

THE DESIGN AND OPTIMIZATION OF A SMALL-SCALE CASSEGRAIN TELESCOPE

Team Members:

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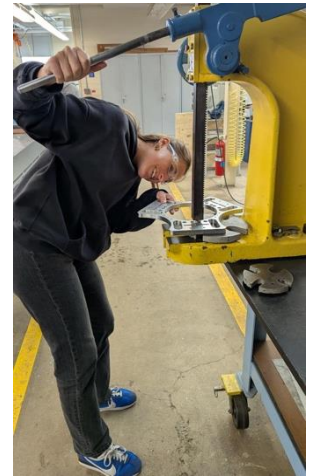
Mahir Abbaker

Customer:

Dr. Christopher Muir

Project Overview

Our project goal was to create a small optical telescope composed of four subsystems: the primary mirror mount, the secondary mirror mount, the camera mount, and the connecting struts. We wanted to design the subsystem in NX, perform thermal, modal, and structural analyses, manufacture it, and then test it in real-world conditions.



Baseline Satellite Iteration:



2025 Satellite Iteration:



Problem Statement

Satellites are complex and resource-intensive systems that deliver essential data and images from space, requiring considerable time, cost, and technical expertise to design and maintain. Developing a small-scale version of these systems provides more accessible and cost-effective platform methods to study performance and test improvements.



Deliverables, Requirements and Specifications

Deliverables:

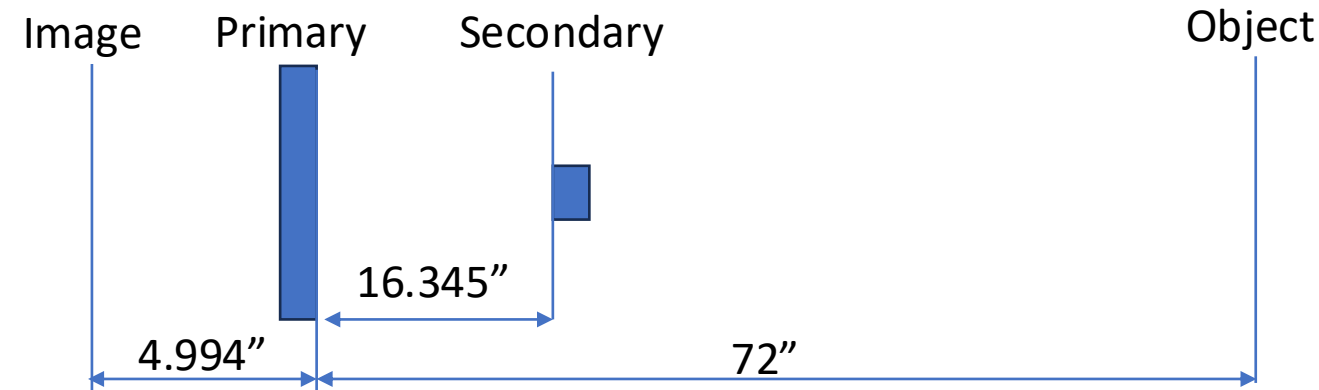
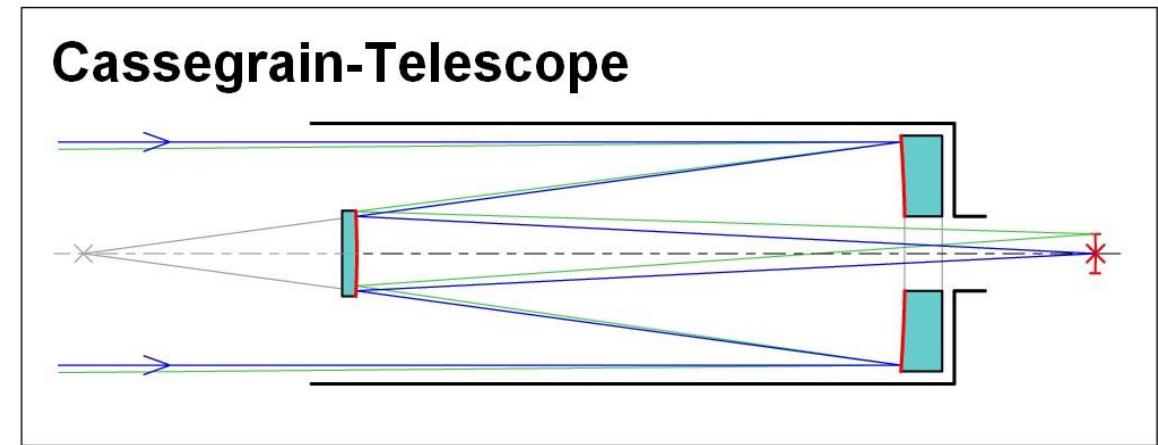
- Primary Mirror Mount Subsystem (PMM)
- Secondary Mirror Mount Subsystem (SMM)
- Camera Mount Subsystem
- Struts
- Manufactured Assembly

Requirements:

- The primary requirement for this optical device is that the device is cost-effective and capable of imaging following a Cassegrain design method.

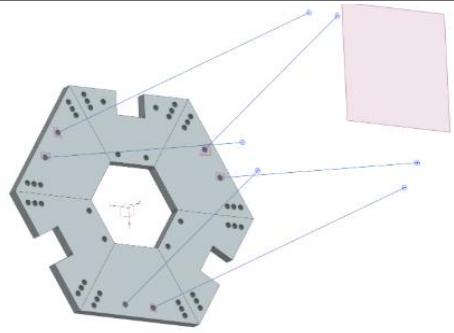
Specifications:

- 180 Hz fundamental natural frequency of entire assembly evaluated via an impact hammer test
- 10% reduction of parts from 2025 iteration
- 10% structural weight reduction from 2025 iteration
- 0.0039 in resolution of Secondary mirror adjustment
- 1.5 Factor of safety against ultimate
- 1.25 factor of safety against yield.

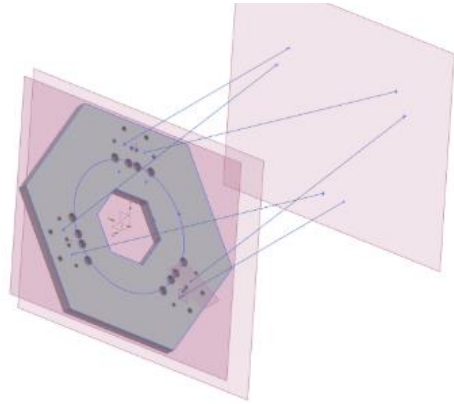


Current Project Status: Design Phase

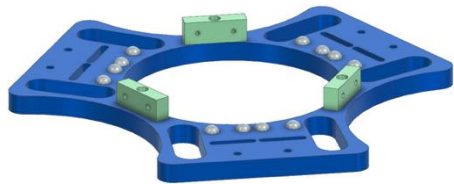
Primary Mirror Mount



6 trapezoidal PMM concept which includes interface area with both the camera struts (5" diameter) and the SMM struts (10" diameter).

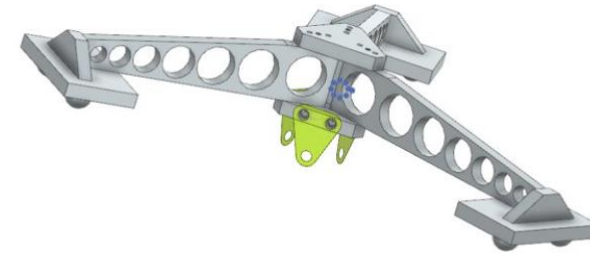
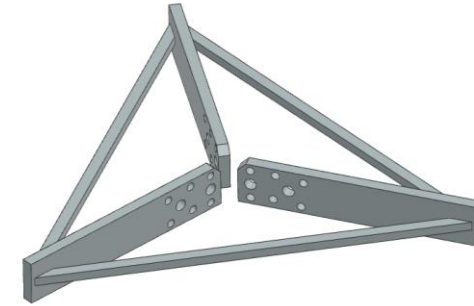


Single hexagon plate concept for PMM selected concept for plate before lightweighting.



