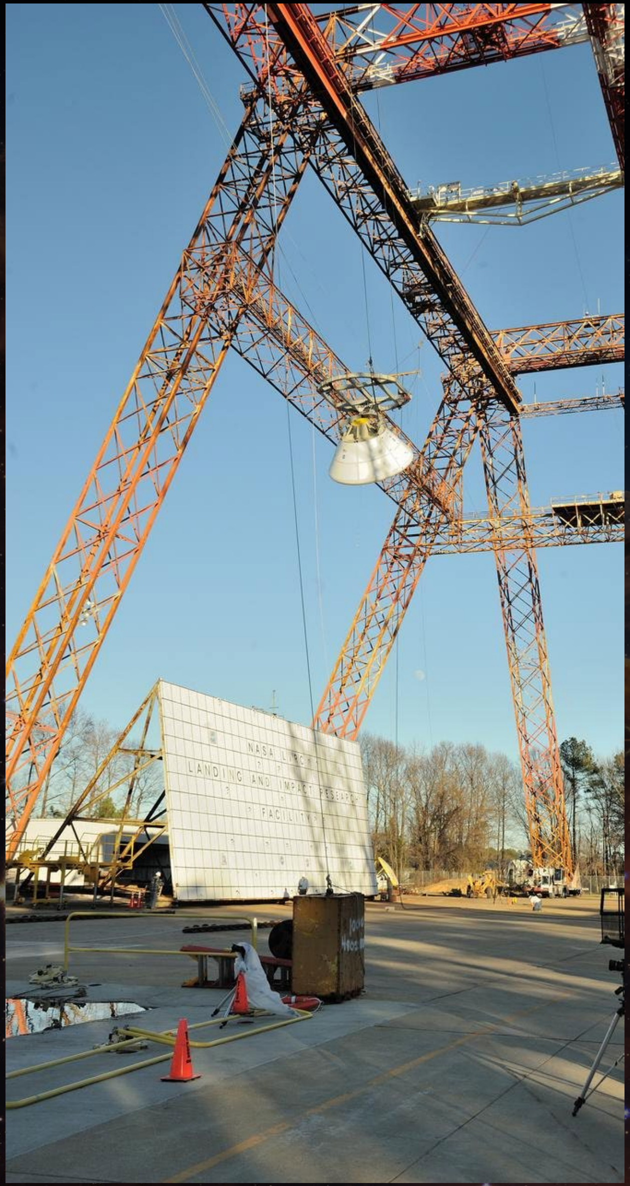
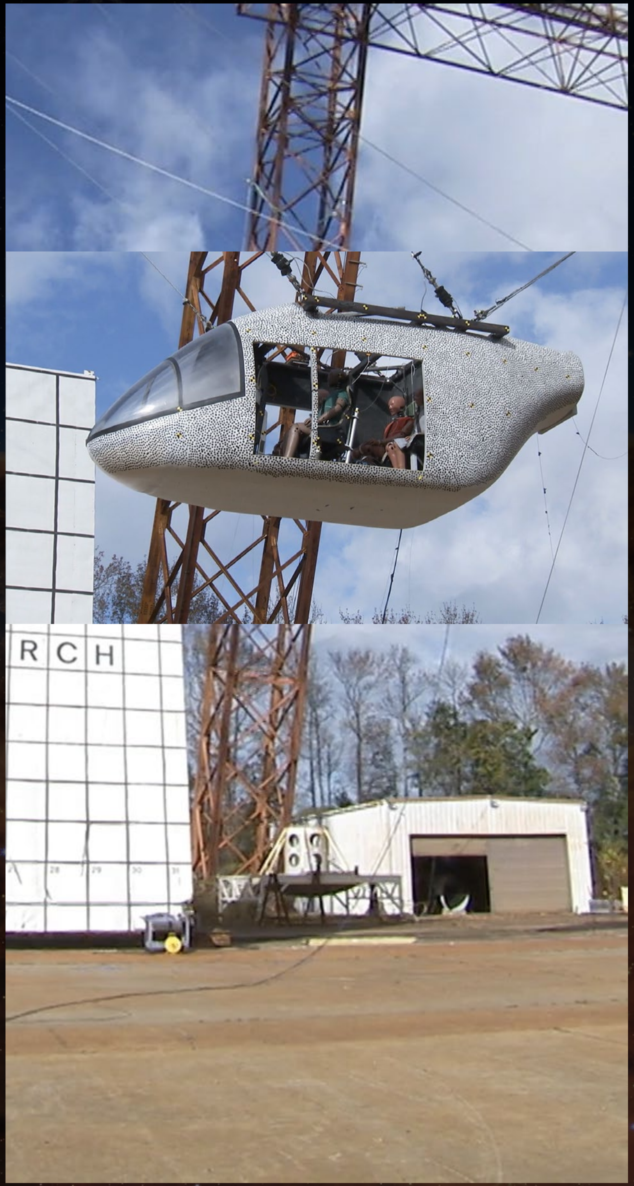
Using DIC for long slender structures

Matlock Mennu

PhotoMechanics-iDICs 2024 Conference

NASA Langley Research Center Structural Dynamics Branch

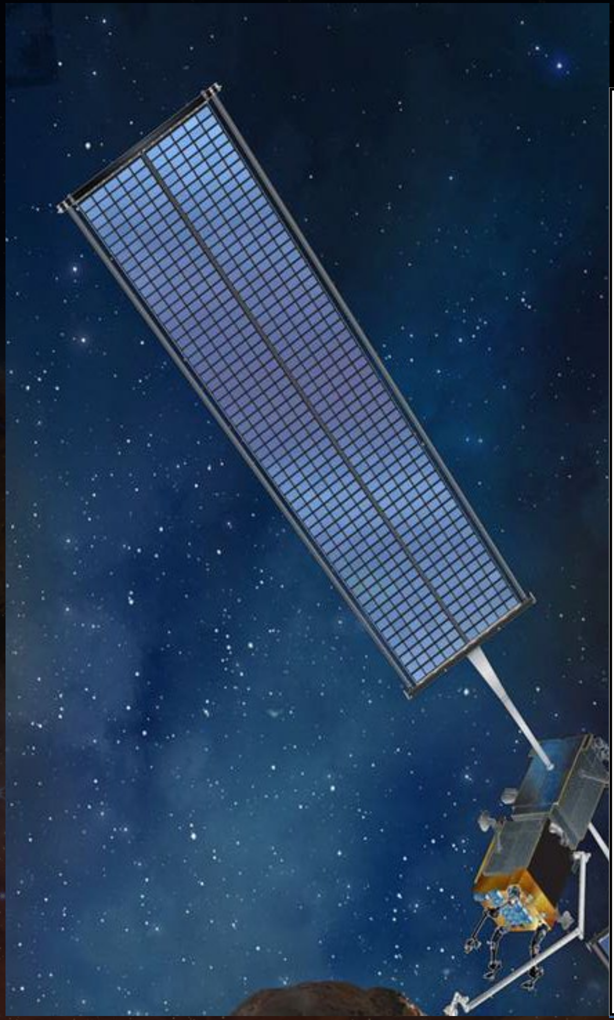




https://images-assets.nasa.gov/image/LRC-2012-00490/LRC-2012-00490~orig.tif
https://www.nasa.gov/centers-and-facilities/langley/nasa-crash-tests-evtol-concept/

