Ares I-X Launch Vehicle Modal Test Overview

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Modal Test Team

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- **MSFC Test: Rusty Parks, Dan Lazor**
- **KSC Integration Leads: Trip Healey, Russ Brucker, Kara Schmitt, Stephanie Heffernan, Todd Reeves**
- **KSC Shaker/Platform Integration: Mark Tillet, Jim Wiltse**
- **KSC Instrumentation Lead: Frank Walker**
- **Aerospace Corp. IV&V : Jeff Lollock, Ryan Tuttle, Joshua Hwung**
- **NASA Consultants: Teresa Kinney (KSC), Kenny Elliott (LaRC)**

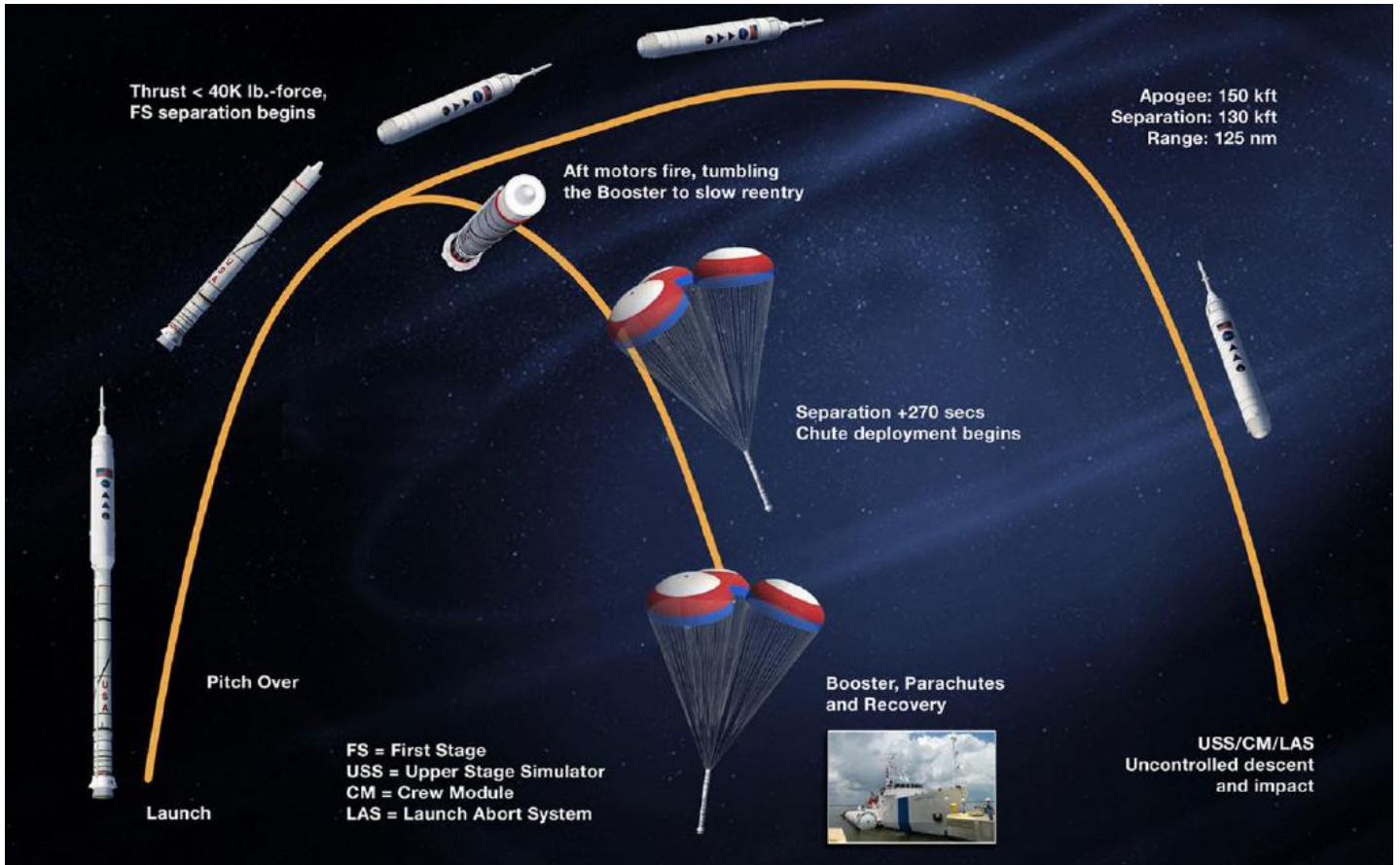
Acronyms: GRC - Glenn Research Center; LaRC - Langley Research Center; MSFC - Marshall Space Flight Center; KSC - Kennedy Space Center

Outline

- Background
- Modal Test Objectives and Requirements
- Challenges for Ares I-X Modal Test
- General Test Approach
- Test Configurations
- Pre-Test Analysis
- Summary

Background: Ares I-X Mission

- 1st flight test for NASA's Ares I crew launch vehicle—October 28, 2009
- *4-segment SRB with mass simulators for 5th segment, USS, CM, LAS*
- Simulated first two minutes of Ares I flight
- Gathered data on: performance, control, loads, staging/separation, 1st stage reentry dynamics and recovery



Background: Model Integration and Modal Verification

- **Subsystem FEMs provided by Independent Product Teams**
- **FEMs combined into Integrated Vehicle Model (IVM)**
- **IVM used for:**
  - Development of flight control parameters
  - Coupled loads analysis
    - Lift-off and ascent
    - Rollout, winds and pad stay
- **Modal test required for IVM verification**

Finite Element Model Integration and Checkout (LaRC) → **Modal Test Verification**

Modal Test Rationale:

