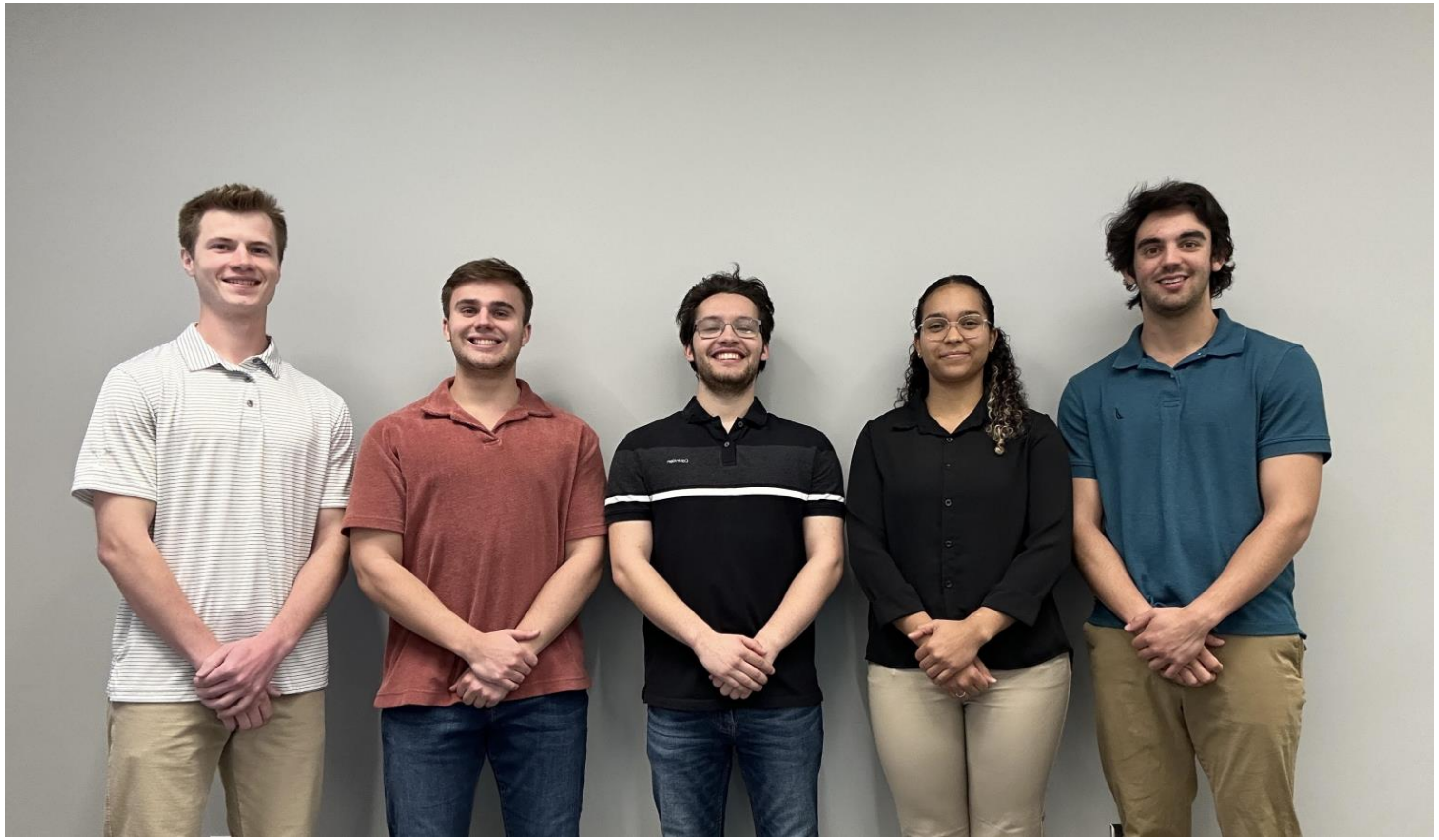
3D METAL-PRINTED SECONDARY MIRROR SUPPORT STRUCTURE



Team Members (left to right)
Calvin Tourangeau
Alex Nagy
Noah Schloff
Shelinee Hernandez Espino
Declan Bhagwat

Customer
L3Harris

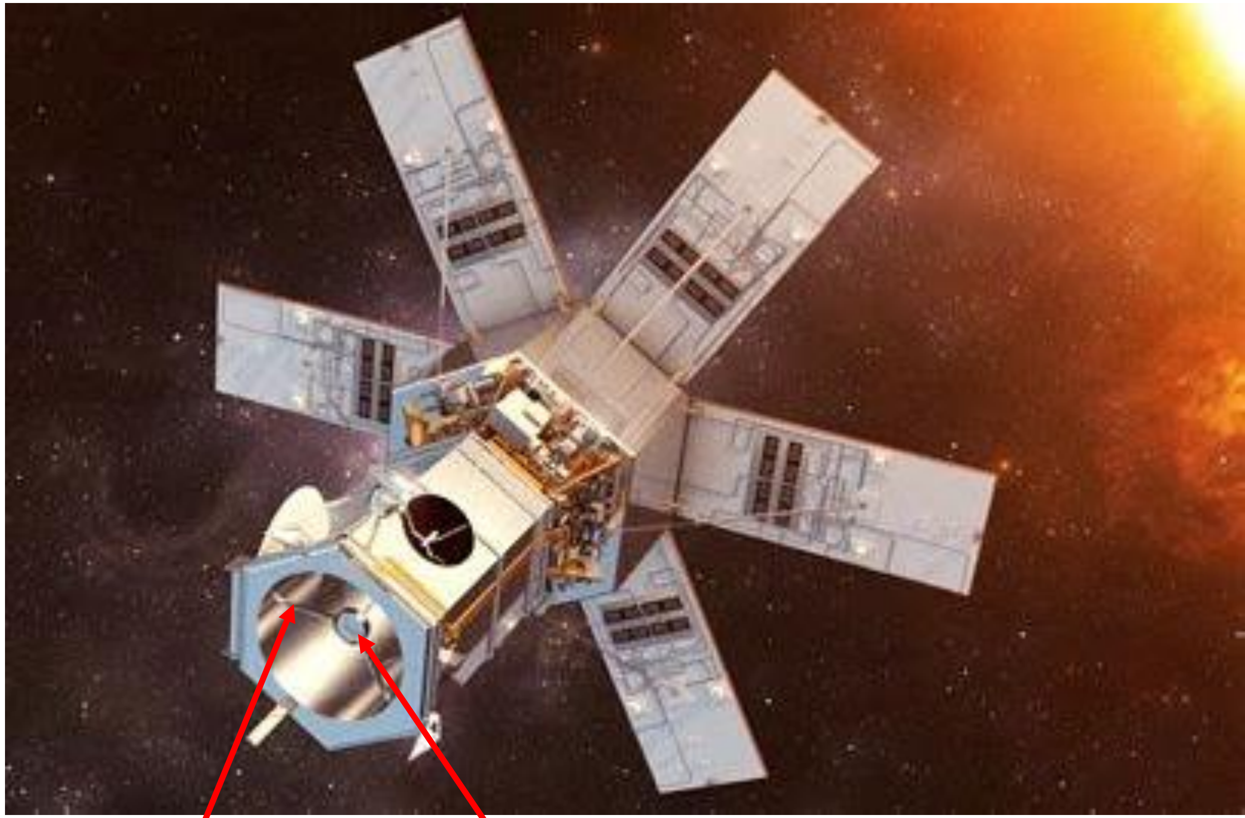
Project Overview

Secondary Mirror Support Structures (SMSS) are essential for properly aligning optical components in satellites. The team is working with L3Harris to develop a design for a 3D-printable SMSS to eliminate waste of material and speed up the manufacturing process while keeping the necessary performance characteristics required for use in space.

Problem Statement

Lightweight SMSS require affordable, fast, and structurally sound manufacturing methods, such as additive manufacturing, to precisely align optical components without obstructing the field of view.

- *With a successful product, L3Harris will benefit through new SMSS design and fabrication ideas.*
- *Additively manufacturing aerospace products is a steppingstone towards rapid prototyping and manufacturing, allowing companies like L3Harris to push the limits within industry.*



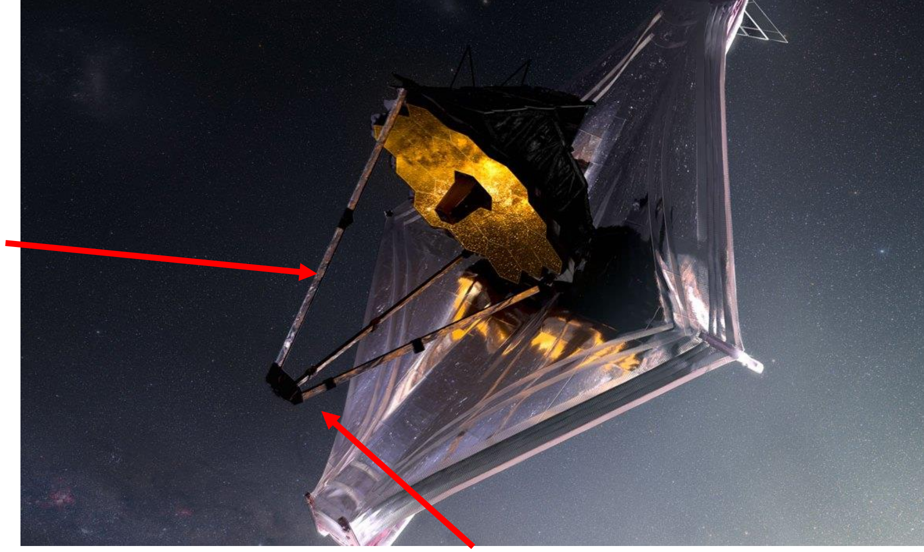
SMSS

Secondary Mirror (SM)

Deliverables and Requirements

The deliverables, requirements and specifications define what will be done and how to be objective about what it means to have a "successful" project.

SMSS



Secondary Mirror (SM)

Deliverables:

- *Preliminary Design Review (PDR)*
- *Creation of a 3D-printed scaled model of SMSS.*
- *Full-scale CAD and finite element model of SMSS.*
- *Final drawings of SMSS.*
- *Final Design Review (FDR)*
- *Final Technical Report.*
- *3D-printed material coupon data test results.*
- *Model Validation of 3D-printed scaled model.*

Requirements:

- *This project consists of the design and analysis of a secondary mirror support structure (SMSS), and the creation of a prototype of this model.*
- *The model shall be created with additive manufacturing (3D printing).*
- *The SMSS shall interface with and support the secondary mirror and its mounts, the actuator assembly, the shade assembly, and all necessary thermal hardware.*
- *There shall be no trapped cavities in the SMSS.*
- *The following factors of safety shall be used: 2.0 for Yield Stress, 1.0 for Micro-Yield Stress, 2.5 for Ultimate Stress and 4.0 for Buckling Stress.*
- *The following mass contingency factors shall be used: 20% for concept design, 15% for preliminary design, 10% for final design, 5% for post final design, and 0.10% for measured hardware.*

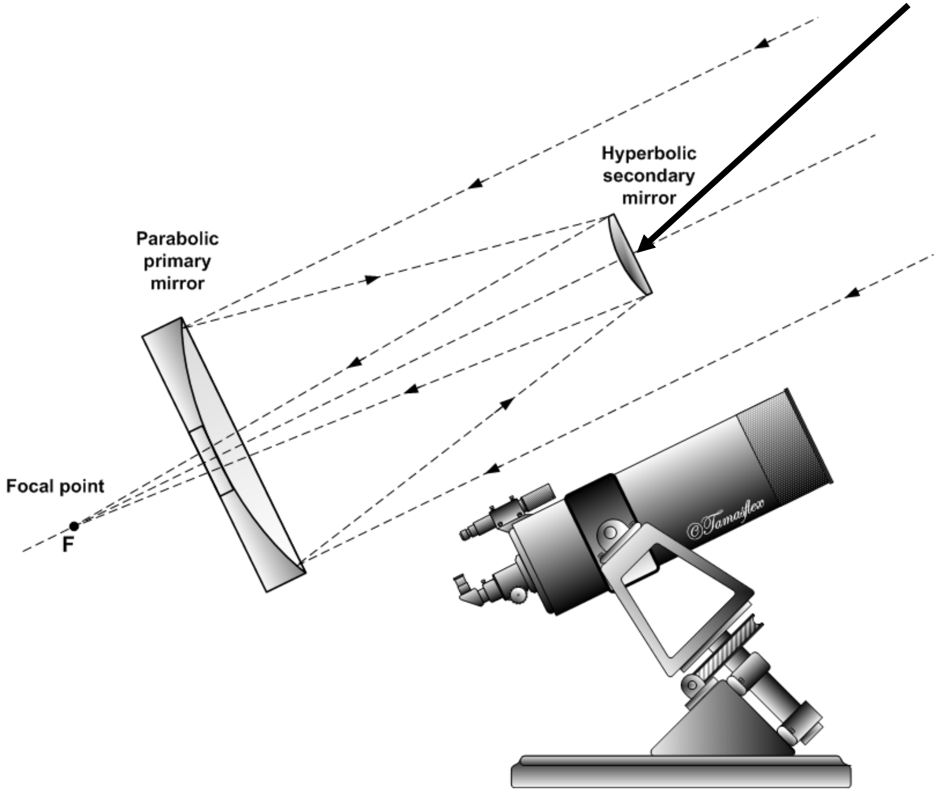
Specifications

The deliverables, requirements and specifications define what will be done and how to be objective about what it means to have a "successful" project.