NASA Langley Research Center Structural Dynamics Branch

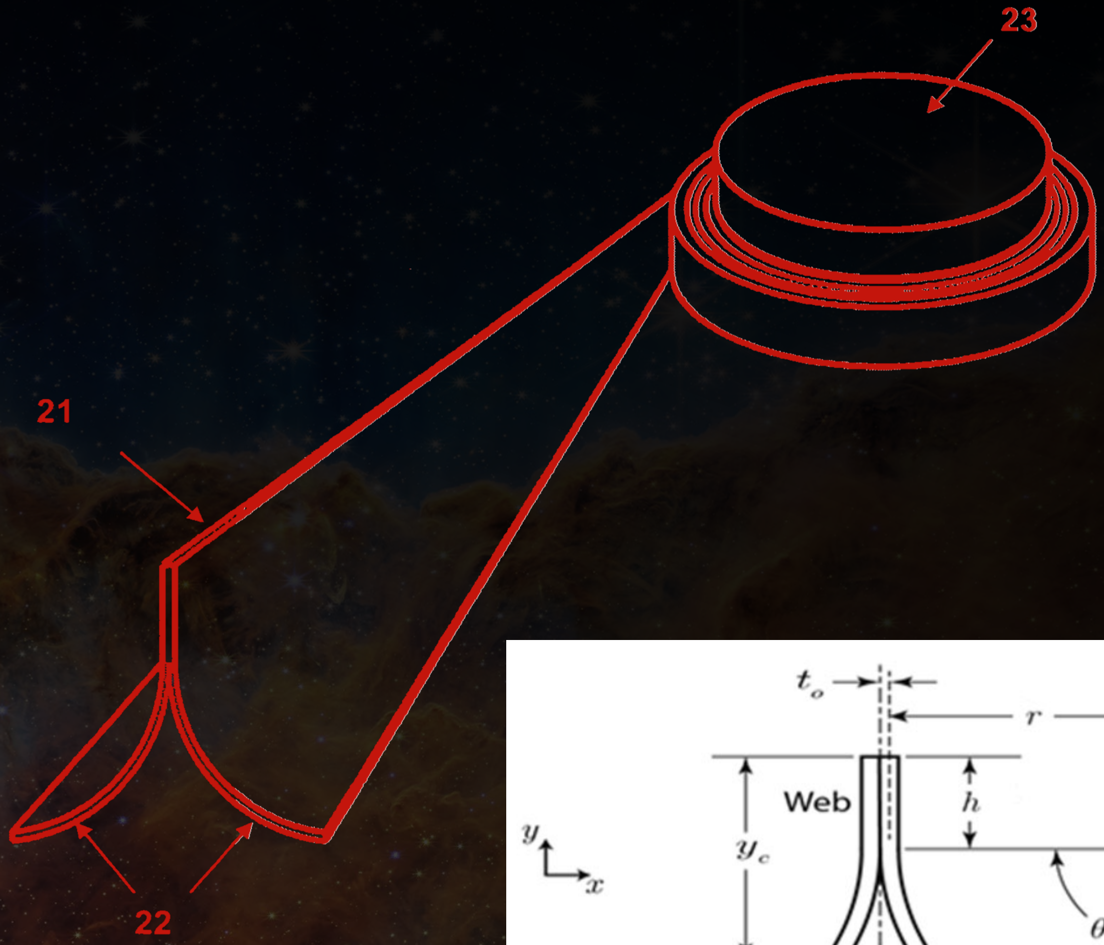
- Additional research on small satellites and deployable structures such as solar arrays, communication antennas and solar sails
- Large deployable booms (5-30 m) are critical for small satellite and must provide stiffness, thermal stability, and reliability after being stowed for many years.
- A project campaign named Gravity Off-loading and Analysis of Long Imperfection-sensitive Elements (**GOALIE**) was initiated to set up capabilities to better understand the mechanical behavior of long slender booms.

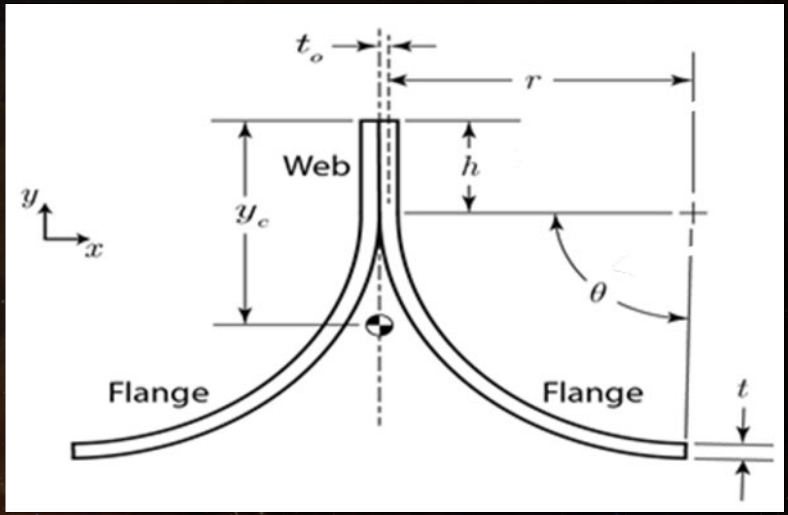


https://www.nasa.gov/directorates/stmd/tech-demo-missions-program/roll-out-solar-array-technology-benefits-for-nasa-commercial-sector/
https://youtu.be/OTdDDbRvHv8

Triangular Rollable and Collapsible (TRAC) boom

- Triangular rollable and collapsible (TRAC) booms use a geometry where two curved flanges are connected at their upper portion.
- The flanges flatten out in the stowed configuration for efficient packing and open when deployed.
- TRAC booms are made with carbon composite materials due to the high stiffness to weight ratio for small satellite applications.



