

Deven Mhadgut

Aerospace Engineer



About me

Innovative, rigorous, and ready to launch my career with a mission-driven and cutting-edge team. I'm passionate about complex system design, simulation-driven analysis, and building robust solutions that push the boundaries of exploration.



Top skills

- **Finite Element Analysis (FEA) – Structural and modal analysis of deployable spacecraft booms**
- **Data-Driven Modeling – Reduced-order modeling, parametric system identification**
- **Composite Structures – CFRP layup design, bistable boom mechanics**
- **Thermal & Structural Analysis – PCBA and spacecraft component qualification**
- **Dynamic Testing – Vibration, shock, and thermal vacuum testing for space hardware**
- **CAD & Simulation Tools – CATIA, SolidWorks, Ansys, Thermal Desktop**
- **Space Systems Design – CubeSat structural and thermal design, deployable mechanisms**



Education

- ◆ **Virginia Tech (Current)**
PhD in Aerospace Engineering
- ◆ **University of Colorado, Boulder**
MS in Aerospace Engineering
- ◆ **University of Mumbai**
B.Tech. in Mechanical Engineering



Publications and Presentations

- **Journal Articles**

- **Mhadgut, D.**, Phoenix, A., Kenyon, S. P., & Black, J. (2025). Modal Analysis of Self-Deployable Tape Spring Booms: A Reverse Engineering Approach. *Journal of Vibration and Acoustics*, 147(5), 051008. **(Published)**
- **Mhadgut, D.**, Balicki L., Phoenix, A., Gugercin, S., Kenyon, S. P., & Black, J. (2026). Input Load Estimation for Bistable Spacecraft Booms using Data-driven Rational Approximation **(In Progress)**
- **Mhadgut, D.**, Balicki L., Phoenix, A., Gugercin, S., Kenyon, S. P., & Black, J. (2026). Estimating Deployment Loads for Bistable Spacecraft Booms using Data-driven Rational Approximation **(Planned)**
- Barbour, B., Kedrowitsch, A., Downs, J., **Mhadgut, D.**, Aryan, S., Black, J., & Kenyon, S. (n.d.). SpaceNet: A Resource-Efficient Simulation Testbed for LEO Mega-Constellation Networks. *IEEE Access* **(Submitted, Under Review)**

- **Conference Papers**

- **Mhadgut, D.**, Davaria, S., Du, M., Engebretson, R., Gargioni, G., Rhodes, T., & Black, J. (2023). Modal Analysis of a Coilable Composite Tape Spring Boom with Parabolic Cross Section. In *Society for Experimental Mechanics Annual Conference and Exposition* (pp. 99-106). Cham: Springer Nature Switzerland. **(Published)**
- **Mhadgut, D.**, Thomas, P., Du, M., Phoenix, A., Davaria, S., & Black, J. (2023). Environmental Tests of a Parabolic Self-Deployable Tapespring Boom for CubeSat Applications. In *Smart Materials, Adaptive Structures and Intelligent Systems* (Vol. 87523, p. V001T02A001). ASME. **(Published)**
- **Mhadgut, D.**, Phoenix, A., & Black, J. (2024). Data-driven rational approximation for composite boom deployment on a cubesat via Vector-Fitting. In *AIAA SCITECH 2024 Forum* (p. 0410). **(Published)**
- **Mhadgut, D.**, Phoenix, A., Gugercin, S., Kenyon, S. P., & Black, J. (2026). Input Load Estimation for Bistable Spacecraft Booms using Data-Driven Rational Approximation. In *AIAA SCITECH 2026 Forum* **(Submitted)**

Publications and Presentations

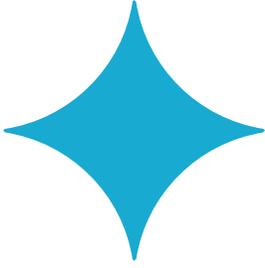
- **Conference Papers (Continued)**

- Engebretson, R., Du, M., **Mhadgut, D.**, Rhodes, T., Spinetta, A., Davaria, S., ... & Black, J. (2022). Ut ProSat-1: A Repeatable Passive Deployer Mechanism for Testing Carbon Fiber Tape Spring Booms. **(Published)**
- Engebretson, R. W., Du, M., **Mhadgut, D.**, Rhodes, T., Spinetta, A., Gargioni, G., ... & Black, J. (2022). A hybrid deployer mechanism for active and passive deployment of a parabolic bistable tapespring for space deployable structures. In *ASCEND 2022* (p. 4338). **(Published)**
- Downs, J. S., Barbour, B., Kedrowitsch, A., **Mhadgut, D.**, Aryan, S., & Kenyon, S. P. (2025). Space Network (SpaceNet) Testbed-Development of a Multi-Functional Testbed for Simulating Space Communication Networks. In *AIAA SCITECH 2025 Forum* (p. 2716). **(Published)**

- **Conference Presentations**

- SES Annual Technical Meeting 2022
- ASME SSDM 2023
- ASME SSDM 2024
- WCCM 2024

Projects and Awards



1. PhD Research : Structural Dynamics of Self-deployable Spacecraft Booms
2. Mechanical Analysis Internship at Benchmark Space Systems
3. Design and Analysis of Small Satellites
4. Estimating wrinkling response of thin, pre-stressed membranes
5. Post-buckling analysis of spherical shells
6. Senior Design Project: Structural design, simulation and analysis of a low altitude sounding rocket

Award

- **Pratt Fellowship (Dean's Scholar) – August 2025**

PhD Research

- A reverse engineering approach for modal analysis of tape spring booms
- An experimental data-driven modeling approach for boom dynamical systems
- Parametric data-driven modeling for boom dynamical systems

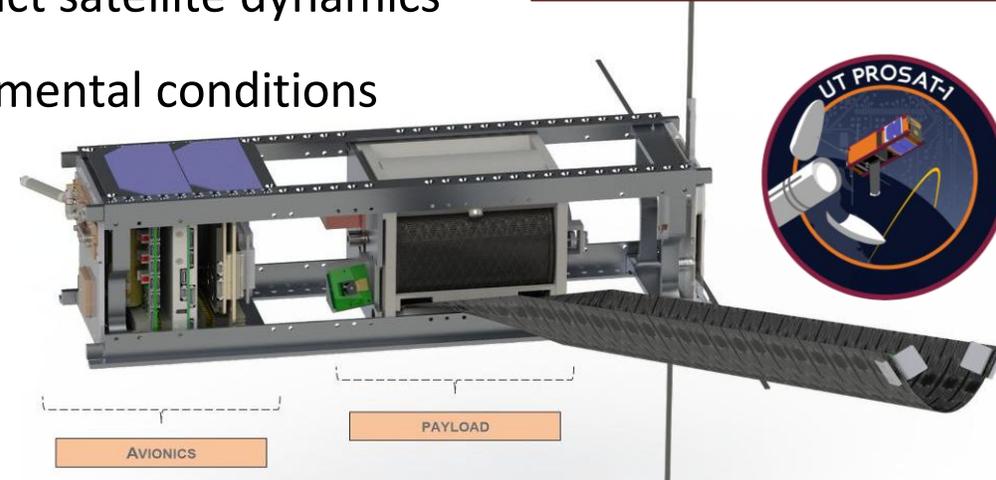
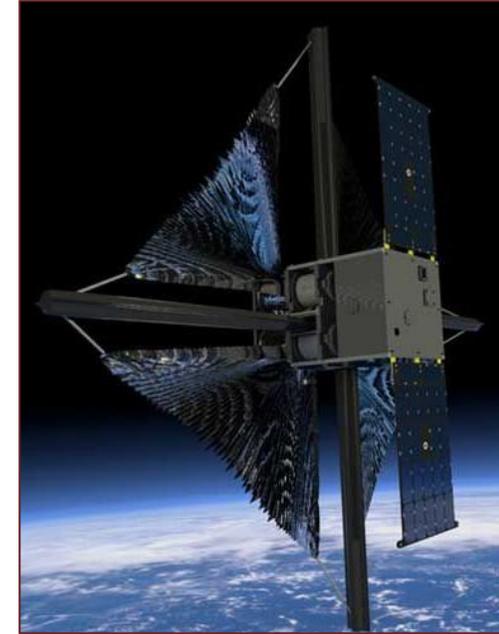
Background and Motivation

Need for CFRP Booms in Deployable Space Structures :

- Viable alternative to massive truss structures for deploying optical and communication systems accurately and can assist in opening massive solar sails
- Lightweight and cheaper compared to standard metallic booms, reduce the fuel mass requirements of ADC systems

Need for Modeling Dynamics of Deployable Booms:

- Passive deployments can be violent and unpredictable, can impact satellite dynamics
- Performance prediction and ensuring reliability in harsh environmental conditions
- Mitigating risk of damage to sensitive satellite components
- Fatigue and long-term reliability issues



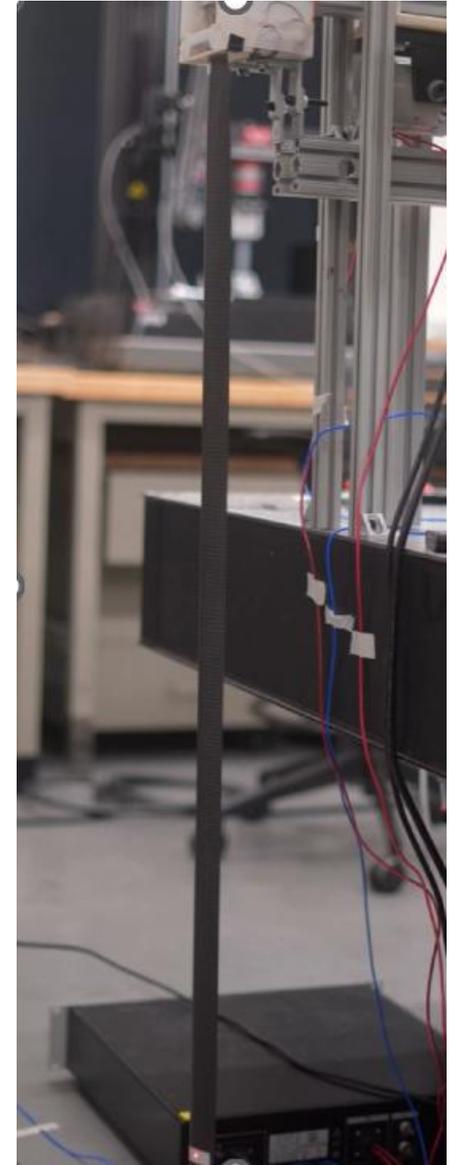
Background and Motivation

Difficulties in Modeling Deployment Dynamics :

- Uncertainties in geometry and stiffness
- Non-uniform cross section and shape with deployer boundary conditions
- Difficulty in direct force measurement due to sensor placement constraints and small-satellite data transmission limits
- Specimen-specific deviations in material properties
- Variable dynamic response with changes in deployment load and temperature

Advantages of prediction of these deployment loads :

- Protect structure & avoid dynamic failure
- Accurate controller design



Research Objectives

- **A reverse engineering approach for modal analysis of tape spring booms**
 - Create a modeling approach for thin deployable booms
 - FEA with conventional CAD approach not sufficient, hence the need for a higher fidelity 3D scanned model
- **An experimental data-driven modeling approach for boom dynamical systems**
 - Data-driven models have higher accuracy, but the system varies significantly with changes in loading
- **Parametric data-driven modeling for boom dynamical systems**
 - Parametric models perform better than individual models. They can be built and used for two parameters: deployment load and temperature.
 - Estimating deployment load from post-deployment boom-tip response
 - Studying effects of temperature on deployment dynamics of tape spring booms

Boom Under Study

- Bi-stable CFRP boom with parabolic cross section
- Composite layup properties [45PWc/0C/-45PWc] as shown in table below.
- Dimensions:
 - Flattened Width and Coil Height: 70 mm
 - Bistable Coil Diameter: ~78.3 mm
 - Thickness: 0.17 mm
 - Parabola Tip Separation: 52.63 mm
 - Parabola Height: 31.56 mm
 - Length: 1219.2 mm (4 ft)

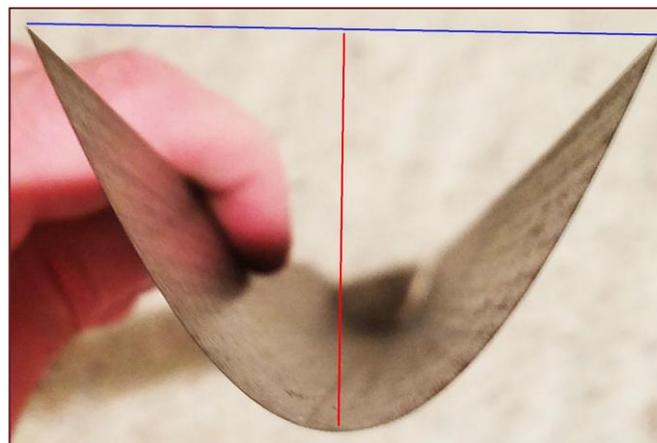


Fig. 1 Boom geometry

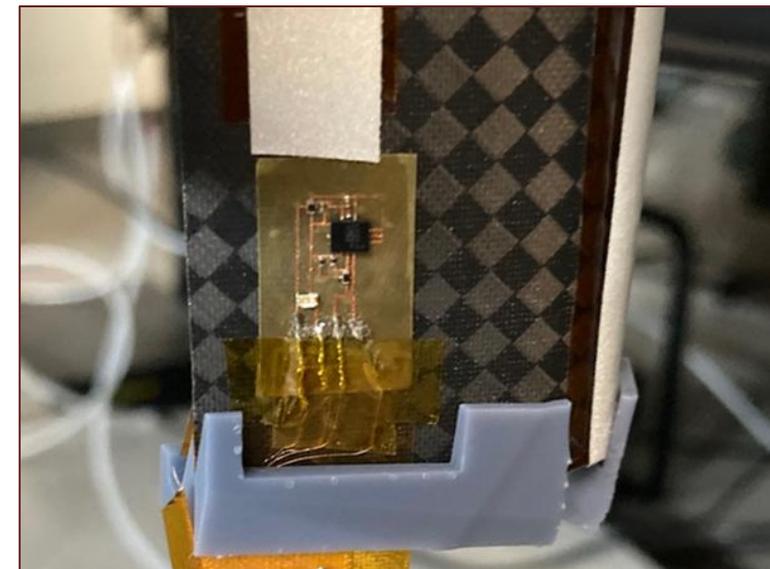


Fig. 2 Boom tip IMU circuit[2]

Ply Material	Fiber/Resin	E_1 [GPa]	E_2 [GPa]	ν_{12}	G_{12} [GPa]	Thickness t [μm]
Unidirectional Carbon Fiber	MR60H/PMT-F7	144.1	5.2	0.335	2.8	40.0
Plain Weave Carbon Fiber	M30S/PMT-F7	89.0	89.0	0.035	4.2	58.2

Table 1 Boom layup properties [1]

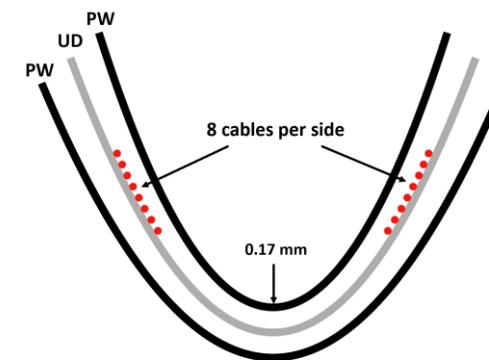


Fig. 3 Cross-section showing plies and embedded wires

[1] Lee, A. J., and Fernandez, J. M. "Bistable Deployable Composite Booms With Parabolic Cross-Sections." 2022, pp. 1–16.

[2] Yao Yao, Alexandre Ambruso, Juan M. Fernandez, Sven G. Bilén and Xin Ning. "Partially Embedded Flexible Electronics for Mechanical Measurement of Deployable Bi-Stable Composite Boom"

Boom deployer setup

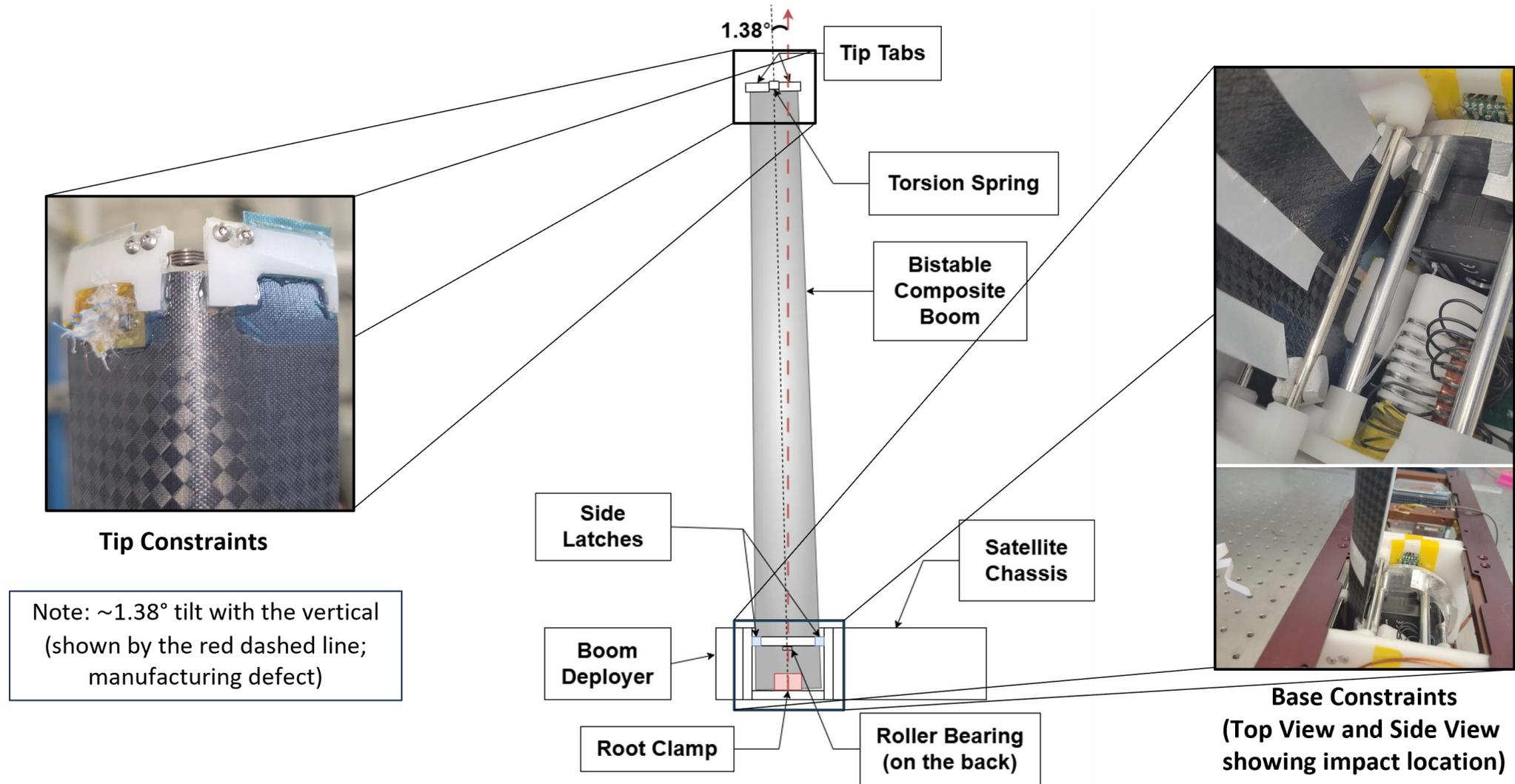


Fig. 4 Boom deployer setup and internal constraints

Objective 1 : Modal Analysis of Tape Spring Booms

Aim : To generate an accurate model for modal analysis of tape spring booms using finite element analysis (FEA)

Methods :

1) Constant Cross Section (CS) Model :

- Model with idealized geometry

2) Discrete Measurement Models (DMM) :

- Capturing variation in cross-section via measurements at multiple points along the length

3) Point Cloud Model (PC) :

- High fidelity geometry capture using 3D scanning

4) Experimental Validation

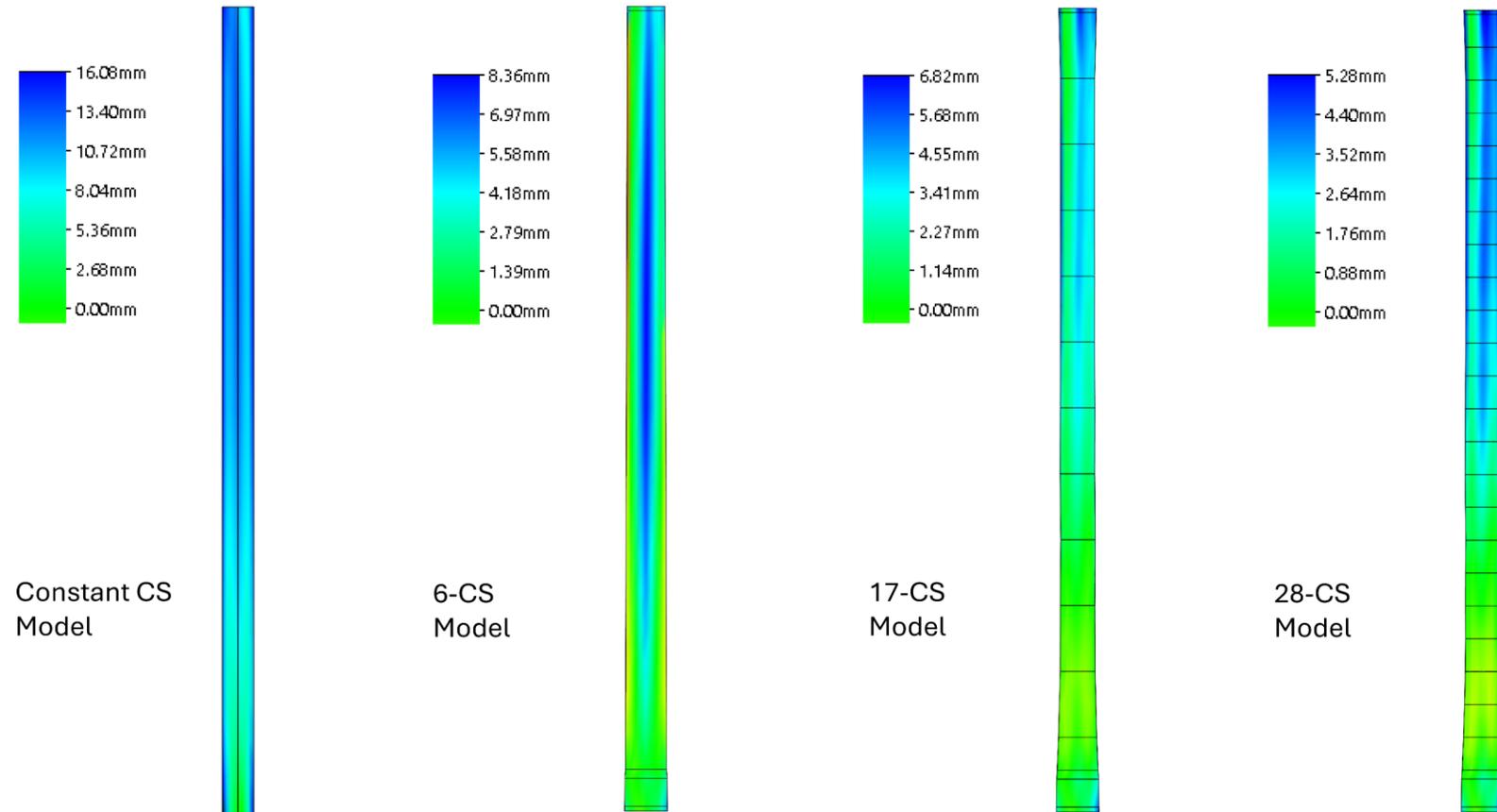
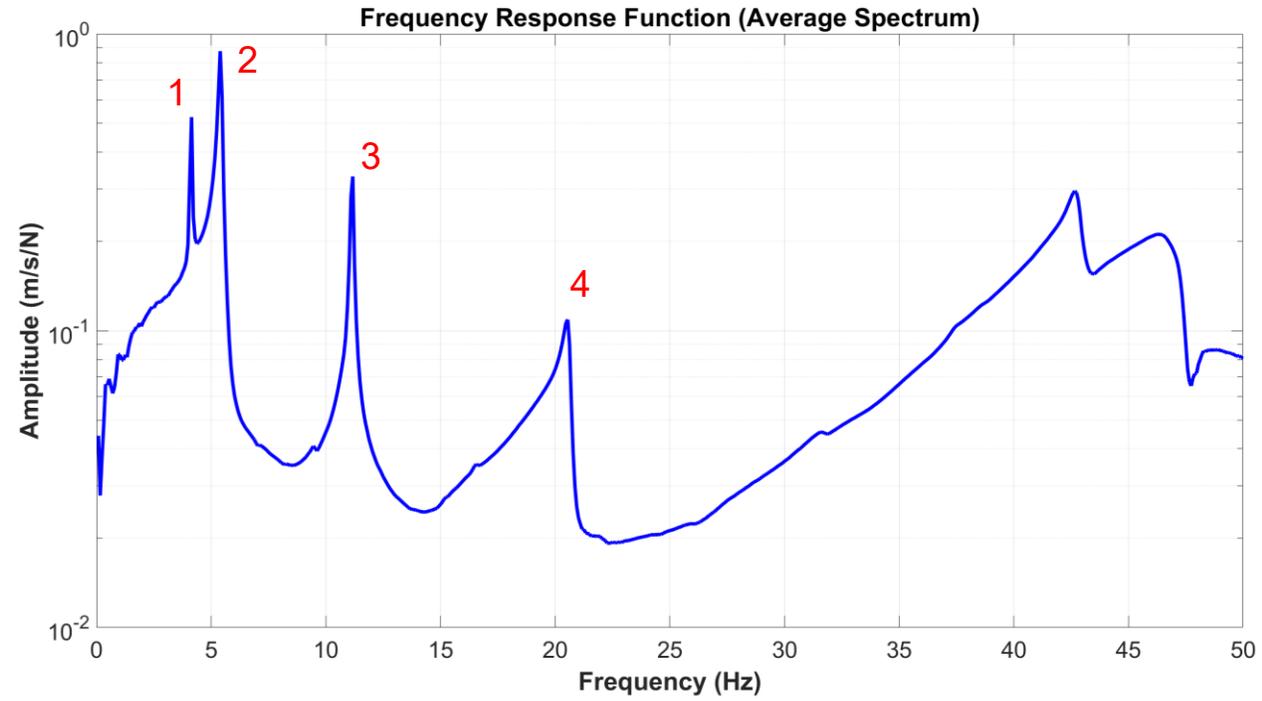
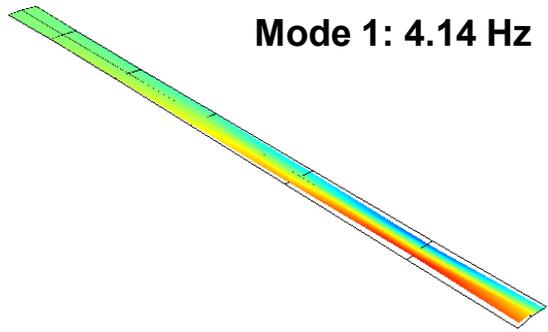


