CoNNeCT Antenna Positioning System Dynamic Simulator Modal Model Correlation

The National Aeronautics and Space Administration (NASA) developed an on-orbit, adaptable, Software Defined Radios (SDR)/Space Telecommunications Radio System (STRS)-based testbed facility to conduct a suite of experiments to advance technologies, reduce risk, and enable future mission capabilities on the International Space Station (ISS). The Communications, Navigation, and Networking reConfigurable Testbed (CoNNeCT) Project will provide NASA, industry, other Government agencies, and academic partners the opportunity to develop and field communications, navigation, and networking technologies in both the laboratory and space environment based on reconfigurable, software-defined radio platforms and the STRS Architecture. The CoNNeCT Payload Operations Nomenclature is “SCAN Testbed,” and this nomenclature will be used in all ISS integration, safety, verification, and operations documentation. The SCAN Testbed (payload) is a Flight Releasable Attachment Mechanism (FRAM) based payload that will launch aboard the Japanese H-II Transfer Vehicle (HTV) Multipurpose Exposed Pallet (EP-MP) to the International Space Station (ISS), and will be transferred to the Express Logistics Carrier 3 (ELC3) via Extravehicular Robotics (EVR). The SCAN Testbed will operate on-orbit for a minimum of two years.

One major subsystem of the CoNNeCT system is the Antenna Pointing System (APS). The APS is attached to the top of the CoNNeCT payload (**Error! Reference source not found.**). System-level protoflight random vibration testing of CoNNeCT was required. Due to the APS flight system's lengthy development schedule, the flight APS hardware was not available at the time of the CoNNeCT system-level protoflight random vibration test. Previous random vibration analysis has shown that the dynamics of the APS has a large effect on the loading seen by other subsystems during random vibration input. Because of this, a dynamic APS mass simulator was designed, fabricated, and used during the CoNNeCT system level protoflight random vibration test.

Welcome

CoNNeCT Antenna Positioning System Dynamic Simulator Modal Model Correlation

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Agenda

- CoNNeCT Background
- APS Simulator Design
- Purpose of Model Correlation and Goals
- Test Results
- Stepwise Correlation Approach
- CoNNeCT System Test Model
- Conclusions/Summary

CoNNeCT Background

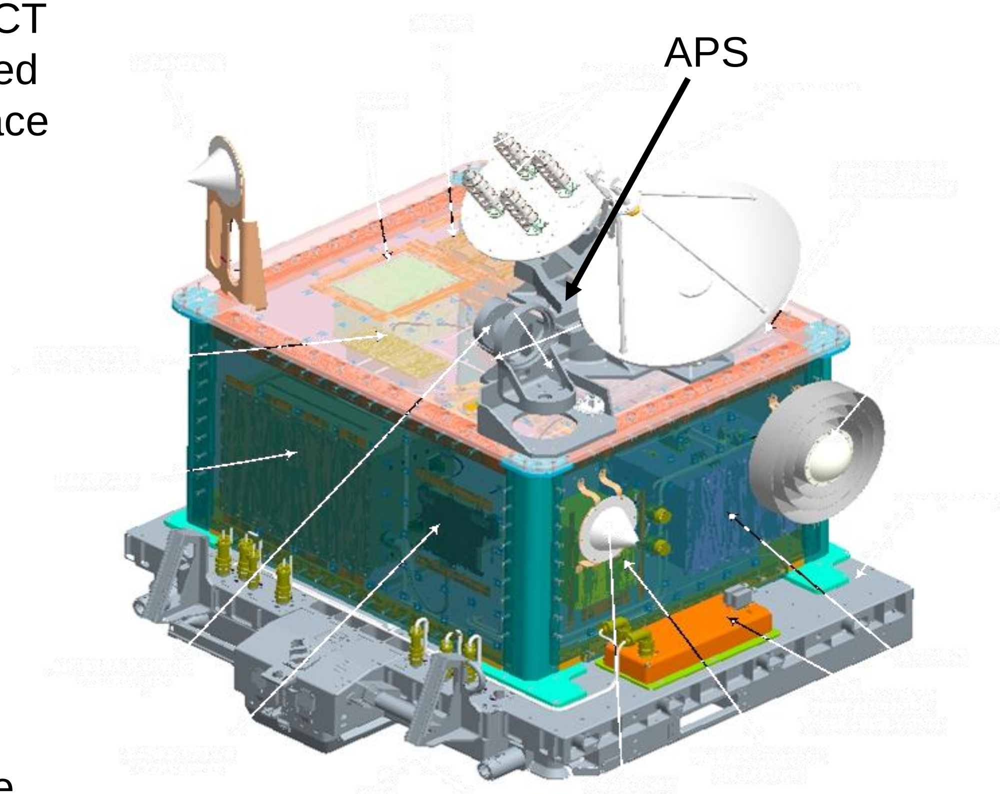
- Communications, Navigation, and Networking Reconfigurable Testbed CoNNeCT is a communications payload being developed at NASA to be used on the International Space Station (ISS)

- CoNNeCT will fly on the Japanese H-II Transfer Vehicle (HTV) later this summer

- The project is utilizing a protoflight test program

- The Antenna Pointing System (APS) flight hardware was not available for the system level random vibration test.

- A simulator needed to be developed for use during the system level random vibration test



CoNNeCT Hardware in Flight Configuration

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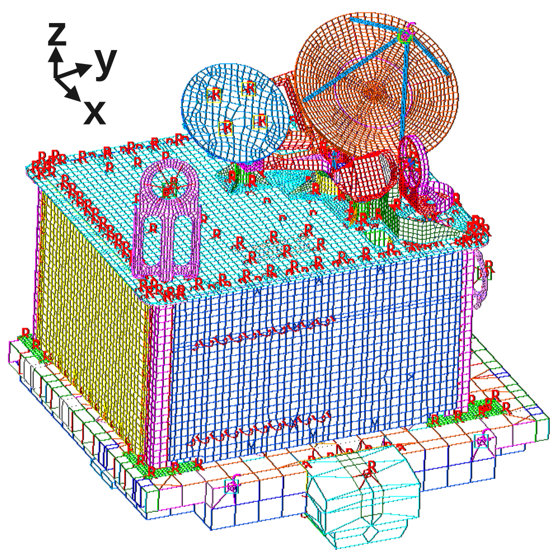
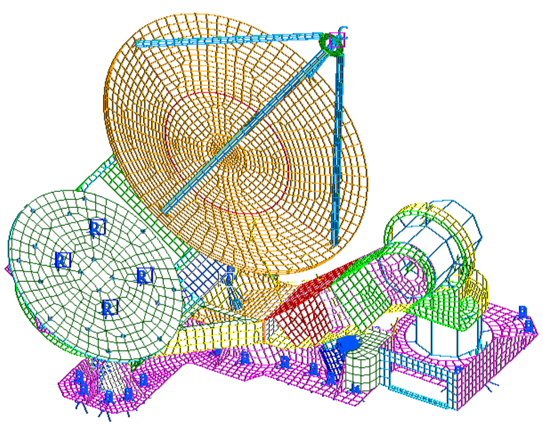
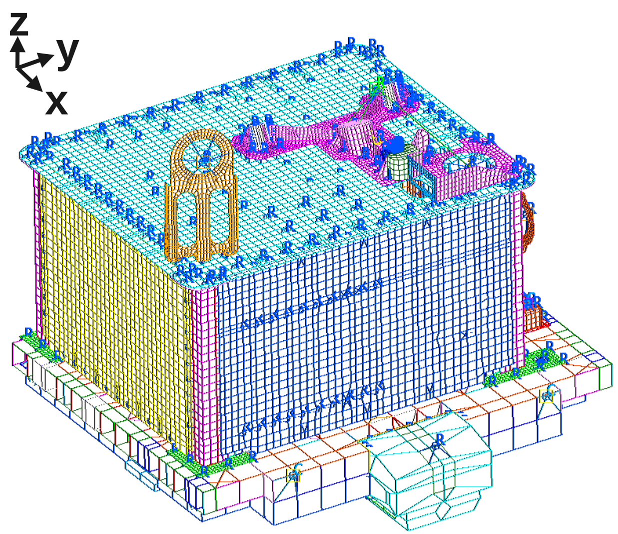
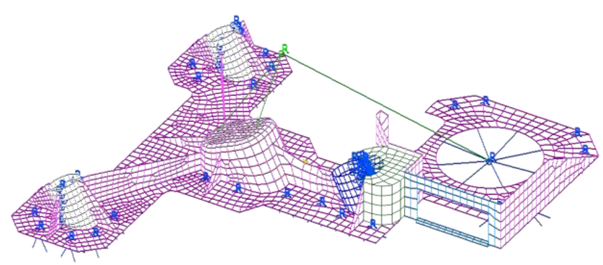
APS Simulator Design





