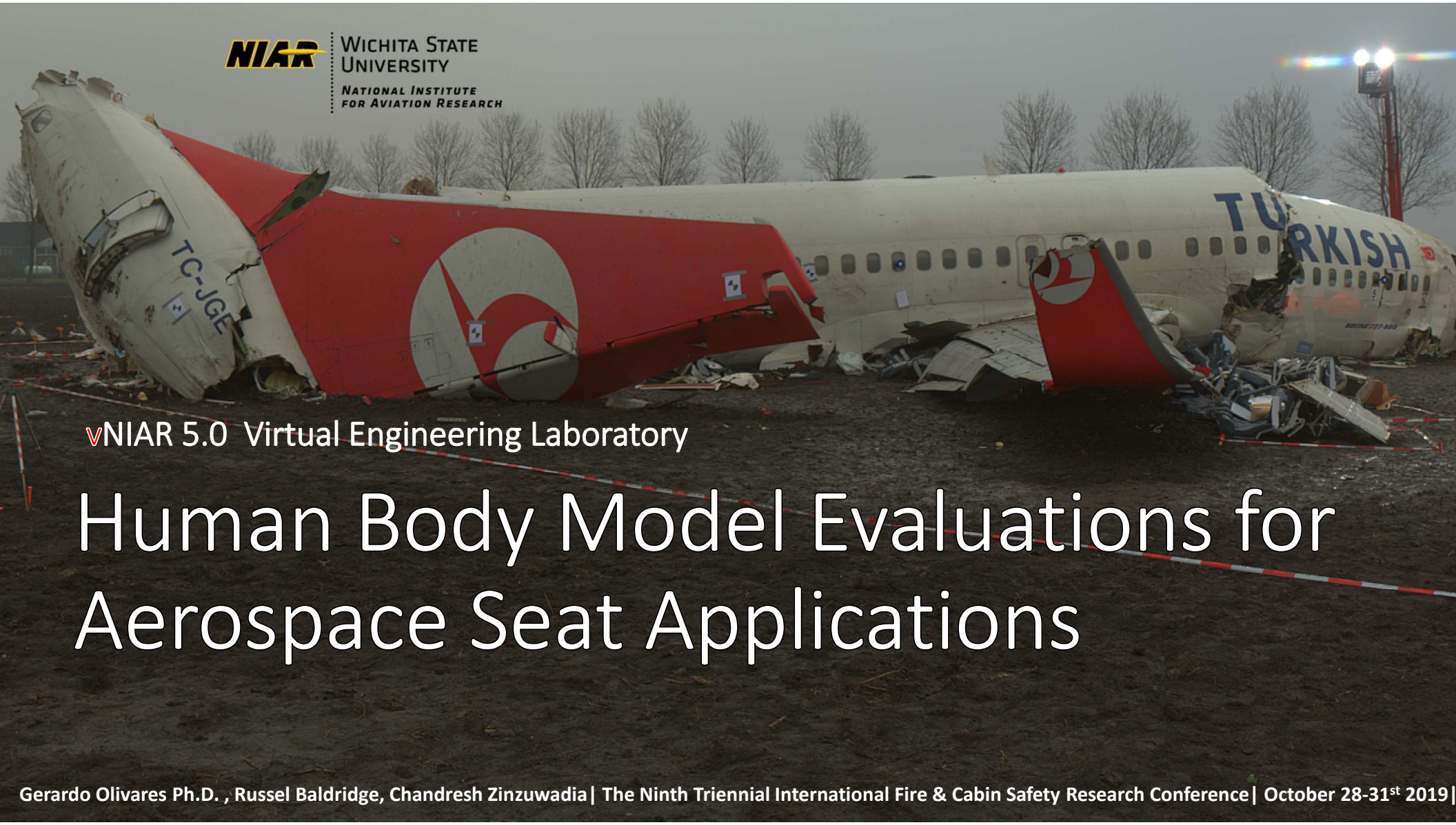


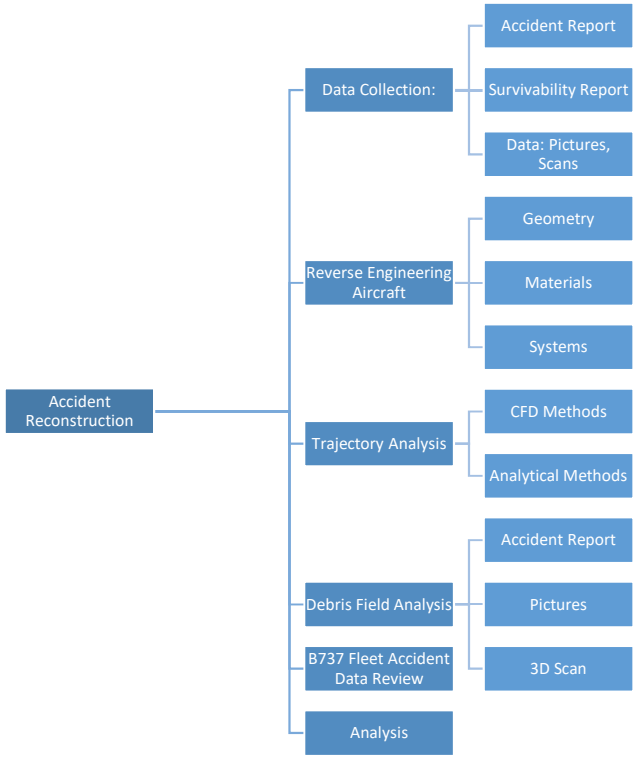
vNIAR 5.0 Virtual Engineering Laboratory

Human Body Model Evaluations for Aerospace Seat Applications

Gerardo Olivares Ph.D. , Russel Baldridge, Chandresh Zinzuwadia| The Ninth Triennial International Fire & Cabin Safety Research Conference| October 28-31st 2019|

Accident Reconstruction Process

Turkish Airlines Flight 1951 Accident Reconstruction

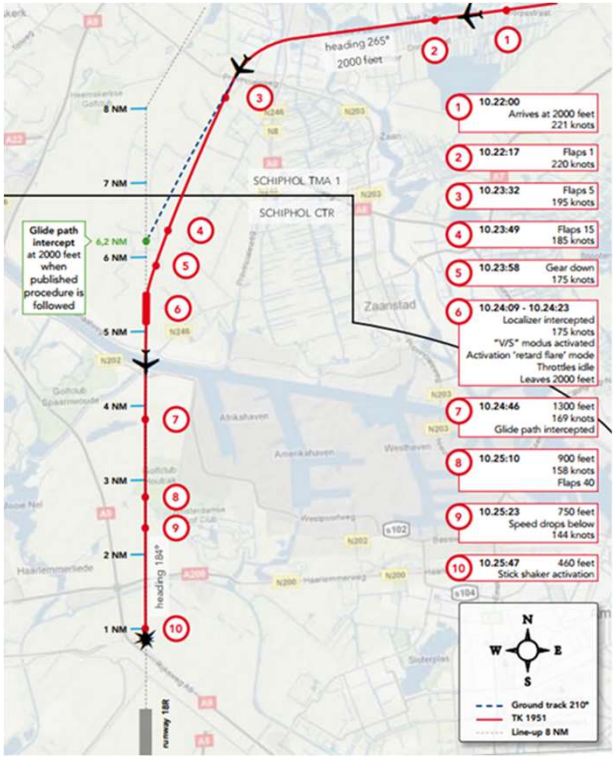


- Accident reconstruction is the scientific process of investigating, analyzing, and drawing conclusions about the causes and events during a collision.
- Accident reconstruction analysis includes processing data collecting, evaluating possible hypotheses, creating models, recreating accidents, testing, and utilizing software simulations.
- Why did we select Flight 1951?
  - High Quality of the Accident Investigation Process:
    - Accident Reports
    - Survivability Thesis Report
    - High Resolution Panorama Photography
    - 3D External and Internal Scan data
  - Section Level Drop Test Validation Dataset – FAA Drop Test
  - Detailed injury data for each passenger

Factual Information Summary

Turkish Airlines Flight 1951 Accident Reconstruction

- **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 autothrottle)
  - Faulty input commanded the autothrottle 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 autothrottle and increased thrust but it was too late
  - The aircraft stalled at 350 ft. and speed of 105 knots