Fig. 5 Geometry deviation relative to Point Cloud Model

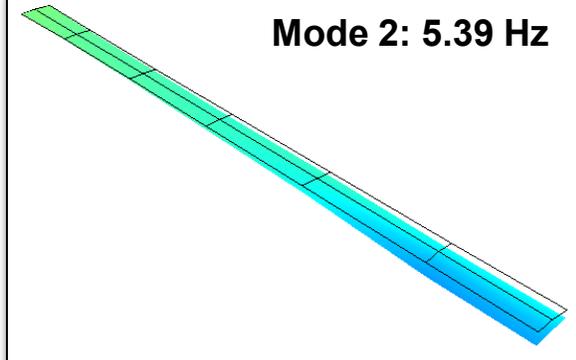
Experimental Modes



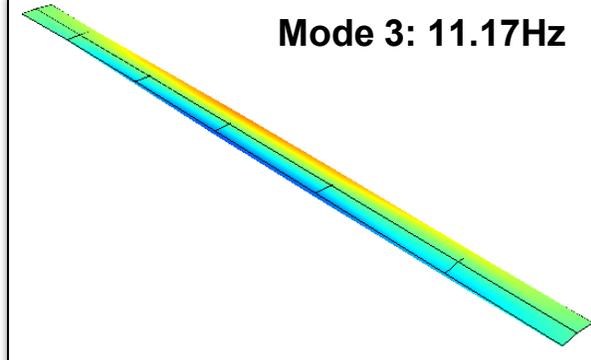
Mode 1: 4.14 Hz



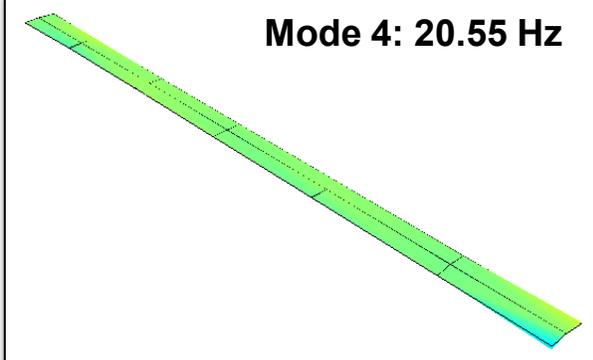
Mode 2: 5.39 Hz

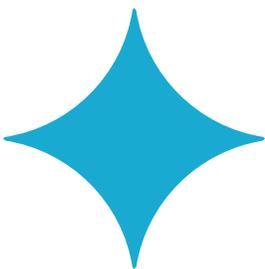
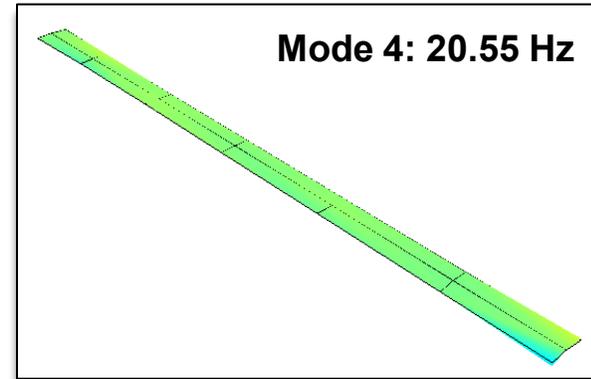
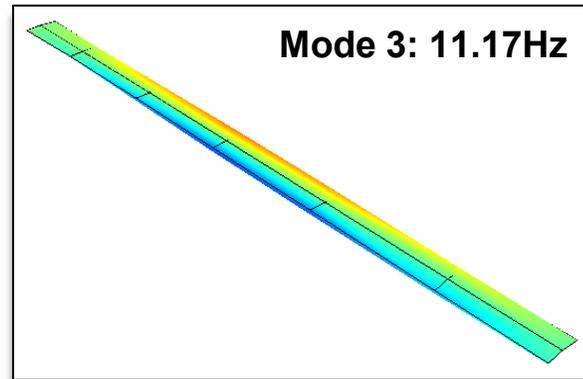
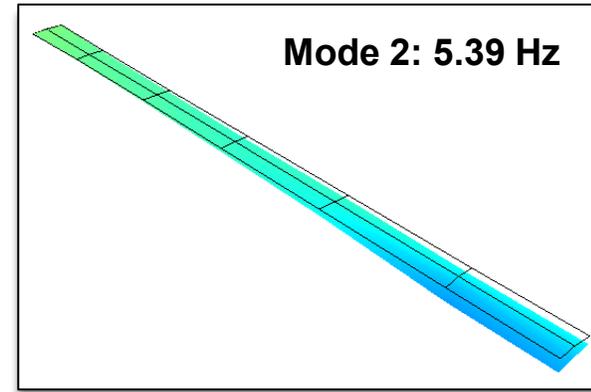
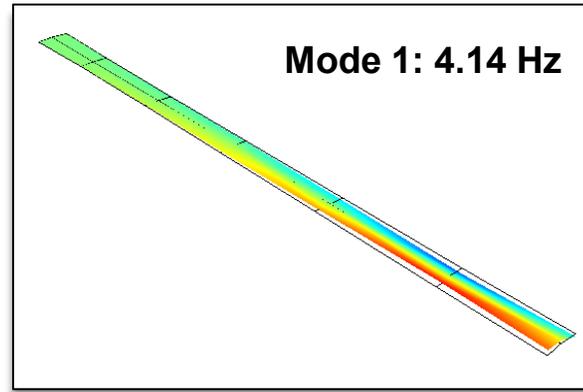


Mode 3: 11.17Hz



Mode 4: 20.55 Hz





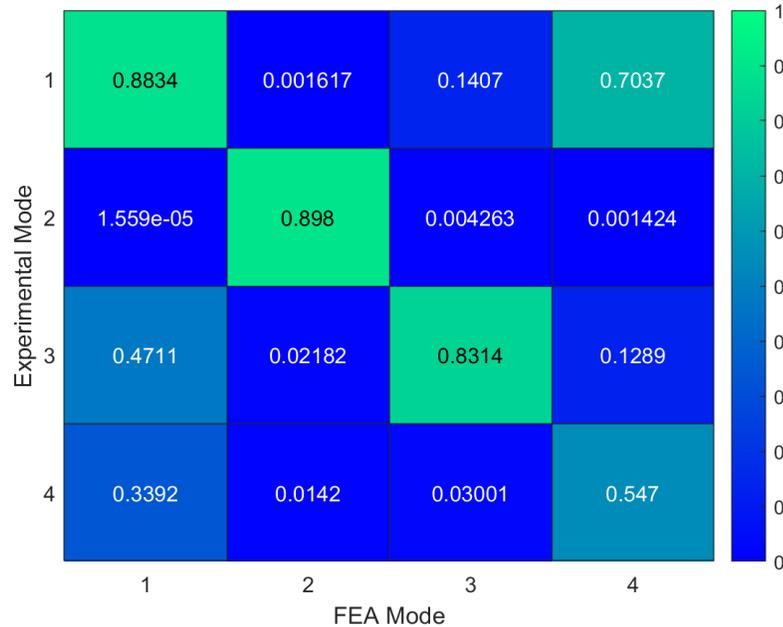
Correlating Mode Shapes using MAC

The **cross modal assurance criterion** (or cross-MAC) was used to correlate the mode shapes from the experimental and the 3D scan-based finite-element model.

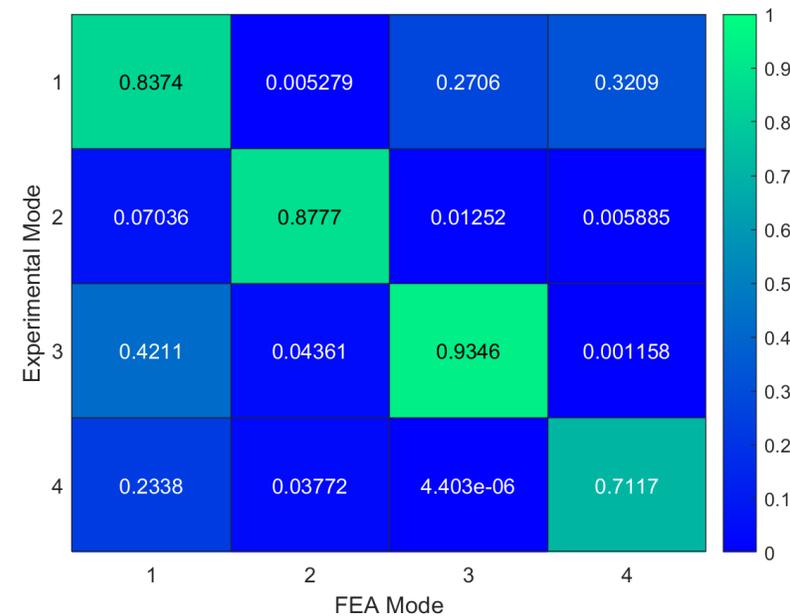
$$\text{MAC}(r, q) = \frac{|\{\varphi_A\}_r^T \{\varphi_X\}_q|^2}{(\{\varphi_A\}_r^T \{\varphi_A\}_r)(\{\varphi_X\}_q^T \{\varphi_X\}_q)}$$

where φ_A and φ_X are the analytical (FEA) and the experimental mode shape vectors respectively and $[r, q]$ is the size of the MAC matrix.

DMM 28-CS Model



Point Cloud Model



Results Summary

Modes	Const. CS	DMM 6-CS	DMM 17-CS	DMM 28-CS	Point Cloud	Experiment
1	5.26	4.54	3.83	3.82	4.09	4.14
2	12.48	5.19	6.40	6.39	5.59	5.39
3	20.79	16.18	15.20	15.03	14.59	11.17
4	N/A	25.45	25.82	25.66	21.42	20.55

Modes	Const. CS [%]	DMM 6-CS [%]	DMM 17-CS [%]	DMM 28-CS [%]	Point Cloud [%]
1	27.05	9.55	7.51	7.69	1.21
2	131.54	3.76	18.77	18.59	3.71
3	86.12	44.85	36.06	34.53	30.61
4	N/A	23.84	25.63	24.88	4.23

Table 2 Comparison of natural frequencies (top) and % errors (bottom) between FEM and Experiment

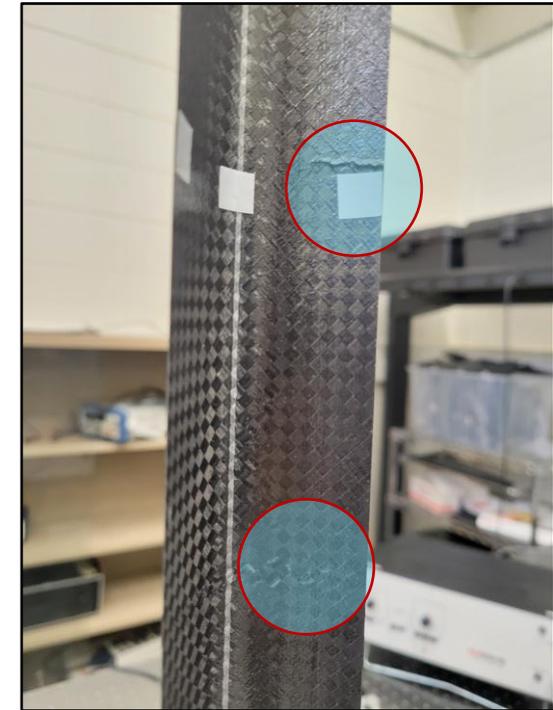


Fig. 8 Boom defects

Key Takeaway: The point cloud approach significantly reduces modeling error, however, there are errors in higher modes due to uncertainties in tip mass, torsion spring stiffness, embedded copper wires, root boundary condition, surface defects/cracks, etc.

Objective 2: Data-driven Modeling for Input Load Estimation

Aim : Accurate prediction of input load from experimental frequency response functions (FRFs) using rational approximation methods.

- Form of FRFs : (Output Velocity)/(Input Force) [(m/s)/N]
- As the tip response is of utmost importance, the FRFs are built and processed for the tip point velocity only
- Periodic chirp signal used for excitation (0.1 – 1000 Hz) over a sweep time of 128 s

State Space Representation of the Mechanical System :

$$M\ddot{q}(t) + C\dot{q}(t) + Kq(t) = Bu(t) \quad \longleftrightarrow \quad \begin{aligned} \dot{x}(t) &= Ax(t) + Bu(t) \\ y(t) &= Cx(t) + Du(t) \end{aligned}$$

$\mathbf{x}(t) \in \mathbb{R}^n$: Internal degrees of freedom (position and velocity),
 $u(t) \in \mathbb{R}$: input (force due to the end of deployment shock),
 $y(t) \in \mathbb{R}$: output (velocity at the tip (near IMU))

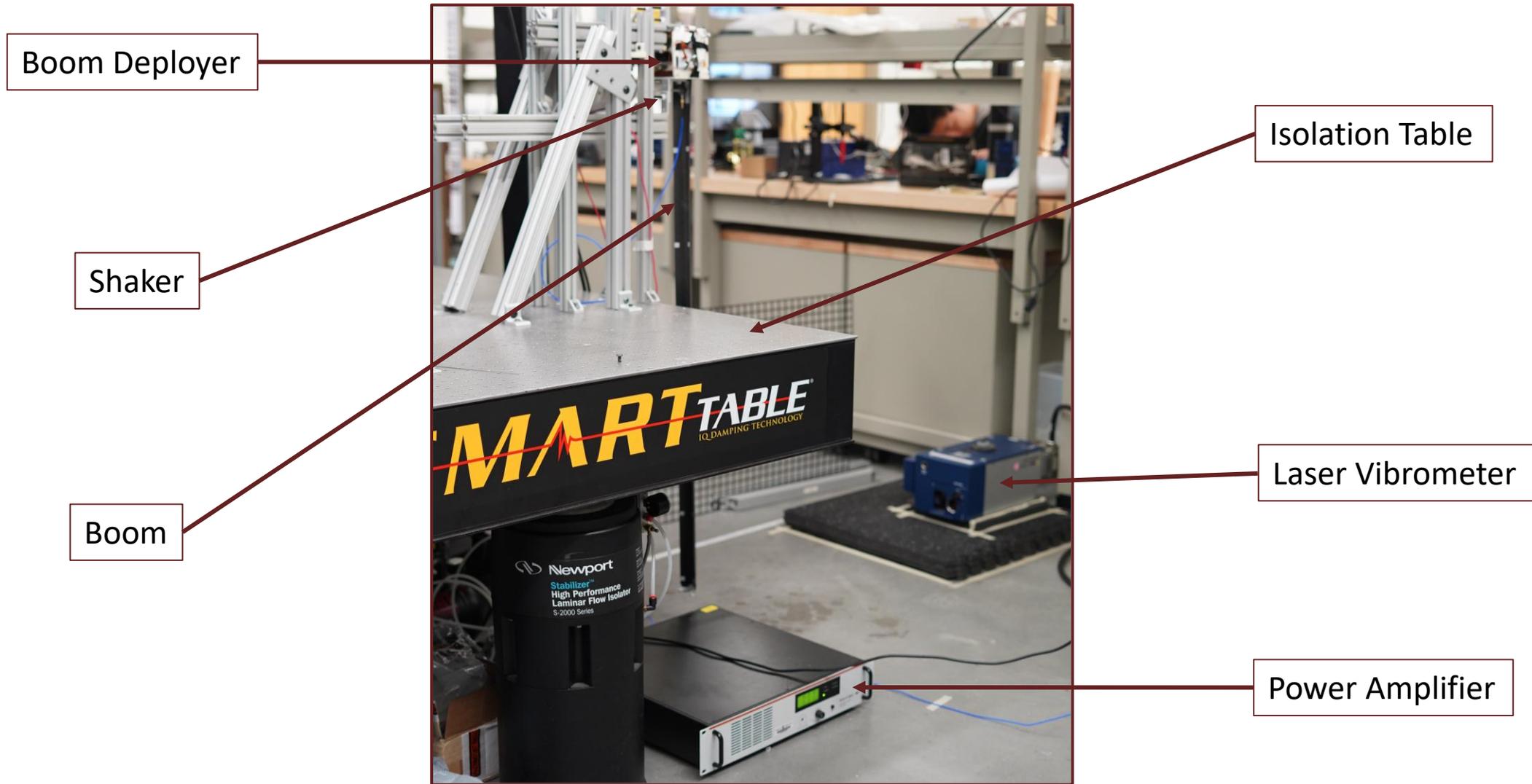
Data Driven Reduced Order Modeling Techniques used :

- 1) Non-parametric Vector Fitting [3]
- 2) Parametric Adaptive Anderson-Antoulas (p-AAA) [4]

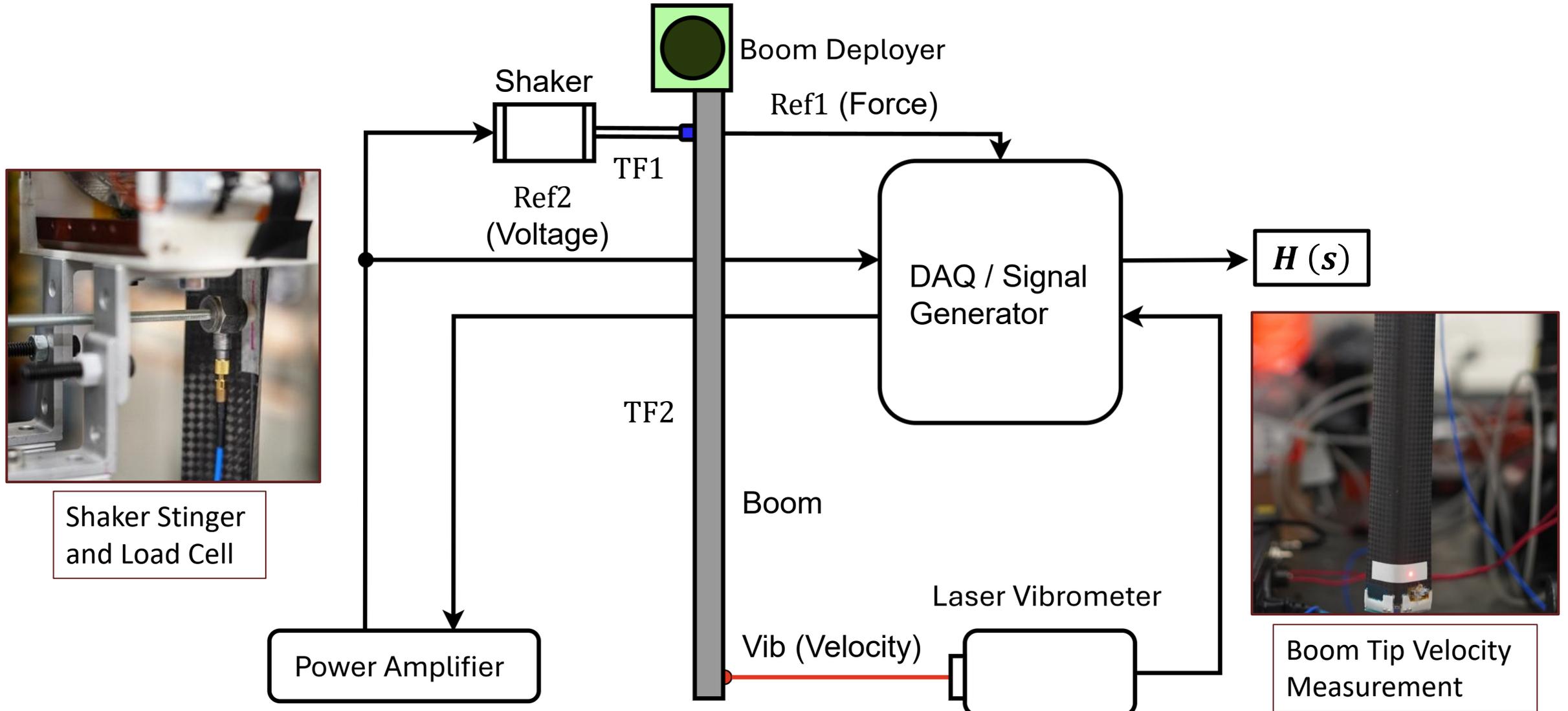
[3] Gustavsen, B., & Semlyen, A. (1999). Rational Approximation of Frequency Domain Responses by Vector Fitting. In IEEE Transactions on Power Delivery (Vol. 14, Issue 3).

[4] Rodriguez, A. C., Balicki, L., & Gugercin, S. (2023). The p-AAA Algorithm for Data-Driven Modeling of Parametric Dynamical Systems. *SIAM Journal on Scientific Computing*, 45(3), A1332–A1358. <https://doi.org/10.1137/20m1322698>

Experimental Setup and Data Collection



Test Schematic



Frequency Domain Inversion for Input Estimation

The dynamic relationship between an input force $f(t)$ and the resulting system velocity $\dot{x}(t)$ can be represented in the time domain using the convolution integral:

$$\dot{x}(t) = \int_0^t h(t - \tau)f(\tau)d\tau$$

where $h(t)$ is the impulse response function of the system. Applying Fourier transforms converts this convolution into a multiplication in the frequency domain:

$$\{\dot{x}(s)\} = [H(s)]\{F(s)\}$$

where H is the frequency response function (FRF). Replace FRF with the H_1 estimator of the transfer function given by:

$$H_1(s) = \frac{\mathcal{G}_{vf}(s)}{\mathcal{G}_{ff}(s)}$$

where $\mathcal{G}_{vf}(s) = E[V(s)F(s)^*]$ is the cross-spectral density and $\mathcal{G}_{ff}(s) = E[F(s)F(s)^*]$ is the auto-spectral density. $E[]$ is the estimator function and $()^*$ is the complex-conjugate of a matrix. The time history of the input force can then be obtained using the inverse Fourier Transform as shown below:

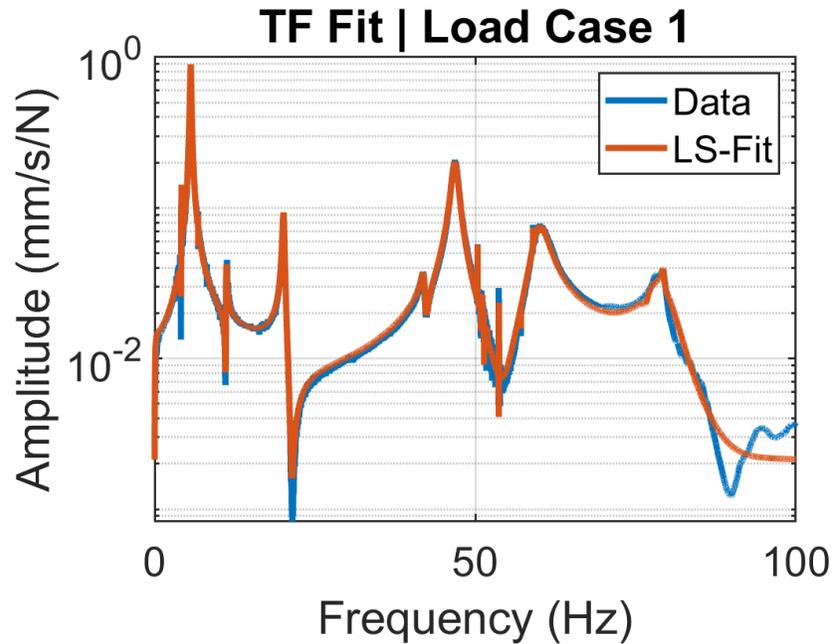
$$\{F(s)\} = \text{pinv}[H_1(s)] \cdot \{\dot{x}(s)\}$$

$$f(t) = \mathcal{F}^{-1}\{F(s)\}$$

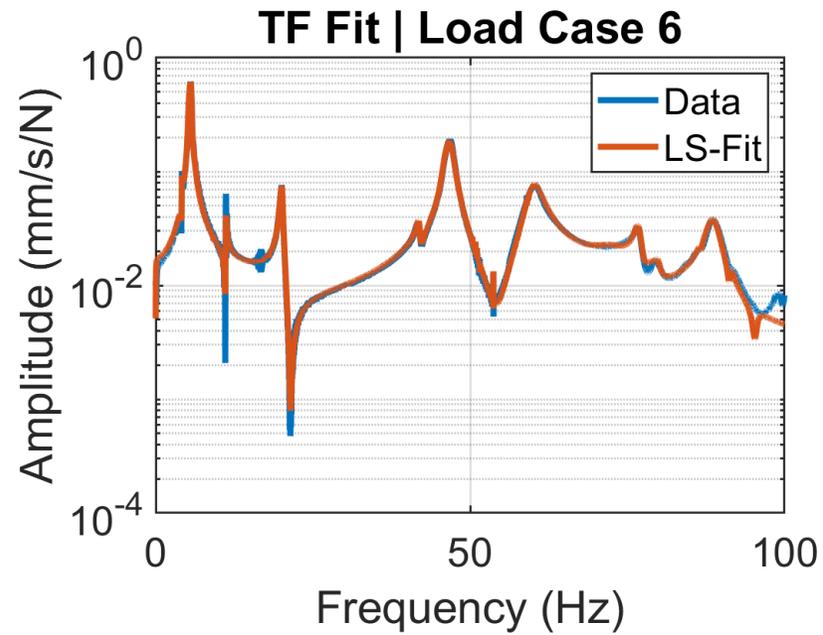
Note: In our work, we replace $H_1(s)$ with $H_r(s)$ obtained from Vector Fitting and p-AAA output of $H_1(s)$ for the non-parametric and parametric studies, respectively.

Data-driven Modeling

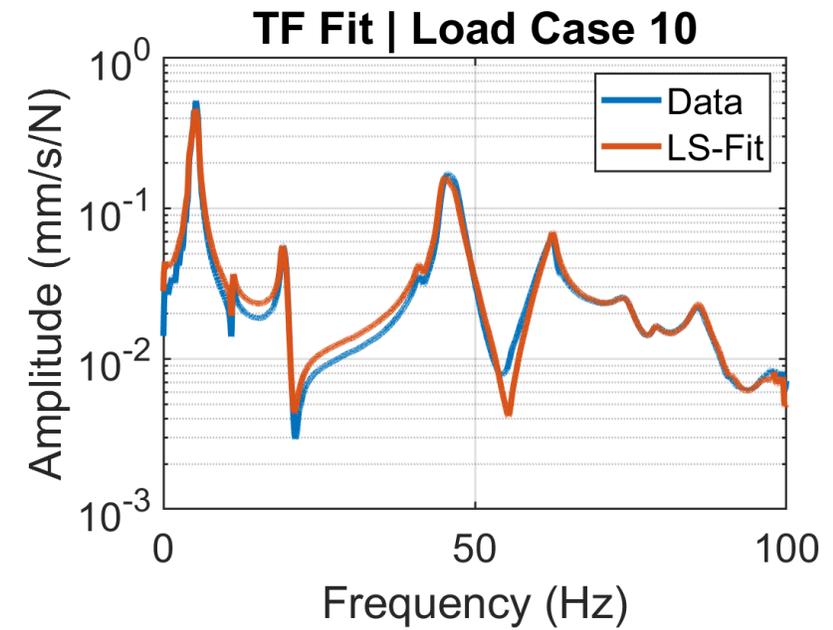
- Vector-Fitting used for least-squares based data-driven rational approximation of the transfer function
- Data: $H(s_k) \in \mathbb{C}, s_k = i\omega_k$, for $k = 1, 2, \dots, 12800$
- We fit an order $r = 200$ rational function $H_r(s)$ to the data for each of the 15 load cases; Load cases 1,6,10 shown here:



Load Case 1: 0.0006 N RMS

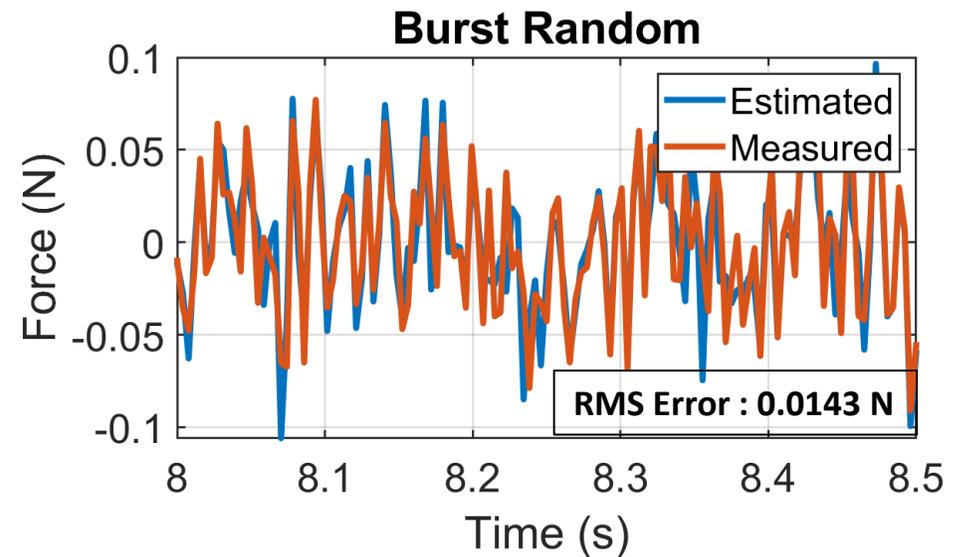
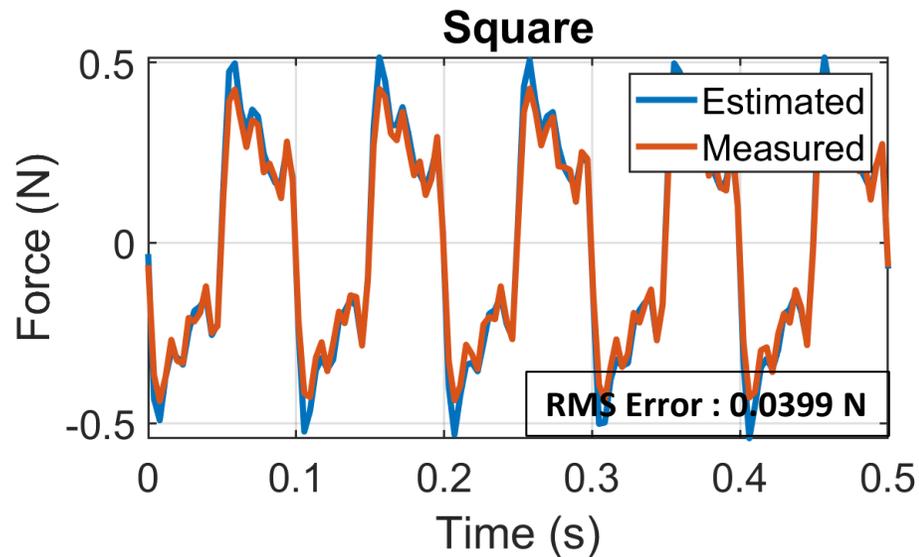
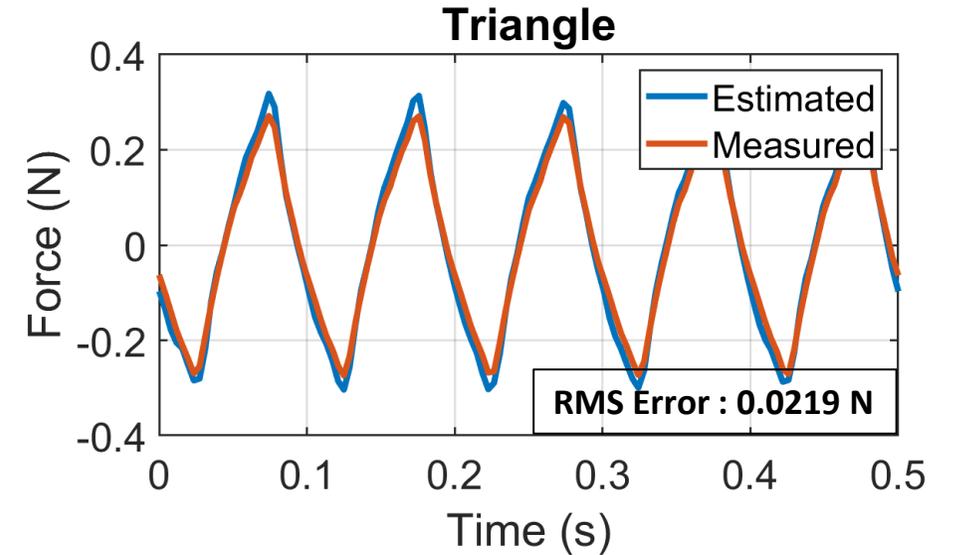
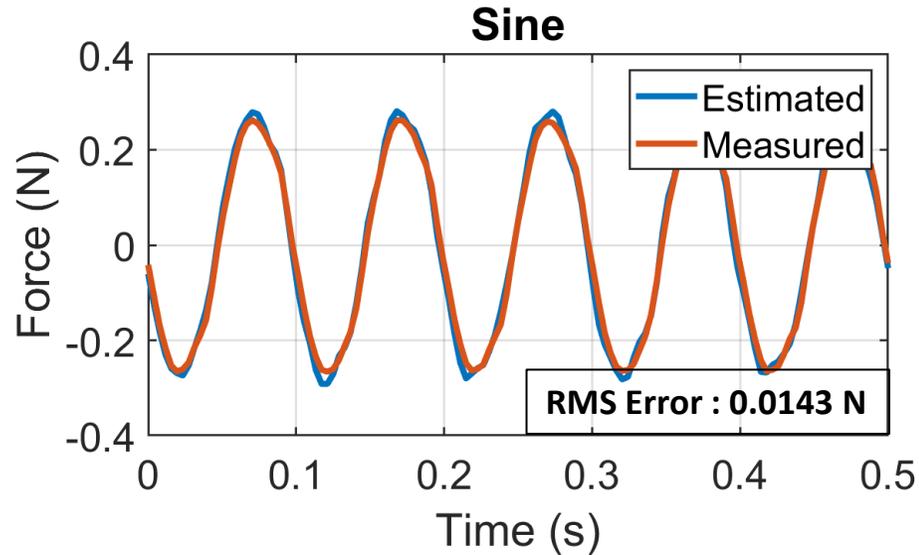