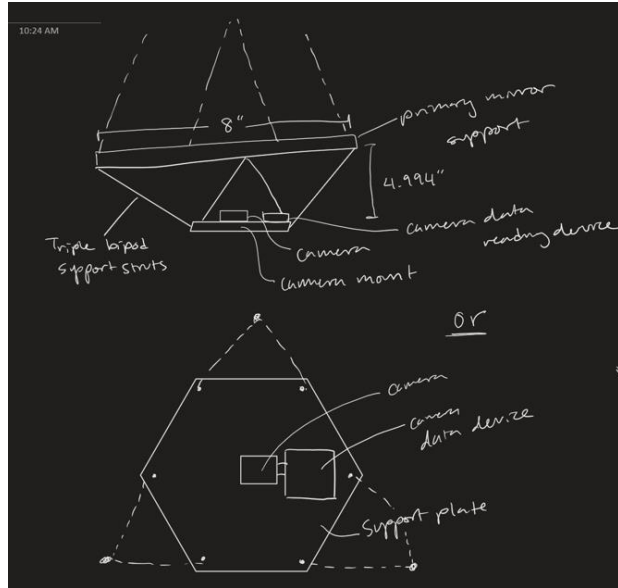
Final concept for PMM which includes interface areas and lightweighting

Secondary Mirror Mount

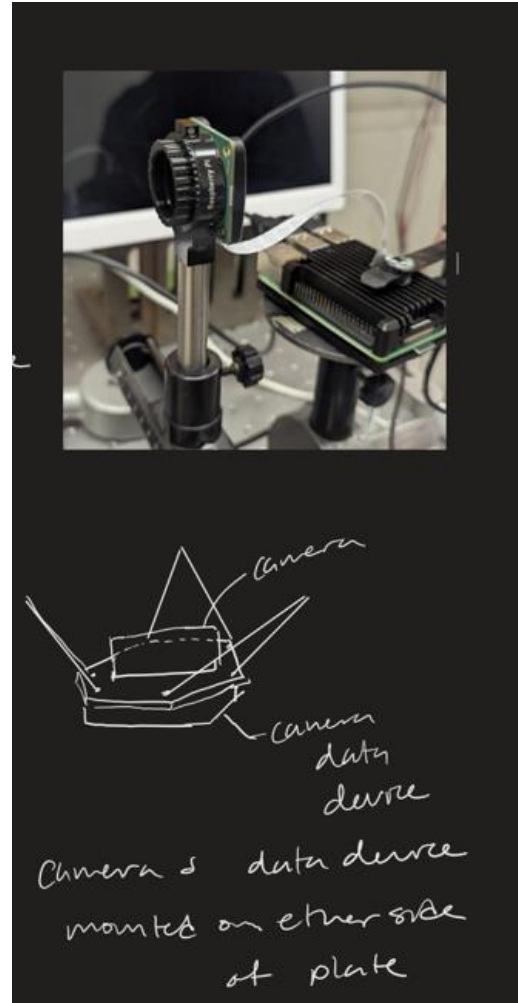


Current Project Status: Design Phase

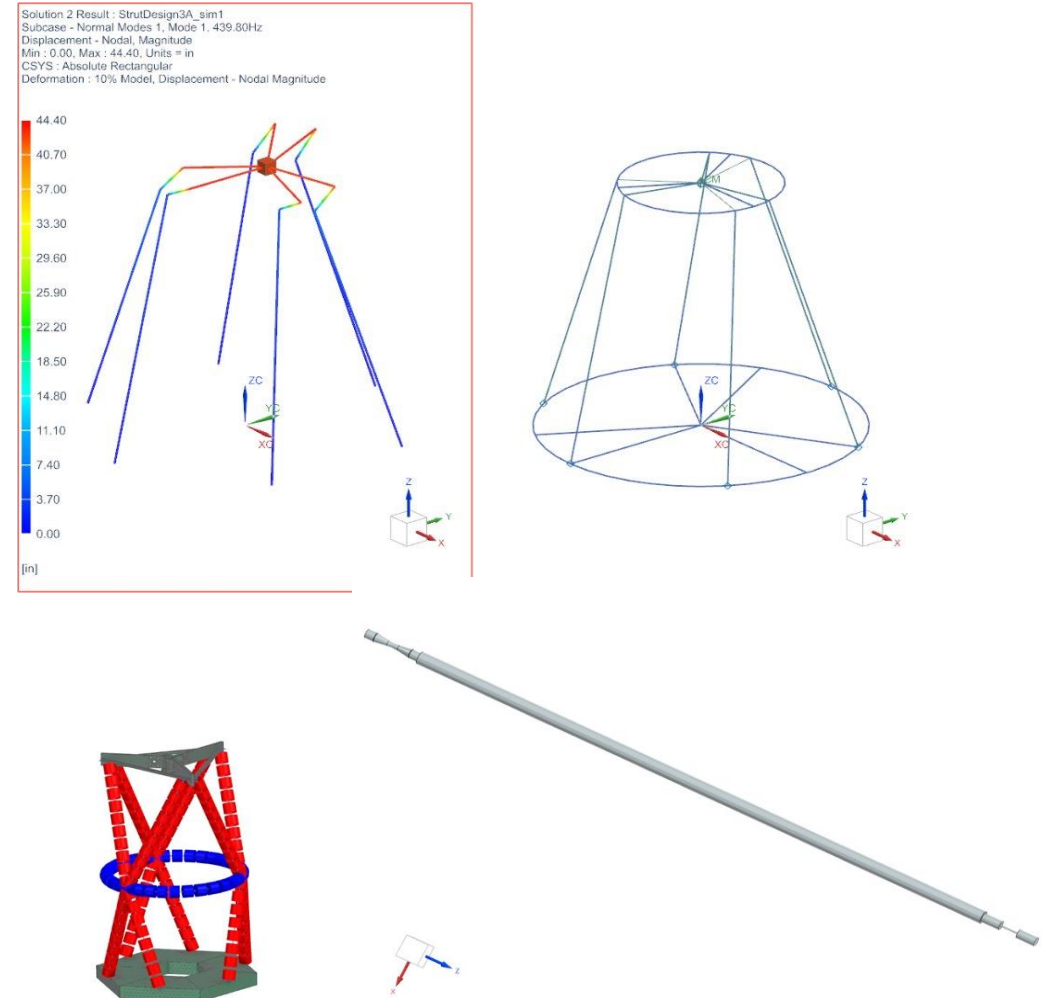
Camera Mount



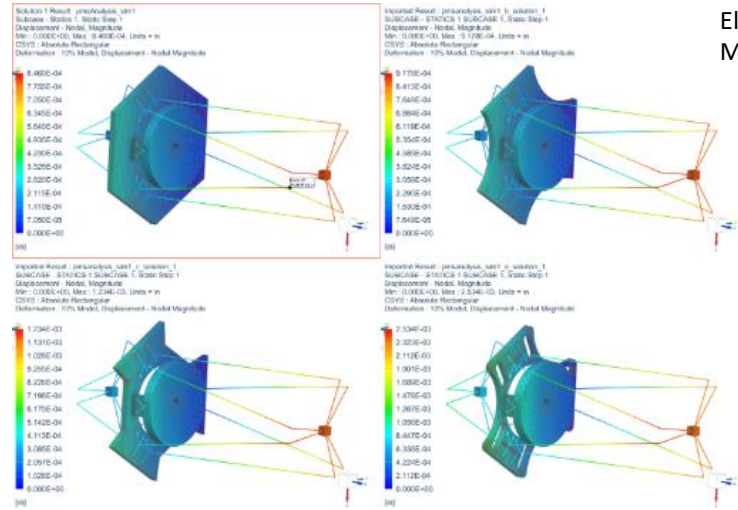
- Aluminum base plate
- Triple bipod connections
- Adjustability as a priority
- Camera and raspberry pi mounted to plate