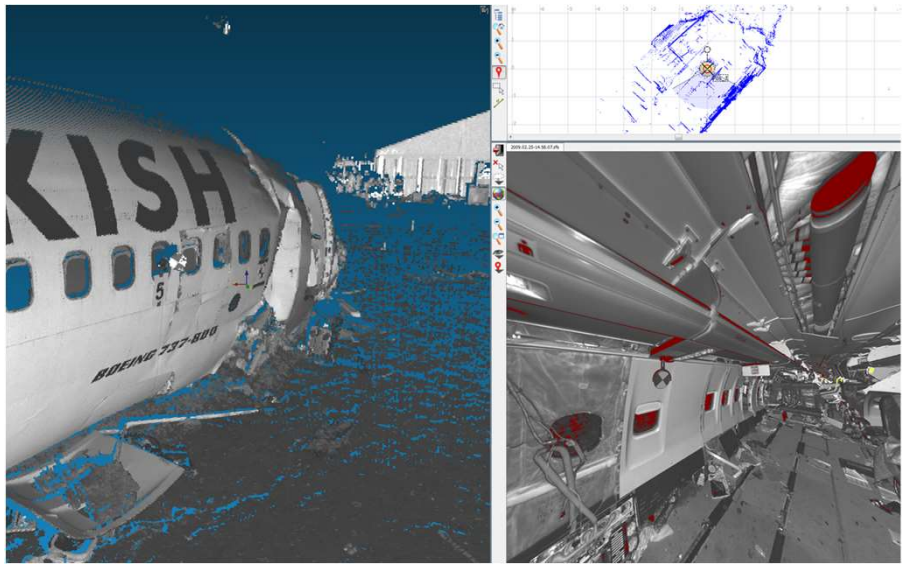


Source: Crashed during approach, Boeing 737-800, near Amsterdam Schiphol Airport, 25 February 2009. The Dutch Safety Board Doc: Rapport_TA_ENG_web.pdf

Accident Data Collection

Turkish Airlines Flight 1951 Accident Reconstruction

External and Internal 3D Scans



High Resolution Panoramic Pictures

Occupant Injuries Evaluation

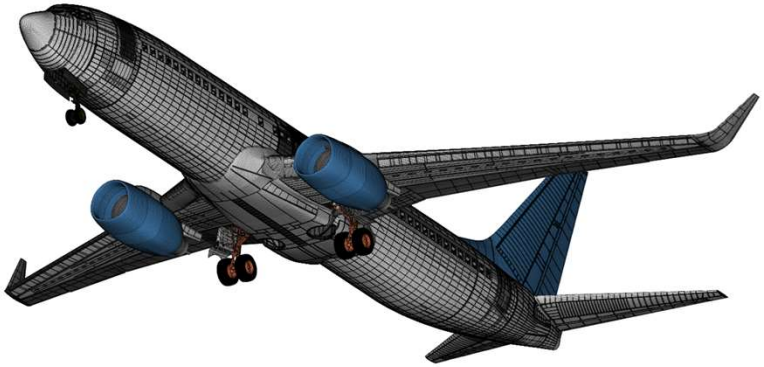
Turkish Airlines Flight 1951 Accident Reconstruction

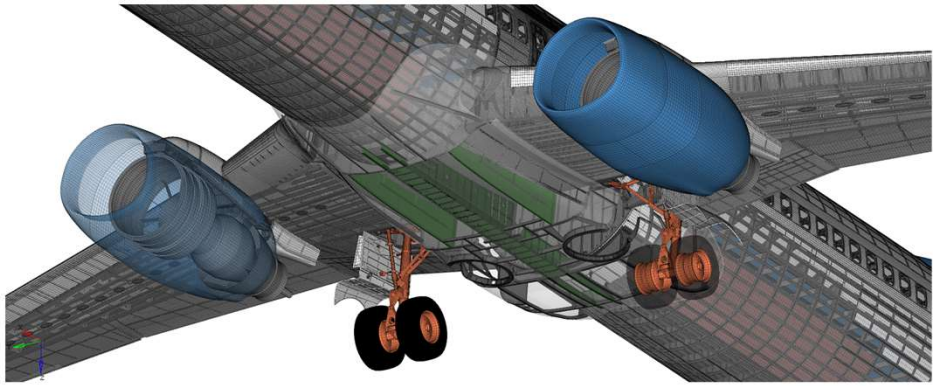
- The airplane crashed during the landing phase and fractured in three parts: a tail part, a large center section and a front section containing the cockpit. Most fatalities and serious injuries occurred in the front part. In this particular section the biggest damage to the fuselage and the interior could be observed.
- Considering the track of the airplane on the ground it can be assumed that the main loading impact on the bodies of the passengers was in a vertical direction. Since the crash occurred during the landing phase, all passengers were sitting in their seats wearing a 2-point lap belt. The surviving crew members were all wearing a shoulder harness during the crash. Nine occupants did not survive the crash. They died at the scene of the accident.
- Of the 135 passengers and crew, 9 suffered fatal injuries, and 120 had injuries ranging from minor to critical; 15 with an injury severity score (ISS) greater than 15, 21 with an ISS between 8 and 15, and 84 with an ISS of 8 or less.
- The severity of the injuries sustained as a function of the seat location:
  - Most fatalities and seriously injured occupants were seated in the front section of the aircraft. Most passengers with minor injuries were seated in the middle section (main cabin).

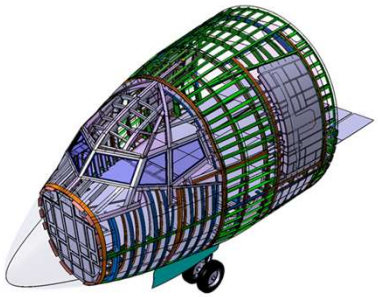
Postma, I. L. E. (2014). Brace for impact! A thesis on medical care following an airplane crash, University of Amsterdam