Baseline Configuration





Lumped Mass APS Flight Base

- Incorporating the APS mass simulator in the system vibration test ensures other CoNNeCT components see appropriate dynamic response.
- Goal was inexpensive mass simulator if possible.
- Analysis was performed to determine required level of fidelity for simulator.
- One design example used flight base with a lumped mass arm and antennas.

APS Simulator Design

Base Shake Analysis Results

- Base shake analysis run on CoNNeCT system with various simulator designs.
- Response vibration levels were recovered at the footprint of each of the CoNNeCT subsystems
- Table shows typical result for representative "GCE" CoNNeCT component.
- Large changes in Grms value at components with changes to APS drove need for dynamically accurate APS simulator.

Baseline			X-input	Y-input	Z-input
Component	Grid	Response Direction	RMS Value	RMS Value	RMS Value
GCE	330424	x	3.27	1.37	0.91
		y	3.88	9.10	4.16
		z	1.95	4.34	3.82

Lumped Mass APS Flight Base			X-input	Y-input	Z-input	X-input	Y-input	Z-input
Component	Grid	Response Direction	RMS Value	RMS Value	RMS Value	Percent Difference		
GCE	330424	x	3.44	1.12	0.90	**5.09**	-18.06	-0.72
		y	3.24	8.13	4.38	-16.68	**-10.62**	5.35
		z	2.09	4.57	3.56	7.49	5.31	**-6.83**

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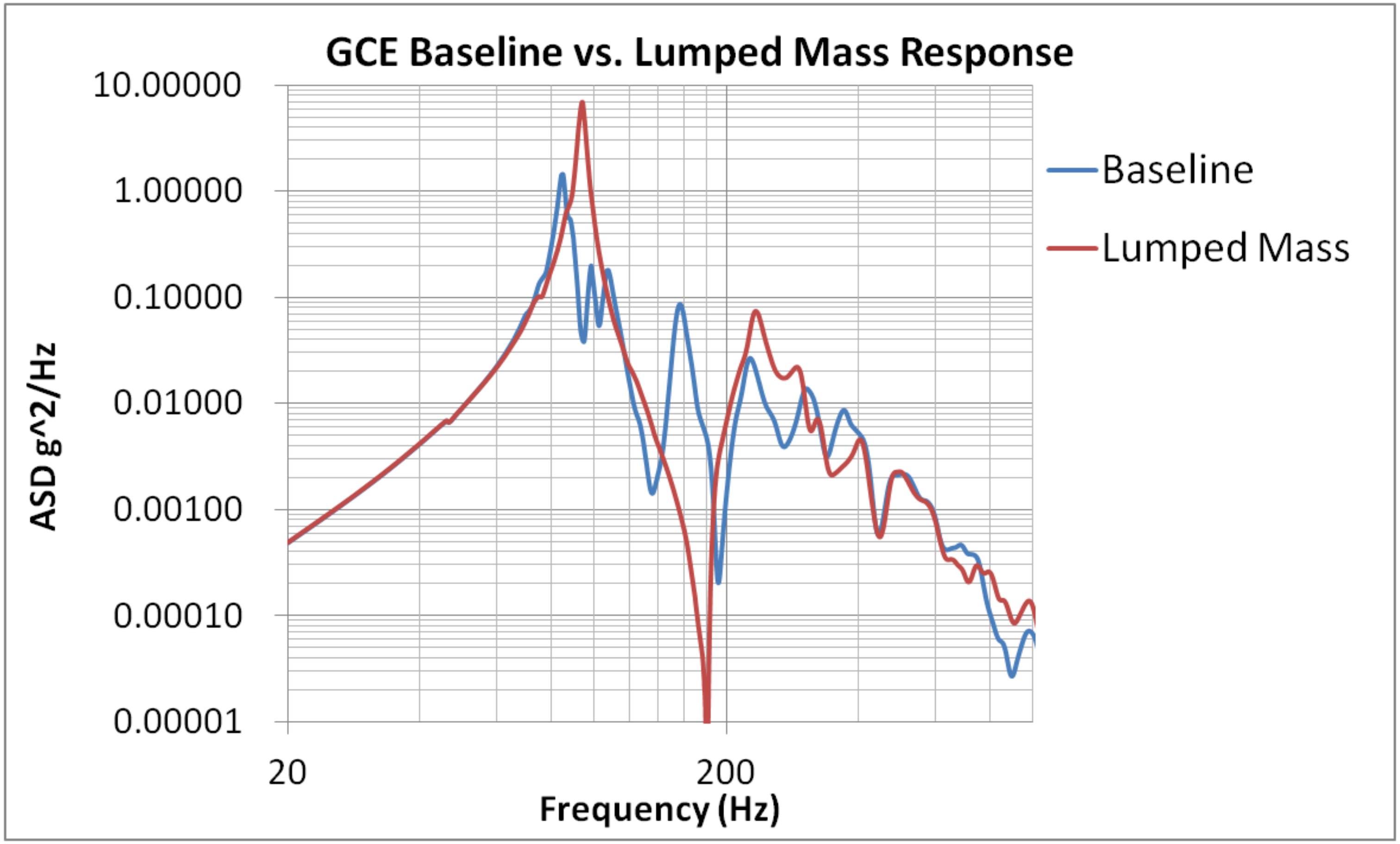
APS Simulator Design

Base Shake Analysis Results

- Vibe spectrums plotted in addition to Grms comparison
- Result showed significant differences in frequency content with a lumped mass APS simulator



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Purpose of Model Correlation and Goals