Struts



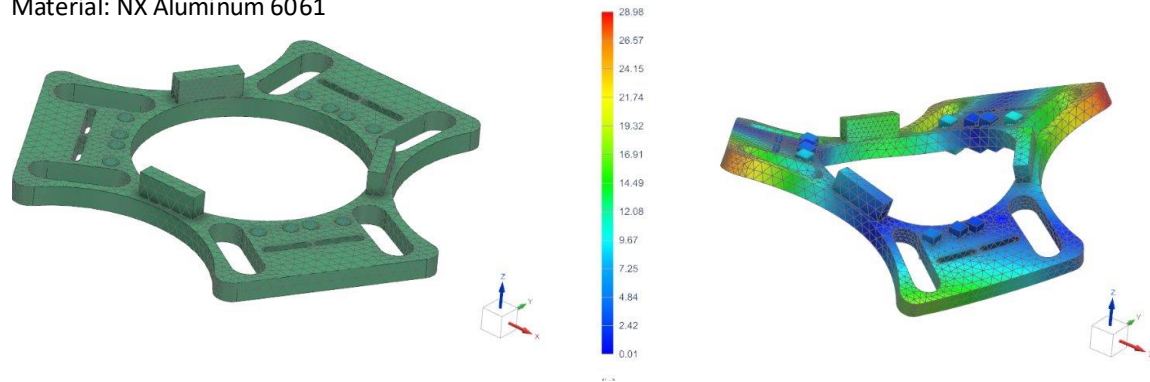
Primary Mirror Mount



Sol 101
 Element Type Tet10 (.3in)
 Material: NX Aluminum 6061

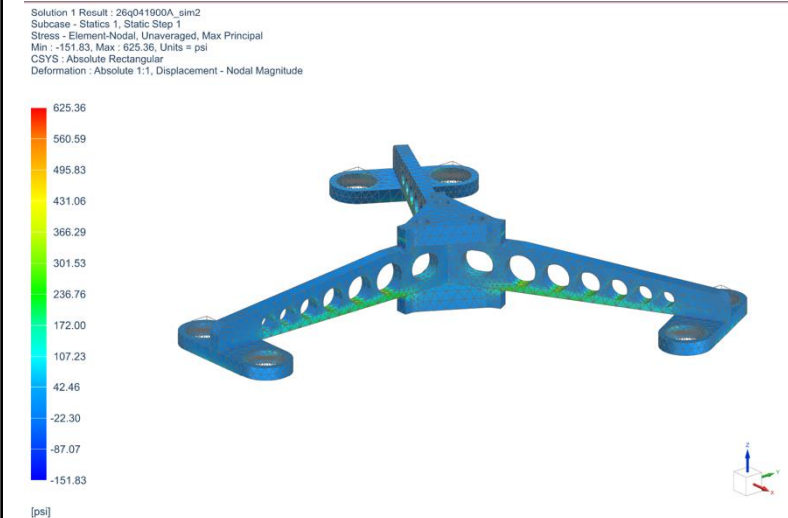
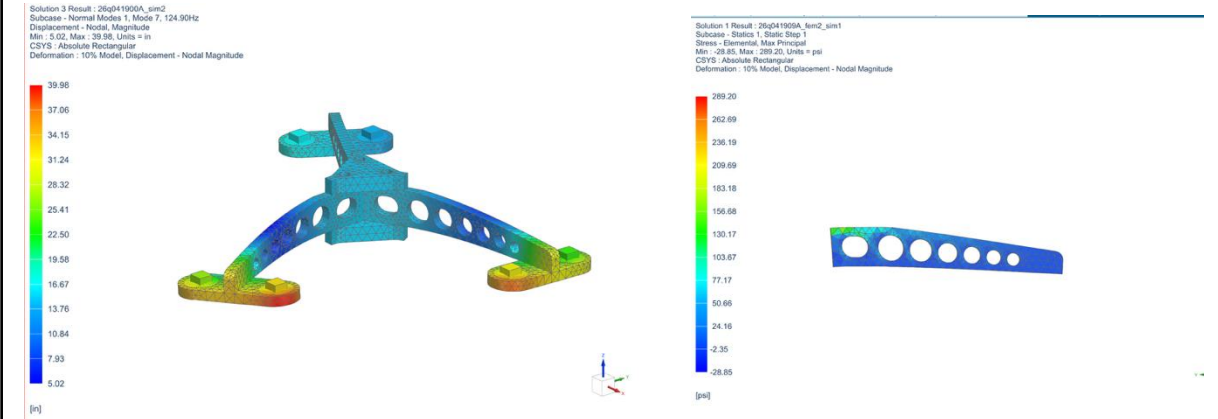
Iteration	Max Deflection [in]	Mass of PPM + Optic [lbm]
A	8.460E-04	10.369
B	9.178E-04	8.975
C	1.234E-03	7.1575
D	2.534E-03	5.3773

Sol 103
 Element Type Tet10 (.375in)
 Material: NX Aluminum 6061



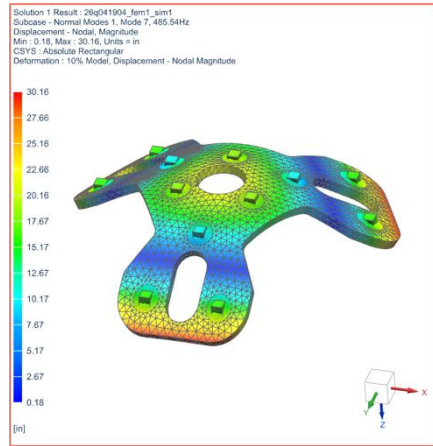
Modal Analysis Primary Mirror Mount: 456.36 Hz

Secondary Mirror Mount

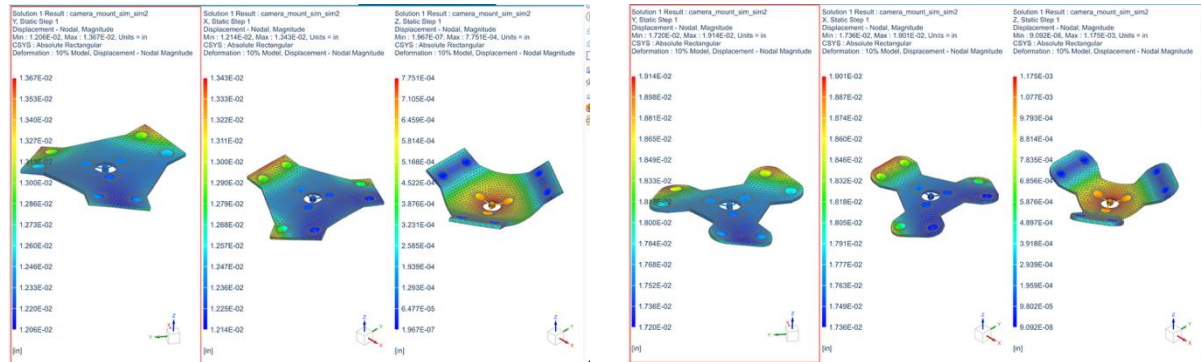


Camera Mount

- Modal simulation

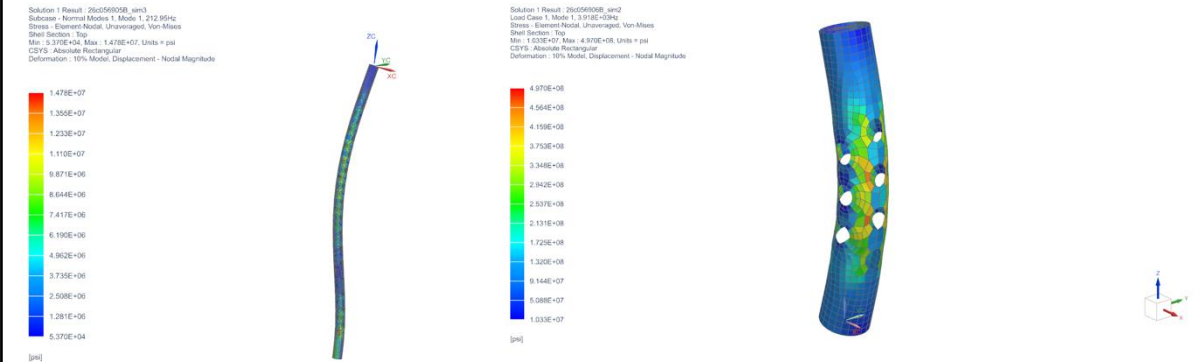


- Lightweighting deformation simulation

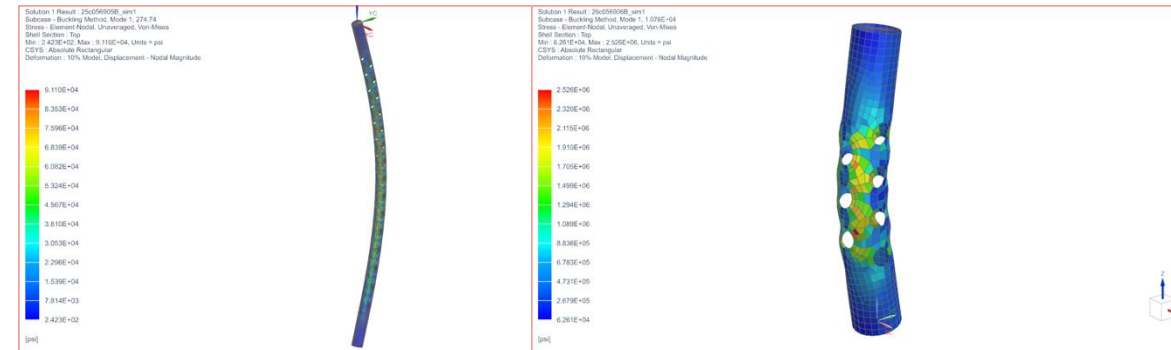


Struts

- Modal simulation

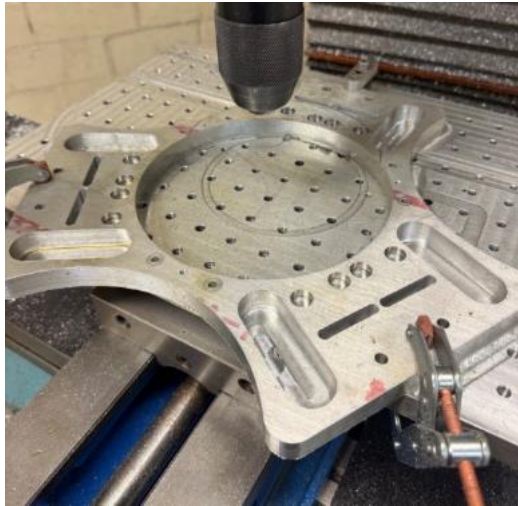


- Buckling simulation

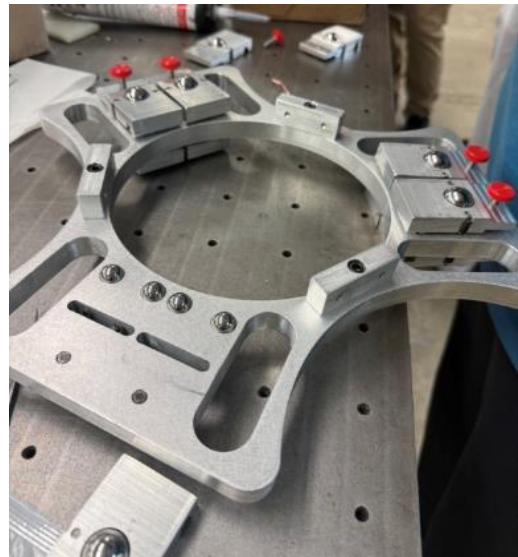


Current Project Status: Manufacturing Phase

Primary Mirror Mount

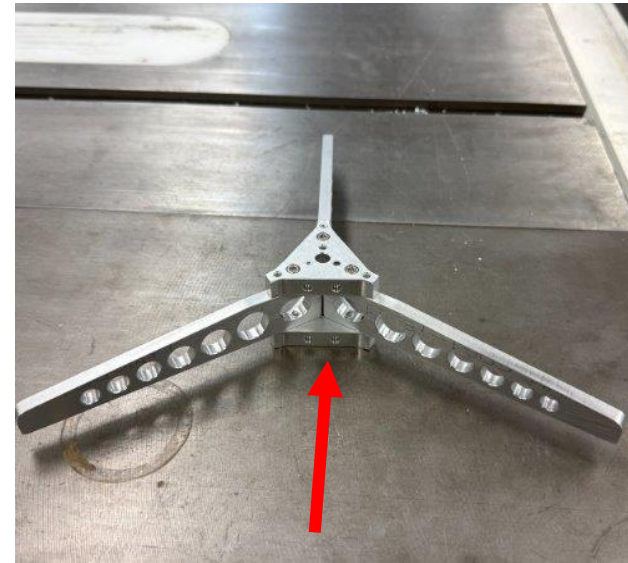


Originally a 18"x18" in x 0.625 piece of Aluminum 6061. Cut to design on a 3-axis CNC Mill by Bill Mildenerger



Primary Mirror mount with the press fit balls, and the adjustment wedges and partial optical mounting blocks installed.