Specifications:

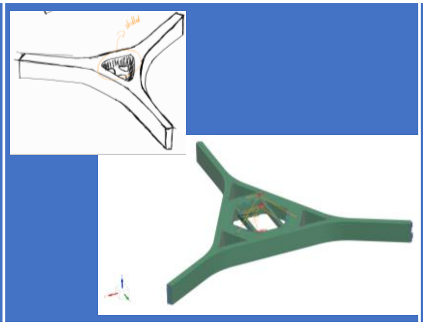
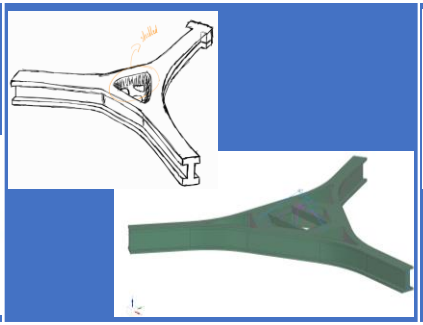
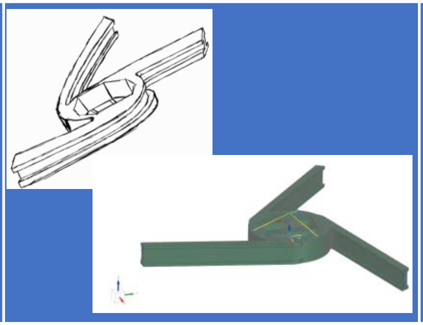
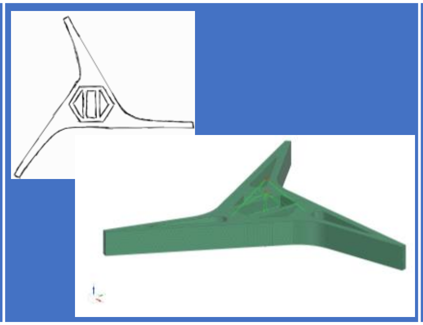
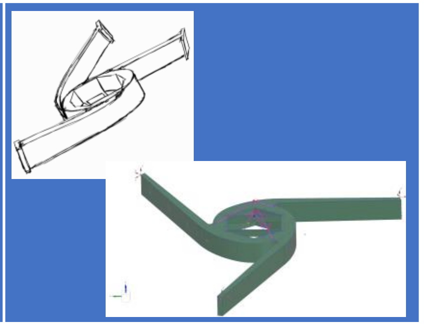
- *The outer diameter of the SMSS (interface to the FMS) shall be 48 inches.*
- *The SMSS shall interface to the Forward Metering Structure (FMS) at three locations 120 degrees apart.*
- *The first mode of the SMSS shall be 120 Hz or greater when grounded at the FMS interface and supporting all hosted hardware.*
- *The mass of the SMSS shall be 18 lbm or less.*
- *The SMSS shall have positive margins of safety against yield and ultimate failure when exposed to a quasi-static load of 12 G laterally and 18 G axially simultaneously (lateral swept 15 deg increments) combined with a 5C to 35C temperature range (nominal room temp is 20C) while supporting all hosted hardware.*
- *The SMSS and hosted hardware shall not obstruct more than 14% of the Primary Mirror (PM) clear aperture area (assume 1.1 m diameter clear aperture).*
- *The SMSS should provide a stable mounting platform for the Secondary Mirror (SM) in thermal environments. The average motion of the SM interfaces under a 1 degree C isothermal load should be 0.66 micro-inches translation (RSS of X and Y) or less and 0.037 micro-radians rotation (RSS of Rx and Ry) or less.*

Secondary Mirror is supported by SMSS

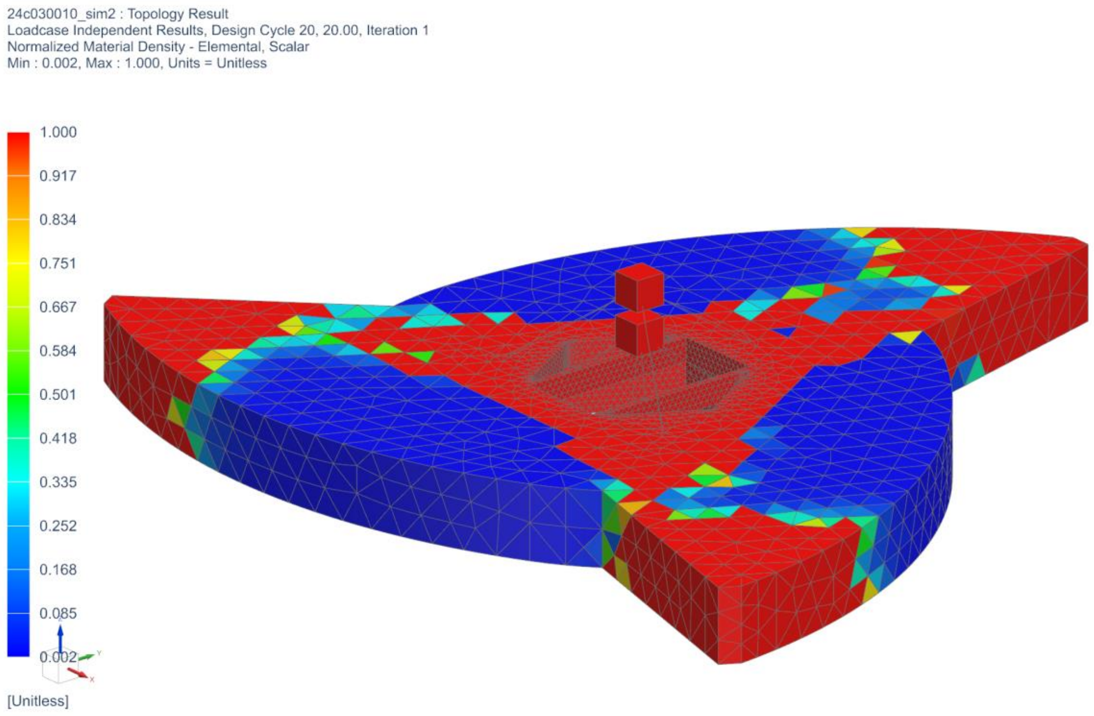


Concepting

Pugh Matrix – Concept Sketches & Preliminary Analyses

					
Concept	**1 (Baseline)**	**2**	**3**	**4**	**5**
Manufacturability	0	-	-	0	-
Strength	0	-	+	-	+
Thermal Stability	0	+	0	-	+
Weight	0	+	+	-	+
Modal Frequency	0	+	-	+	-
Total	0	1	0	-2	1

Model Optimization



Optimization History				
Based on Optimizer				
Design Objective Function Results				
Minimum Weight [lbf]	0	1	2	3
	20.805785	22.092869	16.825496	16.827698
Design Variable Results				
Name	0	1	2	3
"24c041703A"::A_leg_length=9.5	9.5	8.41	10.999633	10.999267
Design Constraint Results				
	0	1	2	3
Frequency Mode 1				
Lower Limit = 120.000000 [Hz]	154.29231	159.11603	134.76999	134.79257
Small change in design, run converged.				

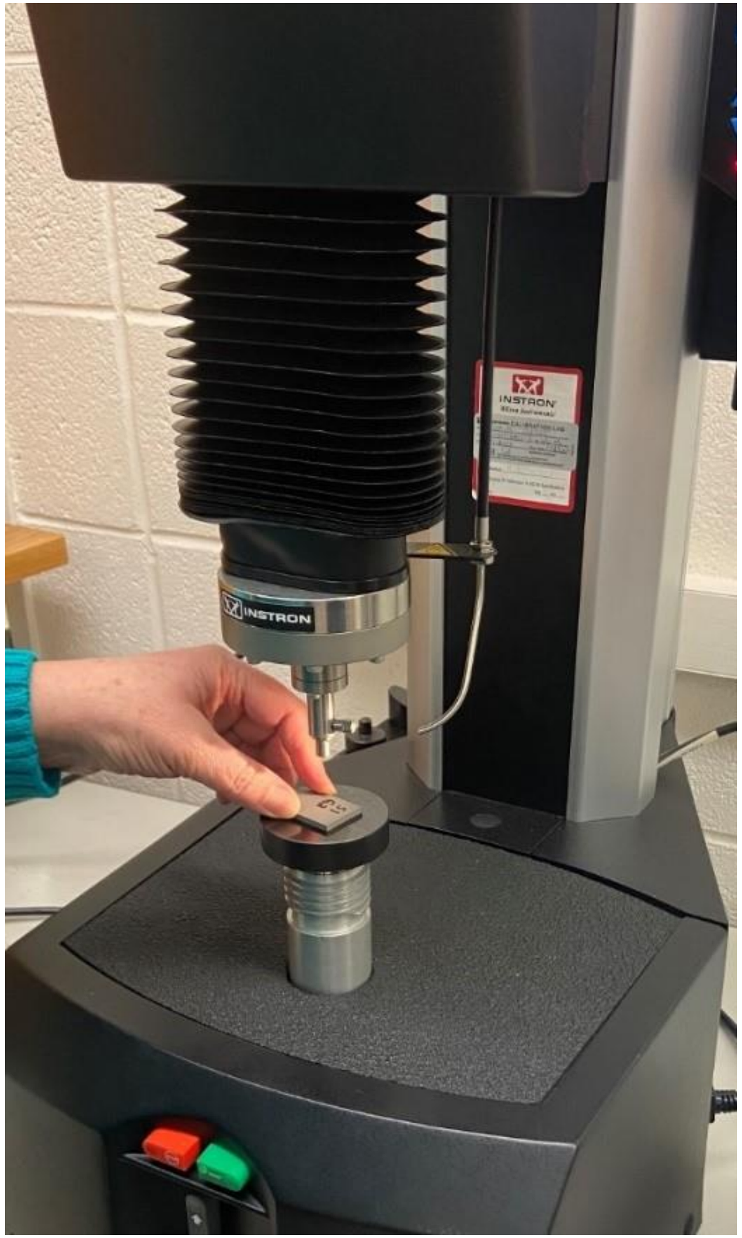
Topology Optimization

- *Determined load path through a solid design space*
- *Showed structural behavior under launch loads*
- *Displayed elements containing zero stresses*

