Crashworthiness by Analysis – Verifying FEM Capabilities by Accident Reconstruction

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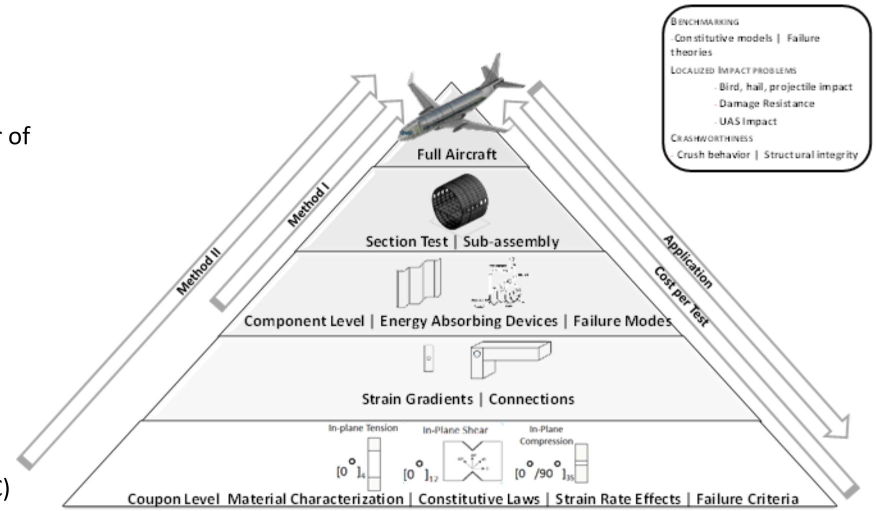
NIAR
WICHITA STATE UNIVERSITY
NATIONAL INSTITUTE FOR AVIATION RESEARCH

Agenda

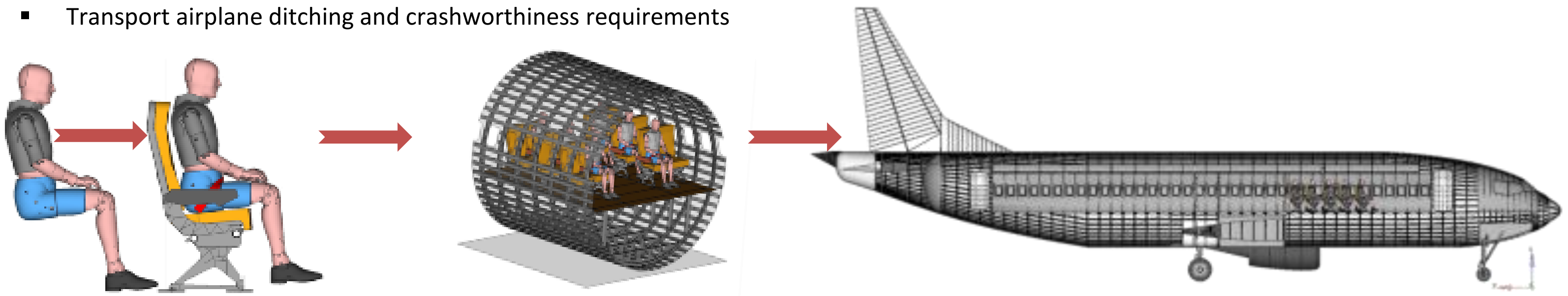
- Physics Based Simulation Method: Building Block Approach
- Accident Overview
- Project Scope
- CAD-FEA Process
- 10-ft Fuselage Section Validation
- Full Scale Preliminary Simulation
- Conclusions and Recommendations

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.

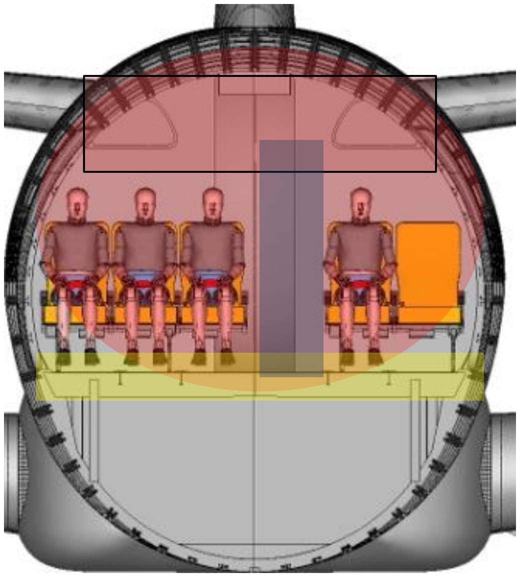


- **Applications**
  - Boeing 787 crashworthiness requirement (Special condition 25-362-SC)
  - Airbus A350 crashworthiness requirement (Special condition 25-537-SC)
  - AC 20-146 Aircraft Seat Certification
    - Demonstrating compliance to standard test requirements for changes to a baseline seat design
    - Establishing the critical seat installation/configuration in preparation for dynamic testing
  - ARAC
    - Transport airplane ditching and crashworthiness requirements



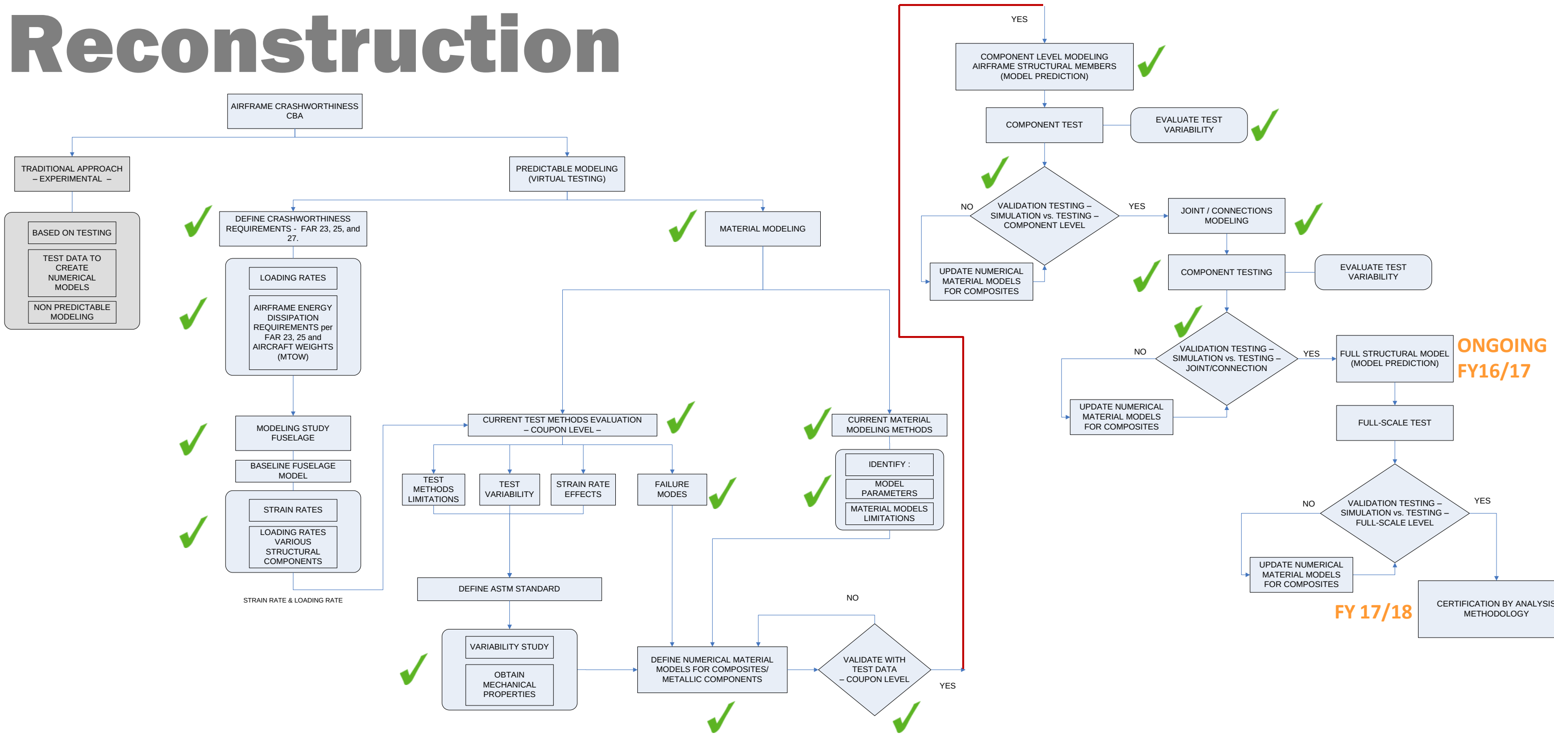
Aerospace Structural Crashworthiness

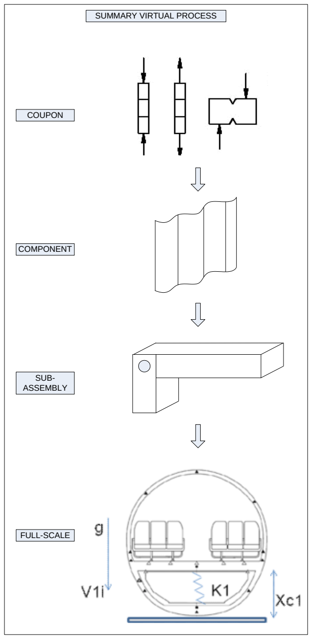
- **Crashworthiness performance of composite structures to be equivalent or better than traditional metallic structures**
- **Crashworthiness design requirements**:
  - Maintain survivable volume
  - Maintain deceleration loads to occupants
  - Retention items of mass
  - Maintain egress paths



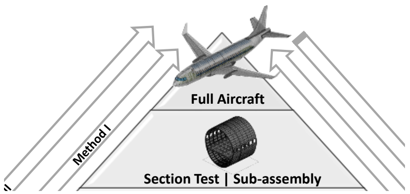
- **Currently there are two approaches that can be applied to analyze this special condition:**
  - **Method I:** Large Scale Test Article Approach
    - **Experimental:**
      - Large Scale Test Articles (Barrel Sections)
      - Component Level Testing of Energy Absorbing Devices
    - **Simulation** 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
    - Predictable modeling

Verifying FEM Capabilities by Accident Reconstruction

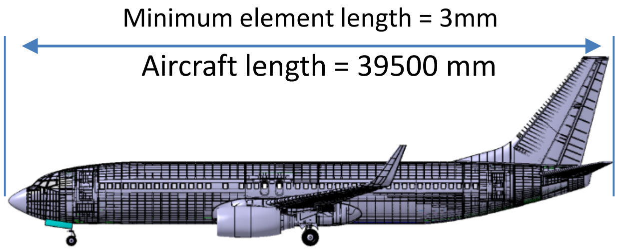




- How do we evaluate Full-scale models at the top of the building block approach?
  - With confidence in element, coupon, component and sub-assembly models
  - Comparison to Test Data
    - Fortunately extensive documentation of Turkish Airline Flight 1951 crash by Dutch Authorities
    - Considered survivable crash (only 9 fatalities out of 128 occupants)



- What are we dealing with?
  - Simulation time-step is dictated by minimum element length
  - Model with around 10 million elements – Typical minimum element length for crash analysis is 3mm
  - Computing Resources
  - Model Stability due to large deformations

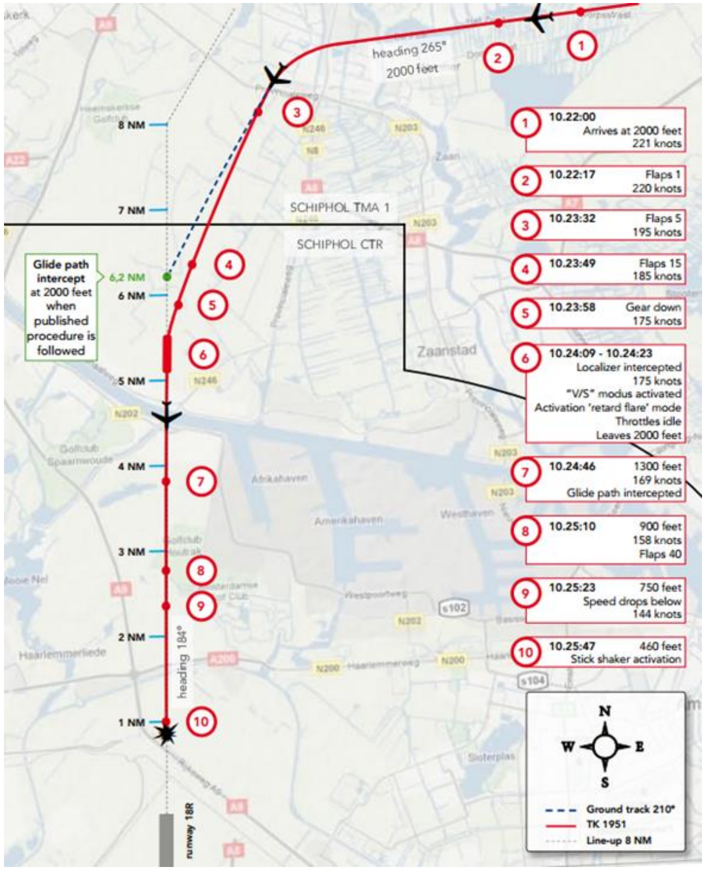


Turkish Airline Flight 1951 on Final Approach to Schiphol Airport

ACCIDENT OVERVIEW

Accident Summary

- **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
- **Final Known Aircraft orientation:** 22 deg Pitch, 10 deg roll to the left
- **Final Known Aircraft Speed:** Approx 107 knots
- **Total Passengers:** 128 Passengers + 7 crew
- **Injury Evaluation:** 9 Fatalities, 120 Injuries (Minor to Serious)
- **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 autothrottle)
  - Faulty input commanded the autothrottle to "RETARD Flare mode"
    - RETARD flare mode 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



Runway

Crash Site

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

Damage to Aircraft

- Observed Damage
  - Traveled approximately 100 m from first impact
  - Horizontal Stabilizer separated and flipped
  - Fuselage breaks into 3 pieces
  - Engines detach and fly away