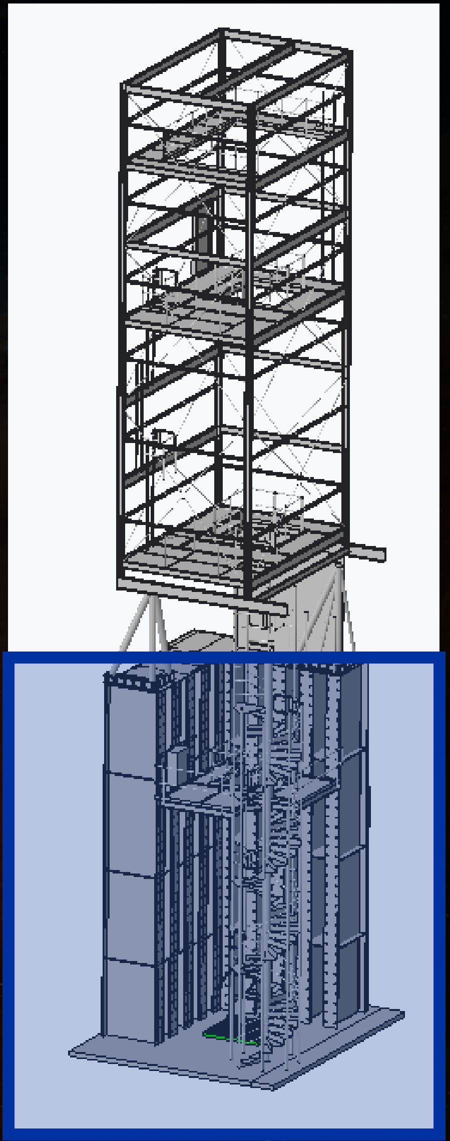


https://patents.google.com/patent/US7895795B1/en

Objective

- Establish capability for testing a 30 m tall composite boom in a vertical configuration.
- Only one building on site large enough to complete full scale test.
- Test a 7 m subscale article to identify test methods and instrumentation to apply to a full-scale article (30 m).
- Use digital image correlation (DIC) to obtain shape, displacement and strain data along the length of the boom.
- Other techniques such as fiber optic strain sensing (FOSS) and laser scanners were used to capture localized strain and shape respectively of the entire boom during loading.

