UF Herbert Wertheim College of Engineering
UNIVERSITY of FLORIDA

The Accu-stat

Section 13335, Group 4

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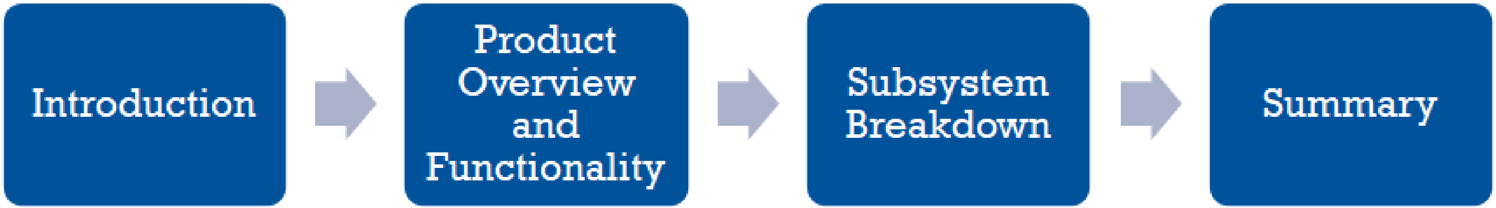
POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE

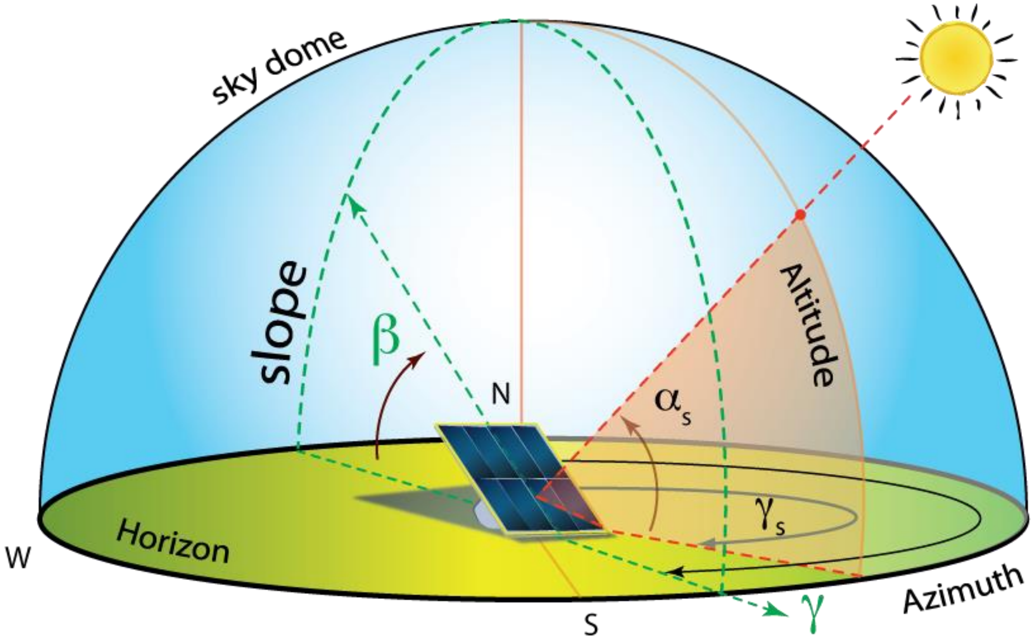
Presentation Outline



Value Proposition

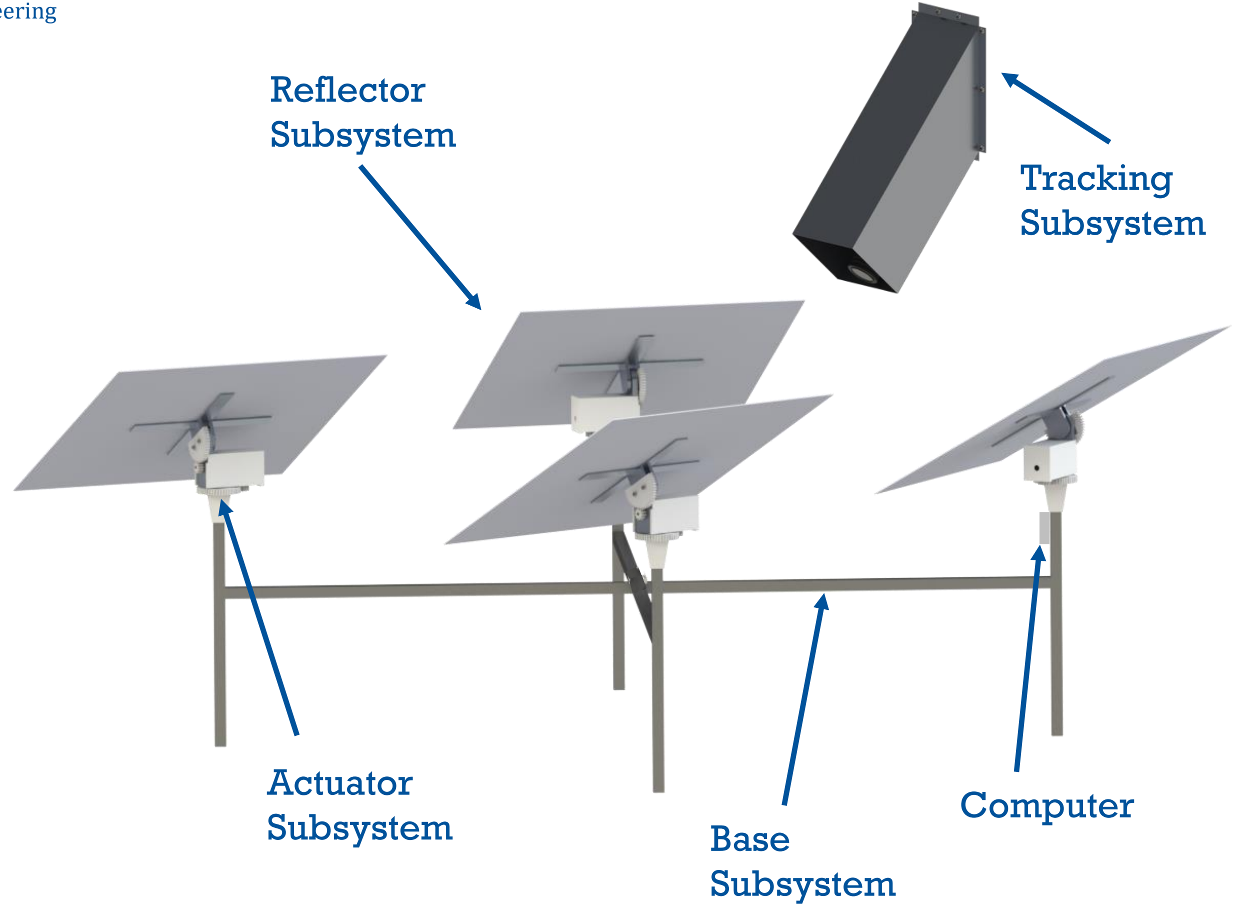
Accuracy

- Actuation
- Tracking



Product Overview

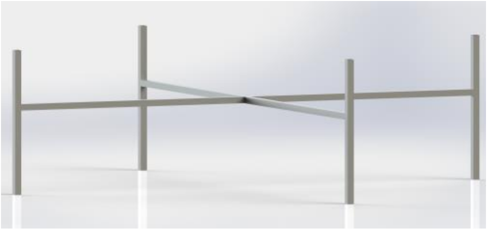
- Full assembly is broken down into four subsystems:
  - Base
  - Actuator
  - Reflector
  - Tracking
- Size: 2.1 m x 2.1 m x 0.78 m (max)
- 1 central computer per module
- 2 motor system per heliostat
- Attachable camera mount to central tower