- Why this Accident is interesting?
  - No fire
  - Doors and escape route accessible – Egress
  - Survivable volume maintained
  - Most items of mass retained
  - Fits the definition of survivable accident (FAA)

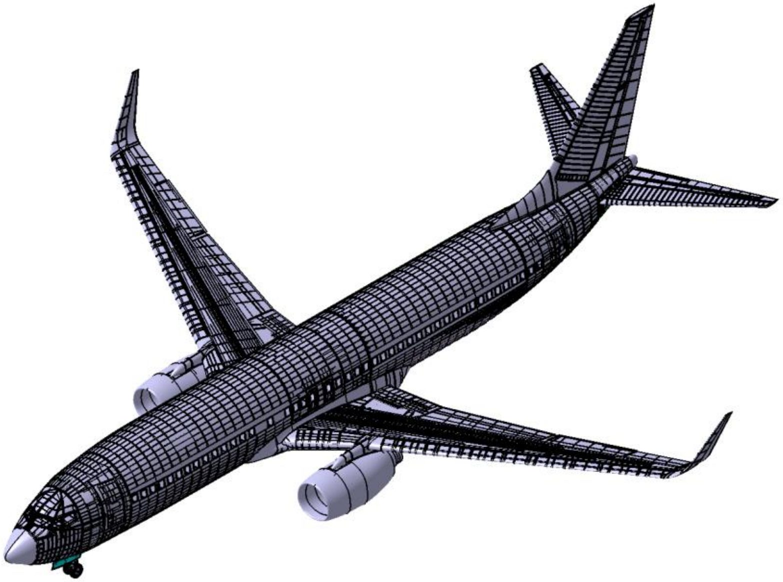
- Areas this allows to explore
  - Defining requirements for Seats
  - Defining crashworthiness requirements
  - Exploring FEM capabilities (CBA / Special Conditions)
  - Exploring injury criteria

- Accident Documentation
  - Extensive documentation available
  - This complements FEM

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

Project Scope and Tasks

Scope - Prediction of overall failure modes and demonstration of critical parameters such as survivable volume and egress paths

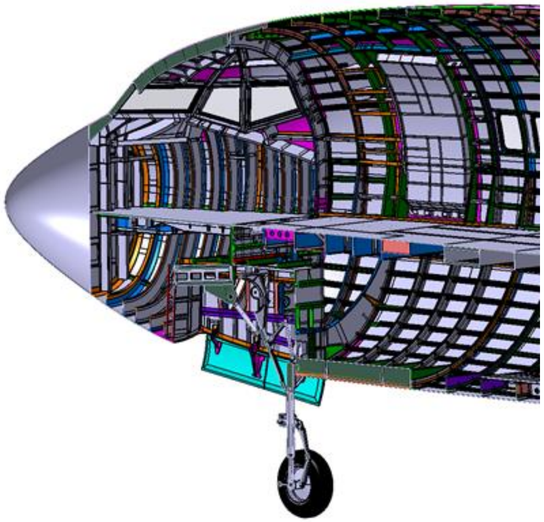


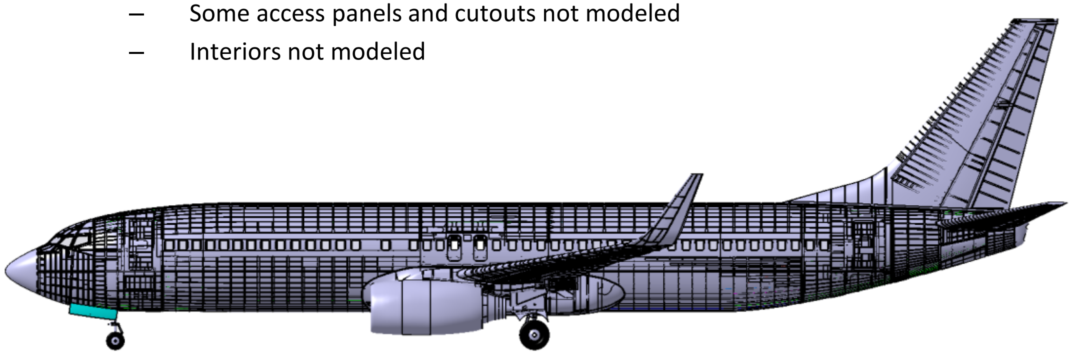
Tasks

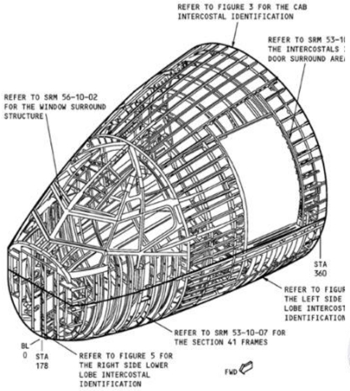
- **Full Aircraft CAD – Similar to B737-800**
  - Challenge
    - Actual drawings not available from OEM
  - Solution
    - Books, Online Resources, Repair Manuals
    - Validation study
- **Full Aircraft FEM**
  - Challenge
    - Model critical assumptions
    - Connections
    - Material Application
  - Solution
    - Document Assumptions and its likely impact on results
    - Create an organized process for FEM assembly
- **150 m of Soil FEM**
  - Challenge
    - What will LS-DYNA be able to handle
    - Material properties of soil at crash site not available
  - Solutions
    - Extensive study of FEM techniques for Soil
    - Extensive literature review for material data
- **Crash Boundary Conditions**
  - Challenge
    - Last data point at Aircraft altitude of 80 ft
  - Solution
    - Extensive study of available data
    - Expert opinions

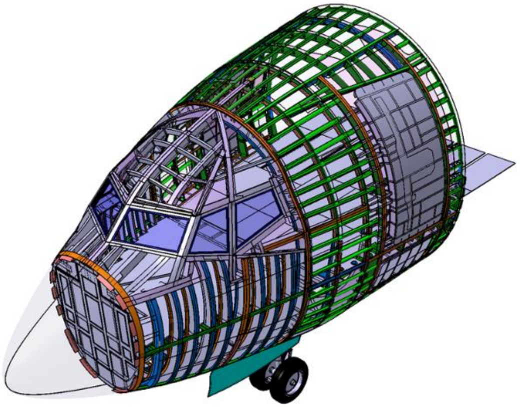
CAD-FEA Model Example

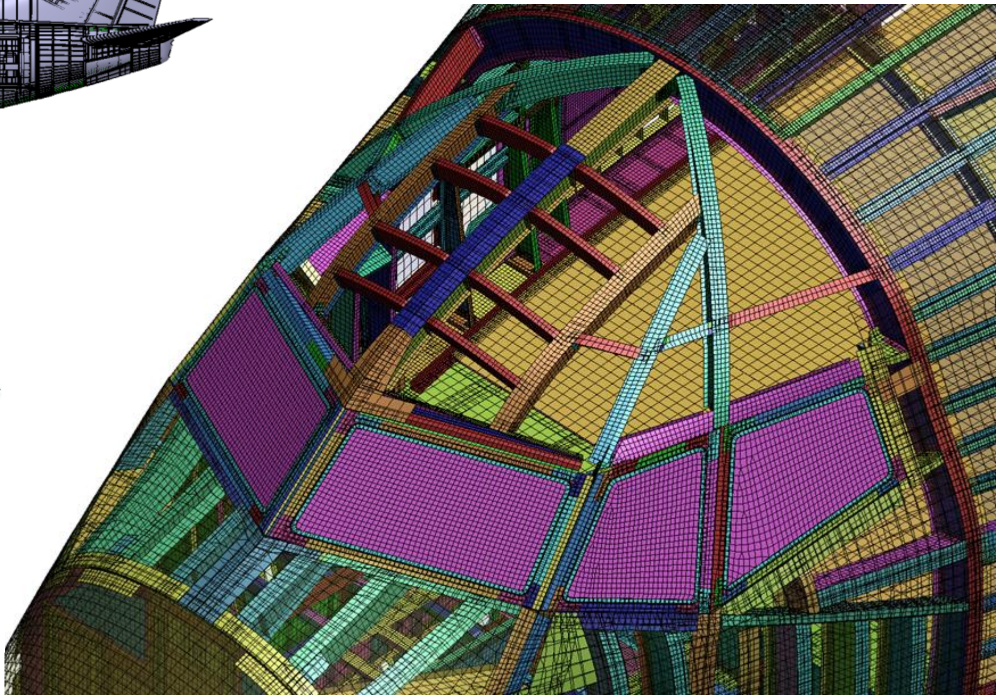
- Constructed using manuals and information in public database
- Model Assumptions
  - Avionics, wires and systems not modeled
  - Lightning holes simplified or assumed
  - Fastener points and locations based on repair guidelines (REF)
  - Thickness of some parts not available so created based on geometric scaling
  - Some access panels and cutouts not modeled
  - Interiors not modeled











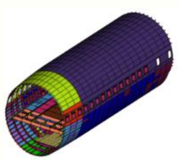
FE Modeling Process

DISCRETIZATION PROCESS

- Inspect CAD Model

- Mesh Parts

- Mesh Quality Check



NUMBERING

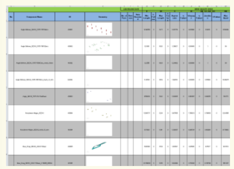
- Check Mesh Quality

- Renumber using Table 1 (slide 3)

Include Sections	Nodes
FUSELAGE	1 - 16,000,000
SEC 41 + NLG	1 - 2,499,999
SEC 43	2,500,000 - 4,999,999
SEC 44	5,000,000 - 7,499,999
SEC 46	7,500,000 - 9,999,999
SEC 47	10,000,000 - 12,499,999
SEC 48	12,500,000 - 14,999,999

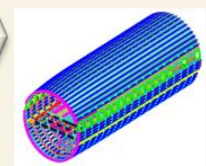
DOCUMENTATION

- Document Part ID's and Mesh Quality



CONNECTION

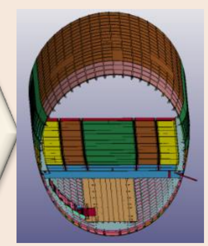
- Parts connected using beam elements



IMPLICIT CHECK

- Eigenvalue analysis

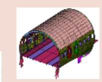
- Natural Frequencies and mode shapes to review connections



ASSEMBLY

- Assemble individual section to create the full aircraft model

- Wing to Fuselage



MATERIALS

- Extract material information from CAD

- Obtain material cards from material database

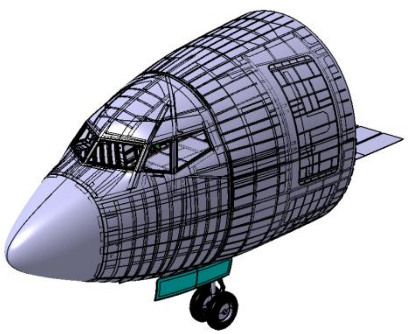
- Apply to over 2500 sub assemblies

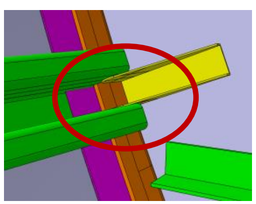
- Other steps include
    - Mass distribution
    - Weight and CG Balance

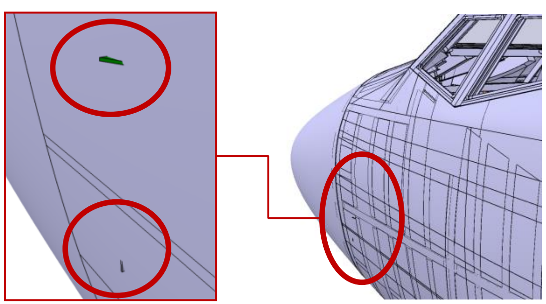
FEA Modeling - Discretization Process

Geometry Cleanup

- Inspect CAD model for
  - Penetration
  - Intersections
- Document and Request corrections



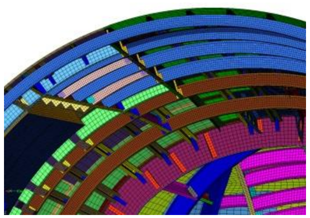




Meshing

- Consistent Element Sizes
- Mesh Flow
- Minimize number of Trias < 5%
- Mesh Quality Criteria for Crash Analysis

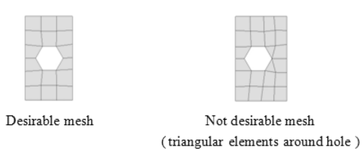
Shell (2D)Mesh

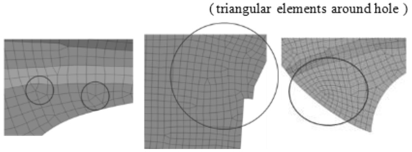


Solid (3D)Mesh

Quality Parameter	Allowable Min./Max.
Min.Side Length	3 mm
Max.Aspect Ratio	5
Min. Quad Angle	45 deg
Max. Quad Angle	140 deg
Min. Tri Angle	30 deg
Max. Tri Angle	120 deg
Max Warp Angle	15 deg
Min. Jacobian	0.7

Quality Parameter	Allowable Min./Max.
Min.Side Length	5 mm
Max.Aspect Ratio	5
Tet Collapse	0.3
Max Warp Angle	15 deg
Min. Jacobian	0.5

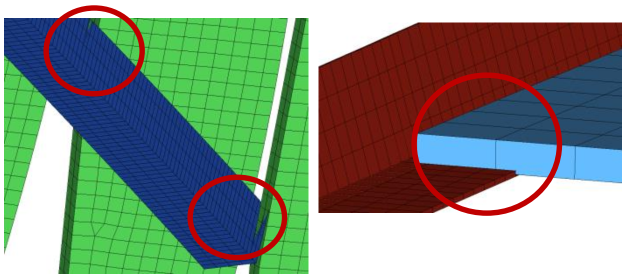




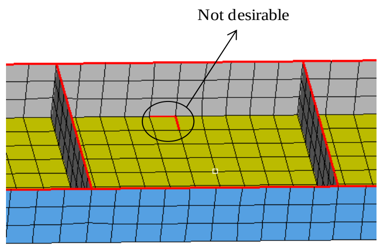
NOT desirable mesh transition

Quality Check

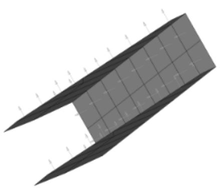
- Check Normals
- Check Penetrations
- Check Intersections
- Check Edges and Element Connectivity
- Check for Duplicates



