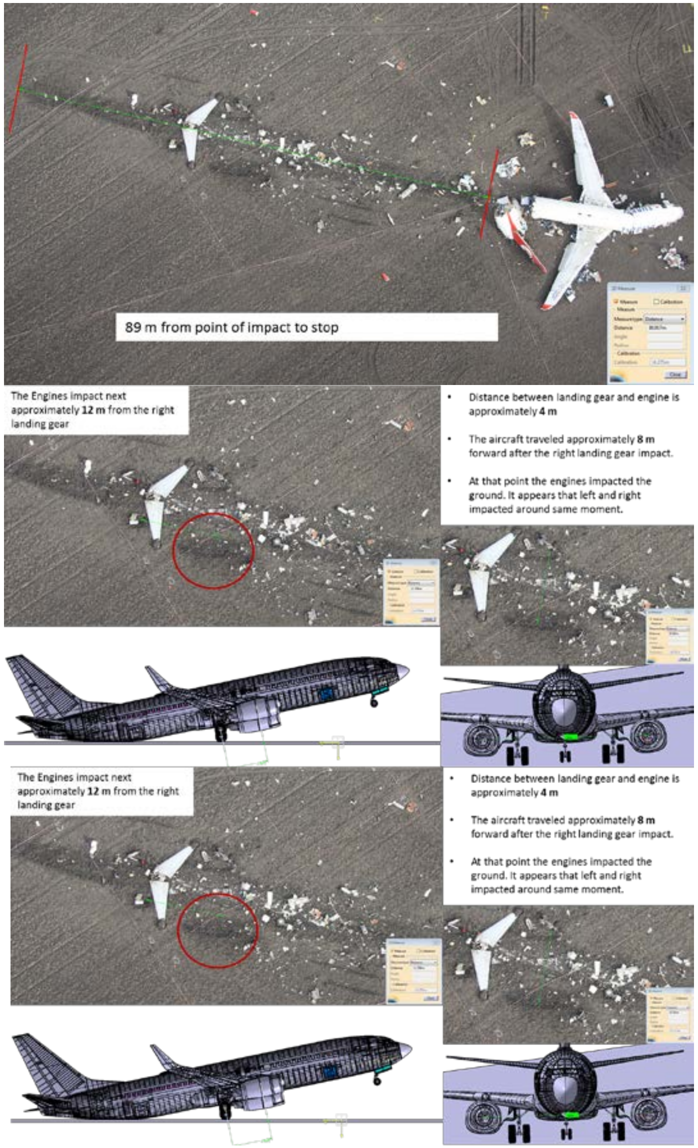


Pre-Impact Orientation Studies









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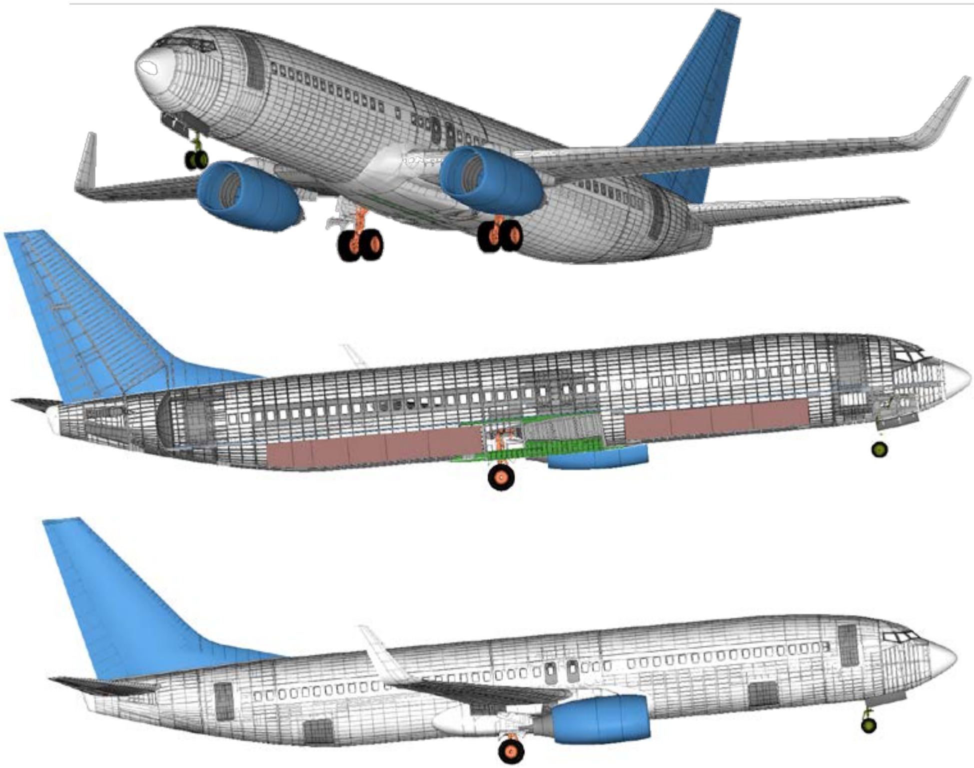
ARAC Parametric Studies - Structural