- **Poorly understood modes can cause vehicle instability**
- **High uncertainty factors required for loads model without calibration**

Ares I-X Modal Test Objectives/Requirements

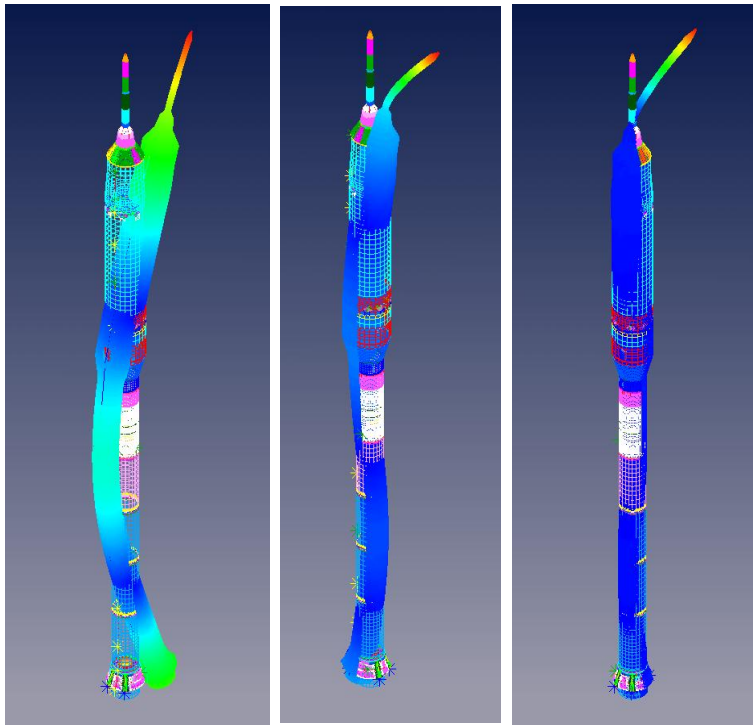
Objectives:

- Verification of robustness of controls algorithm
  - Ensure key mode predictions are within assumed Monte Carlo input variances
    - Frequency: 10%-20% of nominal
    - Node location: +/- 100 inches
    - Deflection: 20%-50% of nominal
- Provide updated model for post flight analysis and data reduction

Requirements:

- **Primary**: Calibrate FEM for prediction of 1st three free-free bending mode pairs
- **Secondary**: Examine influence of local modes on flight control sensors

Key Modes for Controls

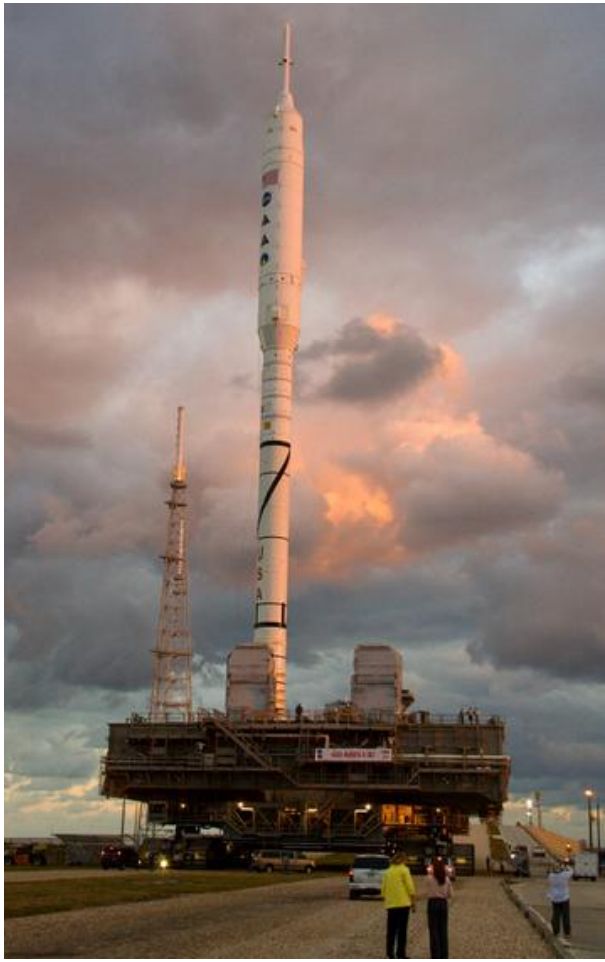


1.31 Hz	3.66 Hz	4.92 Hz
1st Bending	2nd Bending	3rd Bending

Y-Axis Bending Modes, orthogonal set in Z-Axis

Challenges for Ares I-X Modal Test

- **Not able to test in free-free configuration**
- **Modal test not in original project plans**
  - Short test planning period
  - Test configurations in nominal integration flow
  - No resources for modal test specific boundary conditions
  - Minimize instrumentation: target 20-30 locations
  - Test times ≤ 4 days/configuration
- **Flight Test Vehicle (FTV) size: 327 feet, 1.8 Million lbs.**
  - Excitation, instrumentation mounting and cable routing
  - Low frequencies=long data acquisition periods
- **Software tools for pre-test and "near real-time" (on-site) model assessment**