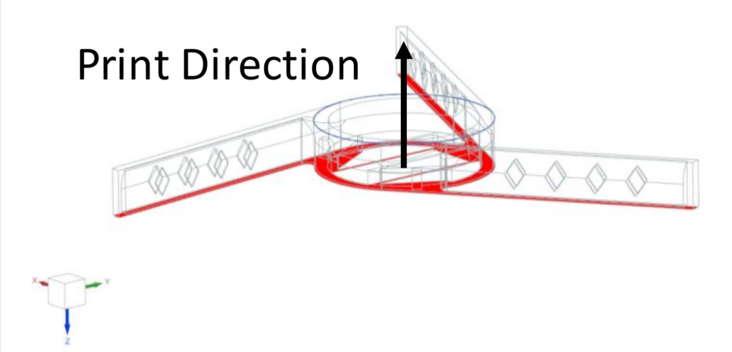
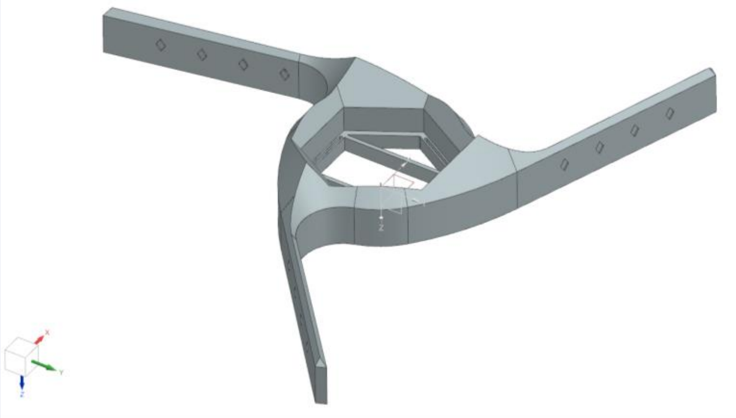
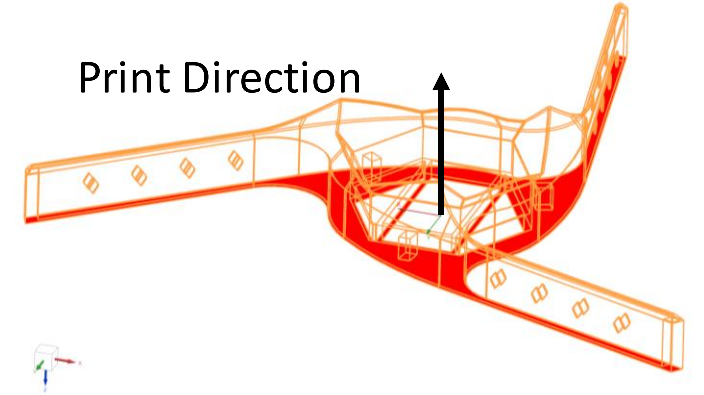
Shape Optimization

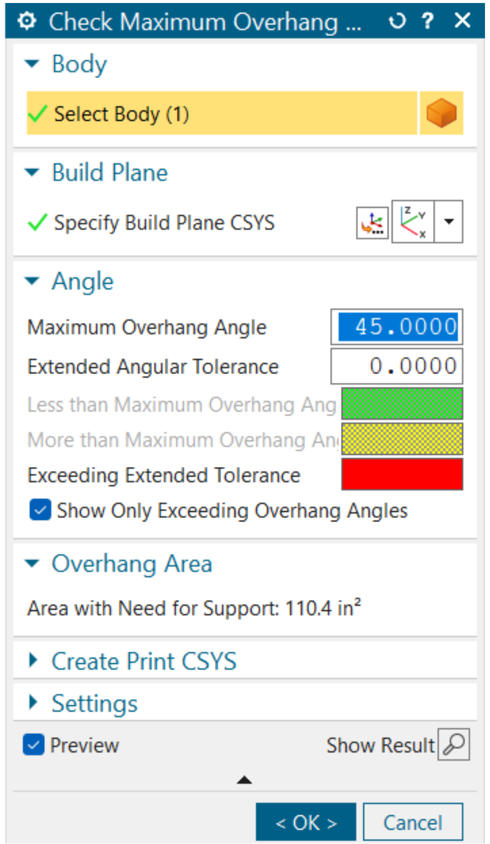
- *Parameterized structure to determine what dimensions have greatest influence on model performance.*
- *Quickly altered variable dimensions to improve design based on the outlined objective.*

Coupon Testing

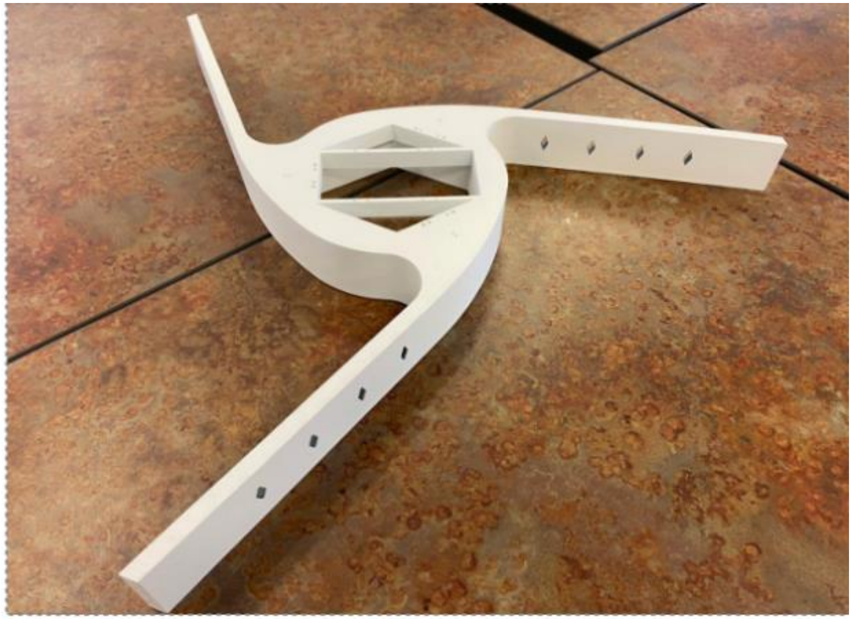


Manufacturing & Printability

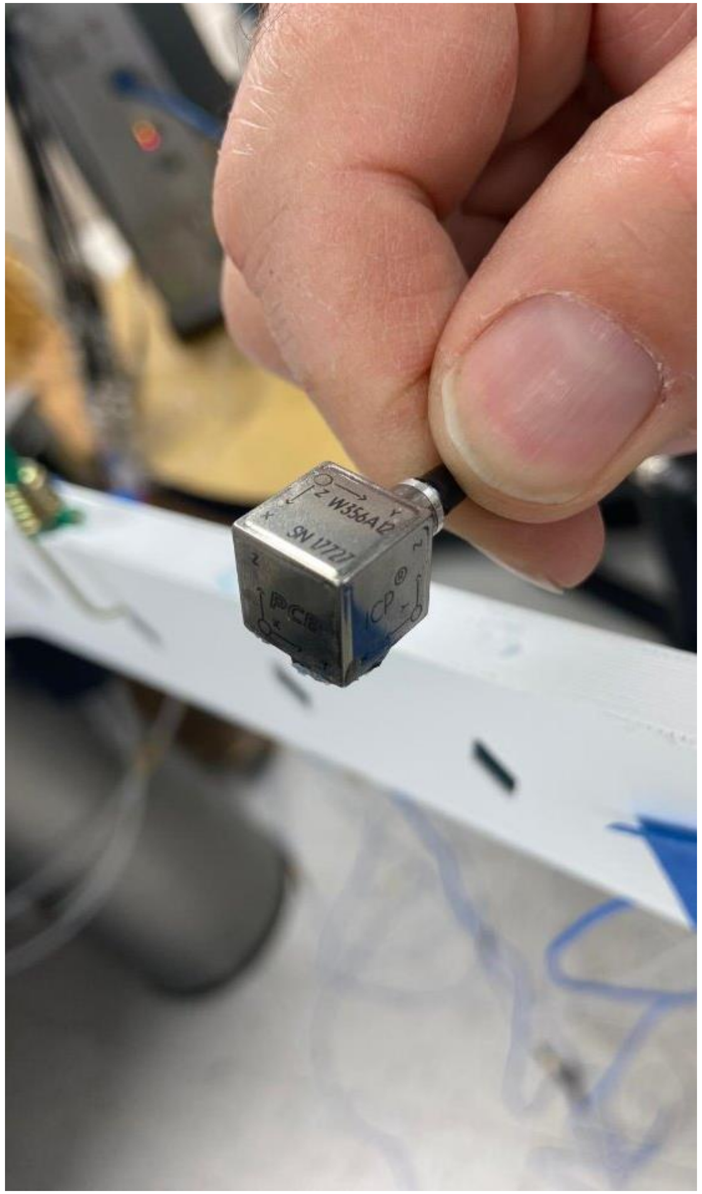
Printability Method	Image of Design	Printability Verification
Internal Printability *Using chamfers and edge blends to create angle roof on inside of shell.*		
External Printability *Using a triangular drafted extrusion to close the shell.*		