- Objective:
  - Evaluate the airframe response of a typical narrow body aircraft subjected to survivable emergency landing conditions
  - Impact Velocity:
    - Horizontal Component: 185 ft./sec
    - Vertical Component: 30 ft./sec
- Parameters:
  - Pitch Impact Angle:
    - -5, 5, and 15 degrees
  - Landing Gear Configuration:
    - Up and Down
  - Cargo Configuration:
    - Full and Empty
  - Impact Surface:
    - Rigid Surface
    - Soft Soil
- Evaluation Responses:
  - Airframe Response:
    - Deformations
    - Energy Distribution
  - Occupant Accelerations
  - Survivable Volume Evaluation



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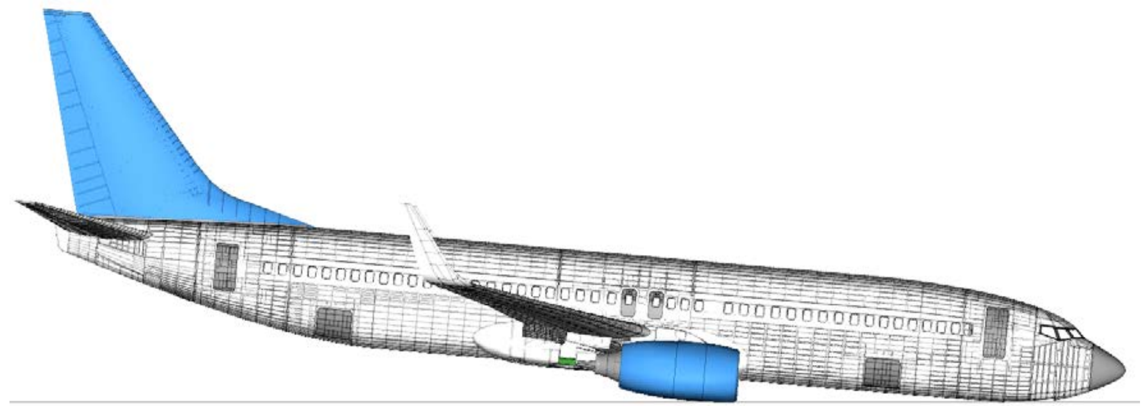
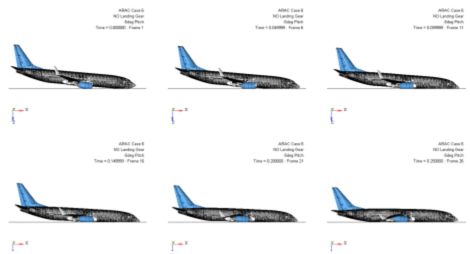
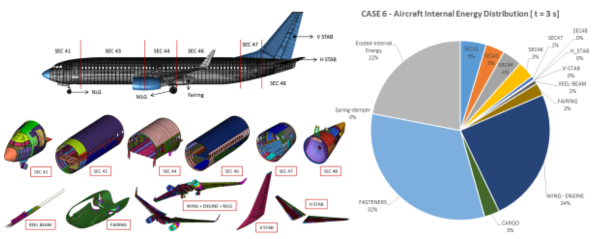
Example Load Case 6



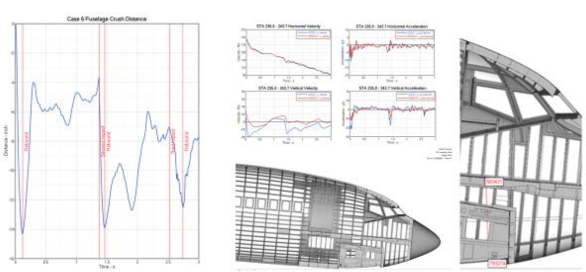
| Impact Kinematics – T= 0 s to T= 0.25 s

