UF Herbert Wertheim College of Engineering
UNIVERSITY of FLORIDA

HelioSmart

Reimagined Solar Energy

Section 13337, Group 9

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Meet the HelioSmart Team


Adrien Arias


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Cristian Hooker

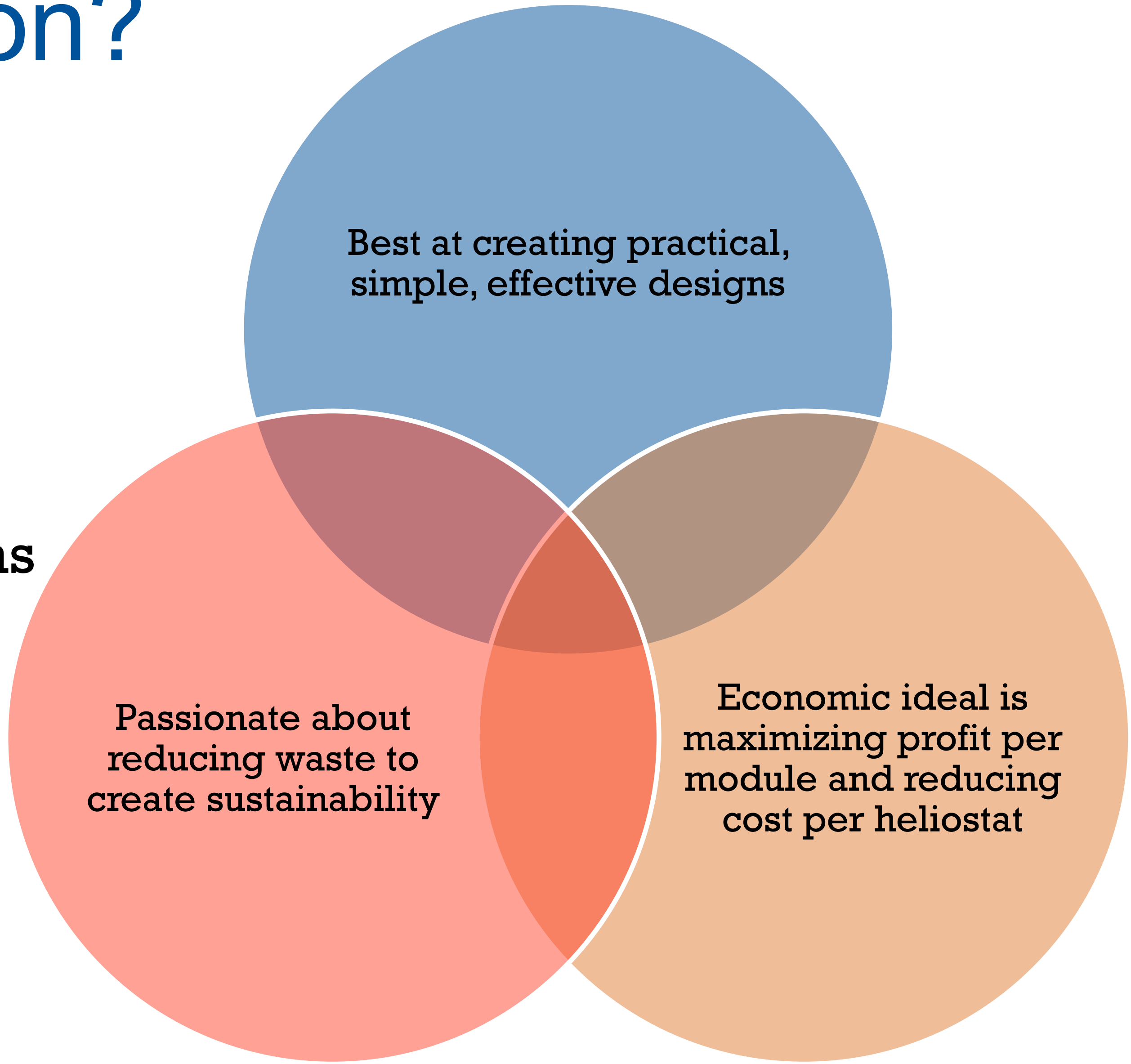

Abraham Sheikh


Noelle Turner

What drives our mission?

