Photogrammetric Techniques Utilized during Sub-scale and Full-scale Testing of Fokker F28 Aircraft Hardware

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Outline

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- Importance
- On-board instrumentation
- Photogrammetry Test Objectives
- Landing and Impact Research Facility (LandIR)
- Subscale Fuselage Drop Testing (2017)
  - Front (Forward) Section
  - Wing Box
- Full-scale Drop Testing (2019)
- Summary and Conclusions

Background

- In 2017, through a collaborative agreement between the Federal Aviation Administration (FAA) and NASA Langley Research Center (LaRC), a research effort was undertaken to obtain impact data through a series of tests which will support the development of airframe level crash requirements for transport category airplanes.
- Two Fokker F28 MK4000 fuselage sections, forward and wing box, were drop tested.
- Following the fuselage section drop testing, a full-scale Fokker F28 MK1000 was drop tested in 2019.

Importance

- Develop the tools and understanding to ensure new and novel aircraft keep occupants safe in an off-nominal event.
- Use the test data to improve the high-fidelity models and identify any potential short-comings between fuselage barrel section drop test (sub-scale) and full-scale model predictions.

On-board Instrumentation

- Accelerometers were instrumented at critical points on the airframe, which included the floor/frame section junctions, seat tracks, overhead lead ballast, overhead ballast/frame attachment points and under the wing box truss structure.
- Self-contained data recorders, logging accelerations and rotational rates, were also used on the seat tracks and lower structure for evaluation as potential crash recording devices for future tests.
- Anthropomorphic Test Devices (ATD's, i.e., crash test dummies) were included to measure the potential of onboard occupant injury.
- One side of each test article was painted with a stochastic black and white speckle pattern, as well as bowtie markers were applied at various locations, for use in full-field two-dimensional (2D) digital image correlation (DIC) and marker tracking.

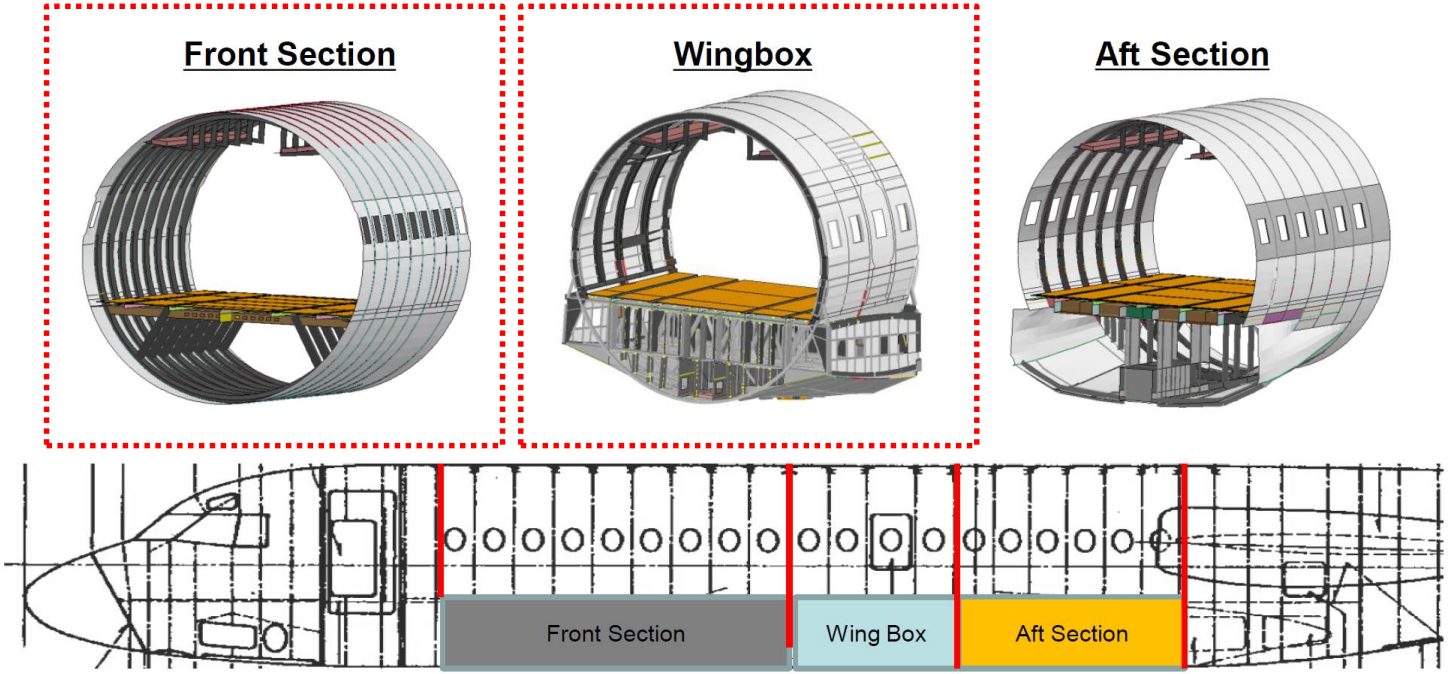
Photogrammetry Test Objectives

- Use multiple photogrammetry techniques to better evaluate and understand transport category aircraft under dynamic conditions.
- Generate test data to improve/validate the computational models and verify predicted impact conditions were achieved.
- Measure the response of the ATD’s during the initial drop and through impact.
- Provide stress analyst with pre- and post-test FARO scans of test article to improve the mesh and verify the accuracy of the model.

Landing and Impact Research Facility (LandIR)

- 240-ft high and 400-ft long steel A-frame gantry structure built in 1965, used to conduct full-scale crash testing under, both under combined horizontal and vertical loading or under purely vertical loading only through a series of overhead cabling and release mechanisms.