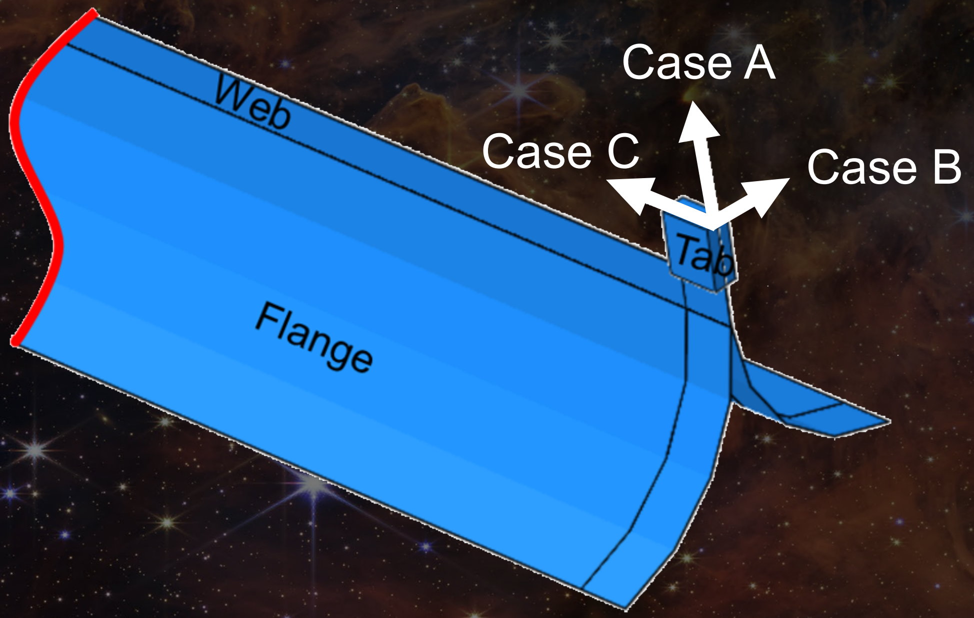
Research facility

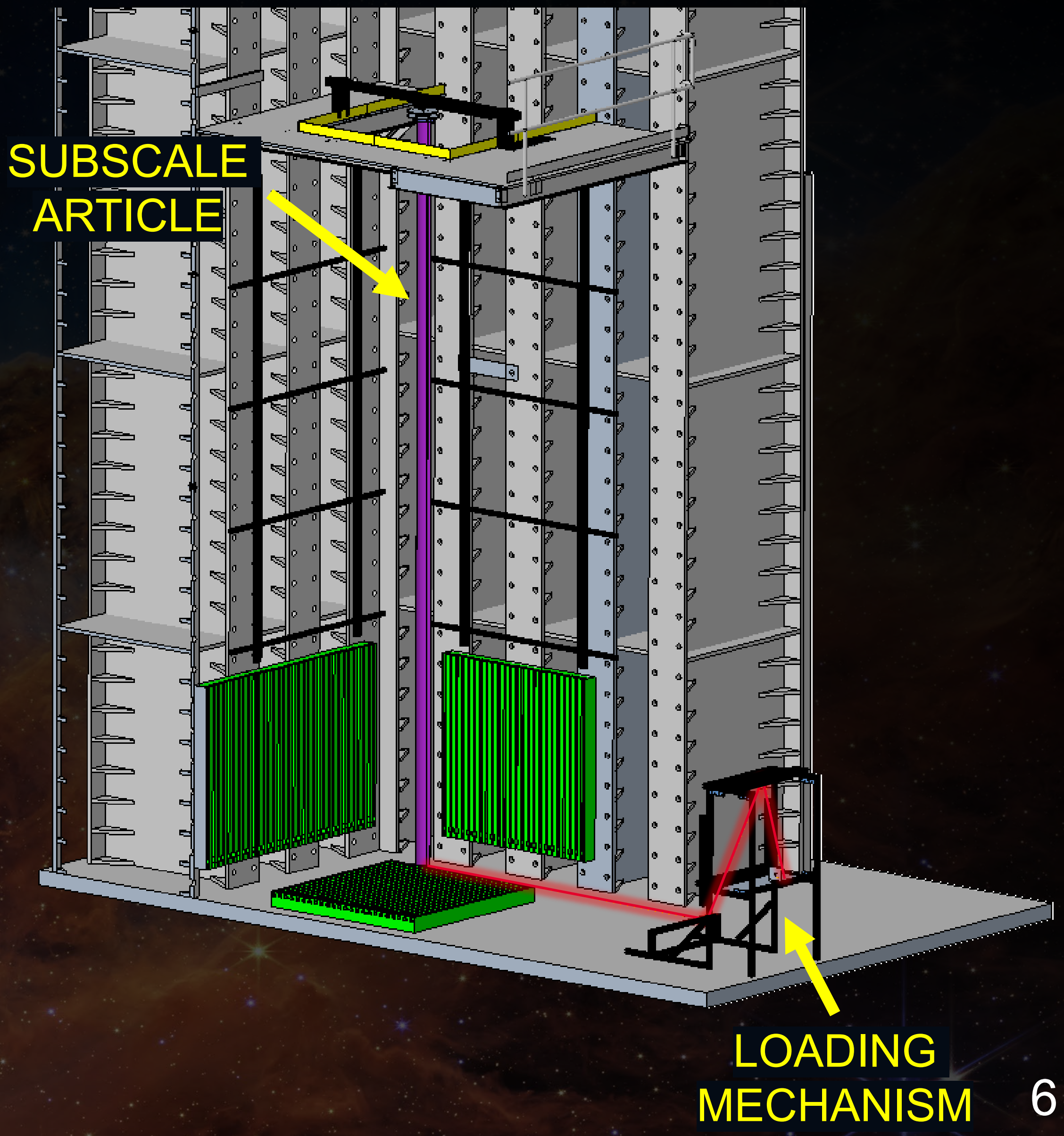


Subscale Test

GOALIE Subscale Test

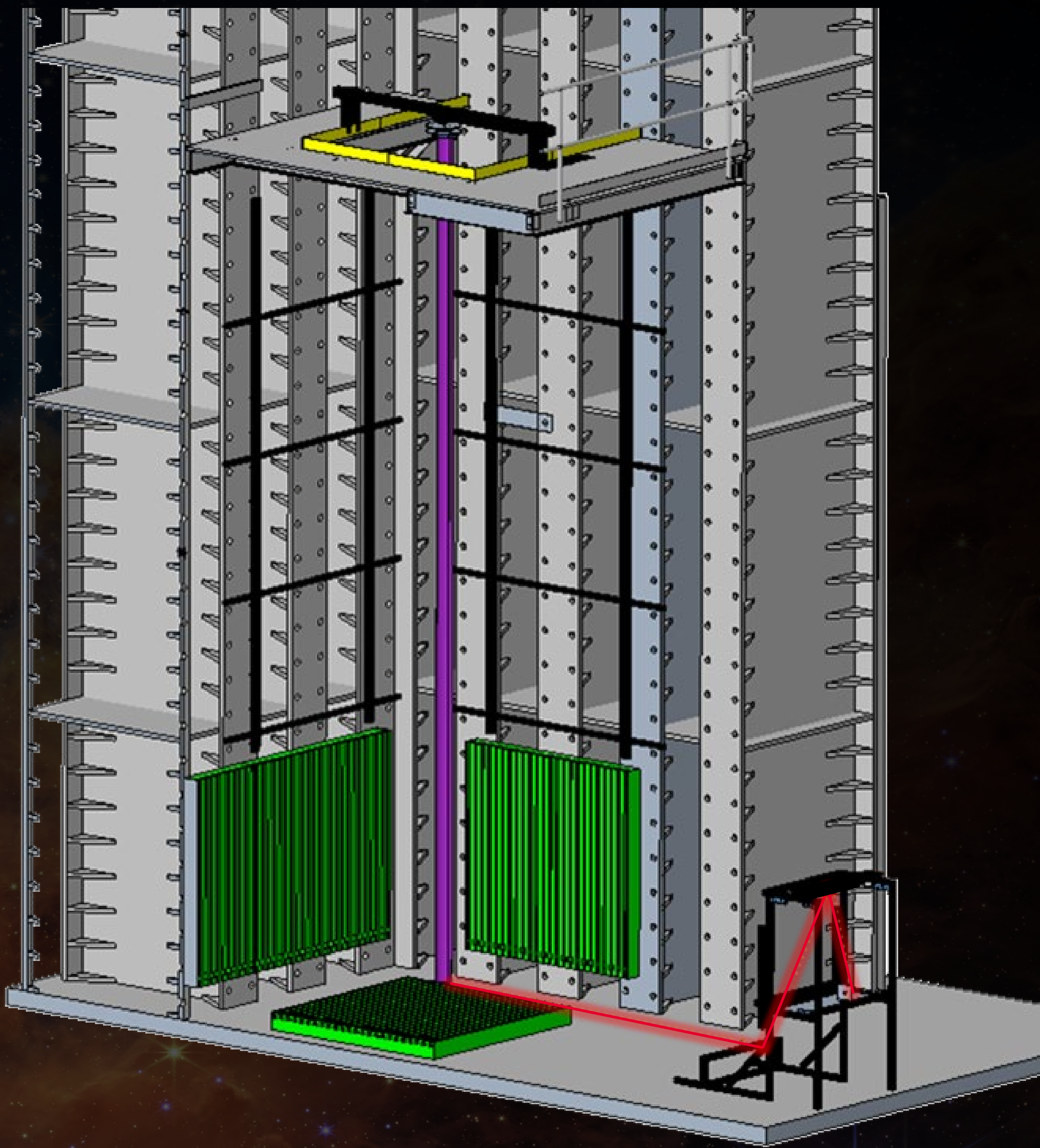
- Three load cases of interest
  - Load case A: Bending out of plane
  - Load case B: Bending in plane
  - Load case C: Axial Compression
- Locations of measurement tools were driven by pre-test analysis predictions.