- The APS simulator was to be used in protoflight system level vibe test
- Verification was needed that the APS simulator would behave like flight hardware
- Random vibe analysis on a test correlated APS simulator integrated with CoNNect flight model would increase confidence
- Per SSP 52005, Section 7.1 correlation goal for modal frequency:
  +/- 5% for target modes
  +/- 10% for secondary modes
- Cross-orthogonality between analysis and test mode shapes:

$$[\emptyset]_A^T [M]_A [\emptyset]_T = [C_{ij}]$$

Where:

$[\emptyset]_A^T$ is the transpose of the analytical mode shape matrix

$[M]_A$ is the analytical consistent mass matrix (as defined in NASTRAN manuals)

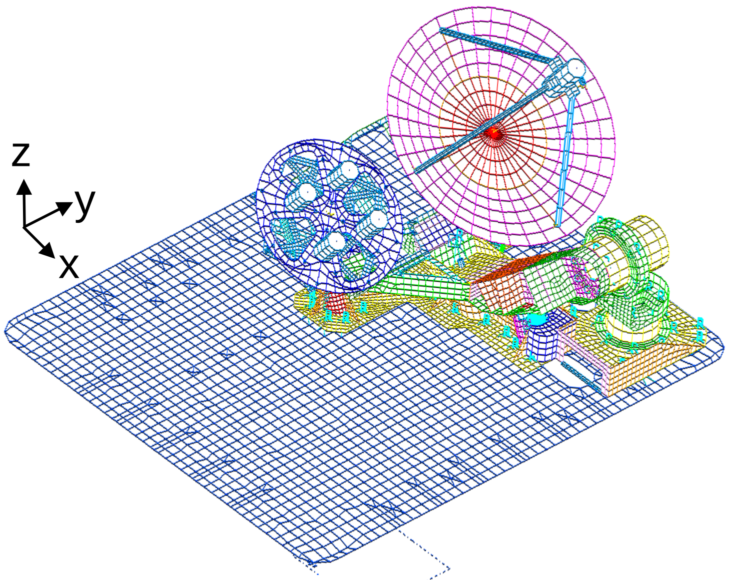
$[\emptyset]_T$ is the test mode shape matrix

$[C_{ij}]$ is the correlation matrix

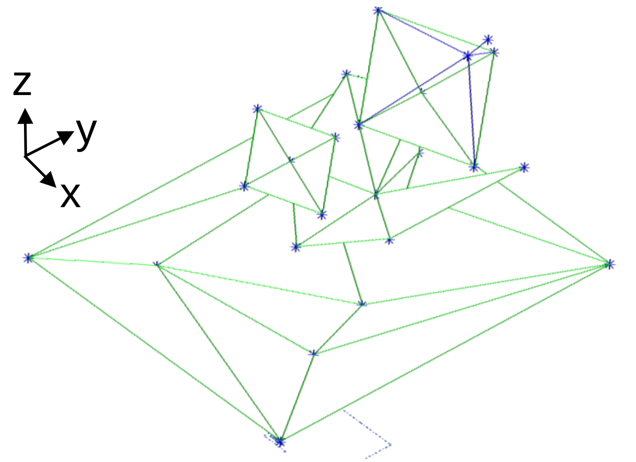
- Correlation goal was diagonals of $[C_{ij}]$ be: greater than 0.9 for target modes and off-diagonals be less than 0.1 for target modes.

APS Simulator

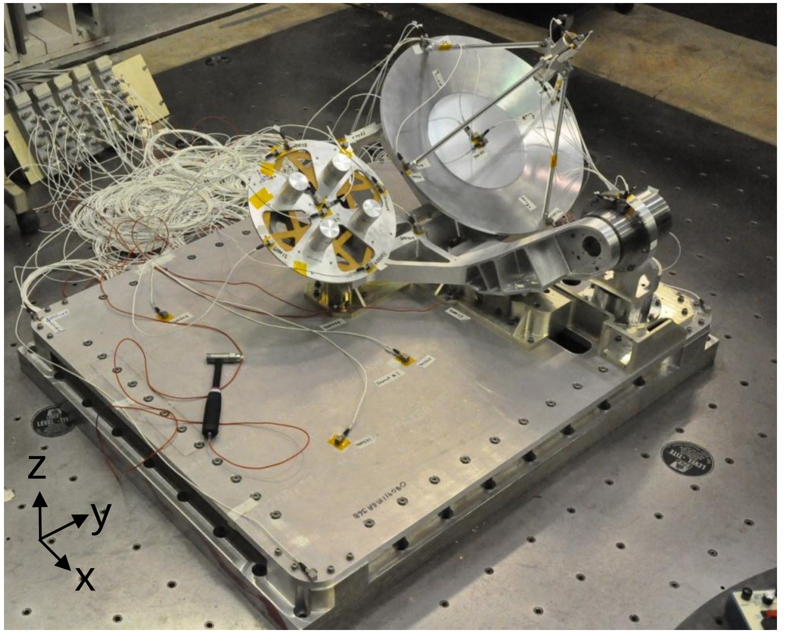
Modal Test and FEM Overview



APS Simulator Full FEM



APS Simulator Test Display Model (TDM)



APS Simulator Test Setup

- A modal survey using a modal hammer was conducted on APS dynamic simulator hardware
- Initial checks during test indicated test and analysis normal modes varied greatly;
  - Mode shapes did not match
  - Frequency of target mode off by over 25% (45 Hz)
  - Test frequencies were higher than FEM
- Model correlation seemed extremely challenging.

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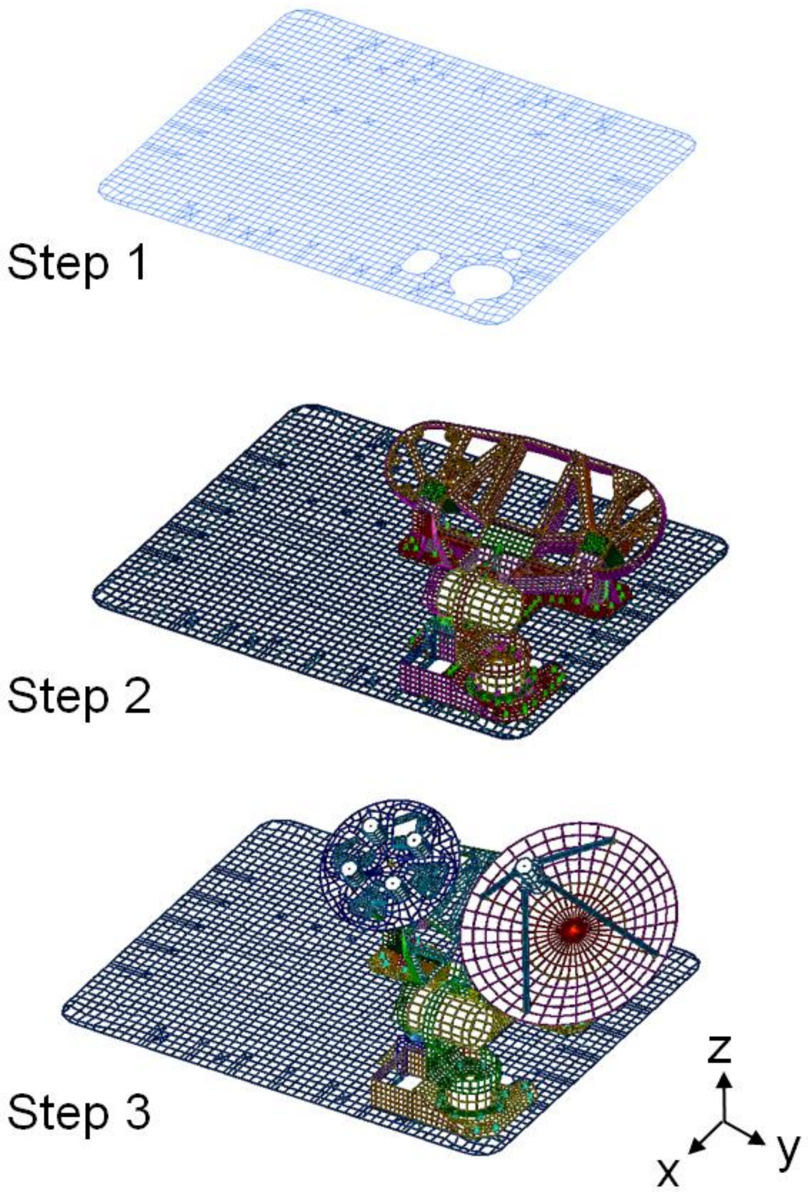
Stepwise Correlation Approach