Secondary Mirror Mount



Base plate

Mirror mount arms



Current Project Status: Manufacturing Phase

Camera Mount

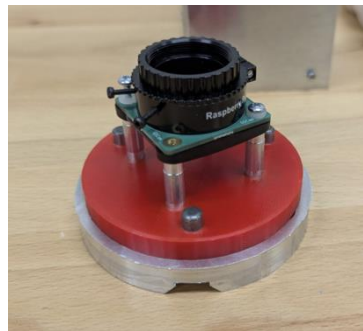
- Base plate + steel balls pressed



Fully assembled camera mount



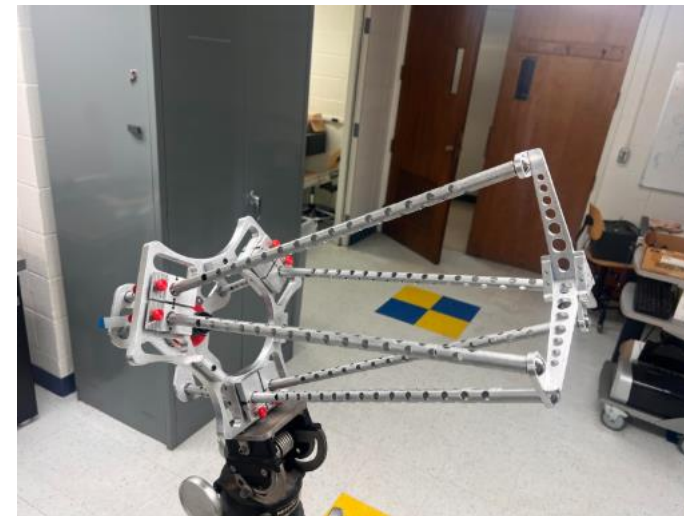
- Camera and optical flat kinematic mounts



Raspberry pi mount



Struts



0.375" through holes
alternating every 90° along
the strut axis at 0.5" spacing
Diameter constrained to
0.375", larger holes
caused crumpling during
drilling

Through-holes reduced
to 0.25 in.
Same patterning as
larger



Current Project Status: Overall Assembly

Baseline:



2025 Satellite Iteration:



2026 Satellite Iteration:



Current Project Status – Addition of Camera Mount

Component Breakdown:

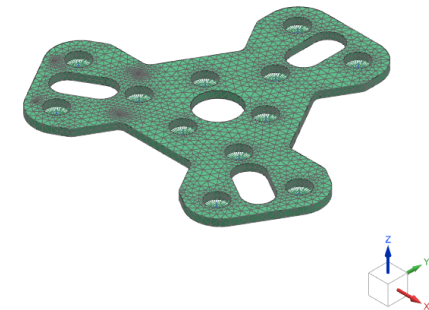
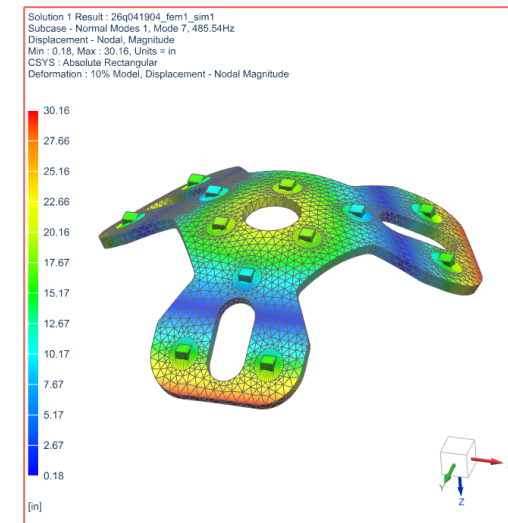
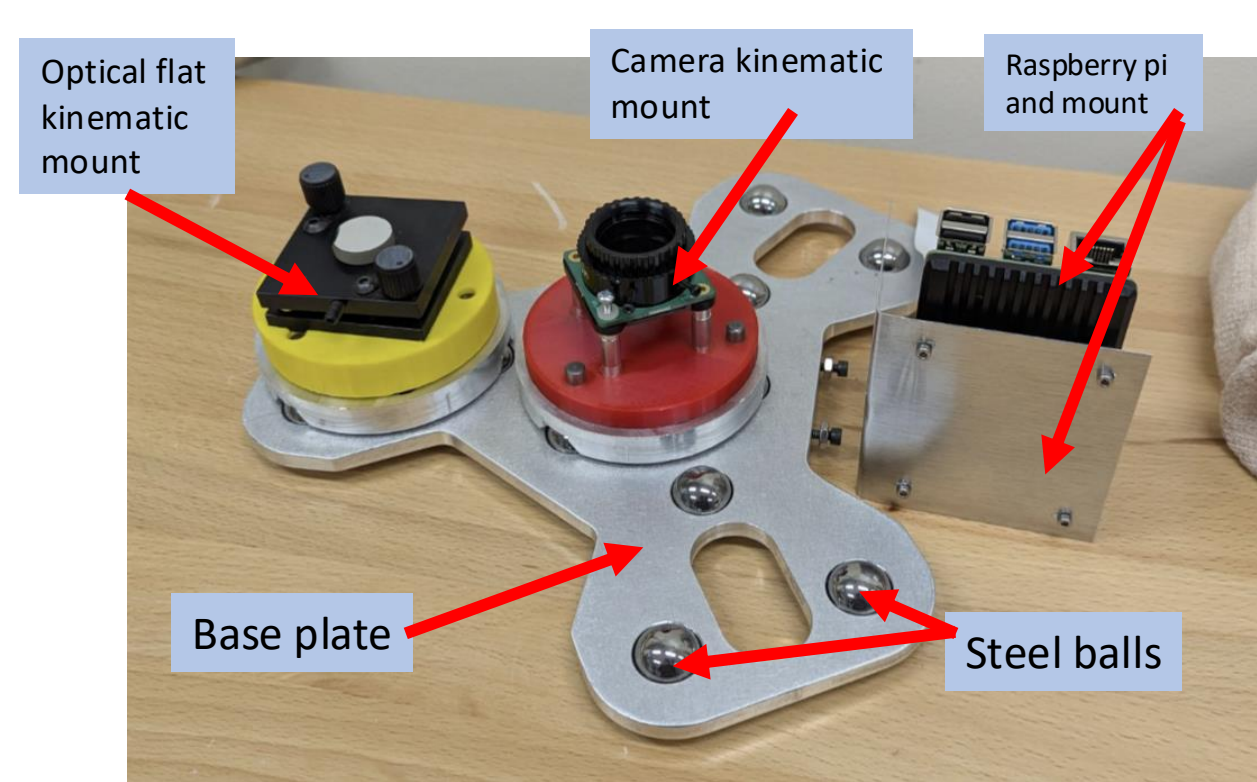
- Base plate
- Steel balls (to interface with magnetic connections)
- Raspberry Pi and mount
- Camera kinematic mount
- Optical flat kinematic mount

Motivation for Inclusion:

- Imaging capabilities allow for data collection in space
- Camera addition verifies satellite alignment
- Inclusive assembly means a fully functional device able to be launched

Design Process and Simulating:

- Starting with a symmetric base plate
- Lightweighting and adjusting design for manufacturability
- Optimized design is finalized
- Vibration test is simulated and verified to pass
- Parts are manufactured
- Vibration hammer test is performed