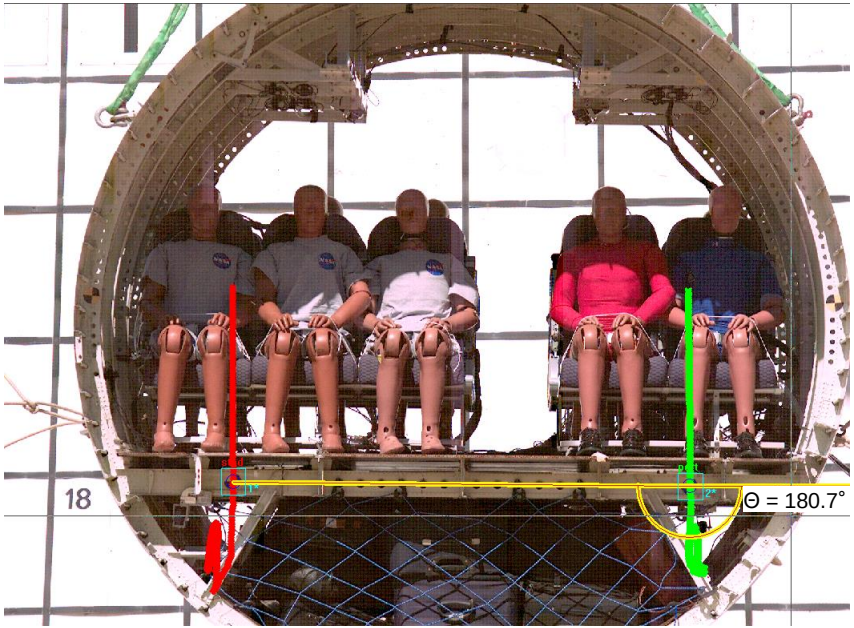
Fuselage Barrel Section Configuration



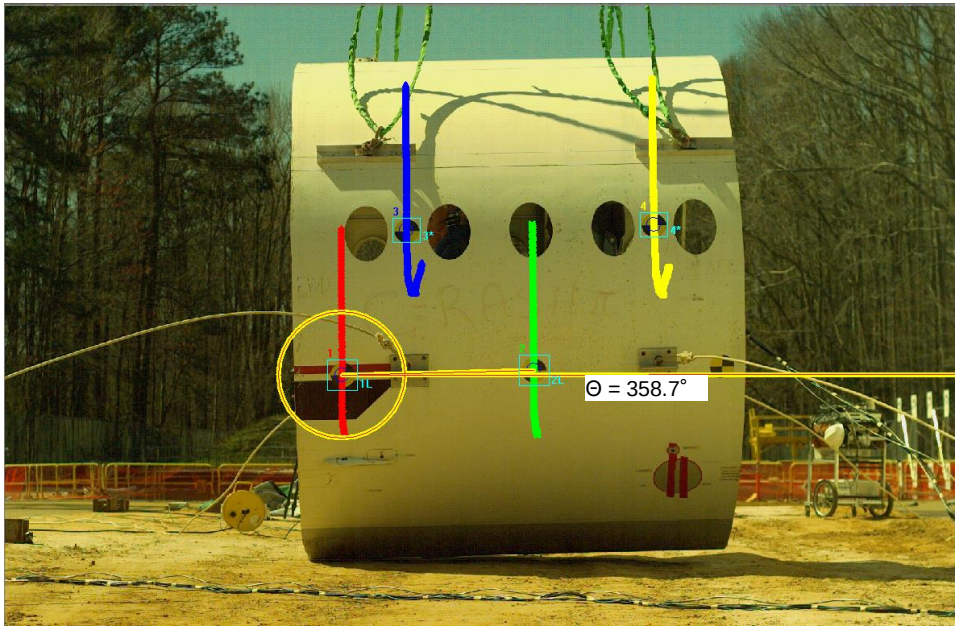
Front (Forward) Barrel Section

- Test Parameters
  - Total weight of 4,465 lbs.
    - Empty Section: 814 lbs.
    - Underfloor Luggage: 922 lbs.
    - Overhead hat rack bin ballast: 232 lbs.
    - Weight of floors, ATD's seats and DAS: 2,496 lbs.
  - Center of Gravity (CG): 1.3 in. Forward and 0.75 in. Starboard of geometric center
  - **Impact Velocity:** 30 ft/sec onto flat soil bed, with nominal pitch angle of zero degrees (purely vertical flat impact)

Marker Tracking – Measured Impact Conditions



Angle From Starboard to Port = 180.7 degrees
Vertical Velocity = -28.9 ft/sec
Roll = 0.7 degrees (starboard down)

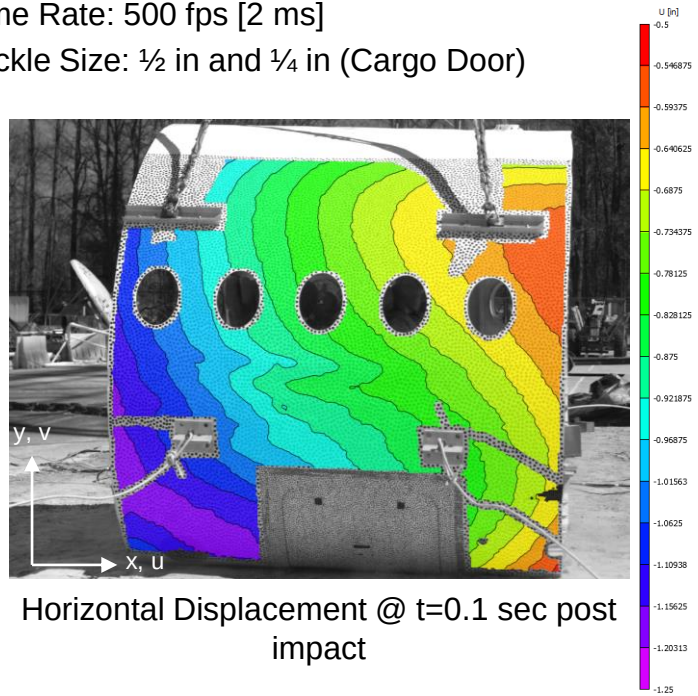


Angle From Aft to Fwd = 358.7 degrees
Vertical Velocity = -28.9 ft/sec
Pitch = -1.3 degrees (nose down)

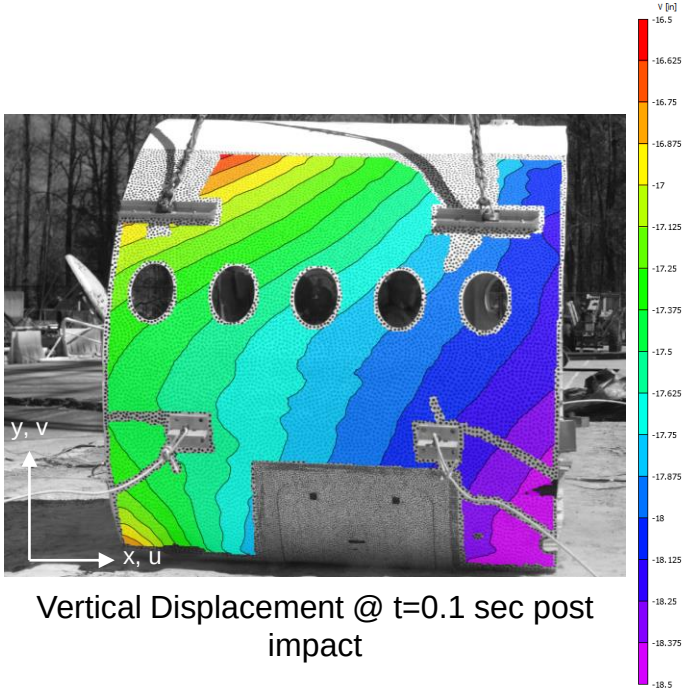
Marker Tracking – Occupant Motion Study (ATD's)

2D Full-field Digital Image Correlation (DIC) – Starboard

- Photogrammetry Parameters
  - High-Speed Camera: Vision Research Phantom v10
  - Resolution: 1800 x 2208 pixels [4 MP]
  - Frame Rate: 500 fps [2 ms]
  - Speckle Size: ½ in and ¼ in (Cargo Door)



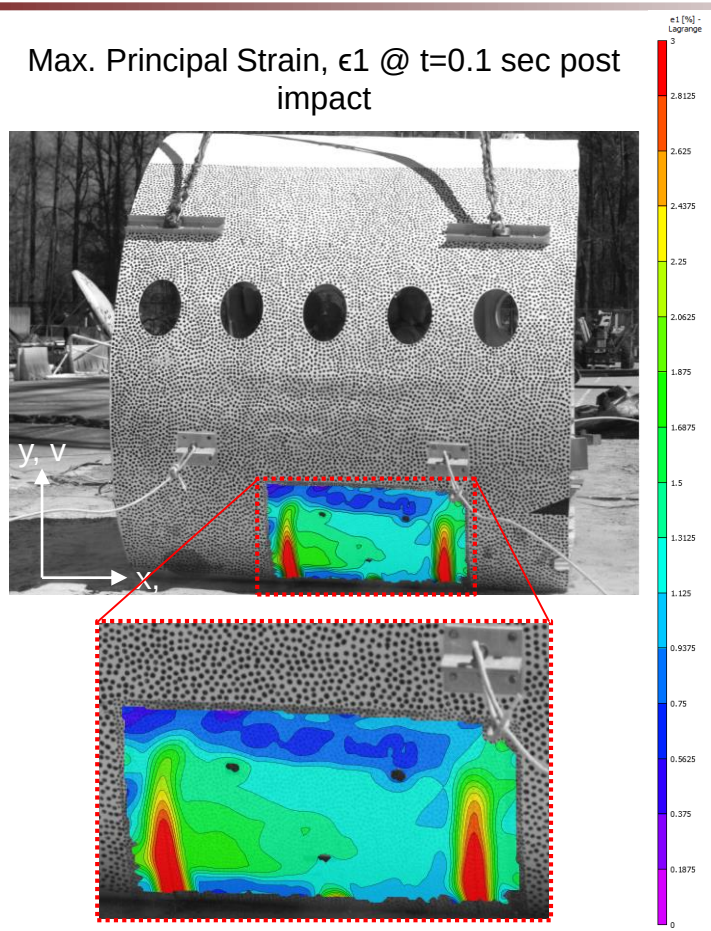
Horizontal Displacement @ t=0.1 sec post impact



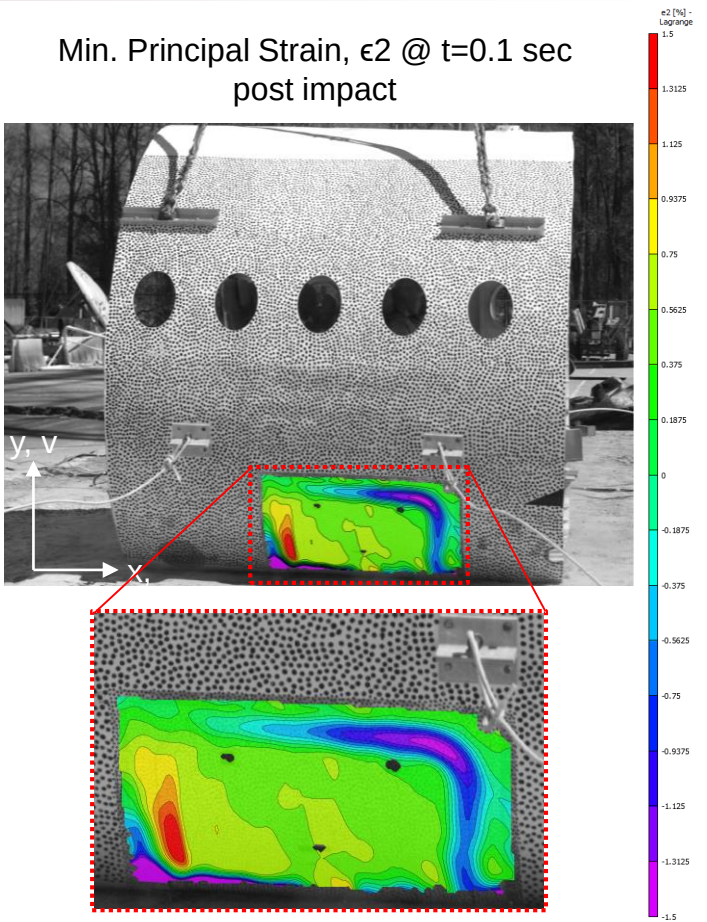
Vertical Displacement @ t=0.1 sec post impact