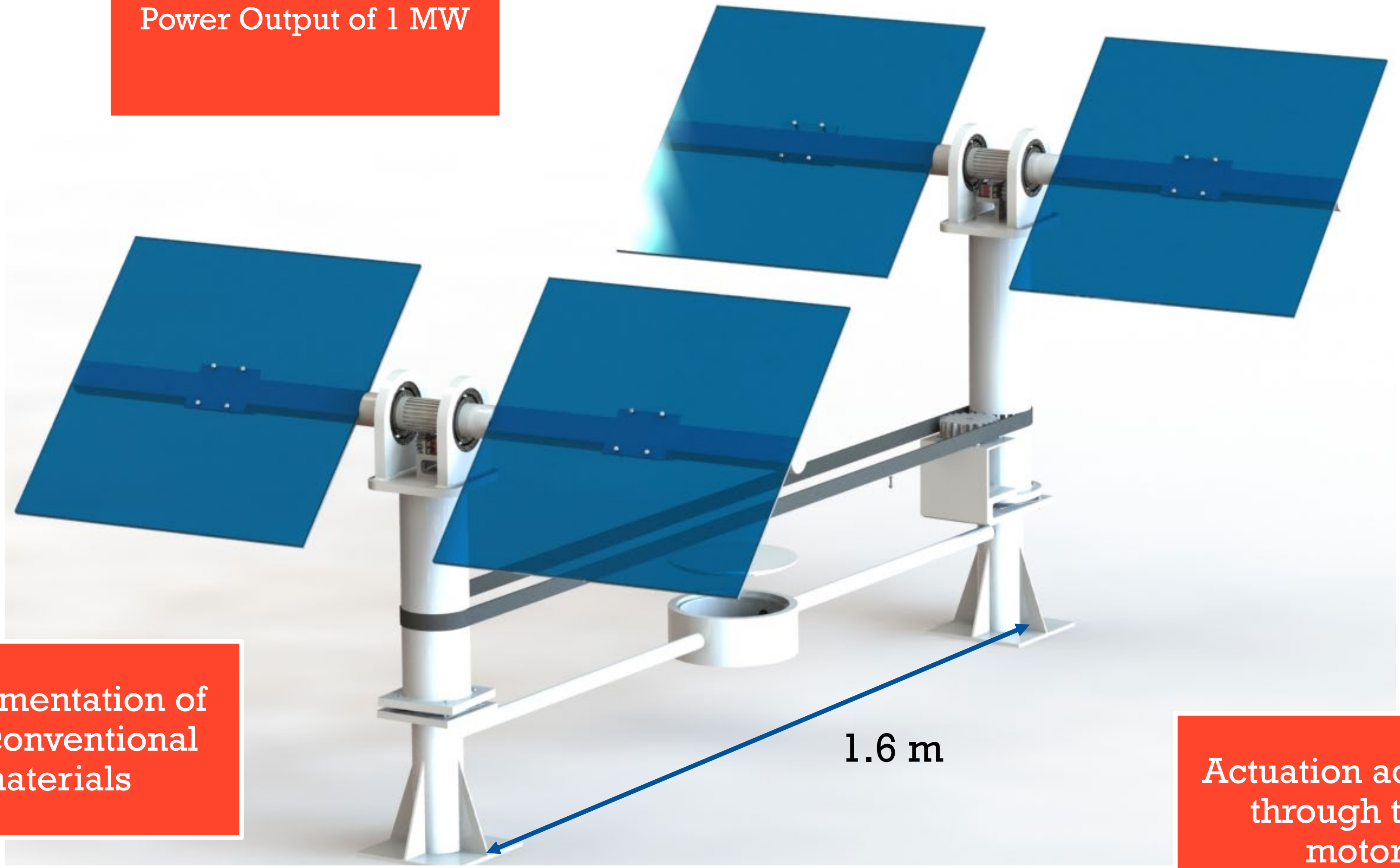
Emphasis on **efficiency and cost**

- Use low-cost novel materials
- Assure 20-year lifetime
- Handle desert conditions in Las Vegas
- Reduce waste



- Designing a heliostat module that is meant to be a part of a plant
- Located in Las Vegas, Nevada
- Reducing cost while optimizing a small and compact design
- Smaller heliostats not currently utilized commercially