Boundary Conditions and Mode Shapes

- A modal test was conducted for each of these three configurations
- Stepwise approach adopted due to large discrepancies between full APS FEM and test results

1. Correlate fixture base plate without APS simulator
2. Correlate fixture base plate plus APS simulator without antennas
3. Correlate full APS simulator assembly



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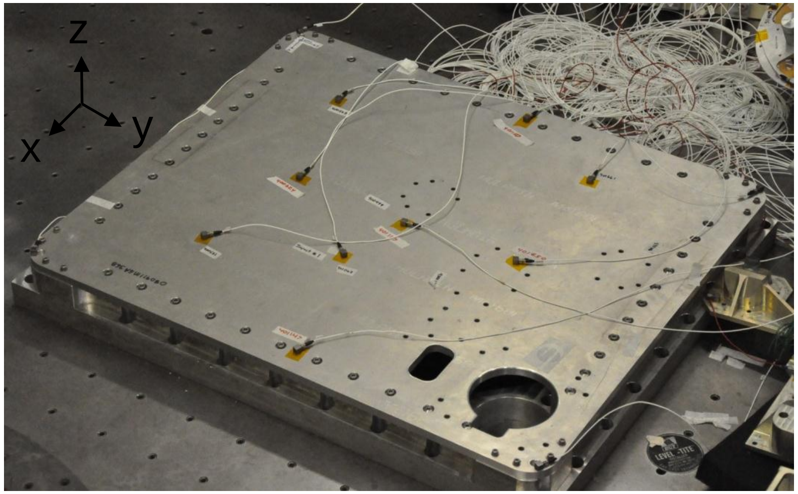
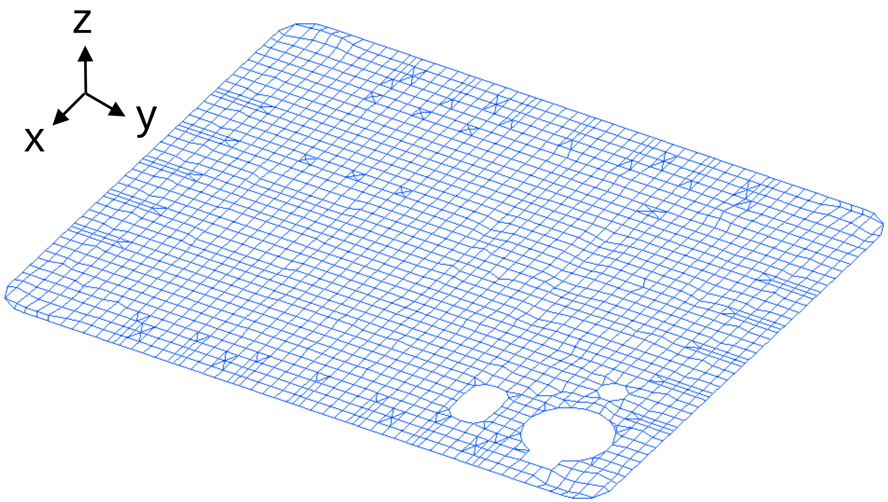
Step 1: Fixture Base Plate Correlation

• A modal test was conducted on the fixture base plate without the APS simulator attached
• The results were correlated to the FEM by adjusting the boundary conditions to account for the 2” wide mounting surface
• Correlation was based on visually matching mode shapes and trying to closely match frequency
• Correlating the base plate alone is a step-wise approach for correlating the full APS simulator test setup

		Test	FEM		FEM new BC	
Mode#	Description	Hz	Hz	%diff	Hz	%diff
1	Panel Mode Z	209.3	183.5	12.3	211.8	1.2
2	Panel Mode Z (2 nodes in Y)	379.0	341.4	9.9	384.2	1.4
3	Panel Mode Z (2 nodes in X)	469.5	408.3	13.0	473.2	0.8