2D Full-field Digital Image Correlation (DIC) – Cargo Door

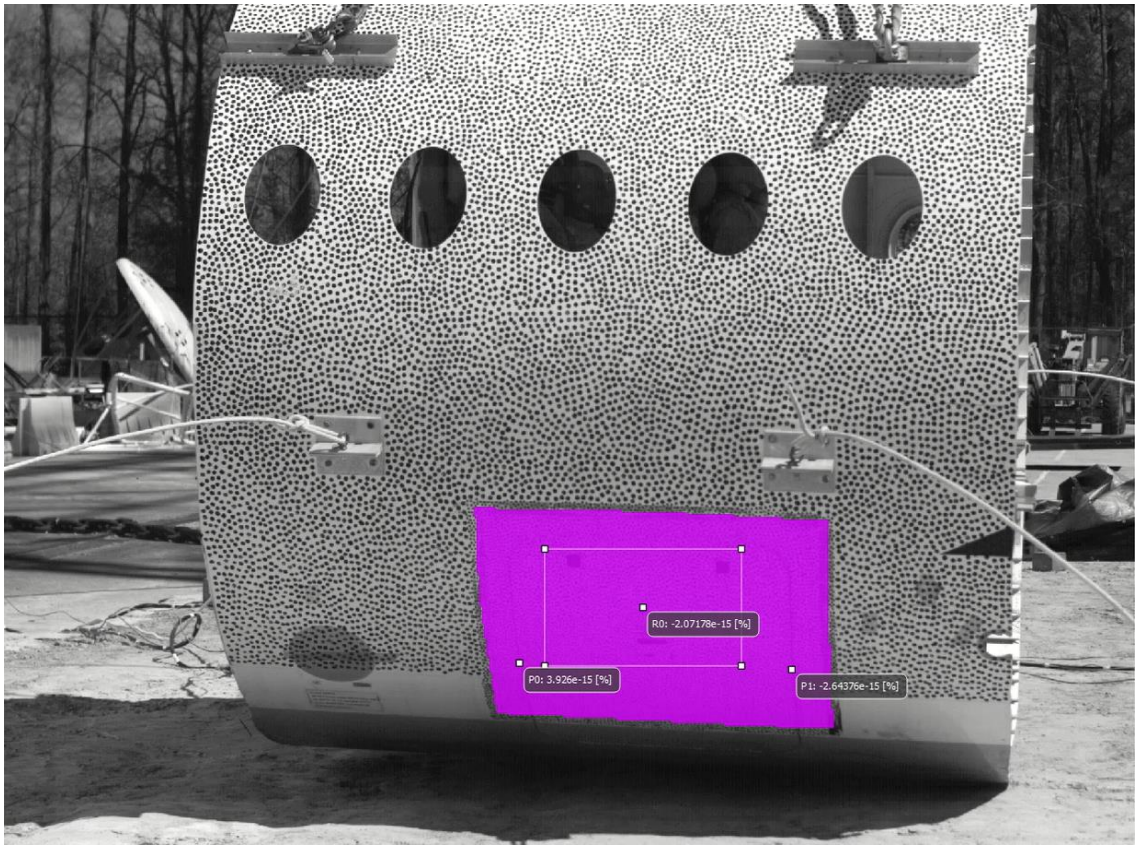
Max. Principal Strain, ϵ1 @ t=0.1 sec post impact



Min. Principal Strain, ϵ2 @ t=0.1 sec post impact



2D Full-field Digital Image Correlation (DIC) – Cargo Door

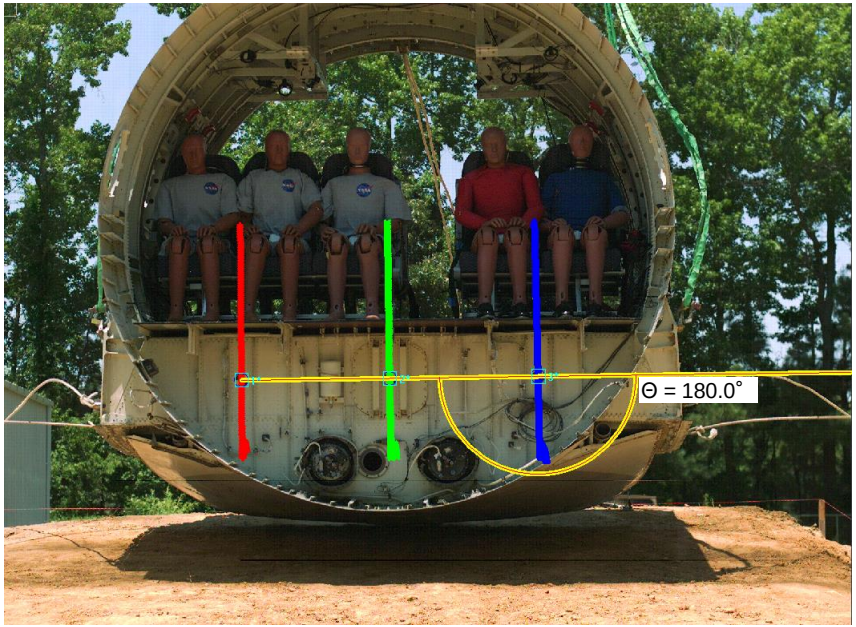


0 ϵ1 [%] - Lagrange 3

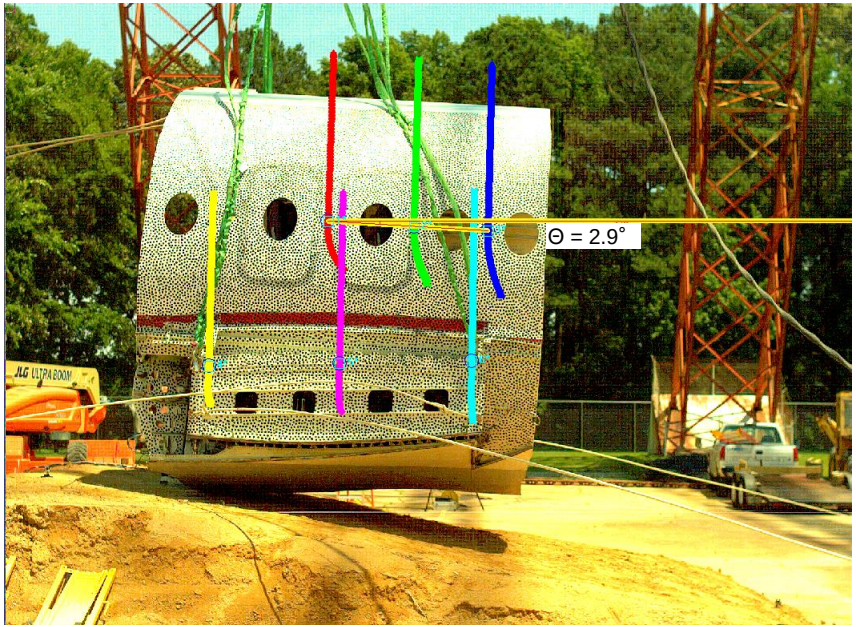
Wingbox Section

- Test Parameters
  - Total weight of 5,182 lbs.
    - Empty Section: 2,454 lbs.
    - Overhead hat rack bin ballast: 232 lbs.
    - Weight of floors, ATD's seats and DAS: 2,496 lbs.
  - Center of Gravity (CG): 2.1 in. Forward and 1.4 in. Starboard of geometric center
  - **Impact Velocity:** 30 ft/sec, with 4-deg nose down angle (measured on floor), impacting onto a 10-deg forward sloping soil bed
    - Allows for 2D loading condition – localized forward velocity