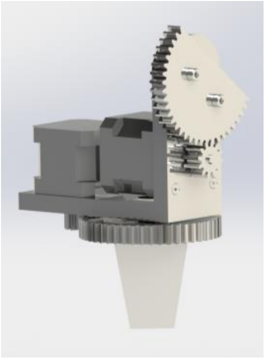
Basic Functionality

High Accuracy Tracking at a Low Cost

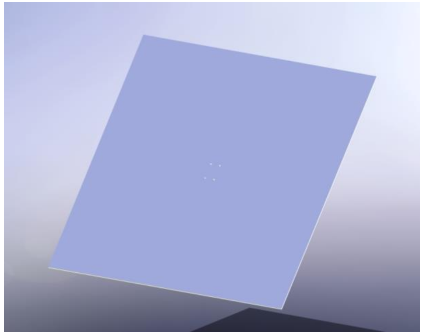
Subsystem Breakdown



Base



Actuator



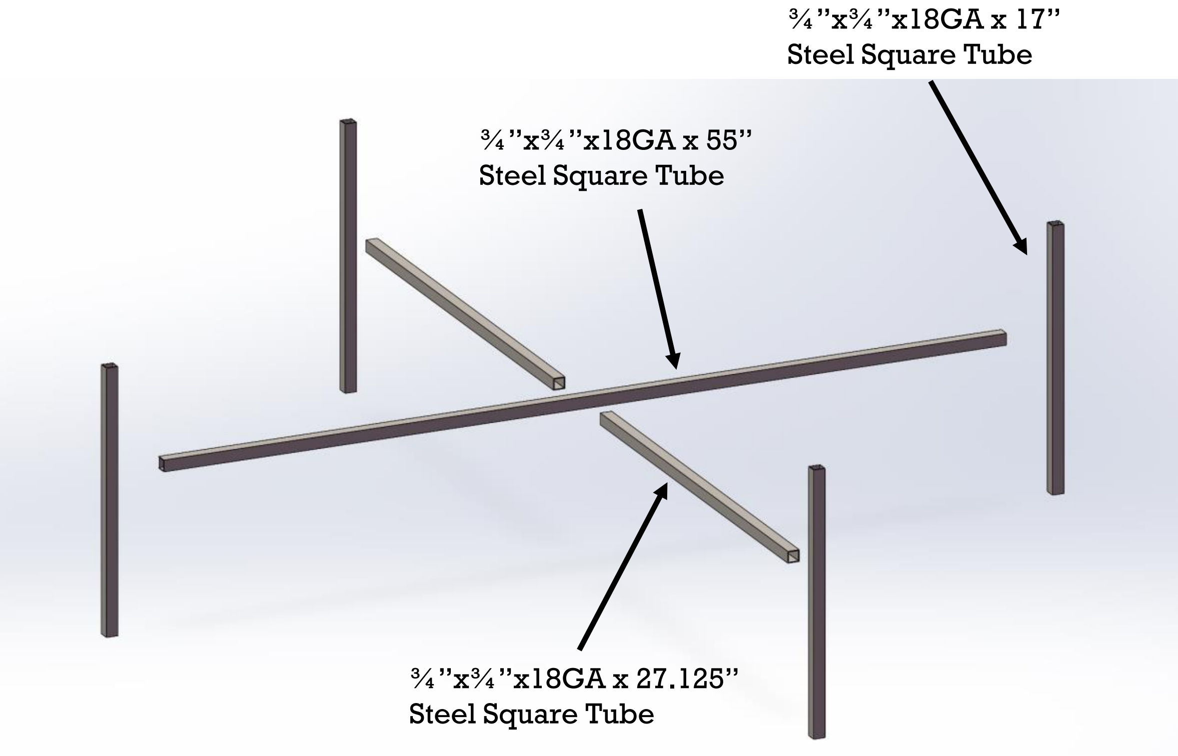
Reflector

Tracking

Base Subsystem

Key Features

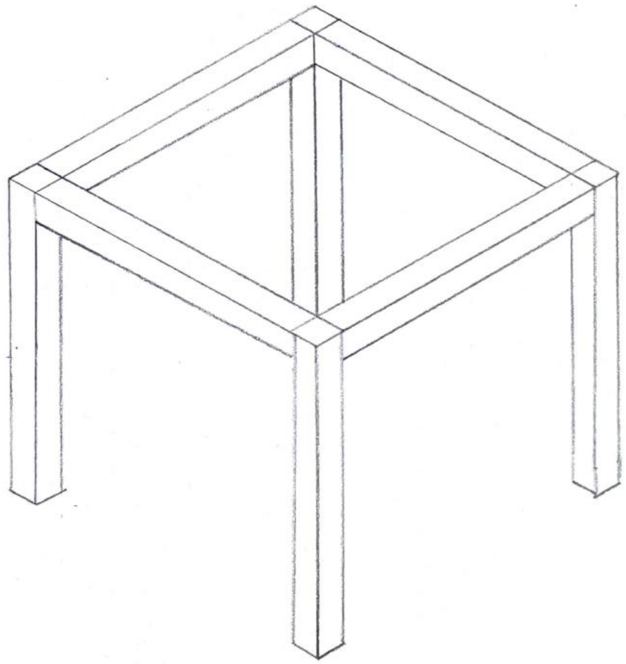
- Minimal Shading
- Will survive in highest winds
- Easy Assembly
- Minimizes Material



Base Subsystem

Original Concept

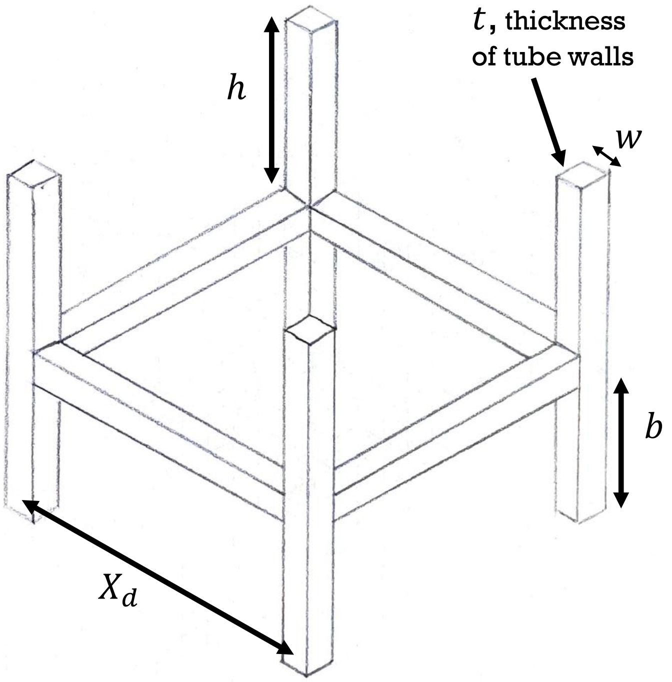
- Cross beams offer extra support
- Eliminates concrete foundation
- Low cost
- Easy manufacturing



Base Subsystem

Revised Starting Concept

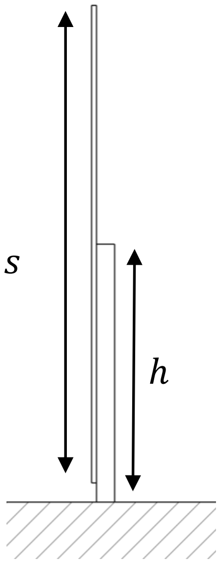
- Section b buried in ground
- Determine variables and material

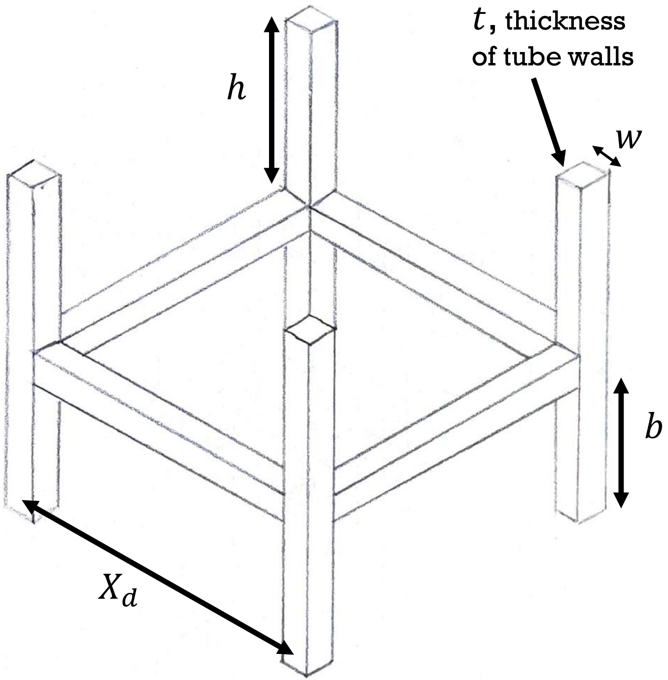


Base Subsystem

Revised Starting Concept

- Section b buried in ground
- Determine variables and material





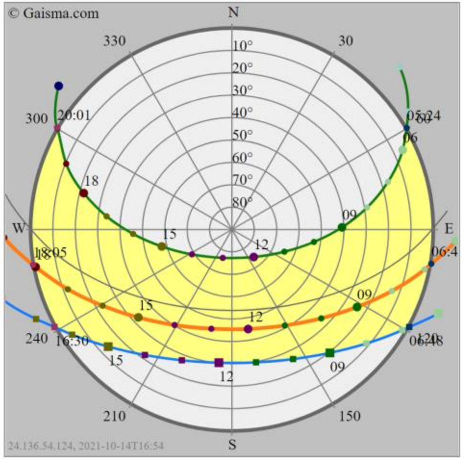
Base Subsystem

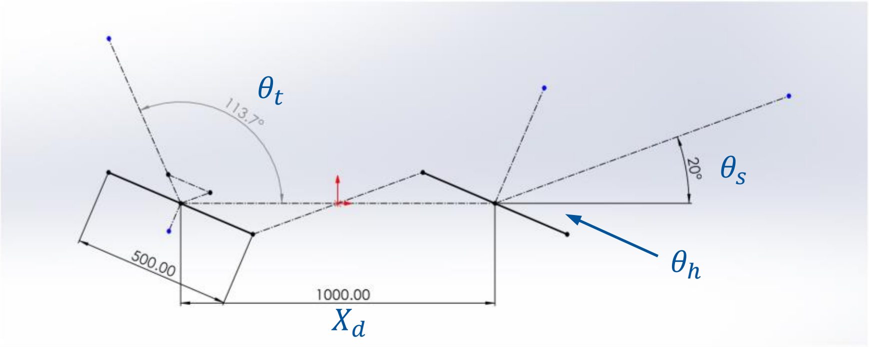
Heliostat Spacing, X_d

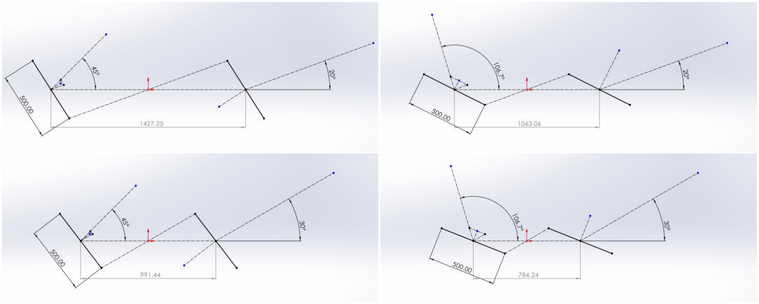
$$\theta_h = 90 - \frac{\theta_s + \theta_t}{2}$$

$$X_d = 2\left(\frac{s}{2}\cos(\theta_h) + \frac{\frac{s}{2}\sin(\theta_h)}{\tan(\theta_s)}\right)$$