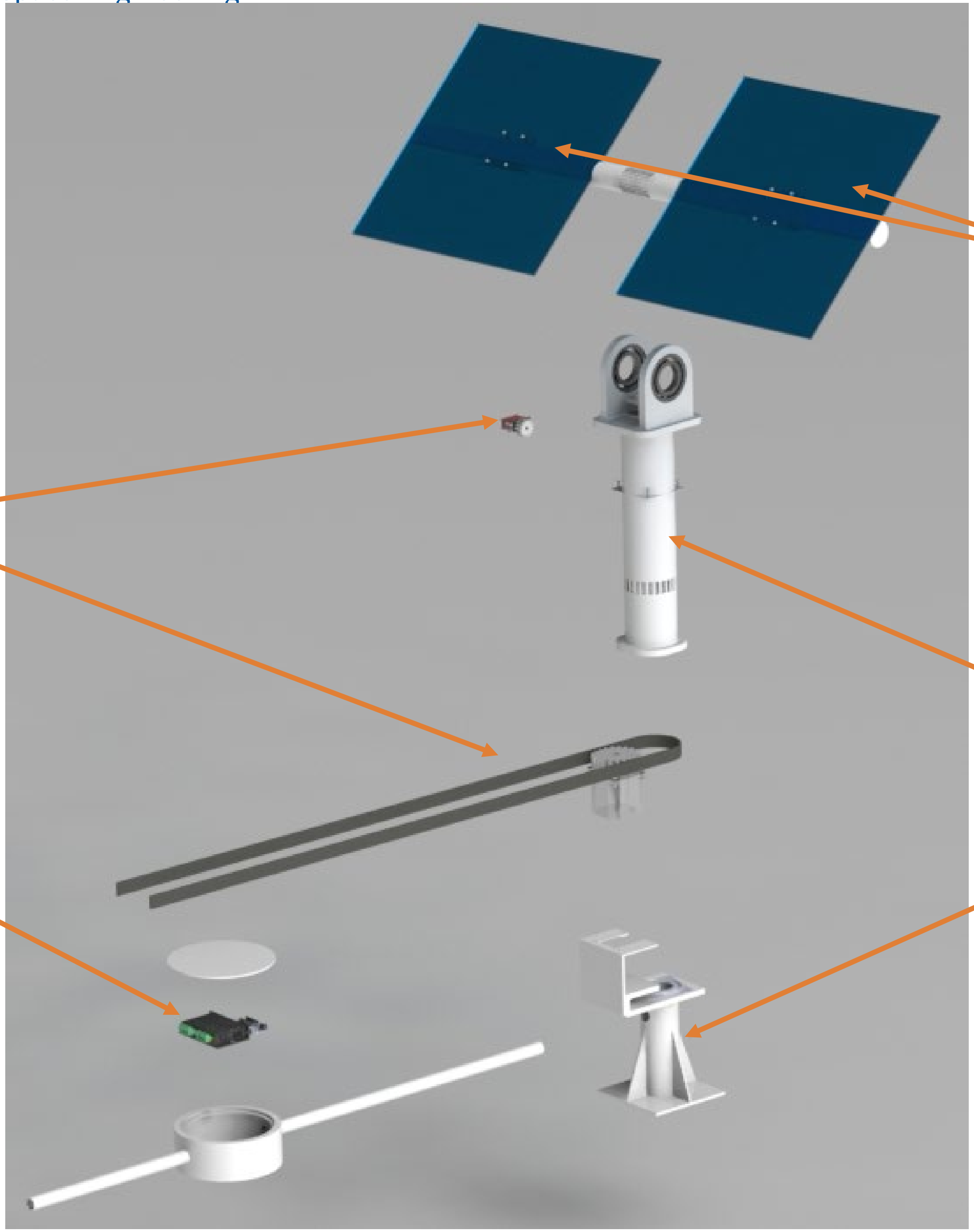
Power Output of 1 MW



Implementation of non-conventional materials

Actuation achieved through three motors

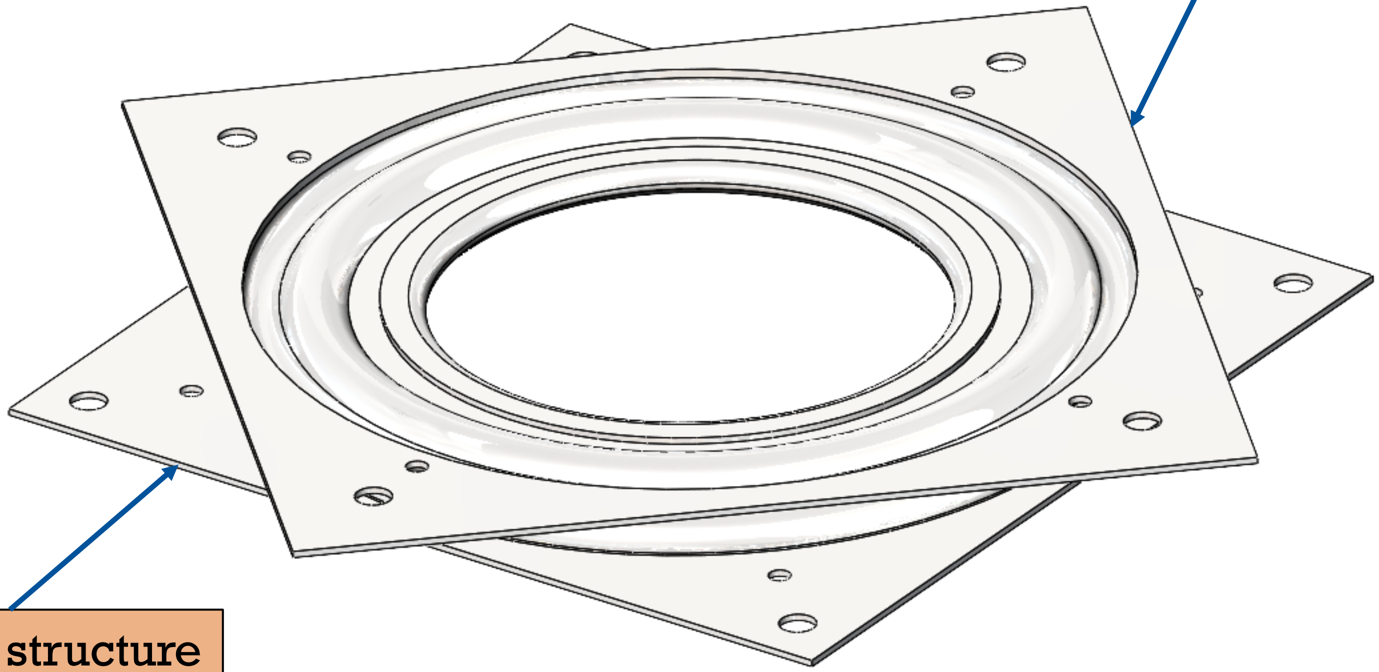
Key Features



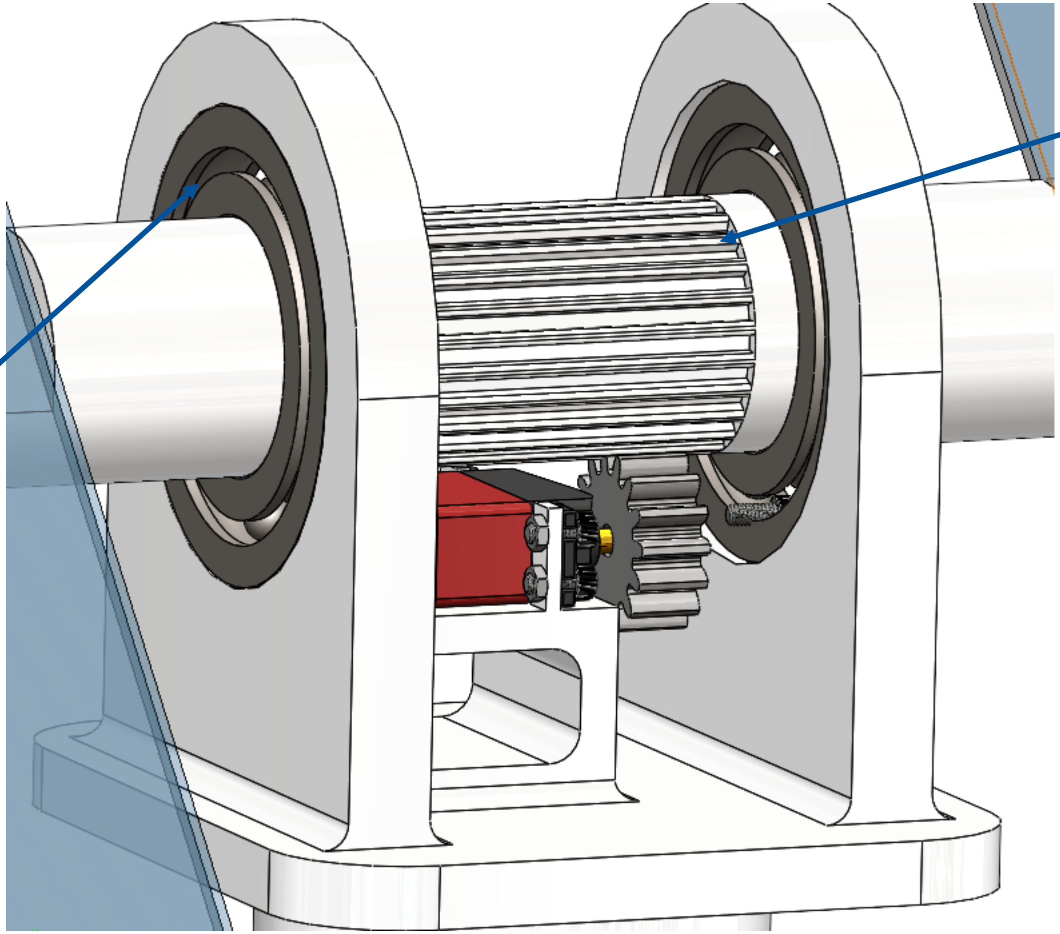
Unique Design Characteristics

Lazy-Susan Bearing

Separates rotation of top pole and structure



Gear to Pole Connection



Shaft has embedded grooves