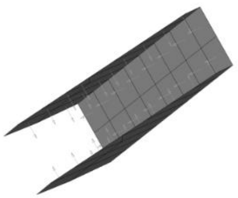
Intersections and Penetrations need to be fixed



Bad element connectivity



Element Normals need fixing

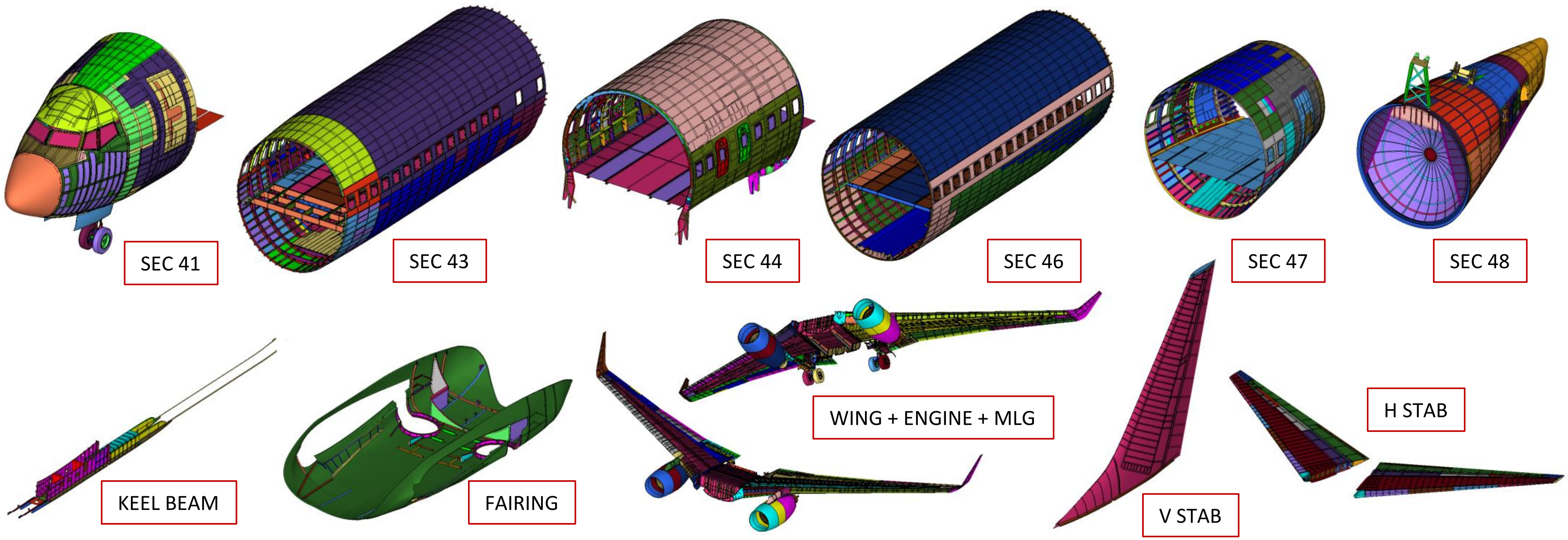


Element Normals fixed

FEA Modeling – Modular FEA Model Approach

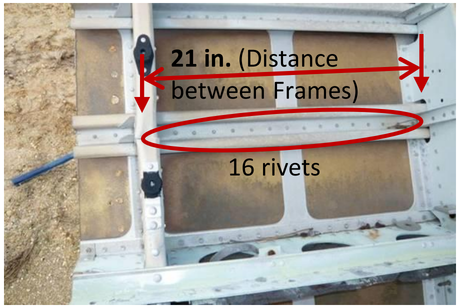
- Enable multiple people to work on the model
- Avoid clashes when assembling model
- Independent editing of sections
- Ease of documentation and tracking
- More manageable amount of work

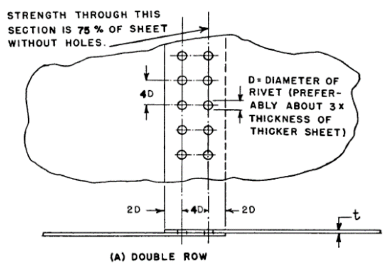
	Numbering Ranges					
Include Sections	**Nodes**	**Elements**	**Parts**	**Sections**	**Sets**	**Others eg. Constraints**
FUSELAGE	**1 - 16,000,000**	**1 - 16,000,000**				
SEC 41 + NLG	1 - 2,499,999	1 - 2,499,999	410000 - 419999	410000 - 419999	410000 - 419999	410000 - 419999
SEC 43	2,500,000 - 4,999,999	2,500,000 - 4,999,999	430000 - 439999	430000 - 439999	430000 - 439999	430000 - 439999
SEC 44	5,000,000 - 7,499,999	5,000,000 - 7,499,999	440000 - 449999	440000 - 449999	440000 - 449999	440000 - 449999
SEC 46	7,500,000 - 9,999,999	7,500,000 - 9,999,999	460000 - 469999	460000 - 469999	460000 - 469999	460000 - 469999
SEC 47	10,000,000 - 12,499,999	10,000,000 - 12,499,999	470000 - 479999	470000 - 479999	470000 - 479999	470000 - 479999
SEC 48	12,500,000 - 14,999,999	12,500,000 - 14,999,999	480000 - 489999	480000 - 489999	480000 - 489999	480000 - 489999
KEEL BEAM	15,000,000 - 15,499,999	15,000,000 - 15,499,999	400000 - 409999	400000 - 409999	400000 - 409999	400000 - 409999
WING-BODY FAIRING	15,500,000 - 16,000,000	15,500,000 - 16,000,000	450000 - 459999	450000 - 459999	450000 - 459999	450000 - 459999
WING	**17,000,000 - 20,500,000**	**17,000,000 - 20,500,000**				
Wing + Engine + MLG	17,000,000 - 20,500,000	17,000,000 - 20,500,000	500000 - 529999	500000 - 529999	500000 - 529999	500000 - 529999
VERTICAL STAB	21,000,000 - 21,999,999	21,000,000 - 21,999,999	700000 - 709999	700000 - 709999	700000 - 709999	700000 - 709999
HORIZONTAL STAB	22,000,000 - 22,999,999	22,000,000 - 22,999,999	800000 - 809999	800000 - 809999	800000 - 809999	800000 - 809999



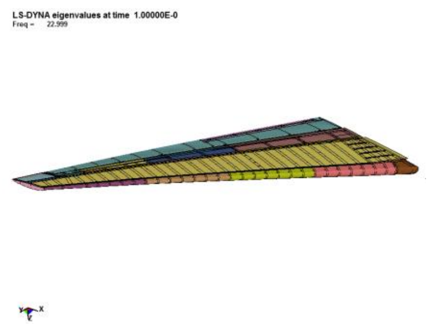
FEA Modeling – Connections and Implicit Check

- Connection Points were derived by research and by following guidelines in FAA Advisory Circular for Repair (AC 43.13-1B)
- Parts were connected using Beam elements (Type 9) in LS DYNA. These are known as Mesh-Independent Spot-weld Beams. Based on our joint modeling R&D this is the most practical solution available in LS DYNA for large structural models.
- Implicit Eigenvalue analysis on connected sections to study natural frequencies, mode shapes and connectivity of parts
- Helps characterize basic dynamic behavior and how structure will respond to dynamic loading

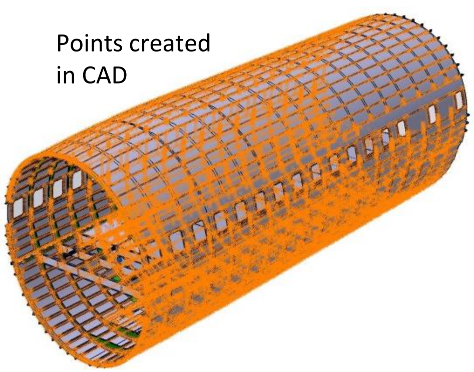


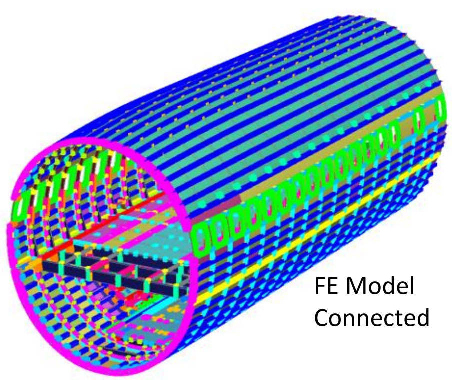


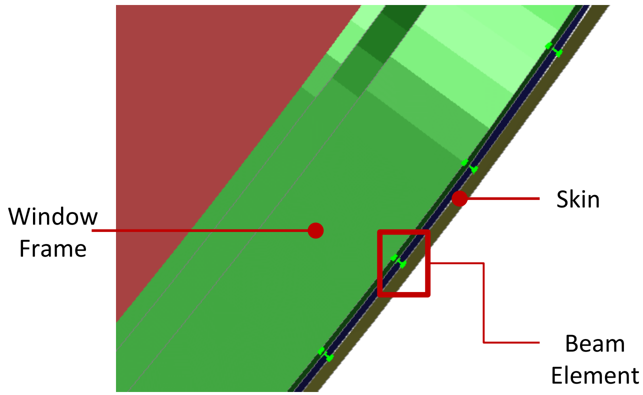
(AC 43.13-1B)



Points created in CAD







FEA Modeling – Materials

Extract Material List

Materials extracted from NIAR COMPMECH MATERIAL DATABASE

Apply MAT ID to PART ID – **SUITE OF MACROS DEVELOPED FOR MATERIAL APPLICATION**

- NIAR COMPMECH Material Database
  - 1800 Materials from MMPDS
    - Steel
    - Aluminum
    - Titanium
  - Each material has information for
    - Direction – L or LT
    - Basis – A, B, S or Typical
    - Thickness – The ranges provided in MMPDS
  - LS DYNA MAT Cards extracted from information
    - MAT 24
    - MAT 82
    - MAT 224
  - Each MAT Card is Validated against
    - MMPDS Properties
    - Test data – IF AVAILABLE