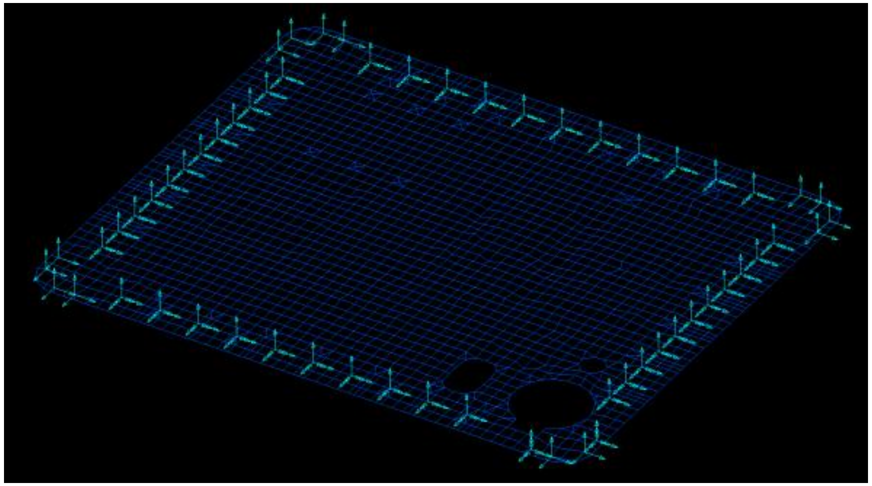
Fixture Base Plate



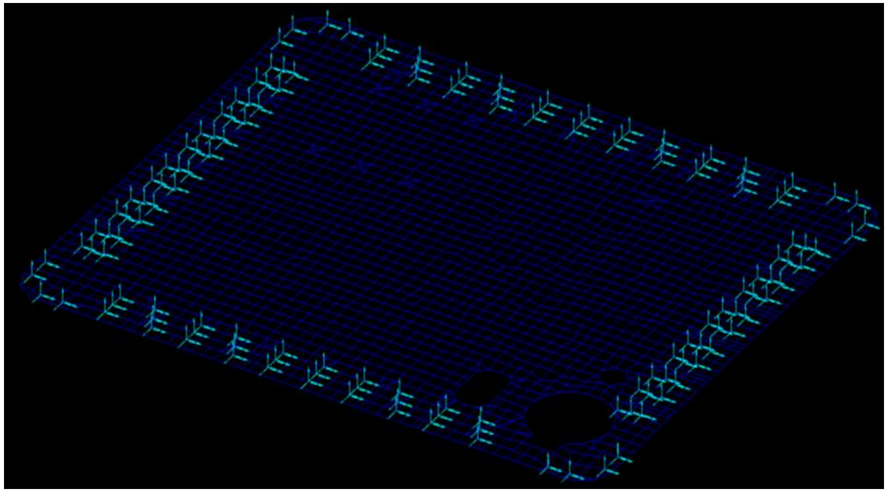
Fixture Base Plate FEM

Step 1: Fixture Base Plate Correlation

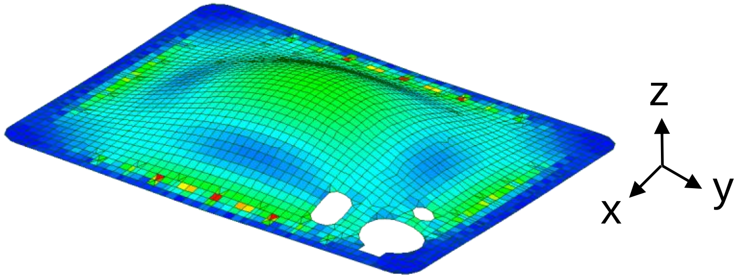
Boundary Conditions and Mode Shapes



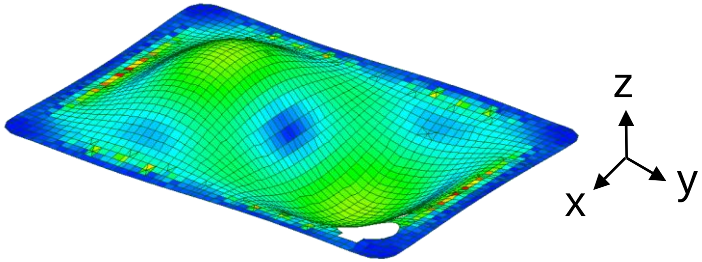
Original FEM Boundary Condition



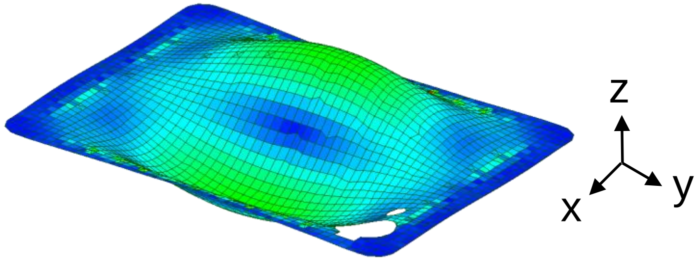
New FEM Boundary Condition



Analysis Mode 1: Panel Mode Z
(209.3 Hz Test Frequency)



Analysis Mode 2: Panel Mode Z (2 nodes Y)
(379.0 Hz Test Frequency)



Analysis Mode 3: Panel Mode Z (2 nodes X)
(469.5 Hz Test Frequency)

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Step 2: APS without Antenna Correlation

Test Results

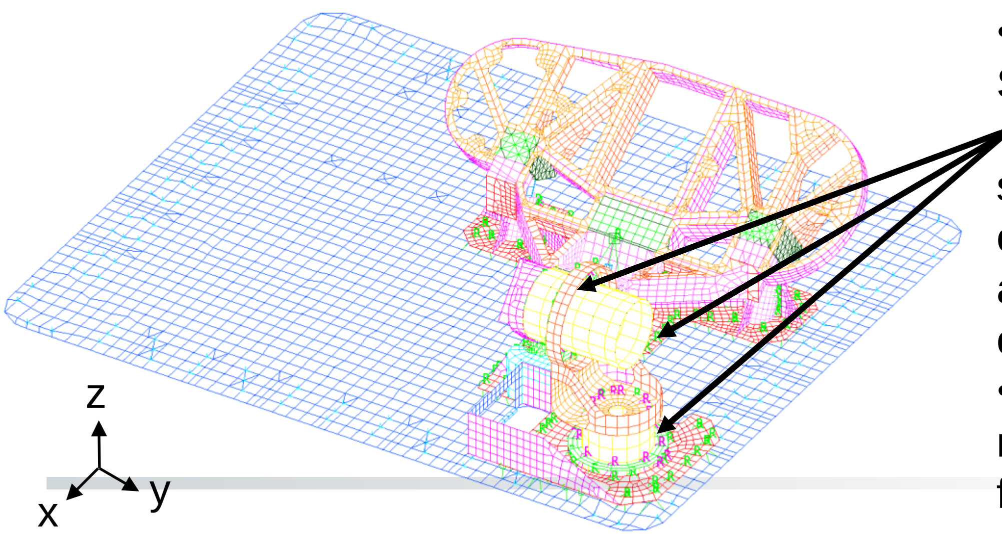
Frequency (Hz)
181.36
237.15
336.83

Baseline FEM with antennas removed (baseplate correlated)

	Hz	%diff	x	y	z	rx	ry	rz
1	156.77	13.56	4	1	33	1	5	1
2	166.32	29.87	5	6	2	7	9	10
3	239.15	29.00	2	2	1	2	5	0
4	258.54		2	0	0	1	2	2
5	280.53		1	4	19	13	5	0
6	314.03		0	0	0	0	0	0
7	314.62		2	1	0	0	1	1
8	361.75		0	1	0	2	0	0
9	398.19		0	3	4	2	0	0
10	437.76		1	2	1	6	1	0

Correlated FEM with antennas removed

	Hz	%diff	x	y	z	rx	ry	rz
1	184.81	1.90	0	3	39	4	0	0
2	225.12	5.07	5	3	0	3	11	10
3	294.24	12.64	1	0	1	0	3	1
4	380.46		7	0	0	0	9	0
5	385.34		1	2	0	1	0	1
6	467.29		1	0	0	2	0	0
7	506.78		0	1	11	6	3	0
8	523.71		0	6	2	7	0	0
9	559.65		0	0	2	2	0	0
10	610.18		3	0	0	1	5	0



- A modal test was conducted on the APS Simulator assembly with antennas removed
- The results were correlated to the FEM by stiffening the interface attach points of the APS components (i.e. APS base, arm, actuator attachments and changing kinematic pin constraints)
- Correlation was based on visually matching mode shapes and trying to closely match frequency

Step 3: Full APS Simulator Correlation:

Target Modes, Frequencies, and Cross-Orthogonality

- The criterion used for primary target modes are modes with greater that 10% effective mass
- Secondary modes are defined based on less that 10% effective mass
- Correlation goals were met

Effective Mass Table:

Secondary Modes → modes 1, 2

Target Mode → mode 3

	Hz	x	y	z	rx	ry	rz
1	115.92	2	0	0	1	3	1
2	120.07	0	2	2	3	0	0
3	155.40	0	3	28	5	0	0
4	181.99	6	0	0	0	11	0
5	190.45	0	0	0	0	0	0
6	219.05	0	0	0	0	1	1
7	232.76	4	3	1	3	9	11
8	259.95	0	1	6	1	0	0
9	300.62	0	1	4	2	0	0
10	331.20	0	0	0	0	0	0