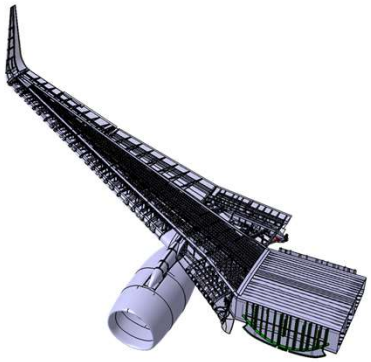
Full Aircraft FEA Model Overview

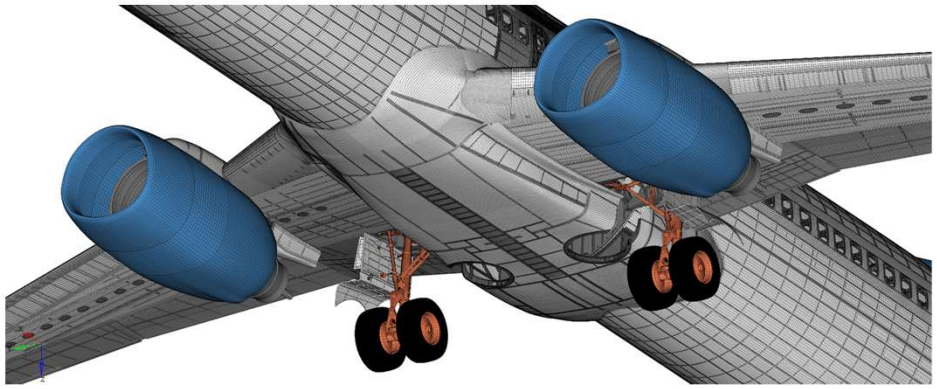
Accident Reconstruction





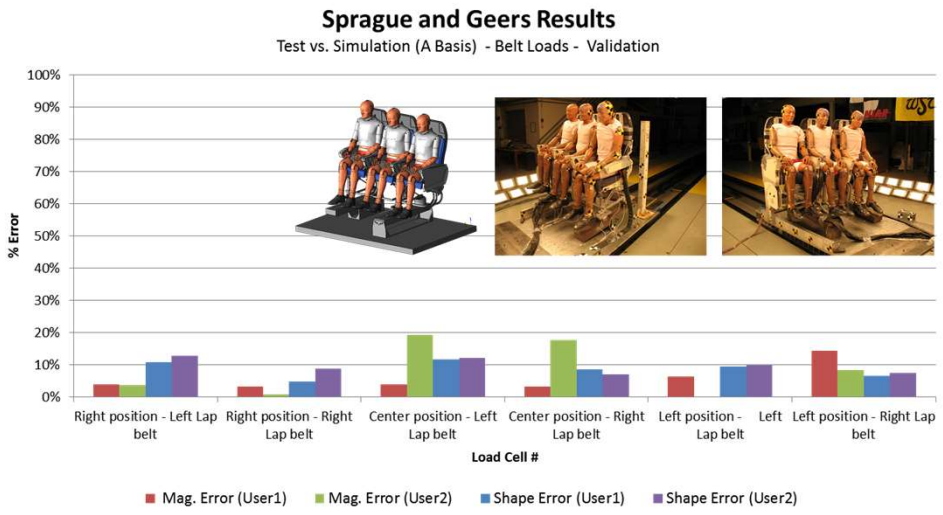


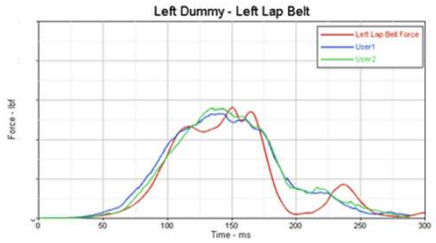


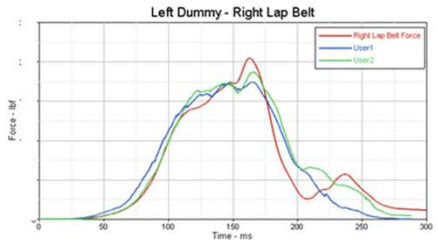


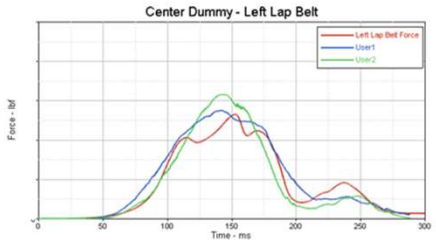
Seat Model FEA Model Overview

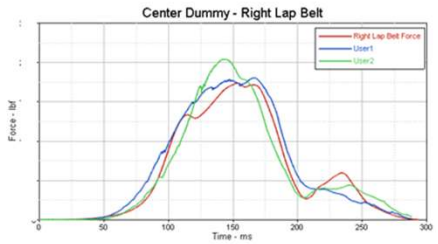
Accident Reconstruction

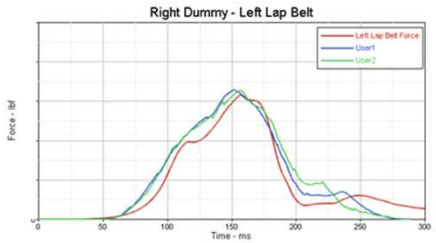


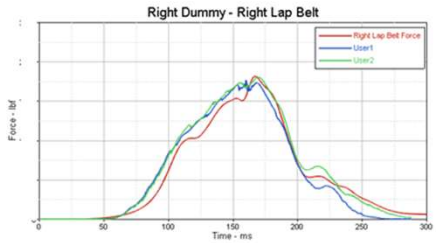








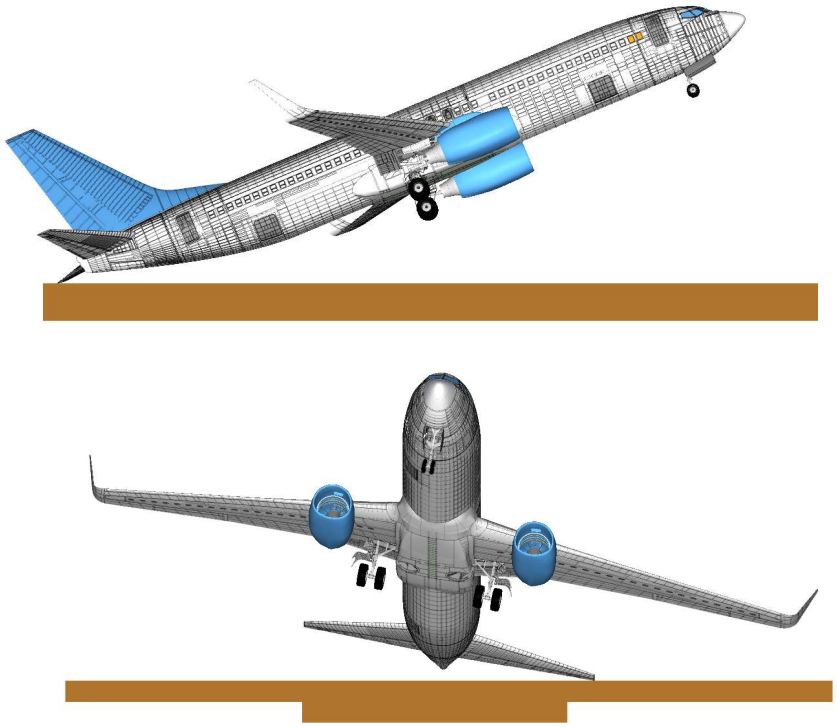




Load Case Description

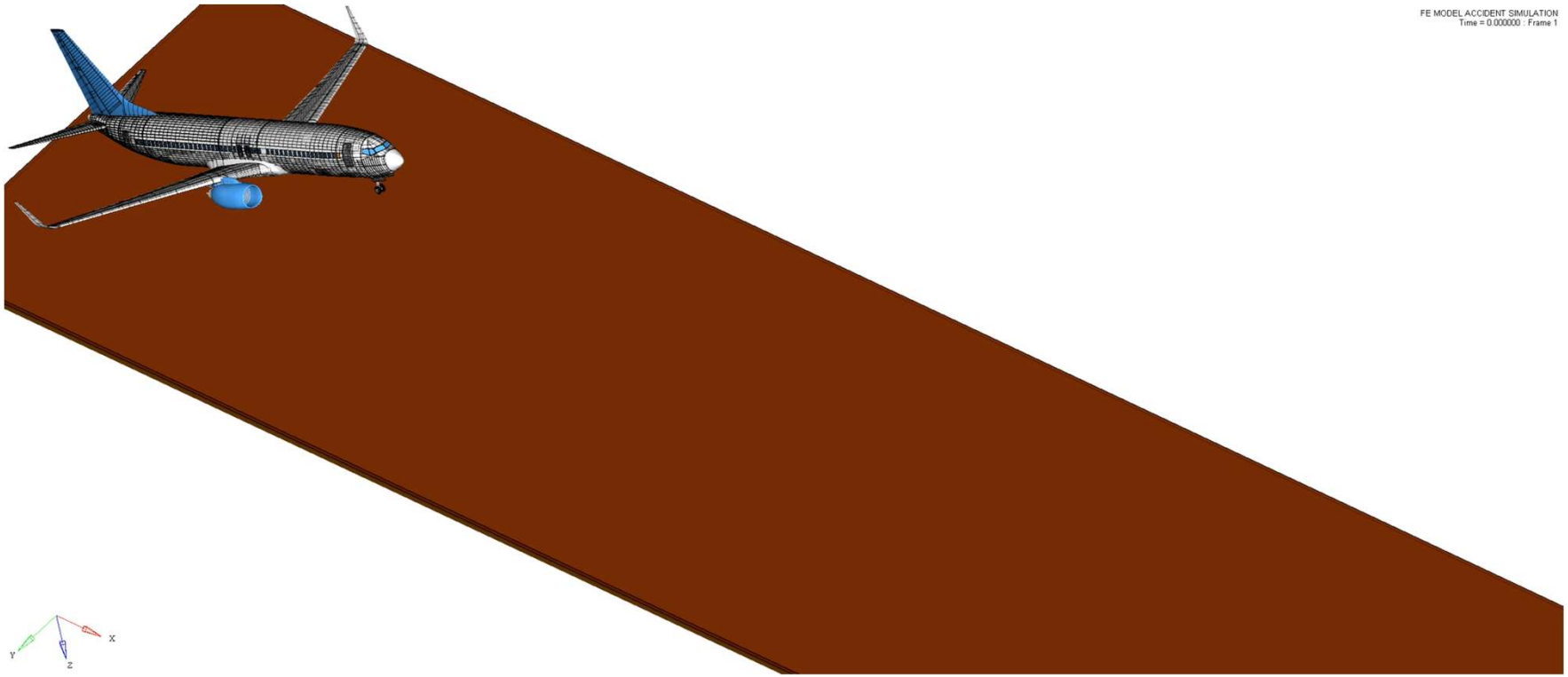
TK 1951 Accident Reconstruction

Parameter	Values
Horizontal Velocity	157 ft/s
Vertical Velocity	42 ft/s
Pitch Angle	22.7 deg
Roll Angle	11.3 deg
Pitch Rate	1.9 deg/s
Roll Rate	-0.8 deg/s
Engine Thrust	73%
Aerodynamic Loads	Yes
Gravity	Yes
Impact Surface	Soft and Hard Soils