MMPDS-09 MATERIALS

Group	#	Material	Temper or Condition	Specifications I				Specifications II		Form	Basis	Direction	t=1	t=2	t=3	t=4	t=5
ALUMINUM 2XXX	1	2013	T6511	AMS 4326	-	-	-	-	-	ExtrudedBar-Rod-Profiles	A	L	x				
	2	2013	T6511	AMS 4326	-	-	-	-	-	ExtrudedBar-Rod-Profiles	A	LT	x				
	3	2013	T6511	AMS 4326	-	-	-	-	-	ExtrudedBar-Rod-Profiles	B	L	x				
	4	2013	T6511	AMS 4326	-	-	-	-	-	ExtrudedBar-Rod-Profiles	B	LT	x				
	5	2013	T6511	AMS 4326	-	-	-	-	-	Extrusion	TYPICAL	L	-				
	6	2013	T6511	AMS 4326	-	-	-	-	-	Extrusion	TYPICAL	LT	-				
	7	2013	T6511	AMS 4002	-	-	-	-	-	Drawn-Tubing	S	L	x				
	8	2013	T6511	AMS 4002	-	-	-	-	-	Drawn-Tubing	S	LT	x				
	9	[illegible]	[illegible]	[illegible]						[illegible]	[illegible]	[illegible]	[illegible]				
	10	2014	T6	AMS 4029	-	-	-	-	-	Sheet	A	L	x	x			
	11	2014	T6	AMS 4029	-	-	-	-	-	Sheet	A	LT	x	x			
	12	2014	T6	AMS 4029	-	-	-	-	-	Sheet	B	L	x	x			
	13	2014	T6	AMS 4029	-	-	-	-	-	Sheet	B	LT	x	x			
	14	[illegible]	[illegible]	[illegible]						[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	15	2014	T651	AMS 4029	-	-	-	-	-	Plate	A	LT	x	x	x	x	x
	16	2014	T651	AMS 4029	-	-	-	-	-	Plate	B	L	x	x	x	x	x
	17	2014	T651	AMS 4029	-	-	-	-	-	Plate	B	LT	x	x	x	x	x
	18	2014	T62	AMS 4028	-	-	-	-	-	Sheet	A	L	x	x			
	19	2014	T62	AMS 4028	-	-	-	-	-	Sheet	A	LT	x	x			
	20	2014	T62	AMS 4028	-	-	-	-	-	Sheet	B	L	x	x			
	21	2014	T62	AMS 4028	-	-	-	-	-	Sheet	B	LT	x	x			
	22	2014	T62	AMS 4028	-	-	-	-	-	Plate	A	L	x	x			
	23	2014	T62	AMS 4028	-	-	-	-	-	Plate	A	LT	x	x			
	24	2014	T62	AMS 4028	-	-	-	-	-	Plate	B	L	x	x			
	25	2014	T62	AMS 4028	-	-	-	-	-	Plate	B	LT	x	x			
	26	2014	T6-CLAD	-	-	-	-	AMS-QQ-A-250/3	-	Sheet	A	L	x	x			
	27	2014	T6-CLAD	-	-	-	-	AMS-QQ-A-250/3	-	Sheet	A	LT	x	x			
	28	2014	T6-CLAD	-	-	-	-	AMS-QQ-A-250/3	-	Sheet	B	L	x	x			
	29	2014	T6-CLAD	-	-	-	-	AMS-QQ-A-250/3	-	Sheet	B	LT	x	x			
	30	2014	T651-CLAD	-	-	-	-	AMS-QQ-A-250/3	-	Plate	A	L	x	x	x	x	x
	31	2014	T651-CLAD	-	-	-	-	AMS-QQ-A-250/3	-	Plate	A	LT	x	x	x	x	x
	32	2014	T651-CLAD	-	-	-	-	AMS-QQ-A-250/3	-	Plate	B	L	x	x	x	x	x
	33	2014	T651-CLAD	-	-	-	-	AMS-QQ-A-250/3	-	Plate	B	LT	x	x	x	x	x
	34	2014	T62-CLAD	-	-	-		AMS-QQ-A-250/3	-	Sheet	A	L	x	x			
	35	2014	T62-CLAD	-	-	-		AMS-QQ-A-250/3	-	Sheet	A	LT	x	x			
	36	2014	T62-CLAD	-	-	-		AMS-QQ-A-250/3	-	Sheet	B	L	x	x			
	37	2014	T62-CLAD	-	-	-		AMS-QQ-A-250/3	-	Sheet	B	LT	x	x			
	38	2014	T62-CLAD	-	-	-		AMS-QQ-A-250/3	-	Plate	S	L	x	x	x	x	x
	39	2014	T62-CLAD	-	-	-		AMS-QQ-A-250/3	-	Plate	S	LT	x	x	x	x	x
	40	2014	T6	AMS 4121	-	-	-	AMS-QQ-A-225/4	-	Bar-Rod-Shapes-Rolled-Drawn-ColdFinished	S	L	x	x	x	x	x
	41	2014	T6	AMS 4121	-	-	-	AMS-QQ-A-225/4	-	Bar-Rod-Shapes-Rolled-Drawn-ColdFinished	S	LT	x	x	x	x	x
	42	2014	T651	AMS 4121	-	-	-	AMS-QQ-A-225/4	-	Bar-Rod-Shapes-Rolled-Drawn-ColdFinished	S	L	x	x	x	x	x
	43	2014	T651	AMS 4121	-	-	-	AMS-QQ-A-225/4	-	Bar-Rod-Shapes-Rolled-Drawn-ColdFinished	S	LT	x	x	x	x	x
	44	2014	T62	-	-	-	-	AMS-QQ-A-225/4	-	Bar-Rod-Shapes-Rolled-Drawn-ColdFinished	S	L	x				
	45	2014	T62	-	-	-	-	AMS-QQ-A-225/4	-	Bar-Rod-Shapes-Rolled-Drawn-ColdFinished	S	LT	x				
	46	2014	T6	AMS 4133	AMS-A-2277	-	-	AMS-QQ-A-367	-	Die-Forging	A	L	x	x	x		
	47	2014	T6	AMS 4133	AMS-A-2277	-	-	AMS-QQ-A-367	-	Die-Forging	A	LT	x	x	x		
	48	2014	T6	AMS 4133	AMS-A-2277	-	-	AMS-QQ-A-367	-	Die-Forging	B	L	x	x	x		
	49	2014	T6	AMS 4133	AMS-A-2277	-	-	AMS-QQ-A-367	-	Die-Forging	B	LT	x	x	x		
	50	2014	T6	AMS 4133	AMS-A-2277	-	-	AMS-QQ-A-367	-	Die-Forging	S	L	x	x	x	x	
	51	2014	T6	AMS 4133	AMS-A-2277	-	-	AMS-QQ-A-367	-	Die-Forging	S	LT	x	x	x	x	
STEEL CARBON	1106	AISI-1025	Annealed	AMS 5046	-	-	-	-	-	Sheet-Strip-Plate	S	L	x				
	1107	AISI-1025	Annealed	AMS 5046	-	-	-	-	-	Sheet-Strip-Plate	S	LT	x				
	1108	AISI-1025	Normalized	AMS 5075	AMS-T-5066	-	-	-	-	Tubing	S	L	x				
	1109	AISI-1025	Normalized	AMS 5075	AMS-T-5066	-	-	-	-	Tubing	S	LT	x				
	1110	AISI-1025	All	ASTM A 108	-	-	-	-	-	Bar	S	L	x				
	1111	AISI-1025	All	ASTM A 108	-	-	-	-	-	Bar	S	LT	x				
STEEL LOW ALLOY	1112	AISI 4130	HT-95	AMS 6374	-	-	-	-	-	Tubing	S	L	x				
	1113	AISI 4130	HT-95	AMS 6374	-	-	-	-	-	Tubing	S	LT	x				
	1114	AISI 4130	Normalized-Tempered-Stress-Relieved - HT-95	AMS 6345	-	-	-	-	-	Sheet-Strip-Plate	S	L	x	x	x	x	
	1115	AISI 4130	Normalized-Tempered-Stress-Relieved - HT-95	AMS 6345	-	-	-	-	-	Sheet-Strip-Plate	S	LT	x	x	x	x	
	1116	AISI 4130	Normalized-Tempered-Stress-Relieved - HT-95	AMS 6360	AMS 6373	-	-	-	-	Tubing	S	L	x	x			
	1117	AISI 4130	Normalized-Tempered-Stress-Relieved - HT-95	AMS 6360	AMS 6373	-	-	-	-	Tubing	S	LT	x	x			
	1118	AISI 4130	Normalized-Tempered-Stress-Relieved - HT-90	AMS 6345	-	-	-	-	-	Sheet-Strip-Plate	S	L	x	x	x		
	1119	AISI 4130	Normalized-Tempered-Stress-Relieved - HT-90	AMS 6345	-	-	-	-	-	Sheet-Strip-Plate	S	LT	x	x	x		
	1120	AISI 4130	Normalized-Tempered-Stress-Relieved - HT-90	AMS 6360	AMS 6373	-	-	-	-	Tubing	S	L	x				
	1121	AISI 4130	Normalized-Tempered-Stress-Relieved - HT-90	AMS 6360	AMS 6373	-	-	-	-	Tubing	S	LT	x				
	1122	AISI 4135	Normalized-Tempered-Stress-Relieved - HT-100	AMS 6365	-	-	-	-	-	Tubing	S	L	x				
	1123	AISI 4135	Normalized-Tempered-Stress-Relieved - HT-100	AMS 6365	-	-	-	-	-	Tubing	S	LT	x				
	1124	AISI 4135	Normalized-Tempered-Stress-Relieved - HT-95	AMS 6365	-	-	-	-	-	Tubing	S	L	x				
	1125	AISI 4135	Normalized-Tempered-Stress-Relieved - HT-95	AMS 6365	-	-	-	-	-	Tubing	S	LT	x				
	1126	AISI 4130	Quenched-Tempered - HT-125	AMS 6361	-	-	-	-	-	Tubing	S	L	x				
	1127	AISI 4130	Quenched-Tempered - HT-125	AMS 6361	-	-	-	-	-	Tubing	S	LT	x				
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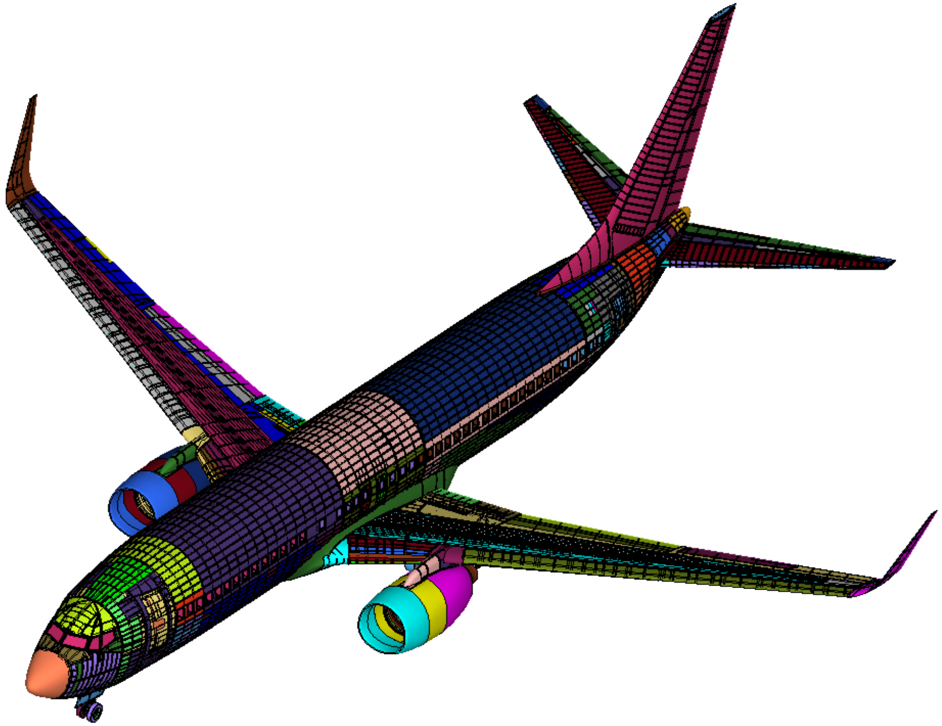
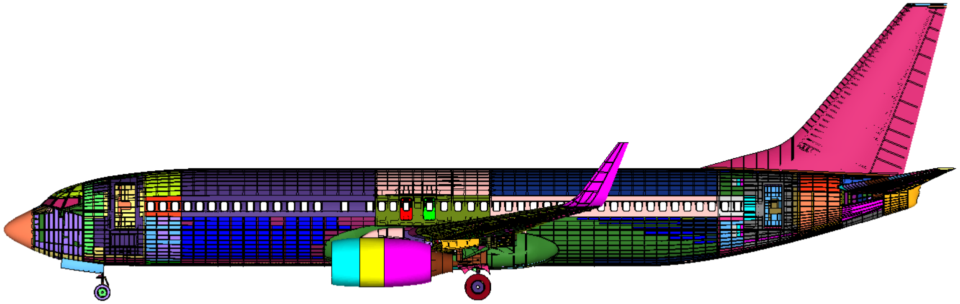
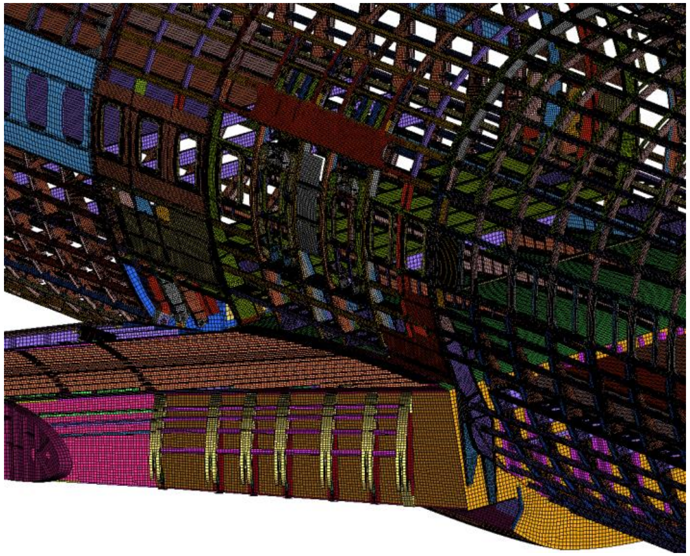
	1129	AISI 4130	Quenched-Tempered - HT-150	AMS 6362	-	-	-	-	-	Tubing	S	LT	x				
	1130	AISI 8630	Quenched-Tempered	-	-	-	-	MIL-S-6050	-	Bars-Forgings	S	L	x				
	1131	AISI 8630	Quenched-Tempered	-	-	-	-	MIL-S-6050	-	Bars-Forgings	S	LT	x				
	1132	AISI 8740	Quenched-Tempered	AMS 6327	-	-	-	-	-	Bars-Forgings	S	L	x				
	1133	AISI 8740	Quenched-Tempered	AMS 6327	-	-	-	-	-	Bars-Forgings	S	LT	x				

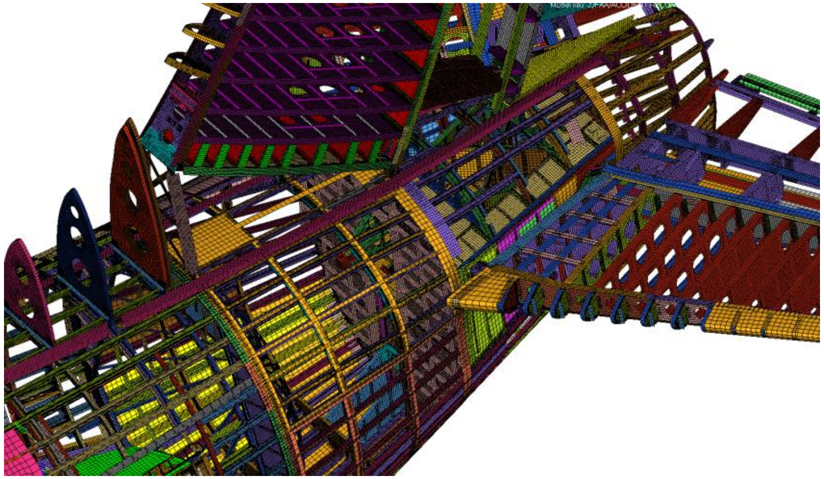
14	2014	T651	AMS 4029	-	-	-	-	-	Plate	A	L
15	2014	T651	AMS 4029	-	-	-	-	-	Plate	A	LT
16	2014	T651	AMS 4029	-	-	-	-	-	Plate	B	L
17	2014	T651	AMS 4029	-	-	-	-	-	Plate	B	LT