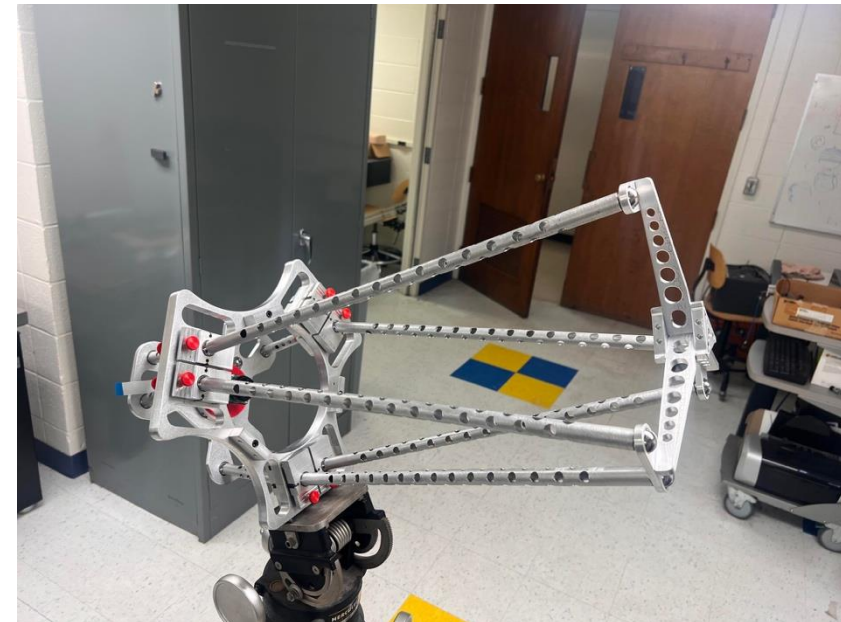


Current Project Status: Assembly

- Primary Mirror Mount:
 - Material: Aluminum 6061
 - Total Mass: 6.12 lbm
- Camera Mount:
 - Material: Aluminum 6061 + PLA
 - Total Mass: 1.565 lbm
- Struts
 - To SMM: 18.753 inches
 - To Camera Mount: 3.635 inches
 - Mass of singular long strut: 0.1829 lbm
 - Mass of singular small struts: 0.0919 lbm
- Secondary Mirror Mount
 - Total Mass: 0.81 lbm

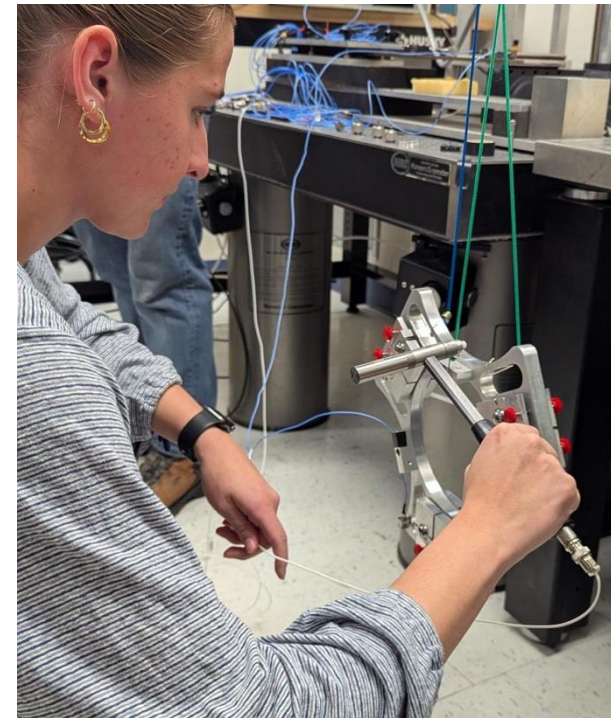
- Mass of Primary Optic: 2.01 lbm
- Mass of Secondary Optic: 0.1150 lbm

TOTAL ASSEMBLY WEIGHT: 10.14 LBM

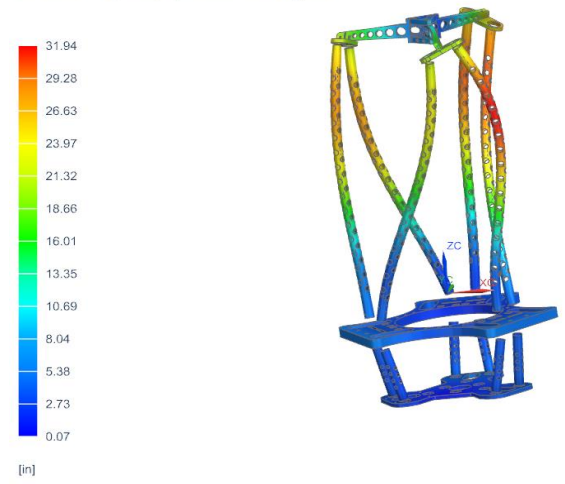


Current Project Status – Testing Results

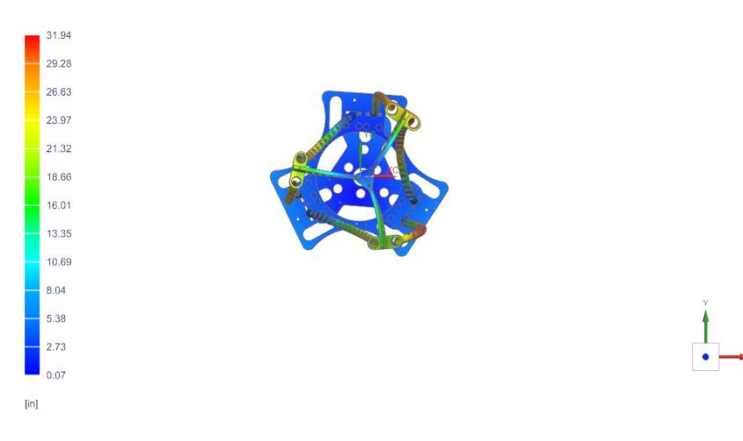
- Modal Simulations for individual parts (first Relevant Mode):
 - Primary Mirror Mount: 456.36 Hz
 - Secondary Mirror Mount: 124.4 Hz
 - Camera Mount: 485.54 Hz
 - Struts: 212.95 Hz, 3.918E3 Hz (long & short)
- Physical Vibration Analysis with Hammer Test (1st Relevant Mode):
 - Primary Mirror Mount: 368.77 Hz
 - Secondary Mirror Mount: 297.99 Hz
 - Camera Mount: 453.85 Hz



Solution 1 Result : 26q041900A_sim2
Subcase - Normal Modes 1, Mode 7, 112.30Hz
Displacement - Nodal, Magnitude
Min : 0.07, Max : 31.94, Units = in
CSYS : Absolute Rectangular
Deformation : 10% Model, Displacement - Nodal Magnitude

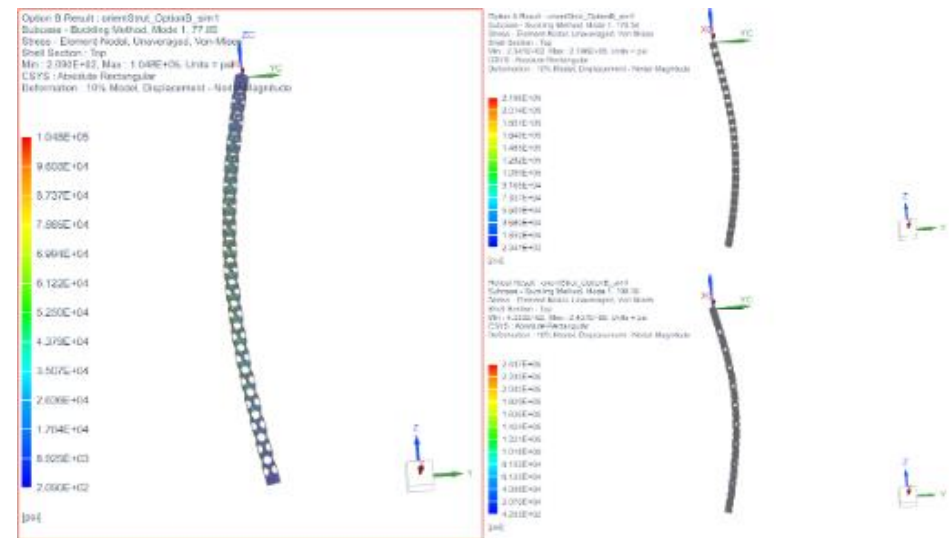


Solution 1 Result : 26q041900A_sim2
Subcase - Normal Modes 1, Mode 7, 112.30Hz
Displacement - Nodal, Magnitude
Min : 0.07, Max : 31.94, Units = in
CSYS : Absolute Rectangular
Deformation : 10% Model, Displacement - Nodal Magnitude



Conclusions/Future Work

- All specifications met except for modal analysis and part count
 - Modal results of 112.30 Hz for assembly simulation
 - 1.89% increase in parts
 - Introduction of a new subsystem and adjustor wedges
- Future Work
 - Optimization of geometry for all parts
 - Strut lightweighting, cross-section selection
 - Interface design
 - SMM design
- Acknowledgements
 - The team would like to thank Dr. Chris Muir for being our sponsor for this project, providing support and guidance through the design and manufacturing process. An additional, sincere thank you is warranted to Bill Mildenberger, Chris Pratt, Sam Kriegsman, and Jim Alkins for their aid and support during this project as well as their flexibility and availability when helping.



FEA Simulation Stress-Element-Nodal results of theoretical optimized strut. Solution 105, CQUAD4 (.15 in mesh), A1 6061 (NX library). Iteration B produced the best reduction in mass and hence possible reduction of FOS closer to proposed specification.