Marker Tracking – Measured Impact Conditions

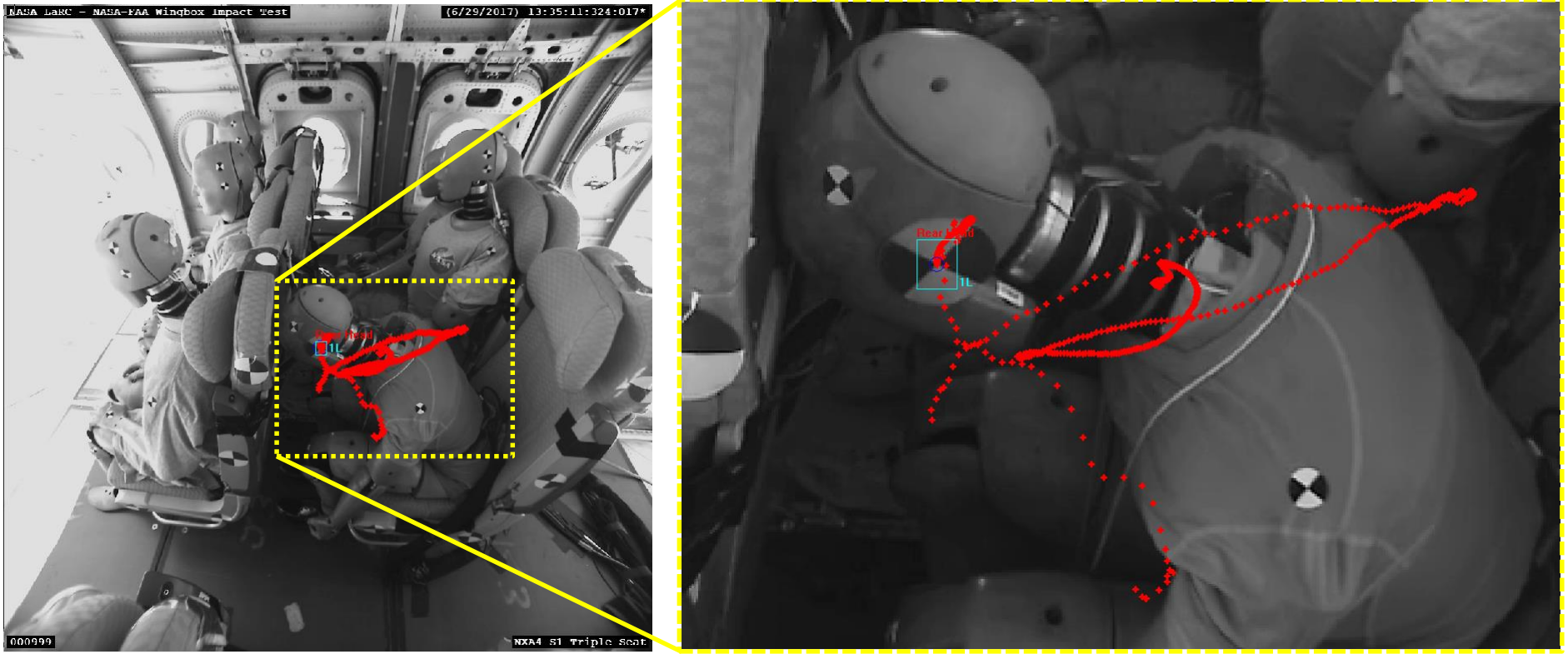


Angle From Starboard to Port = 180.0 degrees
Vertical Velocity = -29.5 ft/sec
Roll = 0.0 degrees



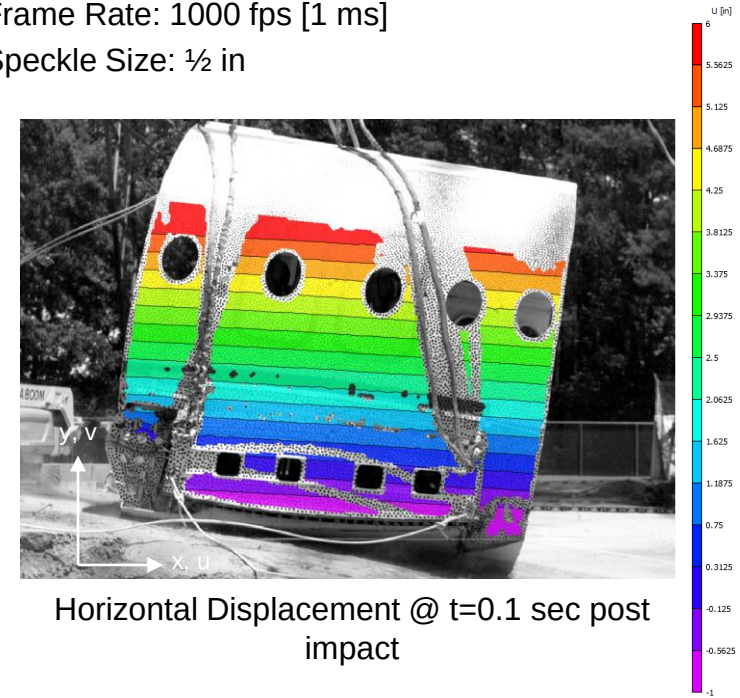
Angle From Aft to Fwd = 2.9 degrees
Vertical Velocity = -29.5 ft/sec
Horizontal Velocity = 1.1 ft/sec
Pitch = -2.9 degrees (nose down)

Marker Tracking – Occupant Motion Study (ATD's)

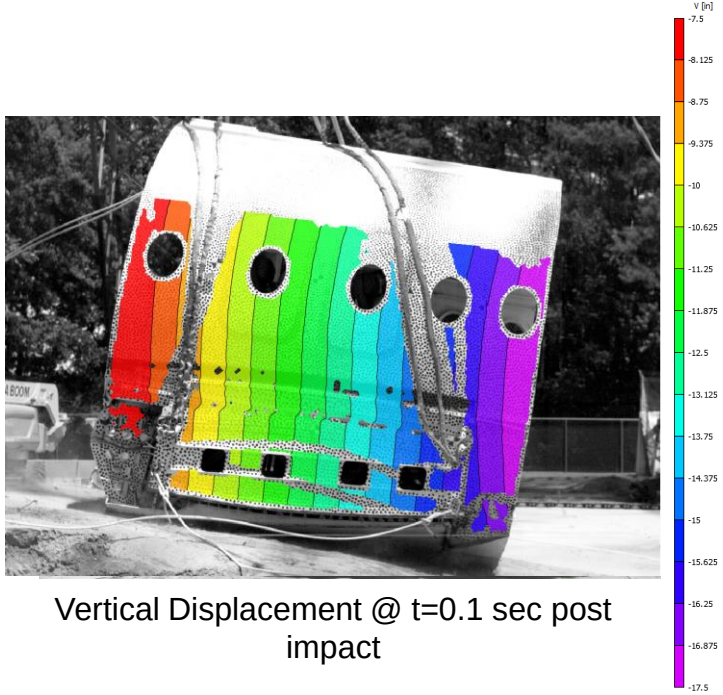


2D Full-field Digital Image Correlation (DIC) - Starboard

- Photogrammetry Parameters
  - High-Speed Camera: Vision Research Phantom v9.1
  - Resolution: 1632 x 1200 pixels [2 MP]
  - Frame Rate: 1000 fps [1 ms]
  - Speckle Size: ½ in