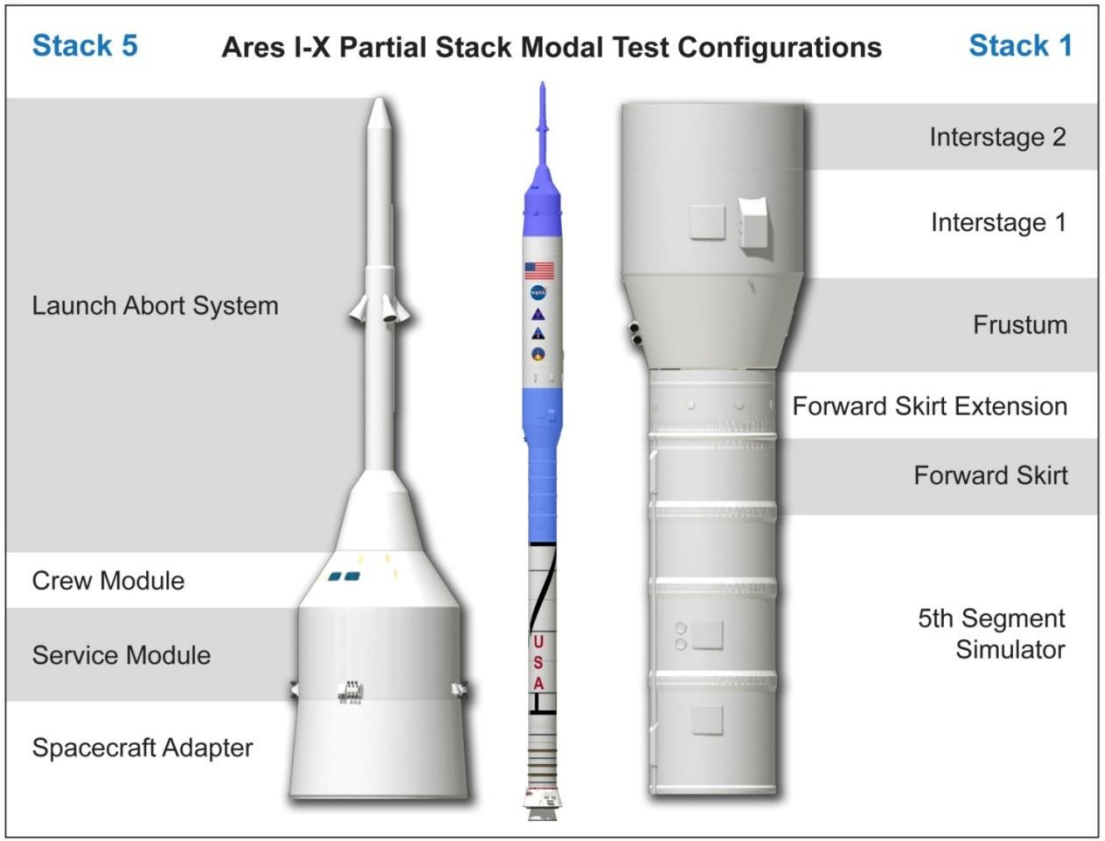
Rollout Configuration: FTV on Mobile Launcher Platform (MLP) and Crawler Transporter(CT)

General Test Approach

- **Calibrate model using modal test data from two partial stacks and the full FTV on MLP**
  - All testing in KSC Vehicle Assembly Building (VAB)
  - Tests integrated into nominal integration flow ~ 6 weeks apart
  - Final test 6-8 weeks before rollout
- **Primary modal data from shaker excitation**
  - FRFs for random or burst-random used for mode estimation
  - Sine sweeps on selected modes to check linearity
- **Impact tests**
  - Identify local mode response
  - Check for global modes
- **Calibrate\update model for tested configurations**
- **Calibrated model available to ensure key free-free mode predictions are within assumed variances for control system**

Selection of Test Configurations

- **Configurations in nominal integration flow**
- **4-segment SRB and MLP FEMs verified from Shuttle heritage**
- **Partial stacks selected based on new hardware and mode participation**
  - Stack 1 flexibility important for first two bending mode pairs
  - Stack 5 dominates 3rd bending mode pair
- **Final step in calibration: test full stack on MLP**



FTV on MLP Test Configuration

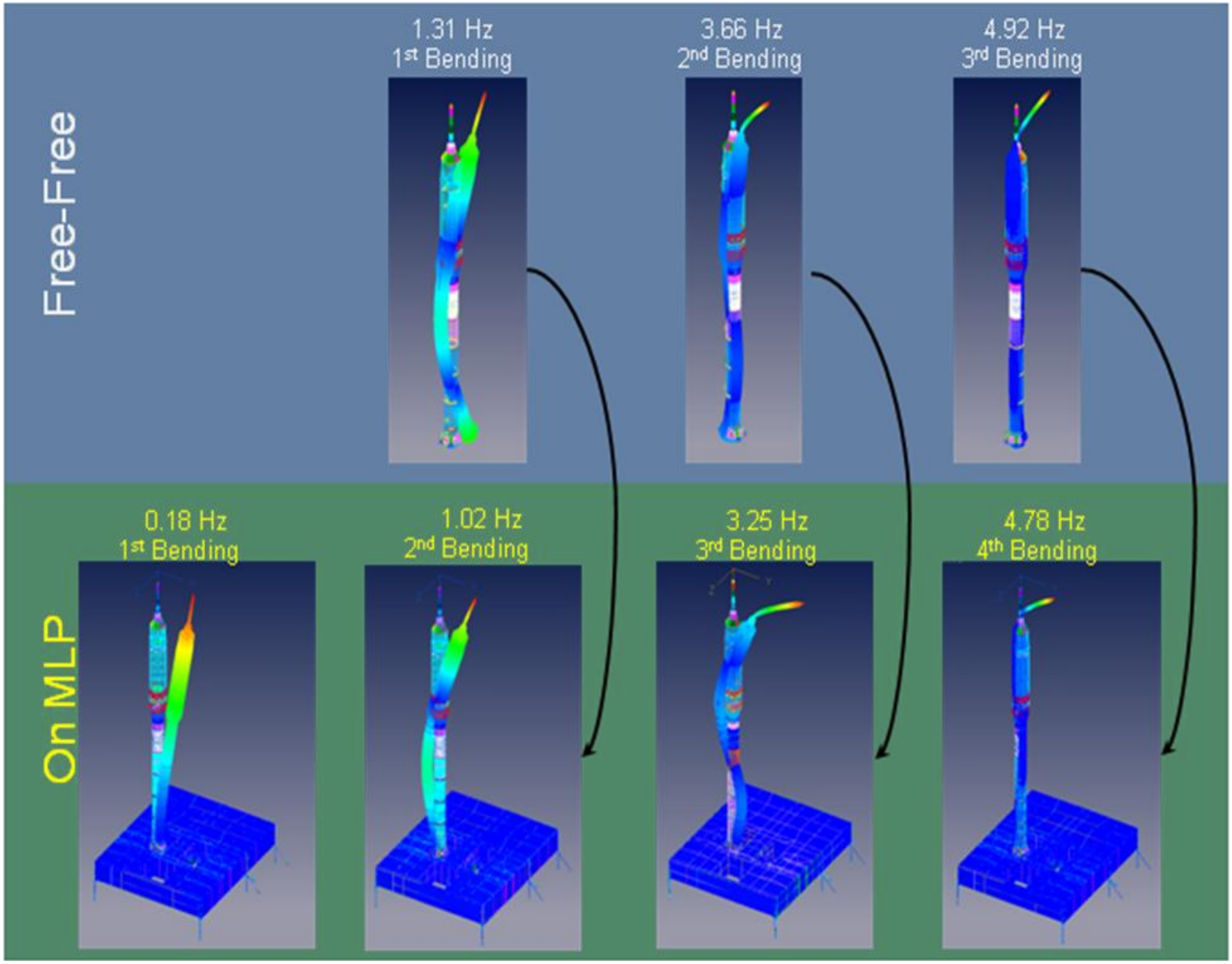
- KSC VAB High-Bay 3
- Launch configuration—simulates fully fueled vehicle
- FTV mounted to MLP at 4 hold-down posts
- Accelerometer/shaker mounting from facility platforms on first stage
- USS/CM/LAS accelerometers mounting from internal access ladders/platforms