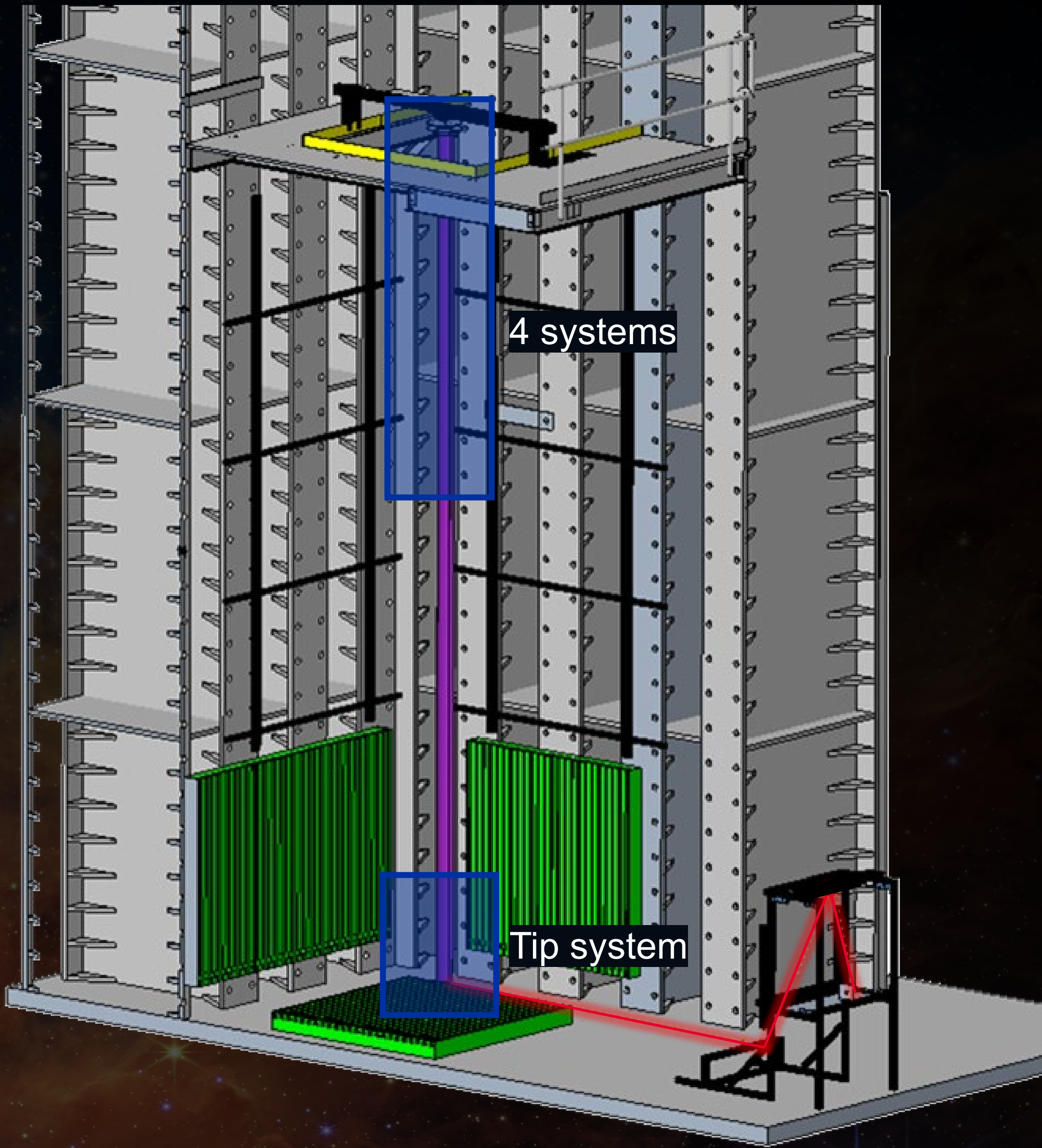
DIC Initial Setup Considerations

- **Camera and Lens Selection**
  - Limited stand-off distance
  - High aspect ratio of test article
  - Number of cameras and locations
  - Speckle pattern
  - Lighting
  - Inherent twist in the test article (Initial shape)
  - Predicted large displacement at the tip
- **Calibration and Synchronization**
  - Calibration of cameras on ground and as installed.
  - Triggering/Sync multiple camera systems and other instrumentations
  - Merging data systems into one coordinate system
  - High-speed cameras at anticipated buckle location



DIC Layout

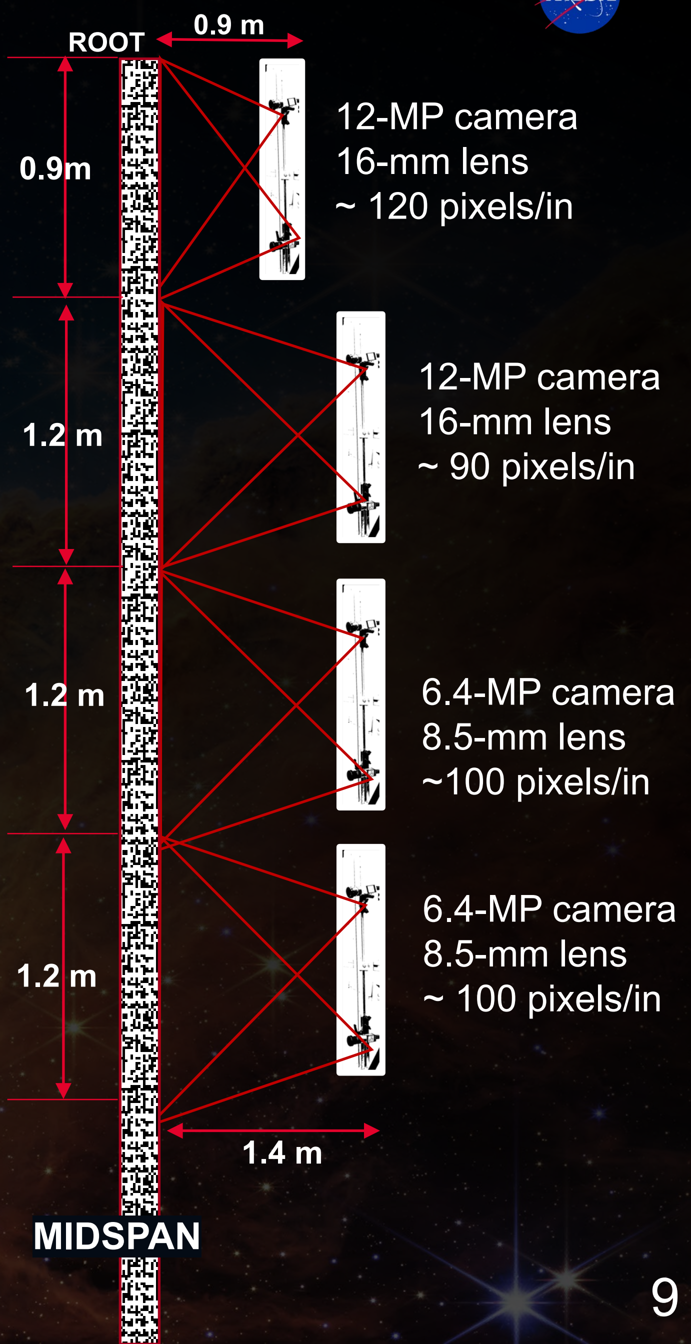
- Pre-test analysis showed regions of interest at the root and tip of the boom.
- Four overlapping stereo camera pair for DIC from the root of the boom up to 4m.
- Additional DIC system looking at the tip of the boom.
- High speed DIC system positioned at the tip and anticipated buckle location.
- T-slot aluminum grid system assembled on two sides of the tower for mounting cameras and lighting.