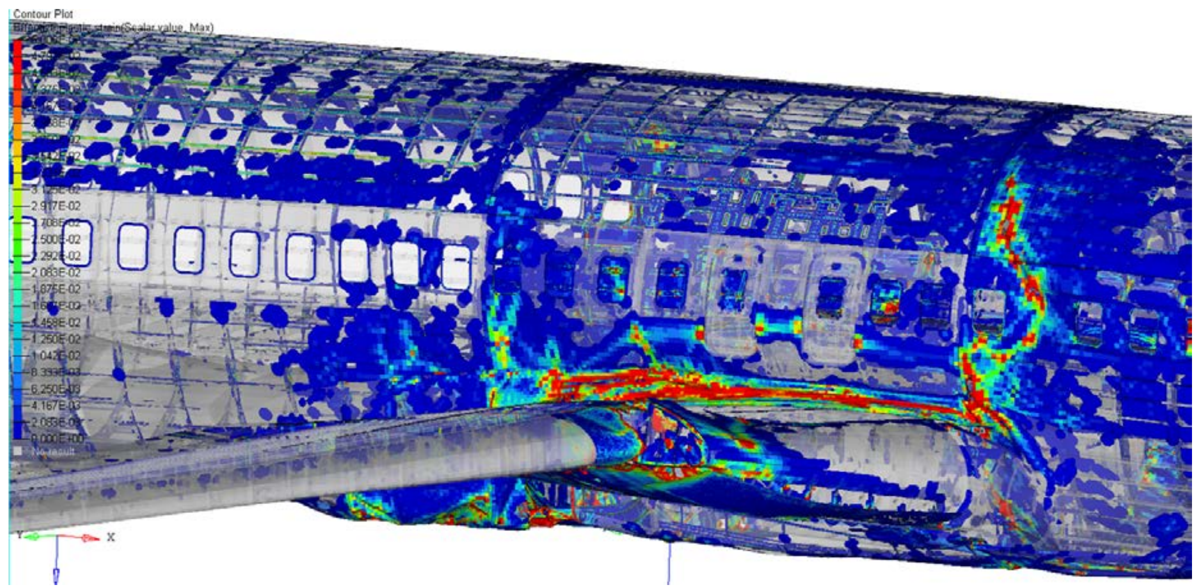


|Internal Energy Distribution at t = 3.0 s



| Critical Location Case 6: Crush Pilot Station Floor





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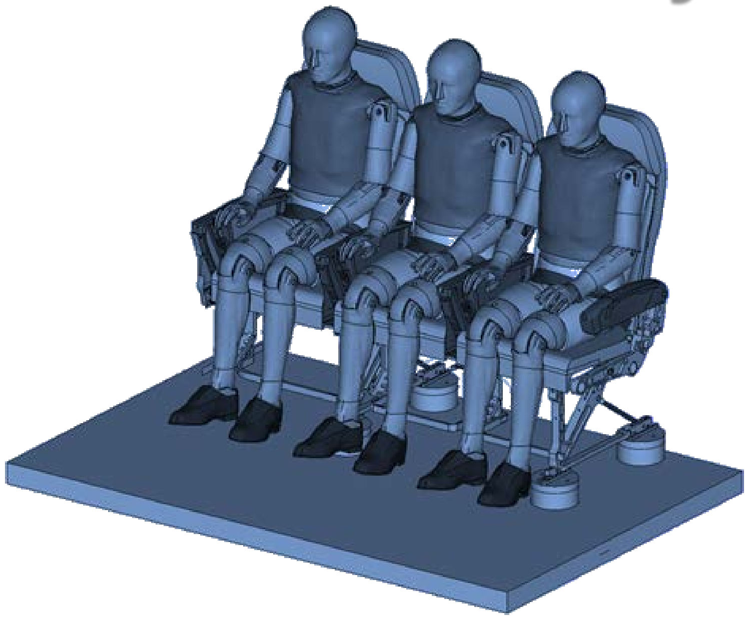
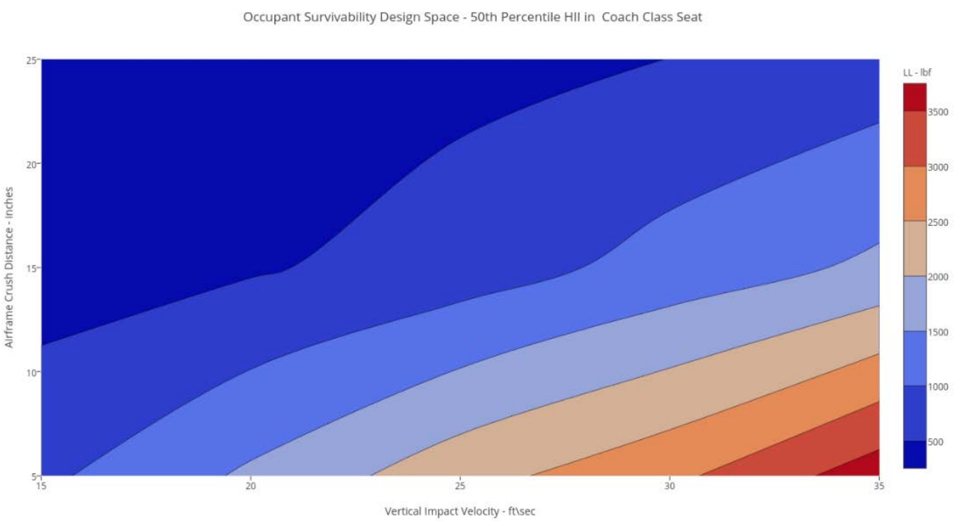
ARAC Parametric Studies - Survivability