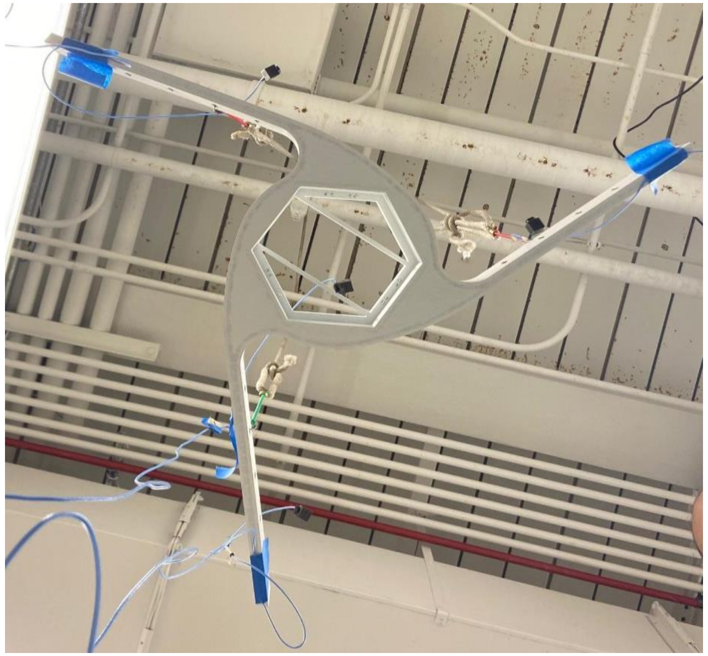


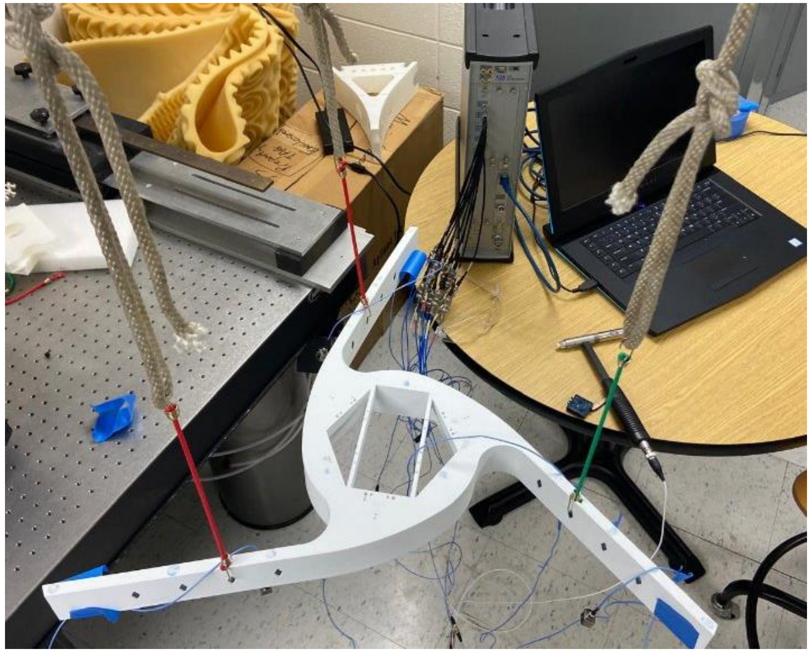
Scaled Prototype

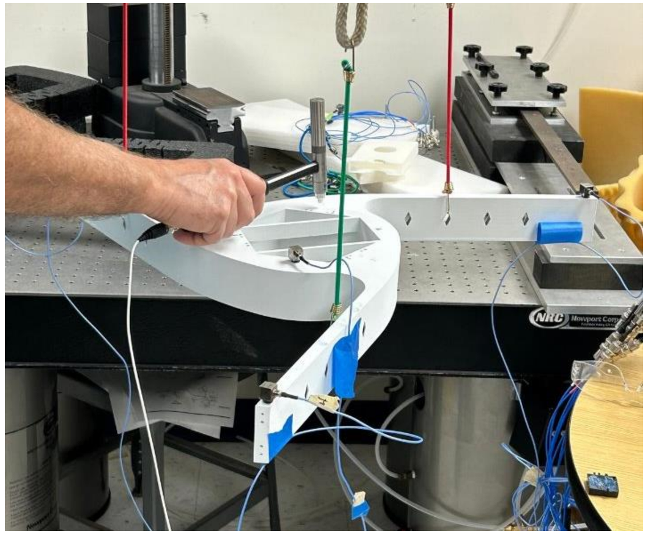


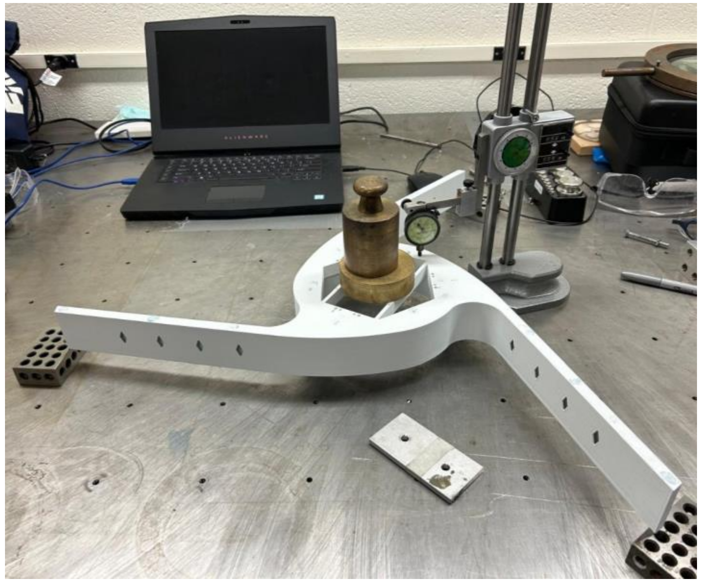
Model Testing & Correlation





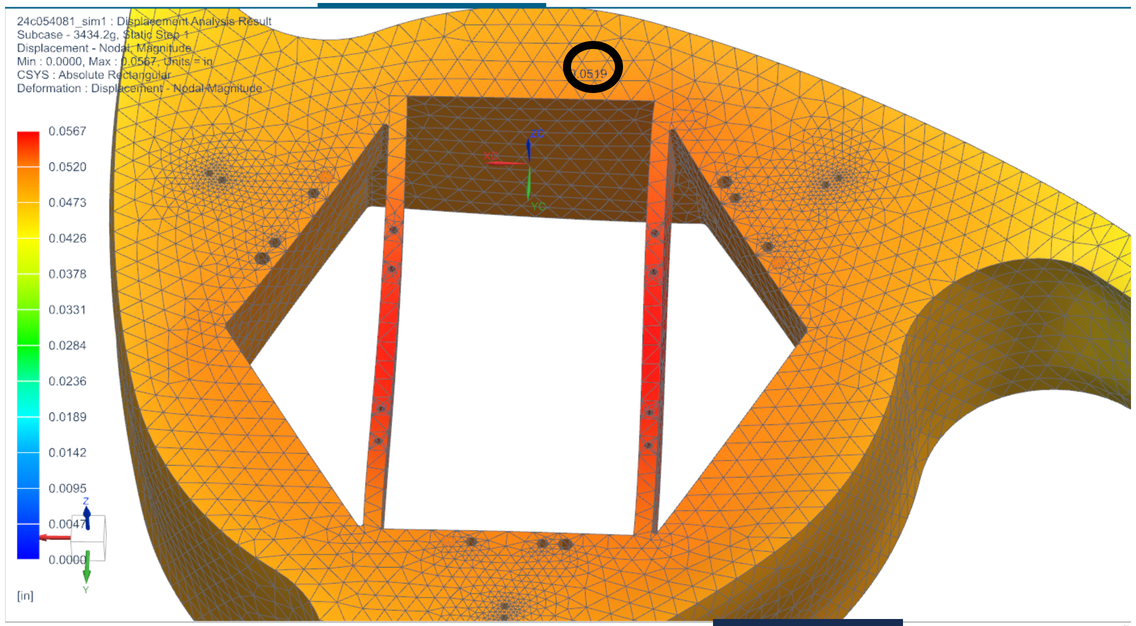






Model Testing & Correlation

Total Mass 3434.2 grams Spot 1

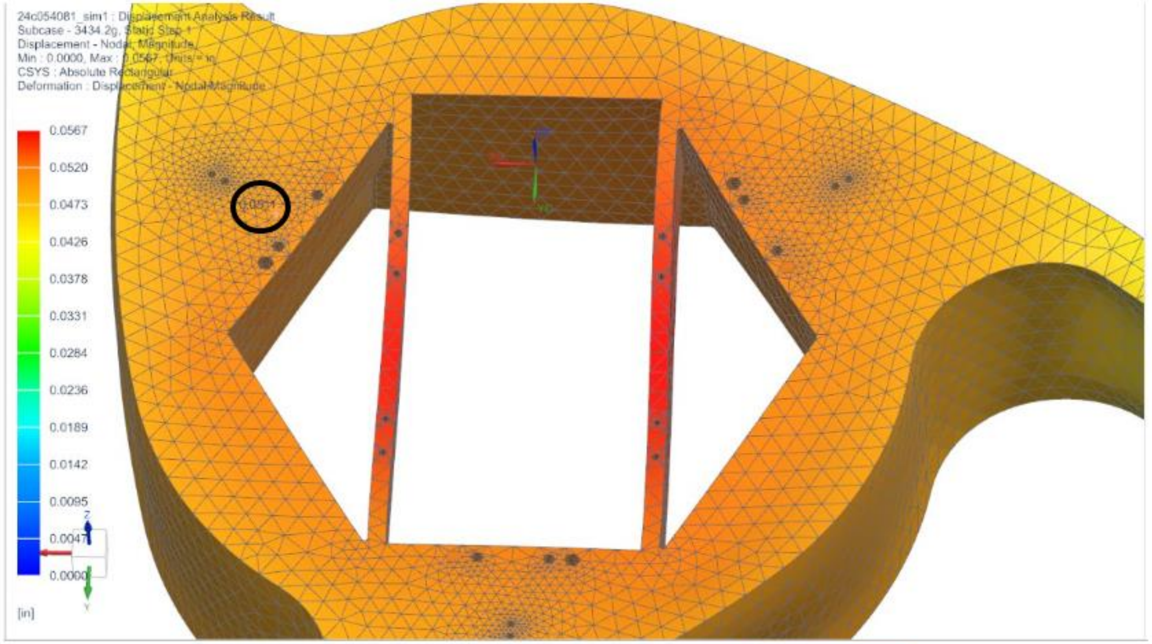


Node ID	X	Y	Z	Magnitude
205908	0.004102	-0.002853	-0.05165	0.05189

Measured Displacement = 0.0515 inches

Percent Error = **0.29%**

Total Mass 3434.2 grams Spot 2

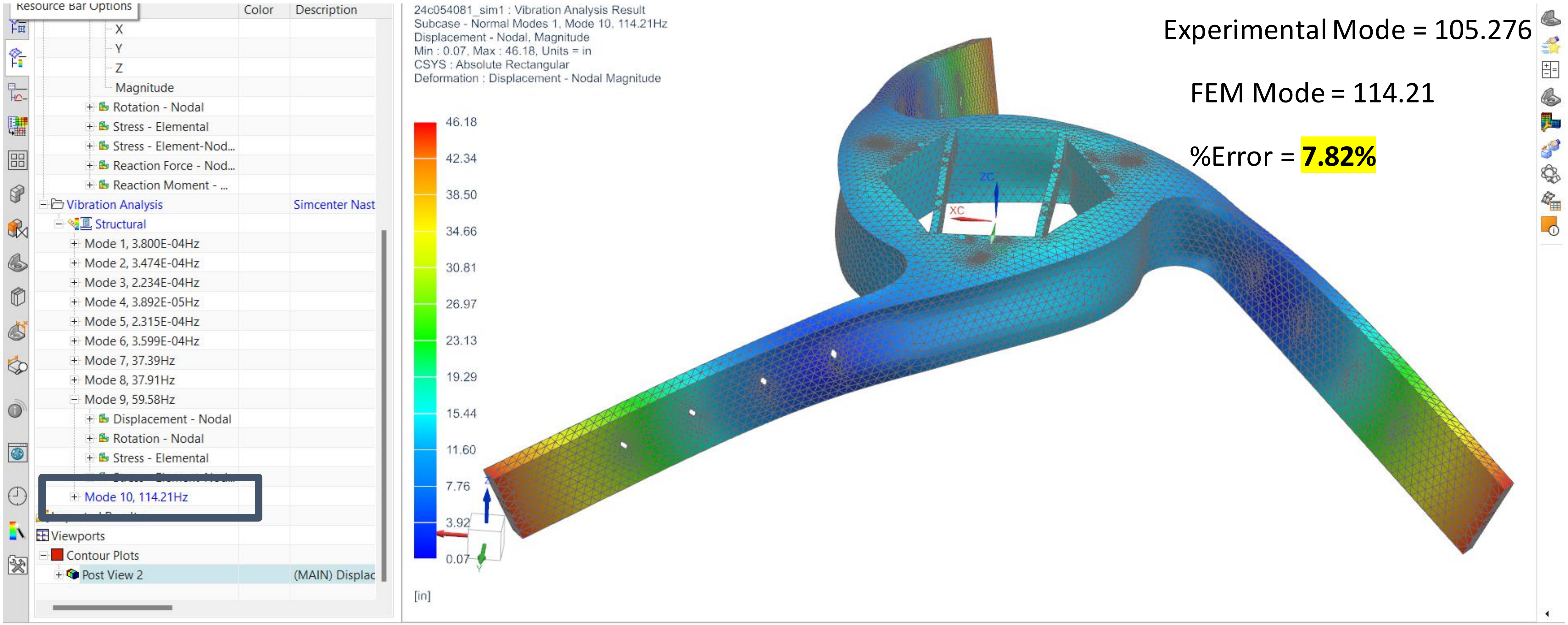


Node ID	X	Y	Z	Magnitude
199974	0.003213	-0.002233	-0.05093	0.05108

Measured Displacement = 0.051 inches

Percent Error = **0.14%**

Model Testing & Correlation



Experimental Mode = 105.276

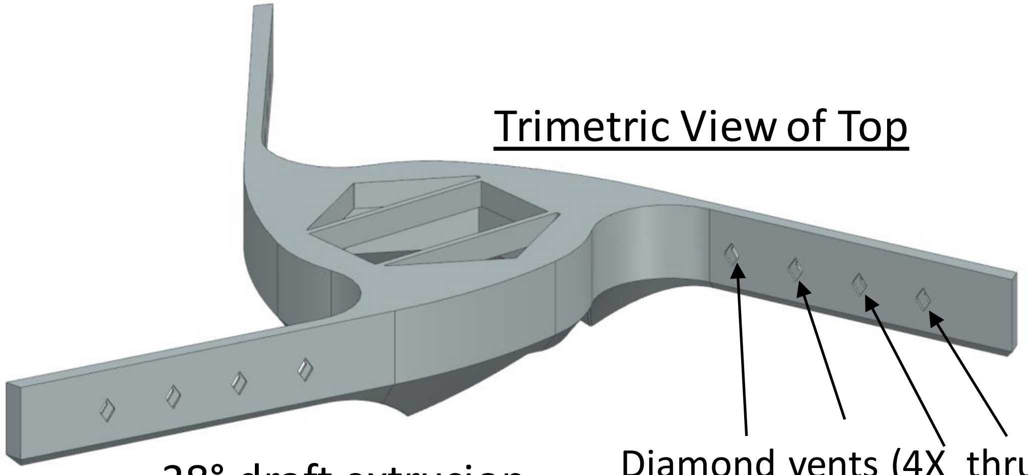
FEM Mode = 114.21

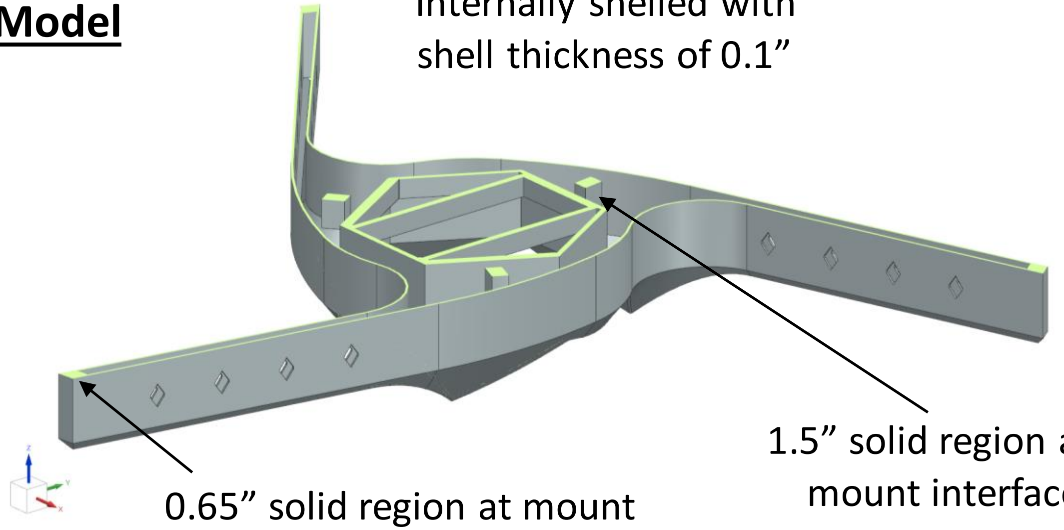
%Error = **7.82%**

Final Model

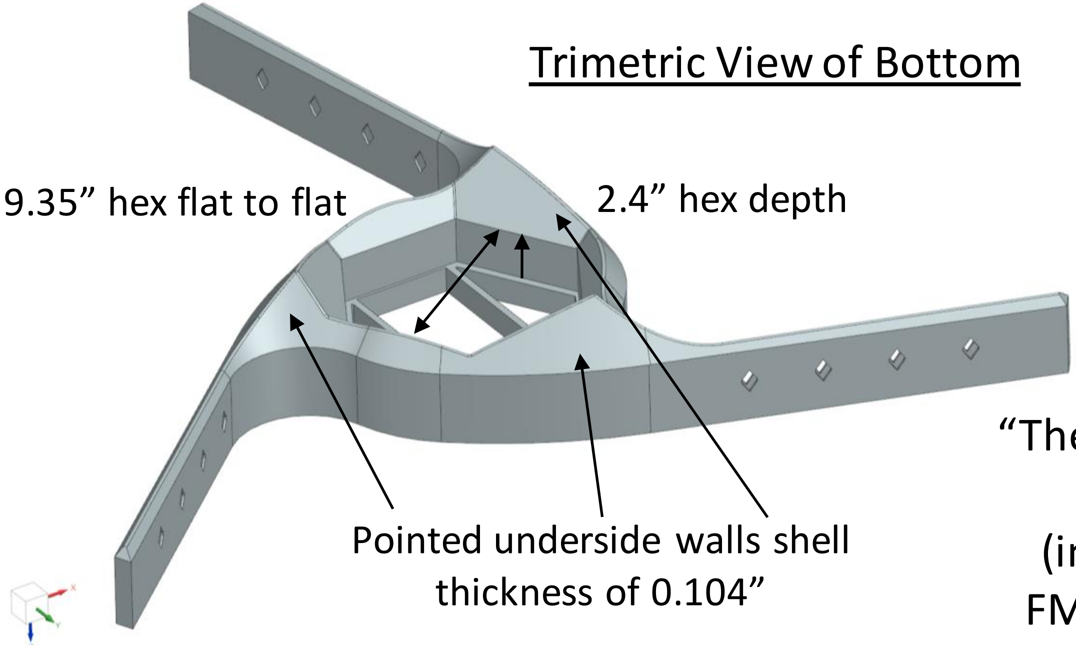
CAD Model

Trimetric View of Top



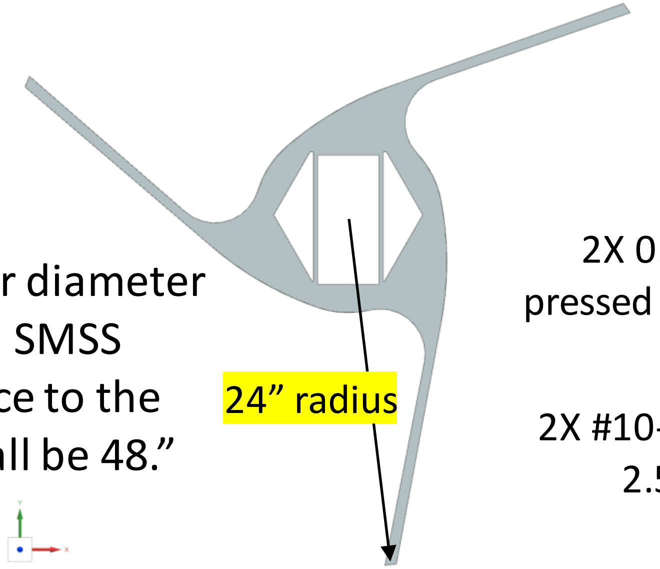


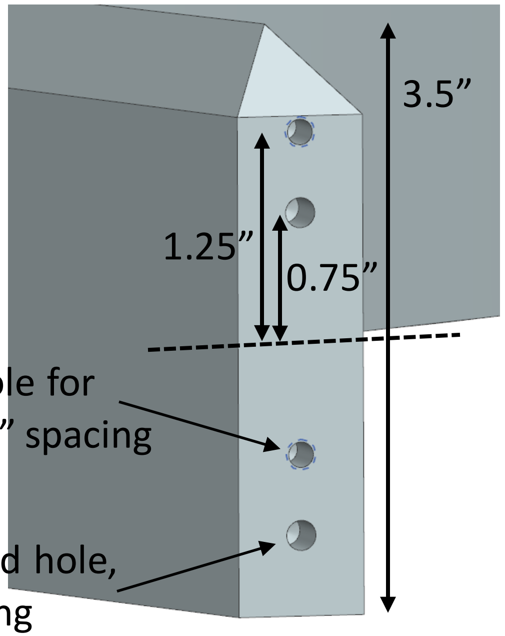
Trimetric View of Bottom



Top View