Full Aircraft FEA Model – 10M Elements

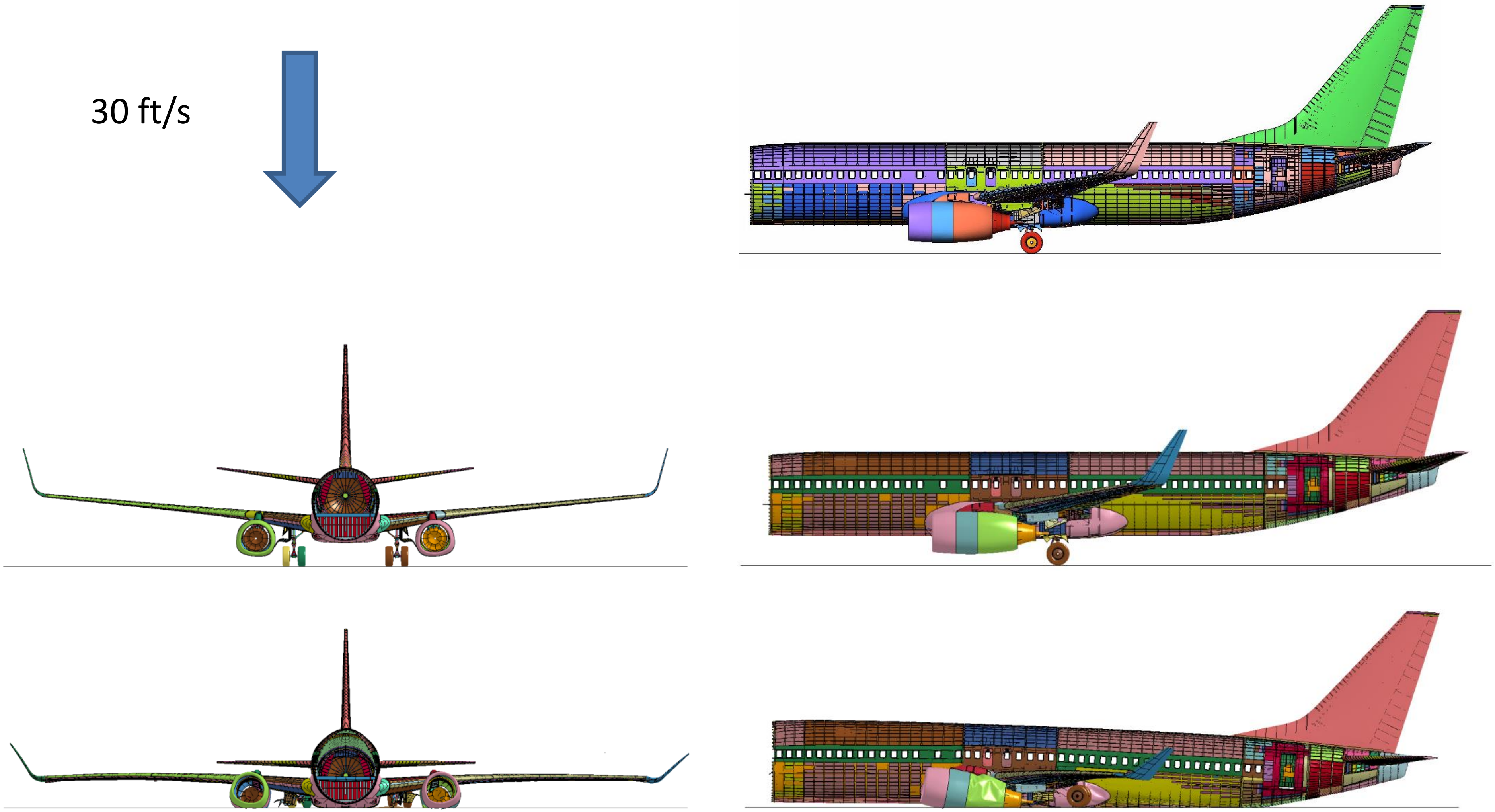


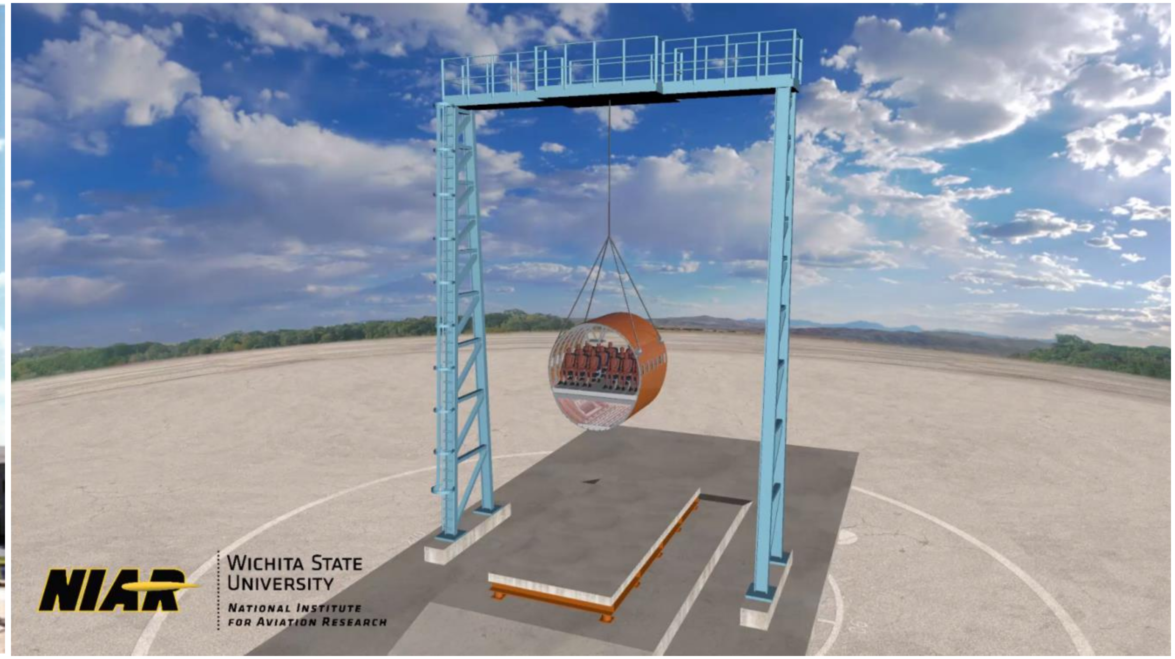






Preliminary Numerical Model Stability Checks





Comparison to FAA 10-FT Aircraft Section Drop Test

FEA MODEL VALIDATION

FAA Vertical Drop Test

- 737-100 Fuselage Drop test
- 30 ft/s
- 10-ft section extracted
- Front cargo bay door included
- Full cargo in Cargo bay
- Extra floor beam for boundary condition
- Two different Overhead bins
- Two different Seat models (UOP and Weber)
- ATD’s and Mannequins placed in seats
- Steel-plates and Camera systems added to fuselage

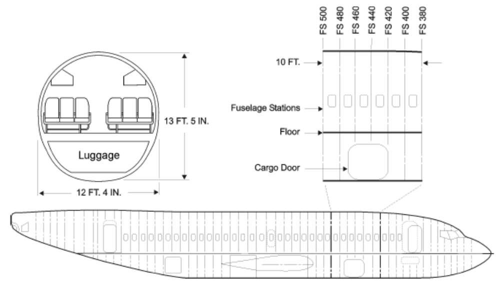


FIGURE 3. FUSELAGE SECTION
(From a Boeing 737-100 Airplane)

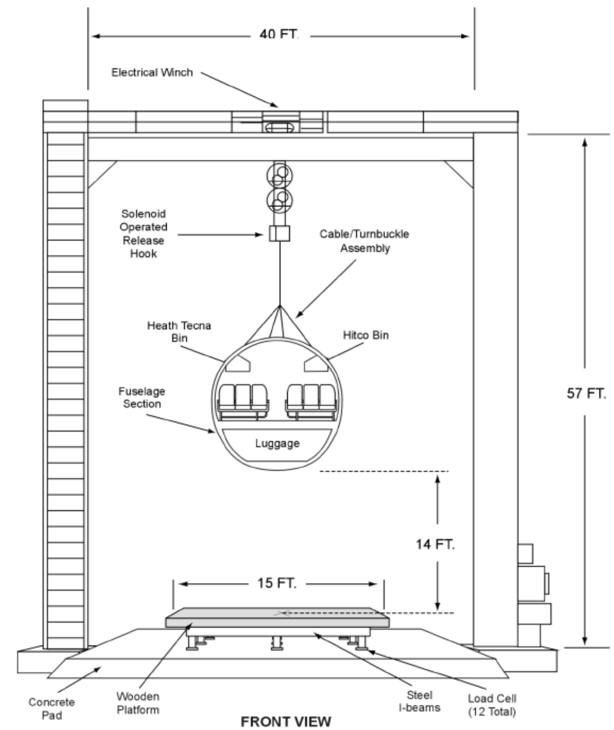
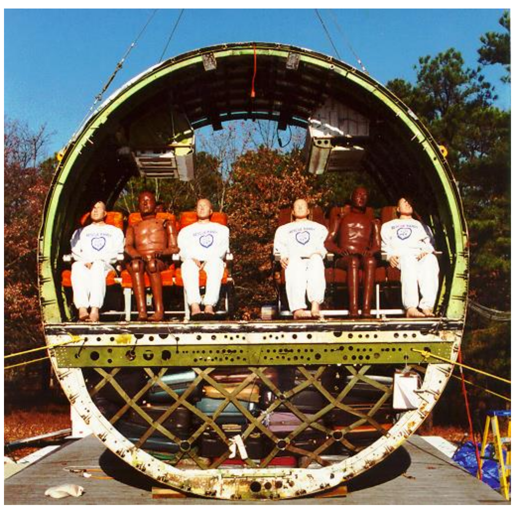
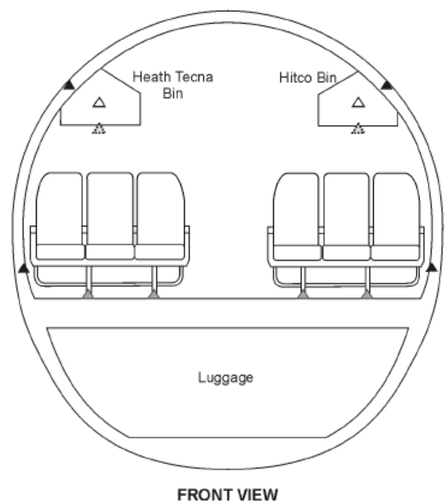
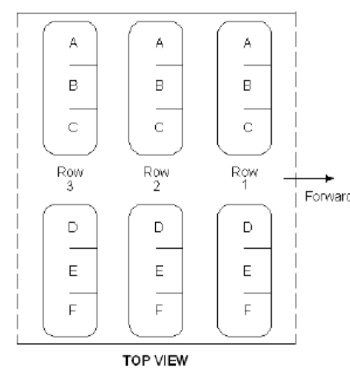


FIGURE 1. DYNAMIC DROP TEST FACILITY







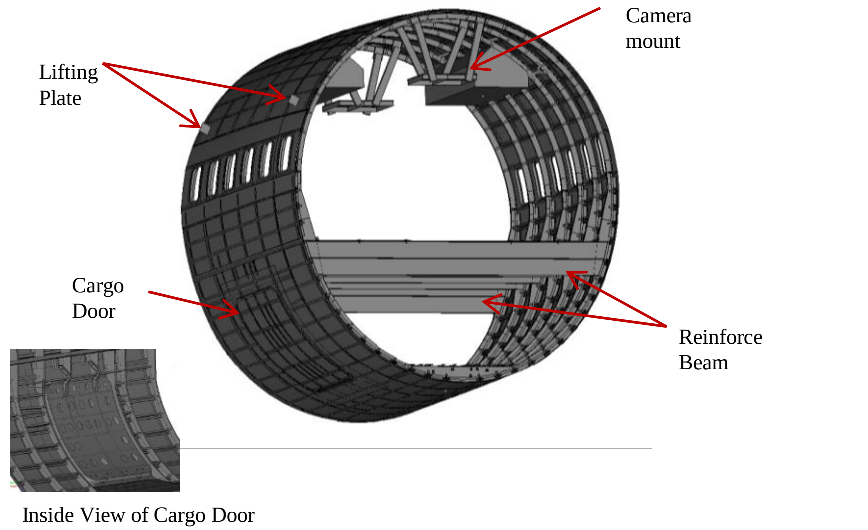
Location	Seat Description	Seat Number	Occupants
FS 406 (Row 1)	Left Side Weber Aircraft Seat	A	Mannequin
		B	ATD #1
		C	Mannequin
	Right Side UOP Seat	D	Mannequin
		E	ATD #2
		F	Mannequin
FS 442 (Row 2)	Left Side Weber Aircraft Seat	A	Mannequin
		B	ATD #3
		C	Mannequin
	Right Side UOP Seat	D	Mannequin
		E	ATD #4
		F	Mannequin
FS 478 (Row 3)	Left Side Weber Aircraft Seat	A	Mannequin
		B	ATD #5
		C	Mannequin
	Right Side UOP Seat	D	Mannequin
		E	ATD #6
		F	Mannequin

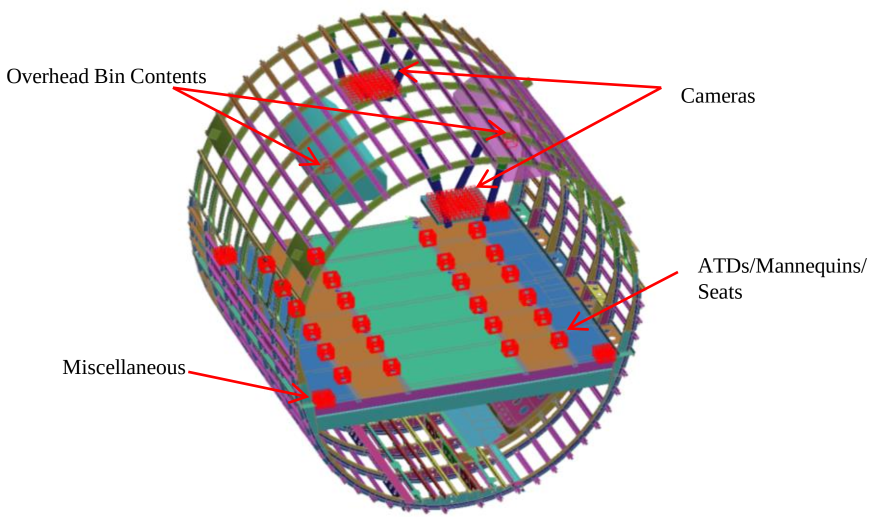
Abramowitz,Allan , Smith,Timothy G. Vu, Dr. Tong and Zvanya, John R. “*Vertical drop test of a narrow-body transport fuselage section with overhead stowage bins*”, FAA Report: DOT/FAA/AR-01/100 ,(2002).