- Objective:
  - Evaluate the occupant survivability envelope for a 50th percentile passenger seated in typical coach class and business jet seats.
- Parameters:
  - Seat Configurations:
    - Typical 3 Place Coach Class – 3 Place
    - Typical 1 Place Business Jet – 1 Place
  - Vertical Impact Velocities:
    - 15,20,25,30, and 35 ft..\sec
  - Fuselage Crush Distance:
    - 5, 15, and 25 inches
- Evaluation Responses:
  - Lumbar Load
  - Seat Structural Performance





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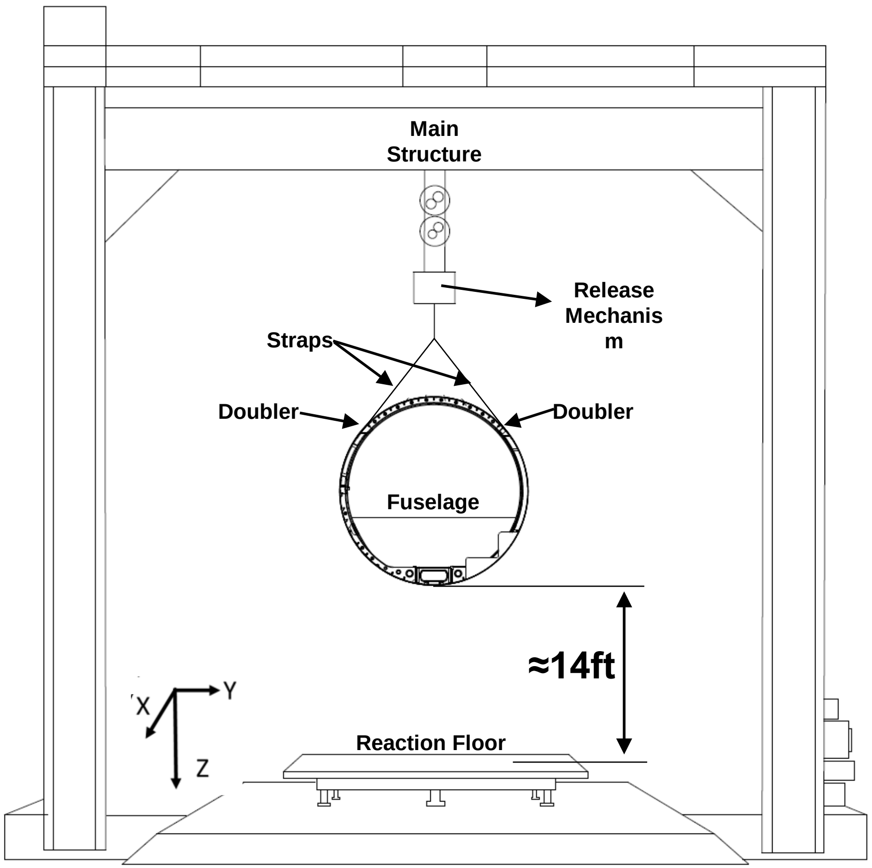
Experimental Work