Elevation angles of the sun throughout day

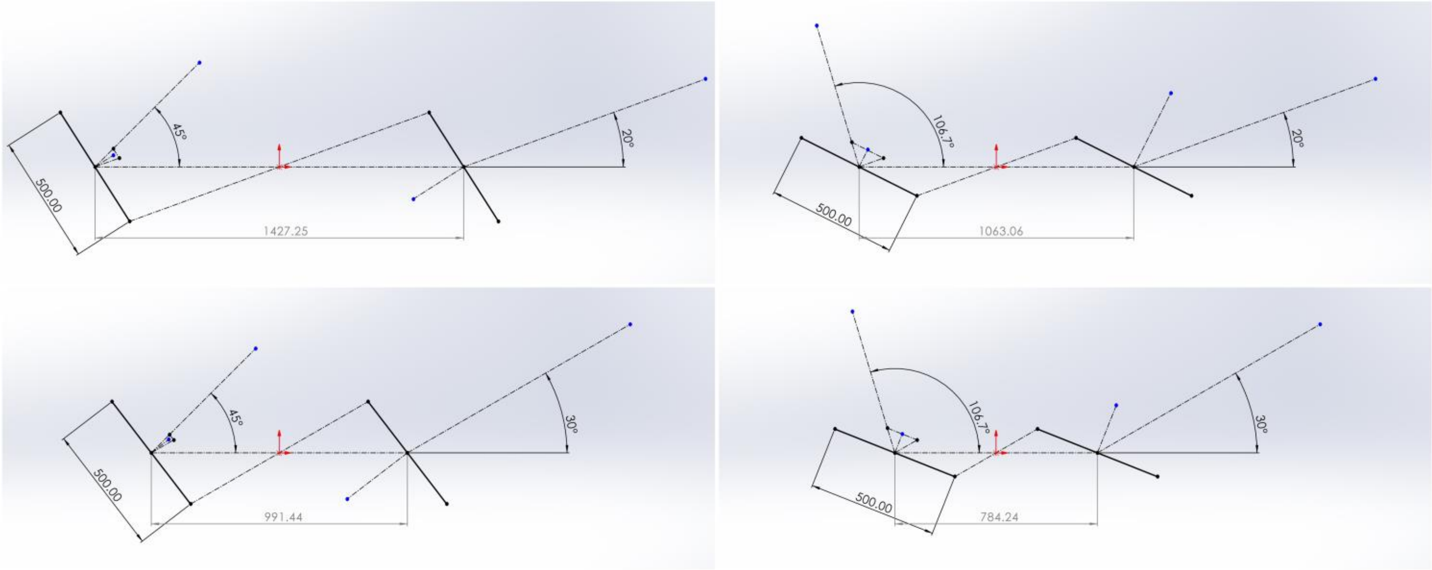






Base Subsystem

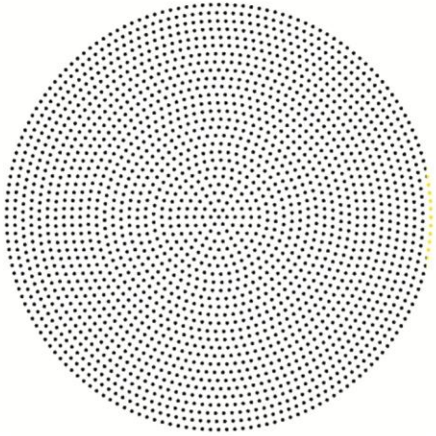
Heliostat Spacing, X_d



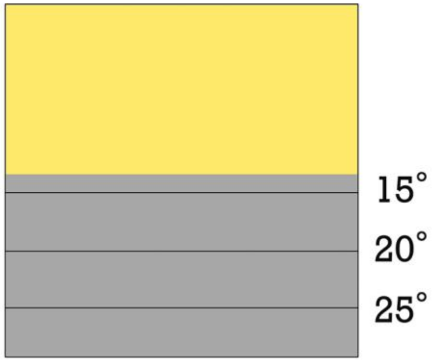
Base Subsystem

Heliostat Spacing, X_d

- 1m compromise
- No shading 30-30
- At least 30% field not shaded at all times from 20-20
- Less than half the field shaded by 25°



14 deg



Base Subsystem

Wind Force – Design

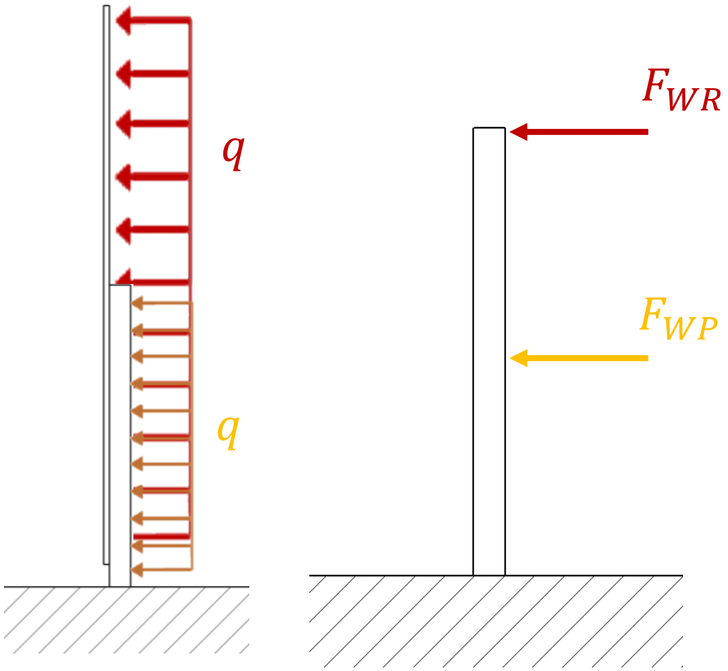
$$q = \frac{1}{2}\rho v^2 = 995.35\ Pa$$

$$F_{WR} = qA_R = 248.84\ N$$

$$F_{WP} = qA_P = qwh = 248.84w\ N$$

$$M_t = (F_{WR} \times h) + \left(F_{WP} \times \frac{h}{2}\right)$$

$$I = \frac{1}{12}(w^4 - (w - 2t)^4) \qquad \sigma_w = \frac{My}{I}$$

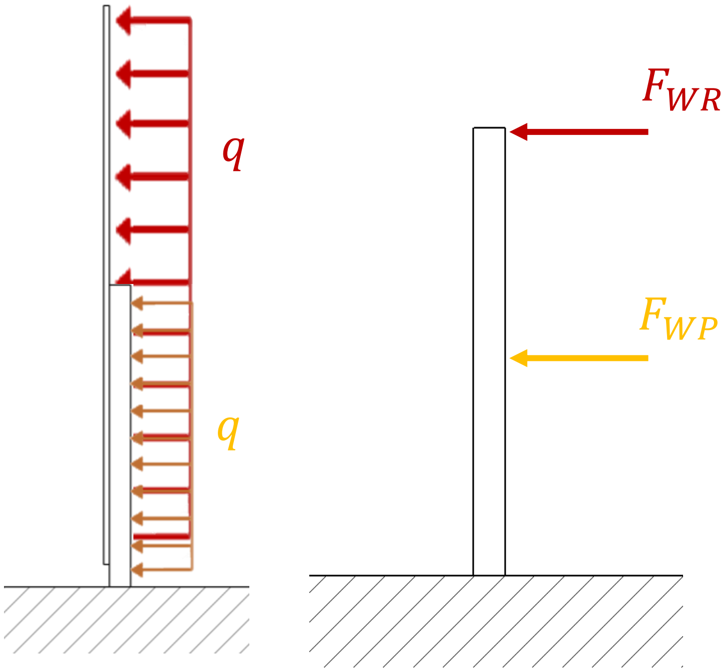


Base Subsystem

Wind Force – Design

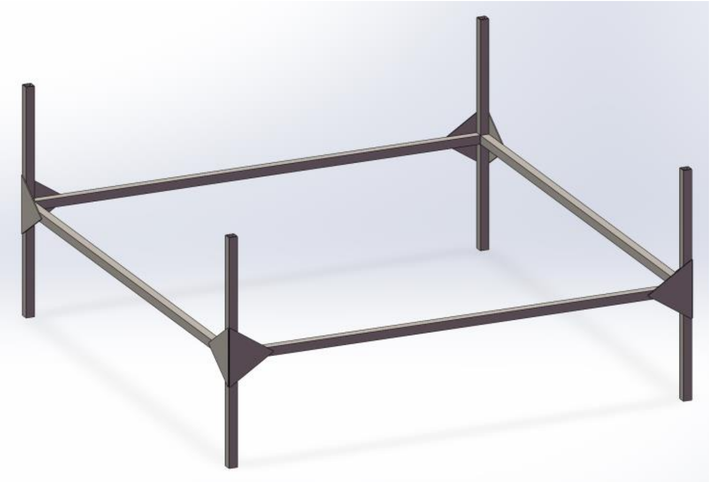
$$n = \frac{\sigma_y}{\sigma_w}$$

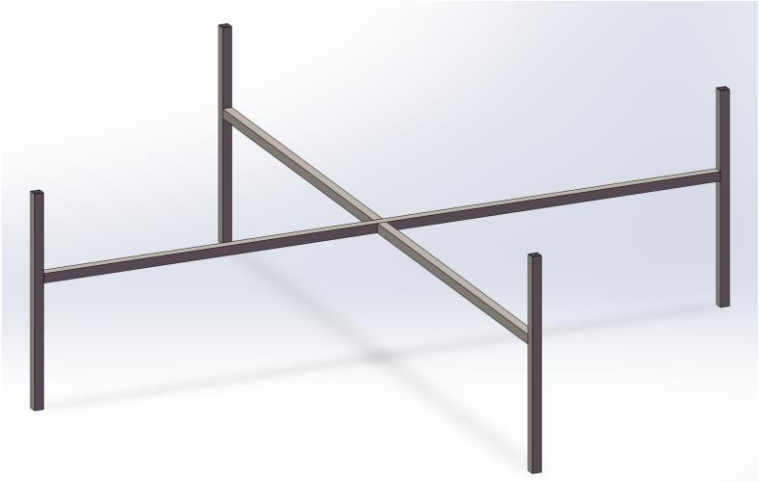
- With t =1.27mm and n = 2
  - Aluminum – w ≥ 18.21mm
  - Steel – w ≥ 16.35mm
- ¾” x ¾” x 18GA square steel tube
- Cost ≈ $1.17 per foot



Base Subsystem

Design Progression





- 6 meters of bar stock
- 8 corner gussets
- Computer mounting on one side

- 4.5 meters of bar stock
- No corner gussets
- Same distancing
- Looks cool

Base Subsystem

Gussets – Have or Have Not

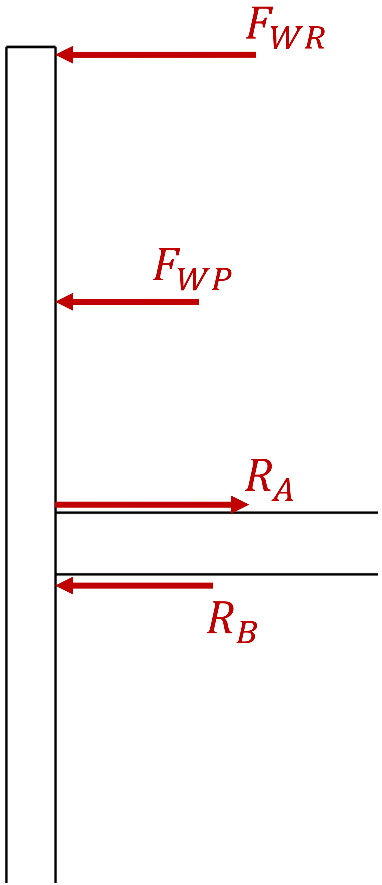
- Weld Gussets
- Rivet/Bolt Gussets
- Weld Crossbars (no gussets)

$$\Sigma M_B = 0$$

$$\mathrm{F_{wr}}(\mathrm{h} + \mathrm{w}) + \mathrm{F_{wp}}\left(\frac{1}{2}\mathrm{h} + \mathrm{w}\right) = R_A \mathrm{w}$$