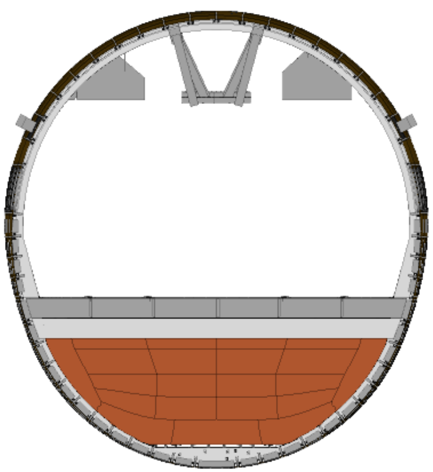
Simulation Setup

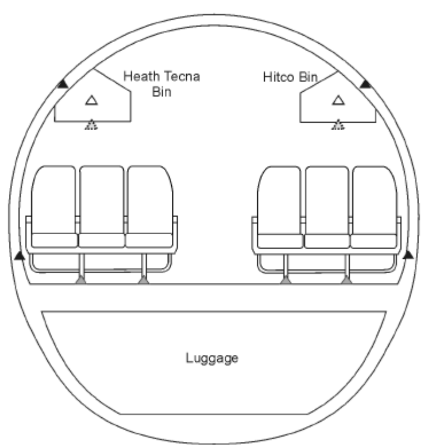
- 10-ft section extracted
- Extra beams added to replicate boundary condition
- Fully filled cargo modeled
- Overhead bins and attachment modeled
- Camera mounts and steel plates for drop added
- Seats, ATD and Mannequin accounted for using added mass
- Camera accounted for using added mass
- Dropped on rigid surface

FEM Summary	
Entity	**Total Number**
Nodes	822481
Lumped masses	32
Beam Elements	23937
Shell Elements	664972
Solid Elements	25080



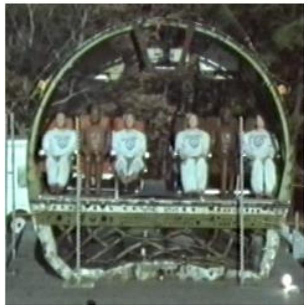
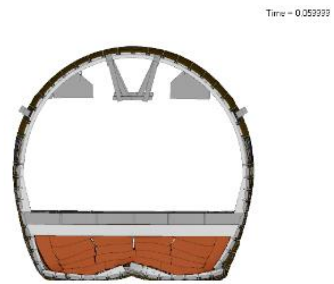
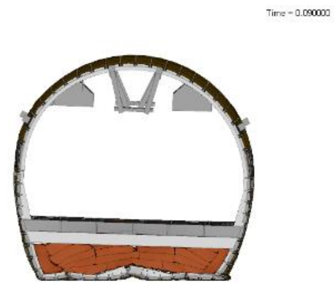
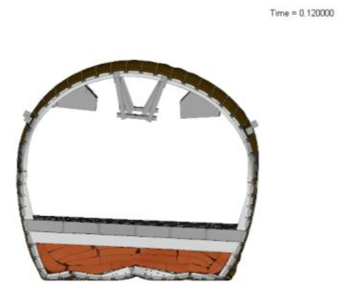
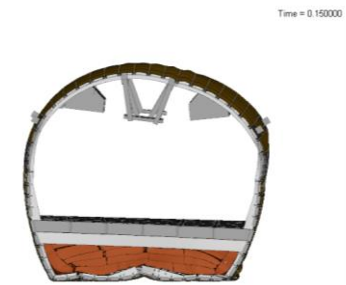


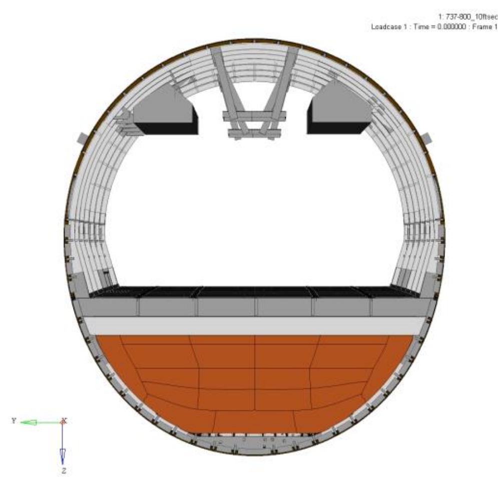


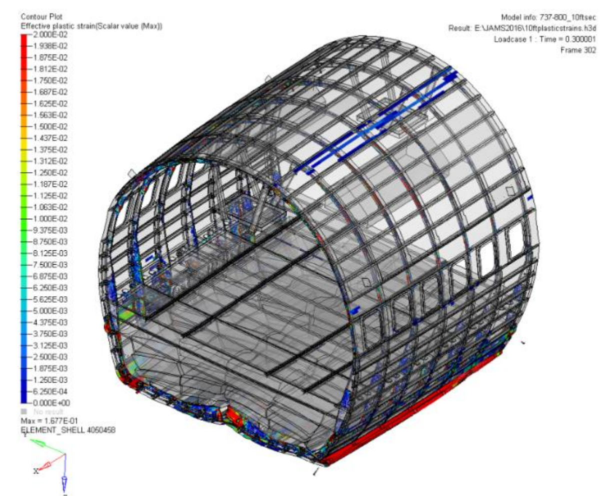


FRONT VIEW

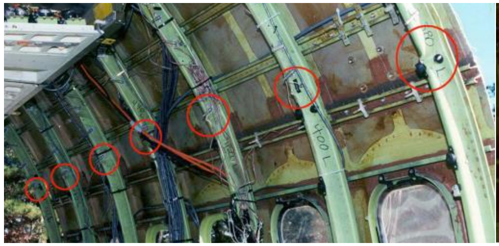
Test Simulation Correlation - Results

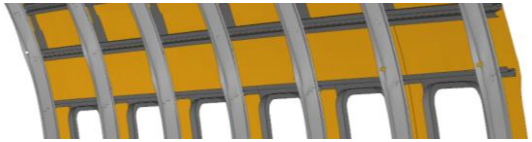
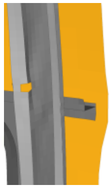
	T= 0.03 s	T= 0.06 s	T= 0.09 s	T= 0.12 s	T= 0.15 s
TEST					
SIMULATION					

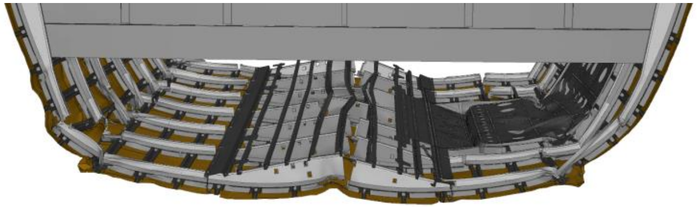
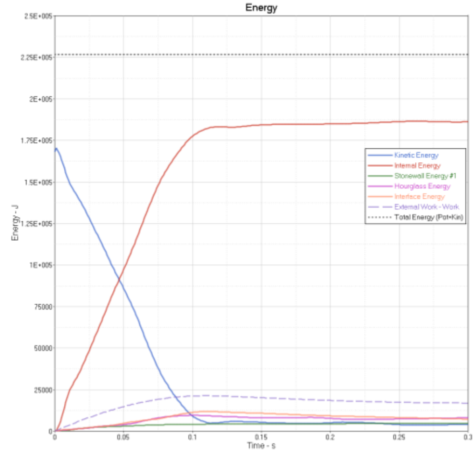