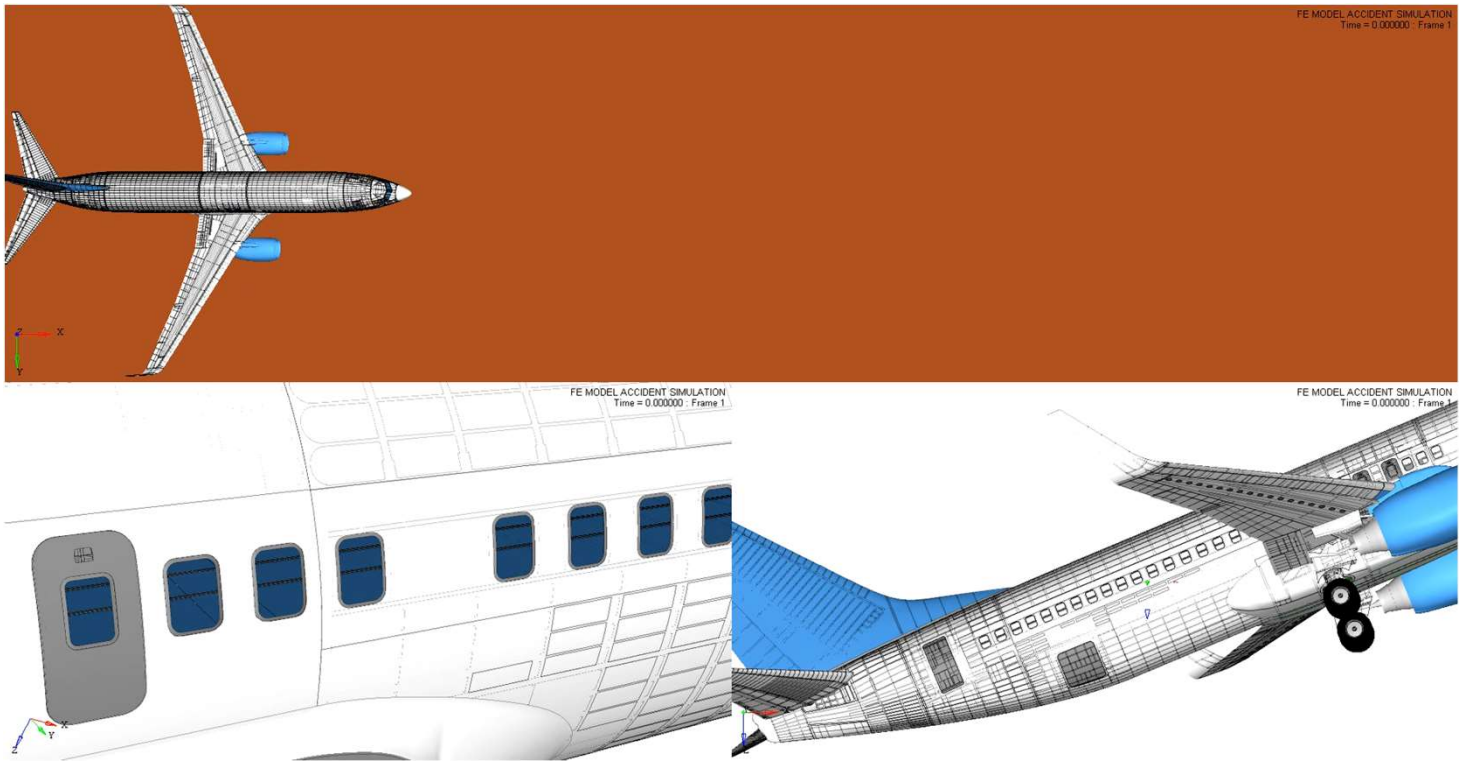
Impact Kinematics – View 1

TK 1951 Accident Reconstruction – Lagrange Soil



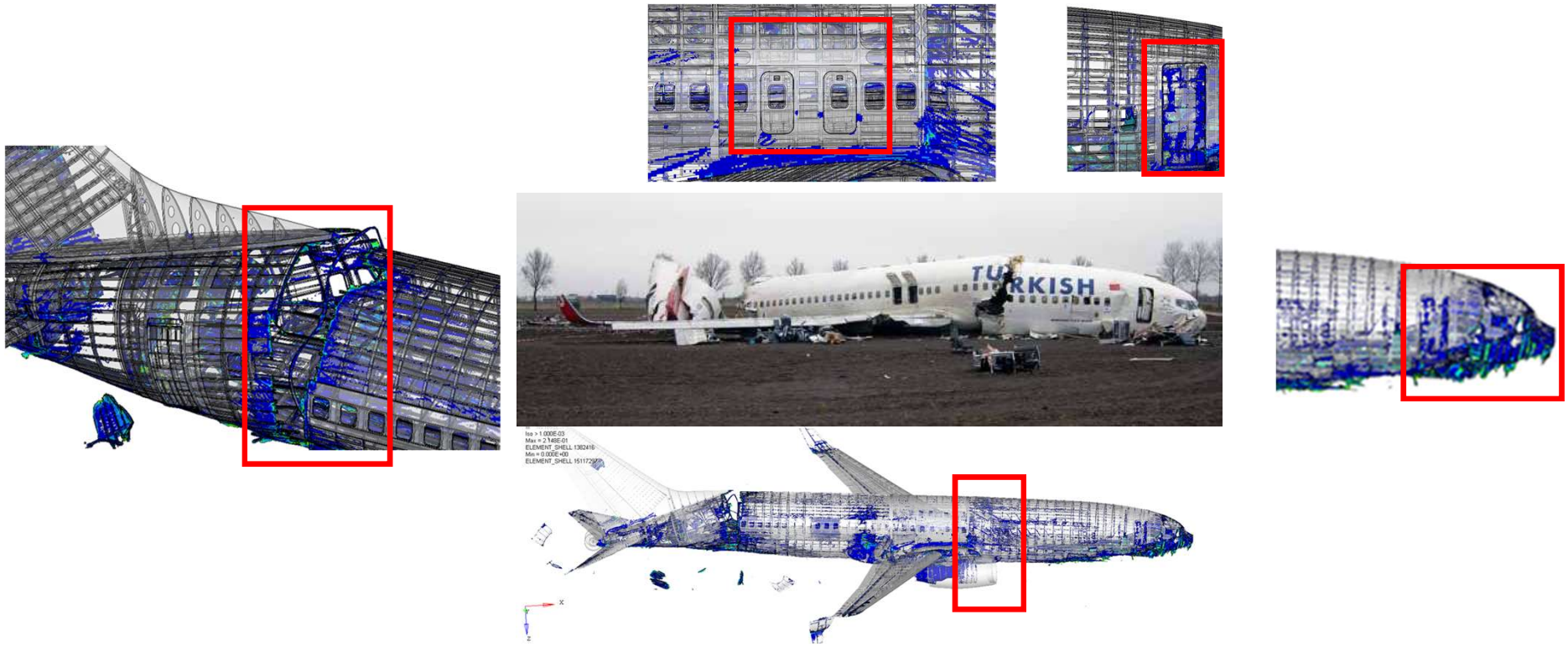
Impact Kinematics – View 2

TK 1951 Accident Reconstruction – Lagrange Soil



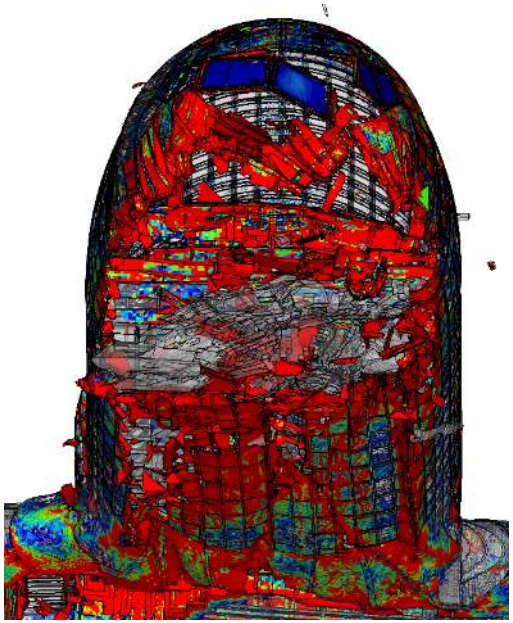
Comparison with Post-Impact Damage

TK 1951 Accident Reconstruction – Lagrange Soil



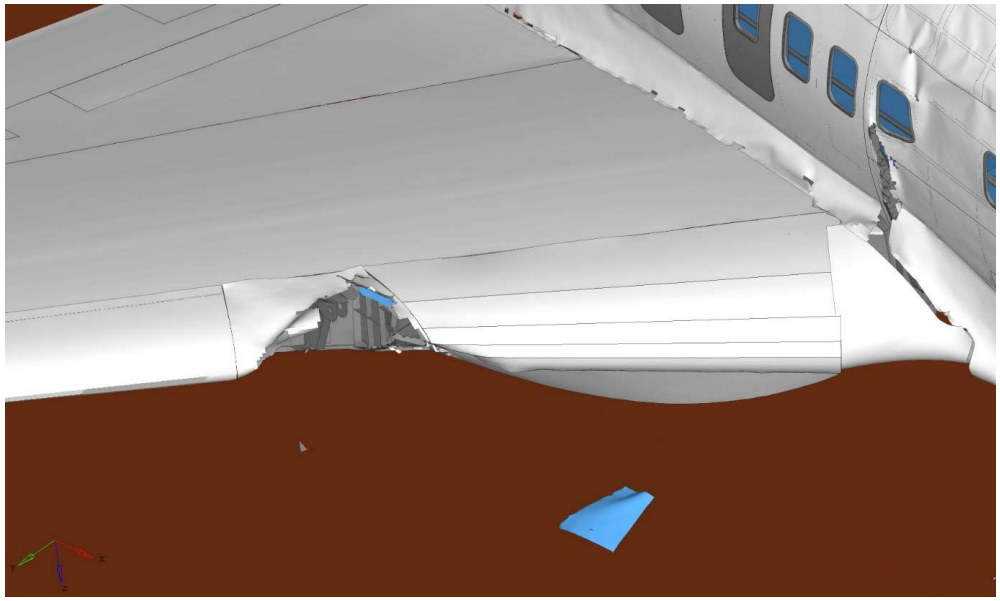
Damage – Forward Fuselage Section

Flight 1951 Post Impact Analysis



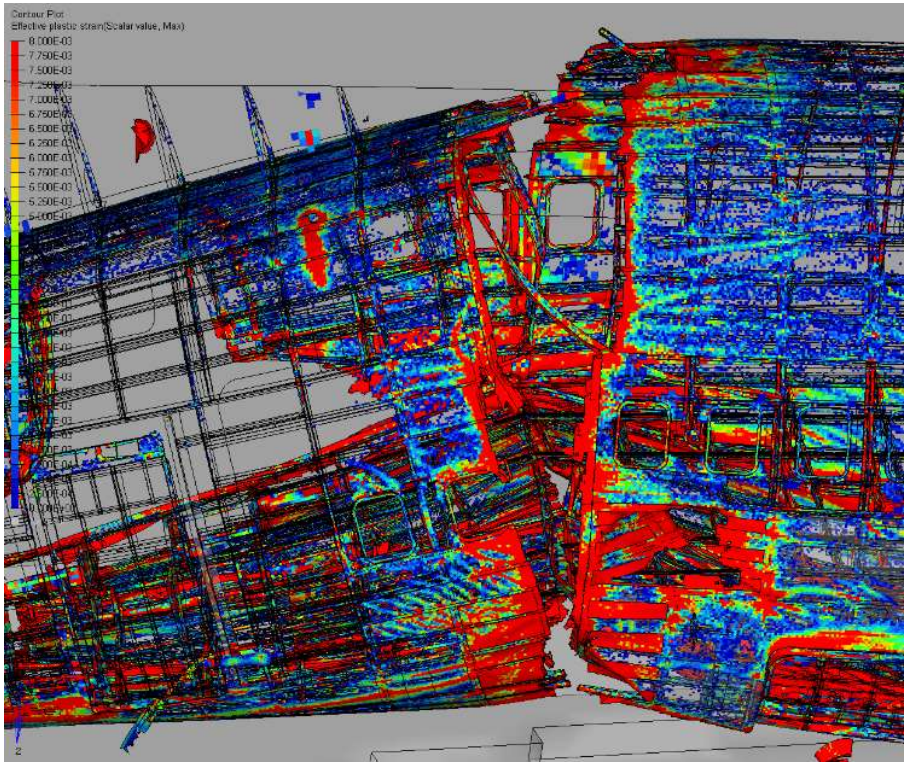
Right Wing Engine Pylon

Flight 1951 Post Impact Analysis



Damage – Tail Cone Section

Flight 1951 Post Impact Analysis



Spinal Injury Severity vs. Vertical Deceleration

Flight 1951 Post Impact Analysis – G-Load Survivability

Simulation Peak Acceleration Outputs

	A	B	C	D	E	F	Average (g)
Captain	48	47	36				30.1
Crew	45	47					
Row 1	35	38	44	36	24	38	
Row 2	22	24	26	30	24	25	
Row 3	27	26	30	37	26	30	
Row 4	27	26	26	29	26	24	
Row 5	21	20	23	25	20	23	
Row 6	26	23	25	23	23	24	23.8
Row 7	26	27	29	22	27	20	
Row 8	25	29	31	26	29	23	
Row 9	20	21	26	26	21	25	
Row 10	18	22	25	25	22	23	
Row 11	22	17	18	28	17	23	
Row 12	12	13	13	18	13	20	13.0
Row 14	10	12	13	15	12	15	
Row 15	10	9	9	12	9	12	
Row 16	10	10	10	9.2	10	10	
Row 17	9	9	9	10	9	9	
Row 18	14	14	15	14	14	11	
Row 19	16	16	18	16	13	14	
Row 20	13	14	16	13	14	12	
Row 21	16	13	15	13	13	11	