DIC Configuration

- High resolution cameras (12 MP, 0.5 Hz) were used for the first two systems.
- Low resolution cameras (6.4 MP, 0.5 Hz) were used for the rest of the low-speed systems.
- High speed cameras at (1 MP, 1 kHz) were used to monitor buckle events.

Camera	Lens	Standoff	Field of View	Spatial Resolution (pixels/mm)	Optimal Speckle Size
12 MP	16 mm	0.9 m	0.6 x 0.92 m	4.65	1 mm
12 MP	16 mm	1.4 m	0.81 x 1.22 m	3.46	1.5 mm
6.4 MP	8.5 mm	1.4 m	0.81 x 1.22 m	2.52	2.25 mm

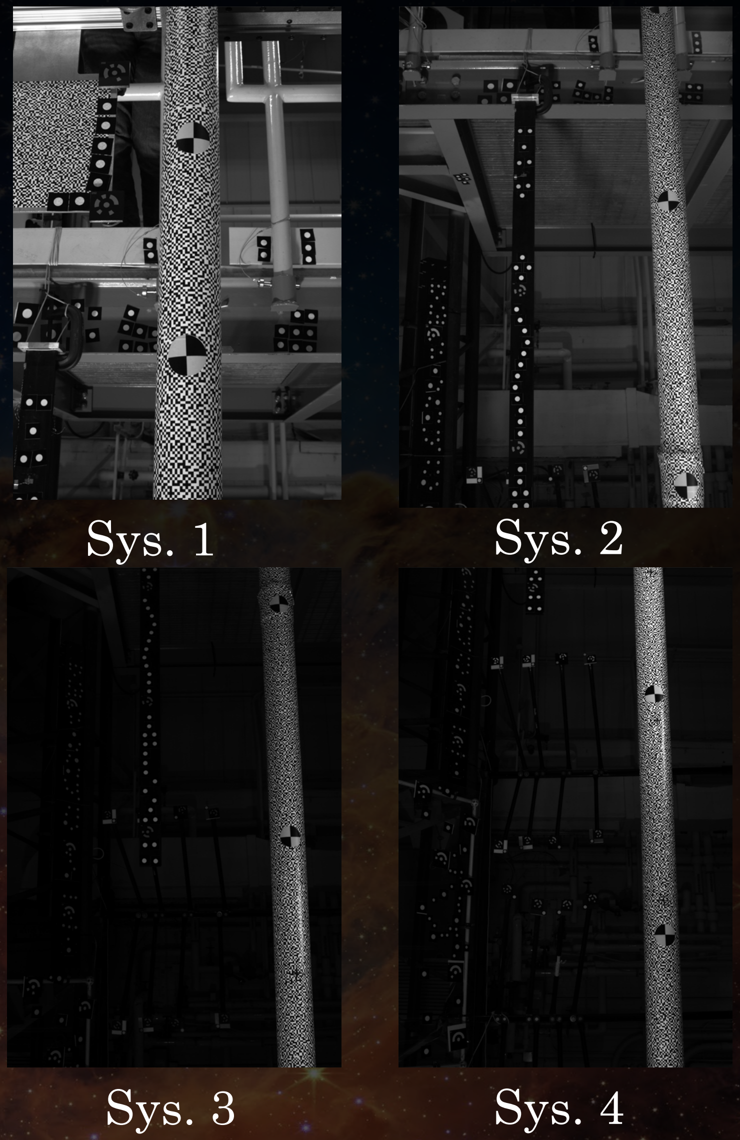


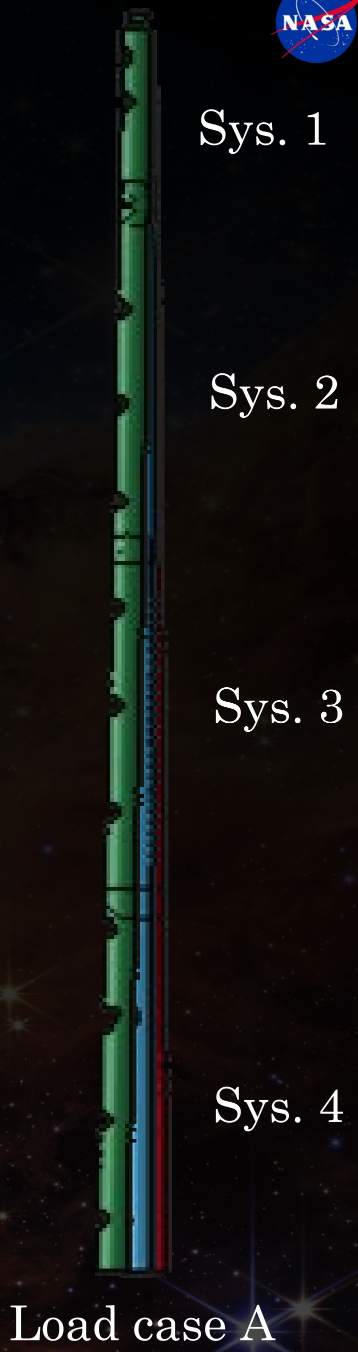
Calibration

- As installed, camera calibration with grid could not be performed due to location and test article installation.
- Grid calibration was performed at ground level of the tower.
- After calibration, stereo camera pairs were remounted in their final test location.
- Bow-tie markers on speckled PVC pipe were used for pole correction.
- Pole correction images were obtained prior to the start of each test.