$$R_A = 3532\ N$$

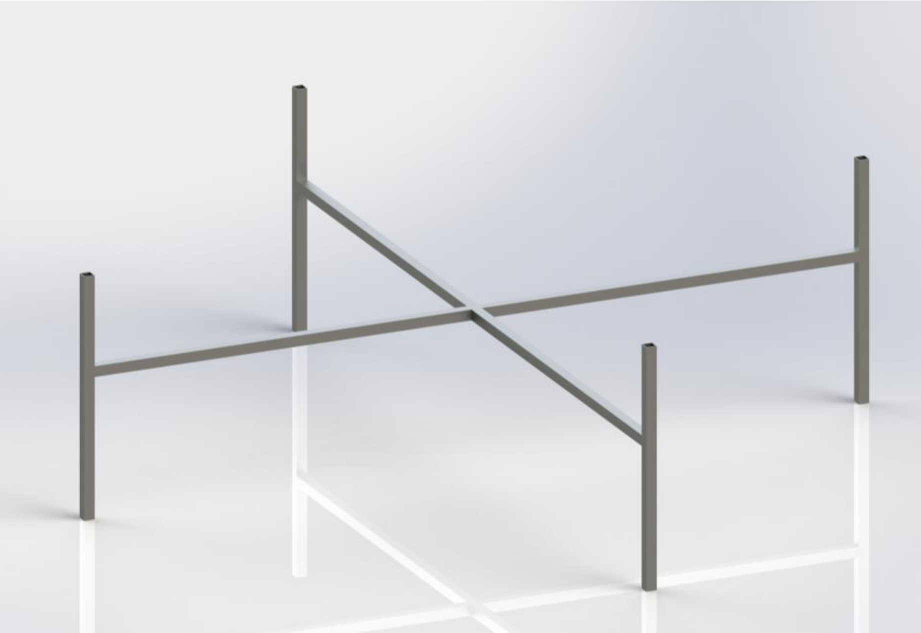
$$\sigma_A = \frac{R_A}{wt} = 146\ MPa$$



Base Subsystem

Final Specifications

- Bending Stress FoS, $n = \mathbf{2.8}$
- Weld FoS, $n = \mathbf{2.4}$
- Beam Deflection, $\delta = \mathbf{1.36\ mm}$
- $18.17 for stock

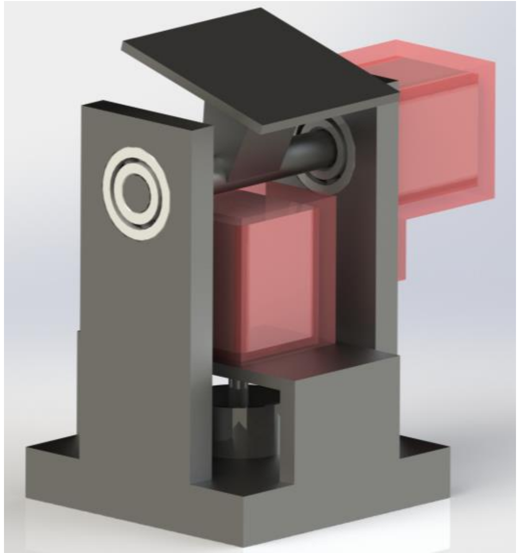


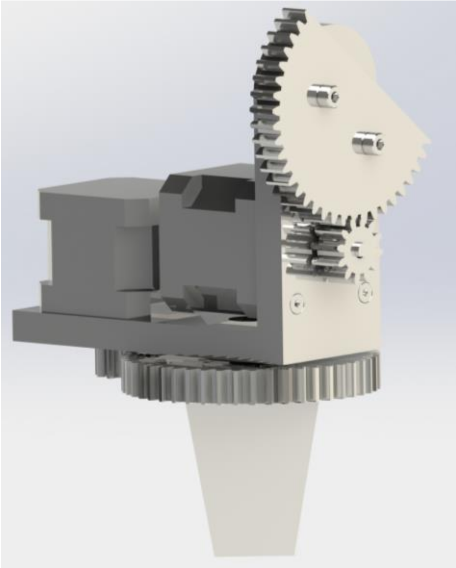
Actuator Subsystem

Key Features and Design Choices

- Azimuth and Elevation rotation
- Gears increase holding torque
- Compact, Simple Design
- Plastic gears to reduce cost
- Structurally Stable

Actuator Subsystem

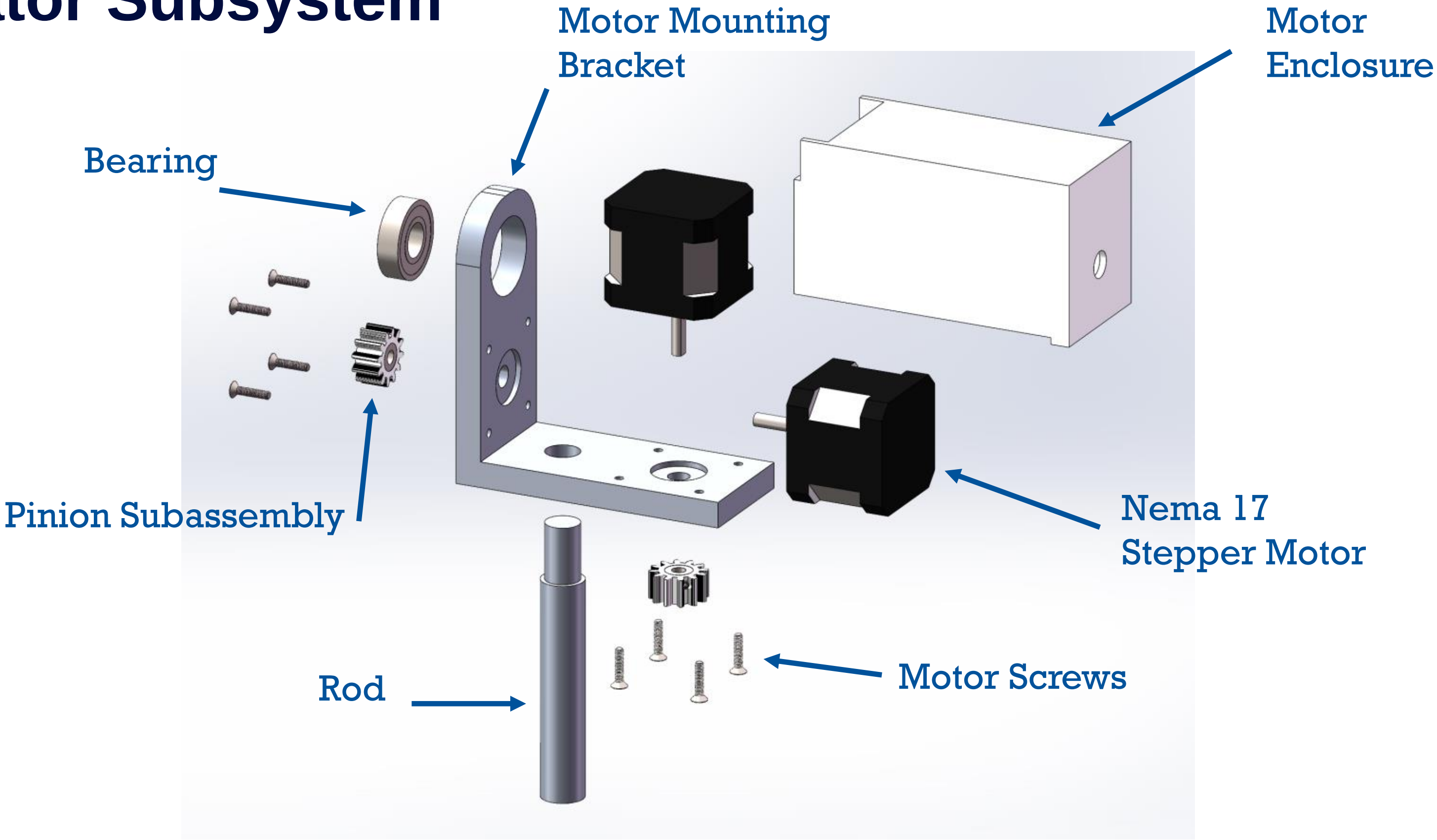




- Not strong enough .4 Nm output
- Load on motor shaft
- Costly: $55 material and OTS

- Strong 1.6 Nm output
- No load on motor shafts
- Cheaper: $45 material and OTS

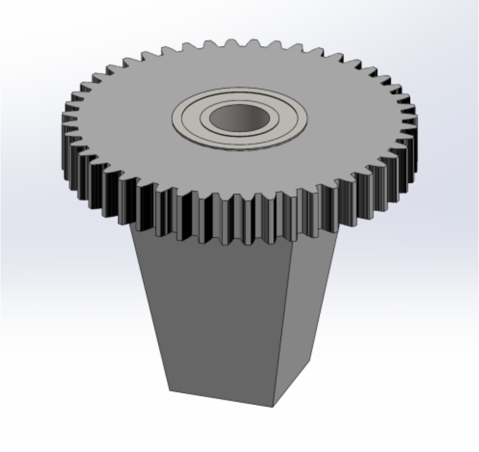
Actuator Subsystem

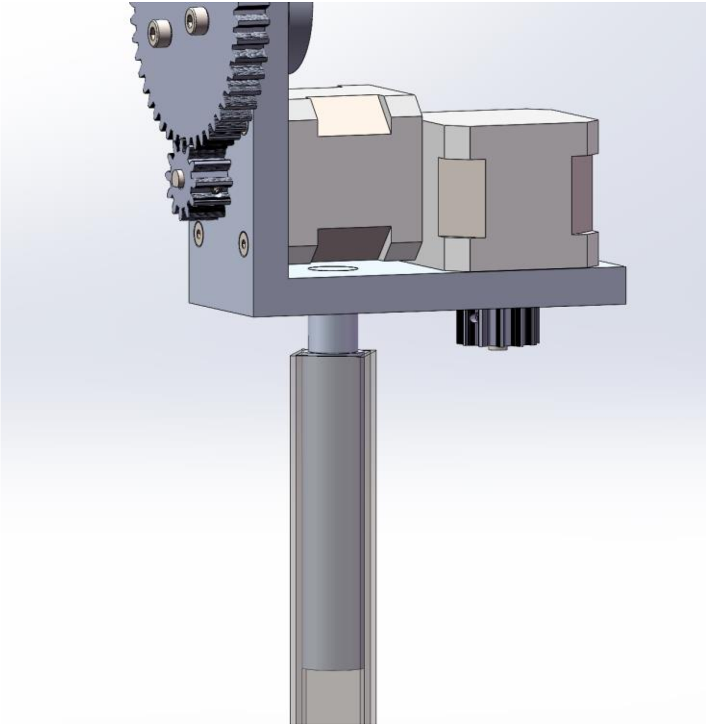


Actuator Subsystem

Base Attachment

- Avoids weak bending points
- Gear doubles as adapter
- Bearing for smooth movement and stability