Hold-down post

FTV on MLP

USS extends above facility platforms

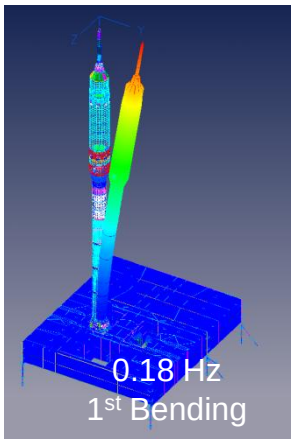
Traceability of Free-Free Modes of Interest to Test Configuration on MLP

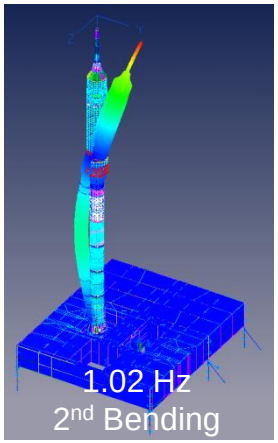


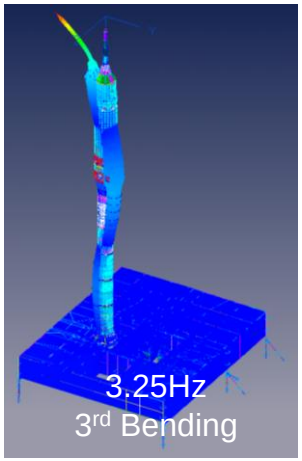
FEM Prediction of Y-Axis Bending Modes

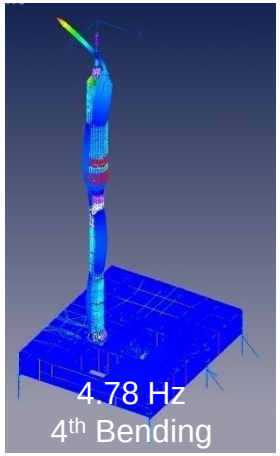
ARES I-X FTV Pre-Test Analysis

Requirements:
Finite Element Model (FEM) Target Modes





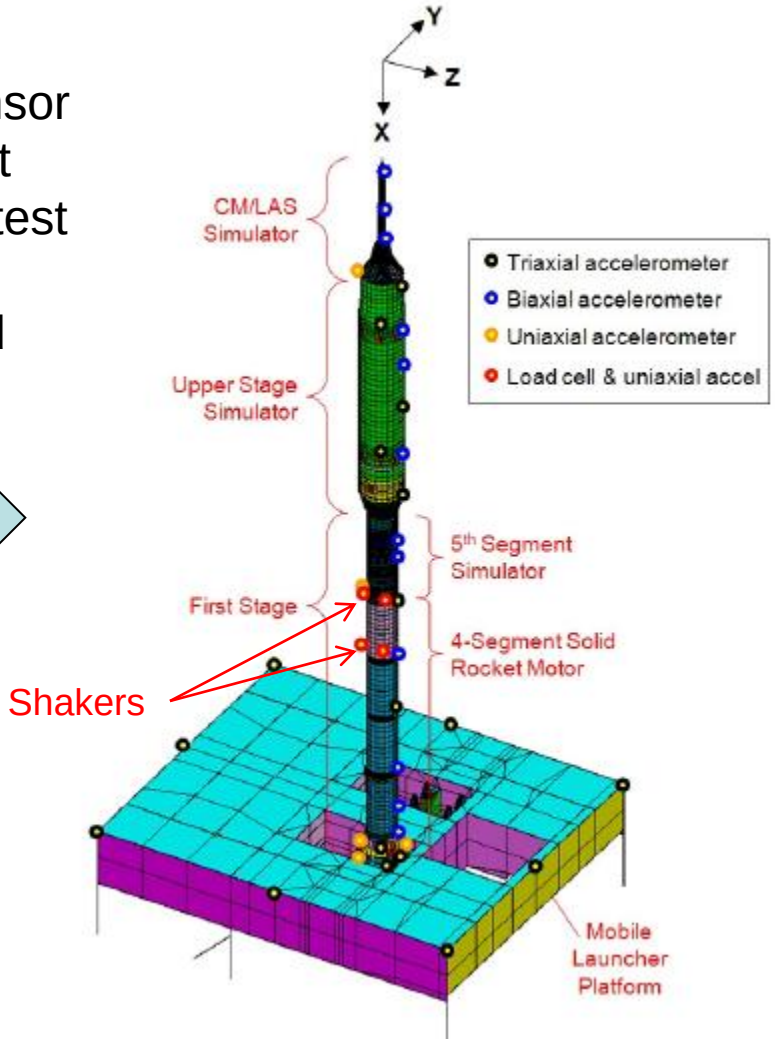




FEM Pre-Test

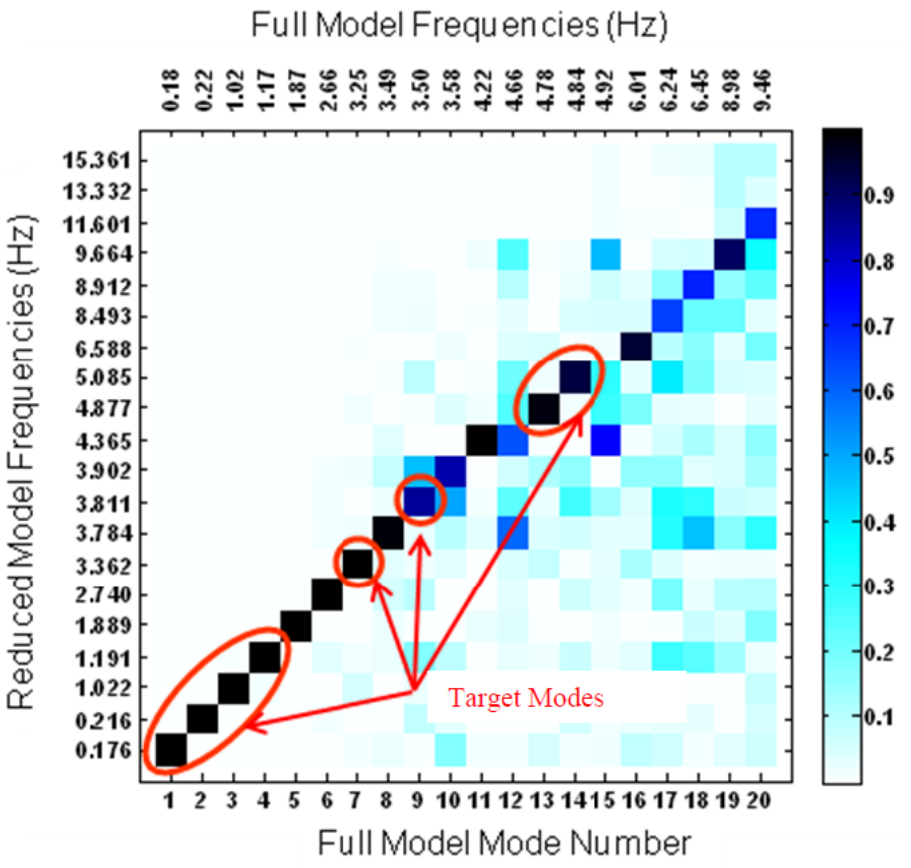
- Identify optimal sensor & exciter placement
- Generate reduced test model
- Perform end-to-end test simulation

Reduced Test Model



ARES I-X FTV Pre-Test Analysis