Row 22	10	11	14	18	11	13	
Row 23	10	12	13	19	12	14	
Row 24	13	15	16	22	15	16	
Row 25	17	19	19	21	19	18	21.8
Row 26	21	27	31	23	27	18	
Row 27	16	15	16	22	15	13	
Row 28	18	20	23	24	20	18	
Row 29	33	50	25				

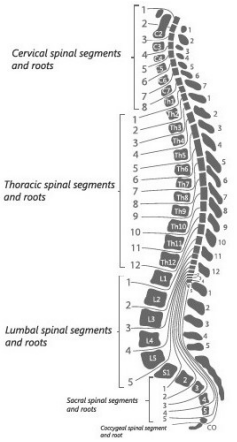
> 30g

20g - 30g

< 14g

14g - 20g

No	Gender	Age	Seat	ISS	Level of Injury	Burst (Y/N)	Complete Burst (Y/N)	Classification	Treatment
1	F	36	Crew front	41	T12-L2	Y	N	T12-L1 C;L1 A3	surgery
14	F	23	Crew front	27	T6-7	Y	Y	T6-T7 B2; T7 A4	surgery
14	F	23	Crew front	27	T12-L1	Y	Y	T12-L2 C; L1 A4	
16	M	33	5B	18	L5	Y	Y	A4	surgery
22	M	38	5C	17	T12-L1	Y	Y	T12-L1 B2; L1 A4	surgery
23	M	28	5E	34	L4	Y	Y	A4	surgery
13	NA	NA	6C	24	L1	Y	N	A3	-
13	NA	NA	6C	24	L3	N	-	A1	-
2	M	42	6D	22	L5	Y	Y	A4	brace
3	F	29	7C	18	C2	N	-	A/A 3; G 3	surgery
3	F	29	7C	18	L1	N	-	A1	brace
17	M	26	7E	10	T?	N	nvt	A1	-
18	M	27	7F	8	C4-5	Y	Y	C4-5 B2, C5 A4	surgery
7	F	49	8A	17	L1	N	-	A1	Brace
15	M	29	9F	14	T12	Y	Y	A4	surgery
10	M	48	10A	4	L1	Y	N	T12-L1 B2;L1 A3	-
20	F	31	10F	9	T12	N	-	T11/12 C, T12 B2 (A2)	surgery
4	F	52	12D	9	T11-12	Y	N	T11-T12 B2, T12 A3,T11 A1	surgery
6	F	47	12E	17	T11-12	Y	N	A0-A3	surgery
21	M	35	18C	4	L1	N	-	A1	-
9	M	42	21E	10	L3	N	-	A1	Brace
19	M	31	22A	9	T12-L2	N	-	A1 (3x)	surgery
5	F	27	23A	8	C7	N	-	A1	Miami-J
5	F	27	23A	8	T3	N	-	A1	Brace
12	M	27	23C	9	T7	N	-	A1	-
8	F	38	25B	21	C7	Y	-	A2	Miami-J
11	M	42	28A	14	T12	N	-	A1	-