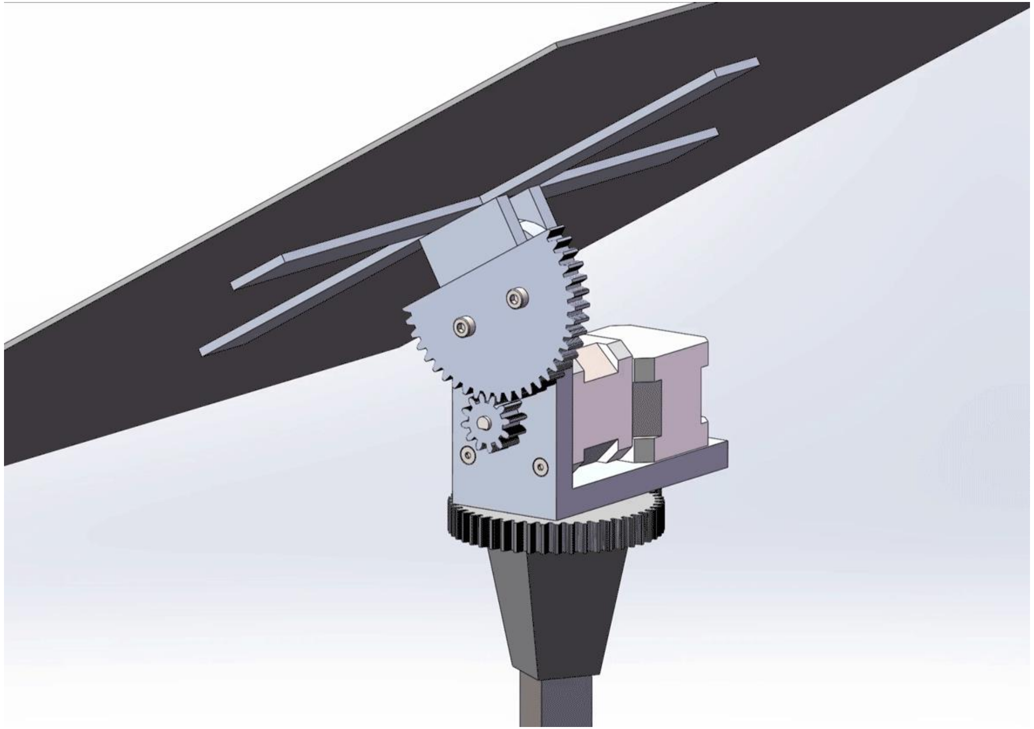




Actuator Subsystem

Functionality

- Big gear adapter remains stationary
- Azimuth motor “crawls” around the big gear
- Elevation motor drives mirror



Actuator Subsystem

System Analysis - Wind

$$F_L = \frac{C_L \rho v^2 A}{2} \qquad C_L = 2\pi\theta_h$$

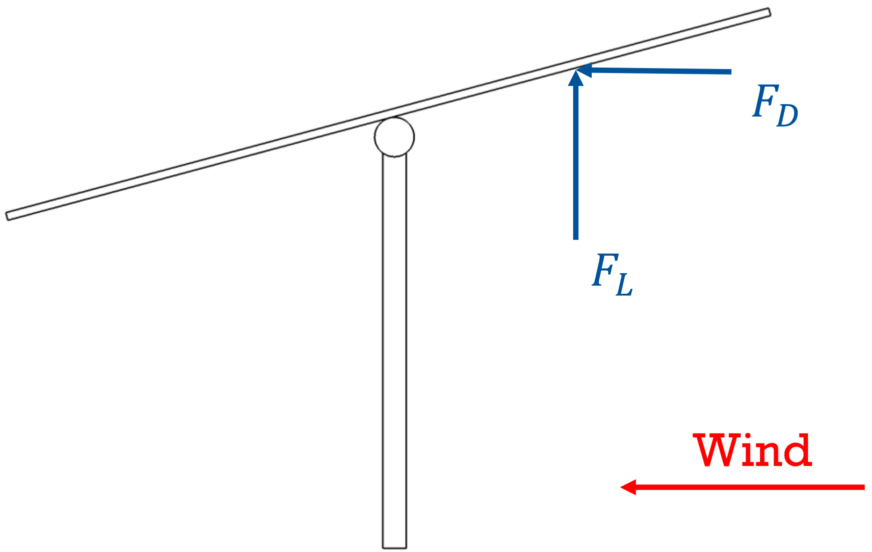
$$F_D = \frac{C_D \rho v^2 A}{2} \qquad C_D = \frac{C_L^2}{\pi e B_{AR}}$$

$$\tau_o = GR \cdot \tau_m = 1.6\ N/m$$

$$\tau_o = (F_L + F_D) \times r$$

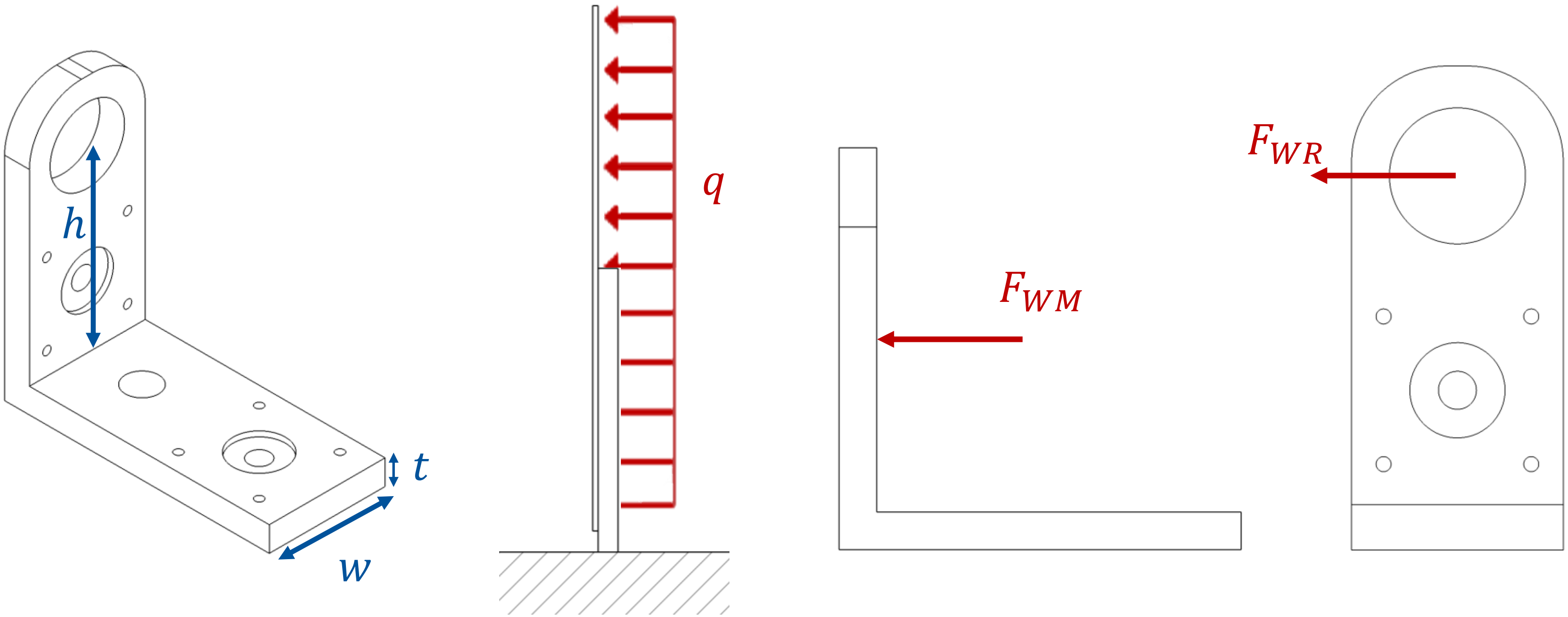
$$\tau_o = \frac{s}{4}(F_L \cos(\theta_h) + F_D \cos(\theta_h))$$

$$v \leq 8.51\ m/s, 19\ mph$$



Actuator Subsystem

Wind Force



Actuator Subsystem

Wind Force

$$q = 995.35\ Pa$$

$$F_{WR} = 248.84\ N$$

$$F_{WM} = qA_P = qwh = 3.933N$$

$$M_M = F_{WM}h = 0.271\ Nm$$

$$M_R = F_{WR}h = 1.17\ Nm$$

$$I_M = \frac{1}{12}(wt^3)$$

$$I_R = \frac{1}{12}(tw^3)$$

$$\sigma_M = \frac{M_M \frac{t}{2}}{I_M} = 0.403\ MPa$$

$$\sigma_R = \frac{M_R \frac{w}{2}}{I_R} = 0.373\ MPa$$

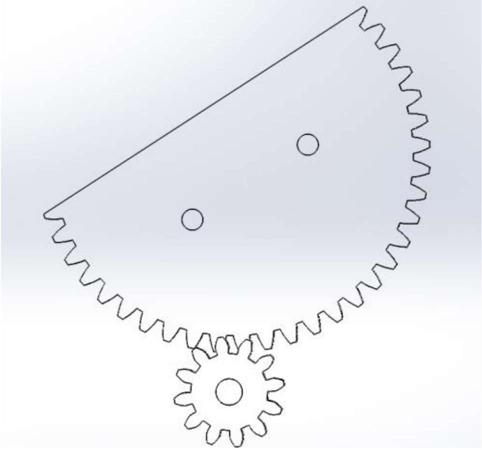
Actuator Subsystem

System Analysis

$$k_v = \frac{C_1 + v}{C_1} \qquad W_t = \frac{\tau_i}{r_i} \qquad r_i = r_{ip}\sin(\phi_c)$$

$$\sigma_b = k_v \frac{W_t}{lMY} = 16.4kPa$$

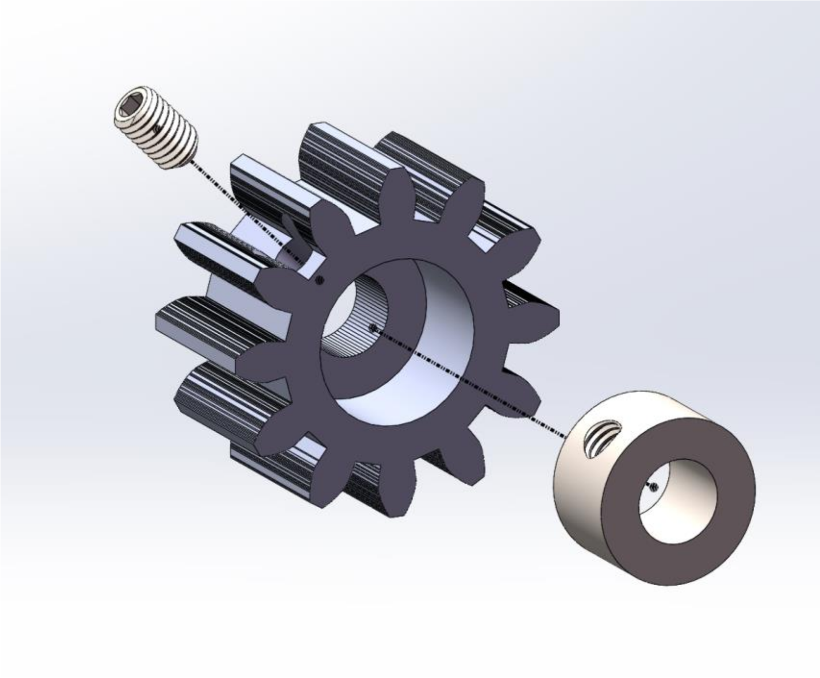
$$\sigma_c = -\left[\frac{W_t\left(\frac{1}{r_1} + \frac{1}{r_2}\right)}{\pi l \cos(\phi_c)\left(\frac{1 - v_1^2}{E_1} + \frac{1 - v_2^2}{E_2}\right)}\right]^{\frac{1}{2}} = -40.4 \text{ MPa}$$