Load Case 6: 0.001 N RMS



Load Case 10: 0.01 N RMS

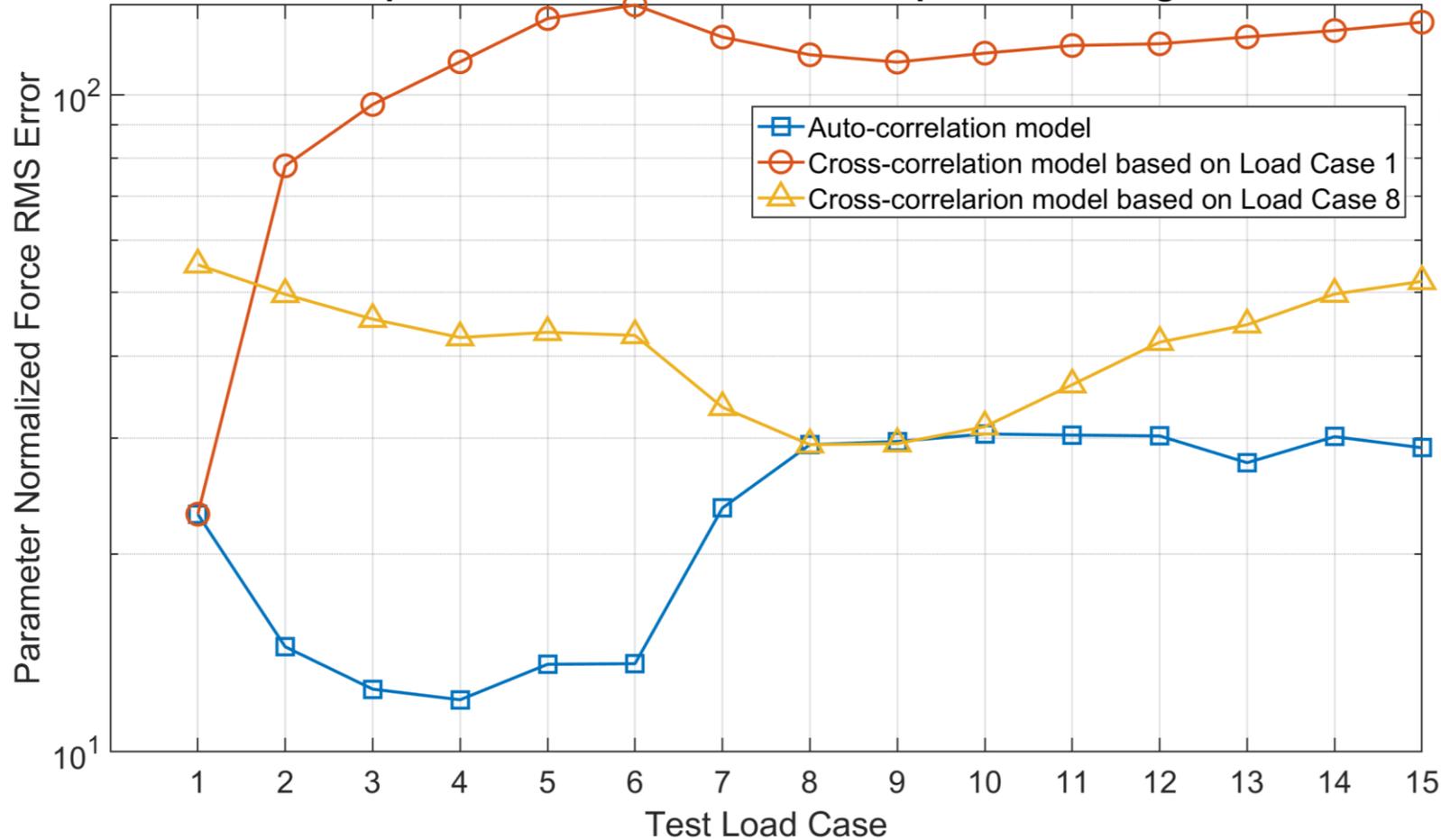
Data-driven Modeling: Test Signals (Load Case 6)



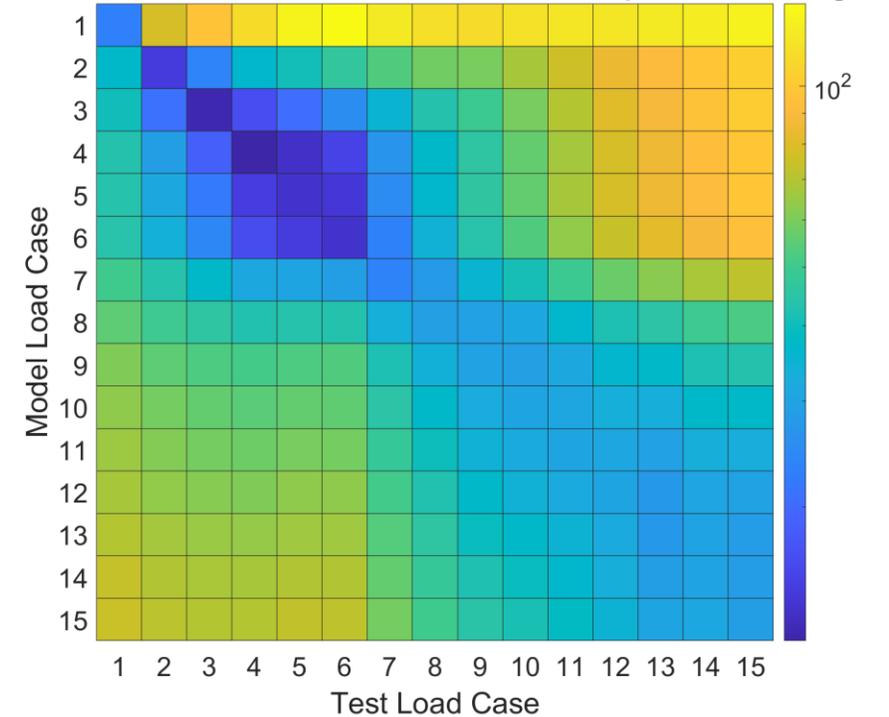
$$F_{\text{test}}(s) = \frac{v_{\text{test}}(s)}{H_{r,\text{ref}}(s)}$$

Frequency Domain Inversion: Other Load Levels and the Need for Parametric Modeling

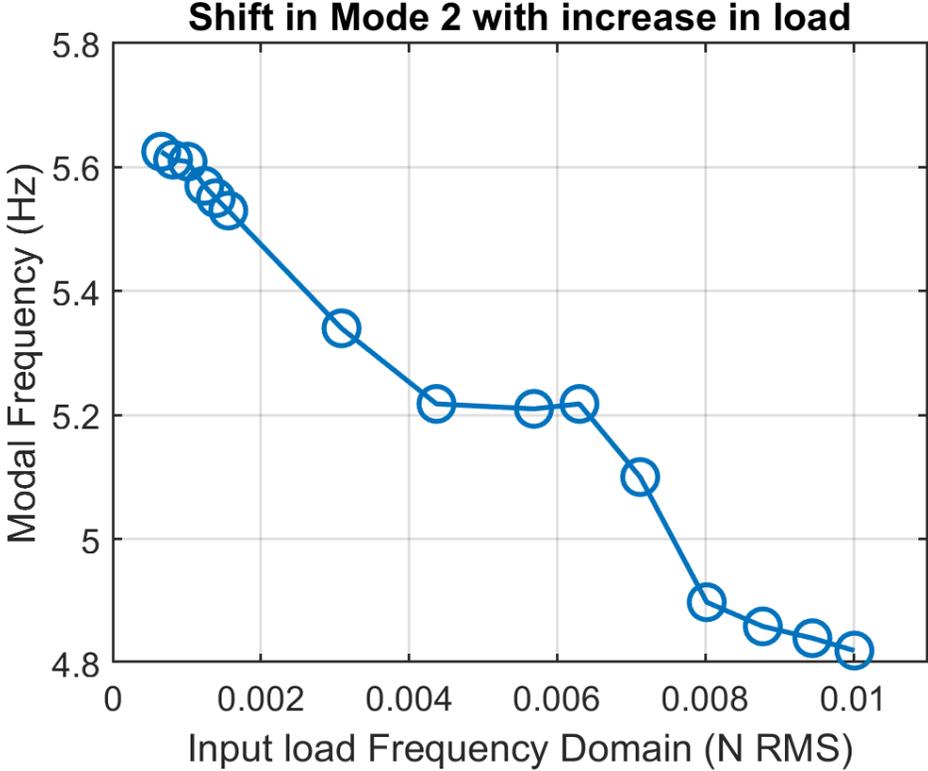
Non-parametric Model : Periodic Chirp Reference Signal



Normalized RMS Force Error for Periodic Chirp Reference Signal



Comparing modal analysis error between FEM and Data-driven Modeling



Modes	Point Cloud [%]	Data-driven Modeling [%]		
		Load Case 1	Load Case 8	Load Case 15
1	1.21	0.00	0.22	1.18
2	3.71	0.09	1.36	0.33
3	30.61	0.17	0.10	0.18
4	4.23	0.00	0.47	0.21

Table 3 Comparison of natural frequencies % errors between FEM and Data-driven Modeling

Key Takeaways:

1. There is a shift in modal frequencies with load amplitude
2. Multiple models required for capturing this variation as seen from increase in errors in the cross-correlation models

Objective 3: Studying effects of temperature on deployment dynamics

Aim : Capturing the variation in dynamic response with temperature as UPS-1 deploys and retracts the boom multiple times along the orbit

UPS-1 On-orbit Data Collection and Instrumentation

- UPS-1 to have a 2-3 year lifetime at an altitude of 400 km
- Two-IMU Configuration with an enclosed IMU at the boom tip and a reference IMU inside the CubeSat chassis
- Boom tip IMU attached to a flexible circuit to measure the transverse vibrations generated due to the shock wave at the end of the boom deployment

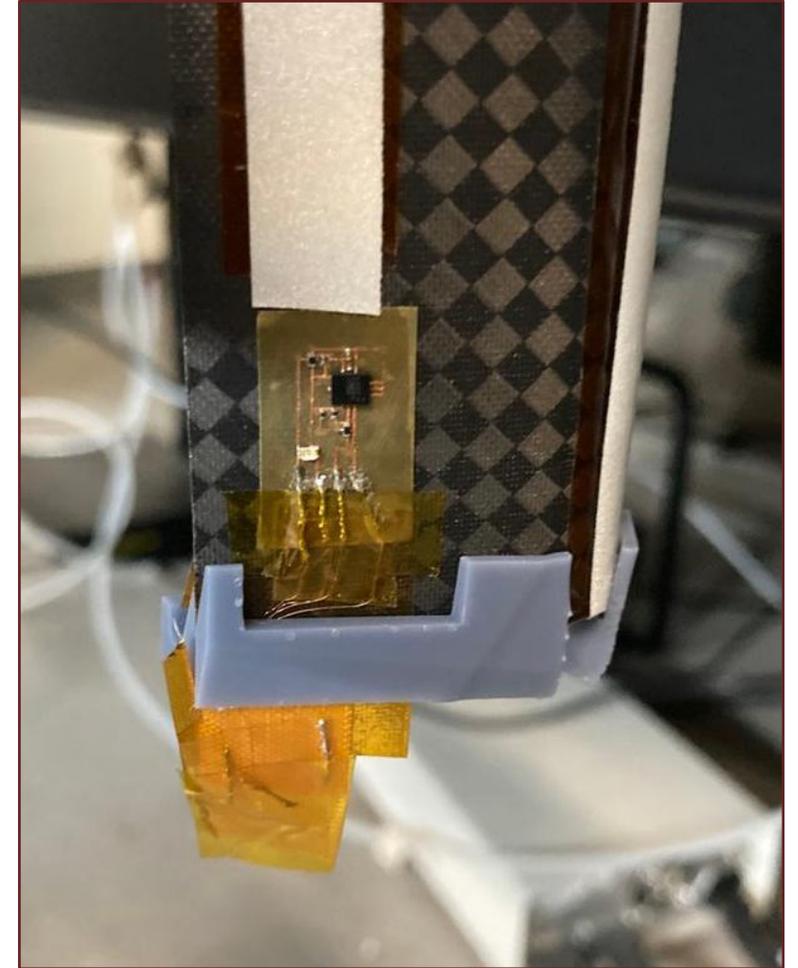


Fig. 10 Boom tip IMU circuit [6]

Thermal Vacuum Tests

- Satellite chassis installed inside a Tenney environmental chamber
- Two IR cameras monitor the temperature on the boom and the PCM board respectively
- The primary aim of the experiments was to simulate on-orbit steady-state scenarios:
 - 25°C No Vacuum (Open Air)
 - 4°C 9 Torr
 - 53°C 9 Torr
 - 70°C 9 Torr
- Aligned the local coordinate systems of the two sensors before processing any data, gravity components removed

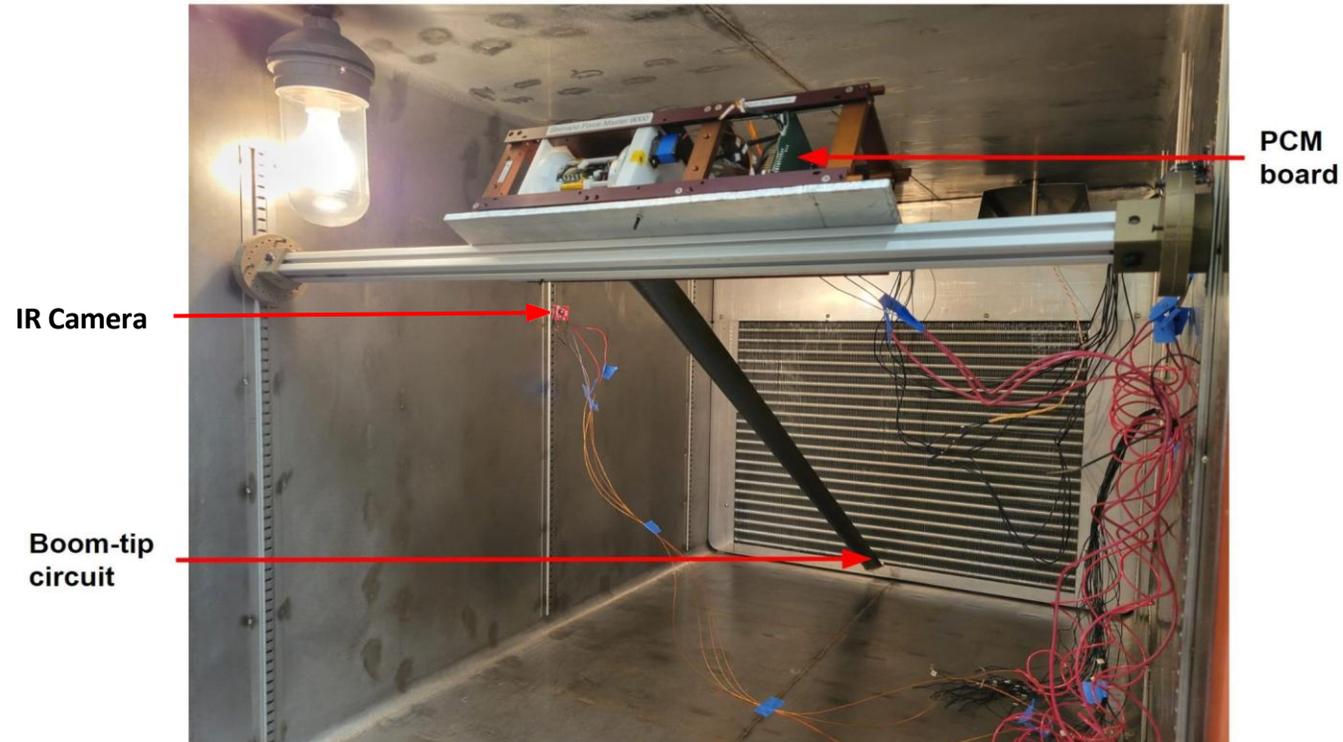


Fig. 10 Satellite chassis and fully deployed boom in the TVAC chamber

Acceleration response of the boom-tip

- Modified periodogram (power spectral density (PSD) estimate) obtained using the Welch's method as the FFT data was noisy
- PSD data from the PCM sensor remains constant with the same three peaks at all the temperatures
- Mode shifts observed for the boom-tip sensor

Test		Mode 1 (Hz)	Mode 2 (Hz)	Mode 3 (Hz)
25°C No Vac	Boom	-	5	-
	PCM	19.6	39.2	59.8
4°C 9 Torr	Boom	3.4	5.2	12.6
	PCM	19	38	59.2
53°C 9 Torr	Boom	-	5	10
	PCM	19	38	59
70°C 9 Torr	Boom	4	5	11.2
	PCM	19	38	59

Table 4 Frequency mode shifts at different temperatures

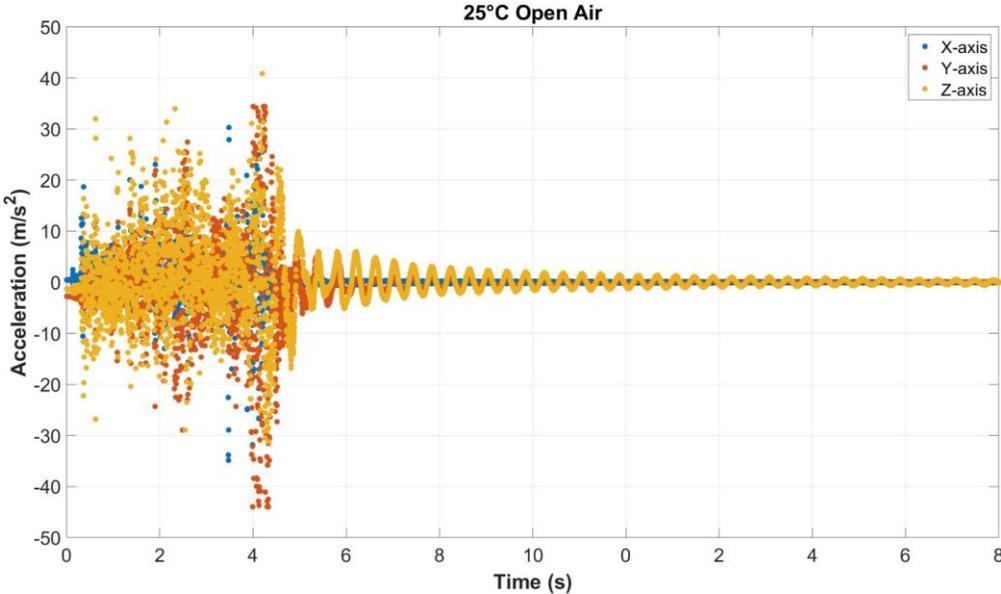
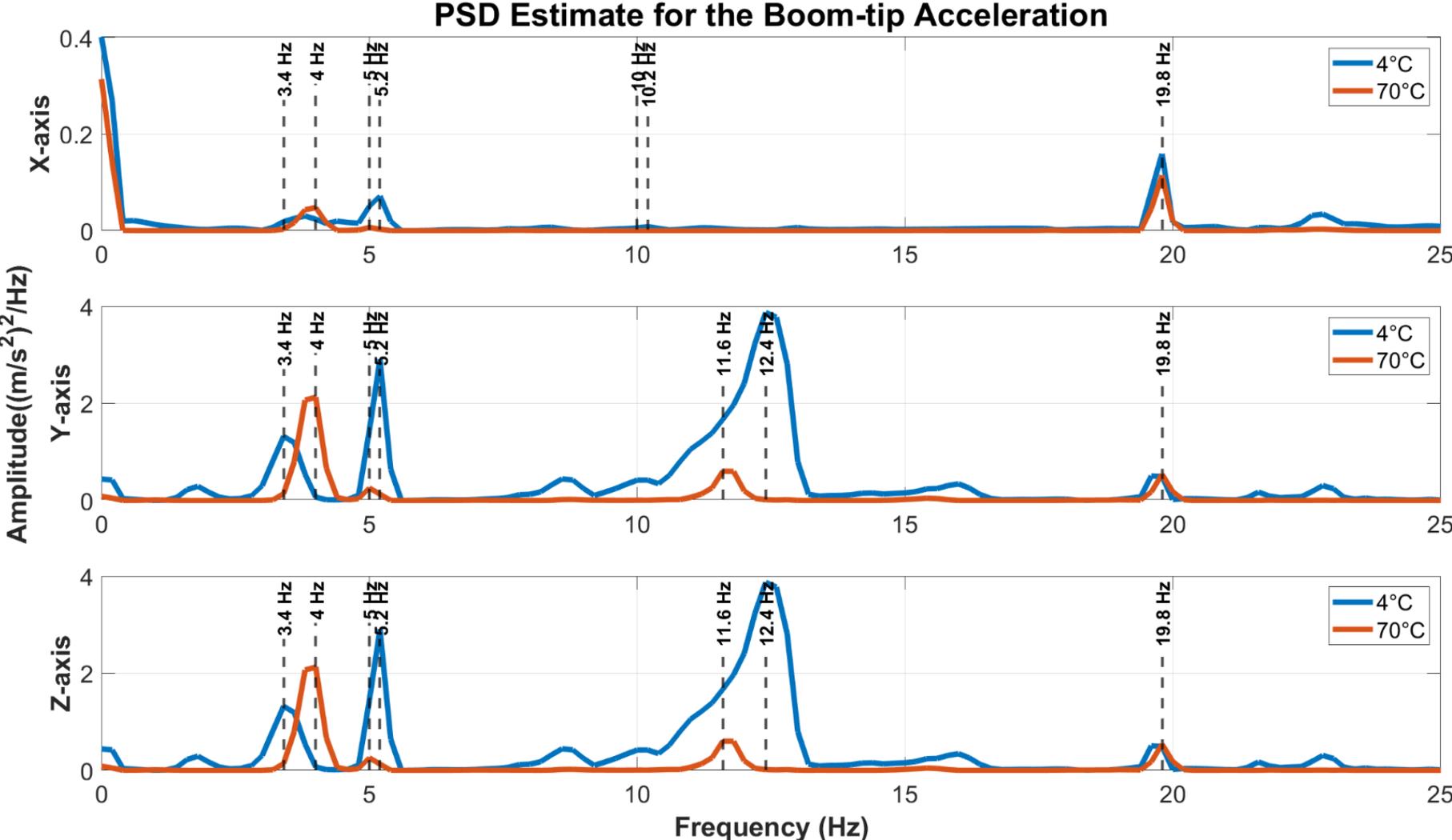


Fig. 11 Acceleration response from the boom-tip IMU

PSD plots and mode shifts (Boom Tip Acceleration)



Other parameters

- Decrease in maximum deployment velocity observed with increase in temperature due to viscous relaxation of the composite
- Damping ratios calculated for the fundamental resonance mode using the 'Half-power' method

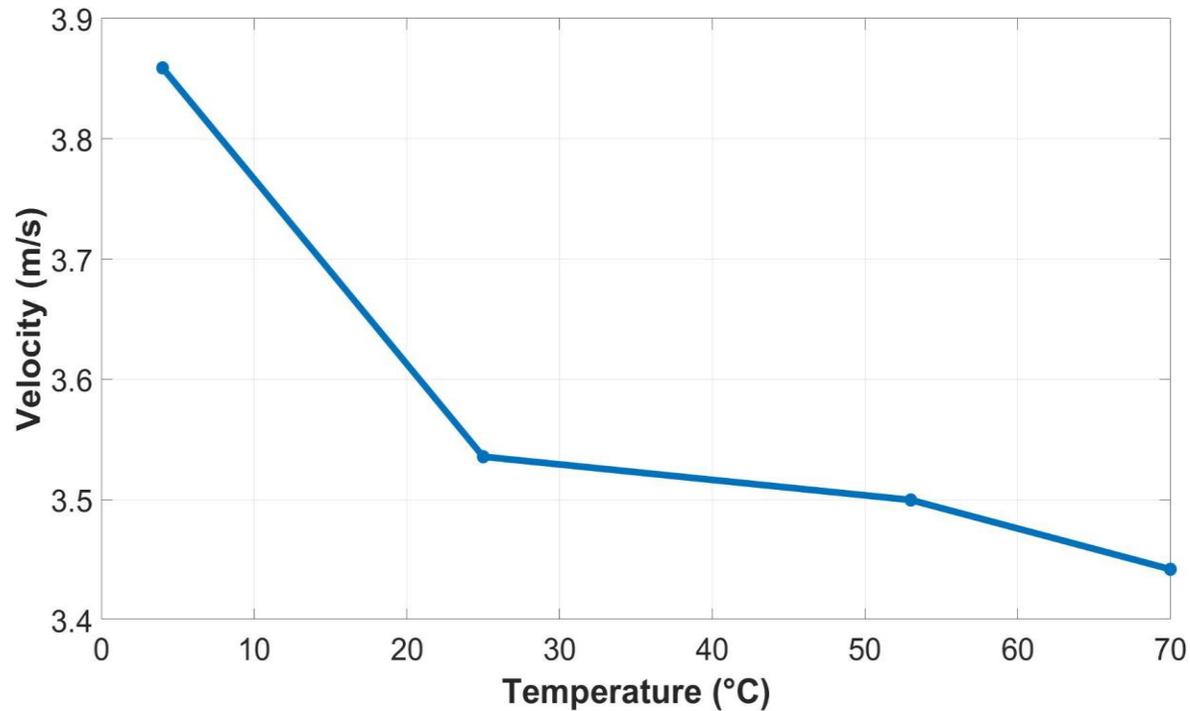


Fig. 12 Peak deployment velocity of the boom (X-component)