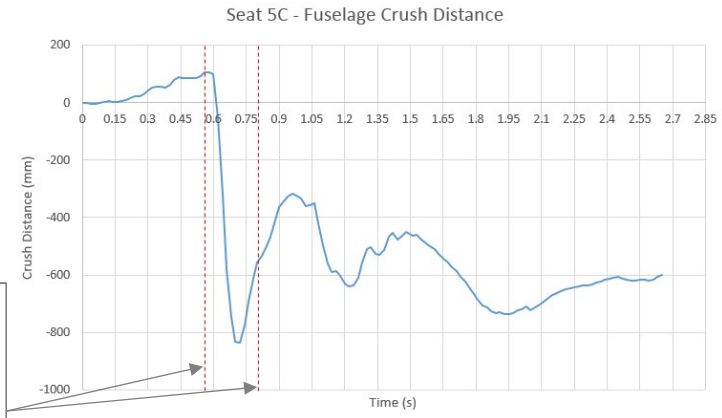
Preliminary Multi-axial Acceleration Profile – Seat 5C

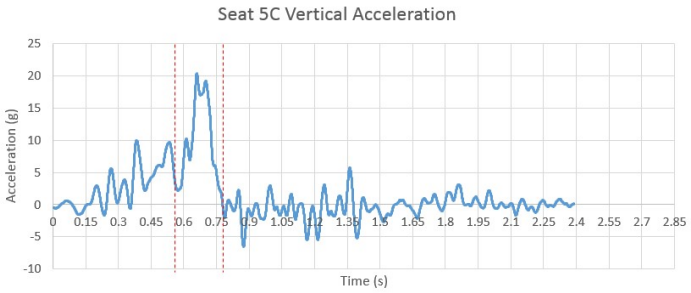
Flight 1951 Post Impact Analysis

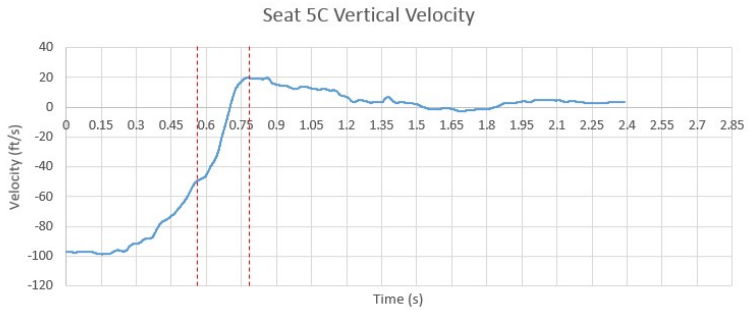
Seat 5C Loads Determination

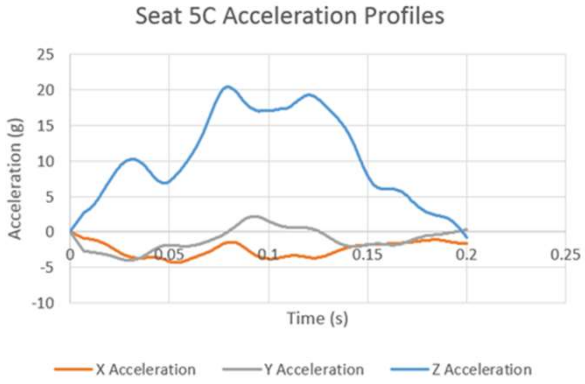
Maximum Delta-V, Crush Distance, & Acceleration Selection

Acceleration pulse extracted b/n t=0.58s and t=0.78s Corresponding to the fuselage crush