Cross-Orthogonality



FTV on MLP Predicted Modes

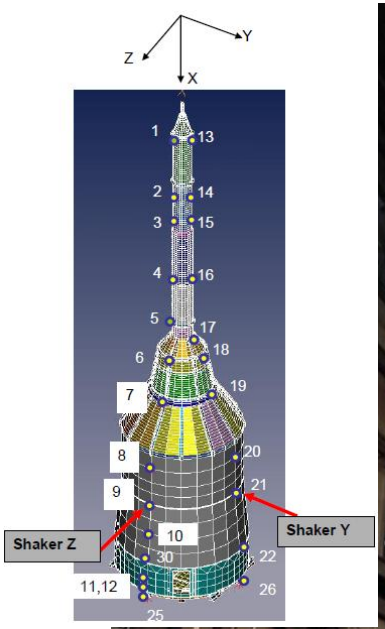
Mode No.	Frequency (Hz)	Mode Description
1	0.176	1st Bending Mode of Ares I-X (X-Y Plane)
2	0.216	1st Bending Mode of Ares I-X (X-Z Plane)
3	1.02	2nd Bending Mode of Ares I-X (X-Y Plane)
4	1.17	2nd Bending Mode of Ares I-X (X-Z Plane)
5	1.87	Ares I-X / MLP System lateral mode
6	2.66	Ares1-X / MLP System lateral mode
7	3.25	3rd Bending Mode of Ares1-X (X-Y Plane)
8	3.49	Ares1-X / MLP System mode
9	3.50	3rd Bending Mode of Ares1-X (X-Z Plane)
10	3.58	Ares1-X Torsion
11	4.22	Ares1-X / MLP System mode
12	4.66	Ares1-X / MLP System mode
13	4.78	4th Bending Mode of Ares1-X (X-Y Plane)
14	4.84	4th Bending Mode of Ares1-X (X-Z Plane)