Coordinate System Alignment

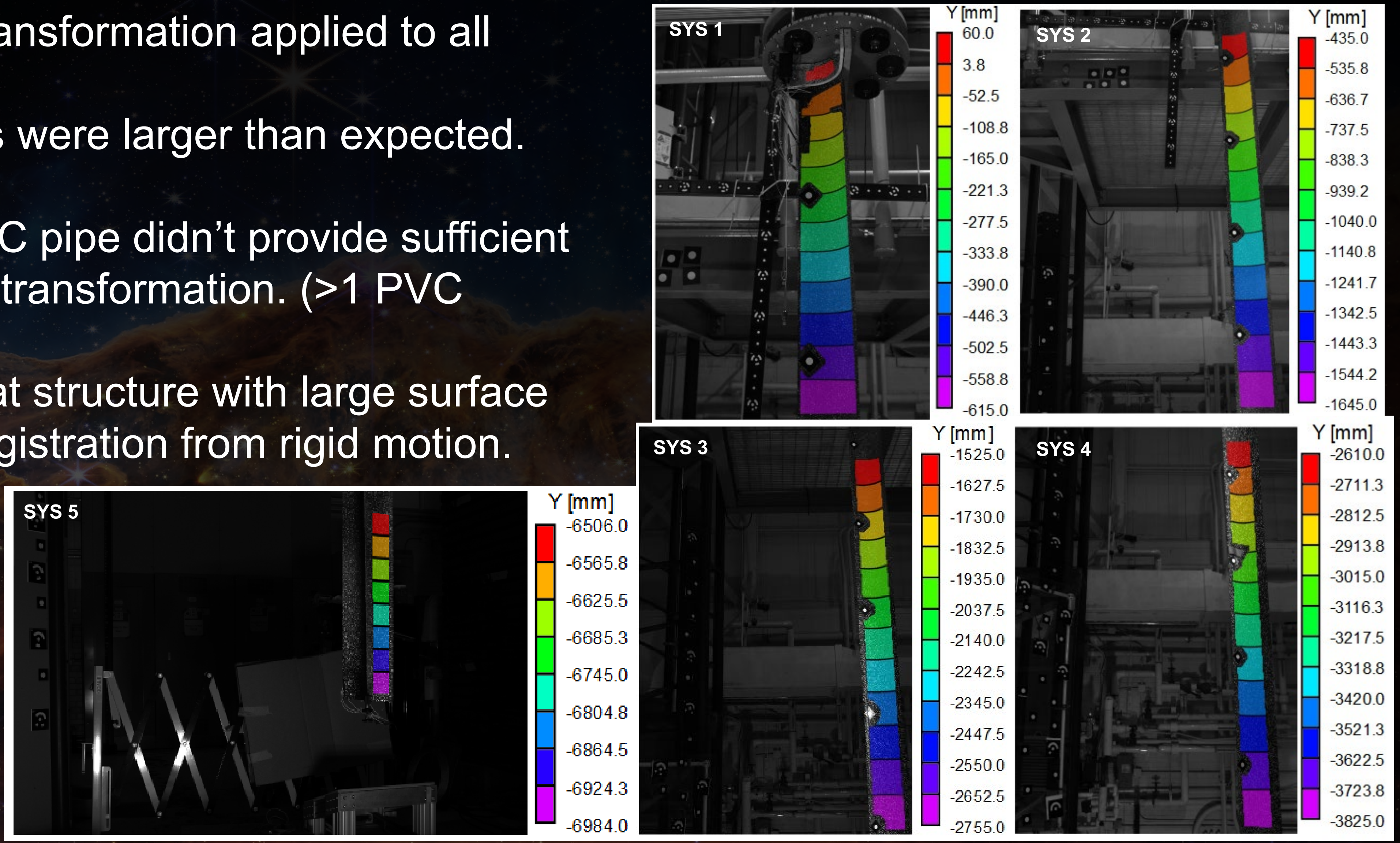
- A method known as multi-view registration from rigid body motion was used for aligning the coordinate system of five low speed systems.
- 3 PVC pipes, 3 m each, were connected to span the total field of view of the five camera systems.
- Speckle pattern printed on vinyl was adhered to PVC for the multi-view correlation and computing coordinate transformation.





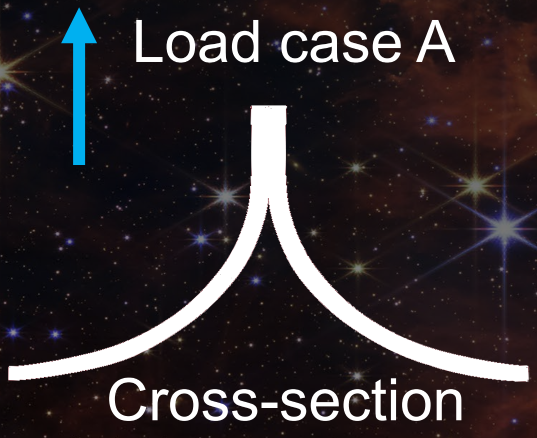
Coordinate System Result

- Coordinate system transformation applied to all systems.
- Transformation errors were larger than expected. (>200 μm)
- 0.075 m diameter PVC pipe didn't provide sufficient stiffness for accurate transformation. (>1 PVC adapter)
- Recommend using flat structure with large surface area for multi-view registration from rigid motion.



