Mechanical Problem Set #1 - Optic Mount

<u>Functional Requirements:</u> *Values in RED apply to Aluminum

Variable (Symbol)	**Value**	**Range**	**Justification**	**Validation**	
Stress applied by Flexures on A and on B (σ_A), (σ_B)	0 kPa	± 7 kPa	Avoid stress build-up due to thermal expansion (from problem statement)		**2.13 kPa**
Maximum Stress in Flexure (σ_F)	17 MPa	± 5 MPa	Prevent yield in acrylic flexure of a given thickness, maintaining safety factor 3	**3.3 MPa**	**6.08 MPa** (Yield Stress w/ SF 3 = 36.67 MPa)
Height of Device (h_d)	150 mm	± 50 mm	Device must not be too big for envelope (from problem statement)	**137.50 ± 0.01 mm** - Height of flexure measured using calipers.	
Height of Flexure (h_f)	110 mm	± 50 mm	Device no taller than 200mm (from problem statement)	**103.93 ± 0.01 mm -** Height of flexure measured using calipers.	
Max Displacement of Flexure (δ_f)	1.2 mm	± 0.2 mm	Expected displacement of Part A due to thermal expansion, assuming no expansion of Part B with an uncertainty of the thermal expansion coefficient of 15%. Reference	Thermal expansion modeled by inserting (2) 0.7mm thick washers between the PP hexagon and the acrylic flexures for a max displacement of 1.4mm at the top of each flexure.	
Displacement of Center of Part A Relative to Part B; visual aid for validation (δ_{Center})	0 mm	± 0.1 mm	Center of Part A must remain in the same position and orientation before and after thermal expansion. 0.1 mm is within the visual resolution of the human eye.	Metal rod attached to the center of the bottom hexagon and passes through the top hexagon to visually inspect centering of hole.	
Lateral Stiffness of Flexure (k_l)	$50 \frac{N}{mm}$	$\pm 5 \frac{N}{mm}$	An average human would have to exert 50 N (~11lbs) to observe a displacement of 1mm. We assume an uncertainty of ~ 5 N.	**46.29 ± 1.02 N/mm** - Measured using a spring scale pulling in the x-y direction and measured displacement with a caliper.	
Rotational Stiffness of Flexure (k_r)	$4 \frac{Nm}{deg}$	$\pm 1 \frac{Nm}{deg}$	Stiff enough so an average human exerting a torque cannot displace the flexures by a discernible distance (0.1mm)	**4.50 ± 0.45 Nm/deg** - Measured using (3) spring scales pulling tangentially to hexagon and measured angle change with protractor.	
Mass (M)	6.5 lbs	± 6 lbs	The model can't be too heavy to where nobody	**0.82 ± 0.02 lbs** - Measured to be using a spring scale.	

			wants to hold or use it. Max volume of device (150mm x 150mm x 200mm) and highest density acrylic gives upper bound for mass 11.5 lbs.	

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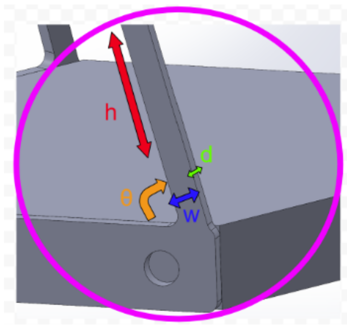
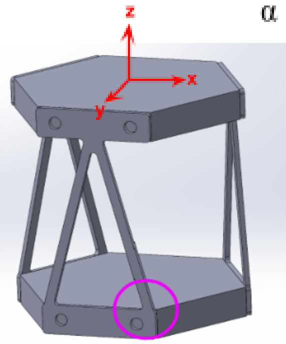
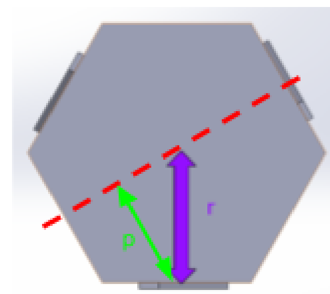
Math Model: [Link to Spreadsheet]

β - Rotation angle about x-axis
α - Rotation angle about z-axis

Input parameters defined in spreadsheet







Stiffness Direction	**Translational**	**Rotational**
X-Y	$\frac{dF}{dx} = 3k\cos^2(\theta)$	$\frac{d\tau}{d\beta} = 4k\,\sin^2(\theta)\,p^2$
	49.3 N/mm (model estimation)	
Z	$\frac{dF}{dz} = 6k\sin^2(\theta)$	$\frac{d\tau}{d\alpha} = 6kr^2\cos^2(\theta)$
		4.0 Nm/deg (model estimation)

Discussion:

Our initial constraint topology included 3 purely vertical constraints and 3 diagonal ones. However, we quickly learned that this did not provide enough lateral or torsional stiffness, so we redesigned our flexure to include 3 symmetric trusses, which also simplified our math significantly. This revealed that CBD is a good tool for ensuring our devices demonstrate requisite DOFs, but additional iteration may be needed to obtain other functional requirements. Furthermore, this project was also a clear indicator that models aren't entirely representative of the real world. There were times where building and testing benchtop wood prototypes revealed discrepancies between our predicted stiffnesses and our test results; a huge contributing factor to this was additional compliance introduced by loose screws.