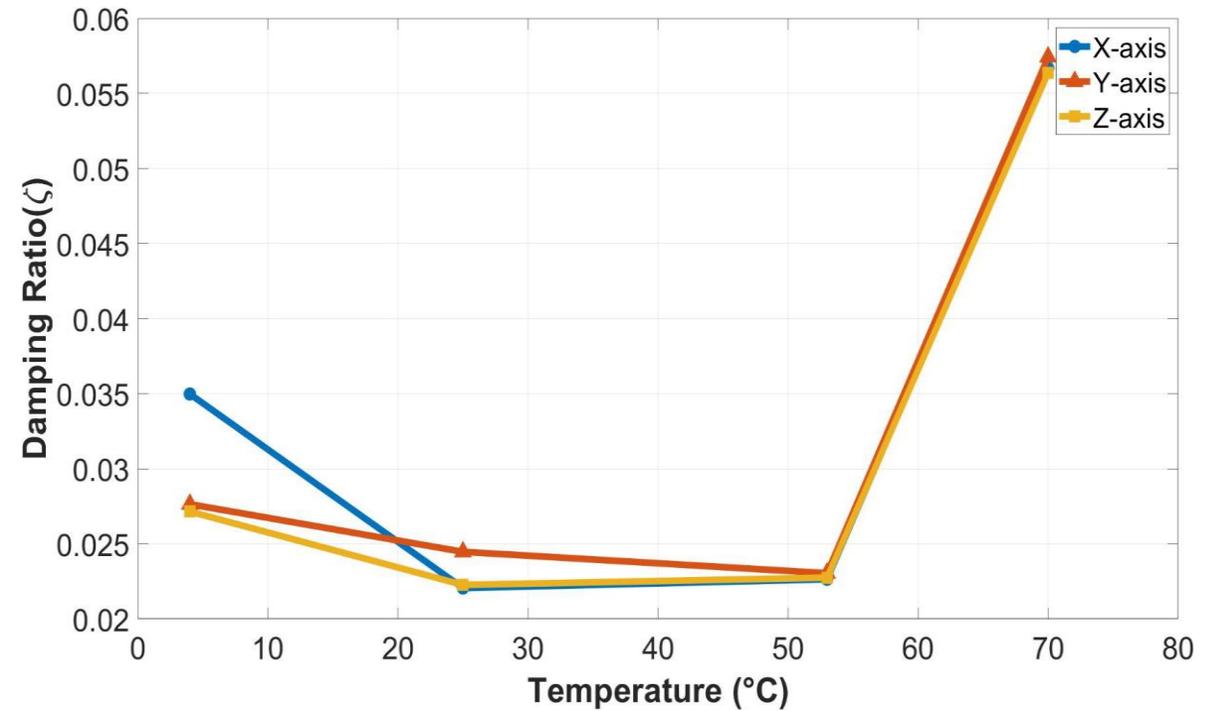


Fig. 13 Damping ratio for the first mode- boom tip

Research Contributions

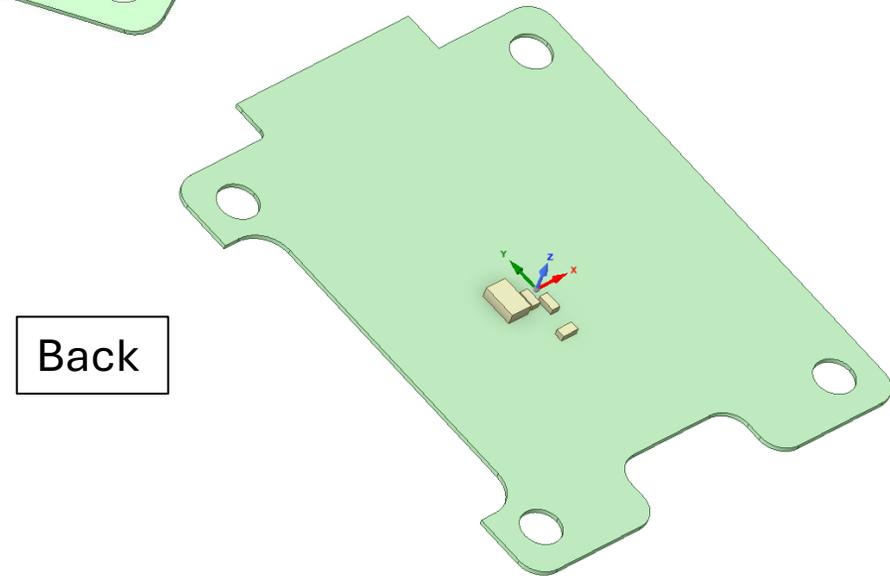
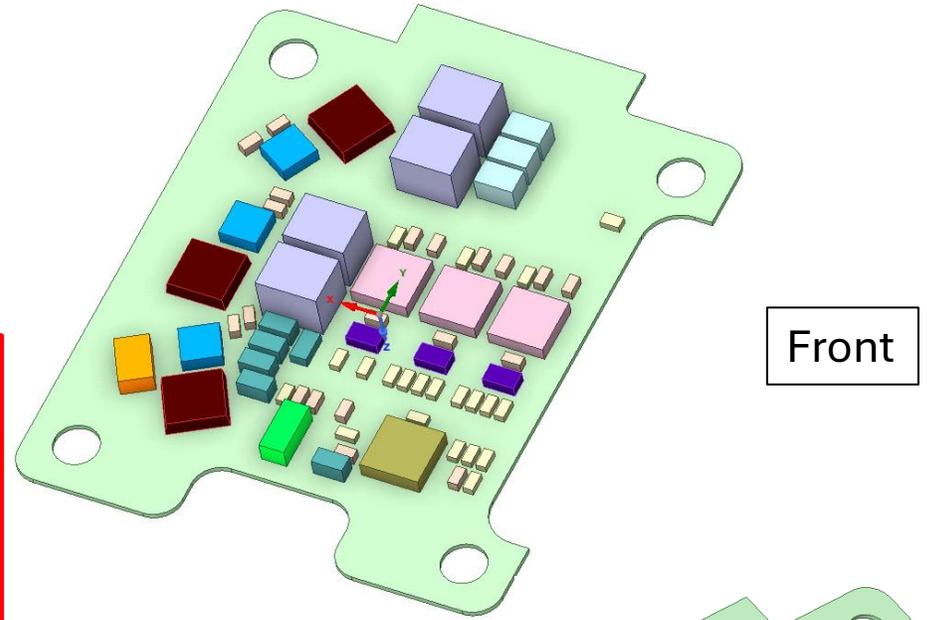
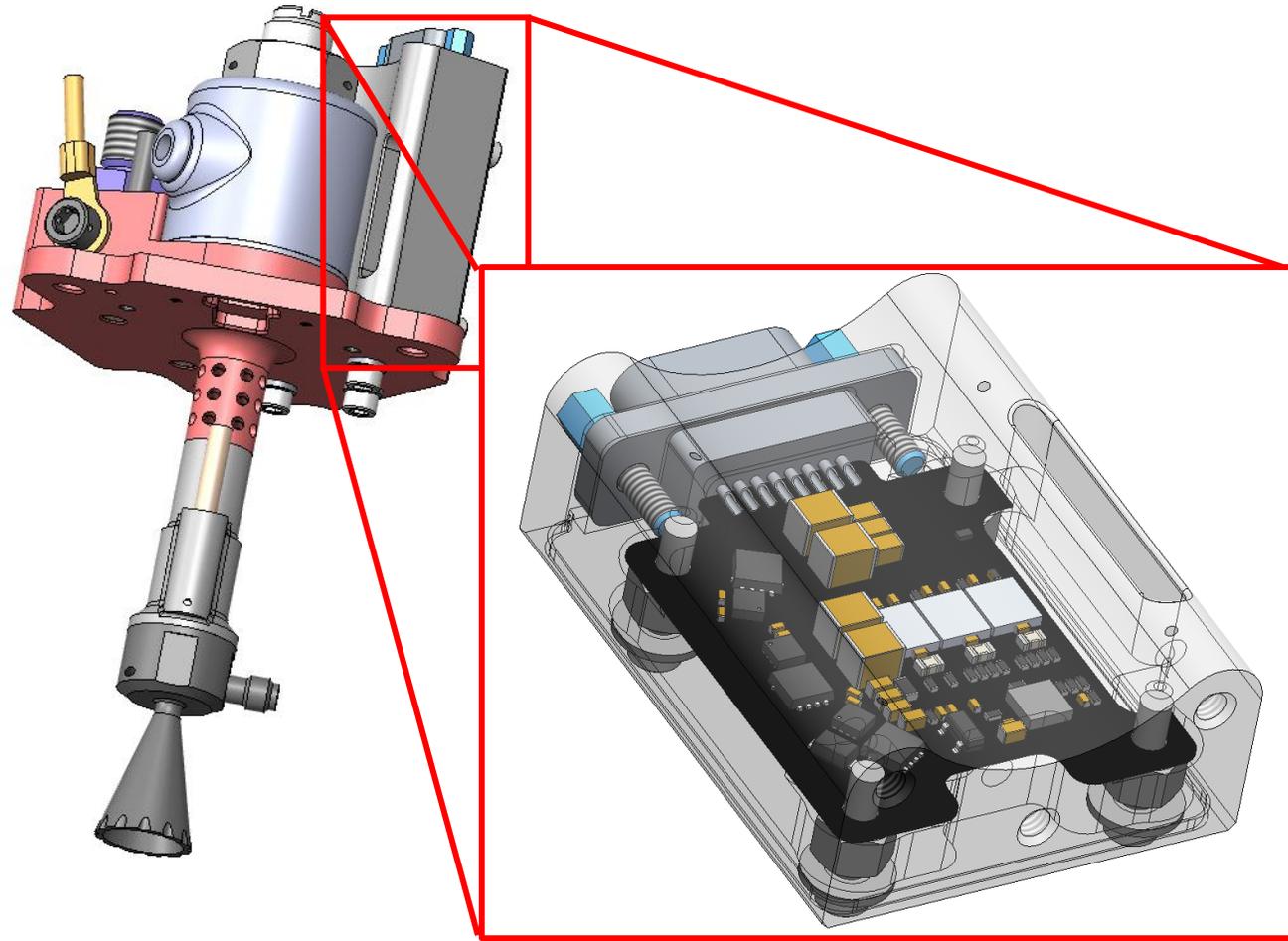
- Developed a novel reverse engineering method to significantly improve the geometric fidelity of thin deployable structure models, establishing that high-accuracy geometry is critical for accurate dynamic characterization
- Created a robust parametric model of the structure's dynamics using a novel input load estimation method and demonstrated, via cross-validation, that this parameter-based model offers superior predictive generalizability over non-parametric approaches.
- Applied this input load estimation method to a deployment tests for self-deployable booms
- Showed the effect of temperature on the dynamic behavior of self-deployable booms via thermal-vacuum tests

Projects at Benchmark Space Systems (Internship)

Project 1: PCBA Analysis

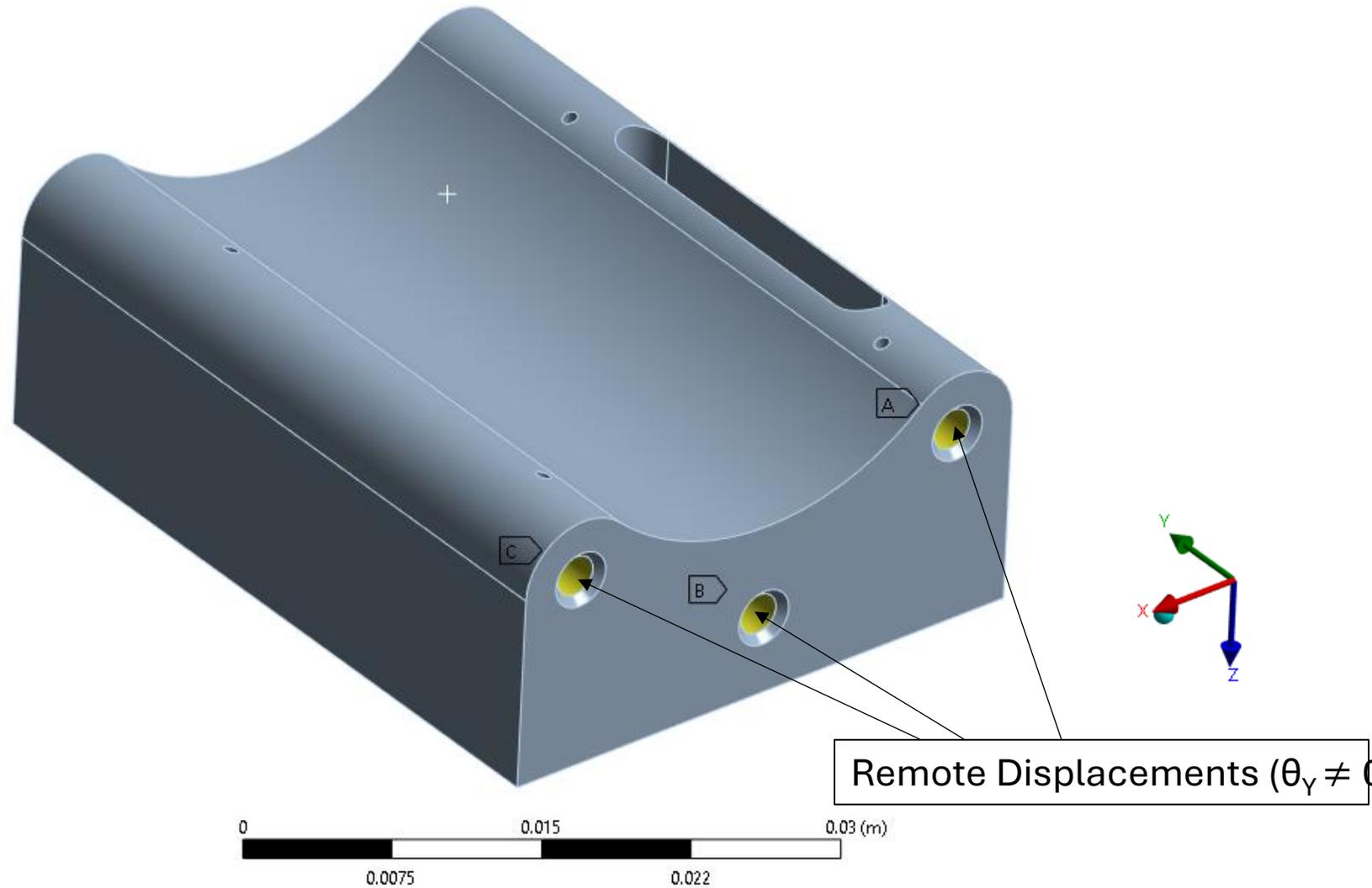
PURPOSE: STRUCTURAL AND THERMAL ANALYSIS TO ASSESS RISK IN THE DESIGN PRIOR TO ENVIRONMENTAL TESTING

Design Overview : Thruster PCBA

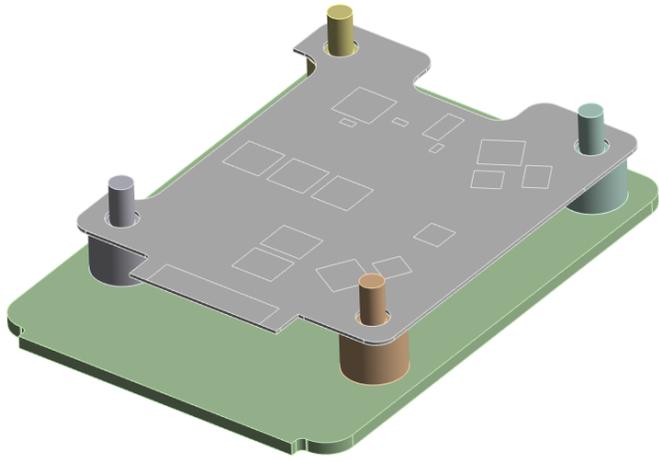


Structural Analysis: 3D Model Details

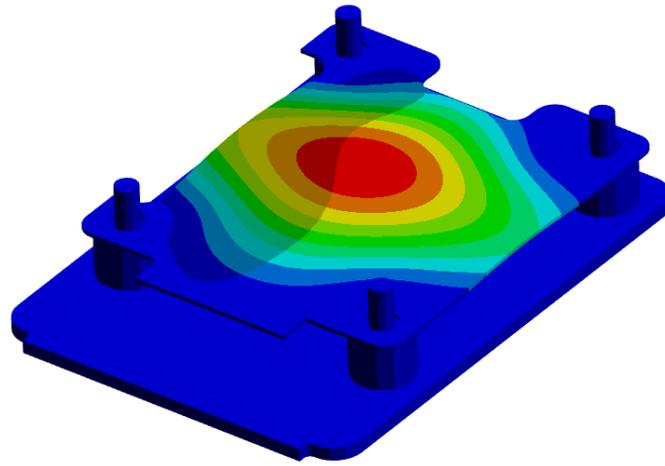
- Remote Displacement boundary conditions applied at the three bolted joints for enclosure mounting to avoid over-constraint, modeled as beams with stiffness based on the bolt material (A286 NAS1352-N)
- Mass of electronic components added via a density scaling factor on the bare PCB density
- Stiffness addition due to components ignored
- J1 connector ignored in the model
- Steinberg PCBA allowable deflection methodology used



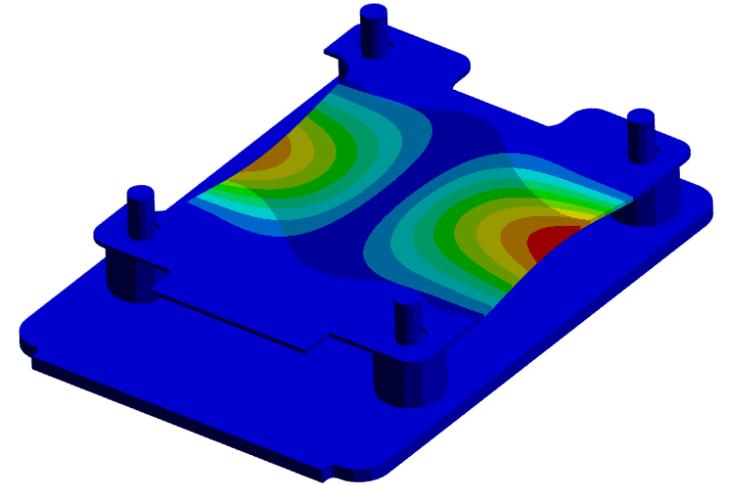
Modal Analysis Results



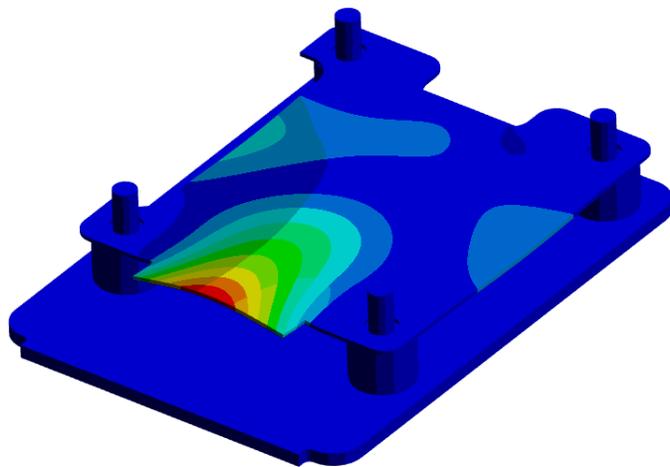
Undeformed Model



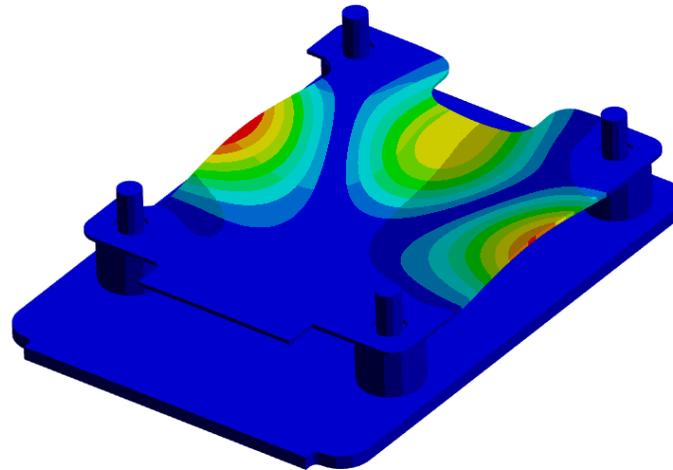
Mode 1 : 1386.7 Hz



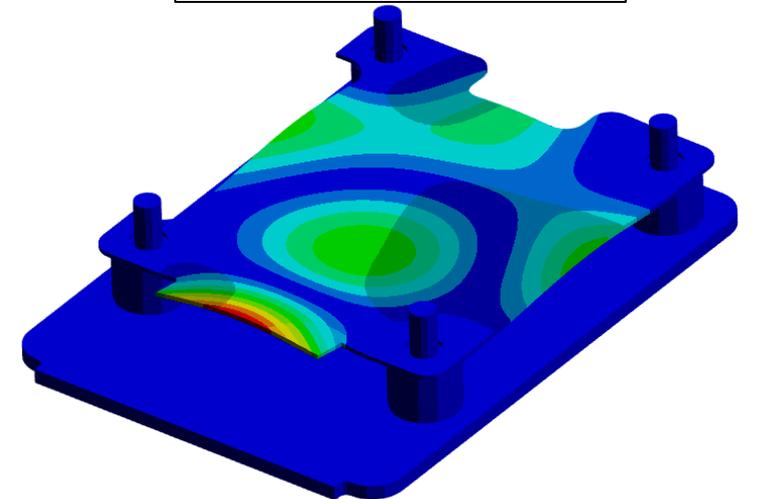
Mode 2 : 2178.8 Hz



Mode 3 : 2611.8 Hz



Mode 4 : 2913 Hz

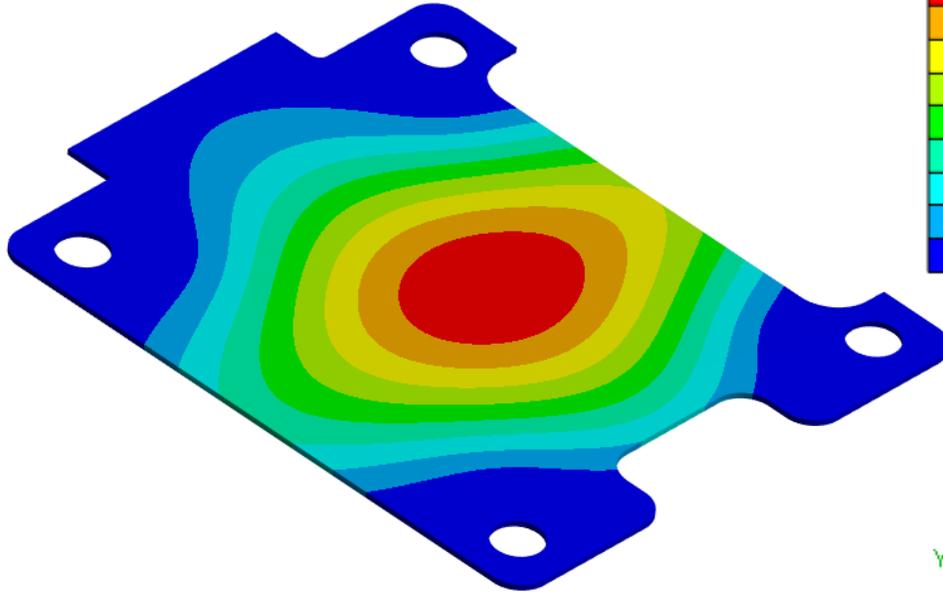
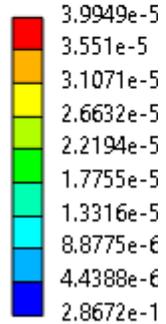


Mode 5 : 3252.9 Hz

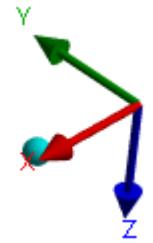
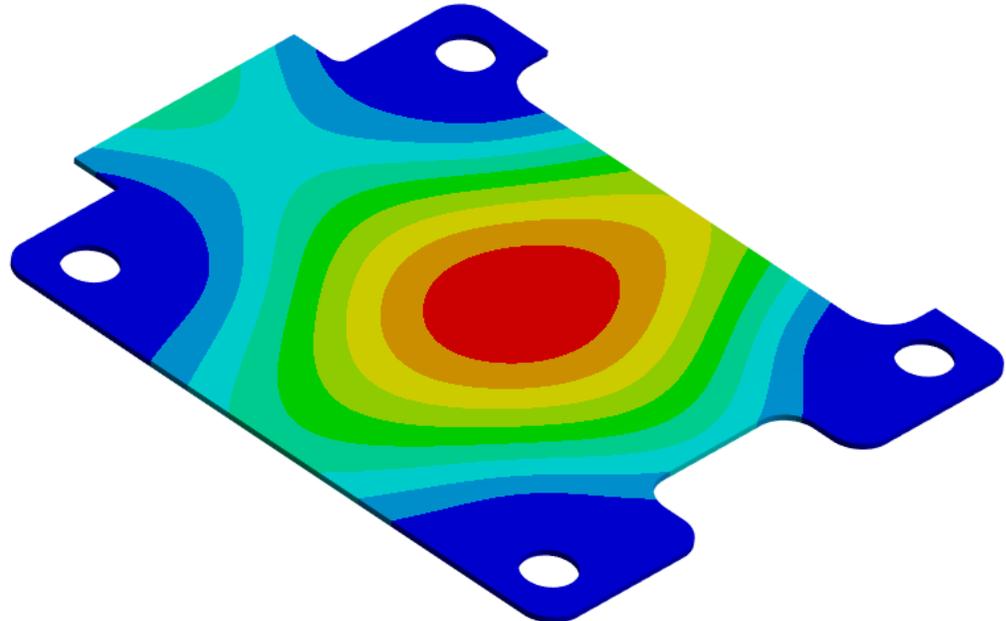
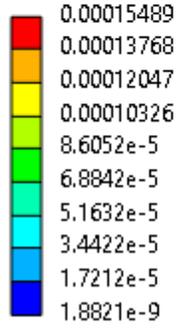
PCBA Deflection Plots

Random Vibe 3σ (Z-Axis)

E: Random Vibration Z-axis
Directional Deformation 2
Type: Directional Deformation(Z Axis)
Scale Factor Value: 3 Sigma
Probability: 99.73 %
Unit: m
Solution Coordinate System
Time: 0 s
Max: 3.9949e-5
Min: 2.8672e-11
7/9/2024 12:42 PM



H: Response Spectrum Z-axis
Directional Deformation 2
Type: Directional Deformation(Z Axis)
Unit: m
Solution Coordinate System
Time: 0 s
Max: 0.00015489
Min: 1.8821e-9
7/9/2024 12:45 PM

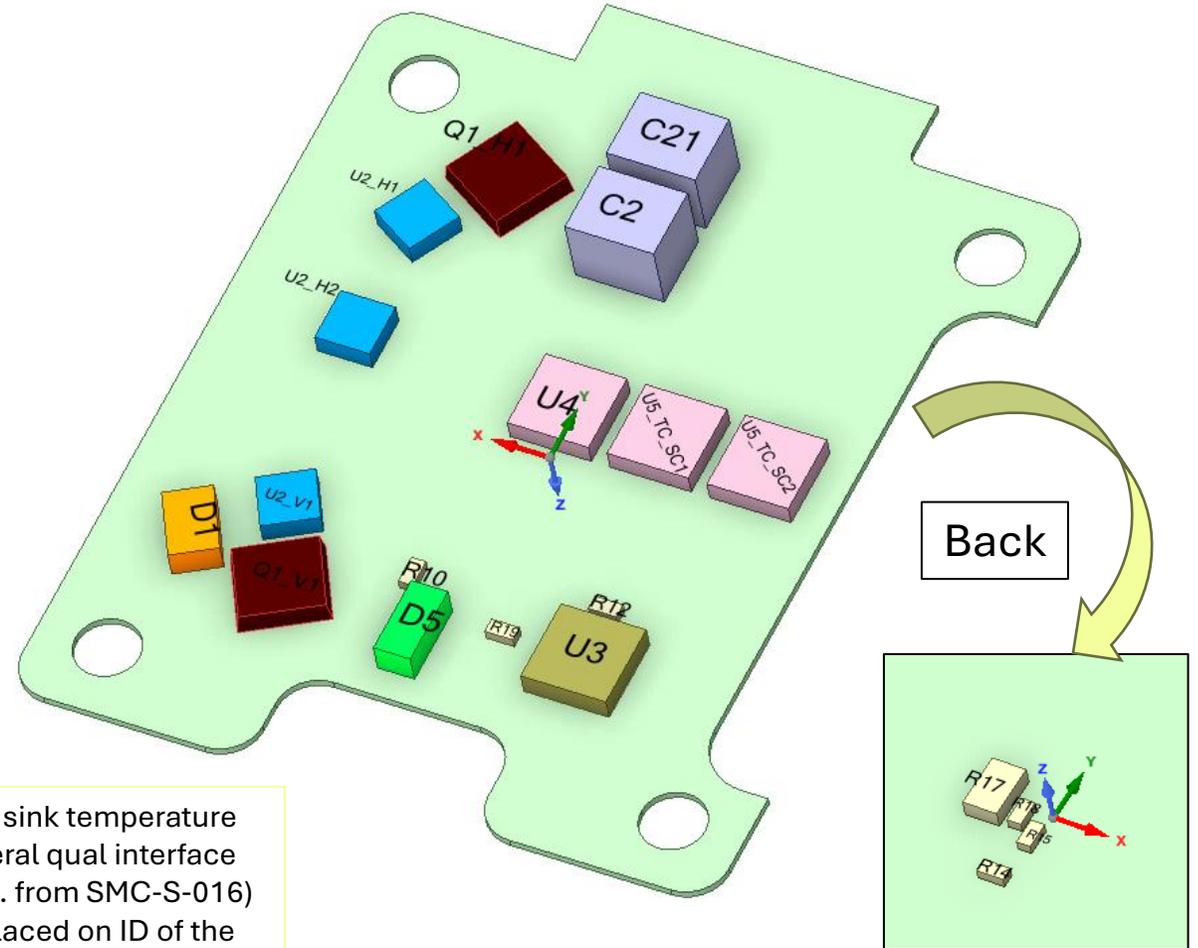


Thermal Analysis: Model setup

- 20 EEE parts discretely modeled with ~203.55 mW power dissipation, amounting to 88% of the total. The remainder is spread over the board surface as a heat flow
- PCBA conductivity estimated using Cu/FR4 volume ratio with isotropic planar properties and reduced normal properties.
- Enclosure, Enclosure Lid, Aluminum standoffs, PCBA included in FEM.
- Conductance between components and board based on EEE part lead data from corresponding data sheets
- Conductance between standoffs and enclosure based on thermal control handbook for size 2-56 screws
- Steady state model with conduction only



71°C sink temperature
(general qual interface
temp. from SMC-S-016)
BC placed on ID of the
enclosure mounting
holes



PCBA Thermal Contour Plot

A: Steady-State Thermal

Temperature(Global)