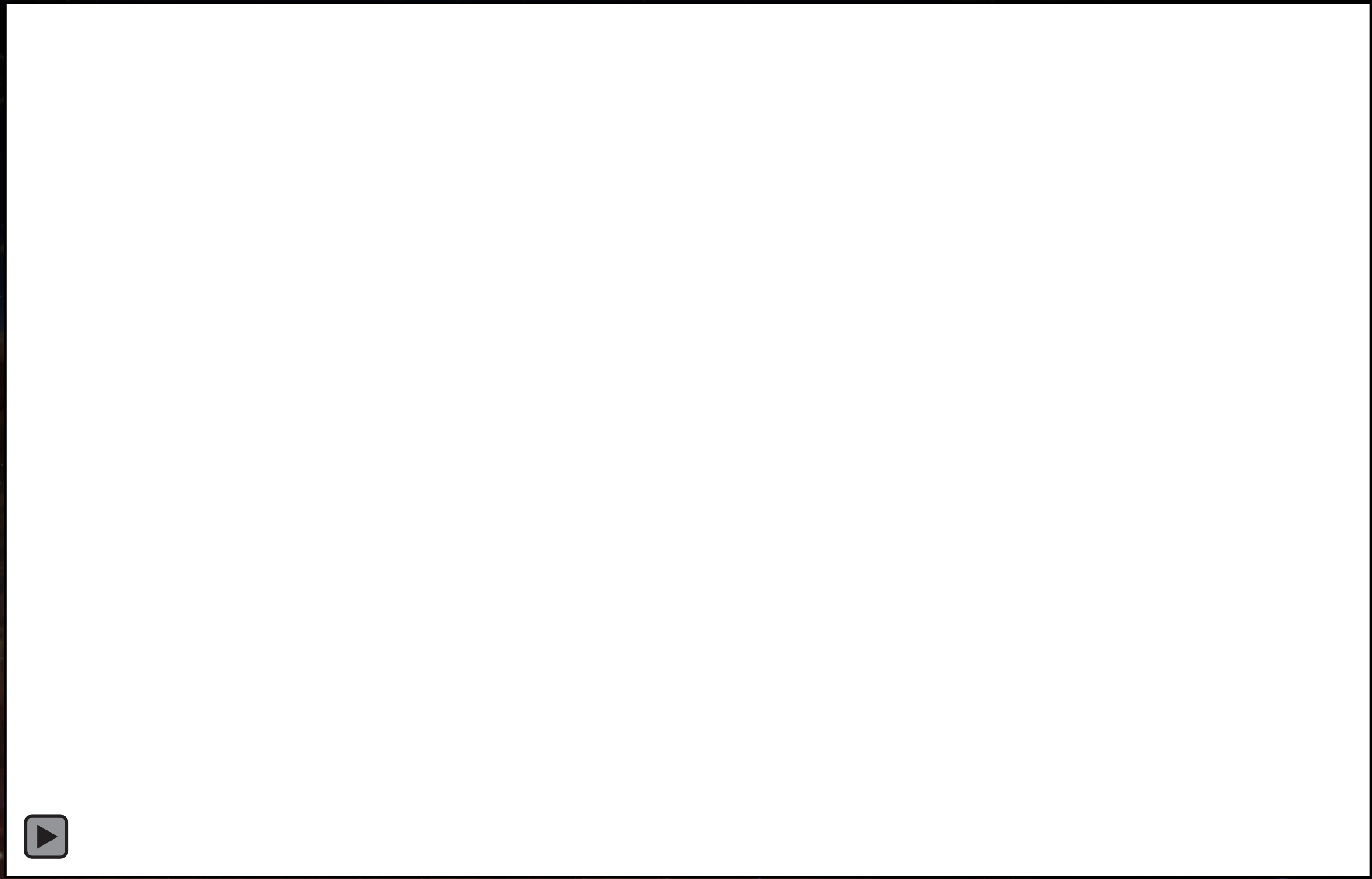
Results

- Load case A, bending out-of-plane.
- Test article loaded to 50% of predicted tip displacement (185 mm) before buckle.
- Data obtained from speckled mounting bracket to monitor boundary condition.
- Maximum deflection of 18.7 mm in the X direction observed in root system.



Results

- Load case B, bending in-plane
- Test article loaded to 50% of predicted tip displacement (124 mm) before buckle.
- Maximum deflection of 5.6 mm in the Z direction observed in root system.



Load case B

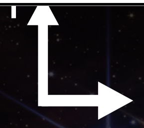
Cross-section

Results

- Load case C, compression
- Test article loaded until buckling.
- Displacement data captured in the root DIC system during buckle event.

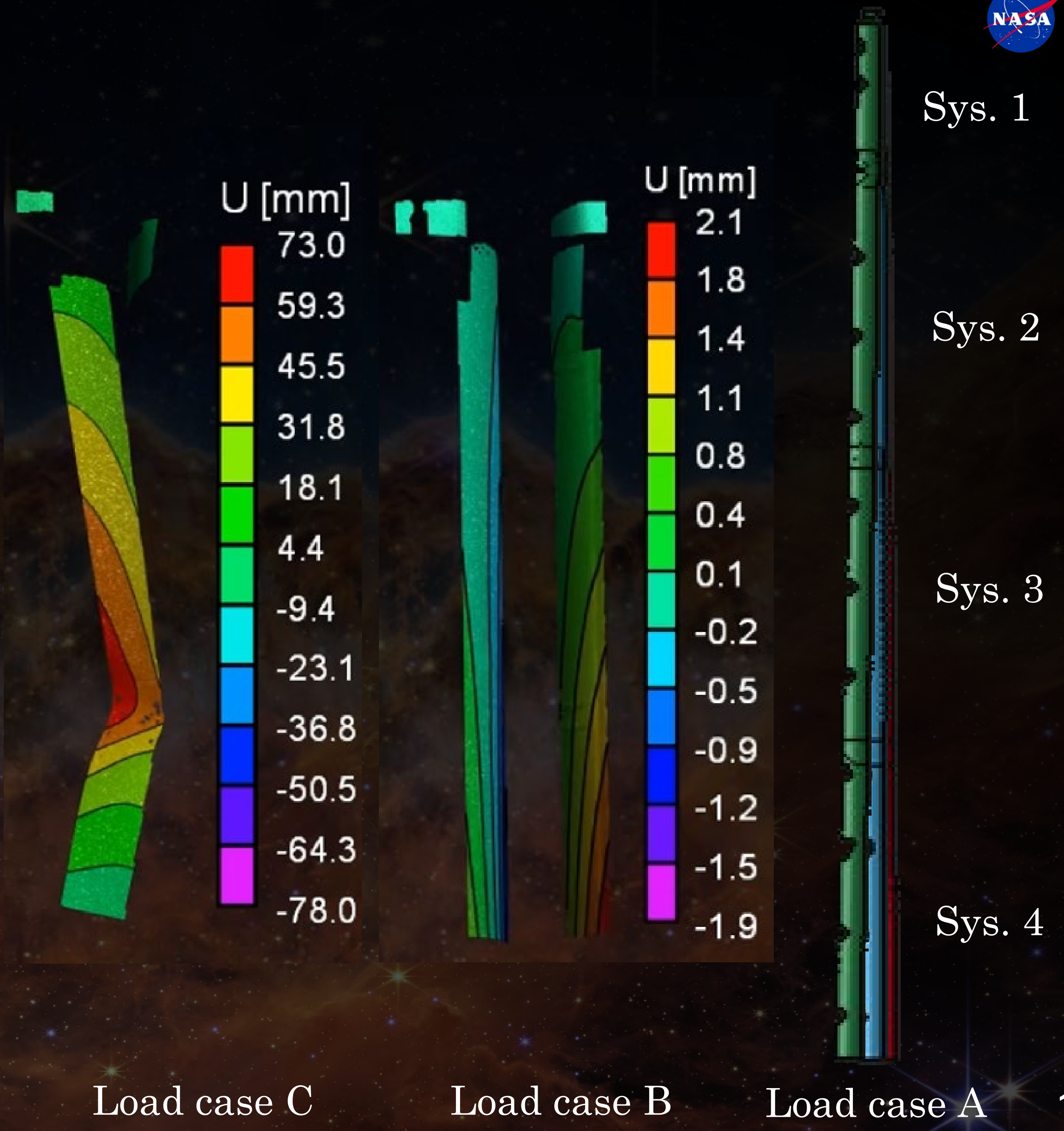
Load case C

Cross-section



Conclusion

- Multiple DIC systems were successfully implemented on long slender 7 m subscale article.
- DIC systems were merged into one coordinated system using muti-view registration of rigid motion with lessons learned for future application.
- DIC system captured the buckle event of the test article.
- Future work includes comparing DIC data with other techniques such as FOSS to guide test-analysis correlation effort.



Acknowledgement

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