FULL SCALE TESTING COMPOSITE AND METALLIC STRUCTURE

NIAR Drop Tests

- Tentative Date: August 2017
- 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
  - Two tests will be conducted:
    - Composites (Hawker 4000)
    - Metallic (Cessna Citation 650)
  - Tentative impact velocity 30 ft./s
  - Instrumented Reaction Floor
  - Hardware
    - Digital Image Correlation
    - Strain-gages
    - Load Cells
    - High Speed Videos



Composite Airframe Test Article

Interior	
Cabin Height	6ft
Cabin Length	25 ft.
Cabin Width	6 ft. 6 in
Cabin Volume	762 ft^3

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 lb./ ISA + 22 °C () each
Cruise Speed	Mach 0.84
Range	6075 km
Service Ceiling	45000 ft.

Composite Test Section – Specifications

- 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

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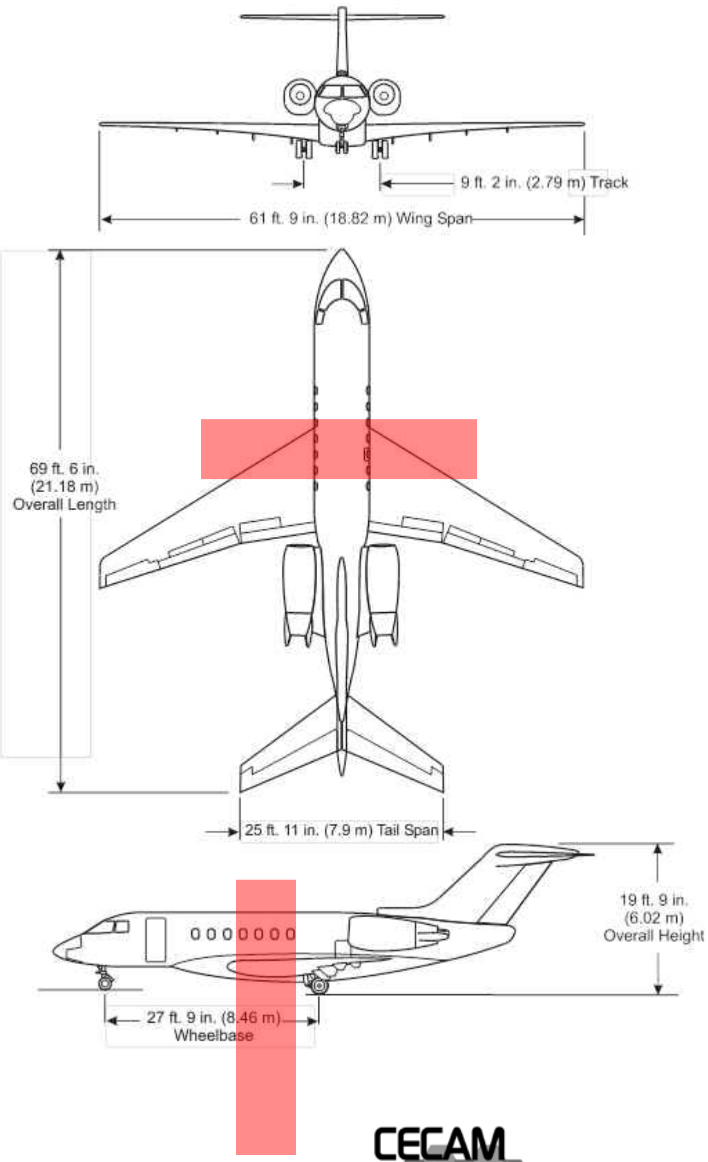
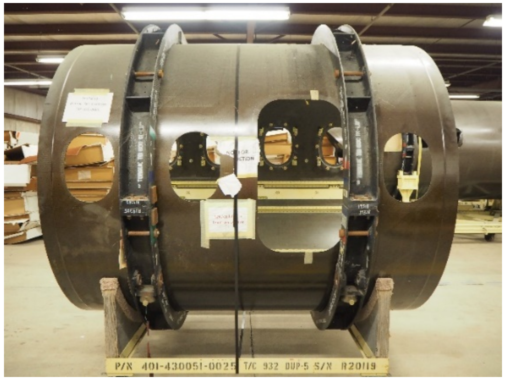
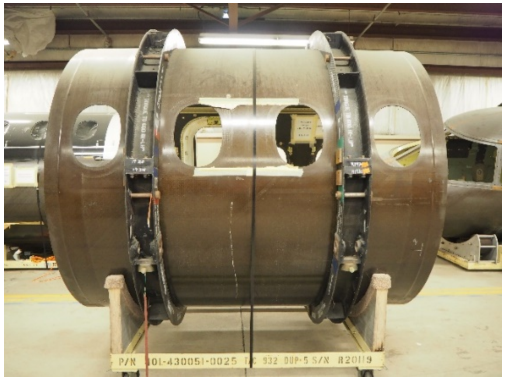
Composite Test Section– Aircraft Location