Type: Temperature

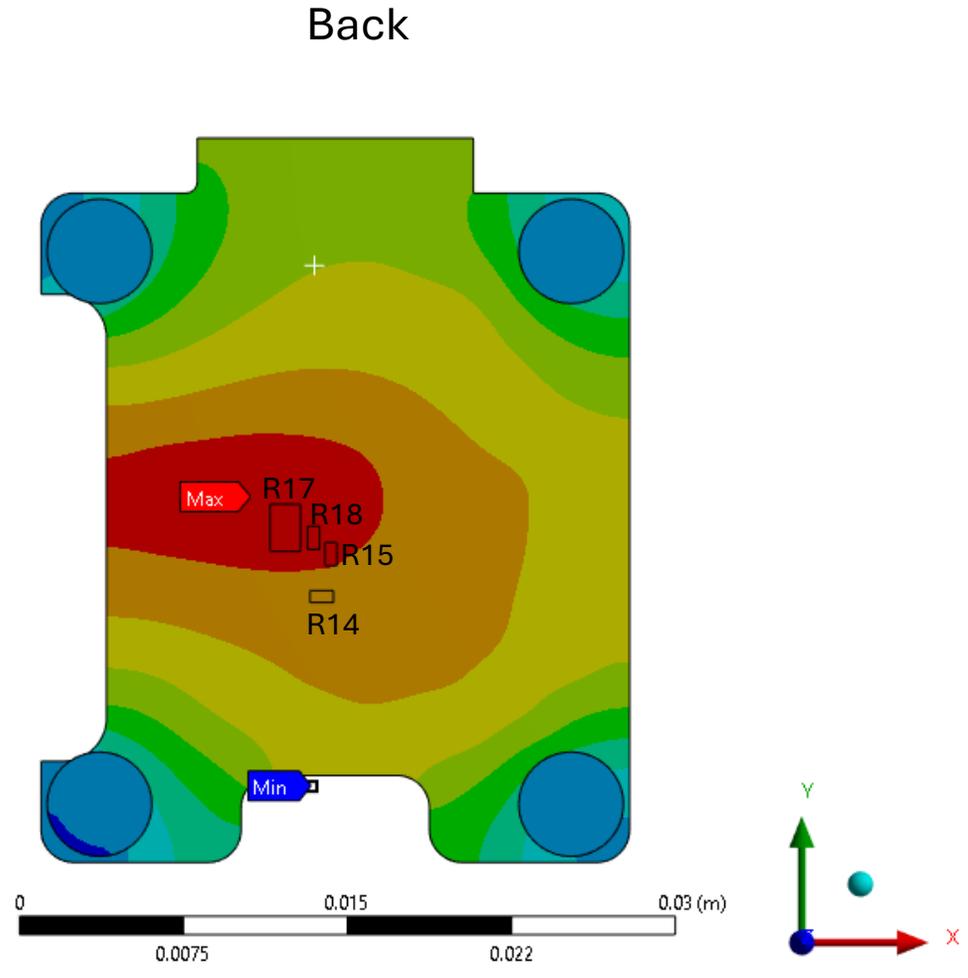
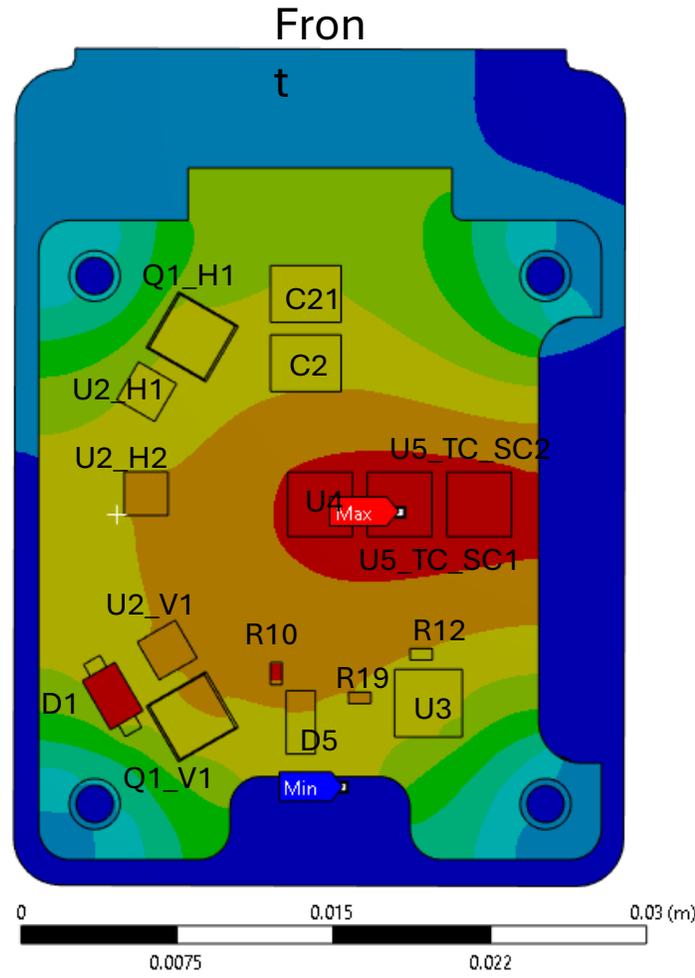
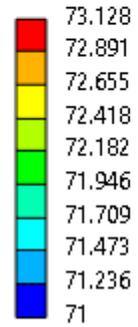
Unit: °C

Time: 1 s

Max: 73.128

Min: 71

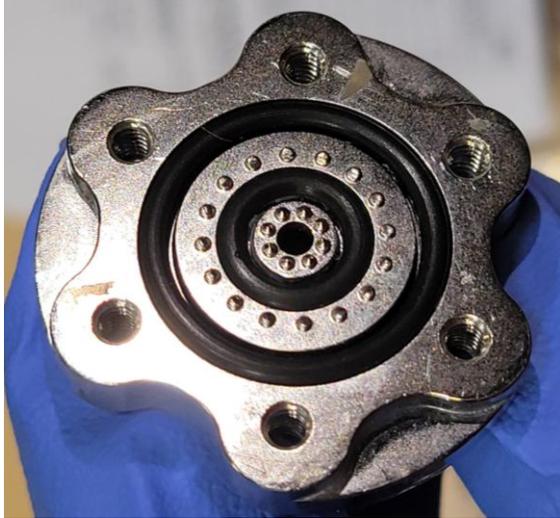
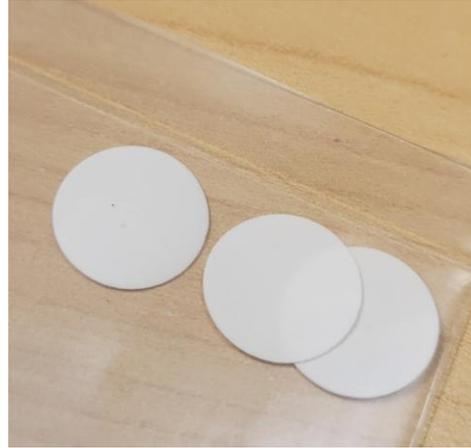
7/10/2024 4:10 PM



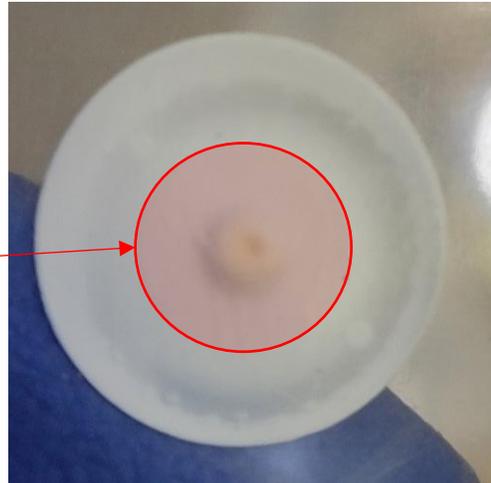
Project 2: Burst Disk Analysis

PURPOSE: STRUCTURAL ANALYSIS TO VALIDATE BURST TESTS FOR
THE LIQUID FILTER

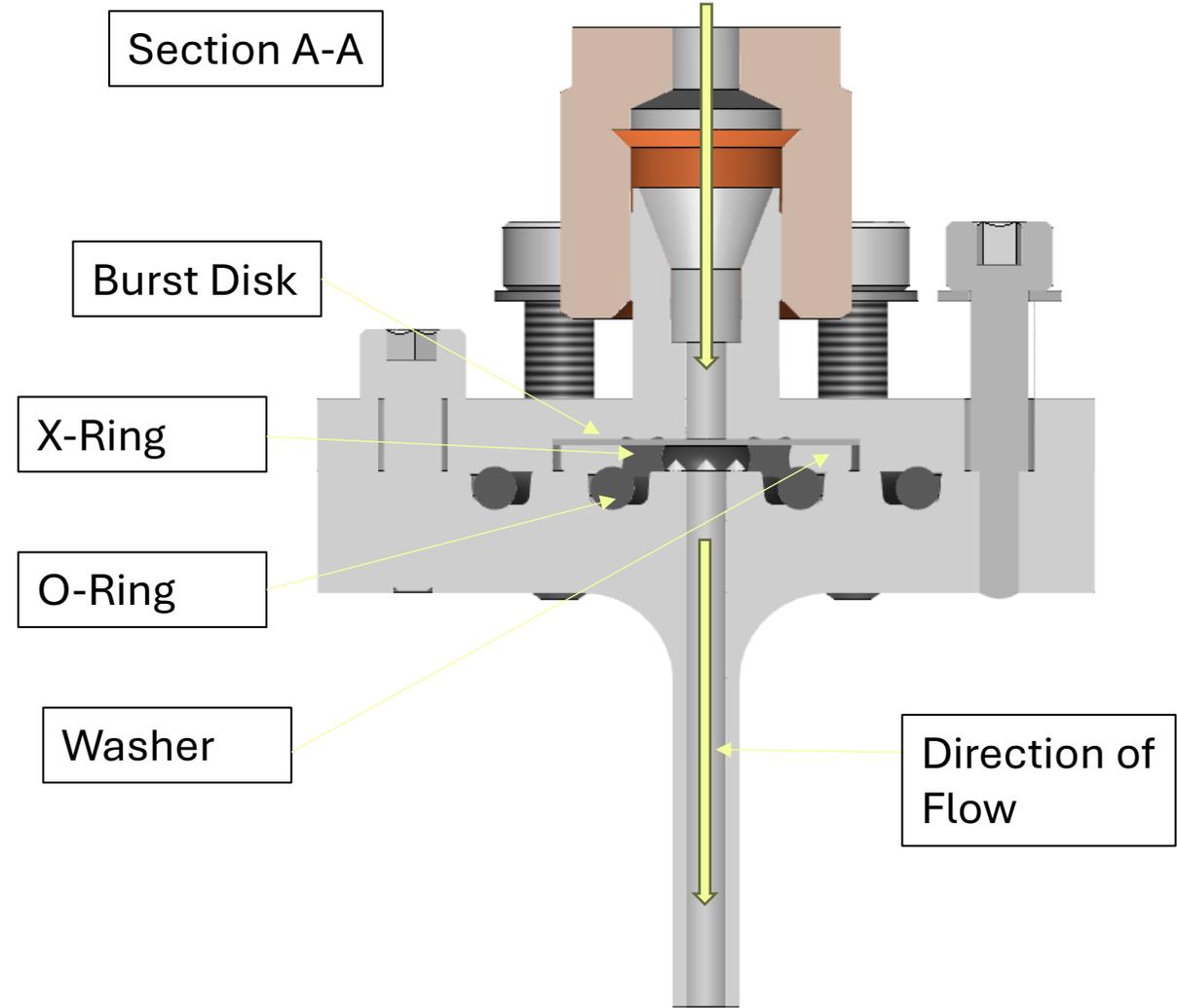
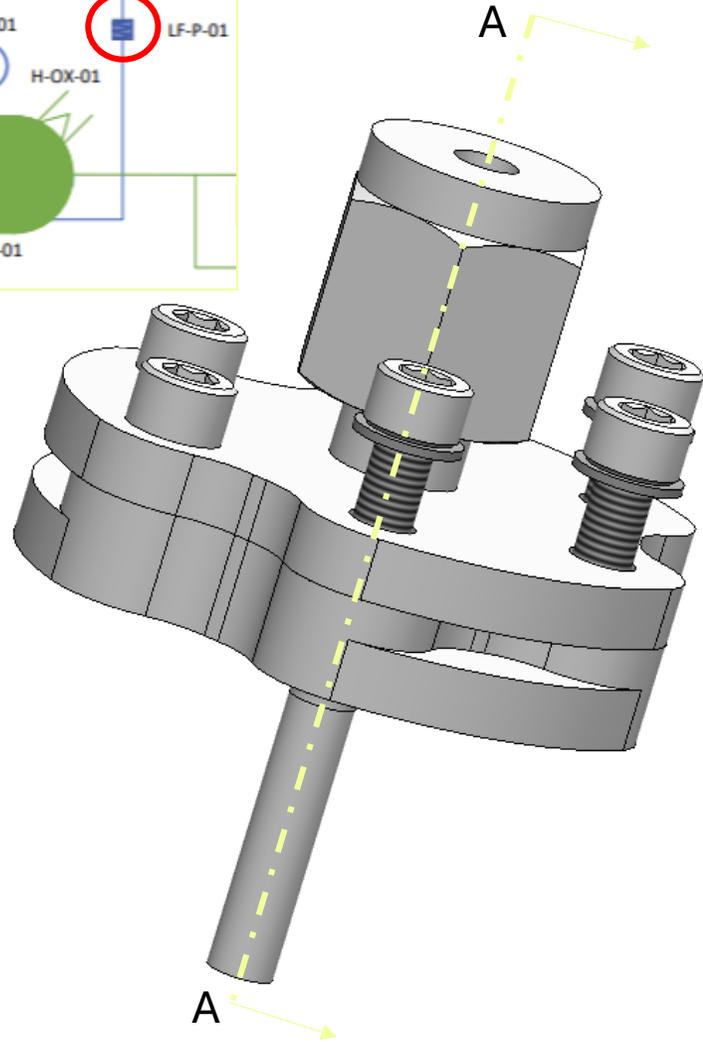
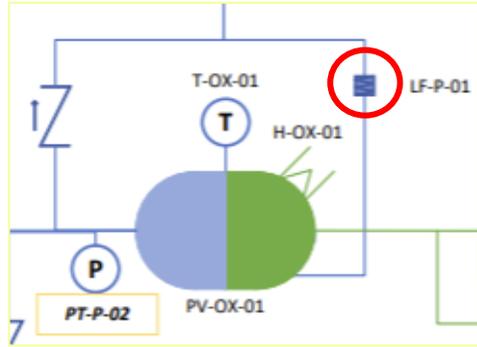
Assembly photos



Modeled Area



Design Overview : Breather Membrane Manifold Assembly



Two Boundary Conditions Tested

Two BCs were analyzed, but only the results for the BC1 case have been presented here as it better represents the edge conditions and avoids over-constraint

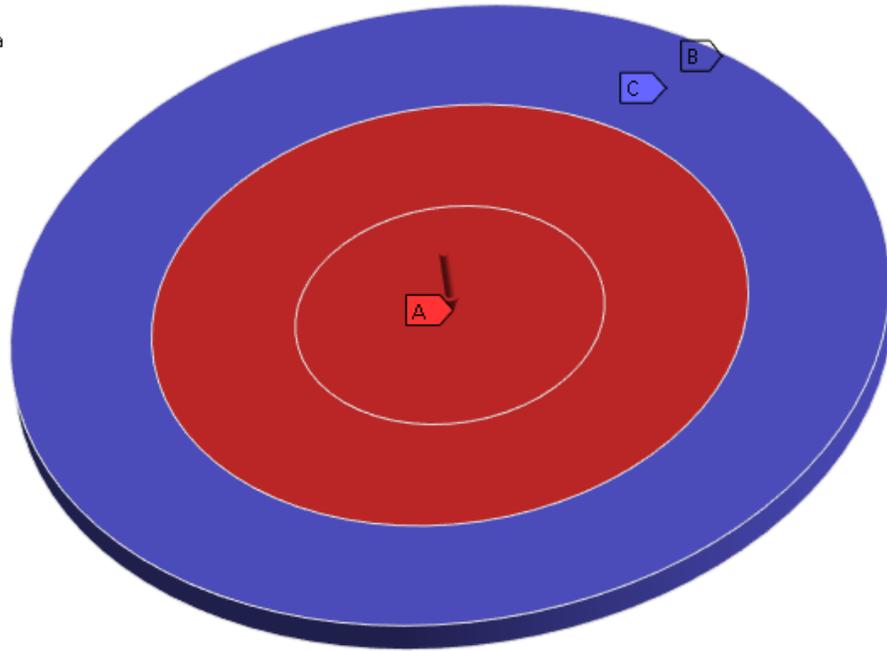
K: Static Structural

Static Structural FrictionLess Support

Time: 60. s

7/23/2024 1:38 PM

- A** Pressure: 0.82737 MPa
- B** Fixed Support
- C** Frictionless Support



BC1

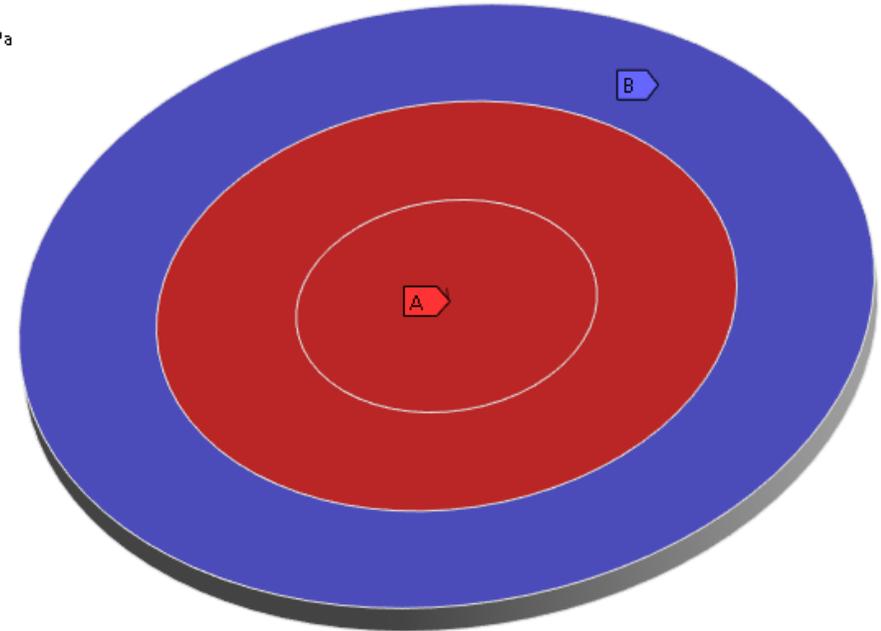
M: Static Structural : Fixed Outer Surface

Static Structural Fixed

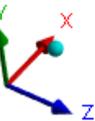
Time: 60. s

7/23/2024 1:39 PM

- A** Pressure: 0.82737 MPa
- B** Fixed Support



BC2



Results: Equivalent Stress

K: Static Structural : Frictionless Support, Fixed Outer Edge

Equivalent Stress

Type: Equivalent (von-Mises) Stress (Unaveraged)

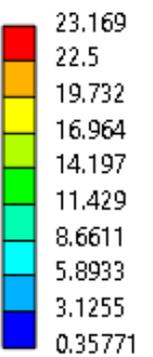
Unit: MPa

Time: 60 s

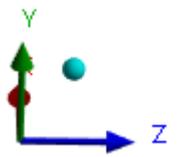
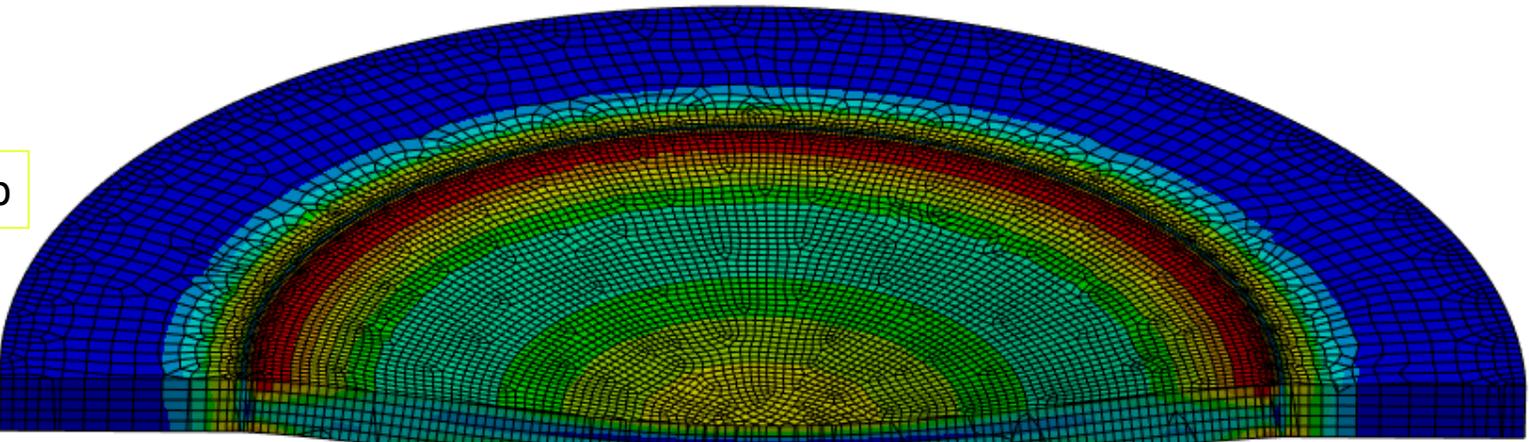
Max: 23.169

Min: 0.35771

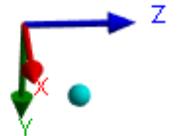
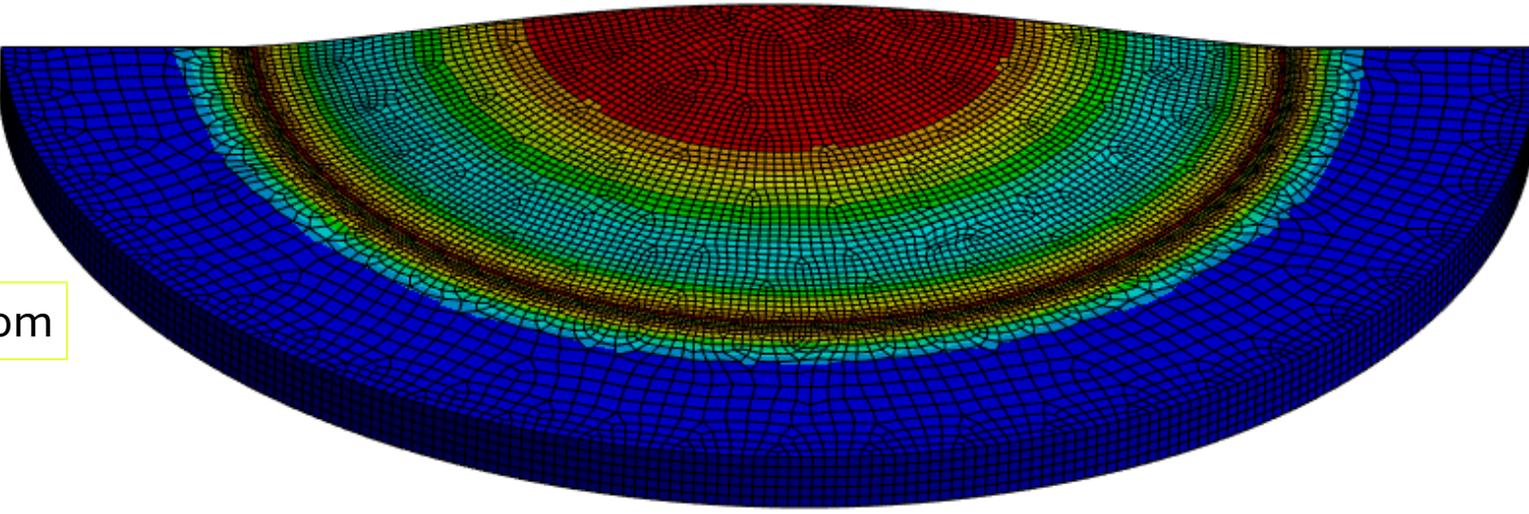
7/31/2024 3:07 PM



Top



Bottom



Results: Total Deformation

K: Static Structural : Frictionless Support, Fixed Outer Edge

Total Deformation

Type: Total Deformation

Unit: mm

Time: 36 s

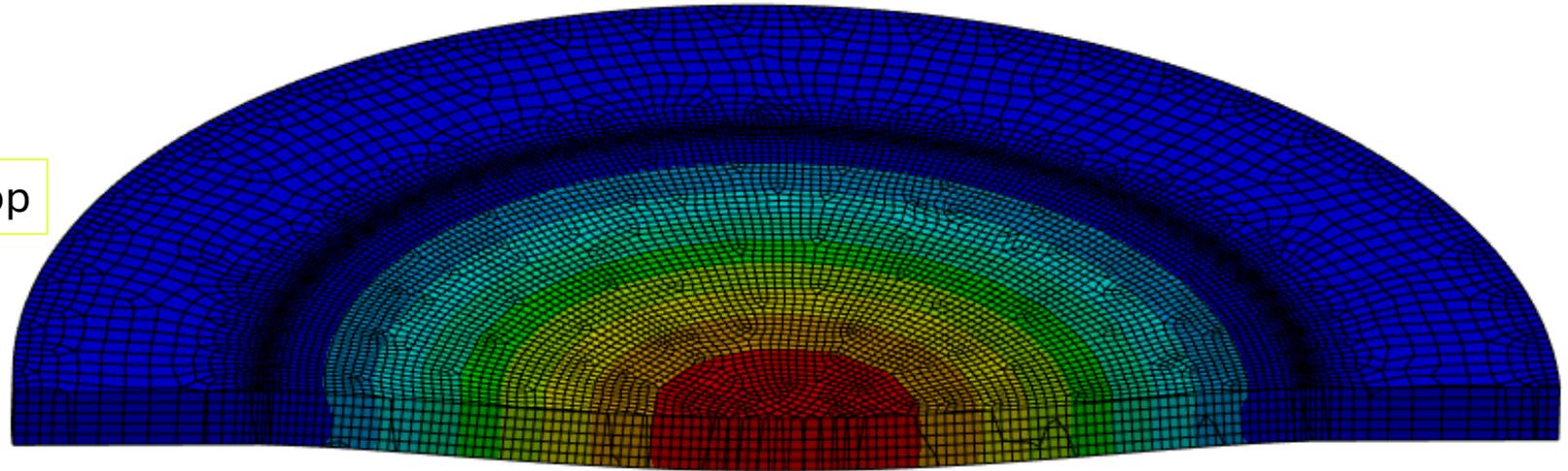
Max: 0.13652

Min: 0

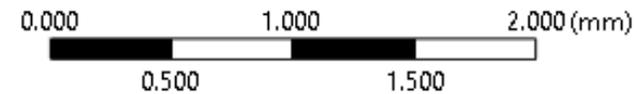
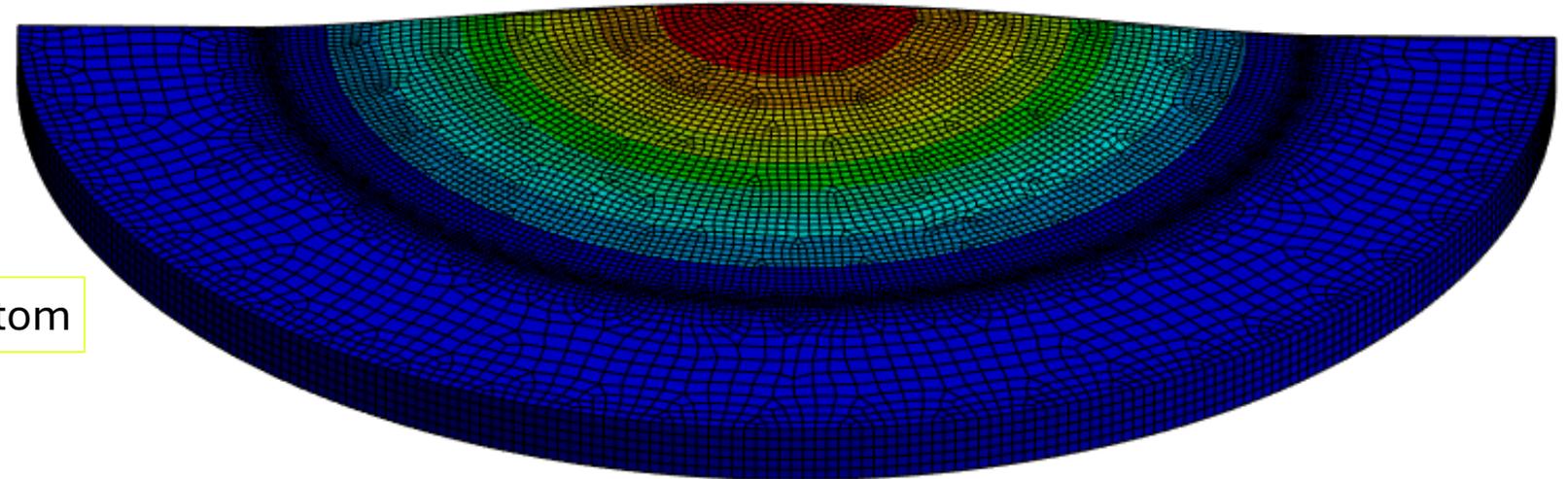
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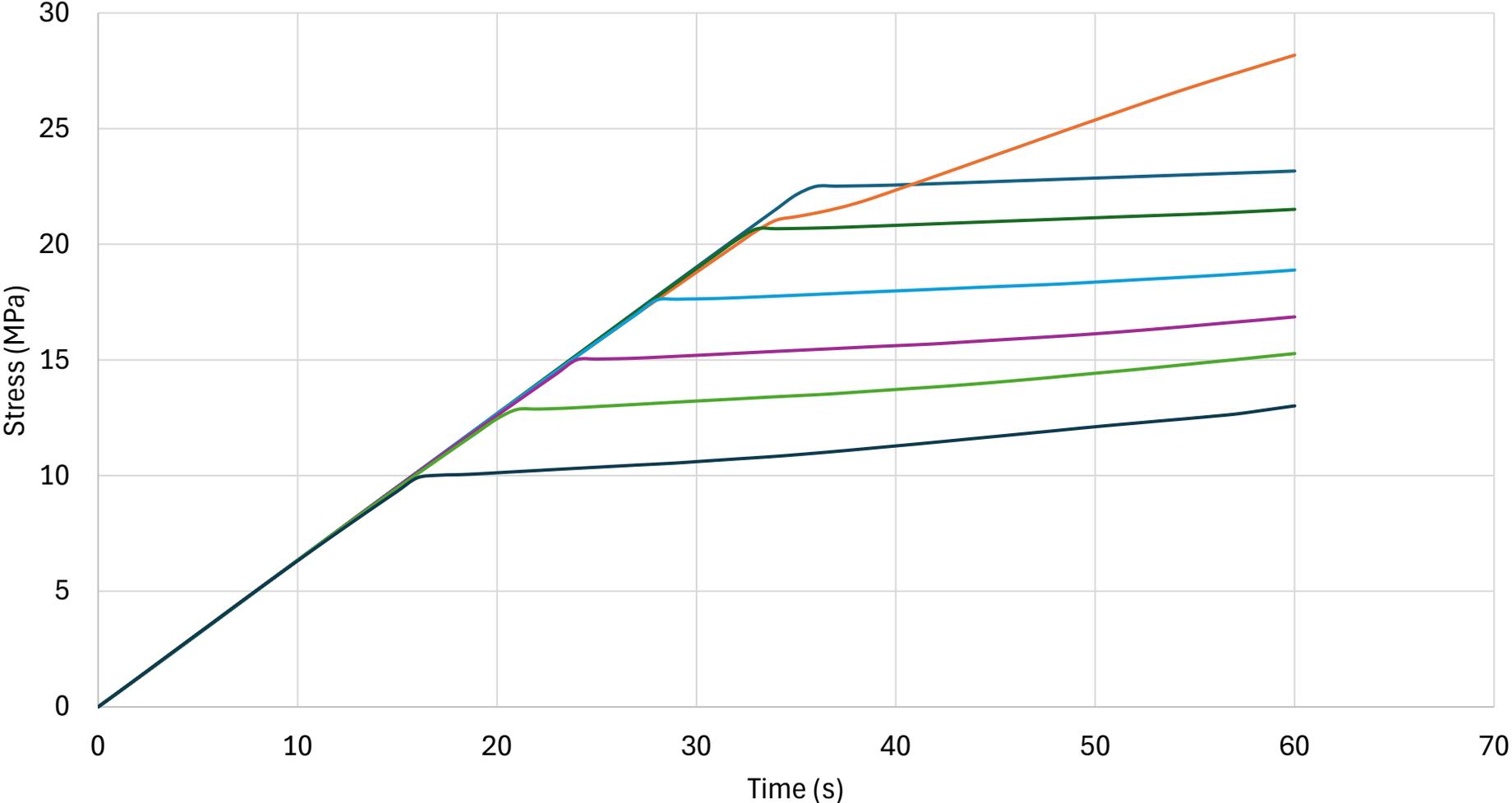
Top