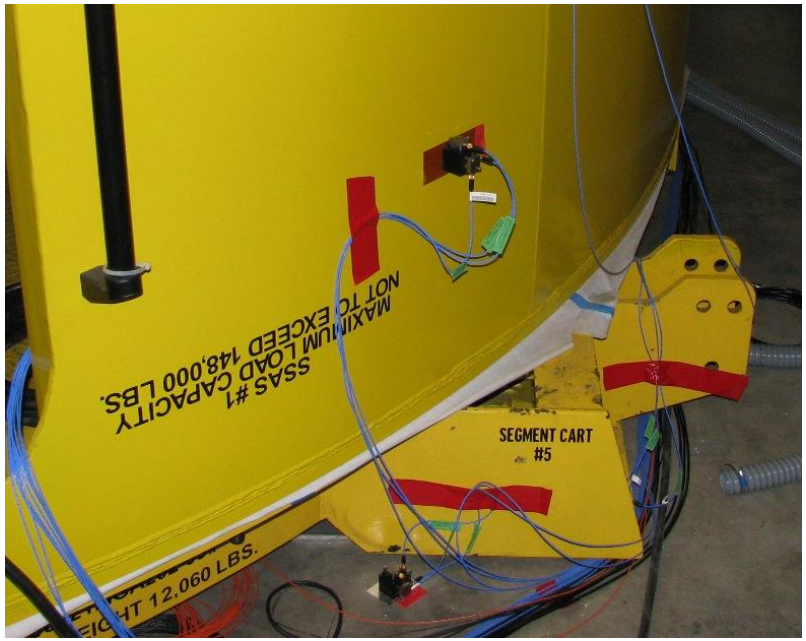
346,860 DOF FEM reduced to 82 DOF test model

Stack 5 Test Configuration

71-feet; ~53,000 lb

- Testing at KSC in VAB High-Bay 4
- LAS, CM, SM, SA on assembly stand and heavy weight cart
- Cart shimmed at 12 locations to floor
- Shakers mounted off telehandlers



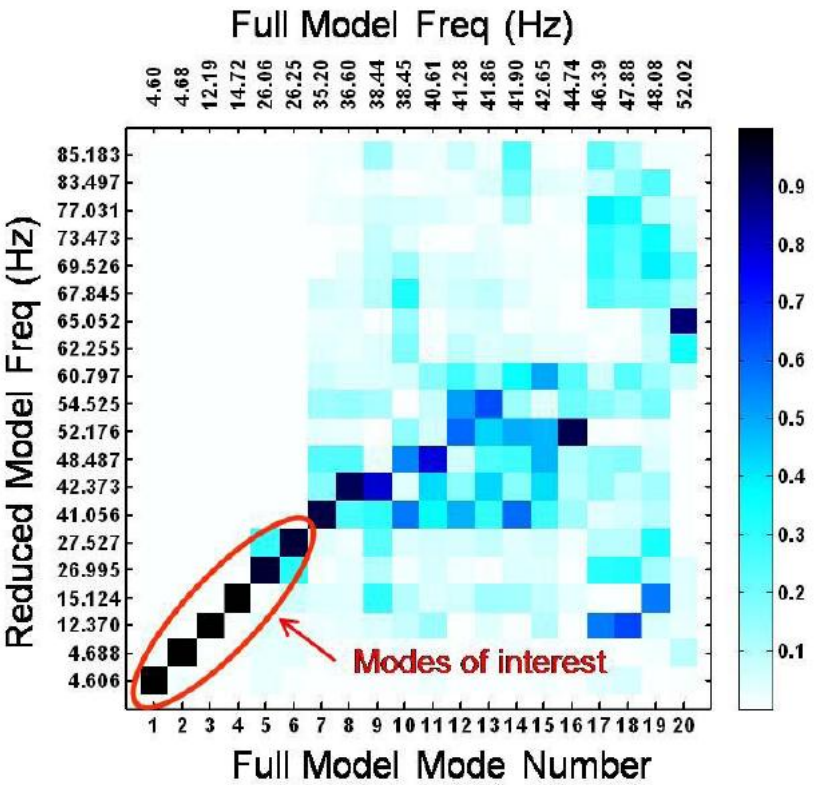


Shim location and boundary instrumentation

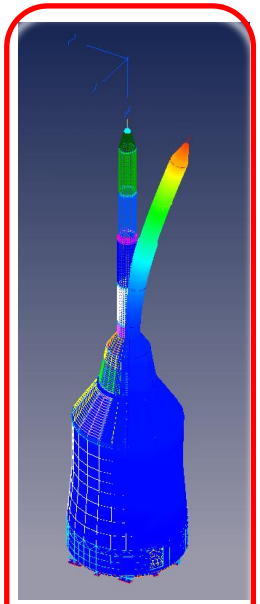
Stack 5 Pre-Test Analysis

- Cart and assembly stand added to FEM of Stack 5
- Shimmed boundary condition modeled as simple springs
- 1st Bending mode pair critical based on Aerospace Corp. traceability study
- 2nd Bending mode pair most influenced by boundary condition