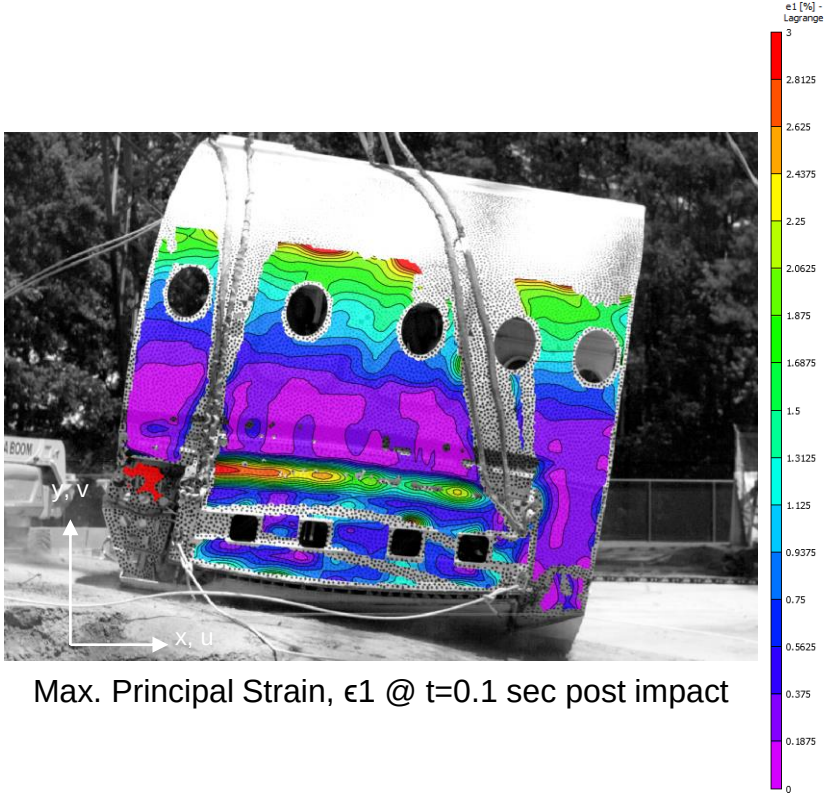


Horizontal Displacement @ t=0.1 sec post impact

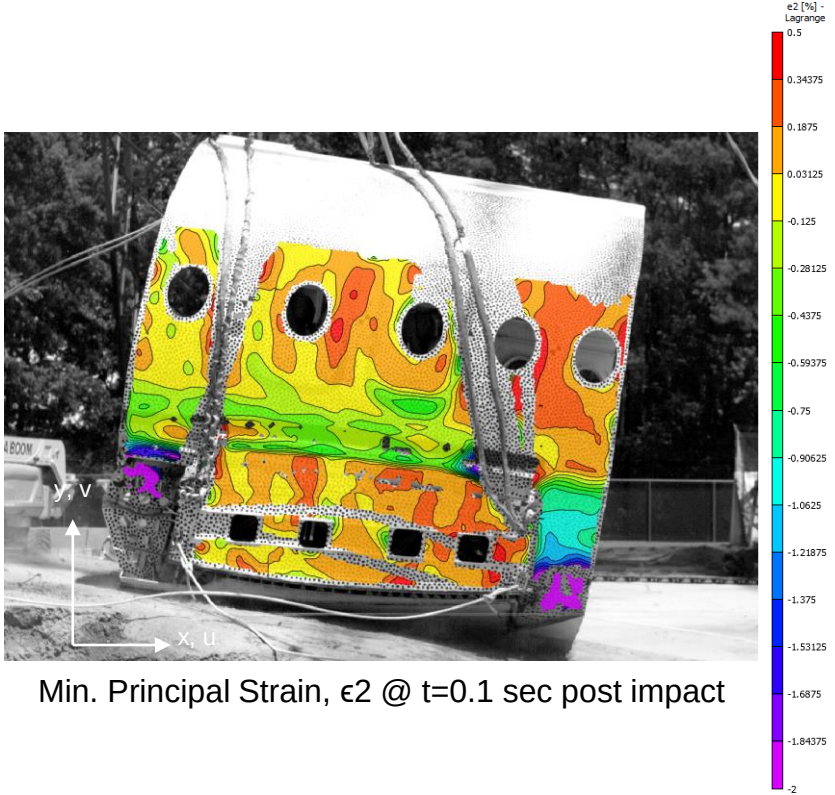


Vertical Displacement @ t=0.1 sec post impact

2D Full-field Digital Image Correlation (DIC) - Starboard



Max. Principal Strain, ϵ1 @ t=0.1 sec post impact

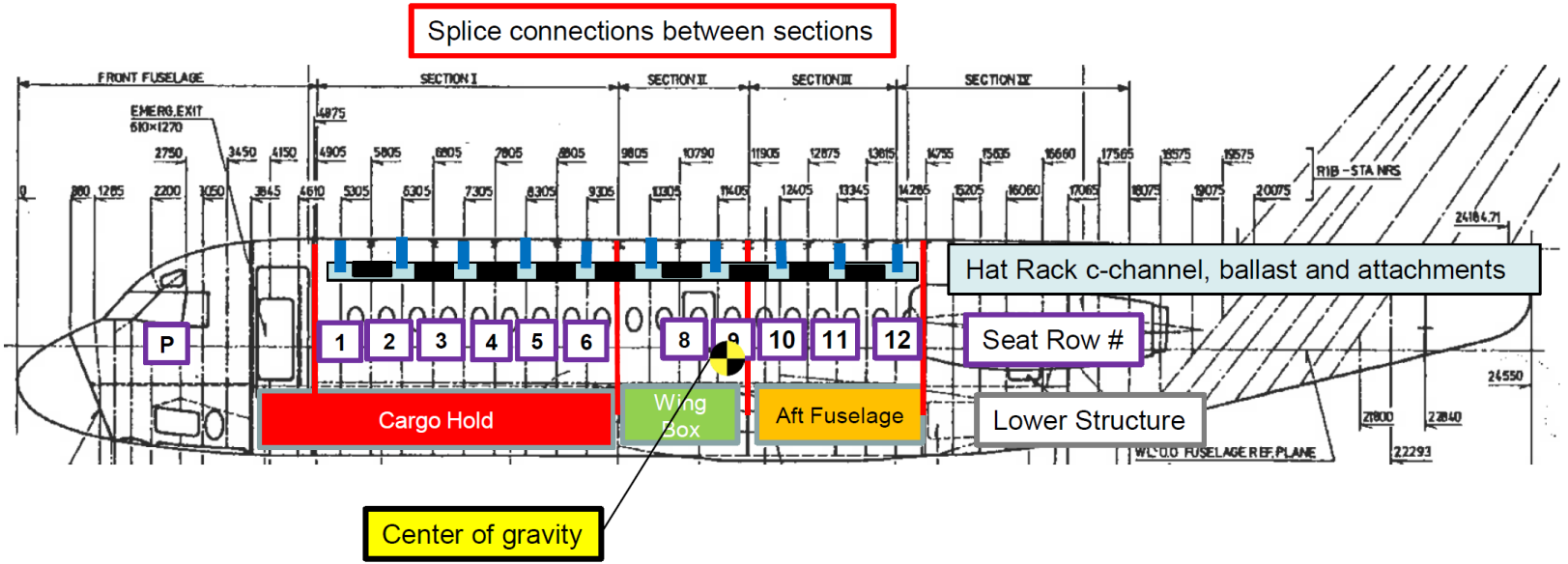


Min. Principal Strain, ϵ2 @ t=0.1 sec post impact

Full-Scale F28-MK1000 Airframe

- Test Parameters
  - Total weight of 33,306 lbs.
    - Airframe: 17,500 lbs.
    - Wings: 4,800 lbs.
    - Luggage: 923 lbs.
    - ATD's + Seats: 5,095 lbs.
    - Data Acquisition System: 500 lbs.
    - Lifting Hardware: 2,000 lbs.
    - Hat Rack Simulators: 500 lbs.
    - Ballast: 2,000 lbs
  - **Impact Velocity:** 70 ft/sec Horizontal, 30 ft/sec Vertical, with < 2-degree Pitch, Roll, Yaw (nominal)
  - Impact Surface: Gantry Unwashed Sand (2-foot soil bed at impact site)