Bottom

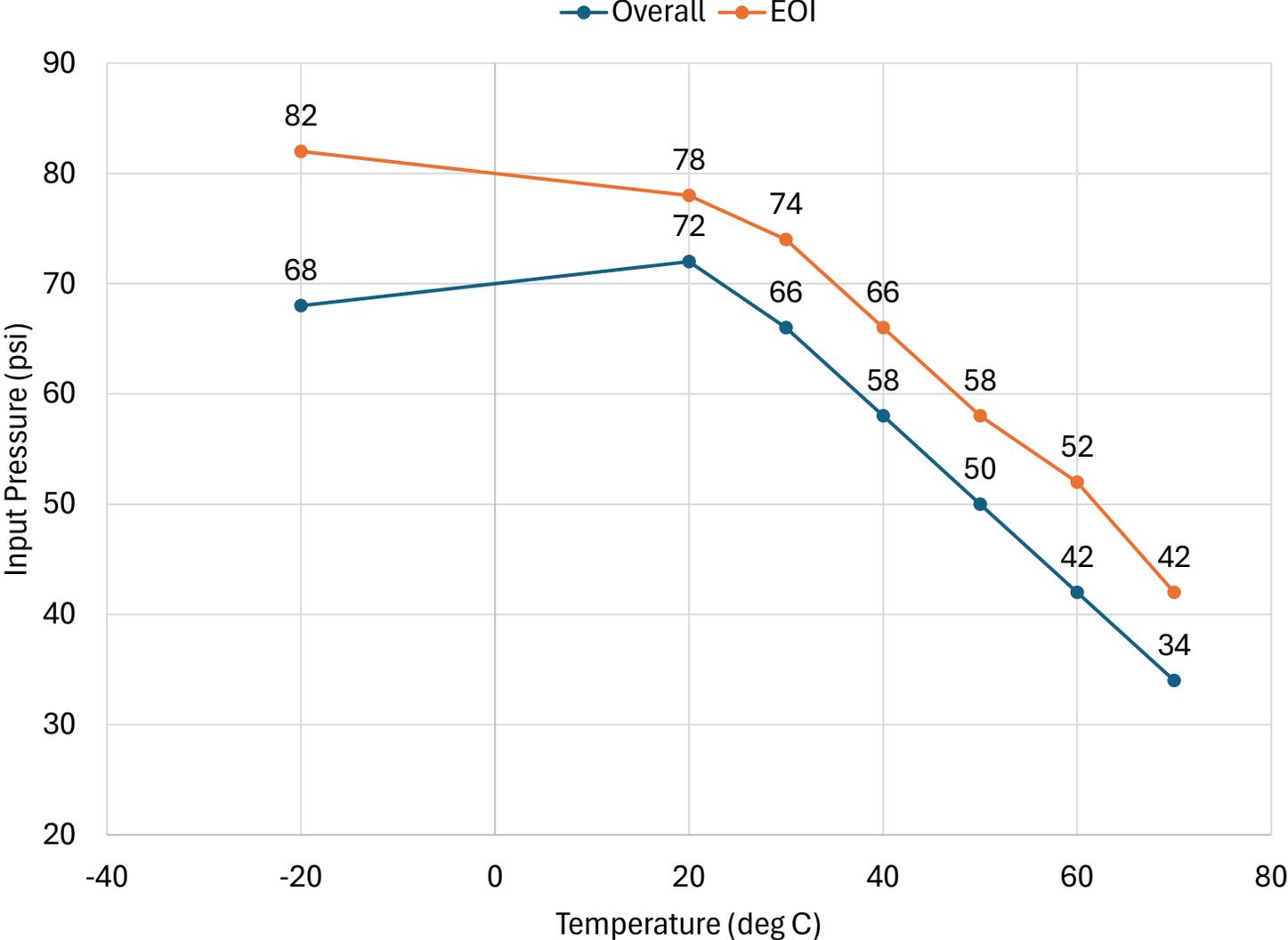


Max. Eq. Stress vs Time



— 20 C — -20 C — 30 C — 40 C — 50 C — 60 C — 70 C

Critical Yield Pressure (Input) vs Temperature



Agreement with Theory

- Within the linear elastic regime, the burst disk can be approximated by a thin circular plate with a large deflection
- Let E = Elastic Modulus; t = thickness of plate; a = outer radius of plate; q = unit lateral pressure; y = maximum deflection; σ_b = bending stress; σ_d = diaphragm stress; $\sigma = \sigma_b + \sigma_d$ = maximum stress due to flexure and diaphragm tension combined. Then the following formulas apply:

$$\frac{qa^4}{Et^4} = K_1 \left(\frac{y}{t}\right) + K_2 \left(\frac{y}{t}\right)^3 \quad (1)$$

$$\frac{\sigma a^2}{Et^2} = K_3 \left(\frac{y}{t}\right) + K_4 \left(\frac{y}{t}\right)^2 \quad (2)$$

$K_1 = \frac{5.33}{1 - \nu^2}$	$K_2 = \frac{2.6}{1 - \nu^2}$	
(At center)	$K_3 = \frac{2}{1 - \nu}$	$K_4 = 0.976$
(At edge)	$K_3 = \frac{4}{1 - \nu^2}$	$K_4 = 1.73$

- First, solve for y in Eq. (1) and then obtain the stresses from Eq. (2).

At yield	Theory (Roark's)	FEM
Max Stress (MPa)	22.45	22.502
Deformation (mm)	0.112	0.145

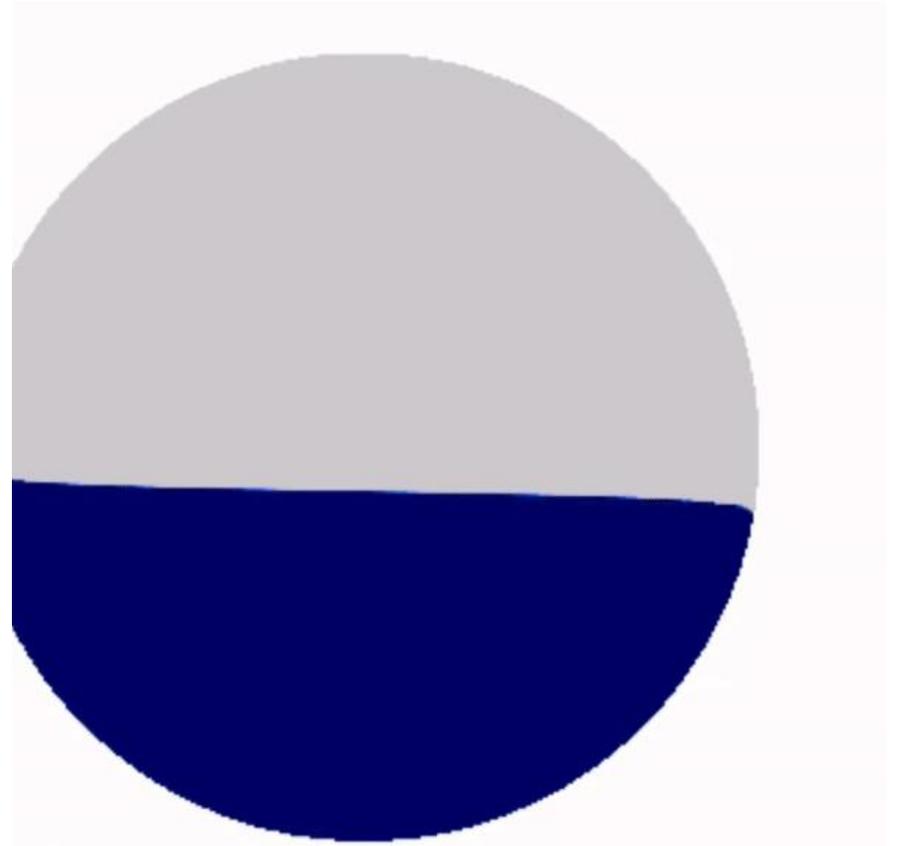
Project 3: SLOSH and Diaphragm Modeling

PURPOSE: PREDICTION OF SLOSH FREQUENCY MODES AND MOTION OF
TANK CG

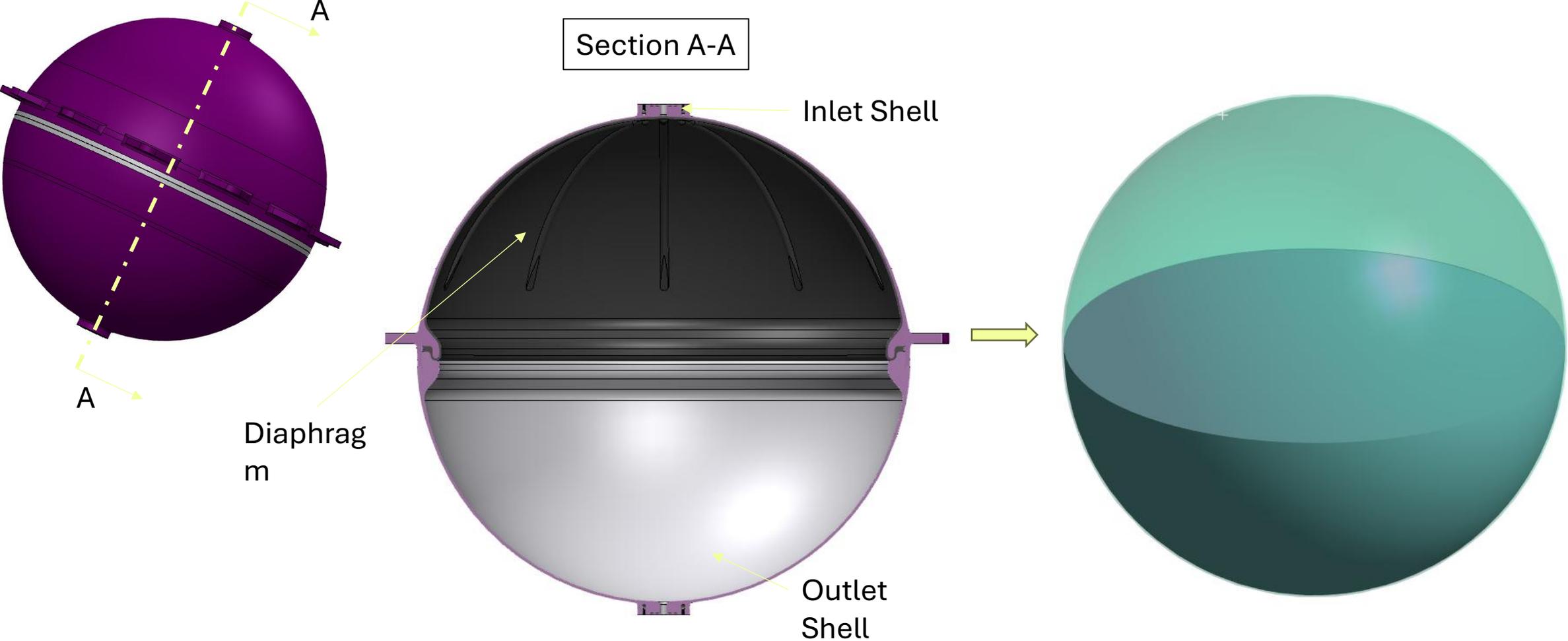
What is Slosh? And why do we care?

Slosh: Oscillatory motion of a fluid enclosed in a container, typically with a free surface

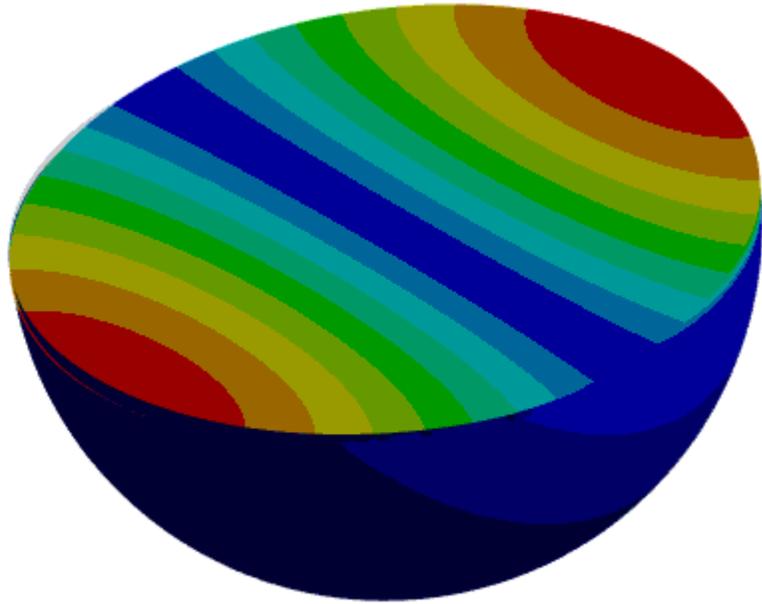
- Caused by lateral, longitudinal or rotational base excitation
- Can influence vehicle dynamics : alter trajectories, structural load distributions
- Secondary effects include cyclic wear, draining issues, tank overpressure, etc.
- Examples: Slosh in spacecraft and rockets, and cargo slosh in ships and trucks carrying liquids like oil and gasoline



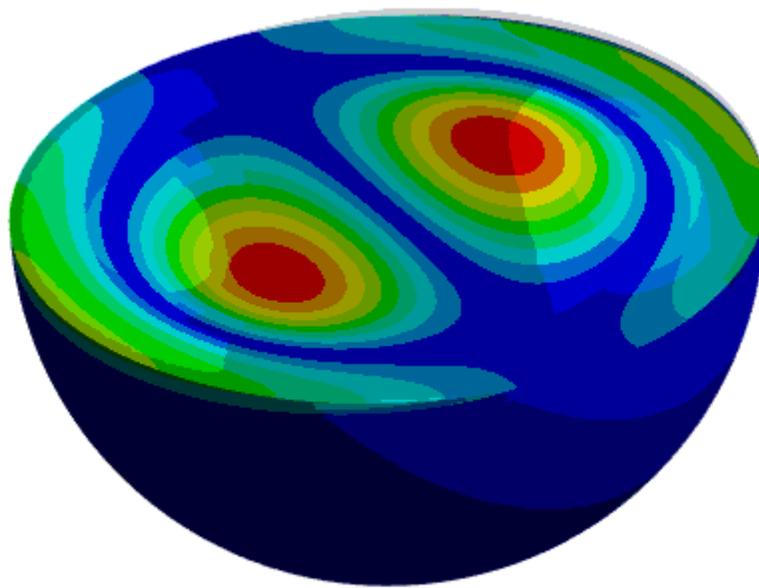
Uncovered Slosh (Free surface)



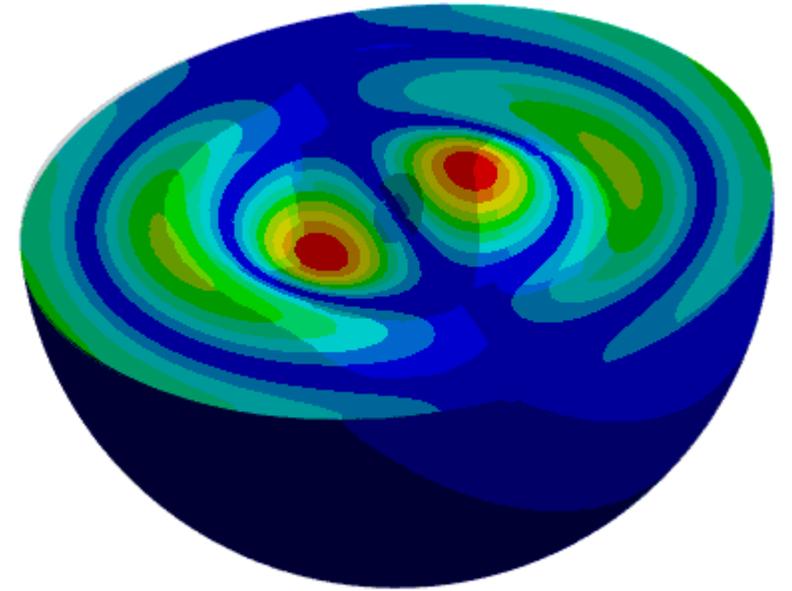
Spherical Sloshing : Lateral Modes (50% fill)



Mode 1: 1.49 Hz



Mode 2: 2.75 Hz



Mode 3: 3.49 Hz

Modeled using Modal Acoustics in Ansys

Agreement with theory

Partially Filled Spherical Tank

The natural frequency from Reference 3 is

$$f_i = \frac{\beta_i}{2\pi} \sqrt{g/r} \quad (10)$$

Note that r is the radius and d is the diameter.

Define a nondimensional parameter: $x=h/d$

The β parameters for the first three modes are

$$\beta_1 \approx 12.1x^5 - 24.2x^4 + 18.7x^3 - 6.22x^2 + 1.27x + 0.975 \quad (11)$$

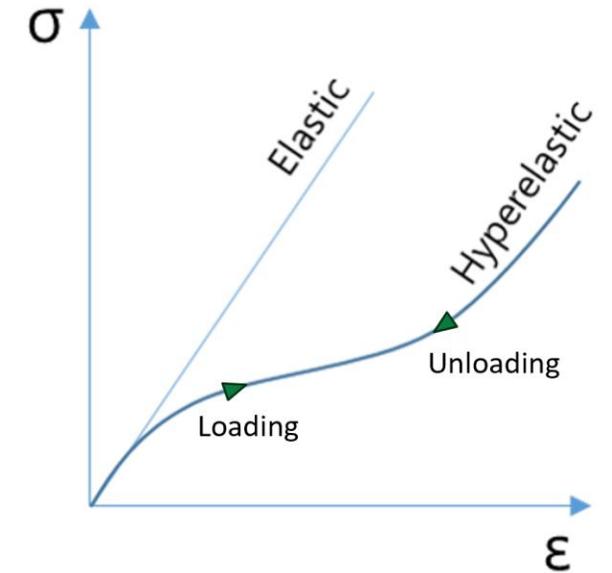
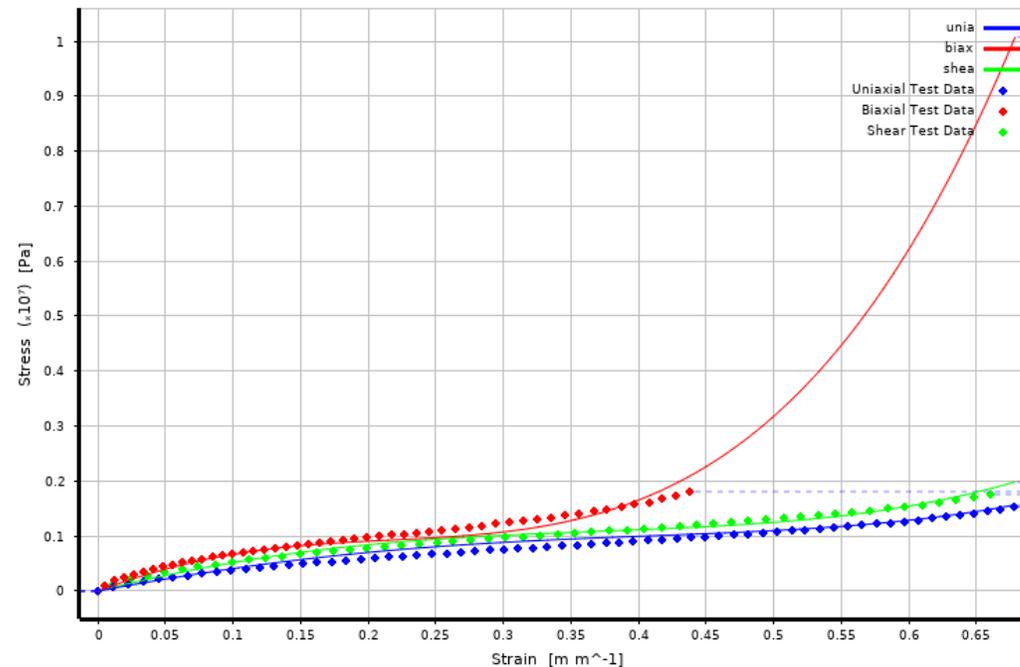
$$\beta_2 \approx -0.200x^5 + 14.11x^4 - 26.19x^3 + 19.87x^2 - 7.04x + 3.28 \quad (12)$$

$$\beta_3 \approx 19.3x^4 - 37.7x^3 + 29.5x^2 - 10.8x + 4.50 \quad (13)$$

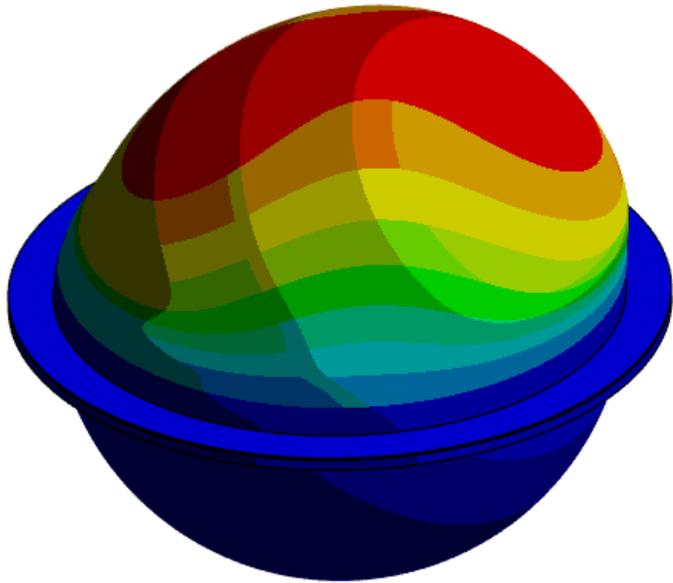
Mode Number	Theory (Irvine, 2013) (Hz)	FEM (ANSYS) (Hz)
1	1.51	1.49
2	2.78	2.75
3	3.55	3.49

Covered Slosh (with Diaphragm)

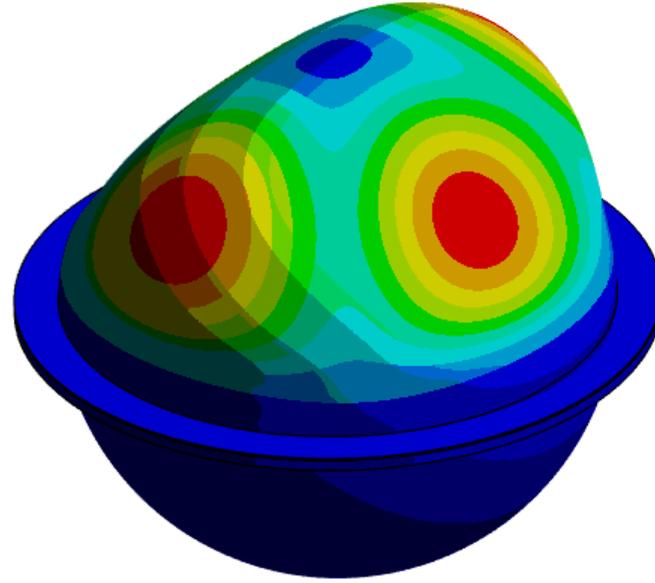
- Modal analysis is linear but hyperelastic materials are not
- Two ways to model hyperelastic materials:
 - 1) Direct approximation through averaging
 - 2) Perform an empty (no load) static analysis first and then export the stiffness matrix to modal analysis



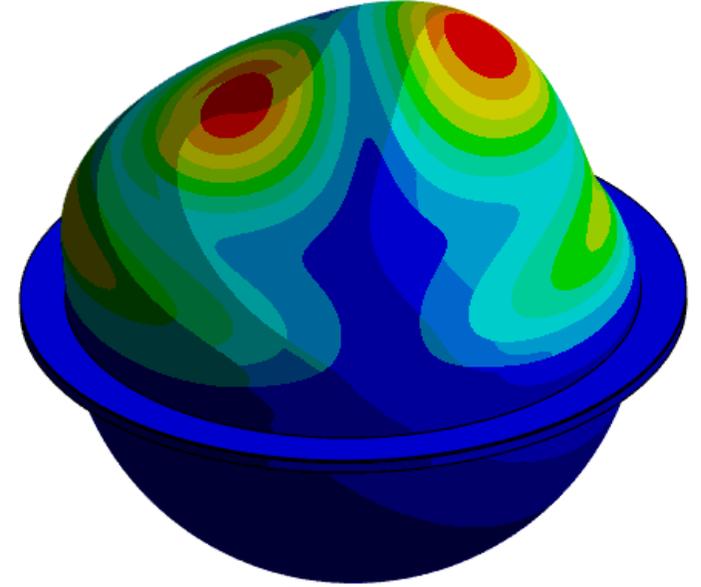
Covered Slosh (with Diaphragm)



Mode 1: 840.79 Hz



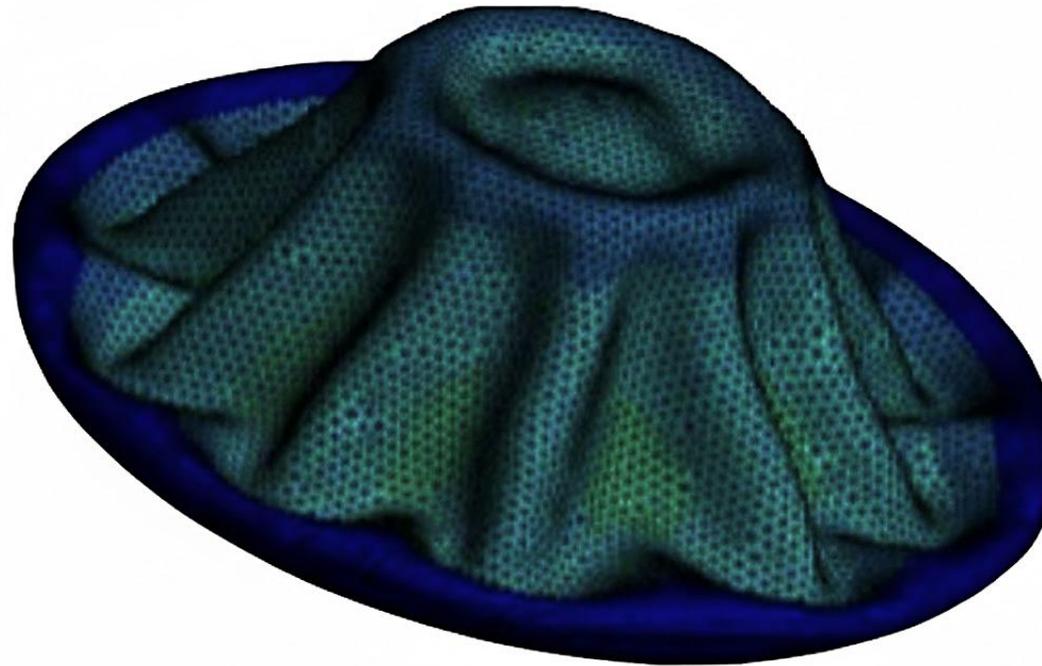
Mode 2: 1309.2 Hz



Mode 3: 1453.4 Hz

Diaphragm motion with a pressure gradient

- What if the tank is partially filled? And has a diaphragm?
- How to model the motion of the diaphragm without modeling the fluid ?
- Two ways:
 - 1) Apply a changing pressure gradient across the diaphragm to mimic fluid expulsion
 - 2) Model a highly compressible fluid with the same density as our propellant



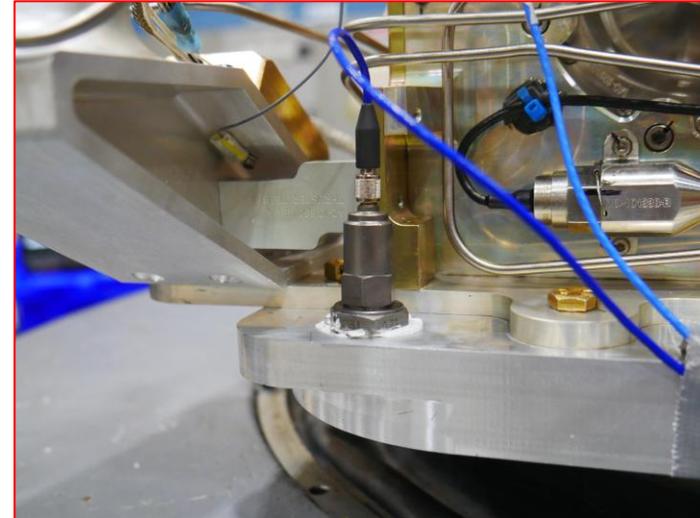
Side Project: Bare fixture Random Vibe Comparison