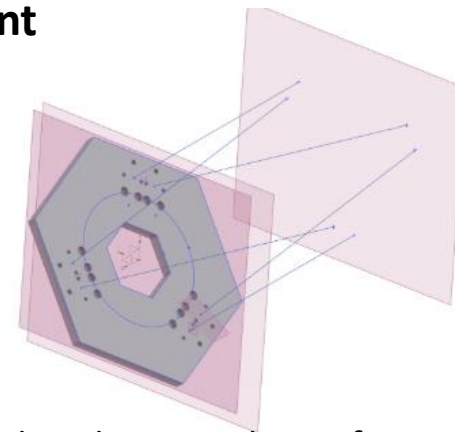
Table 1: Long Strut Design Summary from SOL 105

Design Iteration	Mass [lbm]	Mass Reduction [lbm]	Mass Reduction [%]	1st Mode [psi]	Manufacturable ?
Baseline	0.1186	—	—	—	Yes
A	0.0750	0.0436	36.8%	170.54	Yes
B	0.0572	0.0614	51.8%	77.85	Further work is required
C	0.0820	0.0366	30.9%	190.38	Yes

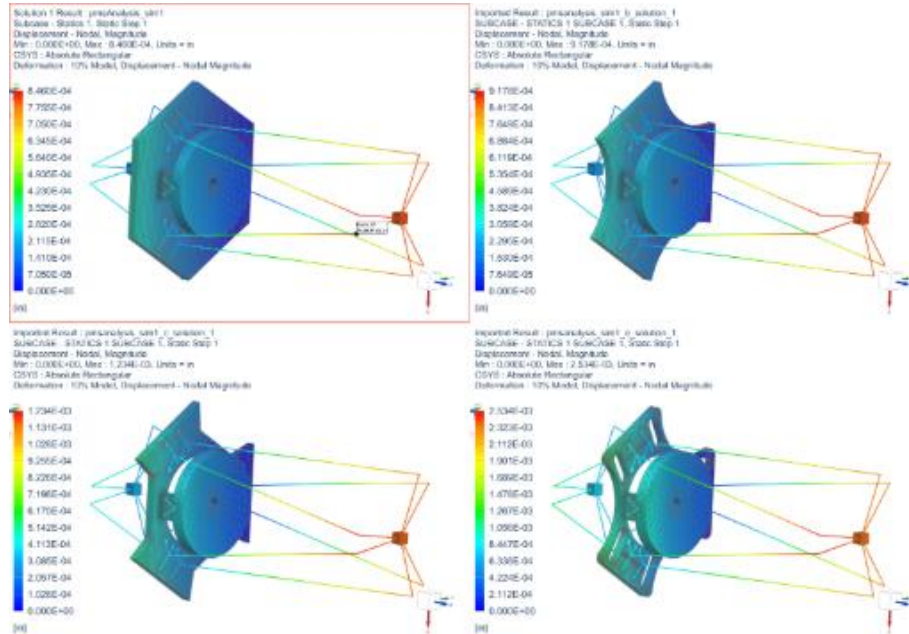
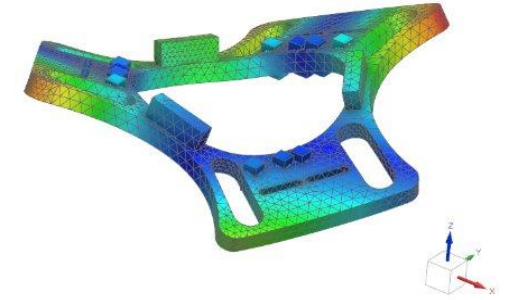
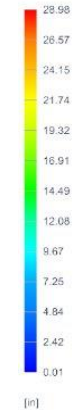


Personal Contributions: Morgan Edstrom (Primary Mirror Mount

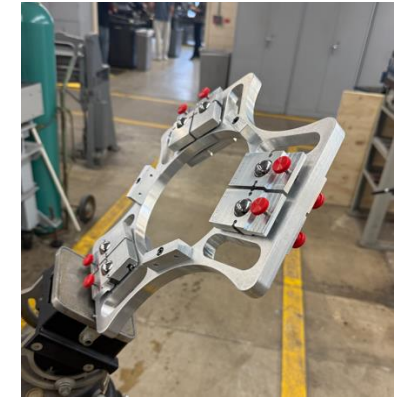
- CAD design
 - Hexagon geometry to account for 5-in diameter and 10-in diameter for struts
- FEA simulation for lightweighting primary mirror mount



Solution 1 Result: 26q041903_sim1
 Subcase - Normal Modes 1, Mode 7, 456.36Hz
 Displacement - Nodal Magnitude
 Min: 0.01, Max: 26.98, Units = in
 CSYS: Absolute Rectangular
 Deformation: 10% Model, Displacement - Nodal Magnitude



- Modal analysis simulation for PMM
 - 456.36 Hz (compared to 368.77 Hz measured creating a 19.19% difference)
- Manufacturing
 - Press-fit 0.5" steel balls into mount
 - Assemble optical mounting blocks with pin-hole pin-slot connections
 - CNC cut the adjustment wedges, tapped 10-32" hole for thumb screw, and press fit the 0.75" ball
 - PMM Mass: 6.12 lbm
 - Primary Optic: 2.01 lbm



Sol 101
 Element Type Tet10 (.3in)
 Material: NX Aluminum 6061
 Fully constrained on bottom face where tripod would sit

Iteration	Max Deflection [in]	Mass of PPM + Optic [lbm]
A	8.460E-04	10.369
B	9.178E-04	8.975
C	1.234E-03	7.1575
D	2.534E-03	5.3773

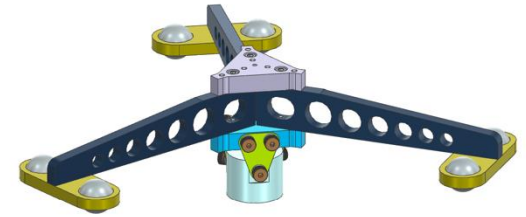
Final Report Analysis

- Torque Calculation for the 10-24 black oxide fastener on the optical mounting block 59.85 lbf*in
 - $F_i = .75 F_p$ (non permanent fasteners) where $F_p = A_t * S_p$ ($A_t = .0175 \text{ in}^2$, $S_p = 120 \text{ kpsi}$)
 - $T = k * F_i * d$ where $k = .3$ (Table 8-15 in Shigley's)



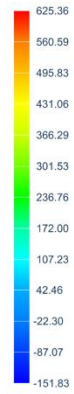
Personal Contributions: Mahir Abbaker

- Design of the Secondary Mirror Mount (SMM):
 - The Secondary mirror mount is made of aluminum
 - Aluminum – Light weight, structurally rigid, thermally stable
 - Yields strength of aluminum: 40,000 psi
 - Primary geometry is a spider web with holes
 - Holes are designed to increase the strength-to-weight ratio
 - Pin holes and pin slots for mounting and connecting mirror mount arms to the plate
- FEA of the secondary mirror mount :
 - Vibration simulation:
 - 1st significant vibration mode 124.40 Hz: 1(NX – solution 103)
 - max principal stress of 1.015E-05 psi, with 180 Hz applied vibration (NX – solution 111)
 - G-load simulation:
 - Max principal stress of 625.36 psi, induced by 18 G's (NX- solution 101)
 - Thermal Simulation :
 - Max principal stress of 8989.18 psi, with a 122 °F temperature soak (NX – Solution 101)
- Results:
 - Hammer test:
 - 1st significant vibration mode: 108.00 Hz
 - 13% difference between simulated and experimental results

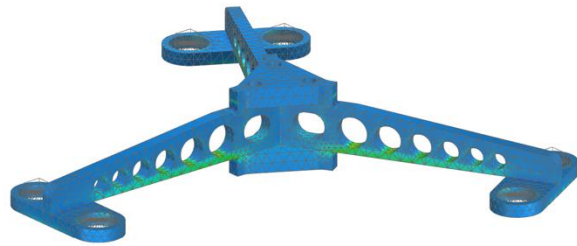


Personal Contributions: Mahir Abbaker

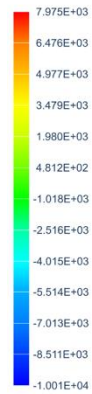
Solution 1 Result : 26q041900A_sim2
Subcase - Statics 1, Static Step 1
Stress - Element-Nodal, Unaveraged, Max Principal
Min : -151.83, Max : 625.36, Units = psi
CSYS : Absolute Rectangular
Deformation : Absolute 1:1, Displacement - Nodal Magnitude



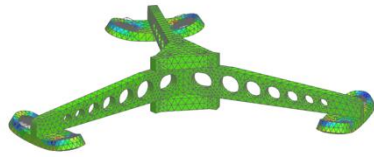
[psi]



Solution 4 Result : 26q041900A_sim2
Subcase - Statics 1, Static Step 1
Stress - Elemental, XX
Min : -1.001E+04, Max : 7.975E+03, Units = psi
CSYS : Absolute Rectangular
Deformation : 10% Model, Displacement - Nodal Magnitude



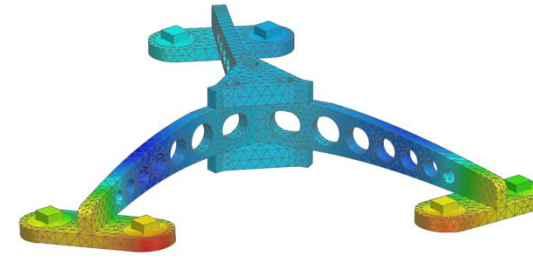
[psi]



Solution 3 Result : 26q041900A_sim2
Subcase - Normal Modes 1, Mode 7, 124.90Hz
Displacement - Nodal, Magnitude
Min : 5.02, Max : 39.98, Units = in
CSYS : Absolute Rectangular
Deformation : 10% Model, Displacement - Nodal Magnitude