Ball bearings are used to allow rotation

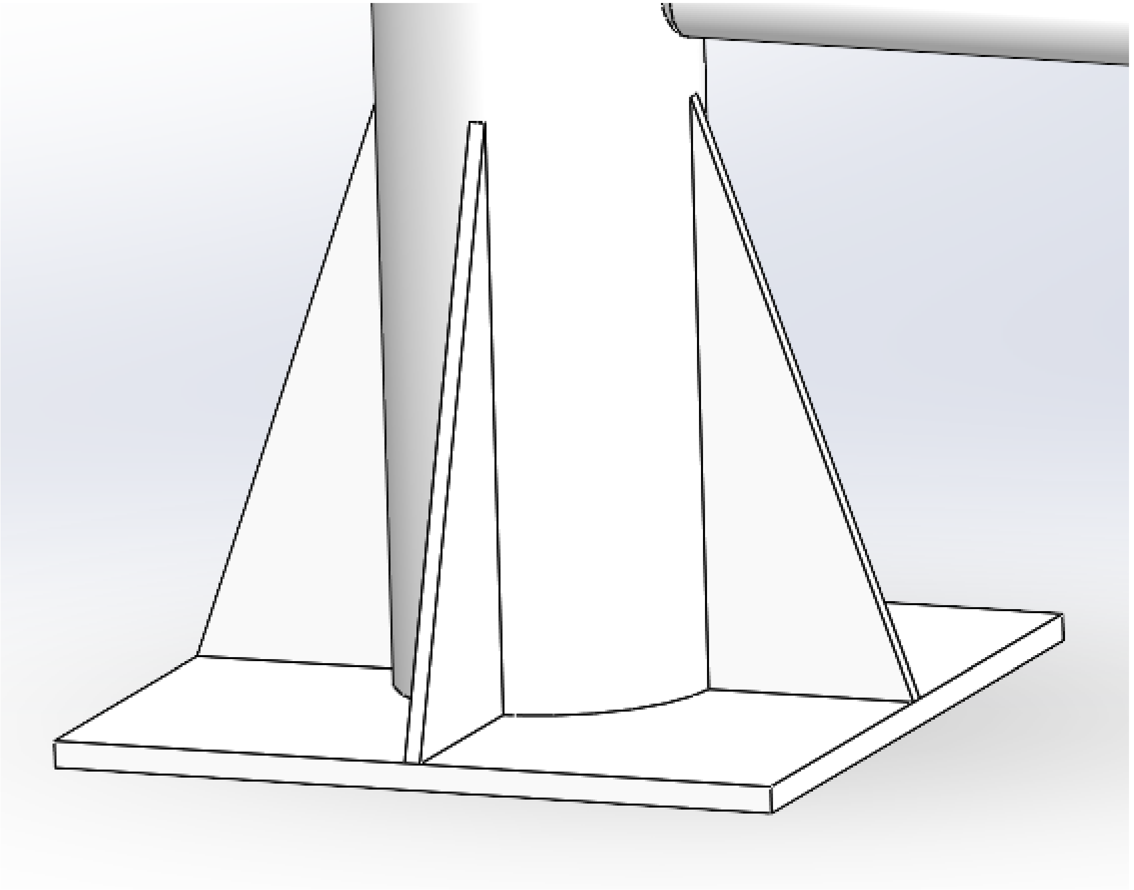
Ground Structure

Anchors module

-underground

-flanges prevent rotation

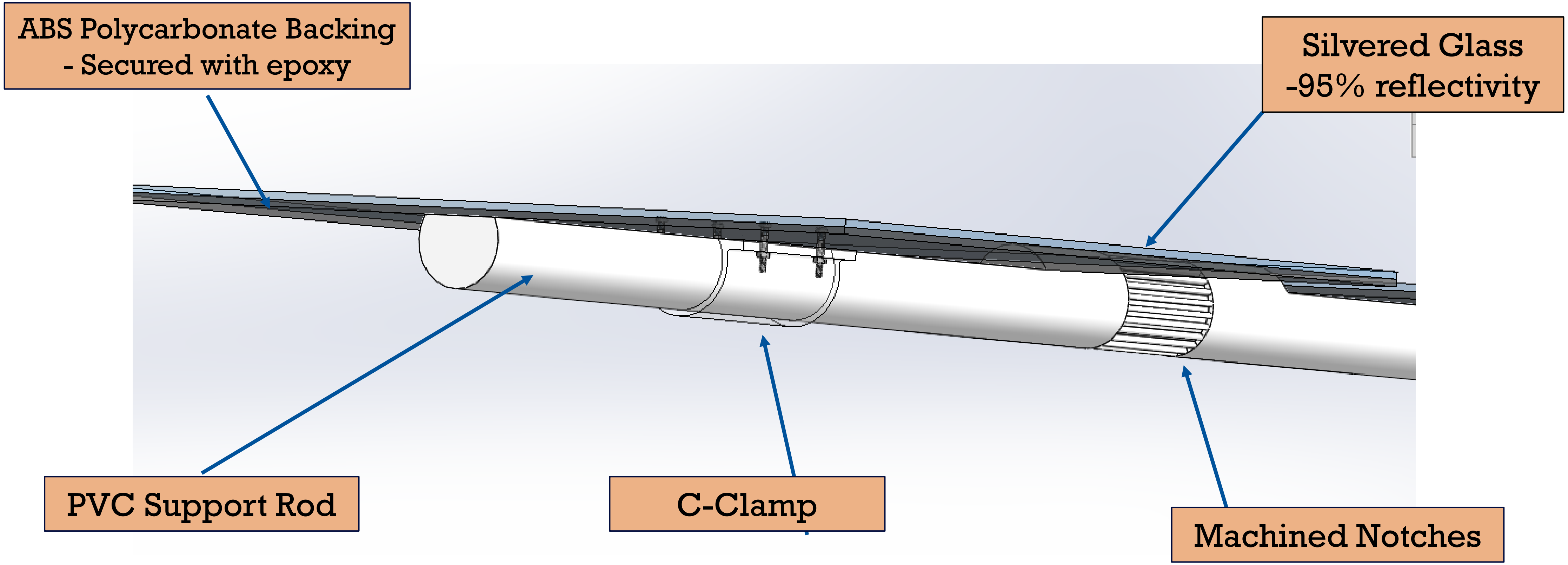
-flat base prevents uplift



Reflective Surface Subsystem

Need	Metric	Solution
1	Number of innovations	0.25 m^2 heliostat size
2	Total Collection area ≤ 1 m^2	4 square 0.25 m^2 reflective surfaces
8	Overall cost ≤ $100/$m^2$	Low-cost plane mirrors
12	Withstand surface pressure up to 500 psi	Standard glass surface
14	Operational lifetime ≥ 20 years	Glass surface with ABS frame
15	35° F ≤ Operating temperature ≤ 110° F	Silver-backed glass mirror
16	$Q_{in} \geq 1.05$ MW	1627 modules to generate power
17	Solar concentration ratio ≥ 1000 kW/m^2	Compact module for higher ratio
18	Total Integrated Scatter ≤ 5%	Smooth reflective surface with 1.65% TIS