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Metallic Airframe Test Article

Performance	
Power	2 × Garrett TFE731-3B-100S Turbofans 3,650 lb. (16.2 ken) thrust each
Cruise Speed	554 mph (875 mph)
Range	2345 mi (3774 km)
Service Ceiling	51000 ft.

Interior	
Cabin Height	5 ft 8 in
Cabin Length	18 ft 7in
Cabin Width	5 ft 6 in
Cabin Volume	762 ft^3

General Characteristics	
Seating	2+7/9
External Length	55 ft. 6 in
External tail Height	16 ft. 10 in
Wing Span	53 ft. 6 in
Empty Weight	11670 lb. (5293 kg)
Gross Weight	22000 lb. (9979 kg)

Metallic Test Section – Specifications

- Complete Fuselage Available
- Tentative Test Article Dimensions
  - Length: ≈9 ft.
  - Diameter: ≈6 ft.
- Tentative Test Article Configuration:
  - One Exit Door Opening (Right Side)
  - Seven Window Openings:
    - 3 Right Side
    - 4 Left Side
- Floor Structure with Seat tracks
- Seat Track Width: 15” (wall mounted)
- No wing box structure
- No upper panels/PSUs

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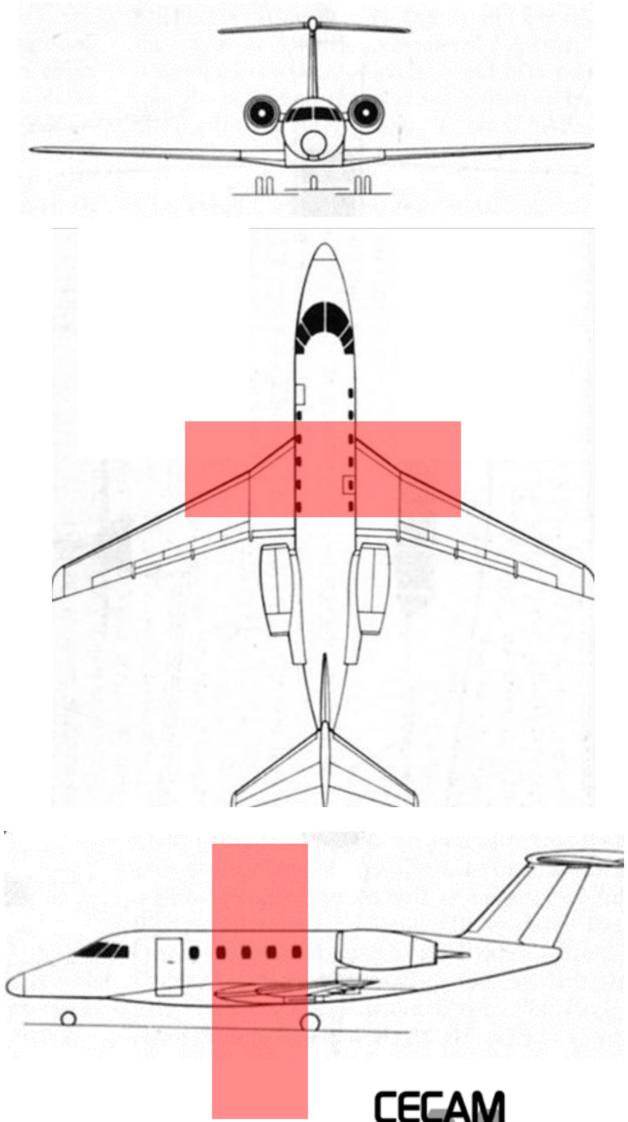
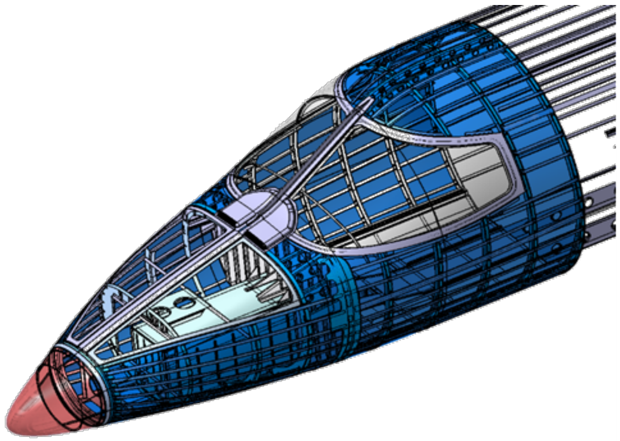
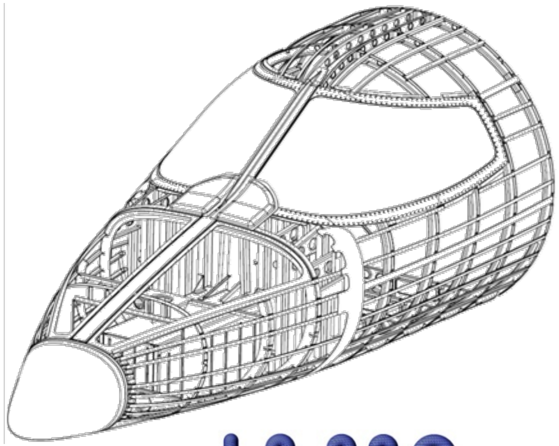
Metallic Test Section – Aircraft Location