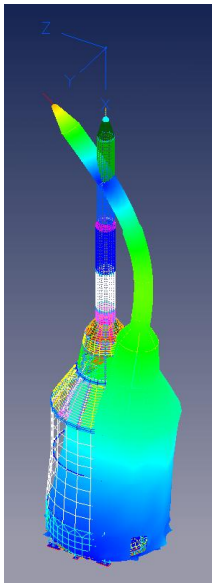
Cross-Orthogonality



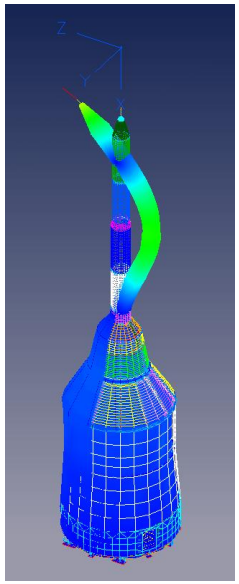
Critical modes from traceability



4.60 Hz, 4.68 Hz
Mode 1 X-Z
Mode 2 X-Y



12.2 Hz, 14.7 Hz
Mode 3 X-Z
Mode 4 X-Y

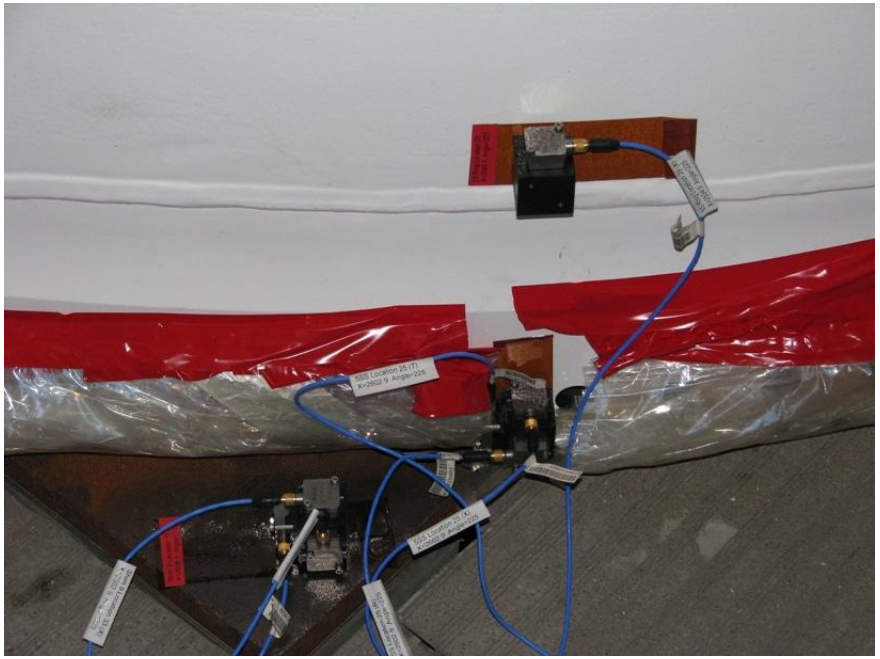


26.0 Hz,26.2 Hz
Mode 5 X-Z
Mode 6 X-Y

45,042 DOF FEM reduced to 70 DOF test model

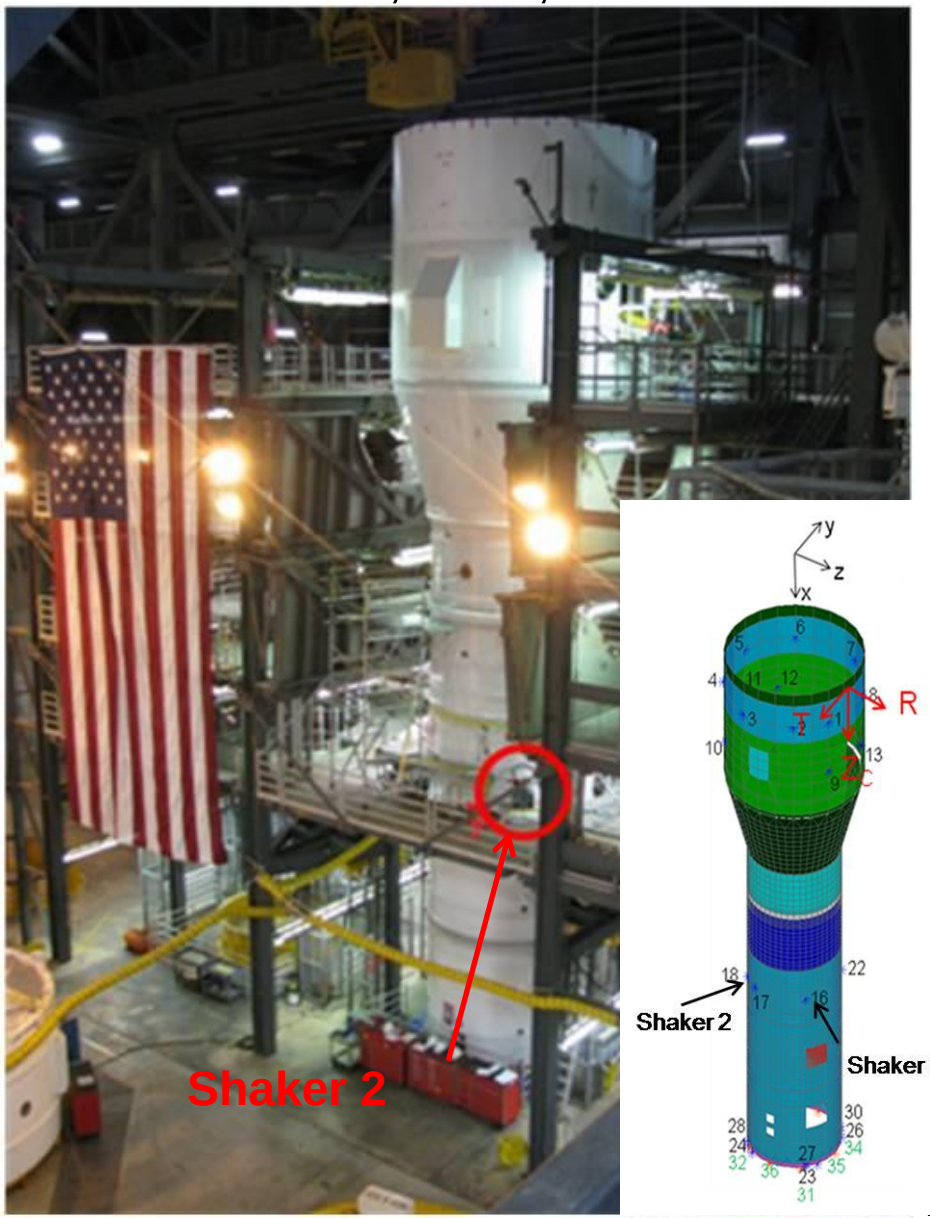
Stack 1 Test Configuration

- Testing at KSC in VAB High-Bay 4 build-up stand
- Stack 1 shimmed at 12 locations-not direct path to ground
- Shakers mounted to facility platform