Reflective Surface Design



Reflective Surface Subsystem Analyses

- Optical Efficiency:

$$\eta_{opt} = \rho * \eta_{cos} = (0.95)(0.77) = 0.71$$

- Solar Radiation Flux:

$$G_{bn} = \int_{0}^{30^\circ} (1000\ \mathrm{W/m^2}) \cos(\theta)\, d\theta = 866\ \mathrm{W/m^2}$$

- $0 \leq \theta \leq 30^\circ$ on December 21st, 2020

Reflective Surface Subsystem Analyses

- Useful Input Power (1 MW)

$$\dot{Q}_{use} = G_{bn} * \eta_{opt} * n * A_{module}$$

Where n is the number of heliostat modules.

$$1\ MW = (866\ \mathrm{W/m^2})(0.71)n(1\mathrm{m^2}) = 1627\ \mathrm{modules}$$

$$\dot{Q}_{use} = \dot{Q}_{in} * \eta_{opt} \Rightarrow \dot{Q}_{in} = \boxed{1.41\ \mathrm{MW}}$$

Reflective Surface Subsystem Analyses

- Solar Concentration Ratio

$$C_{geo} = \frac{\Sigma A_{heliostat\ modules}}{A_{receiver}} = \frac{n * A_{module}}{A_{receiver}} = \frac{1627(1\ \mathrm{m}^2)}{1\ \mathrm{m}^2} = \boxed{1627\ \mathrm{suns}}$$

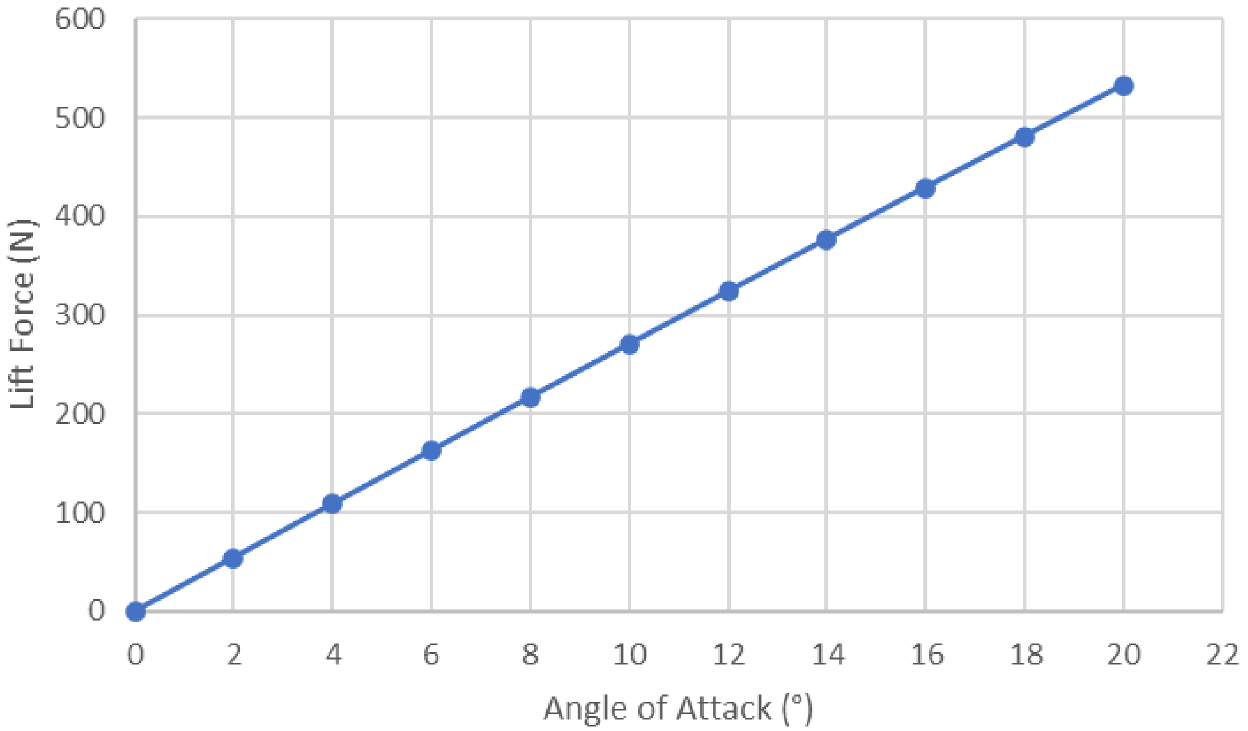
Reflective Surface Subsystem Analyses

- Lift force on a flat plate:

$$L = \frac{1}{2}\rho v^2 A C_L$$

- Coefficient of lift:

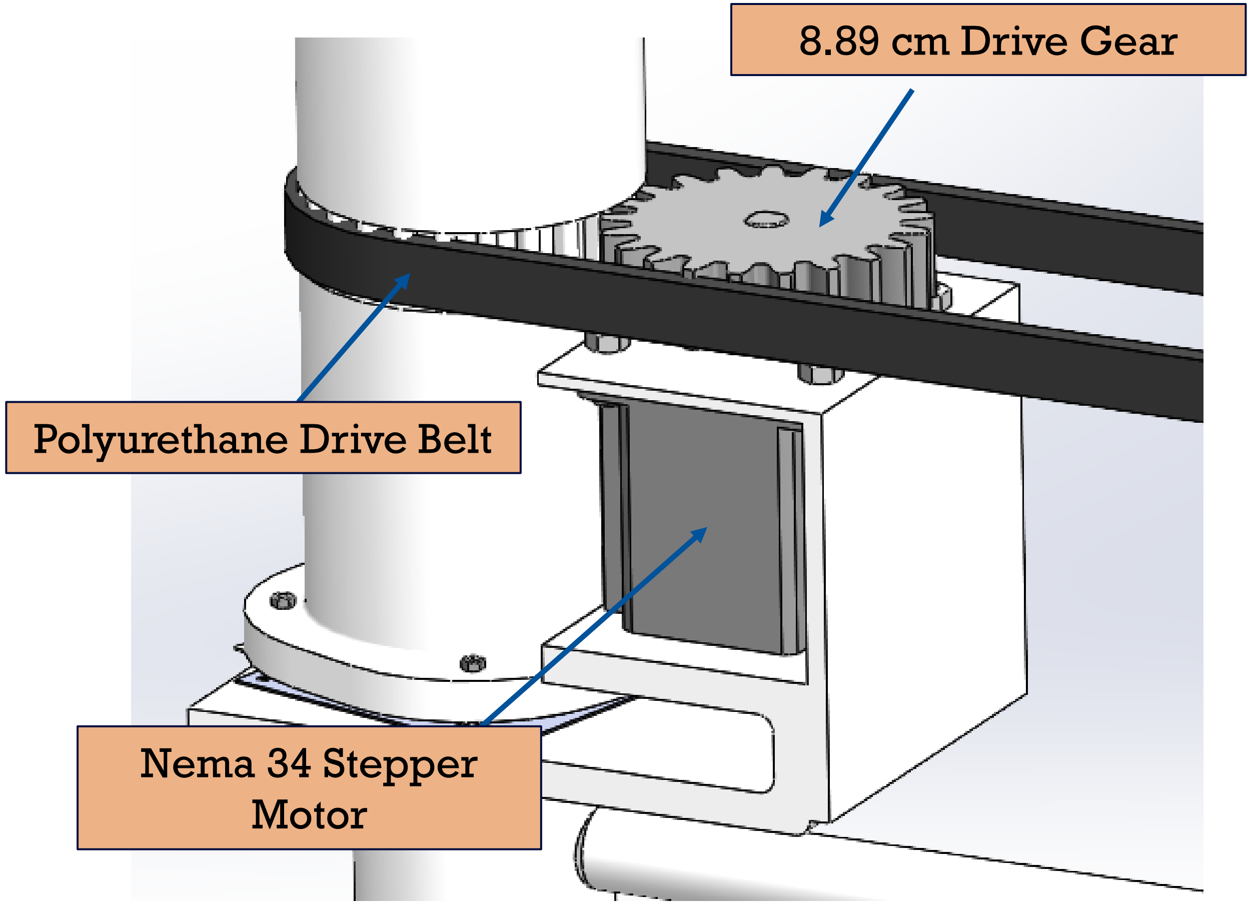
$$C_L = 2\pi \sin \alpha$$

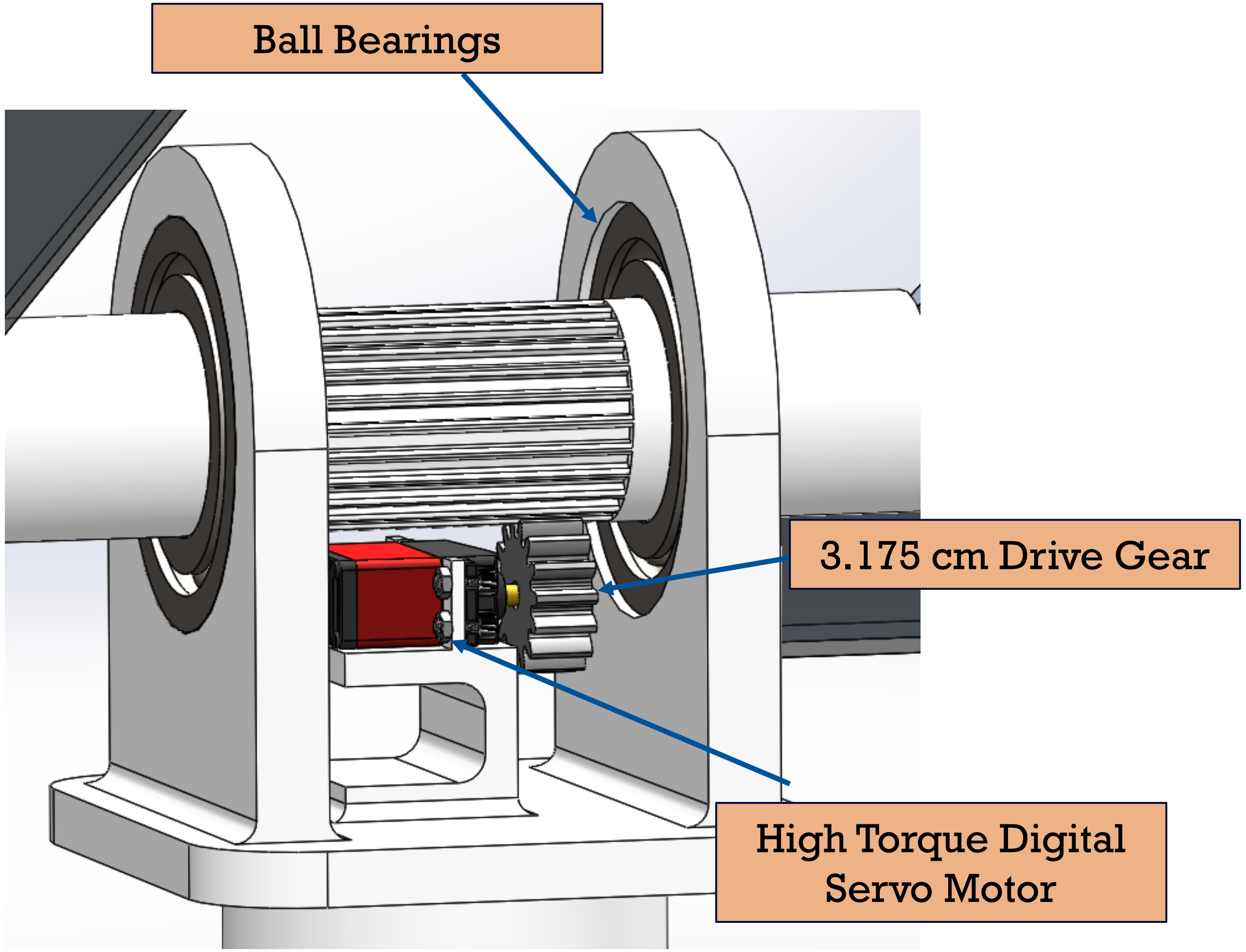


Actuation Subsystem

Need	Metric	Solution
4	Tracking Error ≤ 0.5°	Stepper motor drivers for precision
7	Receiver elevation ≤ 100 m	Range of motion >180°
8	Overall cost ≤ $100/m^2$	Low-cost servo motors
11	Relative part cost ≥ $0	OTS parts preferred
14	Operational lifetime ≥ 20 years	20+ years with maintenance

Actuation Design