“The outer diameter of the SMSS (interface to the FMS) shall be 48.”



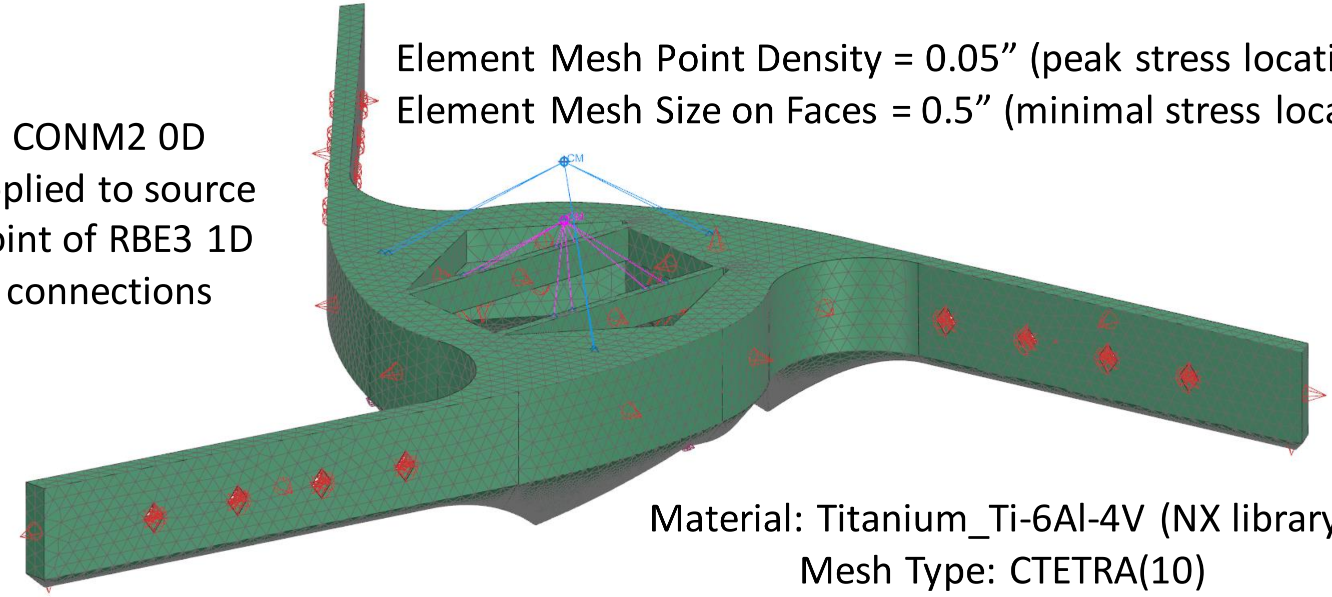


Final Model

Finite Element Model

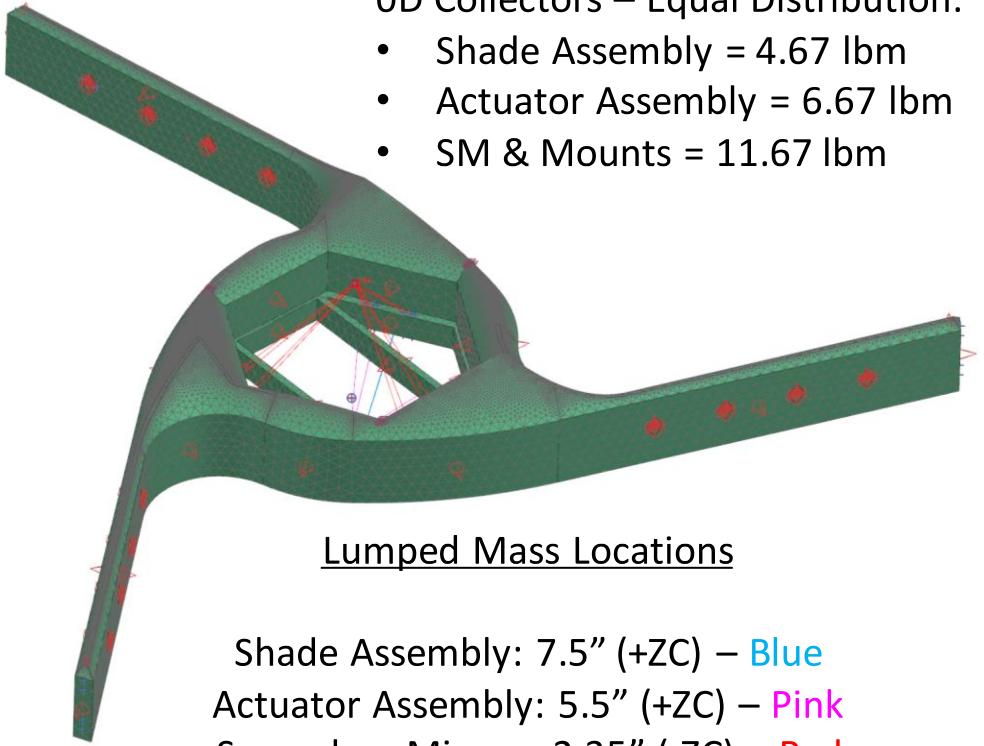
CONM2 0D applied to source point of RBE3 1D connections

Element Mesh Point Density = 0.05” (peak stress locations)
Element Mesh Size on Faces = 0.5” (minimal stress locations)



0D Collectors – Equal Distribution:

- Shade Assembly = 4.67 lbm
- Actuator Assembly = 6.67 lbm
- SM & Mounts = 11.67 lbm



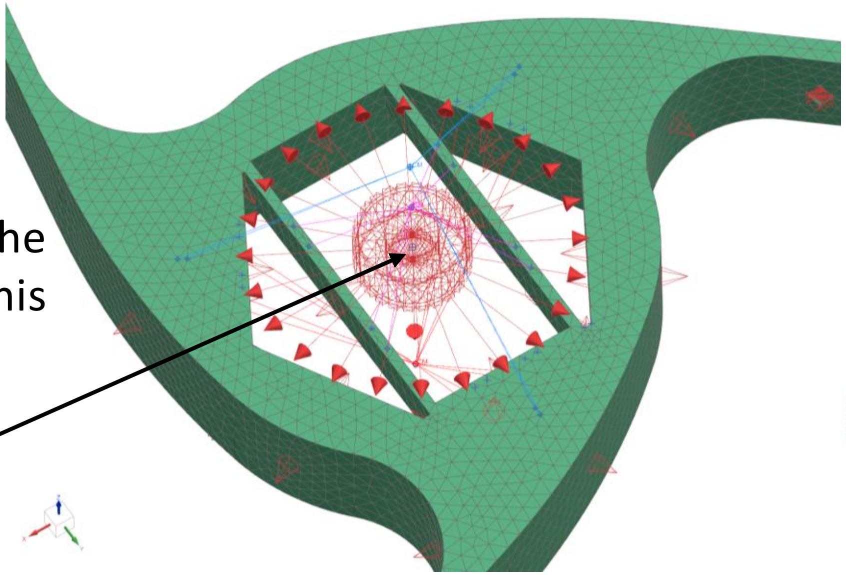
Material: Titanium_Ti-6Al-4V (NX library)
Mesh Type: CTETRA(10)
Element Size: 0.125”
Yield Strength: 116,755 PSI (805,000 KPa)
Ultimate Strength: 122,556 PSI (845,000 KPa)

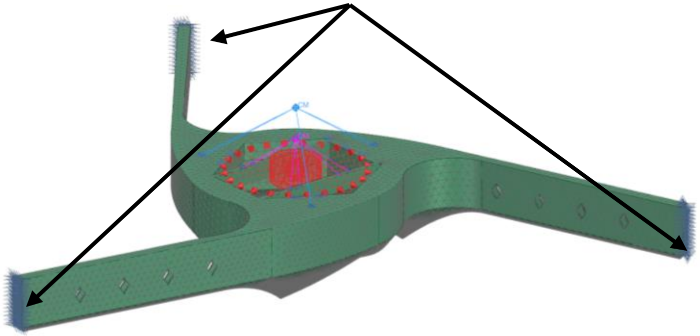
Lumped Mass Locations

Shade Assembly: 7.5” (+ZC) – Blue
Actuator Assembly: 5.5” (+ZC) – Pink
Secondary Mirror: -2.35” (-ZC) – Red

Volume = 110.639 in^2
Mass = **17.707 lbm**
Total Weight (includes hardware) = 40.7071 lbf

“SMSS Mass: Goal is 18 lbs or less (for reference, the state-of-the-art graphite composite structure for this design was 12 lb).”