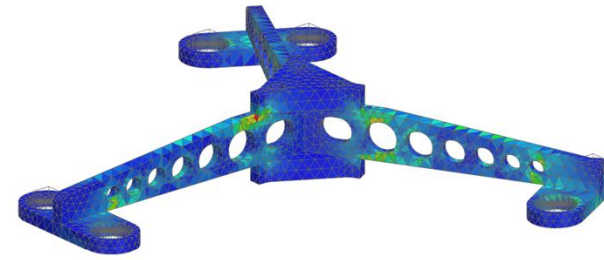
[in]



Solution 2 Result : 26q041900A_sim2
Subcase - Modal Frequency 1, Forcing Frequency 2, 180.00Hz
Stress - Elemental, Max Principal
Complex Options : Amplitude
Min : 1.250E-08, Max : 1.015E-05, Units = psi
CSYS : Absolute Rectangular
Deformation : 10% Model, Displacement - Nodal Magnitude, Complex Options : Amplitude

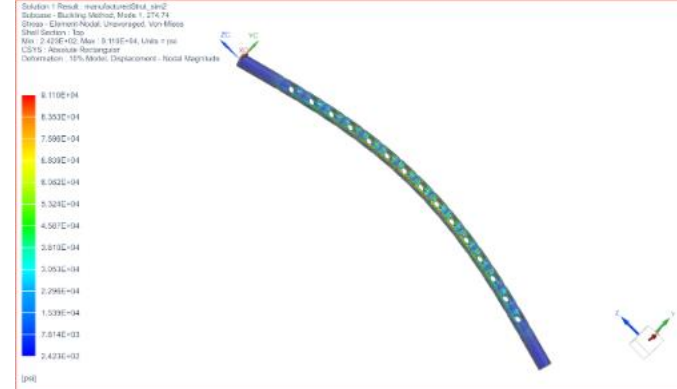


[psi]

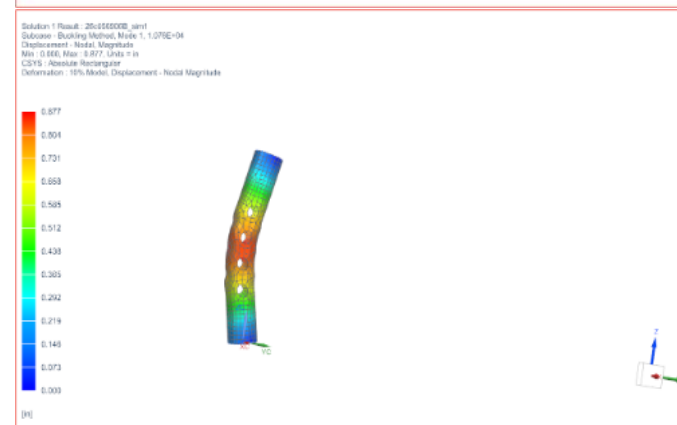


Personal Contributions: Evan Thomas

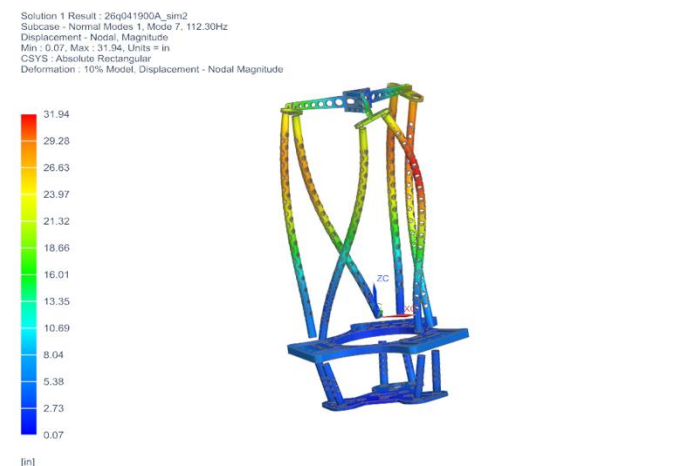
- Design and FEA of Struts
 - Buckling (SOL 105) and Modal (SOL 103) Analysis
 - Both sets of struts and lightweighted iterations
 - FoS of 274.74 psi under 1 lbf axially
 - Optimization of lightweighting for future work
 - Iteration C is most promising
- FEA of entire assembly
 - Solutions 101, 103, 106
 - 103: 112.3 Hz in the 7th Mode as 1st significant mode
 - 101: Max thermal expansion of $1.02E-3''$
 - 106: 18G & 12G (6915.04 psi and 1287.2 psi)
 - +2.6 and +18.3 MoS in yield
 - +2.37 and +17 MoS in ultimate
- Manufacturing
 - Fabrication of adjustment wedges
 - Cutting struts to length, and assembly



FEA Simulation of longer struts. Stress-Element-Nodal results of manufactured strut. RBE2's were used at either edge simulating the ball joint. SPC12 is present at the top and SPC1236 is at the bottom. Solution 105, CQUAD4 (.15 in mesh), Al 6061 (NX Library). FOS determined to be 274.74 psi under 1 lbf axially.



FEA Simulation of shorter struts. Stress-Element-Nodal results of manufactured strut. Solution 105, CQUAD4 (.0833 in mesh), Al 6061 (NX Library). FOS determined to be 1.076E4 psi under 1 lbf axially. Same boundary conditions and constraints present as figure above.

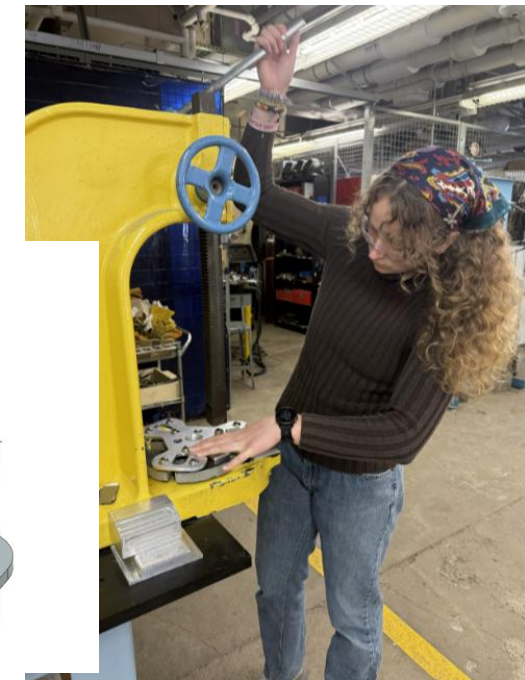
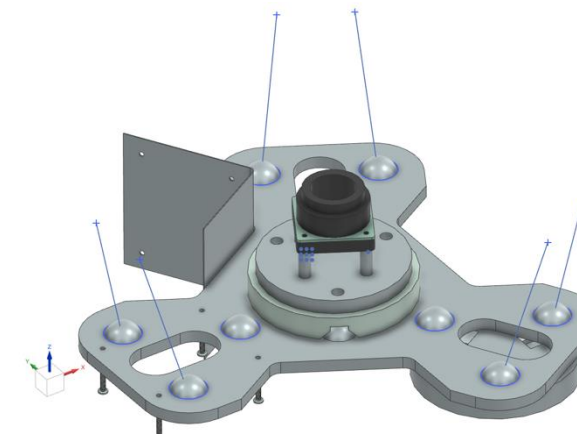
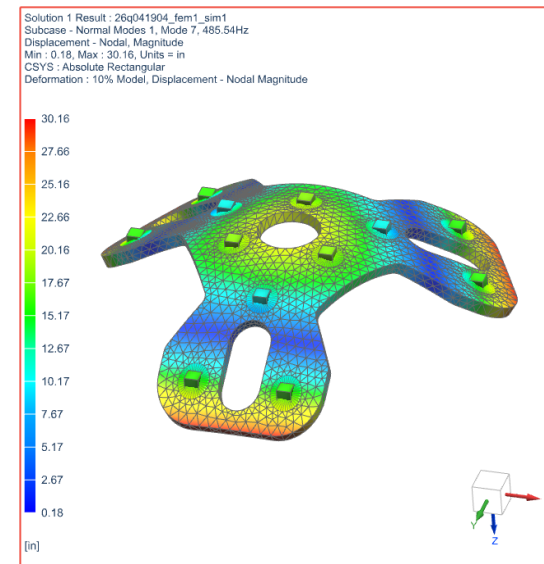