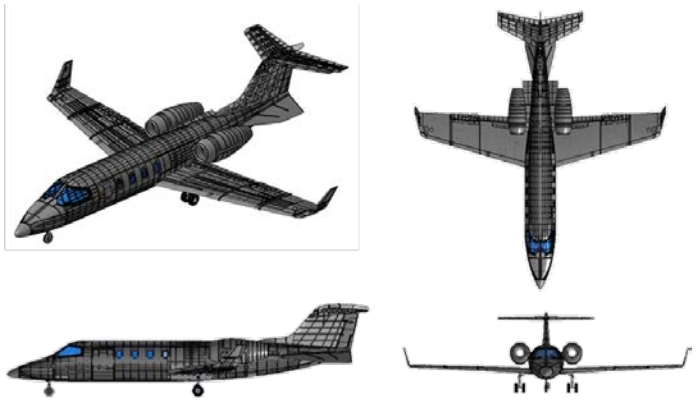


Conclusions and Future Work

- The development of the full aircraft model has provided valuable insights on airframe crashworthiness performance under various emergency landing conditions.
- All computational and experimental findings are being shared with the ARAC group.
- For FY17-18 we need to create and validate the models of the composite and metallic business jet sections tested at NIAR.
- In order to support the ARAC effort it is necessary to conduct the emergency landing studies for business jet size airframes. FY17-18.
- Explore the use of full aircraft models for ditching simulations.
- Will present the results of the Accident Reconstruction at the International Aerospace Structural Impact Dynamics Conference (ASIDIC) in Wichita on October 17-19th [www.asidiconference.org]







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Advanced Materials in Transport Aircraft Structures

Looking Forward

- Benefit to Aviation
  - Provide a methodology and the tools required by industry to maintain or improve the level of safety for new composite aircraft when compared to current metallic aircraft during emergency landing conditions.
  - Improve the understanding of the crashworthy behavior of metallic and composite structures
  - Provide R&D material to the ARAC Transport Airplane Crashworthiness and Ditching Working Group.
  - The FEA models developed for this program are contributing also to ongoing UAS-Aircraft airborne collision R&D. These models may also be used in the near future for ditching evaluations.
- Future needs
  - Development and Validation of a Metallic and Composites business jet section. Use the experimental data generated in FY 17.
  - Develop a representative business jet model to better understand the crashworthiness performance of these type of aircraft certified under 14 CFR 25 – Support ARAC Working group and Industry.
  - Full Aircraft Ditching Events Structural Performance Evaluation.
  - General Aviation Crashworthiness Design Strategies – Composites Crashworthy Structures
  - Training of Industry and FAA personnel on the use of numerical tools to support the development and certification process.

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