3X fixed polygon faces 120°

Loads:
18G Axial (-ZC)
12G Lateral (360° from +XC)

Final Model

Yield Stress Margin of Safety Computations

Von Mises Element Nodal Stresses – Maximum Values Across All Nodes

	Calculation	Failure Mode	Load Case	Margin of Saf	Rank by Global	Rank by Calculation	Rank by Failure Mode	Rank by Load Case
1	YieldStress	margin_of...	H0	1.8643	41	41	41	1
2	YieldStress	margin_of...	H105	1.7316	18	18	18	1
3	YieldStress	margin_of...	H120	1.7440	22	22	22	1
4	YieldStress	margin_of...	H135	1.7793	30	30	30	1
5	YieldStress	margin_of...	H15	1.9006	43	43	43	1
6	YieldStress	margin_of...	H150	1.8368	35	35	35	1
7	YieldStress	margin_of...	H165	1.7730	28	28	28	1
8	YieldStress	margin_of...	H180	1.7028	17	17	17	1
9	YieldStress	margin_of...	H195	1.6545	11	11	11	1
10	YieldStress	margin_of...	H210	2.0247	48	48	48	1
11	YieldStress	margin_of...	H225	1.6282	6	6	6	1
12	YieldStress	margin_of...	H240	1.6507	9	9	9	1
13	YieldStress	margin_of...	H255	1.6965	16	16	16	1
14	YieldStress	margin_of...	H270	1.7648	25	25	25	1
15	YieldStress	margin_of...	H285	1.8538	38	38	38	1
16	YieldStress	margin_of...	H30	1.9590	47	47	47	1
17	YieldStress	margin_of...	H300	1.9489	46	46	46	1
18	YieldStress	margin_of...	H315	1.8936	42	42	42	1
19	YieldStress	margin_of...	H330	1.8607	40	40	40	1
20	YieldStress	margin_of...	H345	1.8509	37	37	37	1
21	YieldStress	margin_of...	H45	1.9093	45	45	45	1
22	YieldStress	margin_of...	H60	1.8323	34	34	34	1
23	YieldStress	margin_of...	H75	1.7762	29	29	29	1
24	YieldStress	margin_of...	H90	1.7424	21	21	21	1

F.S. = 2.0

	Calculation	Failure Mode	Load Case	Margin of Saf	Rank by Global	Rank by Calculation	Rank by Failure Mode	Rank by Load Case
25	YieldStress	margin_of...	L0	1.7696	27	27	27	1
26	YieldStress	margin_of...	L105	1.6400	7	7	7	1
27	YieldStress	margin_of...	L120	1.6515	10	10	10	1
28	YieldStress	margin_of...	L135	1.6845	15	15	15	1
29	YieldStress	margin_of...	L15	1.8036	32	32	32	1
30	YieldStress	margin_of...	L150	1.7381	20	20	20	1
31	YieldStress	margin_of...	L165	1.6736	13	13	13	1
32	YieldStress	margin_of...	L180	1.6079	5	5	5	1
33	YieldStress	margin_of...	L195	1.5628	3	3	3	1
34	YieldStress	margin_of...	L210	1.9065	44	44	44	1
35	YieldStress	margin_of...	L225	1.5383	1	1	1	1
36	YieldStress	margin_of...	L240	1.5593	2	2	2	1
37	YieldStress	margin_of...	L255	1.6020	4	4	4	1
38	YieldStress	margin_of...	L270	1.6655	12	12	12	1
39	YieldStress	margin_of...	L285	1.7481	23	23	23	1
40	YieldStress	margin_of...	L30	1.8581	39	39	39	1
41	YieldStress	margin_of...	L300	1.8470	36	36	36	1
42	YieldStress	margin_of...	L315	1.7971	31	31	31	1
43	YieldStress	margin_of...	L330	1.7664	26	26	26	1
44	YieldStress	margin_of...	L345	1.7571	24	24	24	1
45	YieldStress	margin_of...	L45	1.8055	33	33	33	1
46	YieldStress	margin_of...	L60	1.7338	19	19	19	1
47	YieldStress	margin_of...	L75	1.6815	14	14	14	1
48	YieldStress	margin_of...	L90	1.6500	8	8	8	1

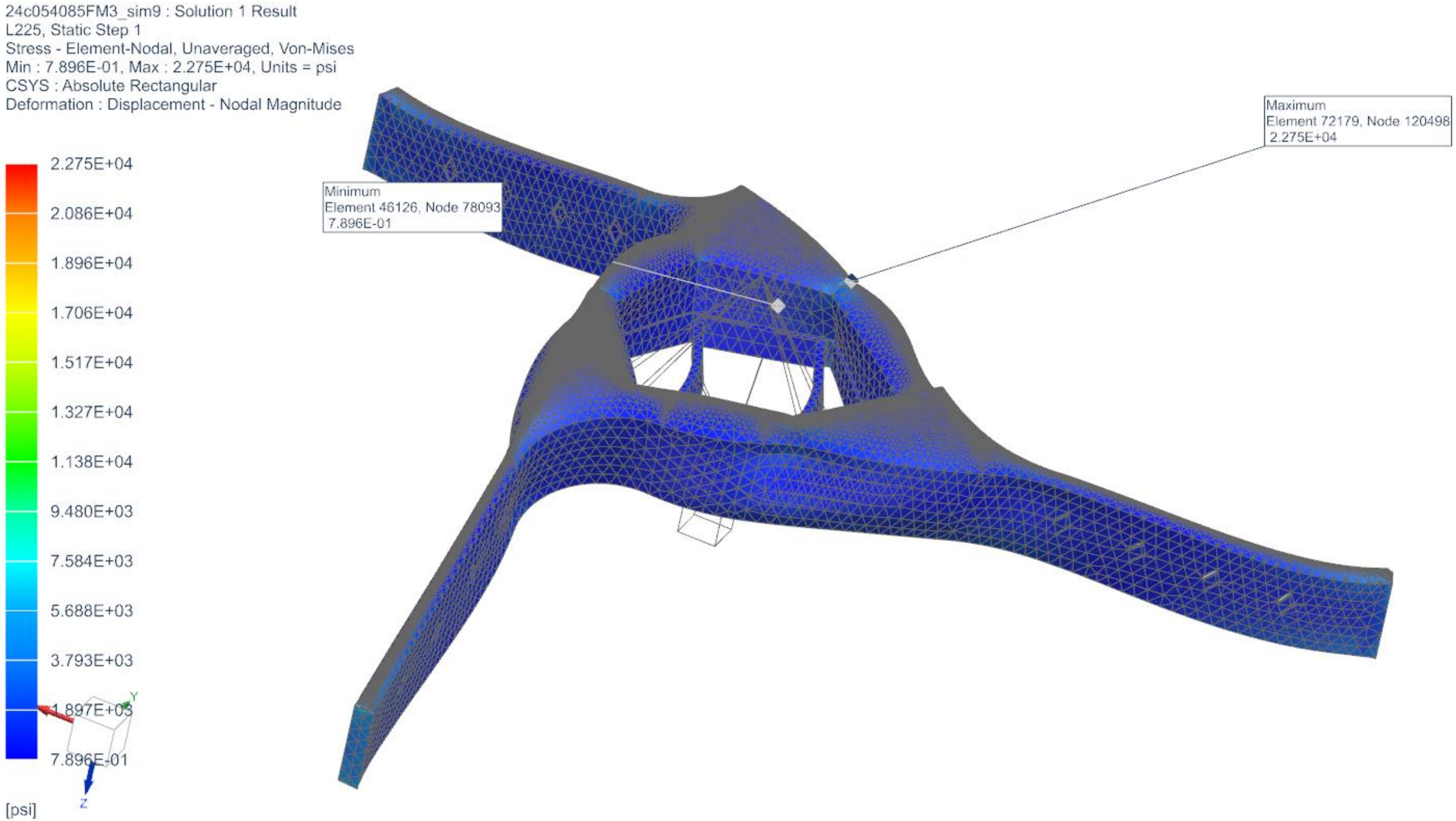
Lowest Margin = **1.538** (low temperature, 225° from +XC)

"The SMSS shall have positive margins of safety against yield and ultimate failure when exposed to a quasi-static load of 12 G laterally and 18 G axially simultaneously (lateral swept 15° increments) combined with a 5° C to 35°C temperature range (nominal room temp is 20°C) while supporting all hosted hardware."

Final Model

Max Yield Stress Subcase Plot

Von Mises Element Nodal Stresses – L225 Subcase



Final Model

Ultimate Stress Margin of Safety Computations

Worst Principal Element Nodal Stresses – Maximum Values Across All Nodes

	Calculation	Failure Mode	Load Case	Margin of Saf	Rank by Global	Rank by Calculation	Rank by Failure Mode	Rank by Load Case
1	UltStress	margin_of...	H0	1.2353	34	34	34	1
2	UltStress	margin_of...	H105	1.2310	33	33	33	1
3	UltStress	margin_of...	H120	1.2428	37	37	37	1
4	UltStress	margin_of...	H135	1.2478	38	38	38	1
5	UltStress	margin_of...	H15	1.2696	43	43	43	1
6	UltStress	margin_of...	H150	1.1677	19	19	19	1
7	UltStress	margin_of...	H165	1.1008	14	14	14	1
8	UltStress	margin_of...	H180	1.0496	11	11	11	1
9	UltStress	margin_of...	H195	1.0153	7	7	7	1
10	UltStress	margin_of...	H210	1.2967	44	44	44	1
11	UltStress	margin_of...	H225	0.9998	6	6	6	1
12	UltStress	margin_of...	H240	1.0188	8	8	8	1
13	UltStress	margin_of...	H255	1.0553	12	12	12	1
14	UltStress	margin_of...	H270	1.1086	16	16	16	1
15	UltStress	margin_of...	H285	1.1773	24	24	24	1
16	UltStress	margin_of...	H30	1.3215	47	47	47	1
17	UltStress	margin_of...	H300	1.2589	41	41	41	1
18	UltStress	margin_of...	H315	1.2426	36	36	36	1
19	UltStress	margin_of...	H330	1.2216	32	32	32	1
20	UltStress	margin_of...	H345	1.2191	31	31	31	1
21	UltStress	margin_of...	H45	1.3802	48	48	48	1
22	UltStress	margin_of...	H60	1.3145	46	46	46	1
23	UltStress	margin_of...	H75	1.2671	42	42	42	1
24	UltStress	margin_of...	H90	1.2391	35	35	35	1