Actuator Subsystem

Pinion Gear Subassembly

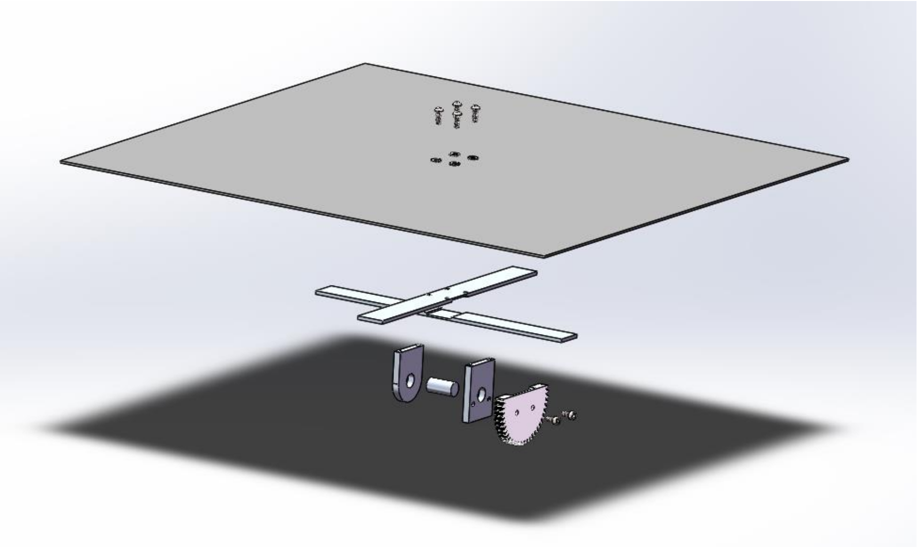
- Concerned about strength of ABS plastic gears
- Use shaft collar for attachment to motor



Reflector Subsystem

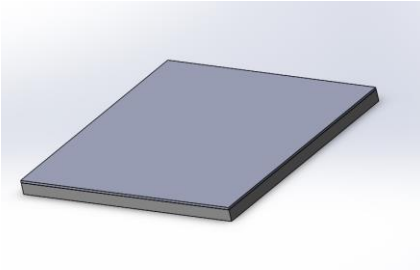
Key Features and Design Choices

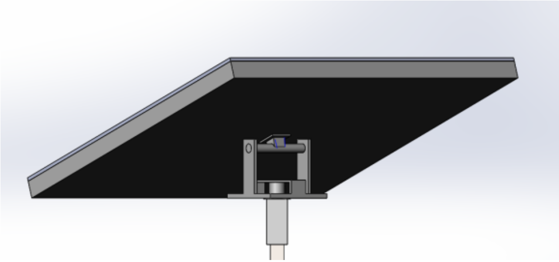
- Acrylic
- Lightweight
- Cheap
- Resistant to breaking
- Washable
- Highly reflective
- Backing support to avoid bending
- Screwed directly in



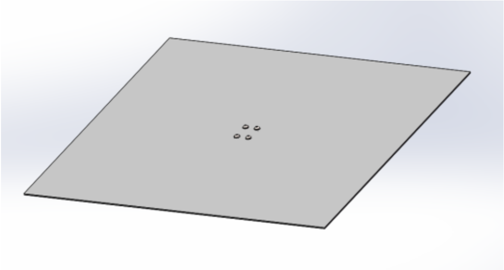
Reflector Subsystem

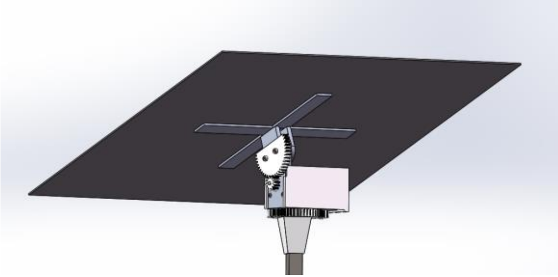
Design Progression





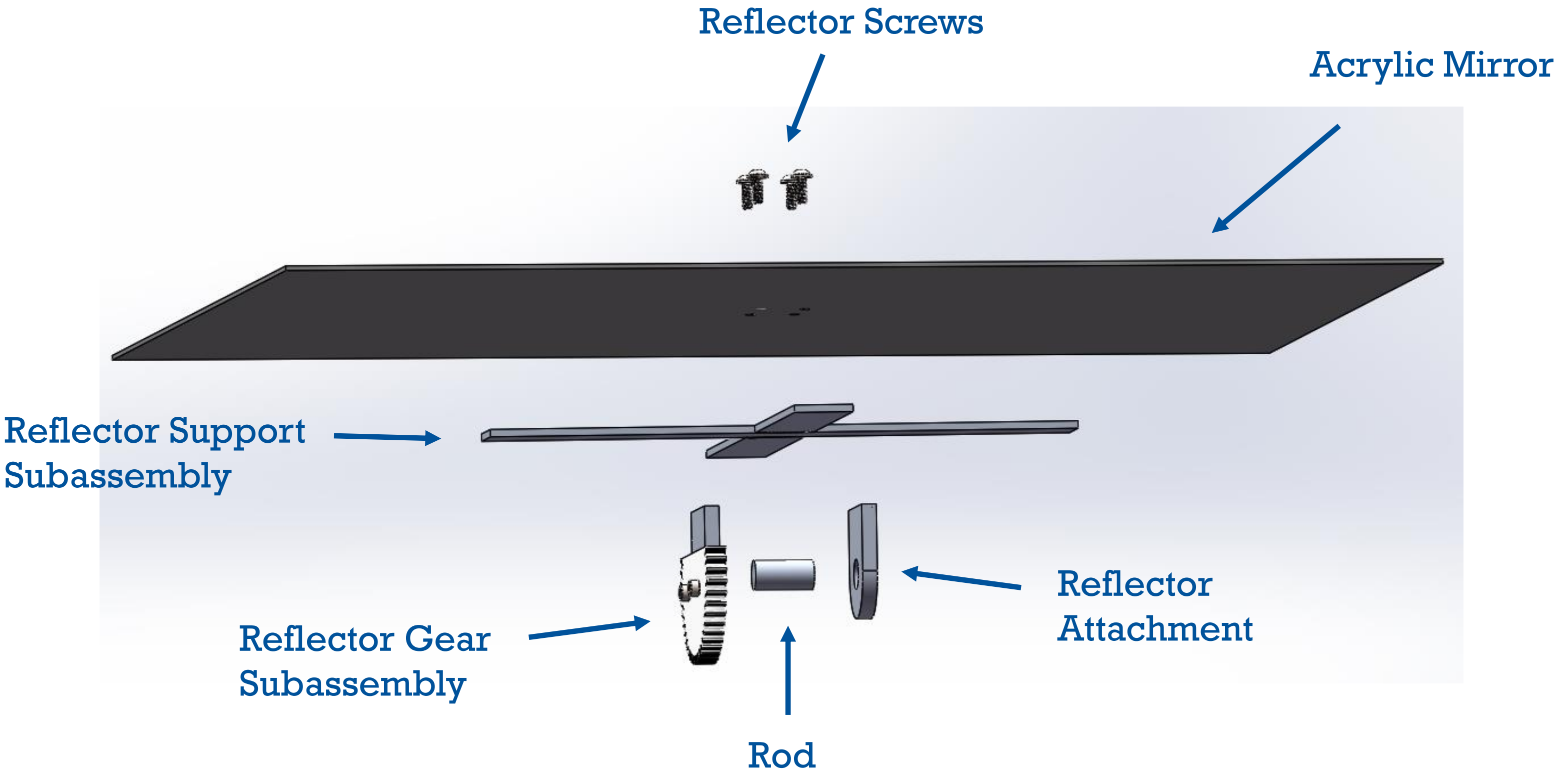
- More expensive
- Excessive support material
- Heavier





- Cheaper
- Minimalistic support design
- More lightweight

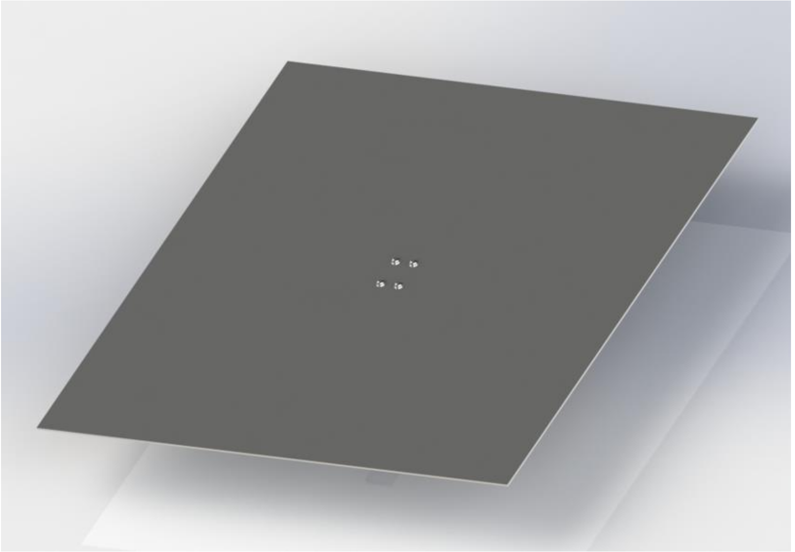
Reflector Subsystem



Reflector Subsystem

Reflectivity

- Thermal Input Capability: $P_{input} = P_{solar} A_{total} \varepsilon = 900W$
  - P_{solar} = Solar constant = 1000 W/m^2
  - A_t = Total collection area = 1 m^2
  - ε = optical efficiency = 90%