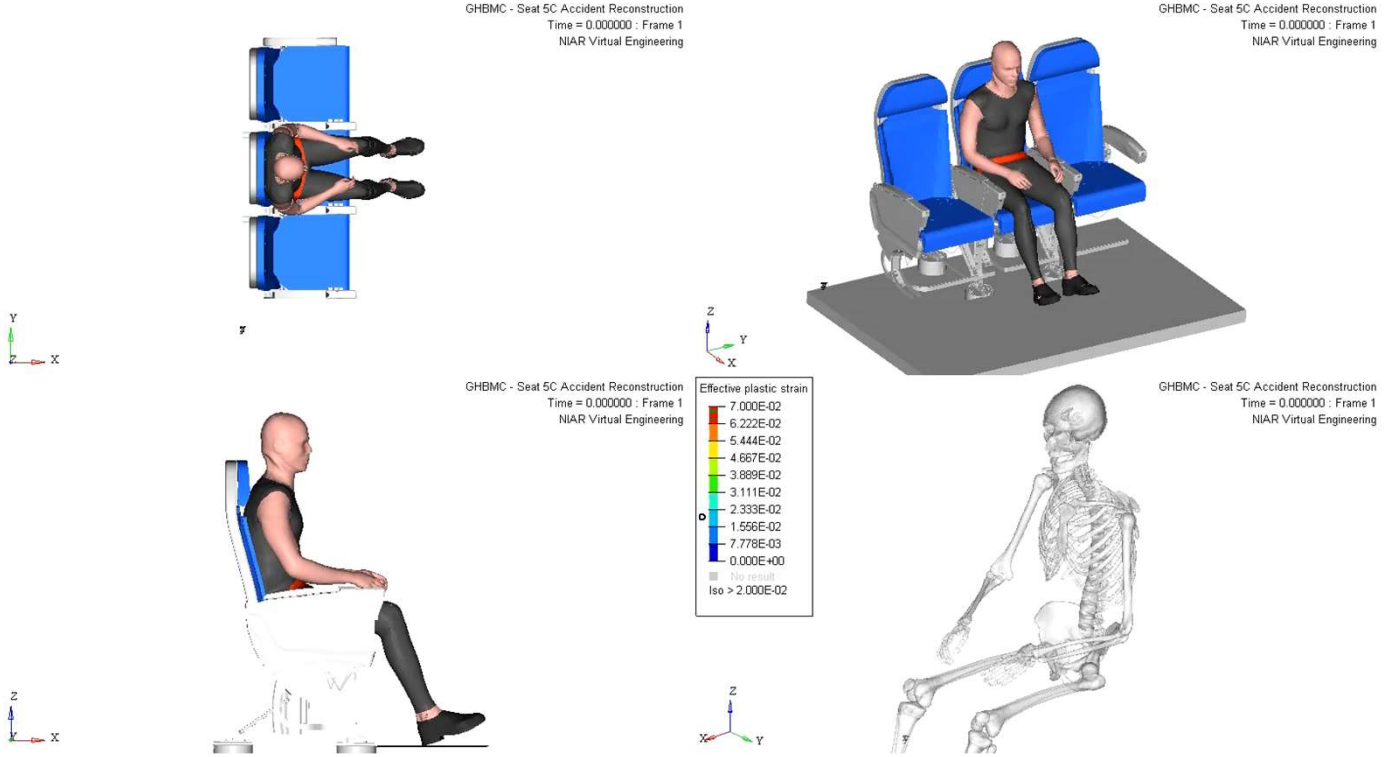






Seat 5C HBM Simulation

Kinematics Overview & Bone Effective Plastic Strain

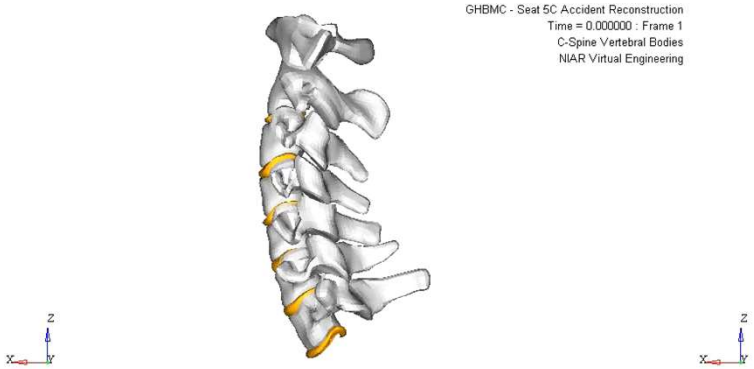


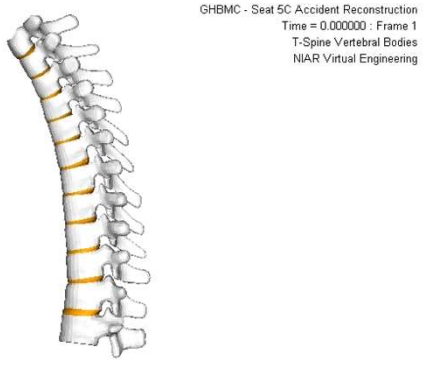
Seat 5C HBM Simulation

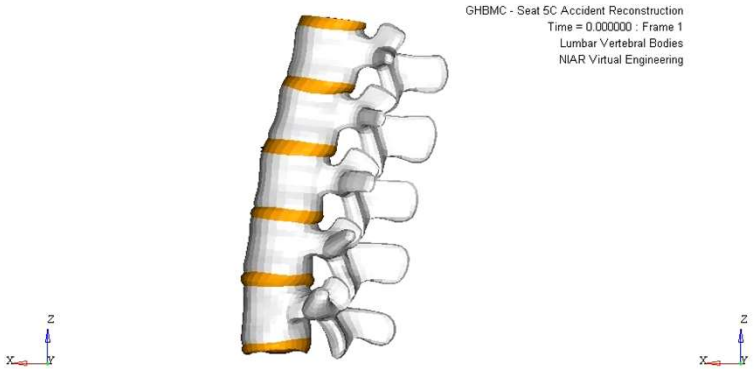
Kinematics - Section Cut View

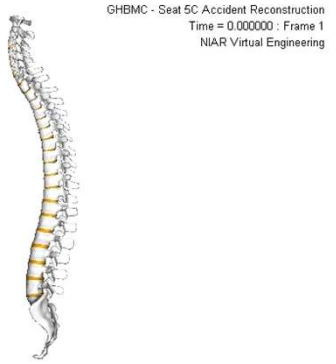
Seat 5C HBM Simulation

Kinematics Overview & Bone Effective Plastic Strain



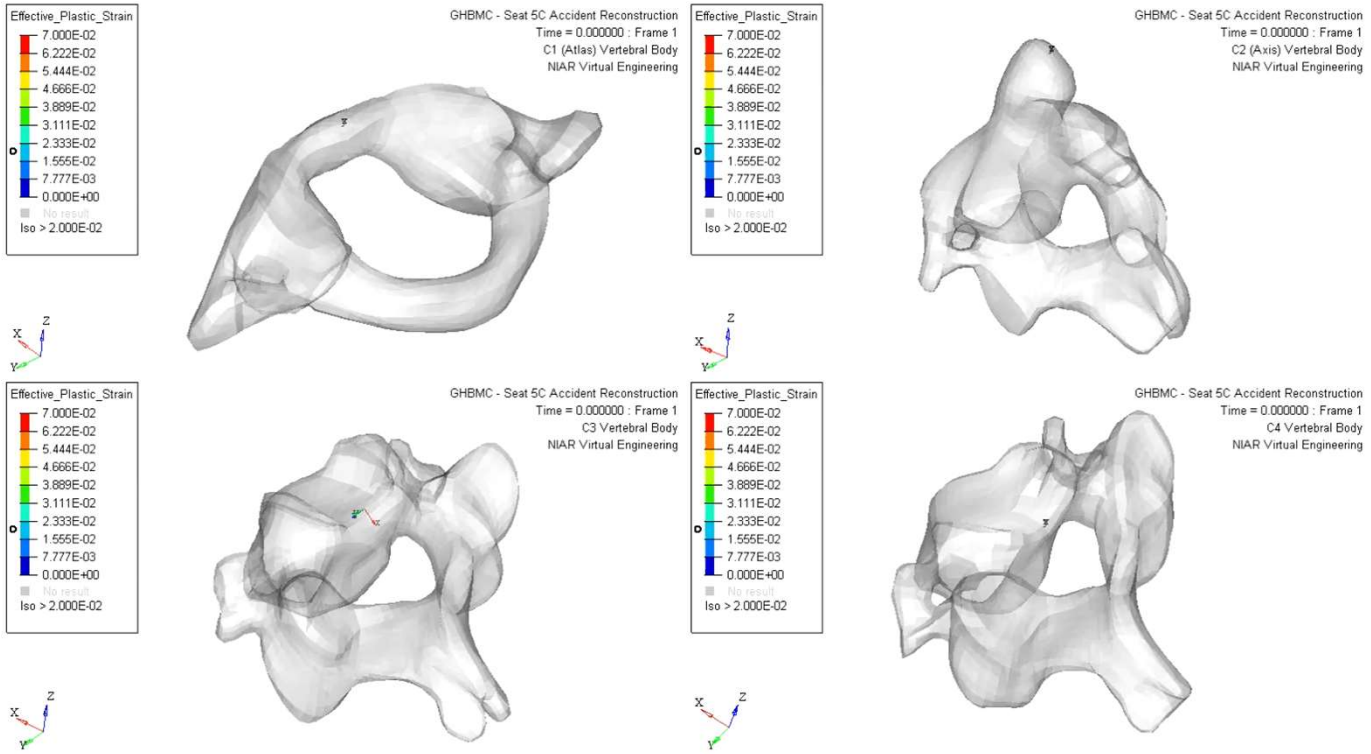






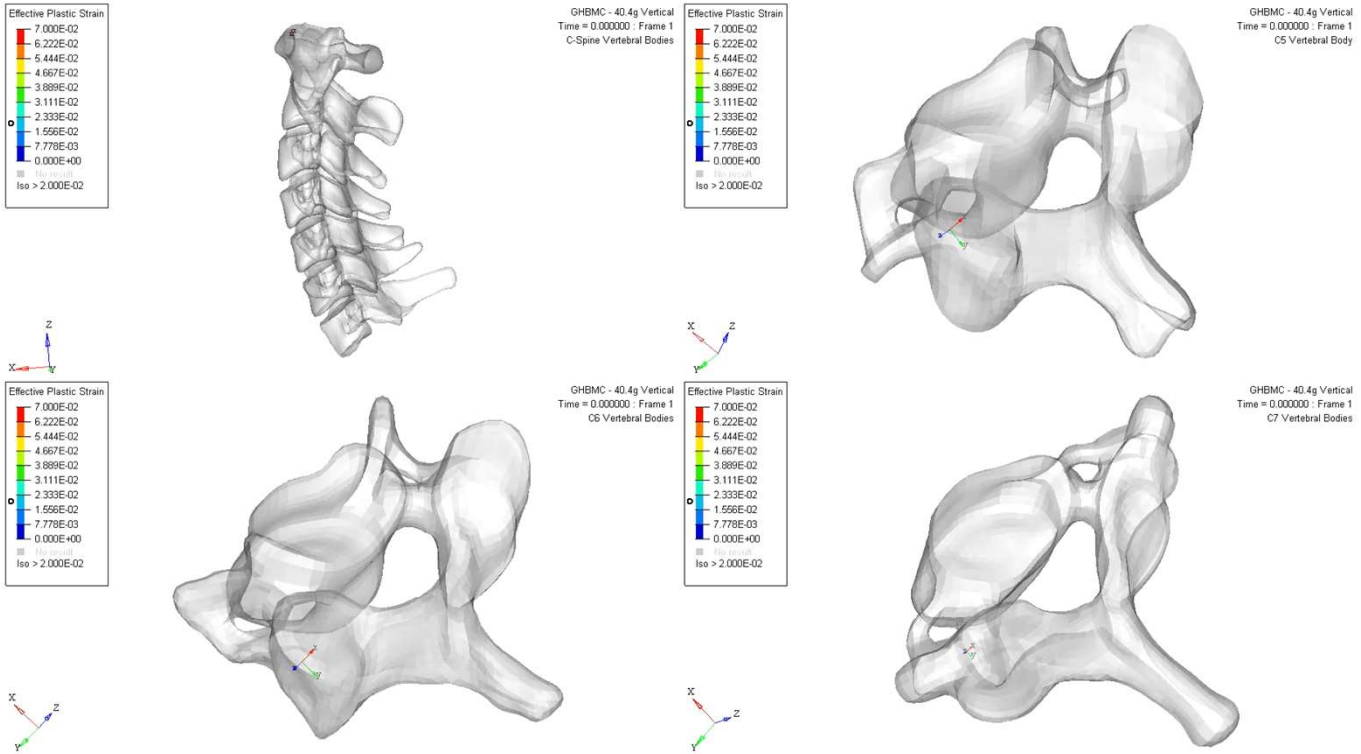
Seat 5C HBM Simulation

Effective Plastic Strain



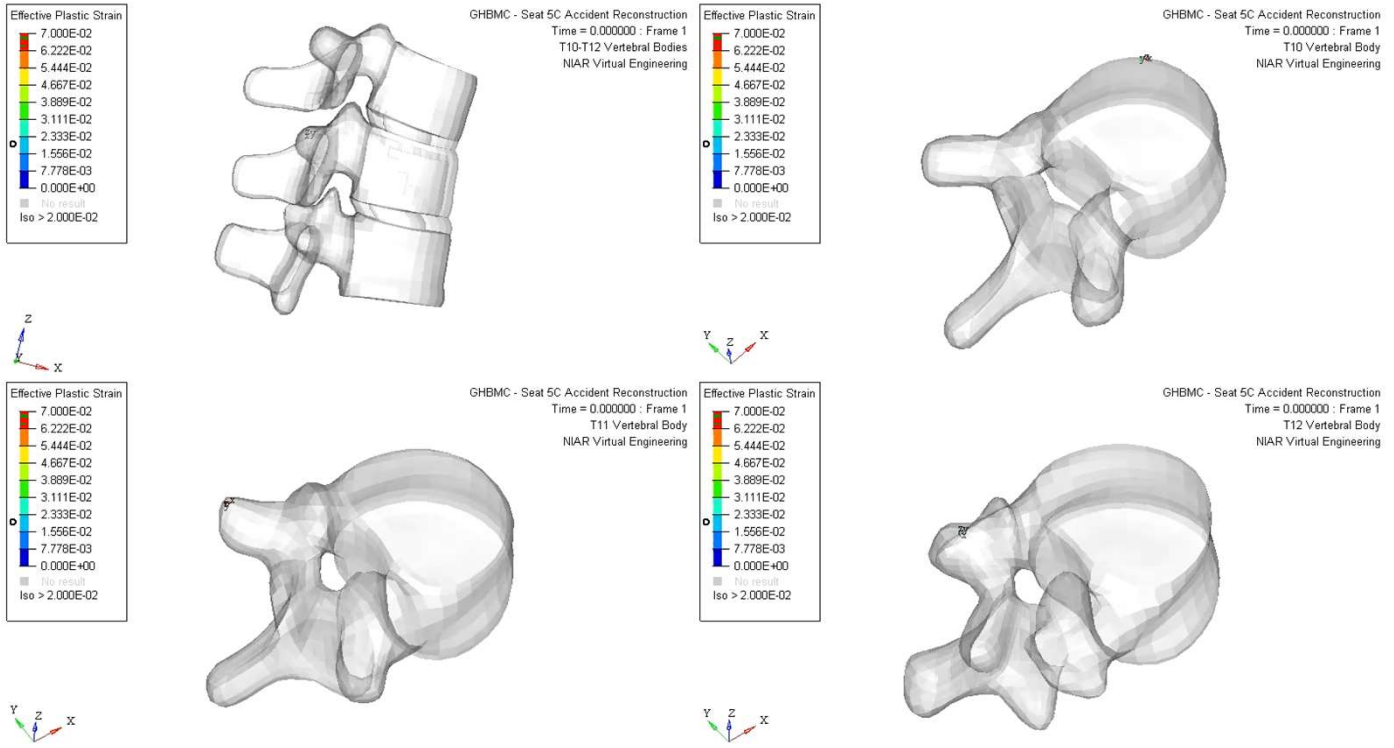
Seat 5C HBM Simulation

Effective Plastic Strain



Seat 5C HBM Simulation

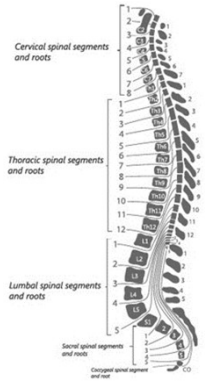
Effective Plastic Strain



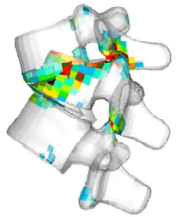
Spinal Injury Simulation Summary

Overview of bone fracture injuries by load case

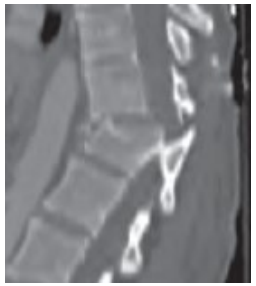
- HBM Accident reconstruction multi-axis loading produced vertebral body fractures in the C- and T-spines
  - C-spine: C4-C5
  - Thoracic spine: T10-T11 Burst Fracture
- Accident Data Seat 5C occupant injury:
  - Thoracic spine T12-L1 Burst Fracture



23.4g Injury Prediction: T10-T11



Example Vertebral Body Fracture: T11-T12



No	Gender	Age	Seat	ISS	Level of Injury	Burst (Y/N)	Complete Burst (Y/N)	Classification	Treatment
1	F	36	Crew front	41	T12-L2	Y	N	T12-L1 C;L1 A3	surgery
14	F	23	Crew front	27	T6-7	Y	Y	T6-T7 B2; T7 A4	surgery
14	F	23	Crew front	27	T12-L1	Y	Y	T12-L2 C; L1 A4	
16	M	33	5B	18	L5	Y	Y	A4	surgery
22	M	38	5C	17	T12-L1	Y	Y	T12-L1 B2; L1 A4	surgery
23	M	28	5E	34	L4	Y	Y	A4	surgery
13	NA	NA	6C	24	L1	Y	N	A3	-
13	NA	NA	6C	24	L3	N	-	A1	-
2	M	42	6D	22	L5	Y	Y	A4	brace
3	F	29	7C	18	C2	N	-	A/A 3; G 3	surgery
3	F	29	7C	18	L1	N	-	A1	brace
17	M	26	7E	10	T?	N	nvt	A1	-
18	M	27	7F	8	C4-5	Y	Y	C4-5 B2, C5 A4	surgery
7	F	49	8A	17	L1	N	-	A1	Brace
15	M	29	9F	14	T12	Y	Y	A4	surgery
10	M	48	10A	4	L1	Y	N	T12-L1 B2;L1 A3	-
20	F	31	10F	9	T12	N	-	T11/12 C, T12 B2 (A2)	surgery
4	F	52	12D	9	T11-12	Y	N	T11-T12 B2, T12 A3,T11 A1	surgery
6	F	47	12E	17	T11-12	Y	N	A0-A3	surgery
21	M	35	18C	4	L1	N	-	A1	-
9	M	42	21E	10	L3	N	-	A1	Brace
19	M	31	22A	9	T12-L2	N	-	A1 (3x)	surgery
5	F	27	23A	8	C7	N	-	A1	Miami-J
5	F	27	23A	8	T3	N	-	A1	Brace