F.S. = 2.5

	Calculation	Failure Mode	Load Case	Margin of Saf	Rank by Global	Rank by Calculation	Rank by Failure Mode	Rank by Load Case
24	UltStress	margin_of...	H90	1.2391	35	35	35	1
25	UltStress	margin_of...	L0	1.1706	22	22	22	1
26	UltStress	margin_of...	L105	1.1693	20	20	20	1
27	UltStress	margin_of...	L120	1.1805	27	27	27	1
28	UltStress	margin_of...	L135	1.1706	21	21	21	1
29	UltStress	margin_of...	L15	1.2030	28	28	28	1
30	UltStress	margin_of...	L150	1.0957	13	13	13	1
31	UltStress	margin_of...	L165	1.0332	9	9	9	1
32	UltStress	margin_of...	L180	0.9852	4	4	4	1
33	UltStress	margin_of...	L195	0.9530	2	2	2	1
34	UltStress	margin_of...	L210	1.2162	30	30	30	1
35	UltStress	margin_of...	L225	0.9384	1	1	1	1
36	UltStress	margin_of...	L240	0.9552	3	3	3	1
37	UltStress	margin_of...	L255	0.9886	5	5	5	1
38	UltStress	margin_of...	L270	1.0379	10	10	10	1
39	UltStress	margin_of...	L285	1.1019	15	15	15	1
40	UltStress	margin_of...	L30	1.2518	40	40	40	1
41	UltStress	margin_of...	L300	1.1781	26	26	26	1
42	UltStress	margin_of...	L315	1.1775	25	25	25	1
43	UltStress	margin_of...	L330	1.1577	18	18	18	1
44	UltStress	margin_of...	L345	1.1554	17	17	17	1
45	UltStress	margin_of...	L45	1.3101	45	45	45	1
46	UltStress	margin_of...	L60	1.2482	39	39	39	1
47	UltStress	margin_of...	L75	1.2034	29	29	29	1
48	UltStress	margin_of...	L90	1.1770	23	23	23	1

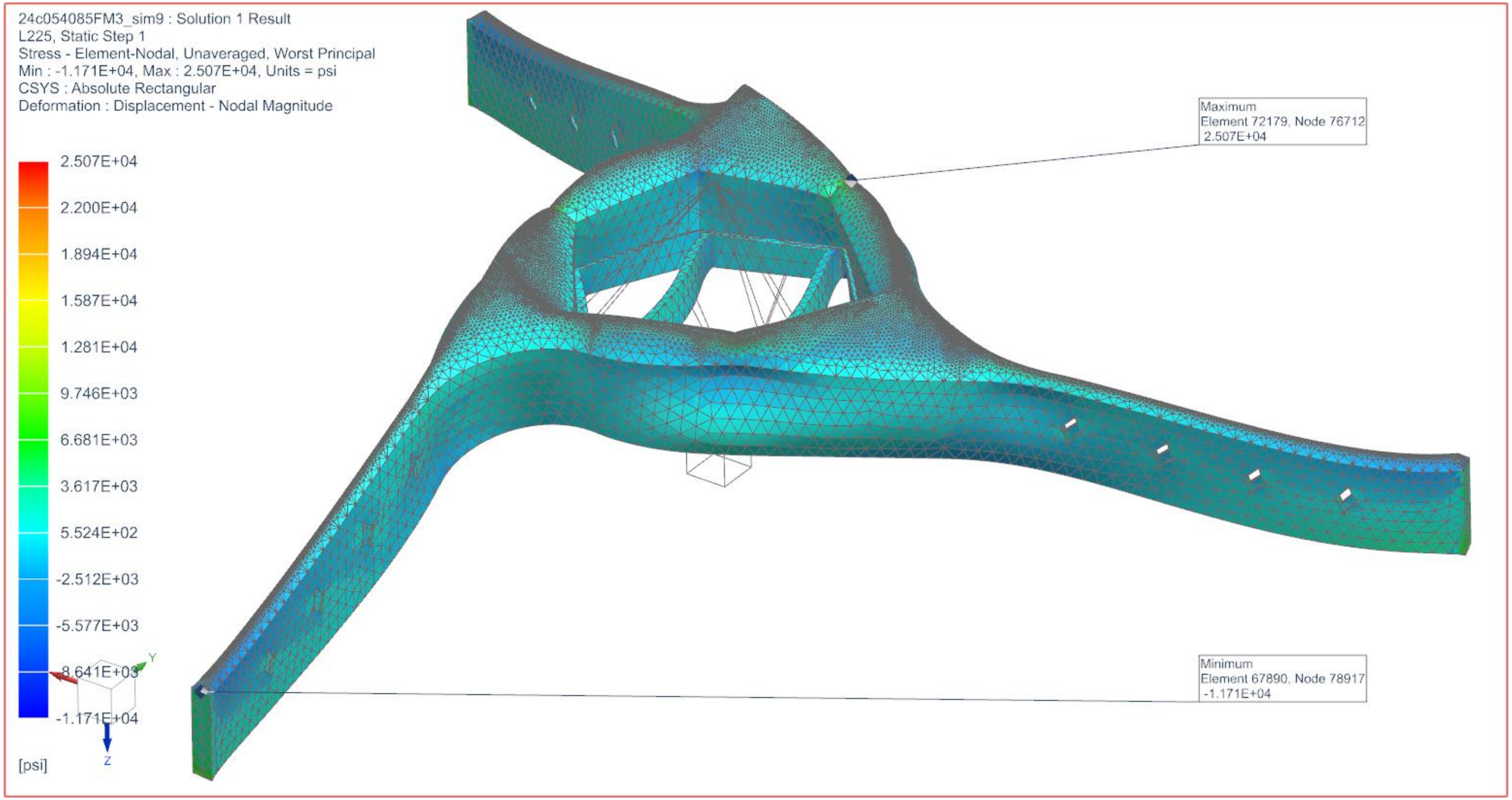
Lowest Margin = **0.938** (low temperature, 225° from +XC)

"The SMSS shall have positive margins of safety against yield and ultimate failure when exposed to a quasi-static load of 12 G laterally and 18 G axially simultaneously (lateral swept 15° increments) combined with a 5° C to 35°C temperature range (nominal room temp is 20°C) while supporting all hosted hardware."

Final Model

Max Ultimate Stress Subcase Plot

Worst Principal Element Nodal Stresses – L225 Subcase



Final Model

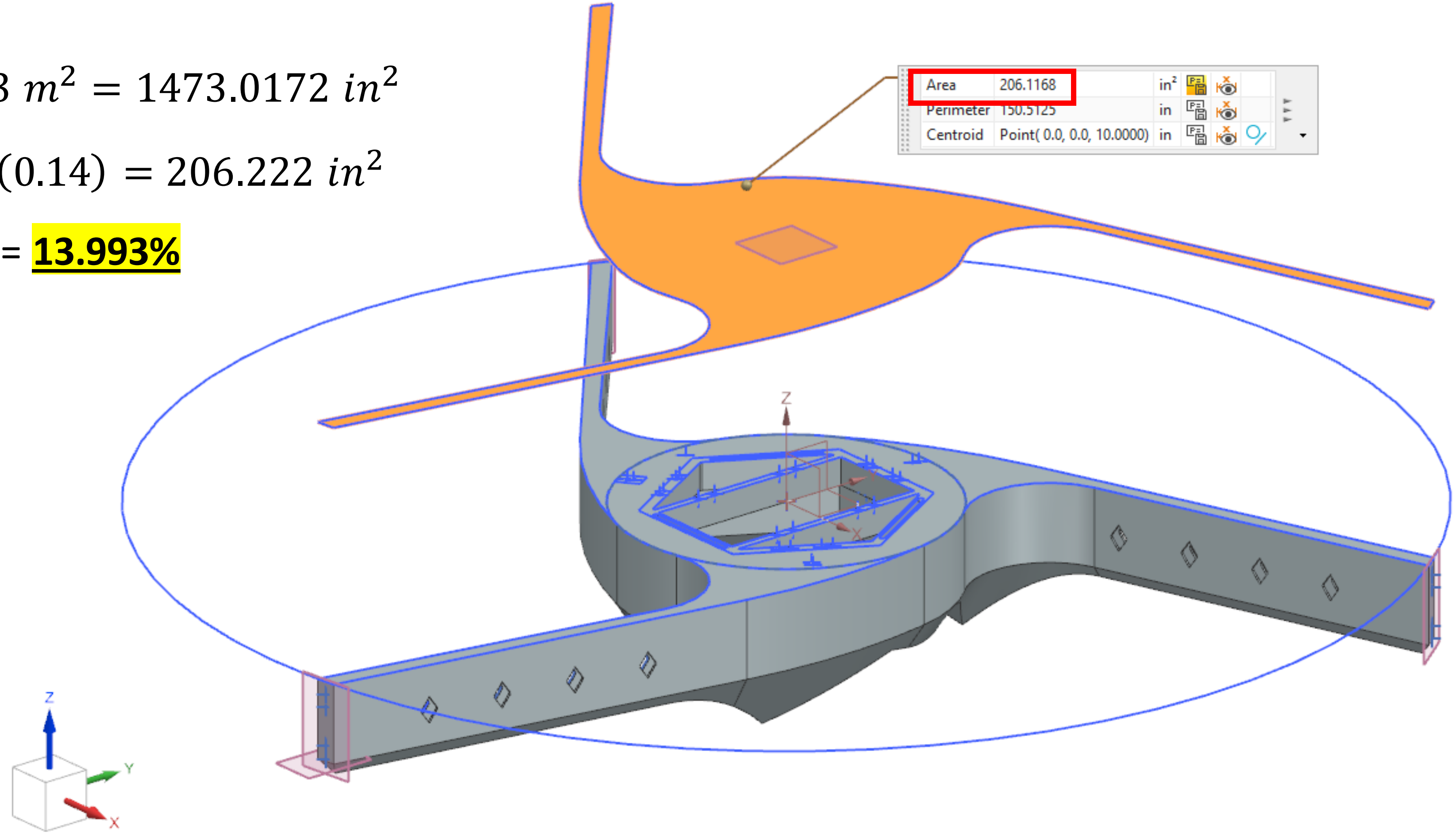
Obstruction Area Specification

"The SMSS and hosted hardware shall not obstruct more than 14% of the Primary Mirror (PM) clear aperture area (assume 1.1m diameter clear aperture)."

$$A_{Aperture} = \pi(1.1\,m)^2 = 0.95033\ m^2 = 1473.0172\ in^2$$

$$A_{Obstructed\ Max} = 1473.0172\ in^2(0.14) = 206.222\ in^2$$

$A_{Obstructed\ Model} = 206.1168\ in^2$ = **13.993%**



Final Model

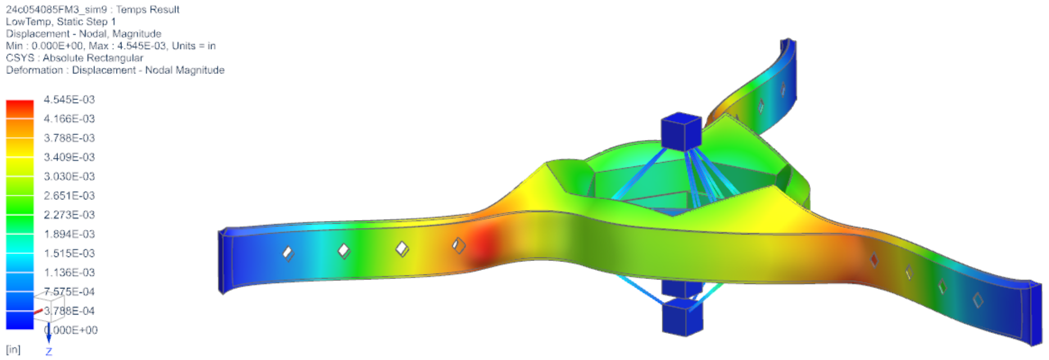
High & Low Temperature Thermal Displacements