Shim location with boundary instrumentation

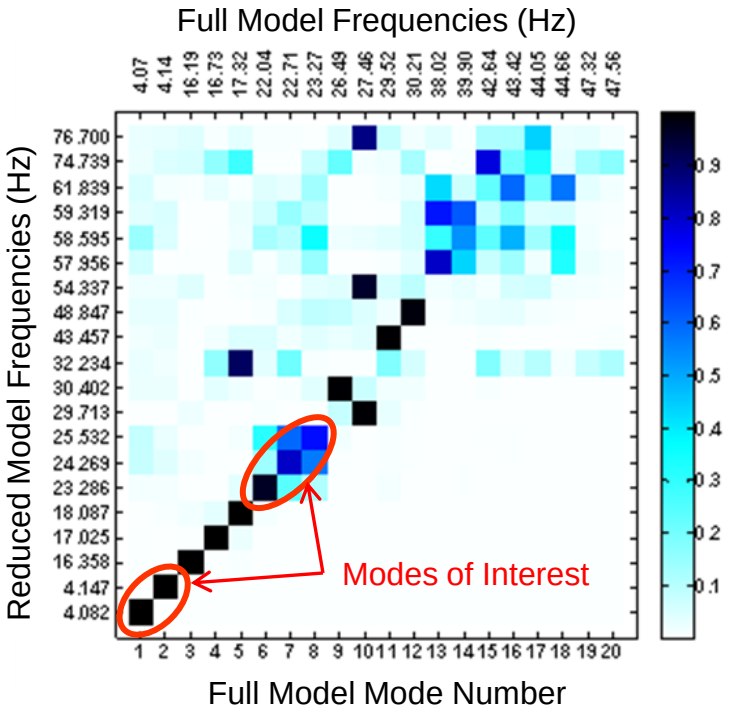
66-feet; ~150,000 lb



Stack 1 Pre-Test Analysis

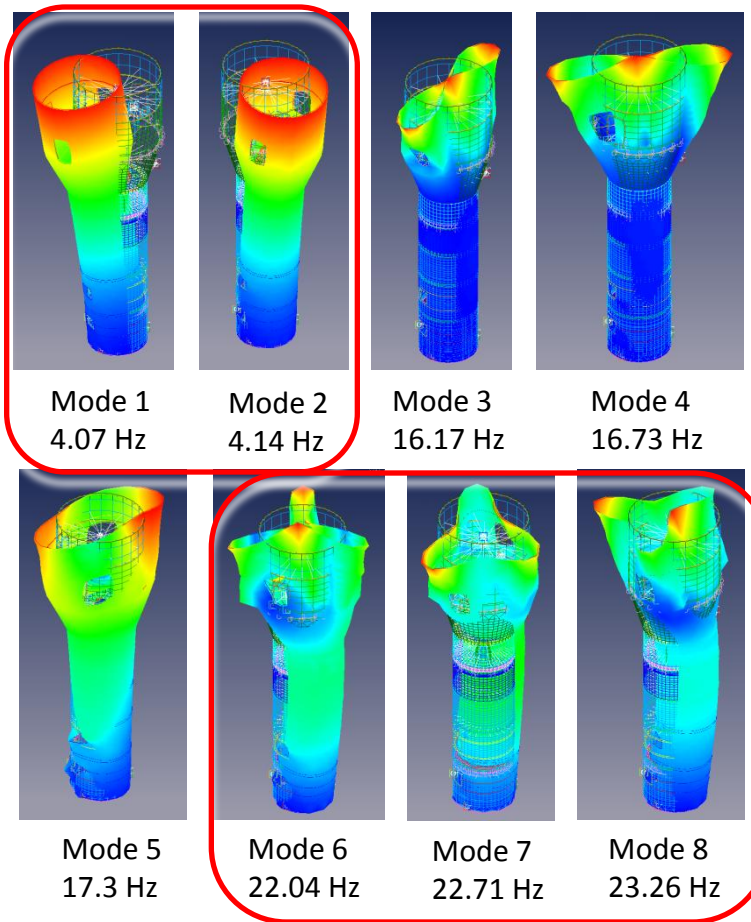
- Shimmed boundary condition modeled as simple springs
- Open end at top results in significant shell motion
- First six modes >.9 diagonal, <.1 off-diagonal
- Modes 7, 8 more qualitative for limited instrumentation set

Cross-Orthogonality



59,574 DOF FEM reduced to 88 DOF test model

Critical modes from traceability



Summary

- Overview of Ares I-X modal test provided
- Three large scale modal tests planned on aggressive schedule
- Test configurations and pre-test analysis described
- Stay tuned for more Ares I-X Modal Test presentations
  - Ryan Tuttle, “Identifying Goals For Ares 1-X Modal Testing”
  - Justin Templeton, “Ares I-X Launch Vehicle Modal Test Measurements and Data Quality Assessments”
  - Ryan Tuttle, “Modal Test Data Adjustment for Interface Compliance”
  - Lucas Horta, “Finite Element Model Calibration Approach for Ares I-X”