PURPOSE: TO COMPARE IN-HOUSE TEST SETUP RESPONSE TO NTS
(EXTERNAL TESTING)

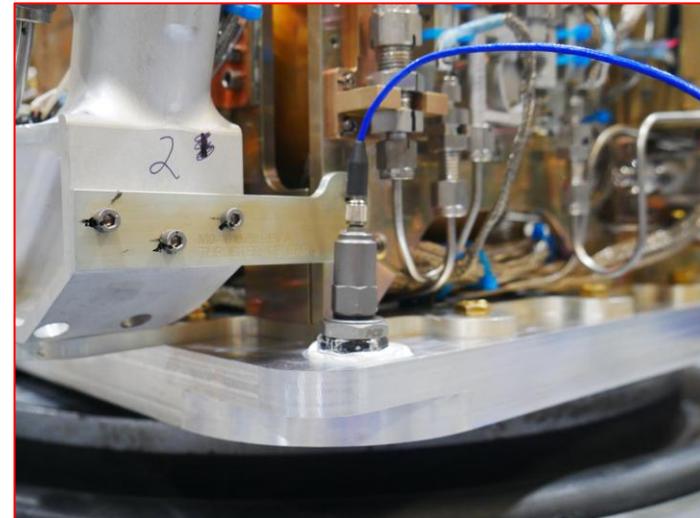
NTS Survey

Test details:

Instrument Used:	UD_T2000
Test Notes:	NTS_Test10
NVH Type:	Autopower Spectrum
Amplitude Scaling:	RMS
Average Mode:	Exponential
Spectrum Format:	Power Spectrum
Window Type:	Hanning
Window Correction Mode:	Amplitude
Default Spectrum Type:	$(EU)^2/Hz$



C1

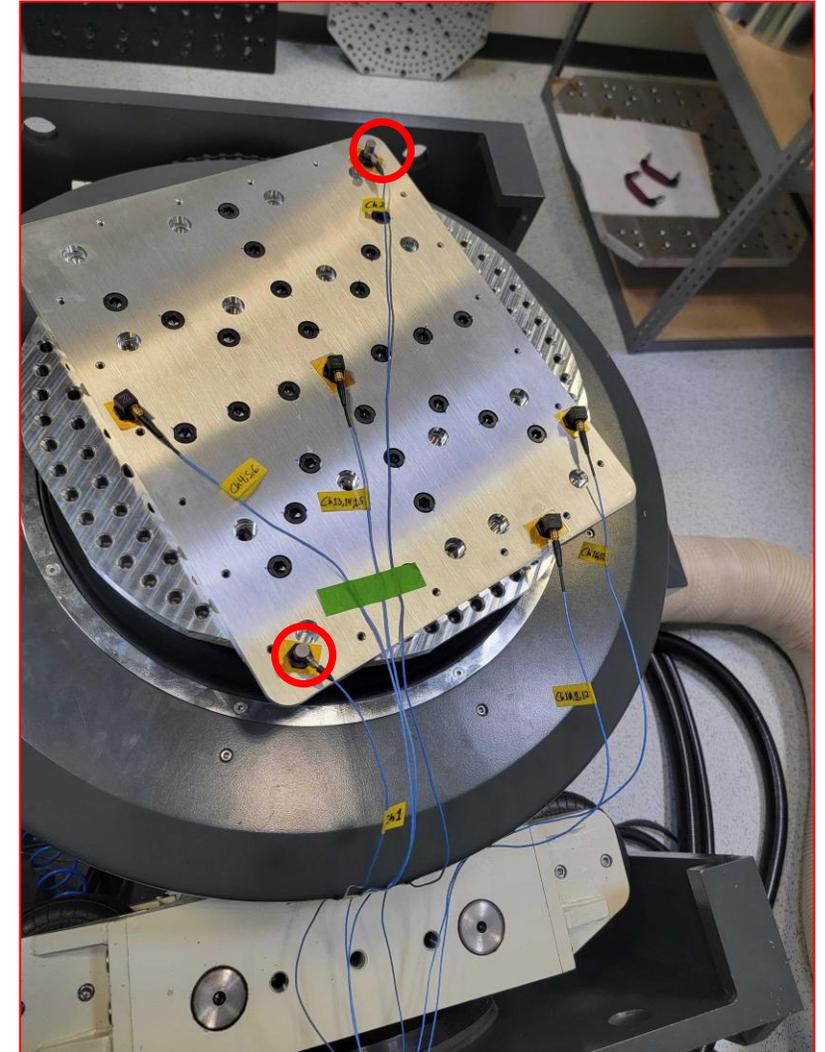


C2

In-house Test : Controlling from Corners

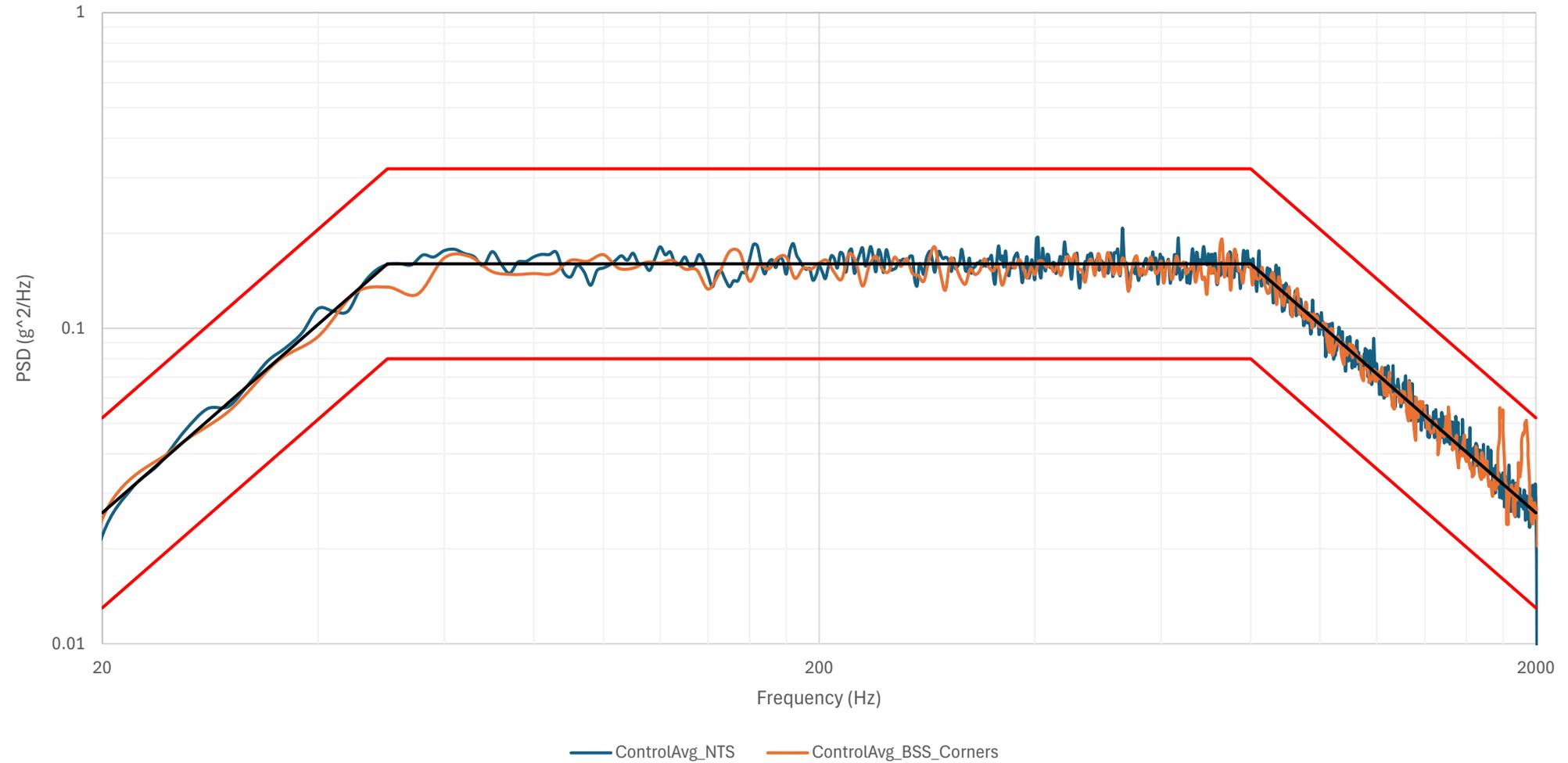
Test details:

Software Used:	Crystal Instruments EDM software Ver.11.1.0.9
Instrument Used:	NVHEnvironment_93425
Test Notes:	Vibe Fixture GEVS random/Run119
Sample Rate:	5.12 kHz
Number of Lines:	400
NVH Type:	Autopower Spectrum
Amplitude Scaling:	RMS
Average Mode:	Exponential
Number of Averages:	50
Spectrum Format:	Power Spectrum
Window Type:	Hanning
Window Correction Mode:	Amplitude
Display Format of Y:	LogMag
Default Spectrum Type:	(EU)^2/Hz



Comparison with NTS Survey (Average)

Control Accels Avg. (Corners) vs NTS



Internship Outcomes

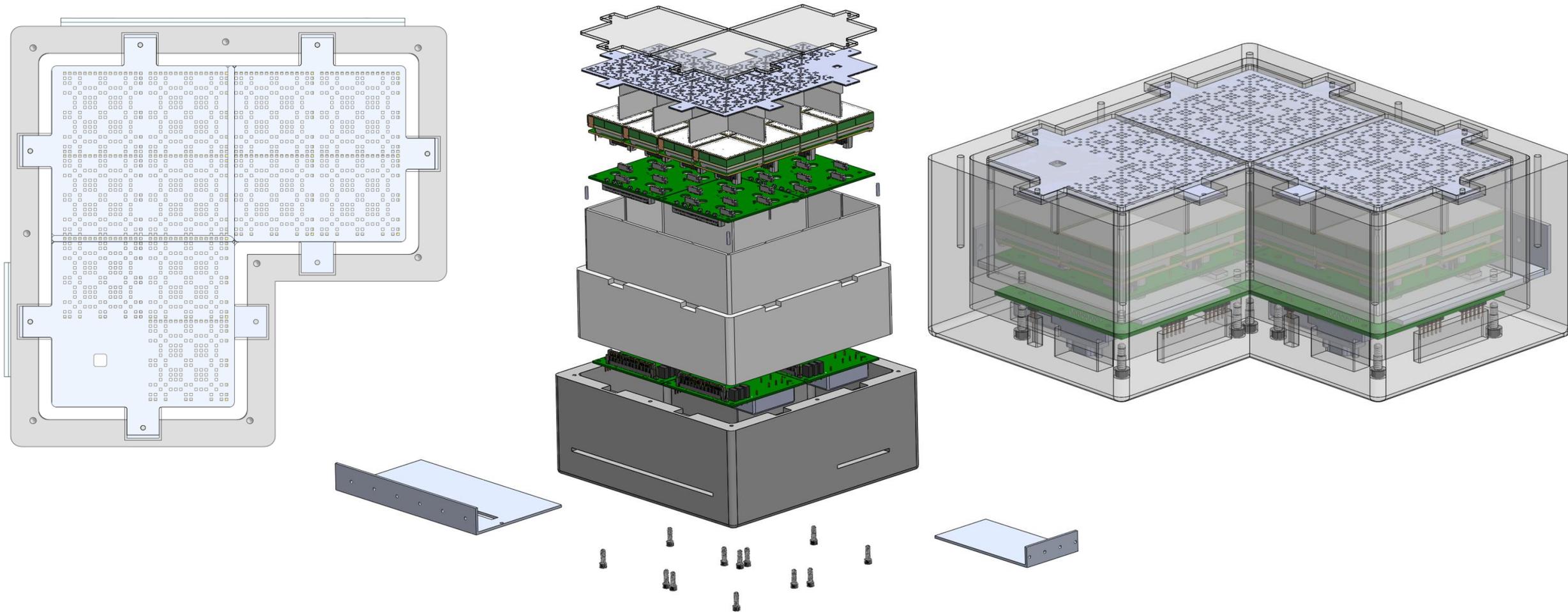
- Part of NTS Survey Comparison
- Slosh Dynamics and Diaphragm Modeling Report and SOP
- 43-1112 Thruster PCBA Structural and Thermal Analysis Report
- 43-1145 Burst Disk Analysis Report
- 40-1146 Membrane Analysis SOP

Cubesat Projects at CU

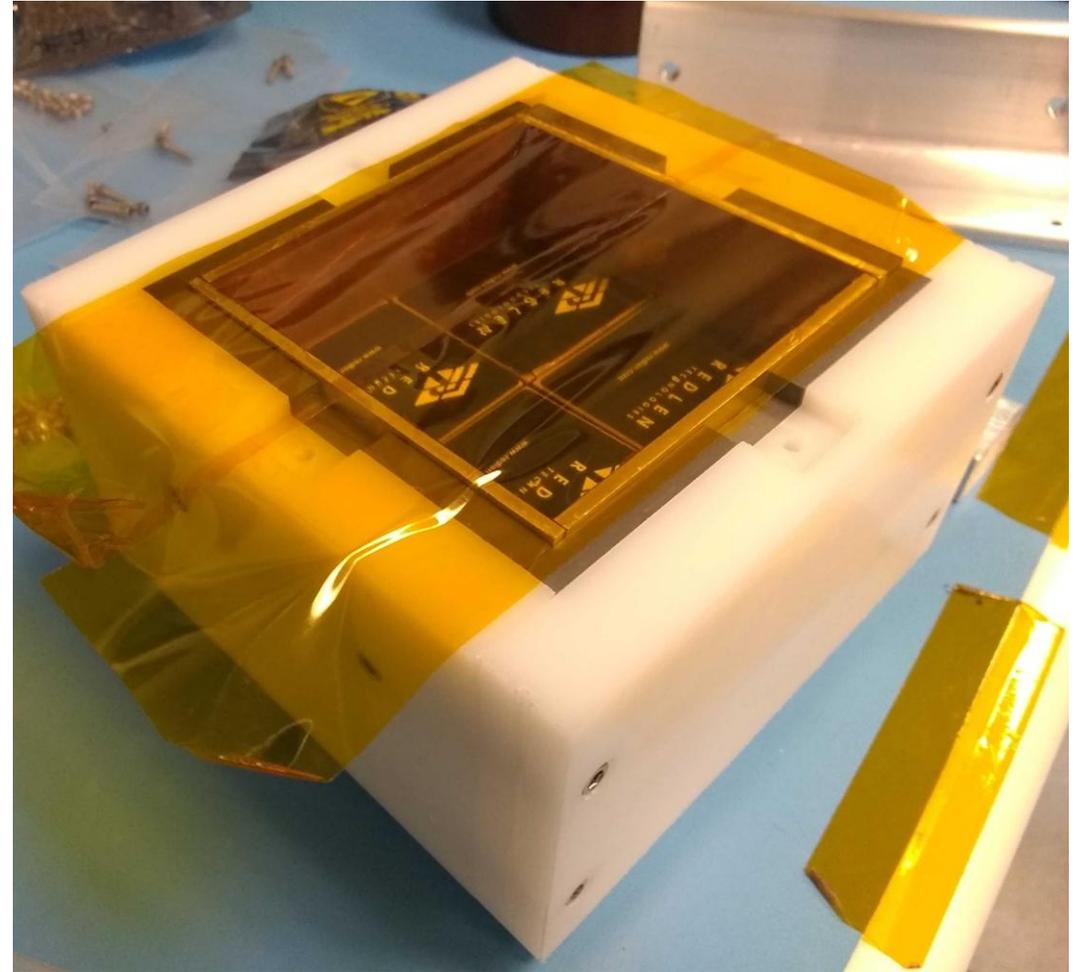
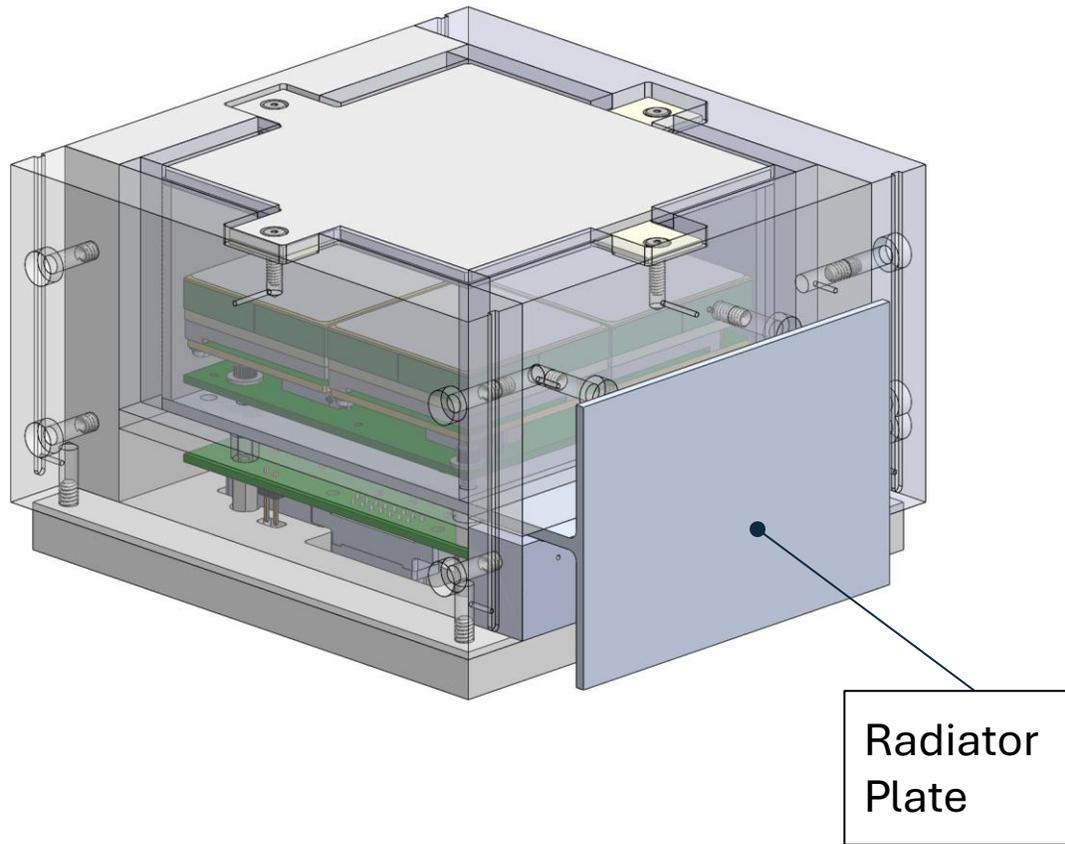
Small-Satellite Projects: (2019-2021)

- **COSMO (6U CubeSat):** Designed and tested a low-noise magnetic observatory
- **CANVAS (4U CubeSat):** Led structural analysis (static, vibration, frequency) and designed payload holder for magnetic coils
- **INSPIRESat-3 (27U Cubesat):** Performed thermal design; optimized payload life with radiator addition and day-in-the-life thermal plots
- **AEPEX (6U CubeSat):** Developed CAD assembly; planned fasteners, harnessing, and thermal analysis in Thermal Desktop

Instrument Design



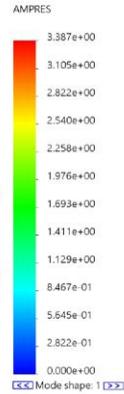
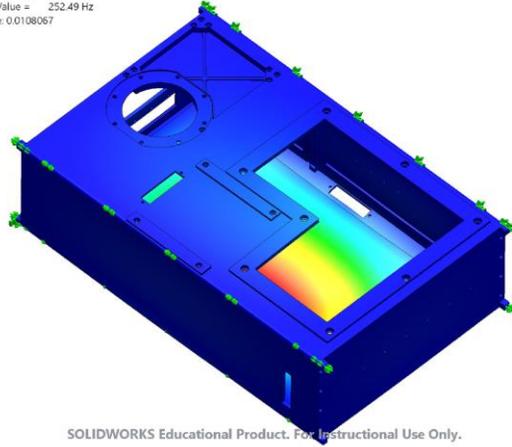
Instrument Design



Structural Analysis

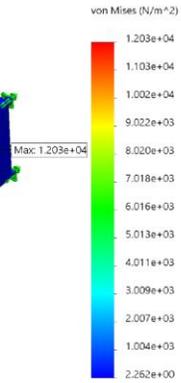
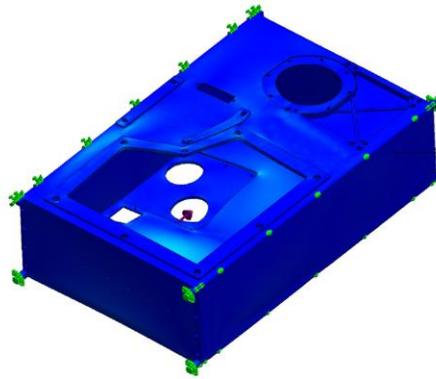
Modal Analysis

Model name: Assem2
Study name: Frequency 1 (Default)
Plot type: Frequency Amplitude1
Mode Shape: 1 Value = 252.49 Hz
Deformation scale: 0.0108067



Model name: Assem2
Study name: Dynamic 1 (Default)
Plot type: RMS Value of nodal stress Stress1
Deformation scale: 583.322

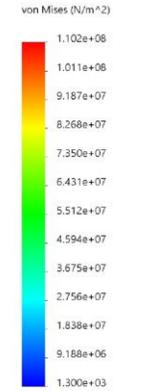
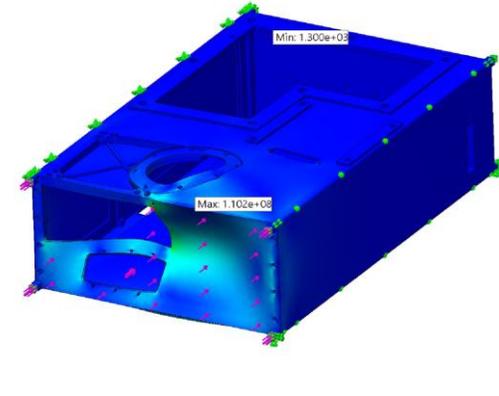
Random Vibe Analysis



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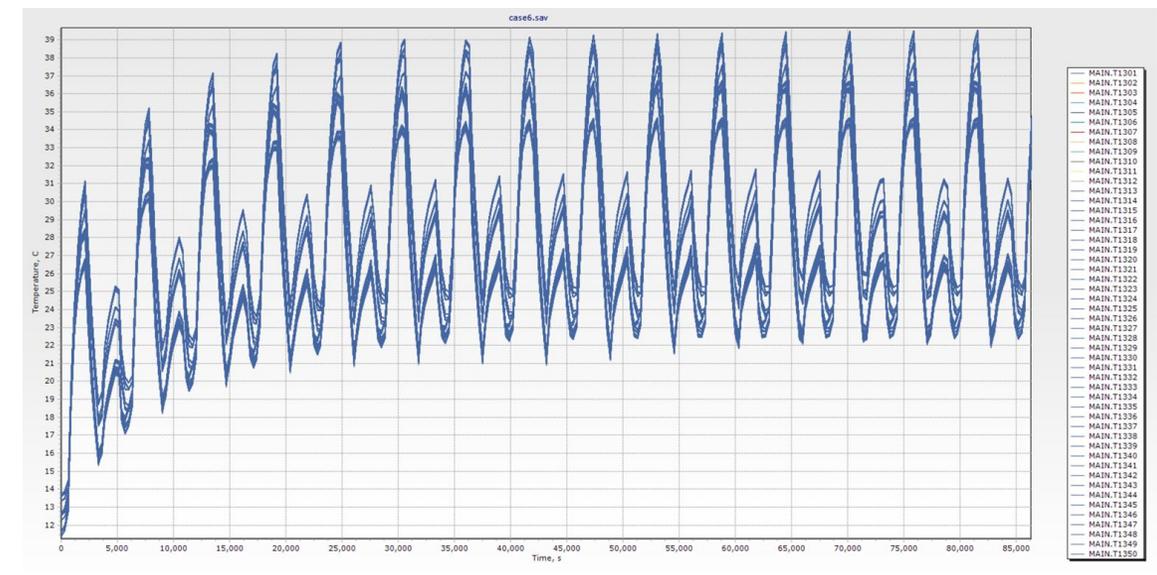
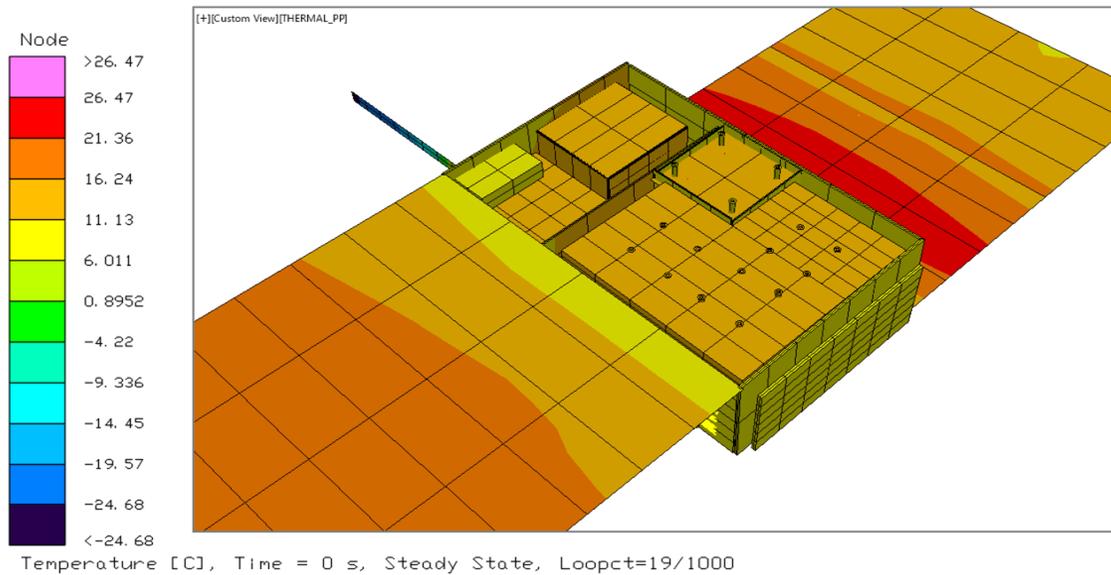
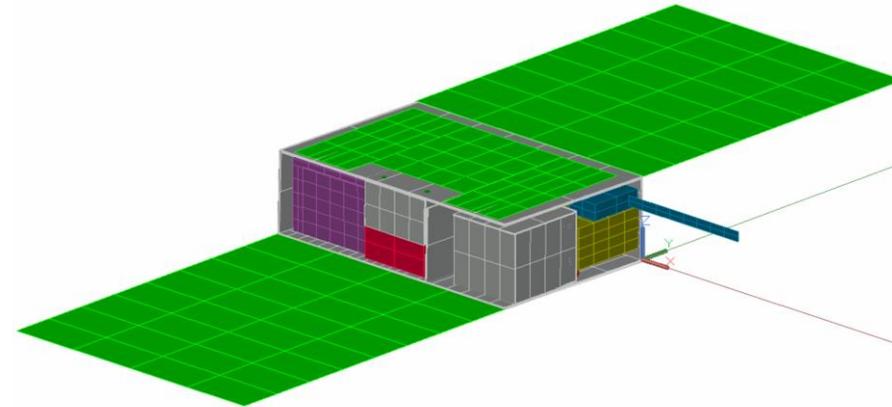
Static Analysis

Model name: Assem2
Study name: Static 1 (Default)
Plot type: Static nodal stress Stress1
Deformation scale: 114.539



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Thermal Analysis : Day-in-the-life Simulation (Thermal Desktop)