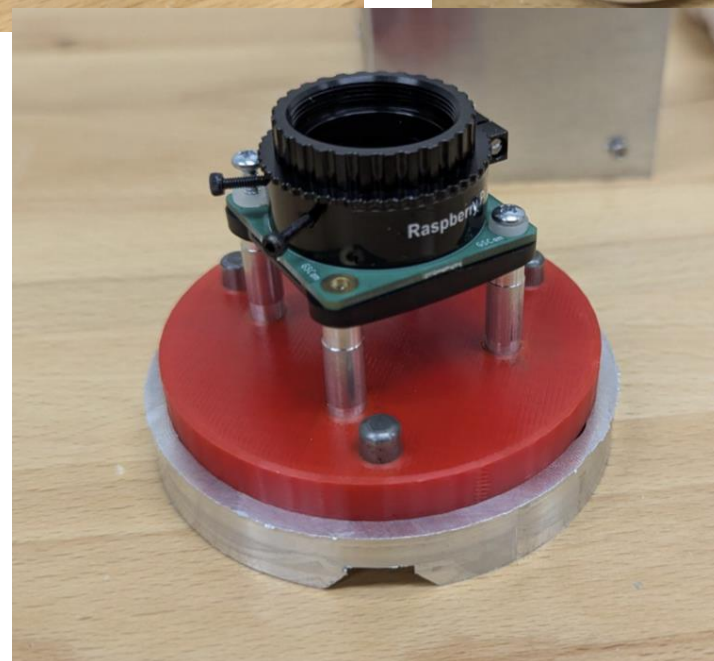
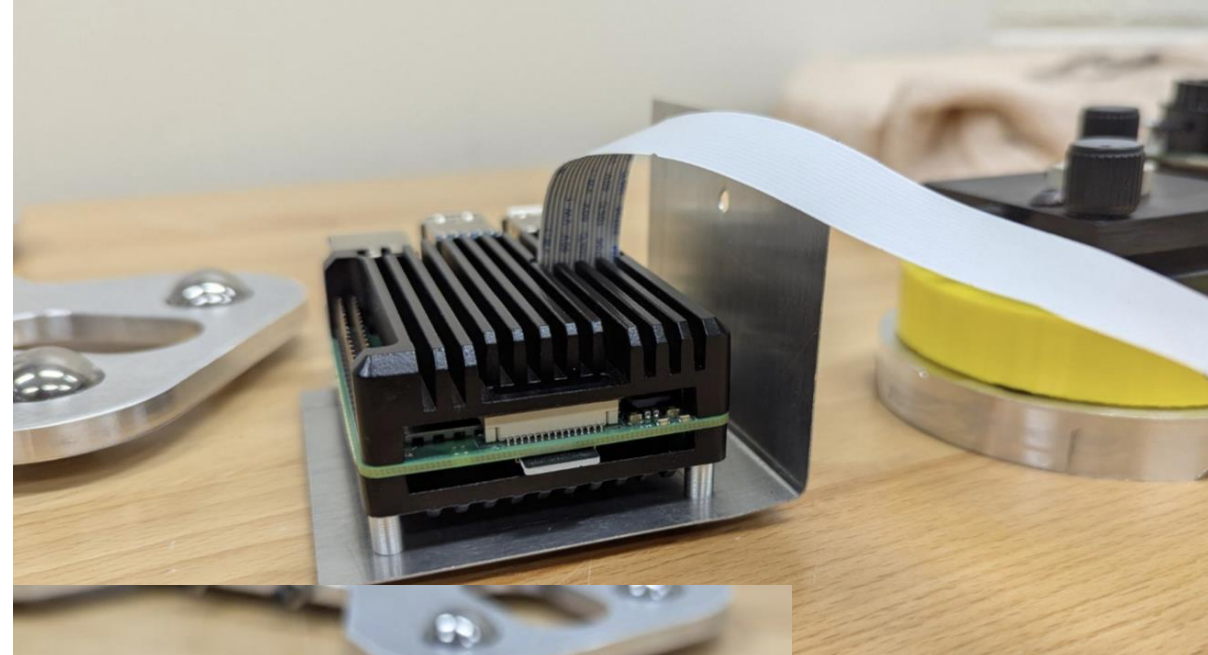
Displacement results from the modal analysis of the assembly in the absolute deformation case. The SMM is seen causing the rest of the assembly to deform. SOL 103, Al 6061, CTETRA(10), mesh sizes of .3" and .7" present. Max displacement 31.94" from 112.3 Hz.



Personal Contributions: Izzy Doty

- CAD design of the **camera mount base plate**
 - Radially symmetric design that accommodates struts to connect the camera mount to the primary mirror mount
- CAD design of the **camera and optical flat kinematic mounts** (including interfaces)
- Manufacturing of camera mount base plate
- Manufacturing of camera and optical flat kinematic mounts (including magnet installation)
- 3D printing of **interface parts between camera and kinematic mount as well as between optical flat tip-tilt stage and kinematic mount**
- Machining **custom standoffs** for camera connection to interface
- Machining and installing **raspberry pi mount** to base plate
- Machining and installing **custom standoffs** for Raspberry Pi
- Vibration testing for camera mount base plate
- FEA simulation for **lightweighting** camera mount
- Gate **D tolerance analysis**





ADDITIONAL SLIDES



TABLE 1: Pugh Matrix Determining PMM Final Design

Criteria	Hoop Base	6 Piece Trapezoidal Base	Single Hexagon Base
Manufacturability	-	+	+
Material Used	+	-	-
Ease of Assembly	+	-	+
Ability to be mounted to tripod	-	+	+
Total	0	0	2

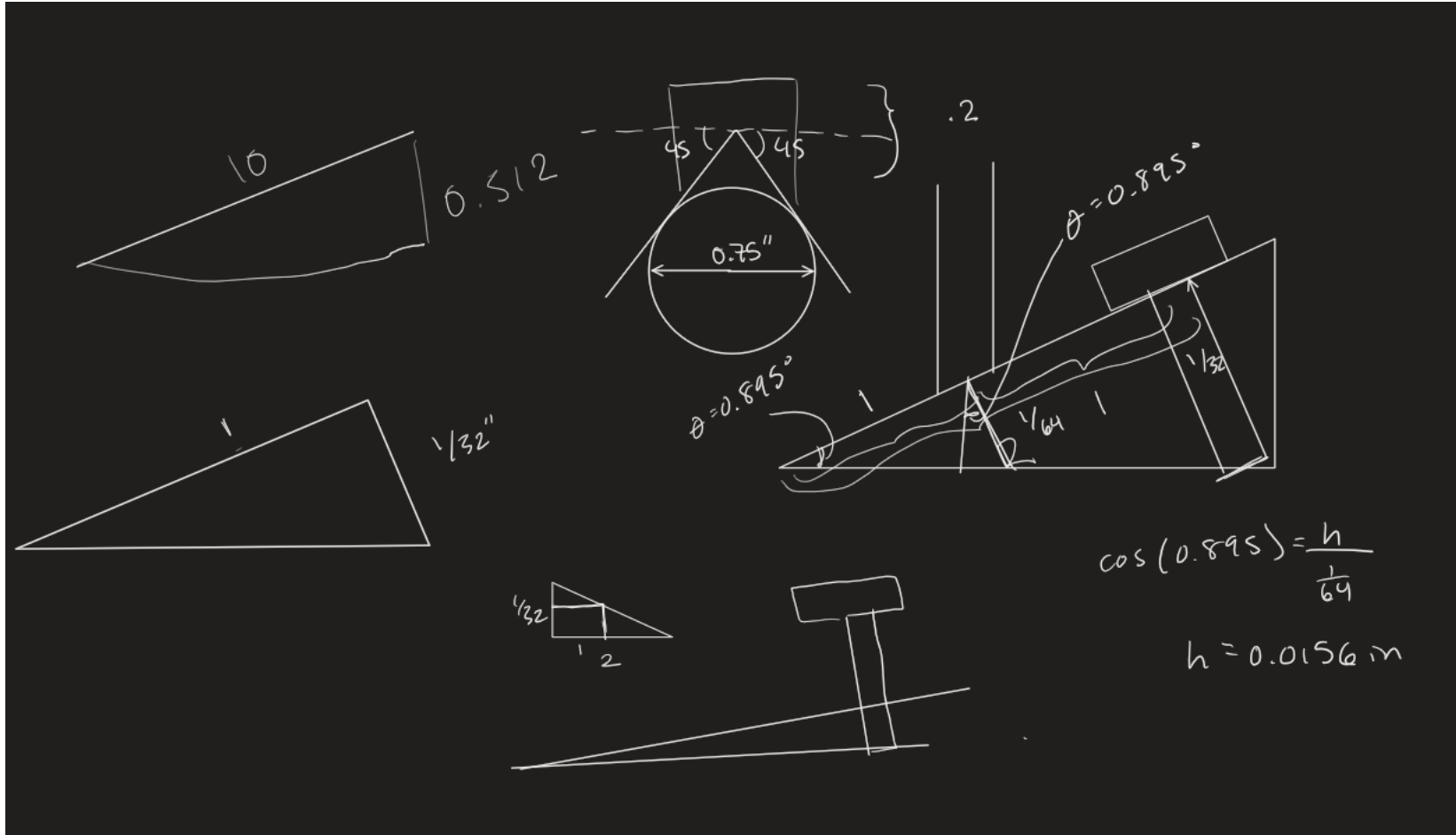
TABLE 3: Pugh Matrix Determining Final Adjustment Method

Criteria	Differential Screw	Wedge Piece	Spring Bias
Slop	0	+	++
Manufacturability	0	+	+
Ease of Assembly	0	+	-
Resolution	0	+	-
Total	0	4	1

TABLE 2: Pugh Matrix Determining Interface Connection

Criteria	Mechanical Ball Joint	Wire Flexure	Ball Joint (magnetic)
Slop	-	+	+
Manufacturability	+	-	+
Ease of Assembly	-	-	+
Cost	-	+	+
Total	1	2	4





Tolerance analysis:

- Each turn of the screw increases height by $\frac{1}{32}$
- Strut therefore raises in the direction of the screw by $\frac{1}{64}$
- Angle of change per rotation is 0.895 degrees
- The strut raises in it's direction by 0.0156 in per turn
- There are 20 full turns possible per screw
- This allows 0.312" of adjustment max
- Max angular displacement is 1.788 degrees on the SMM and 2.1 degrees on the camera mount