Full-Scale Airframe Configuration

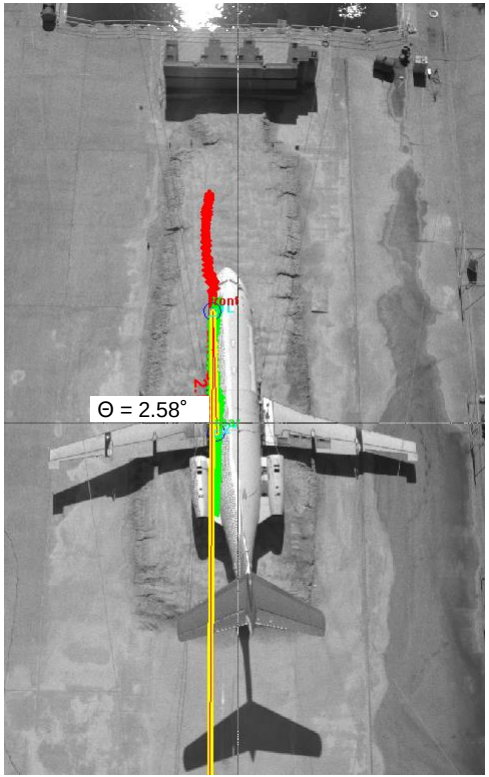


Marker Tracking – Measured Impact Conditions

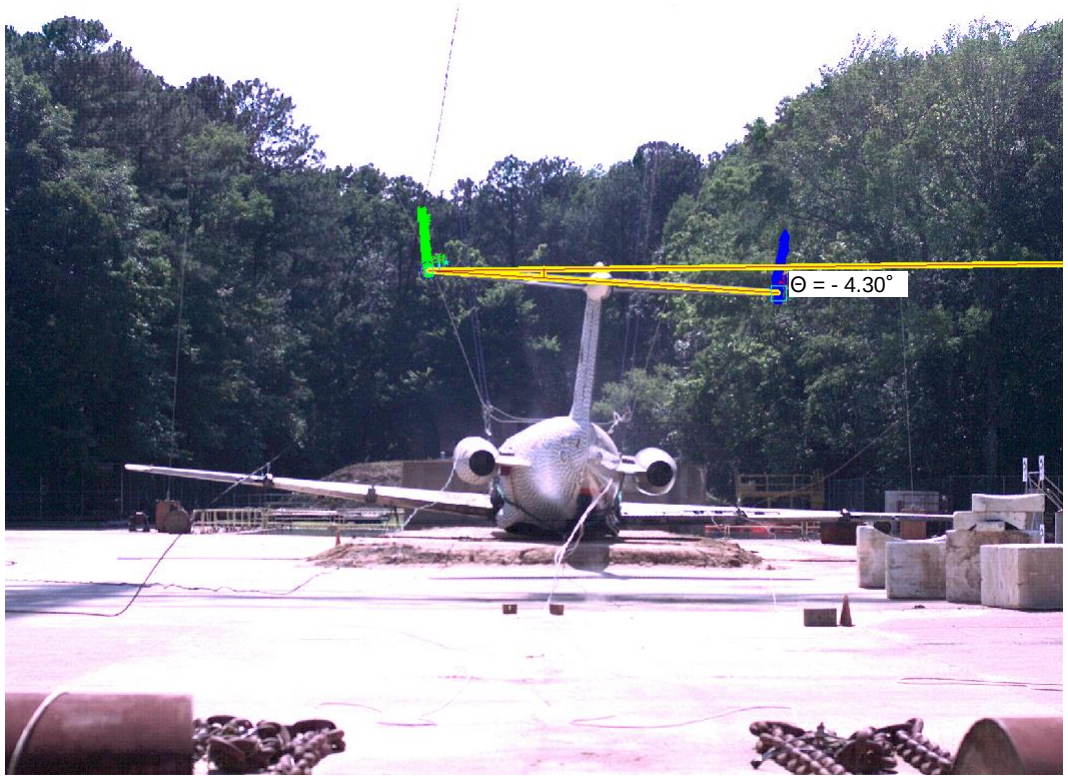
Av. Angle From FWD - AFT = 179.62 degrees
Vertical Velocity = -31.8 ft/sec
Horizontal Velocity = 65.3 ft/sec
Av. Pitch = - 0.38 deg (nose down)

Full-Scale Airframe Displacement Marker Tracking
t=0.5 s post-impact

Marker Tracking – Measured Impact Conditions



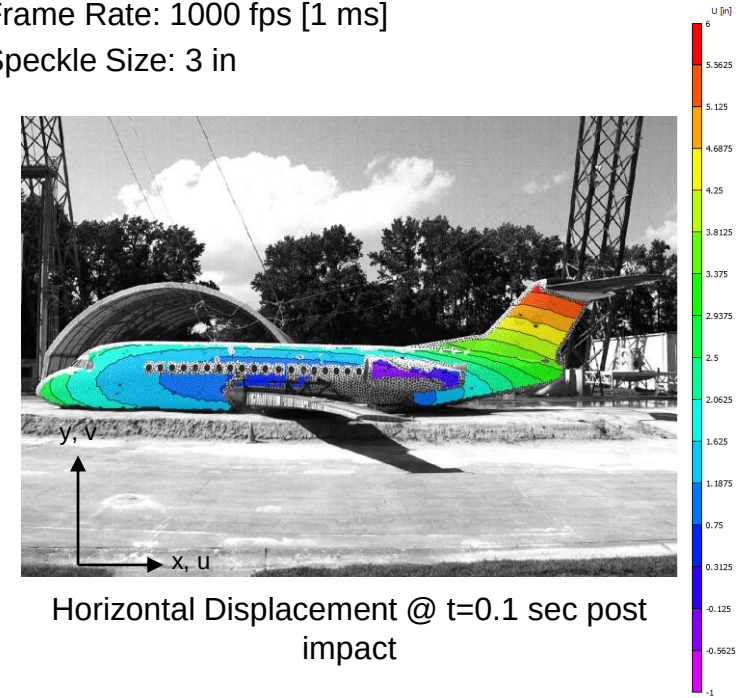
Yaw = 2.53 degrees Nose Left



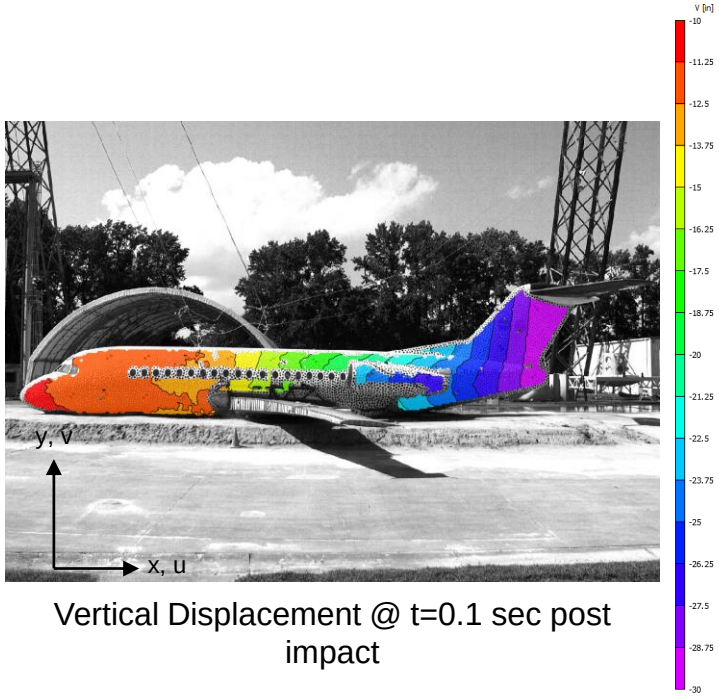
Roll = 4.3 degrees Starboard Side Down

2D Full-field Digital Image Correlation (DIC) - Port

- Photogrammetry Parameters
  - High-Speed Camera: Vision Research Phantom v9.1
  - Resolution: 1632 x 1200 pixels [2 MP]
  - Frame Rate: 1000 fps [1 ms]
  - Speckle Size: 3 in