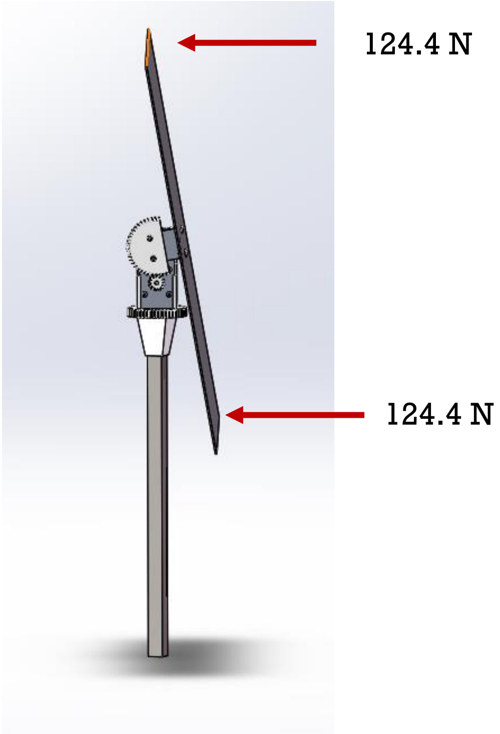
Reflector Subsystem

Bending Stress due to 40 m/s wind

- Wind Force: $F = qA$ = 124.4 N
  - q = Dynamic pressure = 995.35 Pa
  - A = 0.125 m^2
- Bending Moment: $M = (F)(x)$ = 62.2 N-m
  - F = Wind Force = 124.4 N
  - x = Length of half of mirror = 0.25 m
- Bending Stress: $\sigma_b = \frac{(M)(y)}{I}$ = 233.9 MPa
  - M = 62.2 N-m
  - Y = Distance to neutral axis = 0.001 m
  - I = Moment of inertia = $2.66 * 10^{-10}\ m^4$

Bending Stress due to 8.5 m/s wind: 10.4 MPa

Bending Stress due to 3.8 m/s wind: 2.1 MPa



Reflector Subsystem

Deflection due to 40 m/s wind

- Deflection: $\delta = \frac{FL^3}{3EI}$ = 106 mm
  - F = Wind force = 124.4 N
  - L = Length of half of mirror = 0.25 m
  - E = Elastic modulus = 68.9 GPa
  - I = Moment of inertia = $2.66 * 10^{-10}\ \mathrm{m}^4$

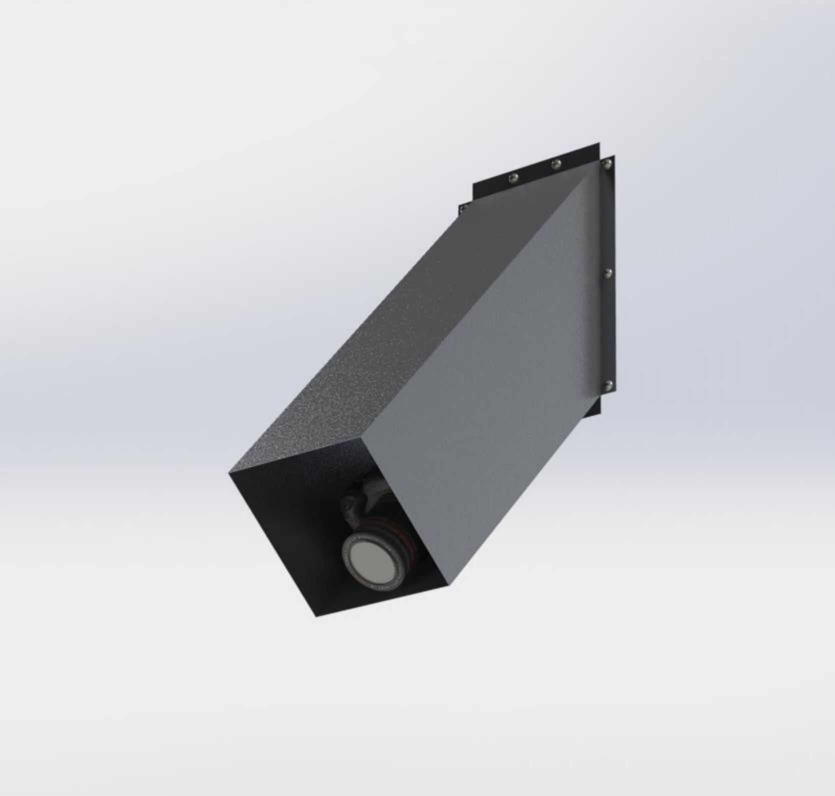
Deflection due to 8.5 m/s wind: 1.5 mm

Deflection due to 3.8 m/s wind: 0.315 mm

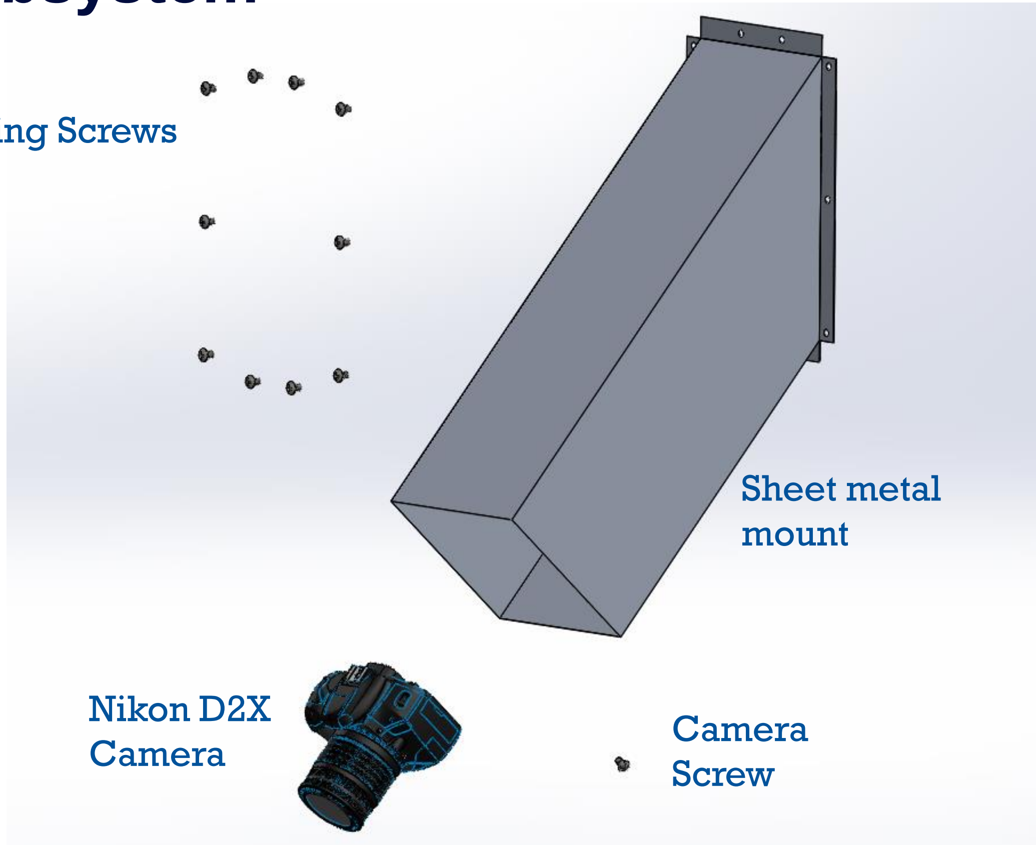
Tracking Subsystem

Key Features and Design Choices

- Nikon D2X Camera
- Sheetmetal Mount for weather protection
- Improved accuracy, average 3mrad uncertainty
- Closed loop feedback control



Tracking Subsystem



Tracking Subsystem

System Analysis: Edge Detection

- Calculated angles and length ratios

$$\theta_1 = a\ cos\frac{\boldsymbol{a}\cdot\boldsymbol{b}}{|\boldsymbol{a}||\boldsymbol{b}|}$$

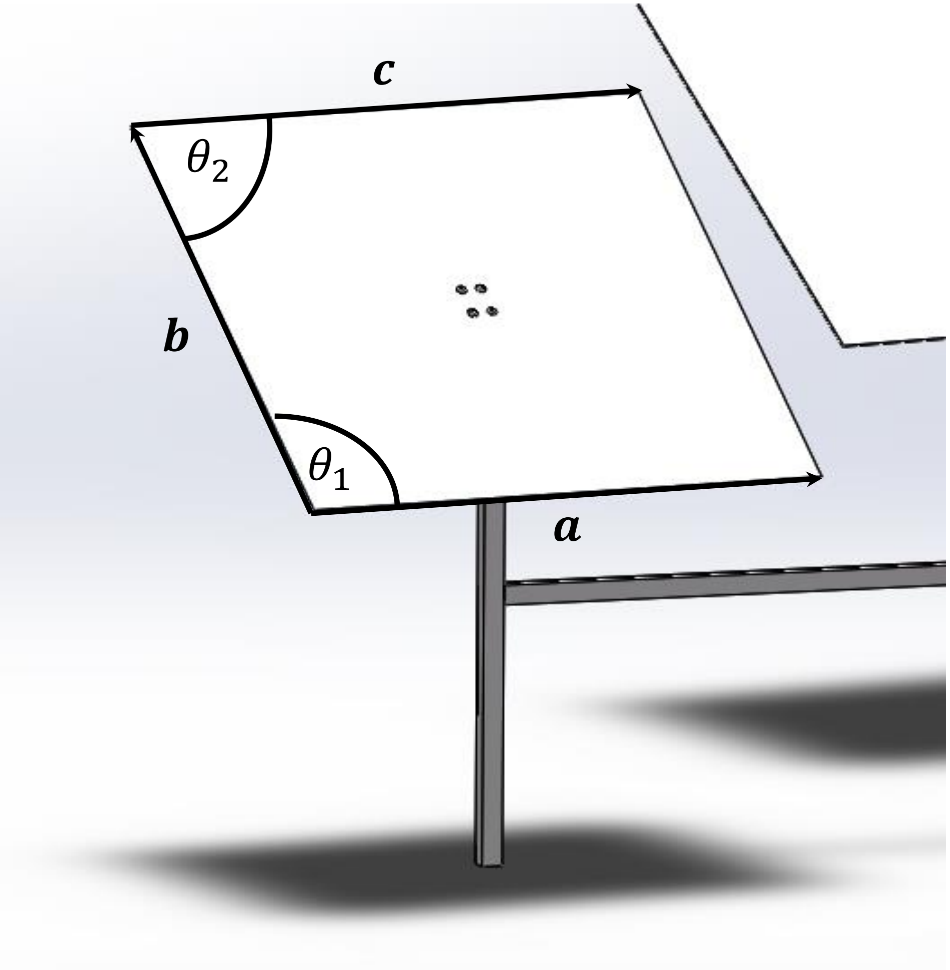
$$\theta_1 = a\ cos\frac{-\boldsymbol{b}\cdot\boldsymbol{c}}{|\boldsymbol{b}||\boldsymbol{c}|}$$

$$\emptyset_1 = \frac{|b|}{|a|}$$

$$\emptyset_2 = \frac{|c|}{|a|}$$

- Global maximum difference
  - $C_k = \emptyset$ and θ values
  - $\sigma_k =$ weighing factor
  - $A, \alpha =$ altitude and azimuth angles

$$\aleph^{-1} = \sum_{k=1}^{4}\frac{\left[C_{k,meas} - C_{k,calc}(A,\alpha)\right]^2}{\sigma_k}$$