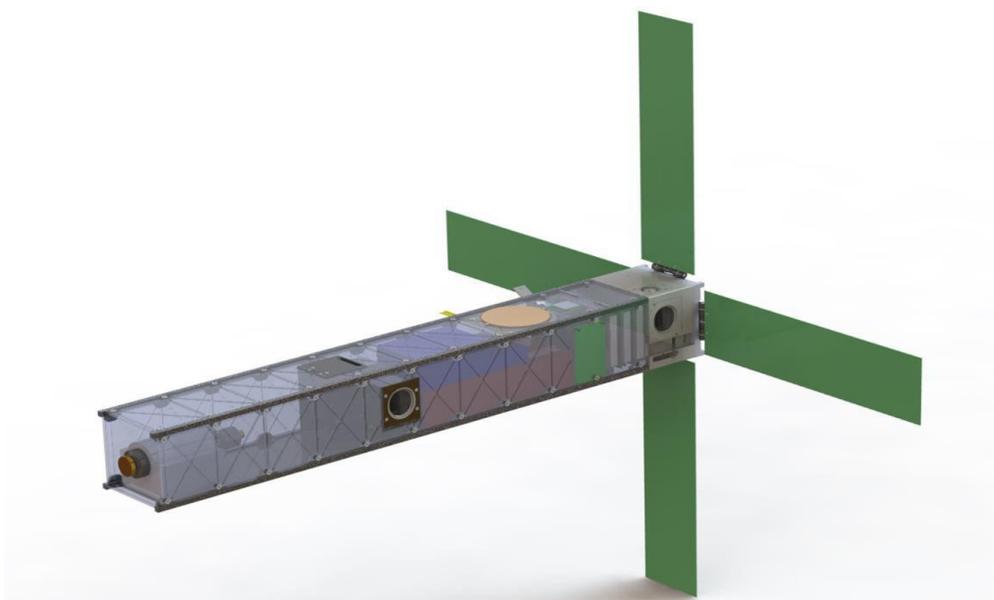
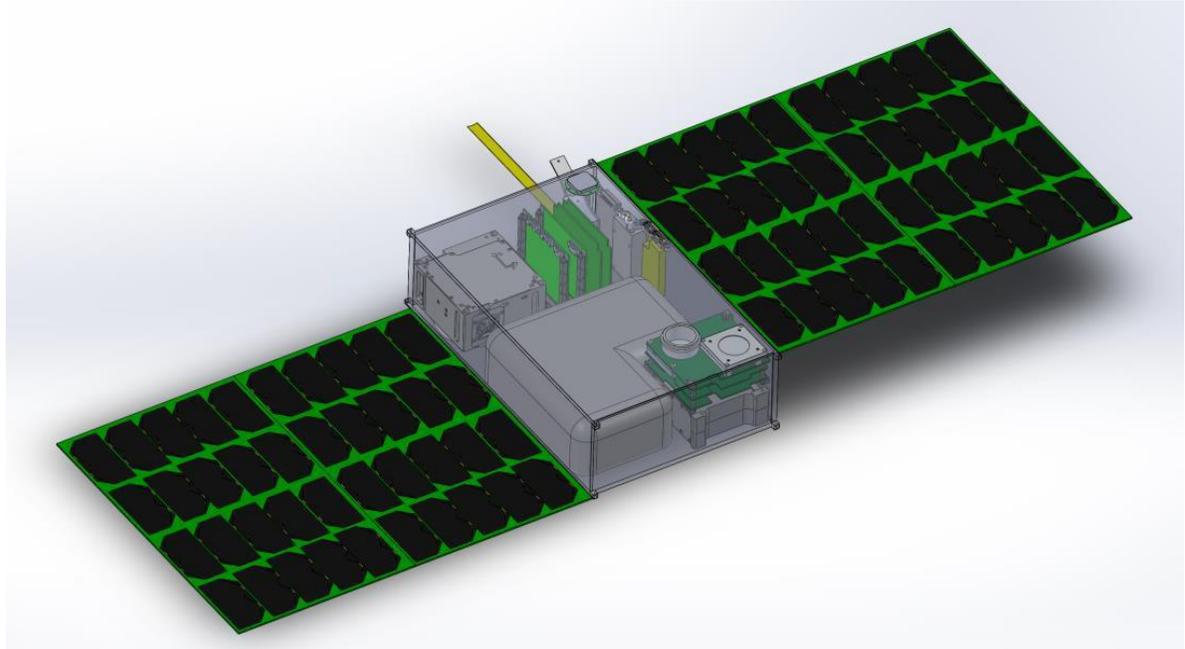
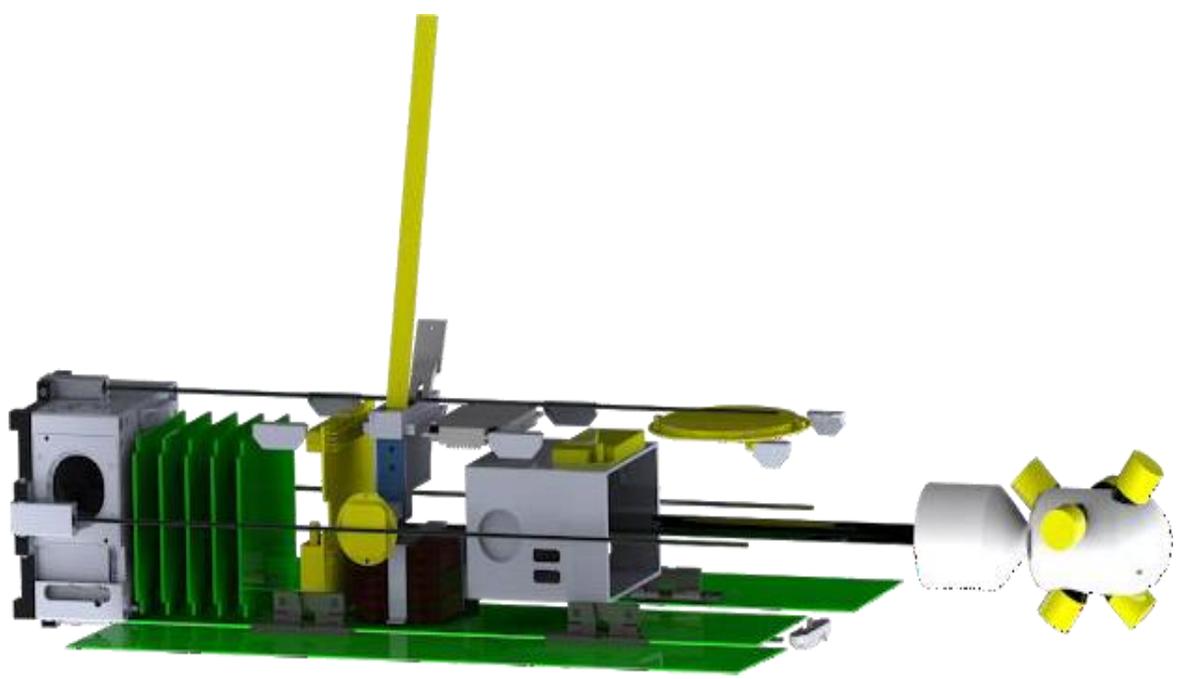


Fig. 13 (Anti-clockwise from top left)

1. COSMO (6U)
2. CANVAS (4U)
3. AEPEX (6U)



Model name:Analysis5
 Study name:Frequency 1(-Default)
 Plot type: Frequency Amplitude1
 Mode Shape : 1 Value = 1,086.8 Hz
 Deformation scale: 0.00710701

Mode 1: 1086.8 Hz

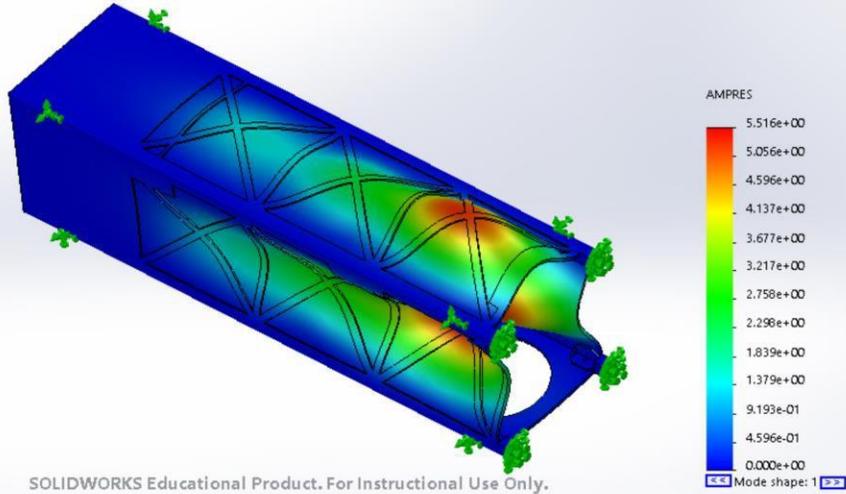


Fig. 14 (Anti-clockwise from top left)

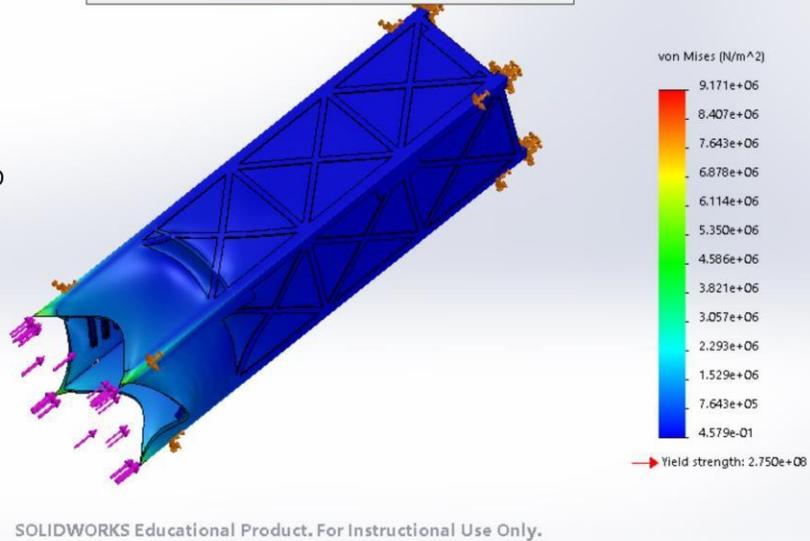
1. Frequency Analysis
2. Static Analysis
3. Dynamic Analysis(Random Vibrations)

Model name:Analysis5
 Study name:Static 1(-Default)
 Plot type: Static nodal stress Stress1
 Deformation scale: 29,934.3

Min. FOS = Yield Strength/Max Von Mises Stress
 = 29.9858

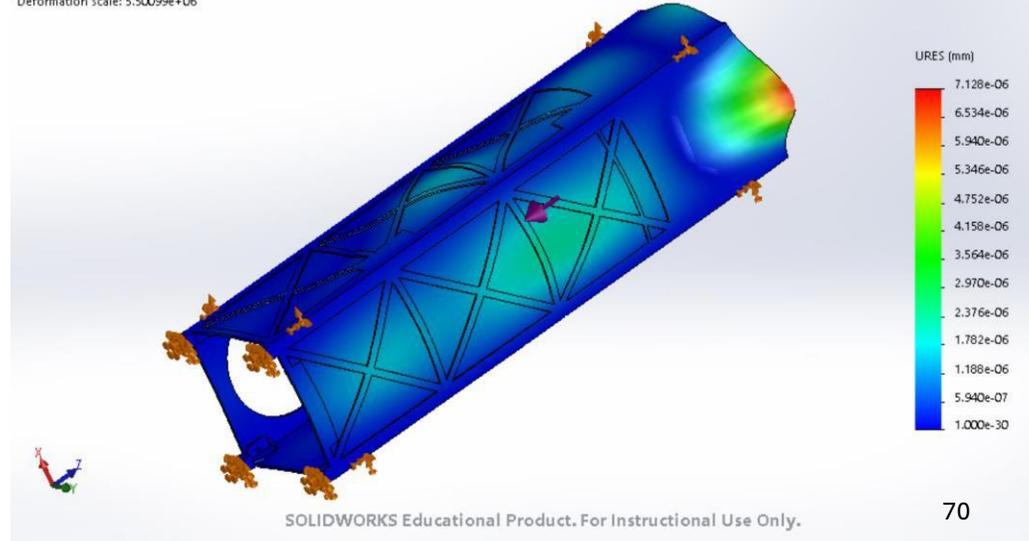
Static Loading:

Nanoracks Deployer IDD
 predicts max. Static
 loading along Z-axis =
1200 N



Model name:Analysis5
 Study name:Dynamic 1(-Default)
 Plot type: RMS Value of displacement Displacement1
 Deformation scale: 5.50099e+06

Max. displacement: 7.128e-06 mm



Other Projects at CU

Estimating wrinkling response of thin, pre-stressed membranes: (Spring 2020)



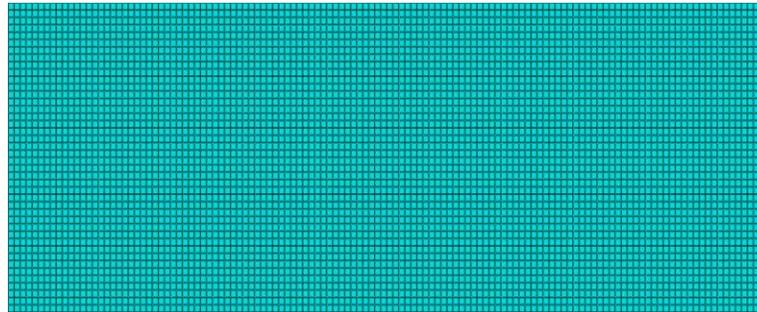
Fig. 5 Wrinkle pattern formation in LightSail 2 [Planetary Society, 2019]

Objectives:

- The ultimate objective of the project is to be able to replicate the experimentally obtained wrinkling response, done by several past studies by extending the shell-based wrinkling approach formulated by Wong and Pellegrino(2006b)[1] to these cases.
- Further, we plan to extend these models to study the wrinkling response of three different configurations of solar sails: Square, Heliogyro and Spinning disk sails, subjected to pre-tension.

Mesh Details:

- Membrane modeled using rectangular elements with reduced integration (S4R5).
- Approximate Global Size = 0.003
- Number of elements = 5461



Model details

Geometry:

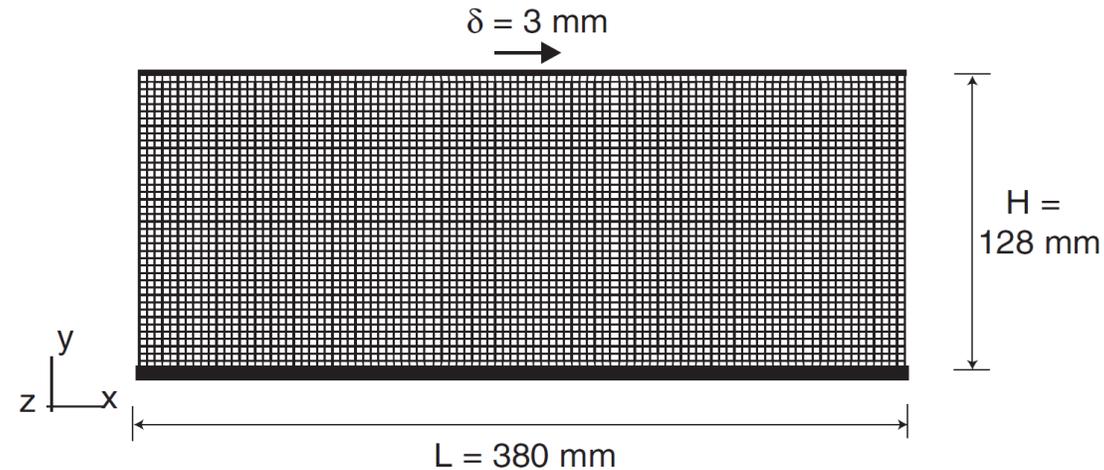


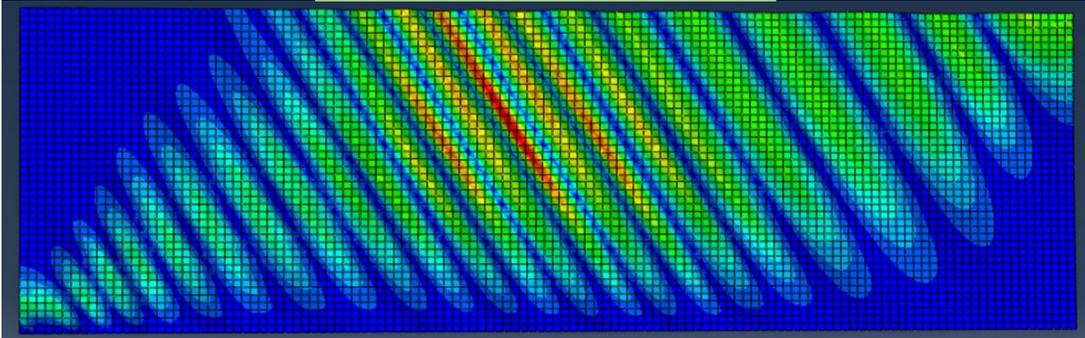
Fig. 6 Geometry based on the experimental set-up of Wong and Pellegrino(2006b)

Analysis Procedure:

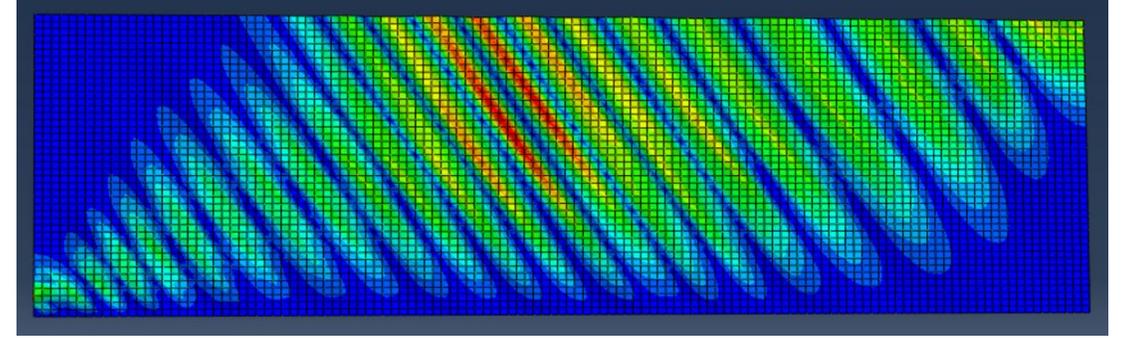
- Apply pre-stress to stabilize the membrane by fixing the bottom edge and displacing side edges along Y.
- Extract eigenvalues to identify buckling mode shapes; introduce selected imperfections into the mesh using IMPERFECTION command.
- Reapply smaller pre-stress and prescribe horizontal displacement at the top edge with constrained rotations for convergence.

Eigenmodes:

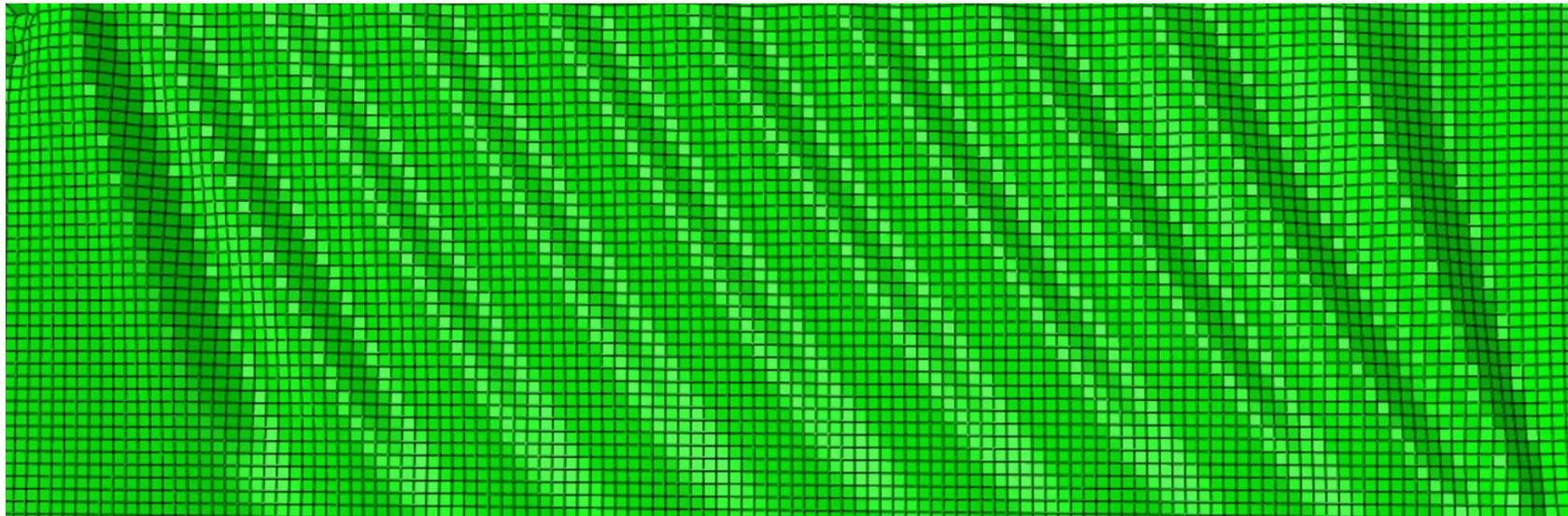
Eigenvalue=0.36249



Eigenvalue=0.36313



Non-Linear Analysis (with Imperfections)



Post-buckling analysis of spherical shells (Spring 2021)

- **Objective** : To understand the different non-linear post-buckling paths
- Buckling of shells takes place under external hydraulic loading (prescribed volume)
- Validate the experimental results(provided by Carlson [1]) via FEA
- Design a hemispherical shell in Abaqus/Explicit and simulated flow of a fictitious fluid into an enclosure containing the shell

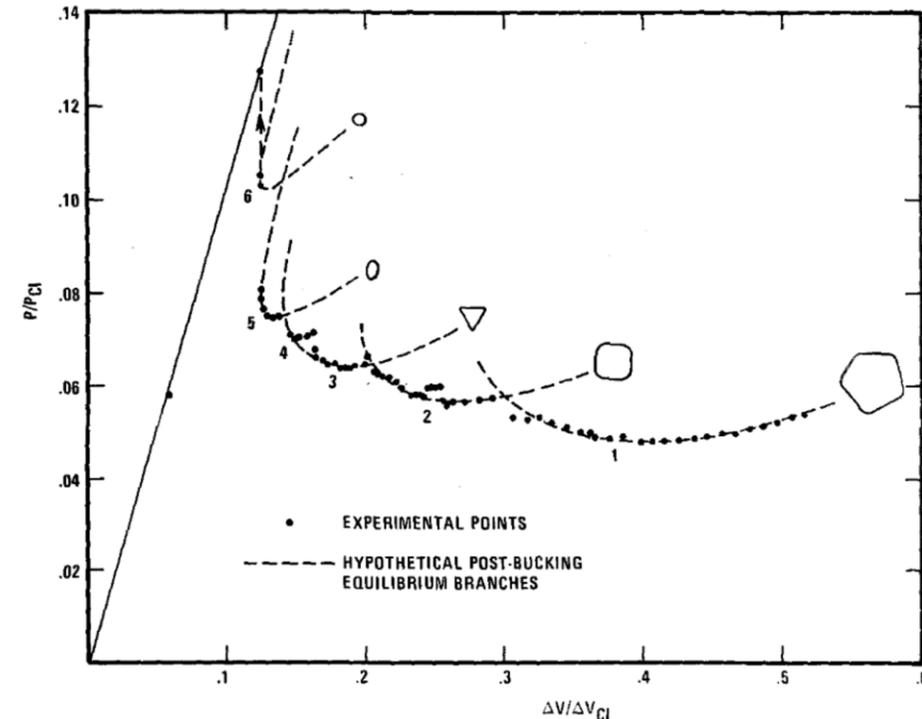
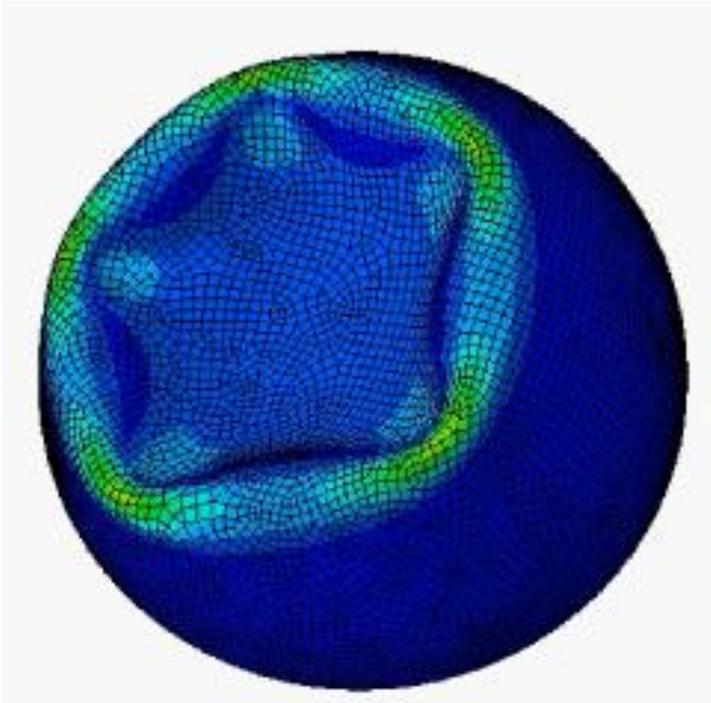


Fig. 3 P/V plot from experiments [1]

Senior Design Project

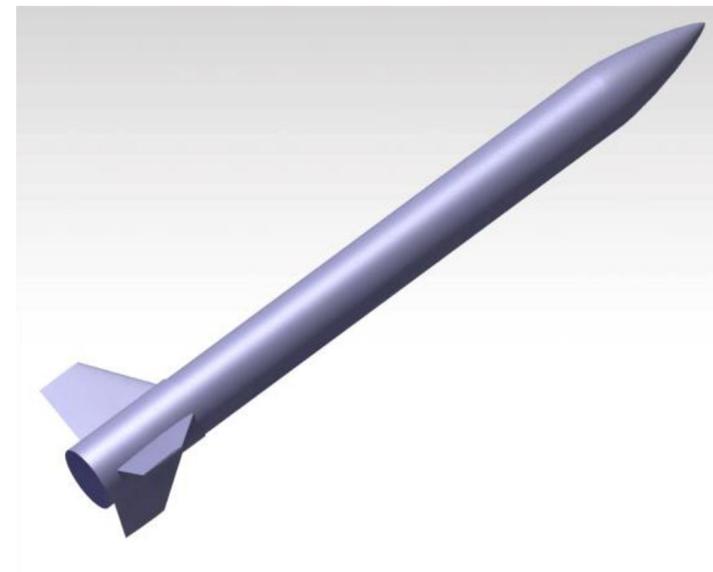
Structural design, simulation and analysis of a low altitude sounding rocket - Senior year project (Undergrad) (2017-18)

- Calculated drag coefficient of a custom rocket using CFD (in Ansys Fluent) and wind tunnel tests; compared results to guide design
- Used drag force to simulate flight trajectory with MATLAB for an F-class Estes motor.
- Selective Laser Sintering (SLS) was used to manufacture the nose cone and the fins of the model rocket.



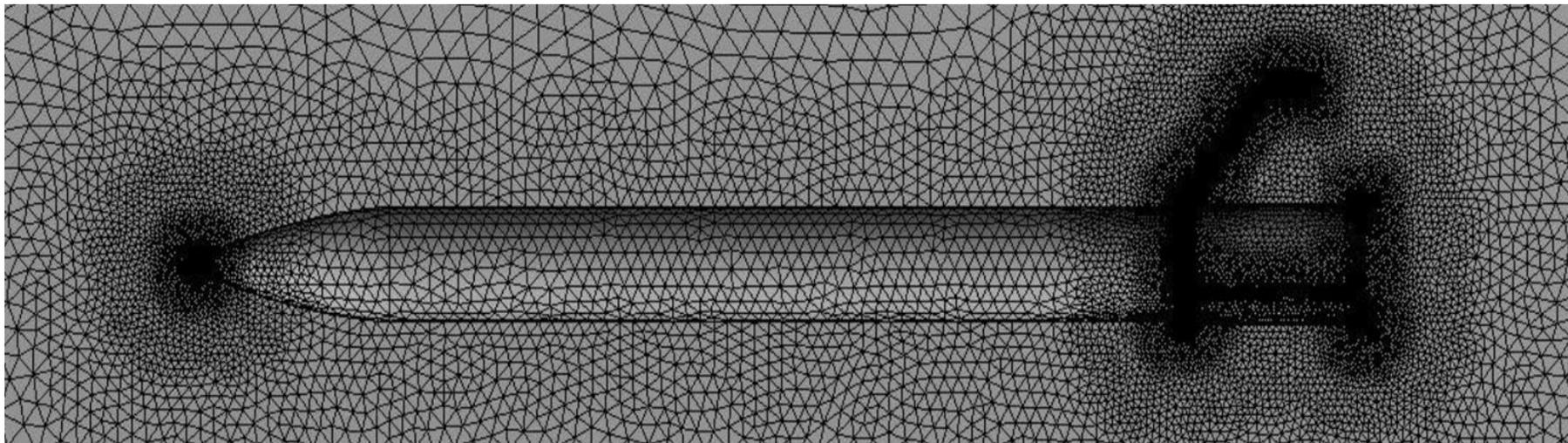
CAD Model (Designed in CatiaV5)

- Nose Cone: LV Haack
- Fins: Standard NACA airfoil



Mesh details:

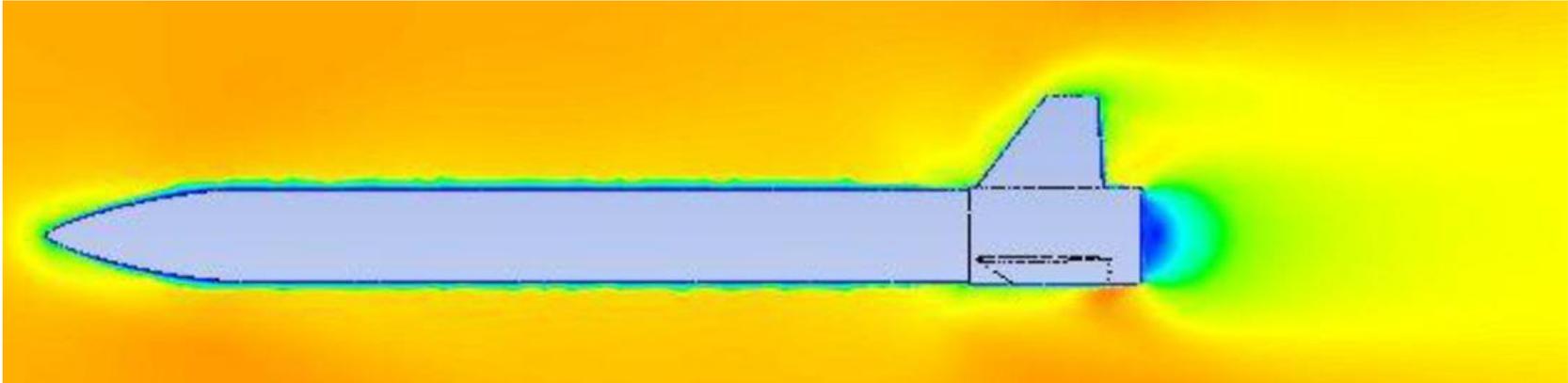
- Tetrahedral Mesh with varying face size (with finer mesh at faces with greater curvature) at Nose Cone, Body tube and Fins to get optimum mesh quality



Pressure Contour



Velocity Contour



Let's work together

I am looking to grow in the aerospace industry and connect with professionals.

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LinkedIn: linkedin.com/in/devenmhadgut



Science can amuse and fascinate us all, but it is engineering that changes the world.

Isaac Asimov