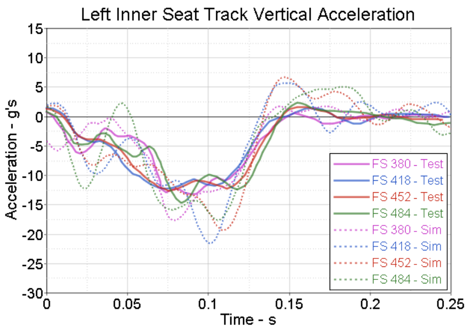


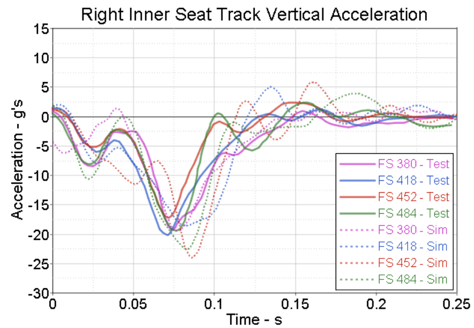
Test Simulation Correlation – Results

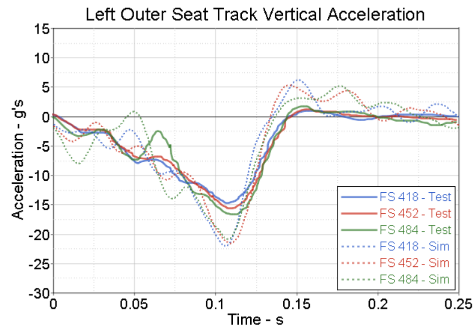


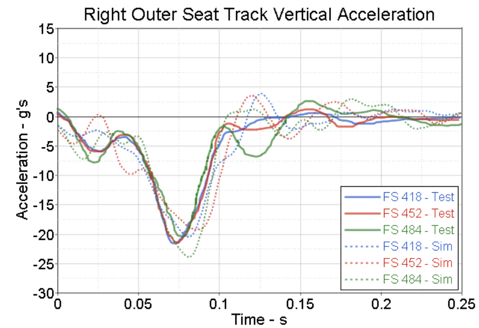




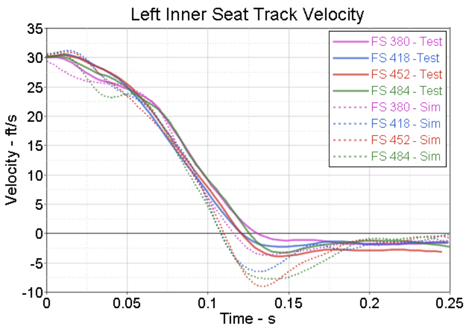



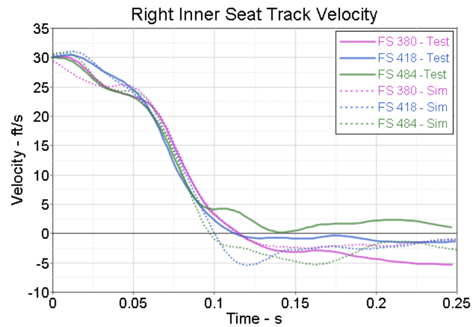


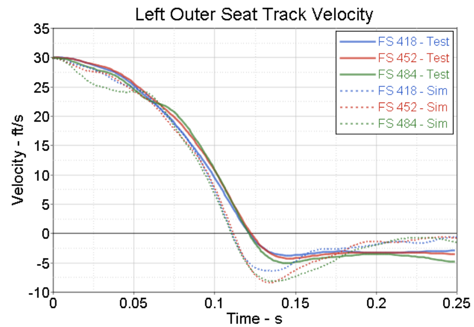


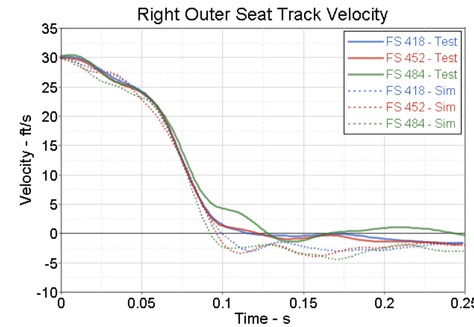






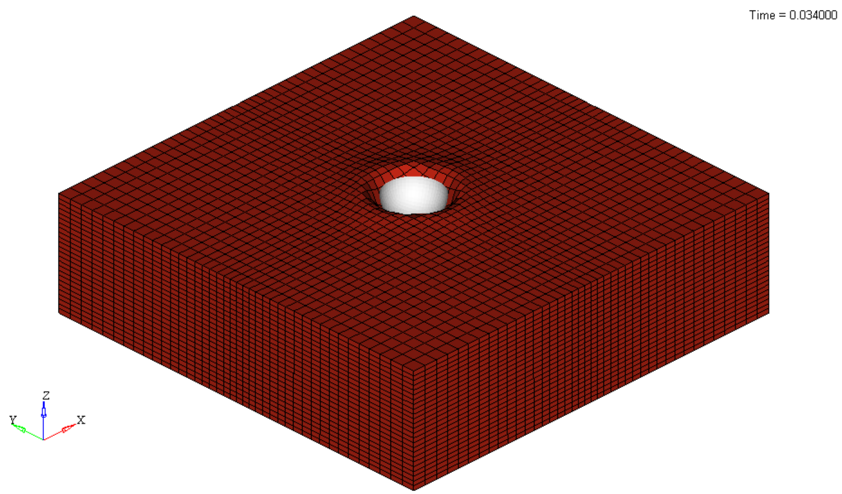


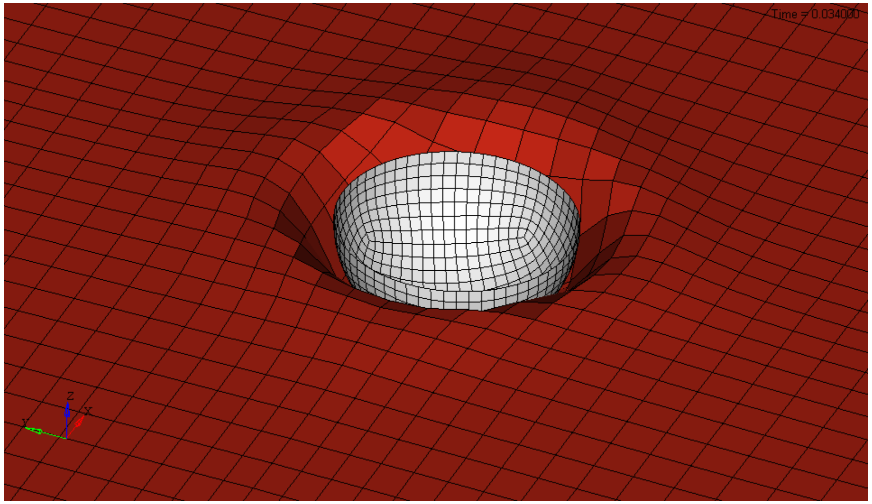


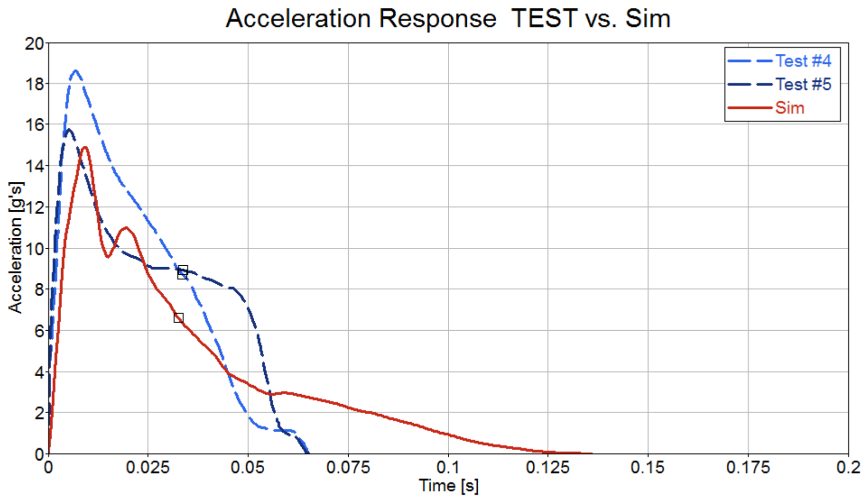


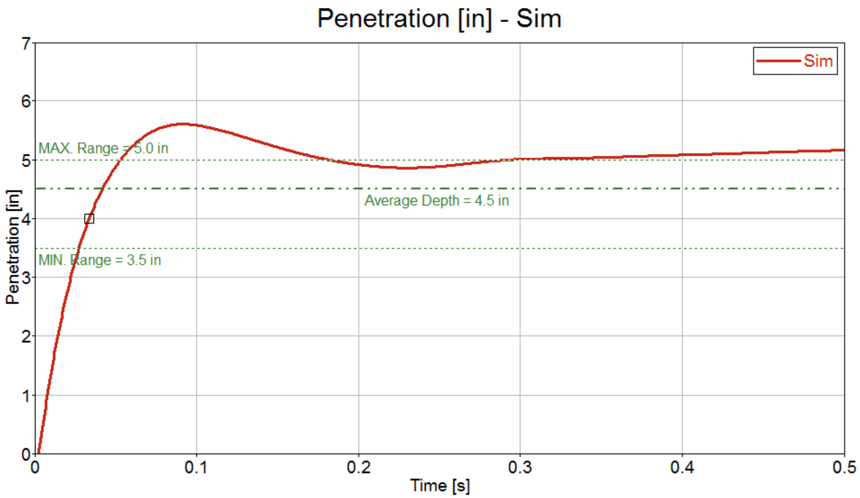
SOIL MODEL STUDIES

Sample Soil Model Validation

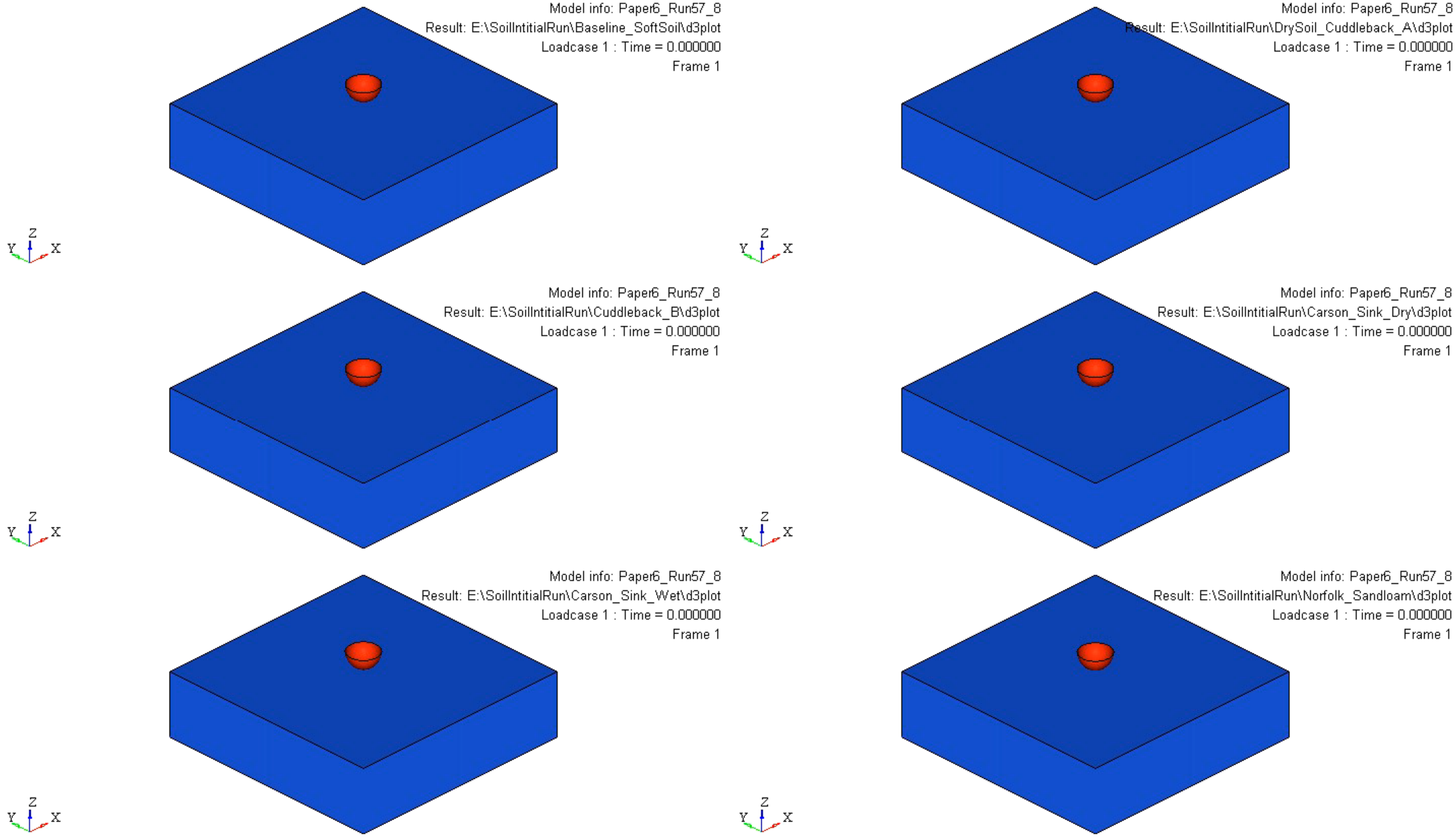








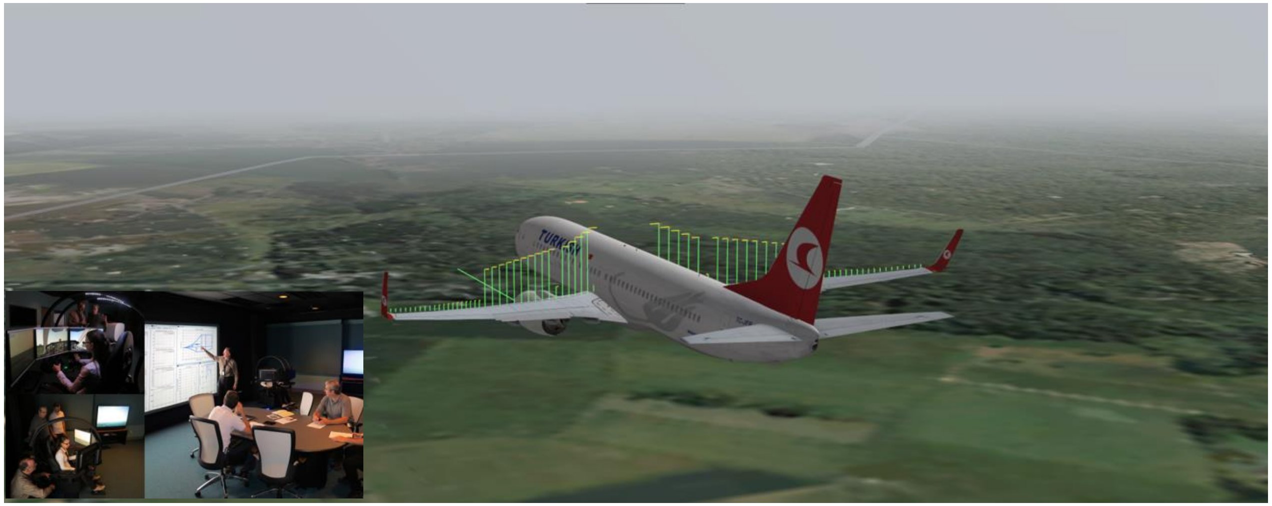
Comparison of the Soil Materials



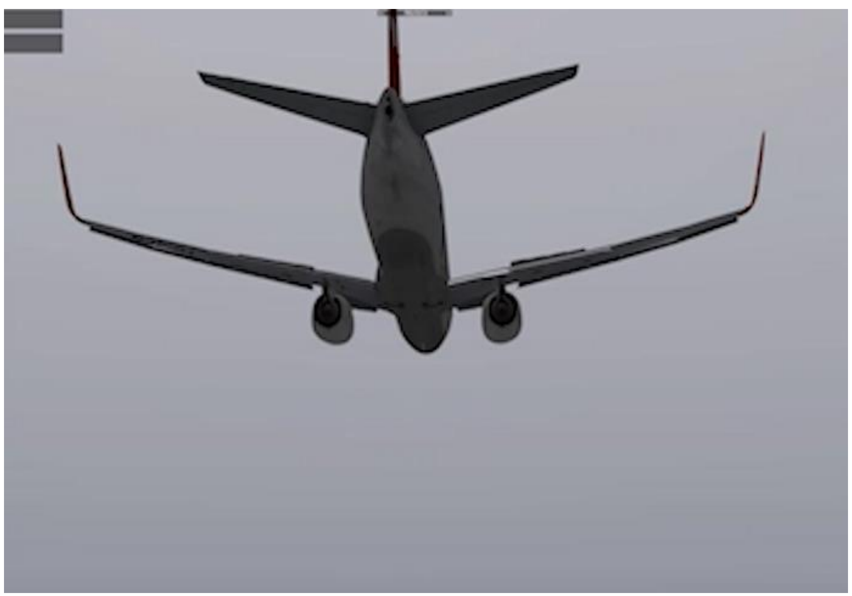
Initial Run for Accident Reconstruction

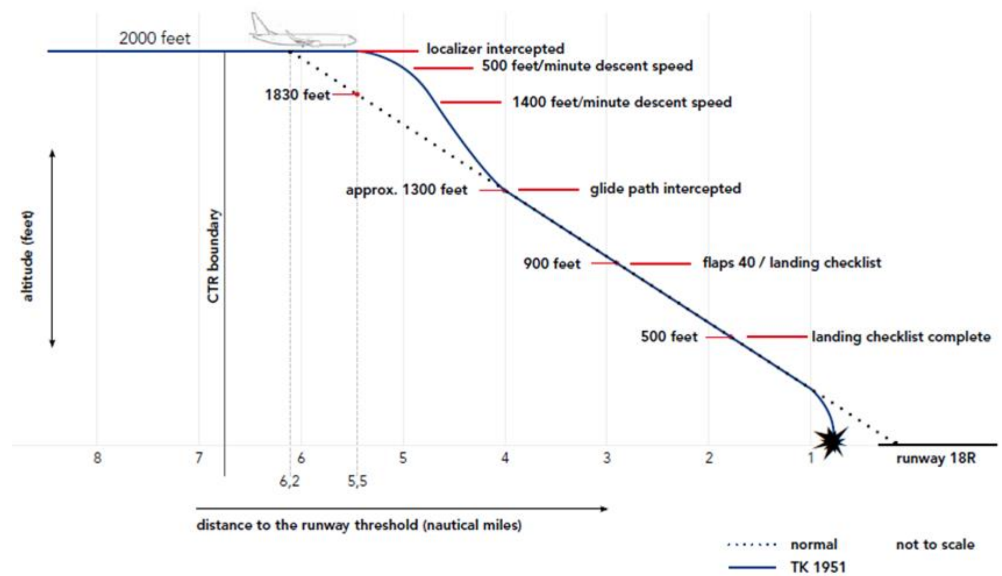
FULL SCALE MODEL VALIDATION

Flight Model Pre-Impact

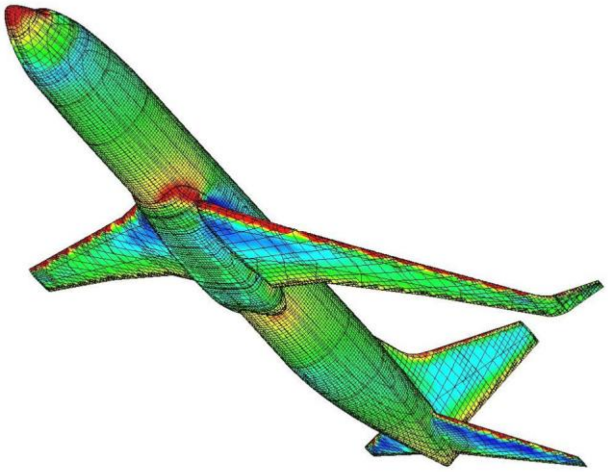


- **NIAR Virtual Flight Testing Lab**
- **Define Aircraft Boundary Conditions prior to impact:**
  - Linear Velocities
  - Angular Velocities
  - Forces and Moments
- **Crash Location:**
  - 1.5km (0.93 miles) from Polderbaan (18R) - Amsterdam Schiphol airport (EHAM)