- **Cross-Orthogonality and Frequency Comparison**:

			Analysis Modes				
			1	2	3		
		Freq (Hz)	115.92	120.07	155.40	%Freq Diff	Mode Shape Description
Test Modes	1	114.83	0.99	0.11	0.04	0.96	APS HGA Local X-Direction Bending Mode
Test Modes	2	121.58	0.06	0.99	0.04	1.24	APS HGA Local Y-Direction Bending Mode
Test Modes	3	161.54	0.03	0.03	0.98	3.80	Global Z Plate Bending HGA/APS out of phase

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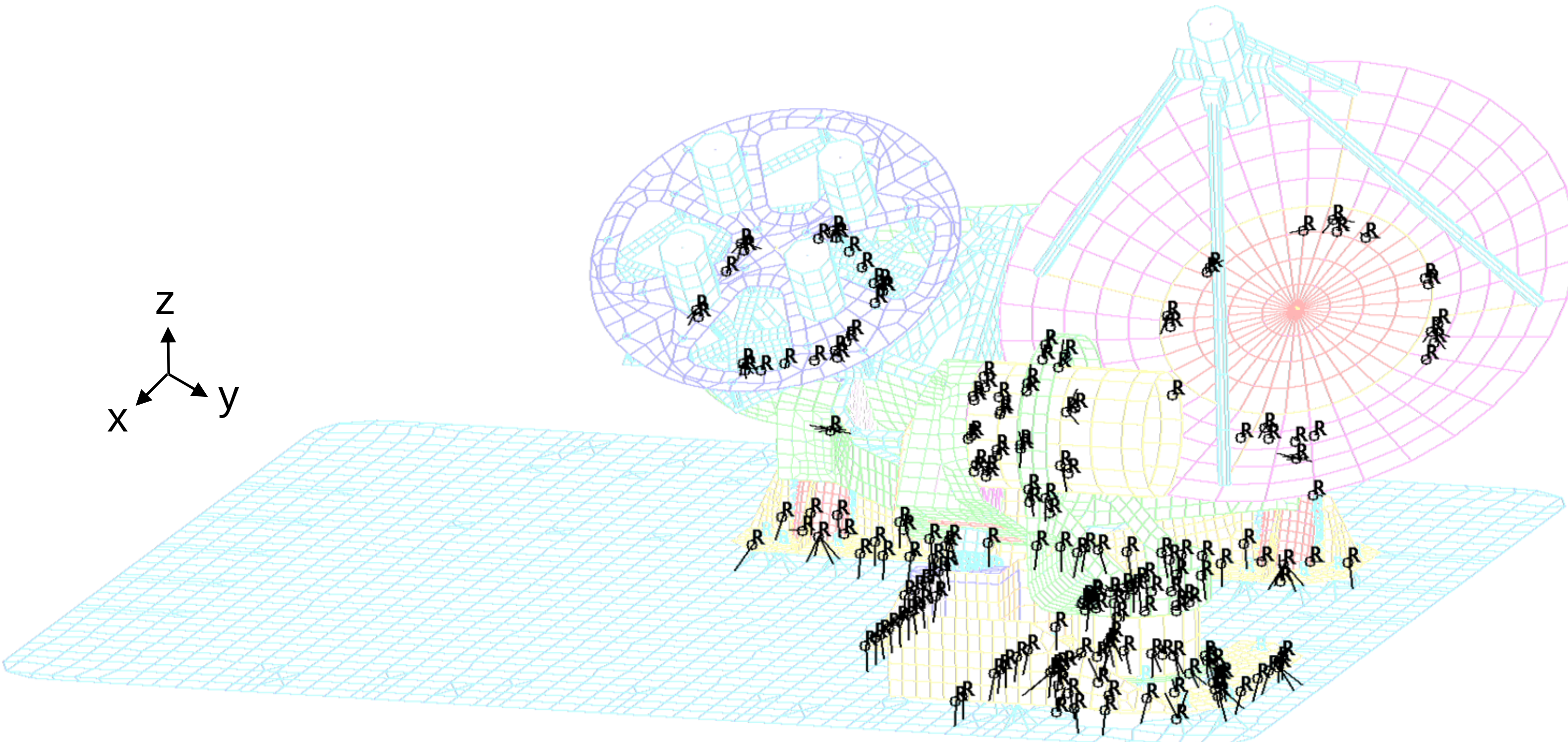
Step 3: Full APS Simulator Correlation:

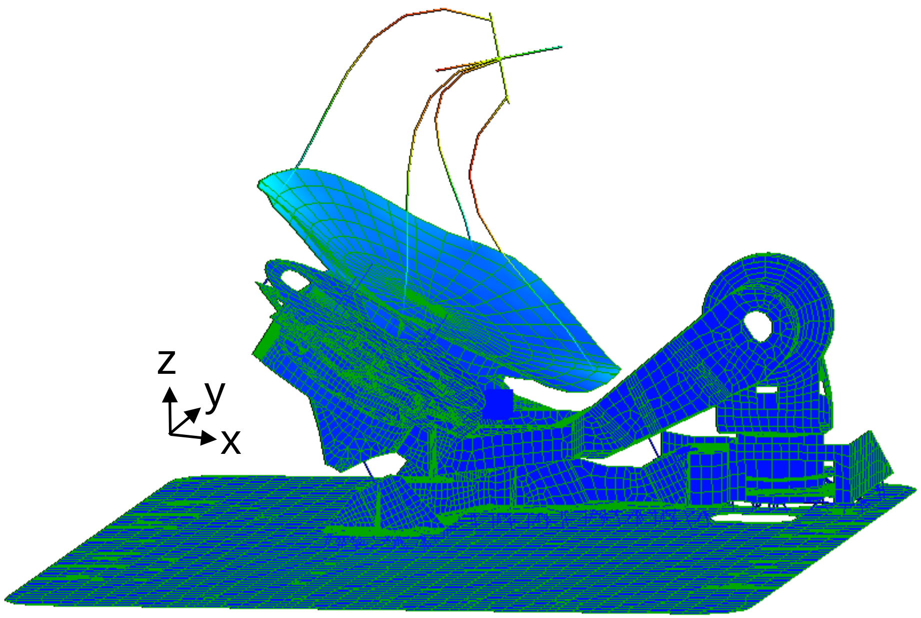
Component Interface Constraint Changes



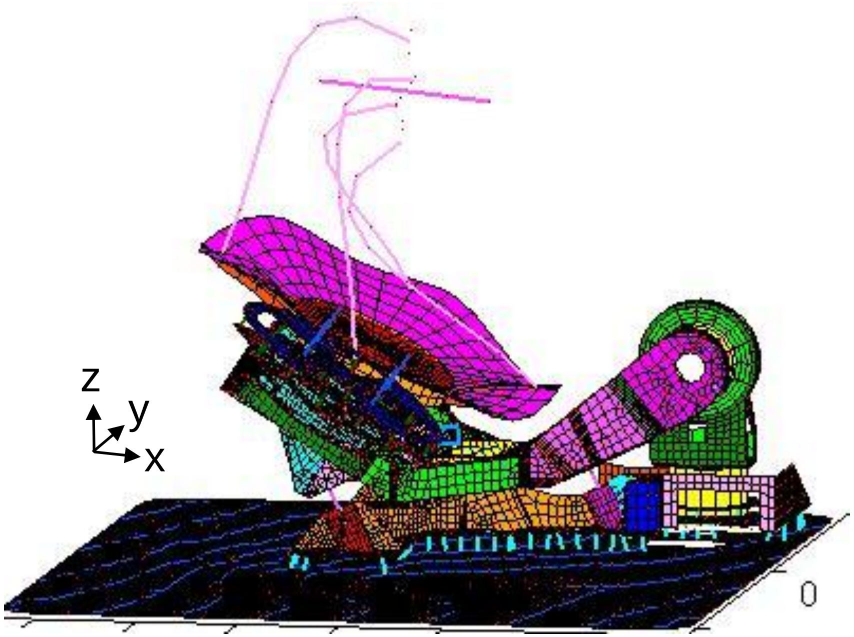
Additional RBE2 Constraints

Step 3: Full APS Simulator Correlation:

Correlated Mode Shapes: Mode 1



Analysis FEM
Mode 1: 115.92 Hz
HGA local X-bending

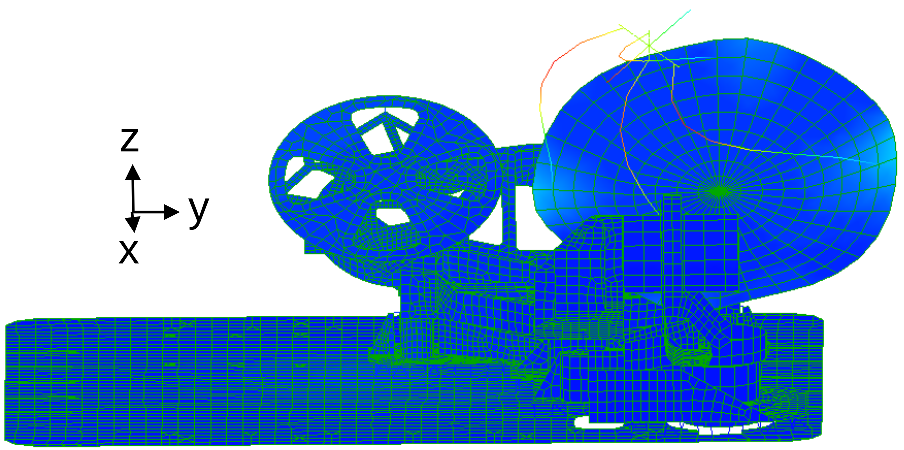


Test Results (Back Expanded)
Mode 1: 114.83 Hz
HGA local X-bending

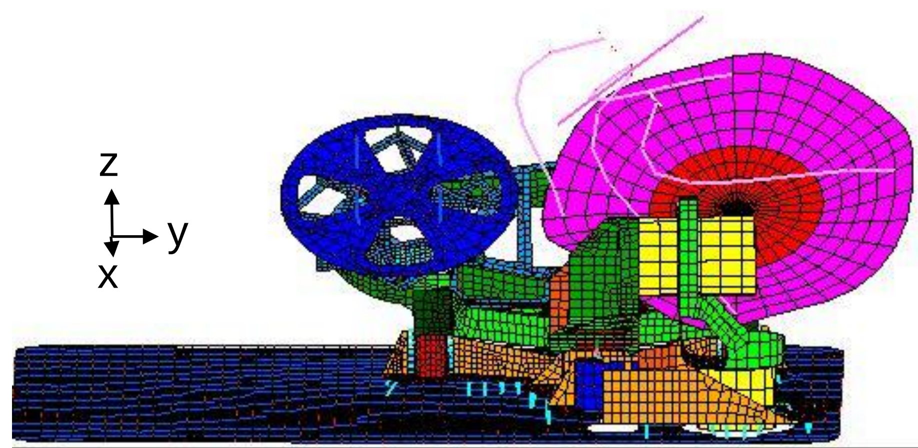
Cross-Orthogonality: 99%

Step 3: Full APS Simulator Correlation:

Correlated Mode Shapes: Mode 2



Analysis FEM
Mode 2: 120.07 Hz
HGA local Y-bending

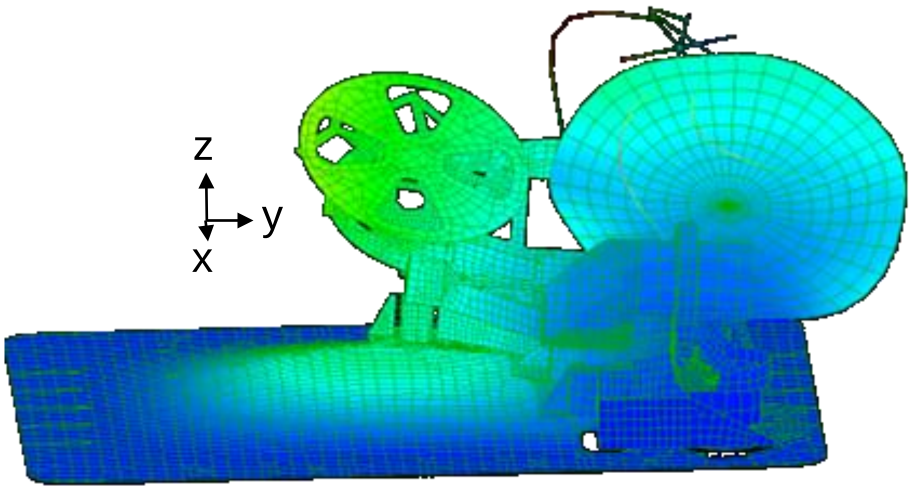


Test Results (Back Expanded)
Mode 2: 121.58 Hz
HGA local Y-bending

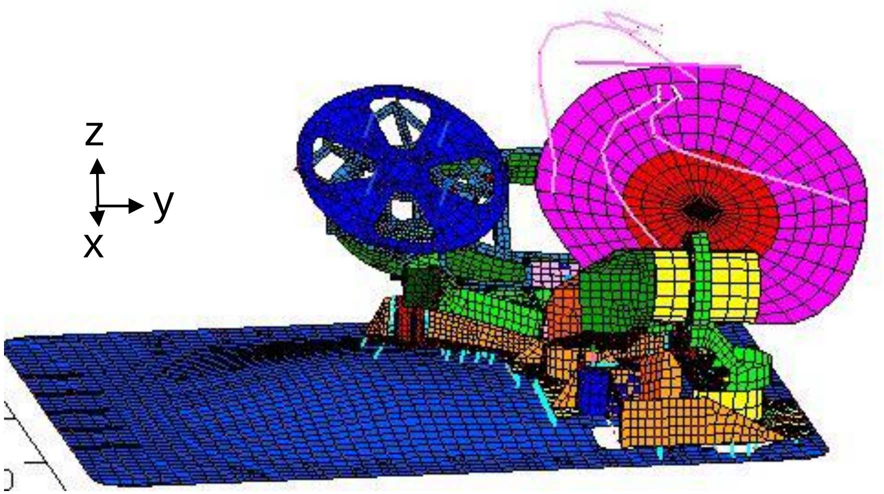
Cross-Orthogonality: 99%

Step 3: Full APS Simulator Correlation:

Correlated Mode Shapes: Mode 3



Analysis FEM
Mode 3: 155.40 Hz
Global Z Plate Bending



Test Results (Back Expanded)
Mode 3: 161.54 Hz
Global Z Plate Bending

Cross-Orthogonality: 98%

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CoNNeCT System Test Model

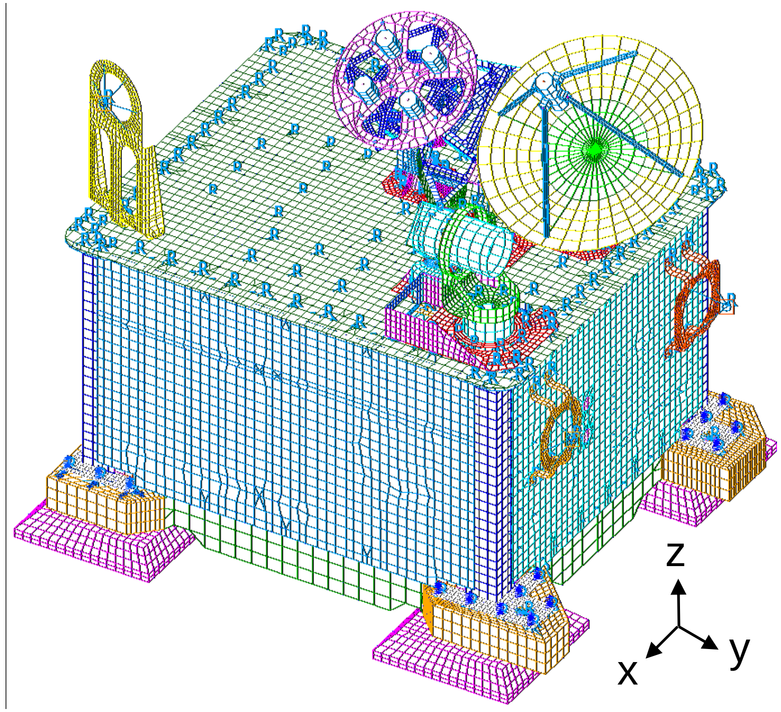
Effective Mass Table Comparison (Correlated vs. Pre-Test FEM)

Test Configuration FEM **before** APS correlation

	Hz	x	y	z	rx	ry	rz
1	47.70	1	0	0	0	3	0
2	47.94	0	0	1	0	0	0
3	67.05	0	0	0	0	0	0
4	67.91	3	1	18	3	5	0
5	74.07	33	1	4	1	39	0
6	77.80	18	0	0	0	30	0
7	81.41	0	10	2	11	0	0
8	85.37	0	25	2	37	0	1
9	90.54	0	8	2	10	0	0
10	102.30	1	5	0	4	1	0
11	107.54	1	0	0	0	0	0
12	110.26	0	0	1	1	0	0
13	110.81	0	0	3	3	0	0
14	112.99	0	0	0	0	0	0
15	113.28	0	0	0	0	0	0
16	115.22	0	0	2	4	0	1
17	130.41	3	0	0	0	0	2
18	136.64	0	1	2	0	0	1
19	137.32	0	0	0	0	0	0
20	141.70	0	0	1	0	0	3

Test Configuration FEM **after** APS correlation

	Hz	x	y	z	rx	ry	rz
1	47.71	1	0	0	0	3	0
2	47.94	0	0	1	0	0	0
3	67.05	0	0	0	0	0	0
4	72.81	10	0	7	2	13	0
5	75.94	20	2	15	3	22	0
6	79.08	26	0	0	0	39	1
7	81.88	0	6	3	5	0	0
8	86.62	0	22	1	31	0	1
9	91.95	0	20	3	24	0	0
10	110.26	0	0	1	1	0	0
11	110.66	0	0	3	3	0	0
12	112.97	0	0	0	0	0	0
13	113.28	0	0	0	0	0	0
14	114.92	1	0	2	2	0	0
15	117.13	1	0	0	2	0	0
16	124.02	0	1	0	2	0	0
17	136.68	0	1	2	0	0	1
18	137.32	0	0	0	0	0	0
19	141.94	0	0	0	0	0	0
20	142.10	0	0	1	0	0	4

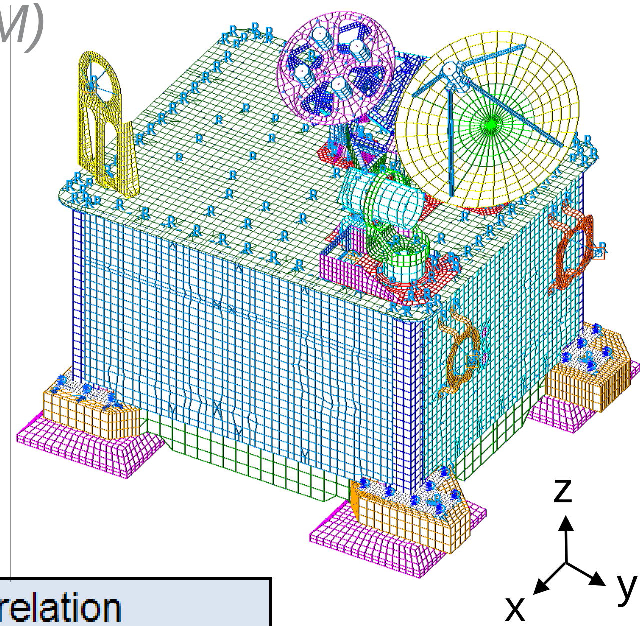


Test Configuration FEM

- These results show significant effective mass changes and cross coupling or shifting of mass between modes

CoNNeCT System Test Model

Cross Orthogonality (Correlated vs. Pre-Test FEM)



- The Cross-Orthogonality table below compares the first 9 modes of the full test configuration FEM before and after APS correlation
- The results show that the first 9 modes still line up with a max freq shift of 6.73%
- The result also shows the cross coupling between some of the modes
- Correlation of APS impacted modes of system FEM

			Test Configuration FEM after APS correlation									
			1	2	3	4	5	6	7	8	9	
		Freq (Hz)	47.71	47.94	67.05	72.81	75.94	79.08	81.88	86.62	91.95	%Freq Diff
Test Configuration FEM before APS correlation	1	47.70	1.00									0.02
	2	47.94		1.00								0.00
	3	67.05			1.00							0.00
	4	67.91				0.86	0.47	0.22				6.73
	5	74.07				0.47	0.88					2.46
	6	77.80				0.20		0.97	0.11			1.62
	7	81.41				0.13			0.98	0.10		0.57
	8	85.37								0.96	0.25	1.44
	9	90.54								0.23	0.95	1.53

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Summary/Conclusions

- Using analysis it was determined the APS simulator would need to be a dynamic simulator.
- Using a step-wise approach the APS simulator FEM was correlated.
- Modeling of the boundary conditions was the key area of uncertainty.
- System level random vibe test was successful – levels seen by all components were within design limits.

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Thank you

SCIV

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