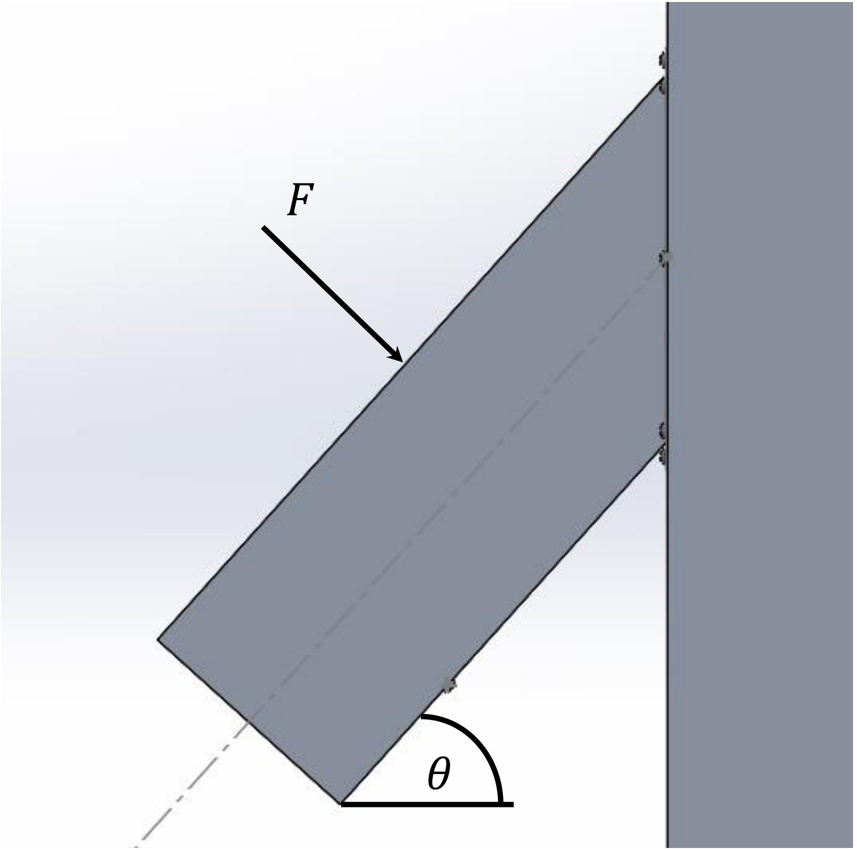


Tracking Subsystem

System Analysis:

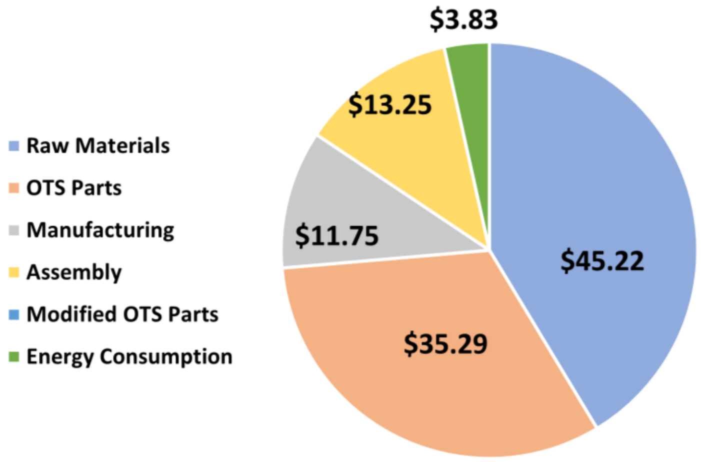
Sheetmetal wind resistance

- Wind Force: $F = qA = 98.01\ N$
  - q = Dynamic pressure = 995.35 Pa
  - A = top side area = .098 m^2
- Bending moment: $M = F\left(\frac{L}{2}\right) = 26.60\ Nm$
  - L = length of top = .54 m
  - θ = 48 degrees
- Bending Stress: $\sigma_b = \frac{(M)(y)}{I} = 0.652\ MPa$
  - y = 0.0875 m
  - I = 3.567×10^{-6} m^4



Cost Overview

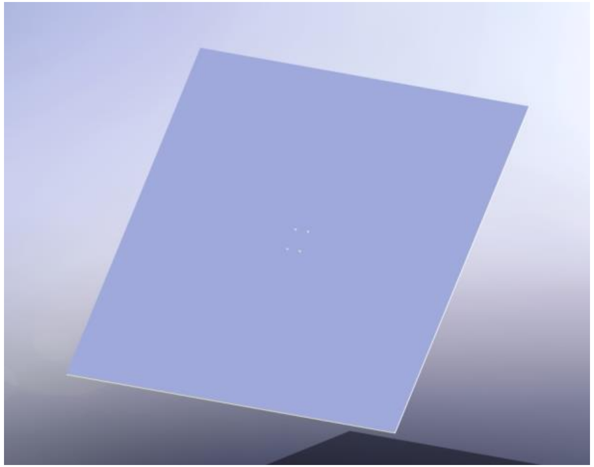
Subsystem Materials	Cost
Base	$18.17
Actuator	$45.24
Reflector	$14.51
Tracking System	$2.58
Total	**$80.50**

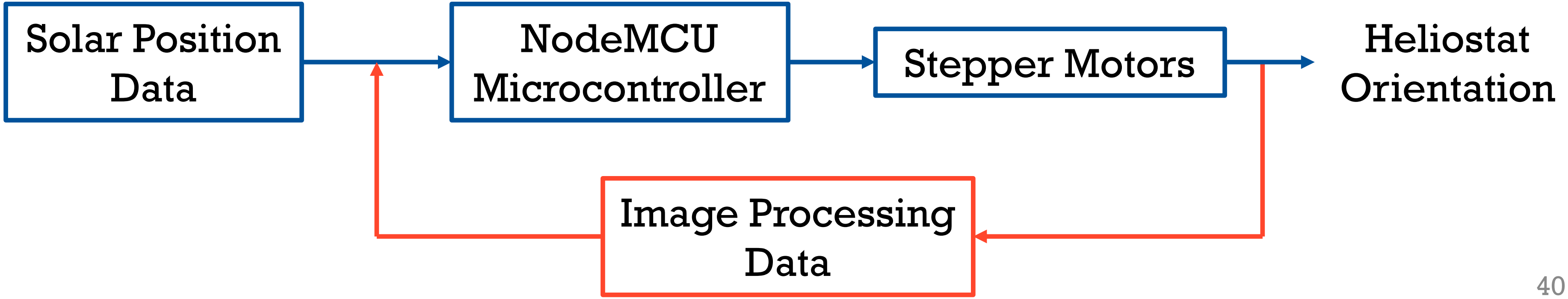


Total Cost: $109.34

Design Highlights

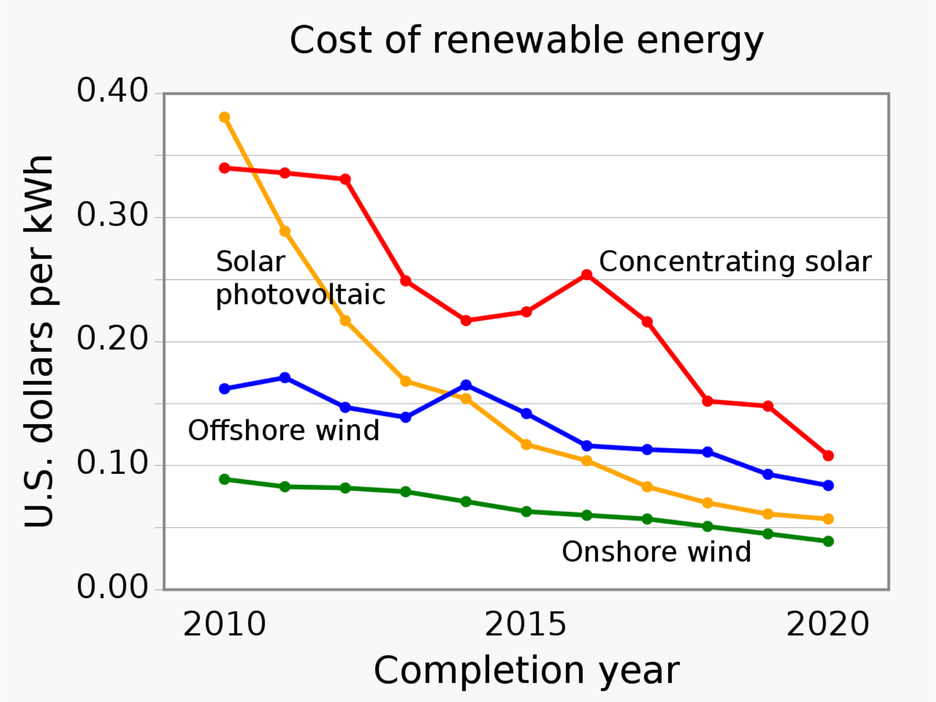
- Acrylic Mirrors
- Gear Reduction
- Tracking System





Why Accu-Stat?

Efficiency.



Source: International Renewable Energy Agency

Conclusion

Key Takeaways:

- Extremely accurate design (4 mrad uncertainty)
- Optimized frame to reduce material amount
- Lightweight, low-cost acrylic mirror

Thank You

We would like to thank our corporate sponsors Cummins, Northrop Grumman, Carrier, and Aurigo for their support on this project.