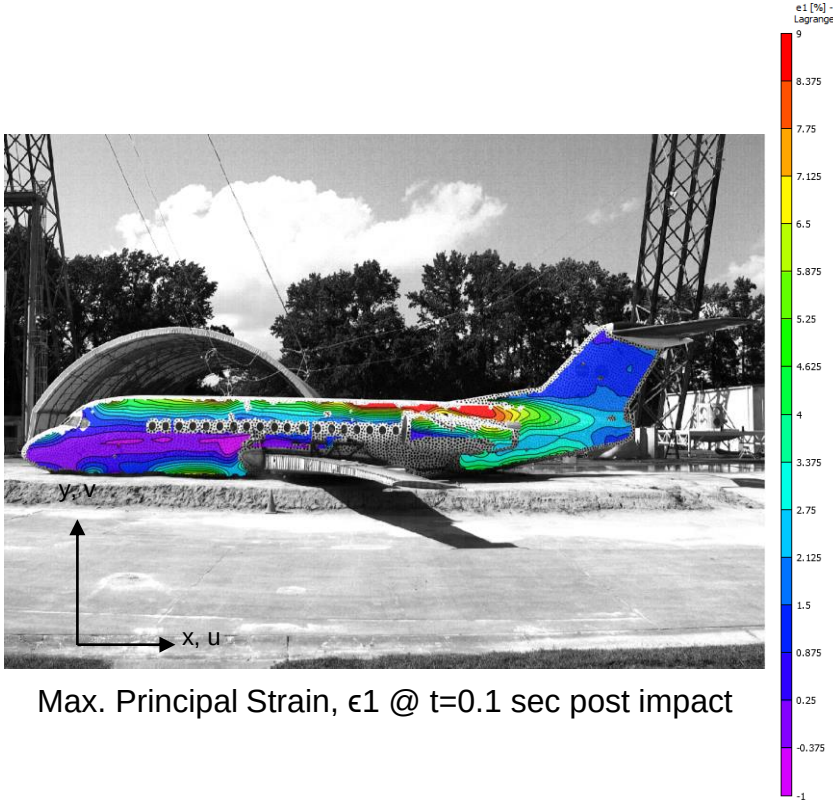


Horizontal Displacement @ t=0.1 sec post impact

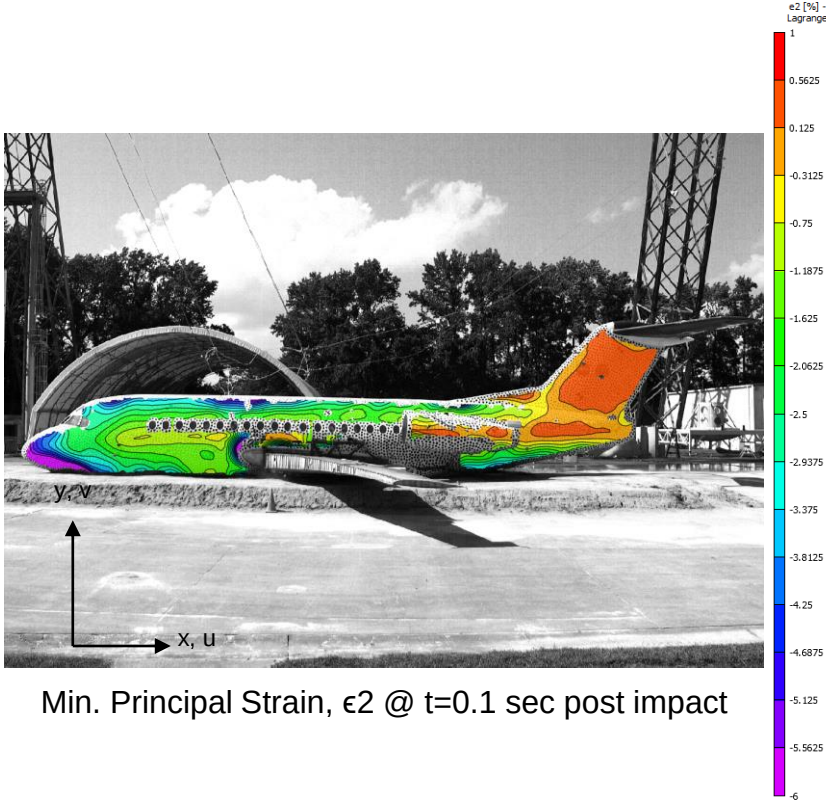


Vertical Displacement @ t=0.1 sec post impact

2D Full-field Digital Image Correlation (DIC) - Port

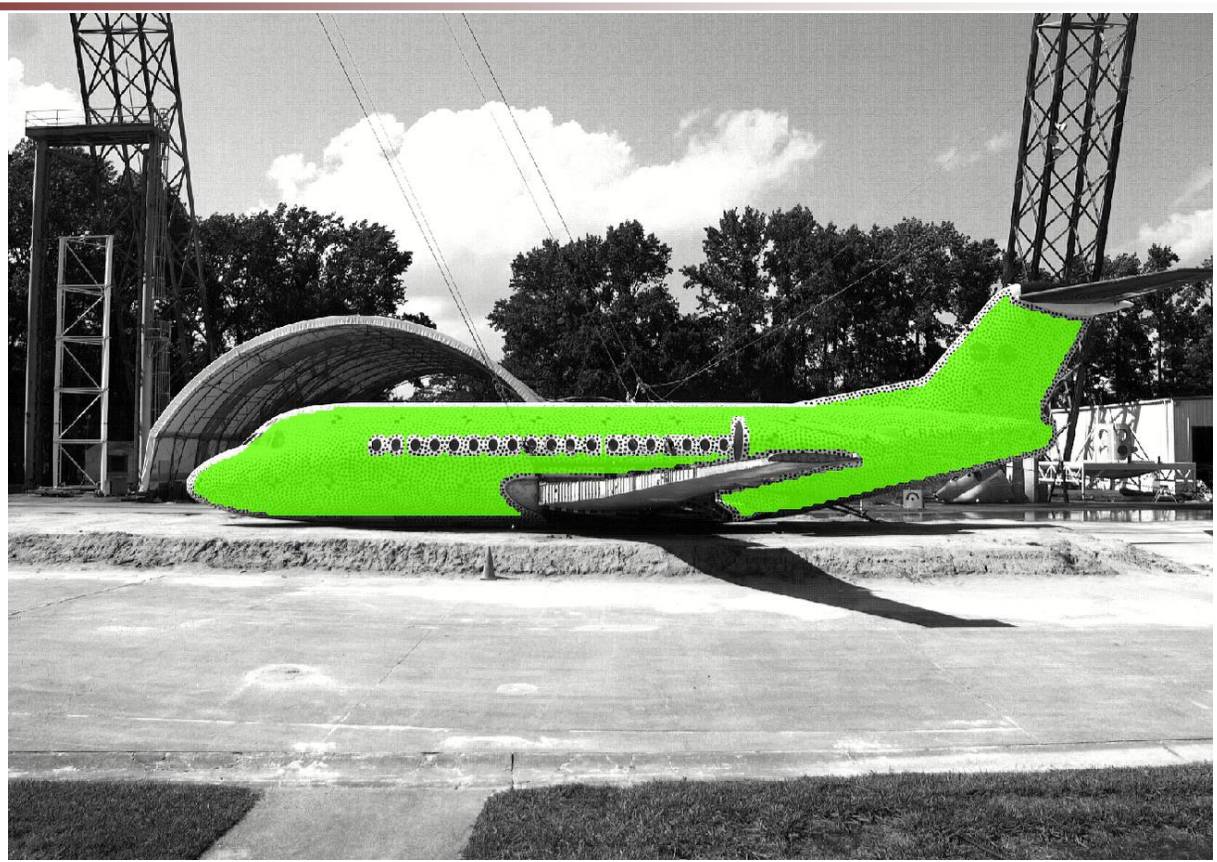


Max. Principal Strain, ϵ1 @ t=0.1 sec post impact

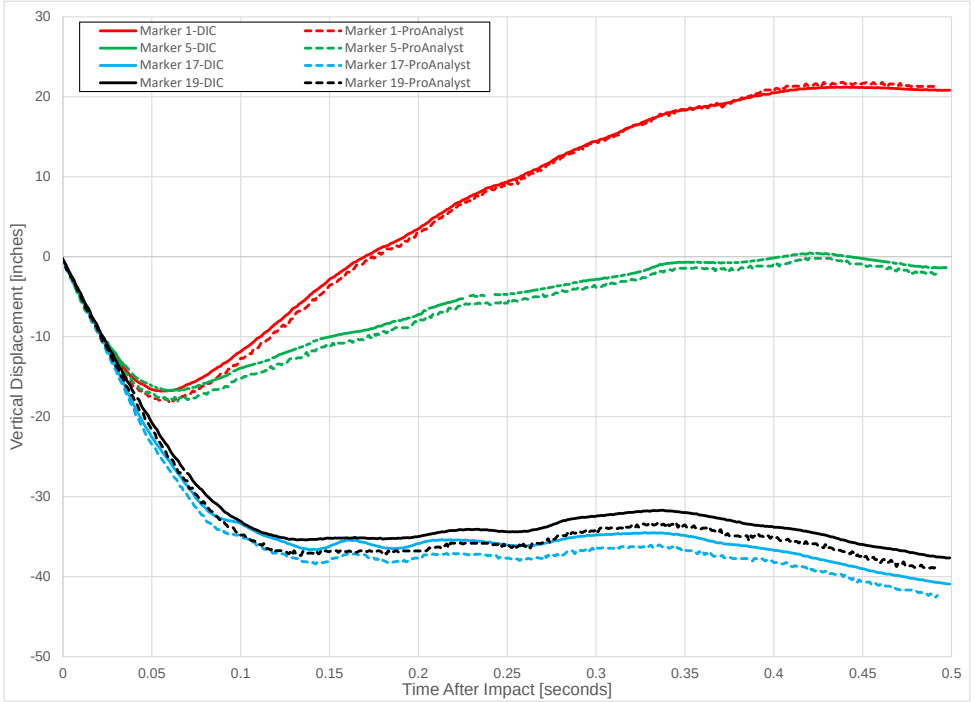


Min. Principal Strain, ϵ2 @ t=0.1 sec post impact

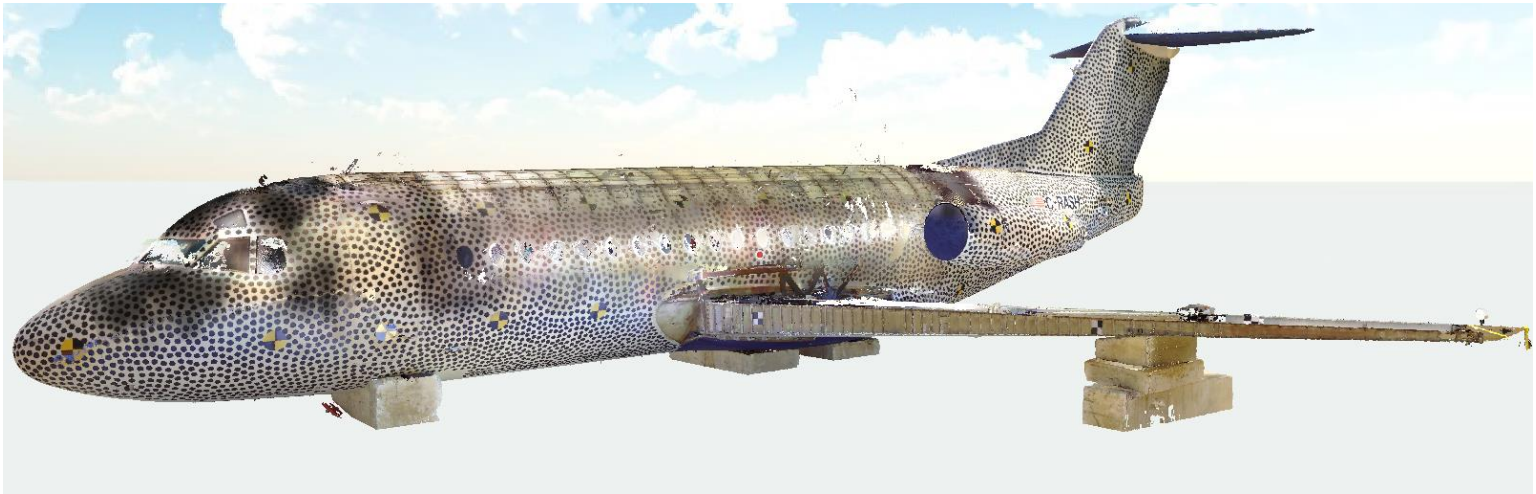
2D Full-field Digital Image Correlation (DIC) - Port



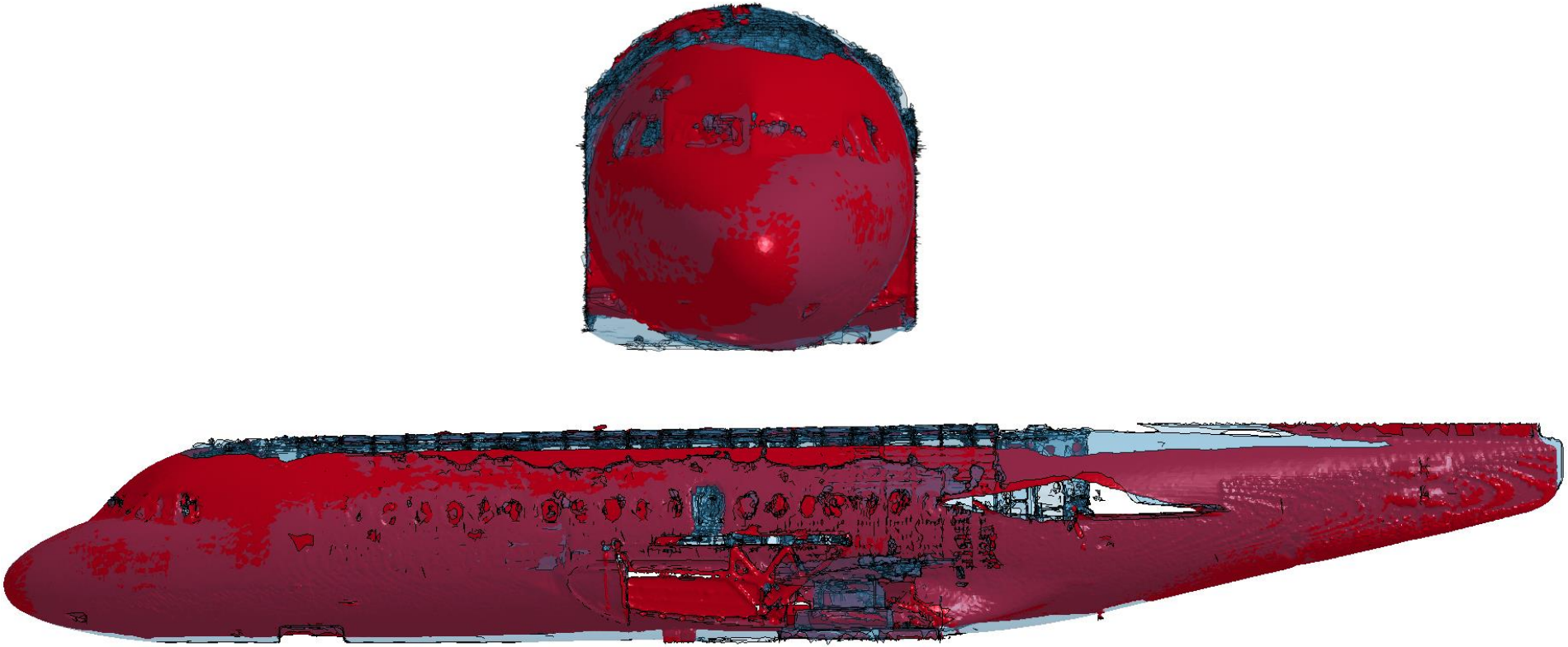
2D Full-field Digital Image Correlation (DIC) - Port



NTSB Pre-Test 3D FARO Scan

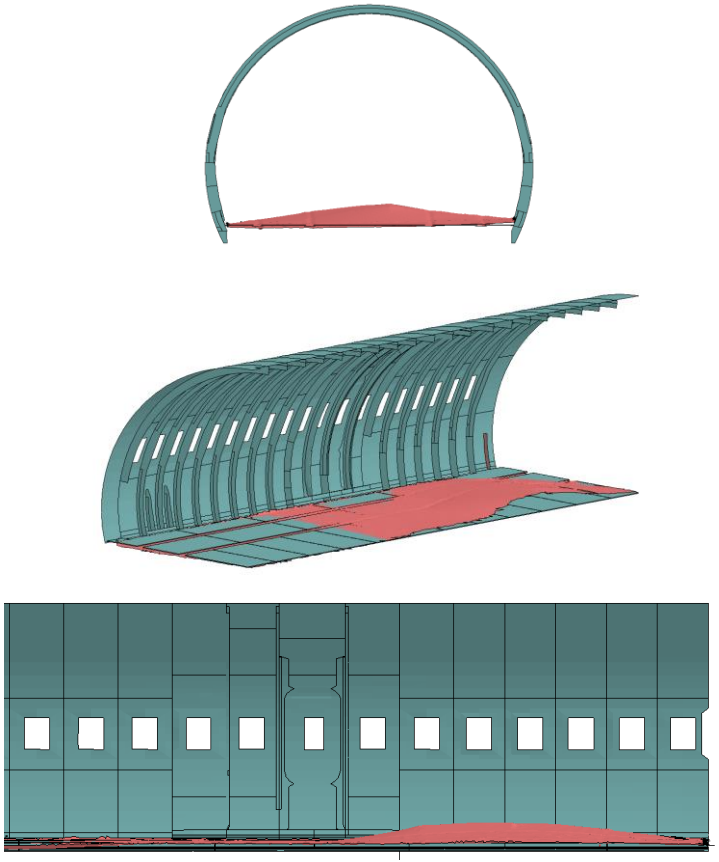


NTSB Pre-Test 3D FARO Scan Overlay with Model



NTSB Post-Test 3D FARO Scan

Post-Test Interior Floor 3D FARO Scan Overlay with Model



Summary and Conclusion

- Photogrammetry was successfully implemented on sub-scale and full-scale drop testing.
- ProAnalyst (Marker Tracking) and full-field 2D-Digital Image Correlation was critical in measuring impact conditions, as well as post-impact deformation and strains.
- FARO Scanning, both pre- and post-impact, is an extremely useful technique for generating a mesh for the model and viewing damage and deformations.
- Photogrammetry combined with traditional instrumentation allows for a more comprehensive understanding of sub-scale and full-scale drop testing and aids in model fidelity.

	Desired	Measured	Desired	Measured	Desired	Measured	Desired	Measured	Desired	Measured
Test Article	Vertical Impact Velocity [ft/sec]	Vertical Impact Velocity [ft/sec]	Horizontal Impact Velocity [ft/sec]	Horizontal Impact Velocity [ft/sec]	Pitch [deg]	Pitch [deg]	Roll [deg]	Roll [deg]	Yaw [deg]	Yaw [deg]
Forward	30	-28.9	N/A	N/A	0	-1.3	0	0.7	0	0
WingBox	30	-29.5	N/A	1.1	4	-2.9	0	0	0	0
Full-scale Airframe	30	-31.8	70	65.3	<2	-0.38	<2	4.3	<2	2.58