12	M	27	23C	9	T7	N	-	A1	-
8	F	38	25B	21	C7	Y	-	A2	Miami-J
11	M	42	28A	14	T12	N	-	A1	-

Conclusions and Future Work

Flight 1951 Post Impact Analysis

- This is the first time we have been able to correlate injury mechanisms to actual aircraft deceleration profiles extracted from a validated full scale FEA aircraft accident reconstruction model.
- This Real-World data set will be used as part of the validation load cases required to improve HBM responses to aerospace impact loading conditions. Most of the HBMs available today have been validated only for automotive type loading conditions and need to be improved to meet aerospace industry requirement's.
- HBM modeling in conjunction with full aircraft FEA models, and real world accident data will enable us to better understand injury mechanisms and their causes. In the future we envision replacing virtual ATD models with Human Body Models from conceptual design to CBA.
- Further research is ongoing to evaluate on a case by case basis Twenty-three (18.3%) of the survivors that sustained a total of 27 spinal injuries :[1]
  - Four (17.1% of the patients with spinal injury) suffered a single cervical spine fracture.
  - Eight (29.6%) injuries were at the thoracic spine, 15 (55.6%) at the lumbar spine level.
  - More than half of the injuries included a burst component.
  - Most of the thoracolumbar spinal injuries 14 (60.7%) were at the thoracolumbar junction (T10-L2), 4 at the upper thoracic and 5 at the lower lumbar spine.
  - There were no sacrum fractures.
  - All patients had both plain radiographs and CT imaging of their spinal injuries.
- A high number of spinal injuries were found after this airplane crash. The morphology of the injuries consisted of a high rate of burst type fractures, presumably caused mainly by vertical trauma mechanism, as shown by the preliminary accident reconstruction analysis.

[1] Postma, I. L. E. (2014). Brace for impact! A thesis on medical care following an airplane crash, University of Amsterdam

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Accident Reconstruction of Turkish Airlines Flight 1951

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Thank you for your attention.

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