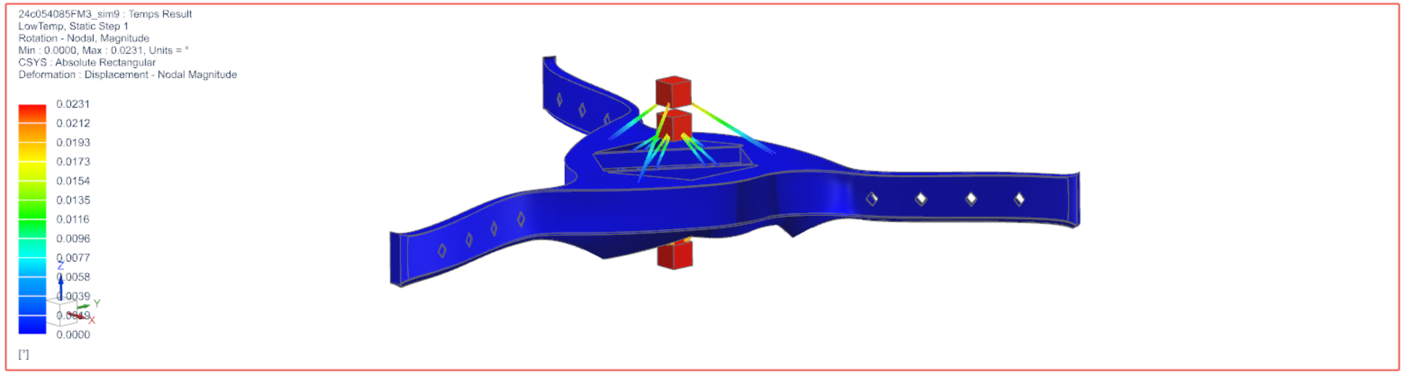
24c054085FM3 Titanium Final Model

	Max X [in]	Max Y [in]	Translation RSS [in]	Max R_X [radians]	Max R_Y [radians]	Rotation RSS [radians]
1°C Isothermal Load	-6.191E-08	-2.637E-07	**2.708E-07**	1.489E-08	2.808E-08	**3.178E-08**

Translation RSS [in]	Rotation RSS [radians]
ABIDES BY SPEC	ABIDES BY SPEC

"The SMSS should provide a stable mounting platform for the Secondary Mirror (SM) in thermal environments. The average motion of the SM interfaces under a 1 degree C isothermal load should be 0.66 micro-inches translation (RSS of X and Y) or less and 0.037 micro-radians rotation (RSS of Rx and Ry) or less."



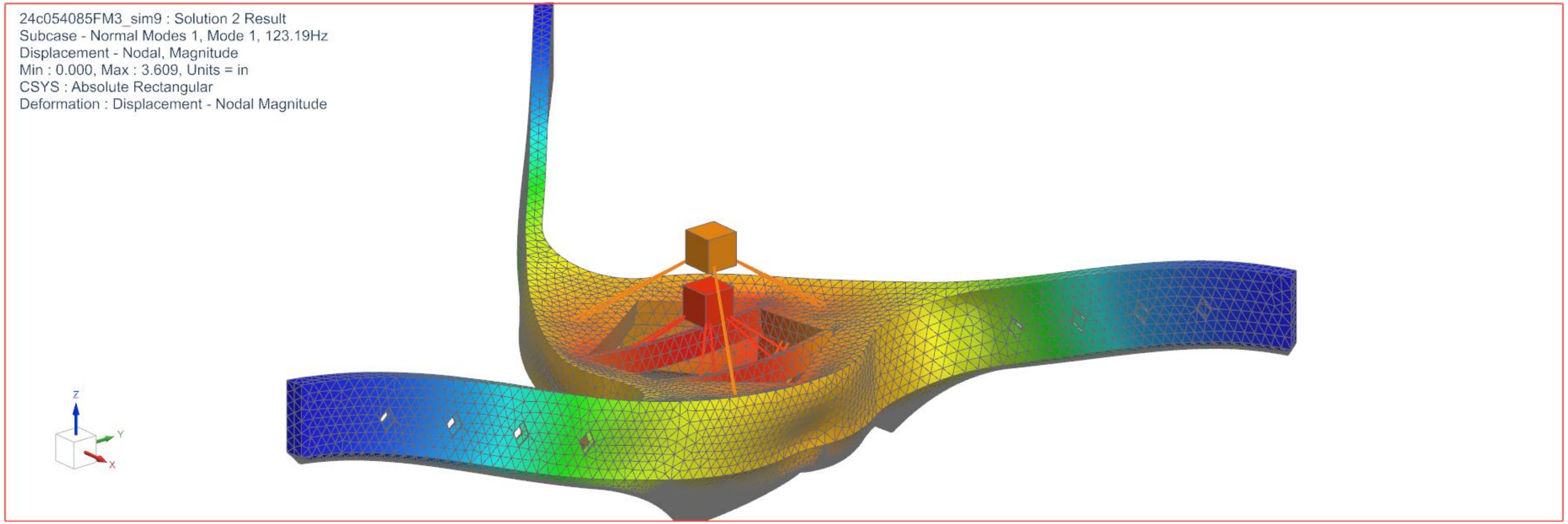


Final Model

Modal Analysis – Solution 103: Real Eigenvalue

1st Mode Displacement

Mode 1 = 123.38 Hz

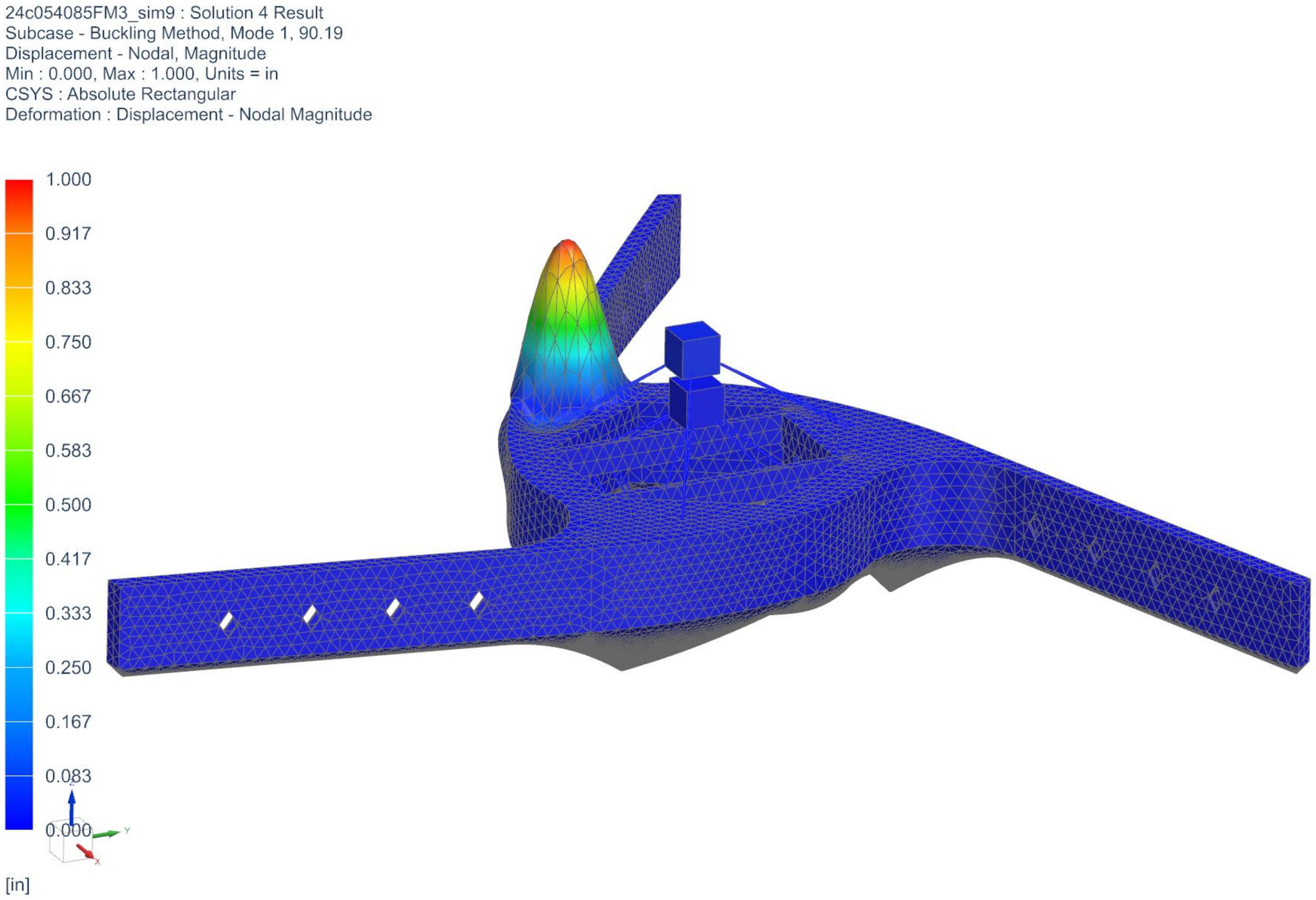


"The first mode of the SMSS shall be 120 Hz or greater when grounded at the FMS interface and supporting all hosted hardware (note a flexure exists in the system between the SMSS and FMS that is not part of this scope)."

Worst Case Buckling Analysis – Solution 105

The worst-case buckling eigenvector was **90.19**. This occurred with a high temperature load, 18G axial load, and 12G lateral load at 135° from the XZ plane.

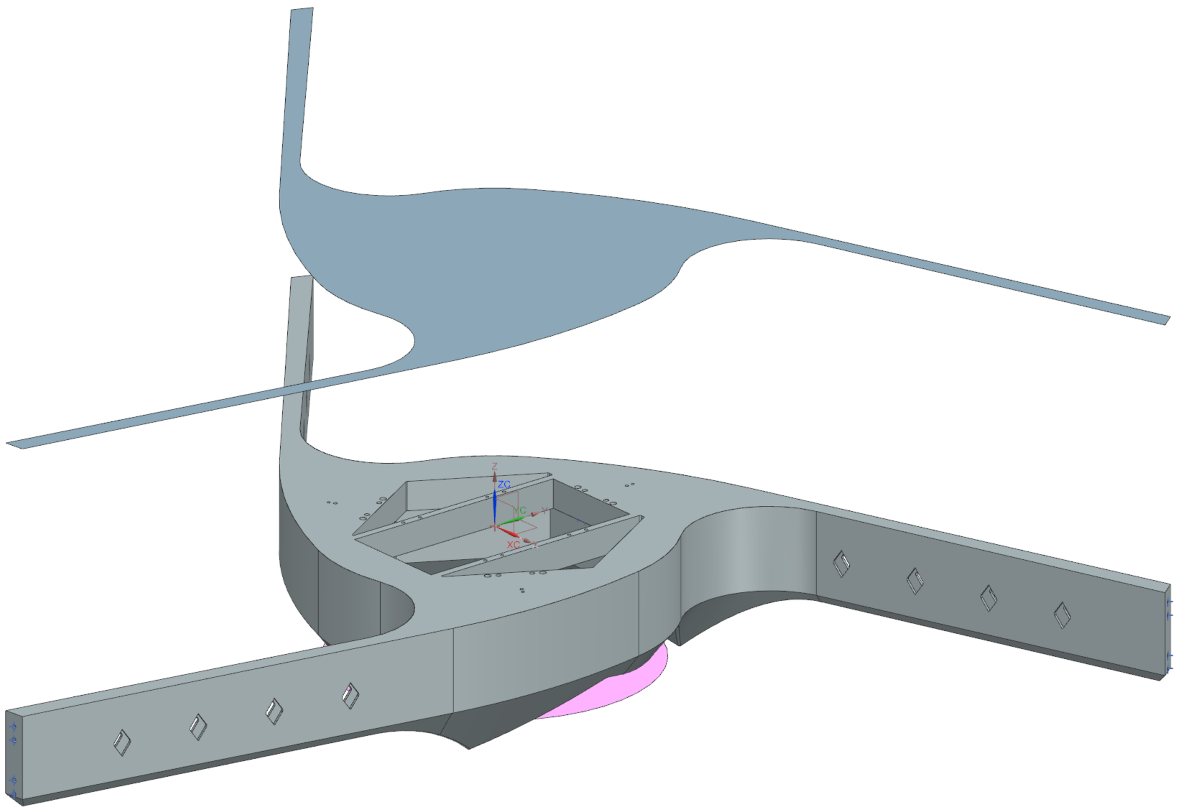
The specifications require a factor of safety of 4.0 for buckling, so our model is well within that requirement.



Conclusions/Future Work

Future Work:

- *Implement a 2D mesh → convergence & accurate modeling*
- *Nonuniform shell thickness optimization*
- *Internal support exploration*
- *Continued topology and shape optimization*
    - *Decrease weight, obstruction area, cost*
- *3D printed metal data correlation*
    - *Relevant material testing → 3D printed titanium samples*
- *Further develop post-processing procedures for powder bed printed shelled models*



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