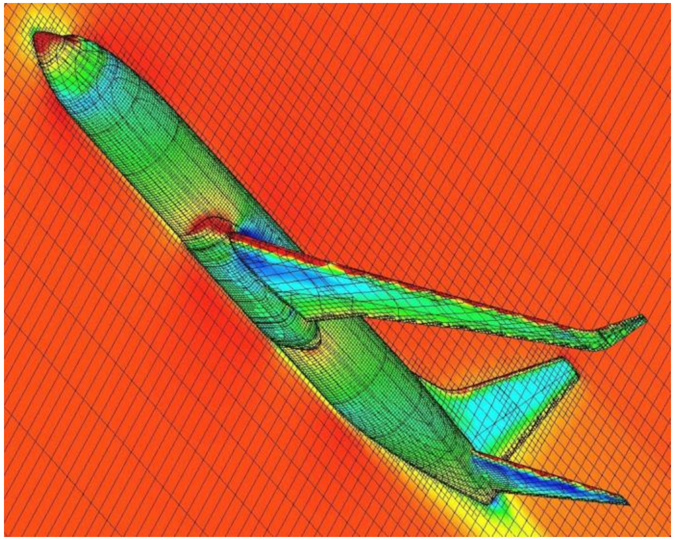


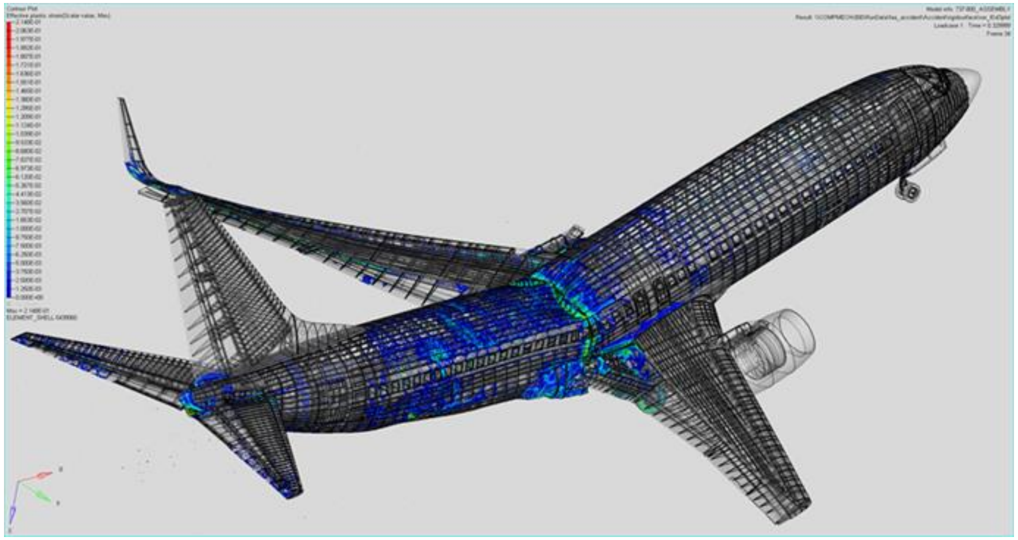


CFD Analysis Pre-Impact & Impact BC's

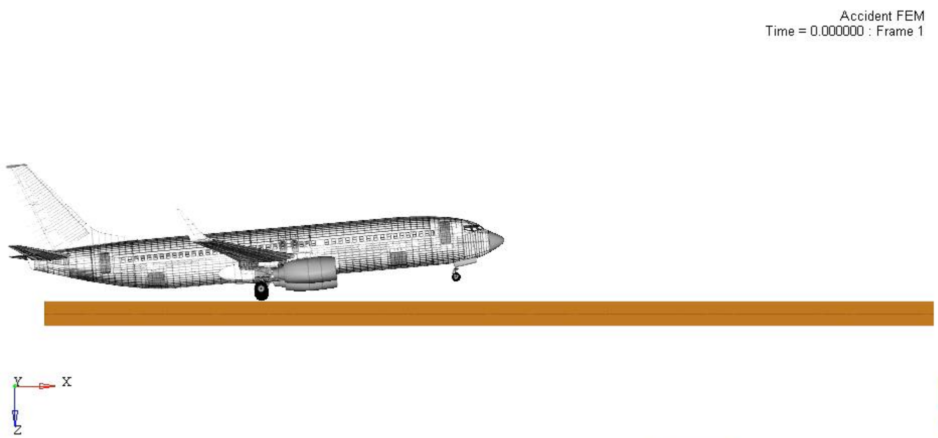


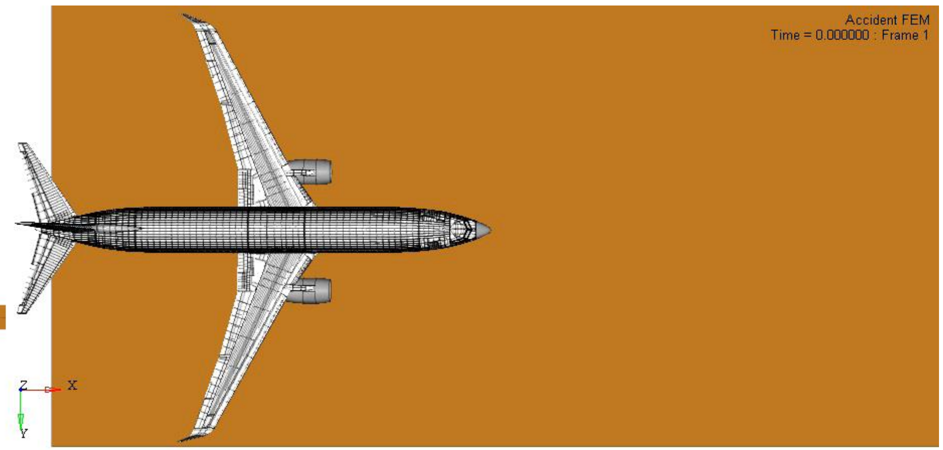
- Pre-impact Boundary Conditions Definition: Pressure Mapping
- Impact BC's :Pressure Mapping vs. Aircraft Orientation
- CFD Analysis Ongoing

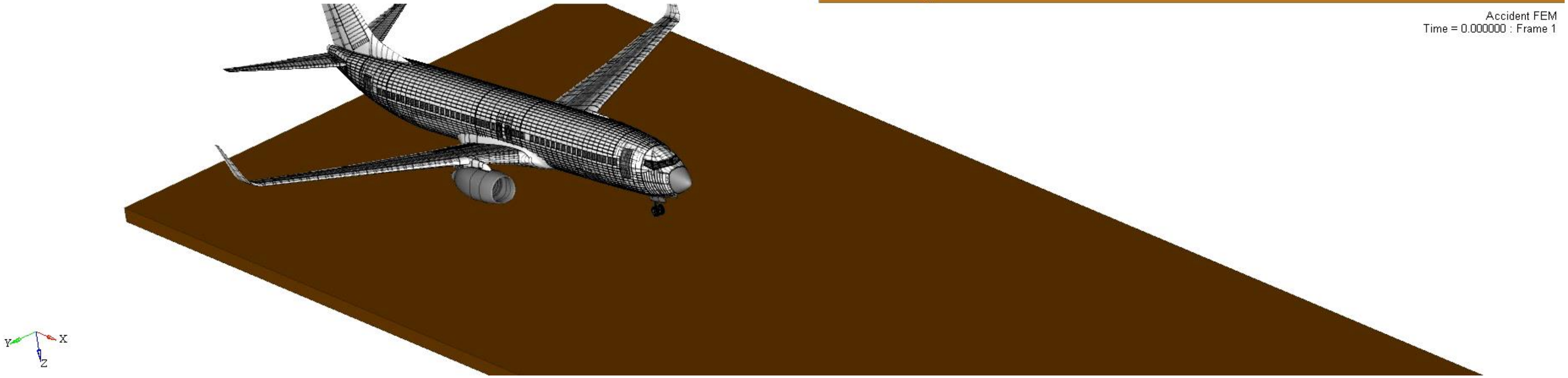




Preliminary Results

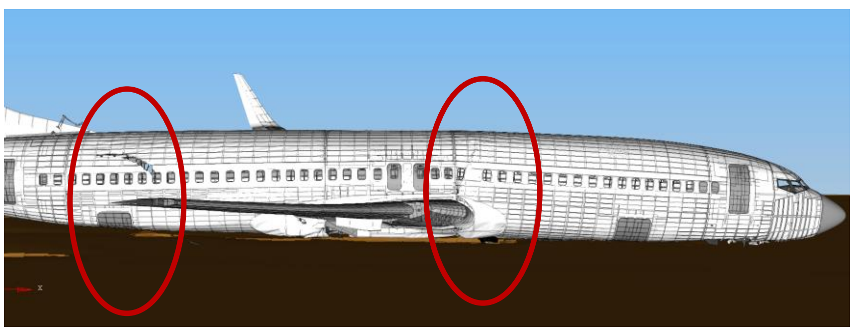


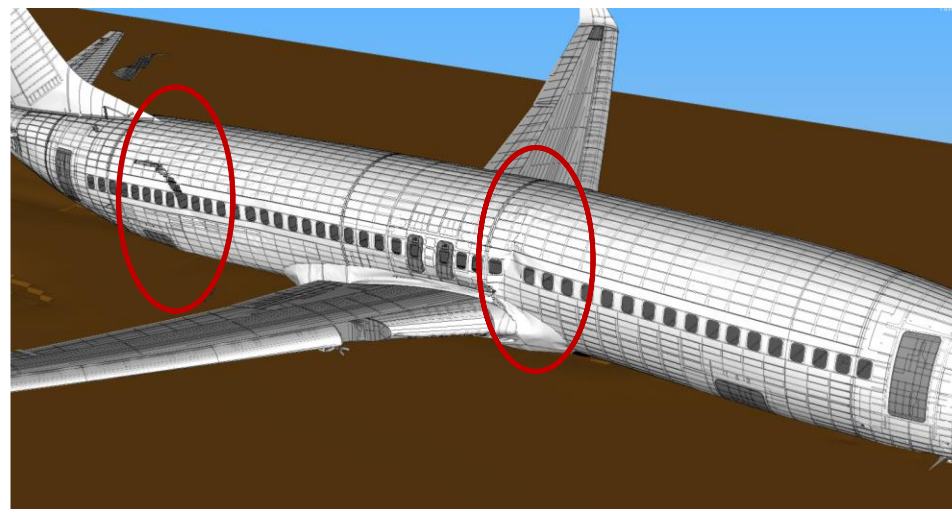




Preliminary Results

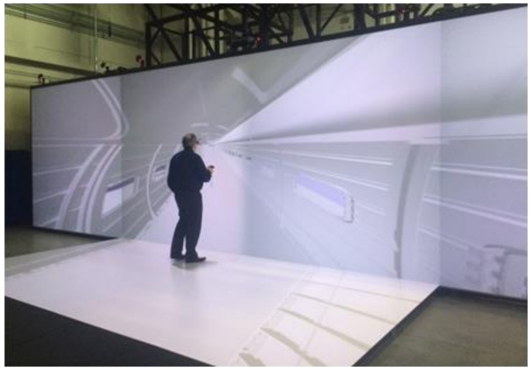
- Initial runs show promising results
- Current run only up to 700 ms
- Areas that need more work
  - Engine failure
  - Soil and Landing gear interaction
  - Tail section failure
  - Stability of model for running up to 3 seconds
  - Re-evaluate boundary conditions

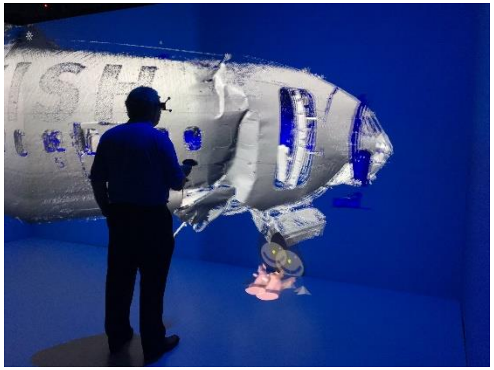


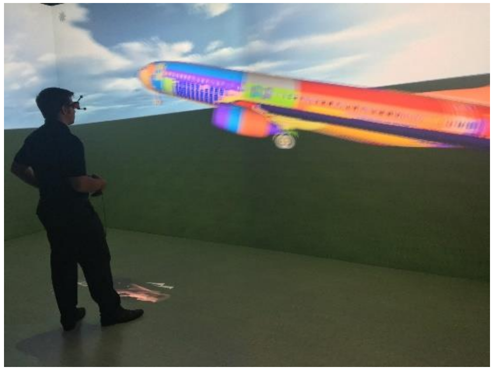


Conclusions and Future Work

- Full aircraft model impact simulations need to address not only the structural component of the analysis but also include aerodynamic, propulsion and control input data to define the proper boundary conditions
- The model is a representative narrow body structure therefore obtaining the exact same failure locations and mechanisms may not be possible
- Preliminary analysis results look promising in terms of overall deformations and damage
- Continue understanding boundary conditions to improve correlation to actual event
- Summarize findings in an interim report to support the ARAC Transport Airplane Crashworthiness and Ditching Working Group
- In parallel we are working in High End Visualization for Accident Data and Simulation Data using NIAR's new CAVE VR Environment
- Working on the definition of a full scale test and simulation program for a part 25 composite and metallic business jet configuration







Looking Forward

- Benefit to Aviation
  - 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
  - Improve the understanding of the crashworthy behavior of metallic 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 impact R&D
  - These models may also be used for ditching evaluations
  - FEA models can help accident investigators understand different damage characteristics resulting from various accidents for better understanding of the event
- Future needs
  - Development of a High Strain Rate Testing Standard for material characterization
  - Training of Industry and FAA personnel on the use of numerical tools to support the development and certification process
  - Conduct a baseline business jet size metallic aircraft drop test

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Thank you

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