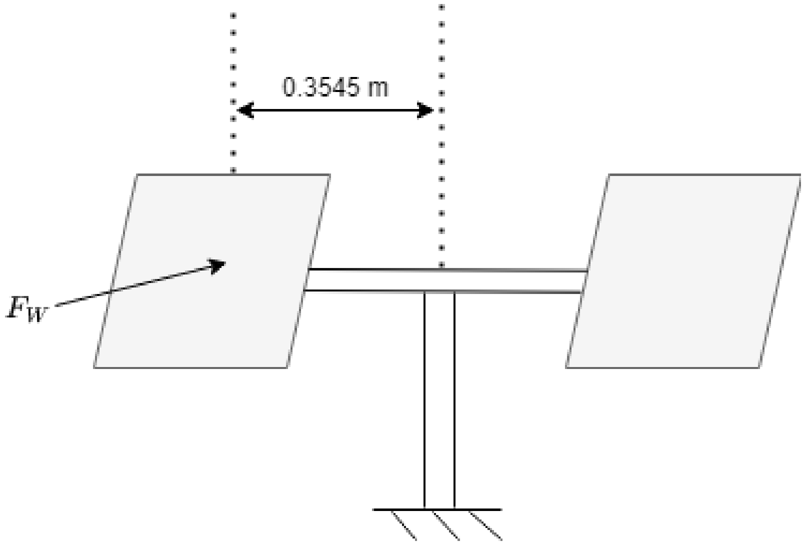


Actuation Subsystem Design Analyses

- Required torque for azimuthal axis

Wind force on each mirror:

$$F_w = \frac{1}{2}\rho v^2 A = \frac{1}{2}\left(1.2\,\frac{\text{kg}}{\text{m}^2}\right)\left(4.47\,\frac{\text{m}}{\text{s}}\right)^2 (0.25\ \text{m}^2) = 3.0\ \text{N}$$



Torque due to the wind:

$$T = F_w * r = 2(3\ \text{N})(0.3545\ \text{m}) = \boxed{2.125\ \text{N}\cdot\text{m}}$$

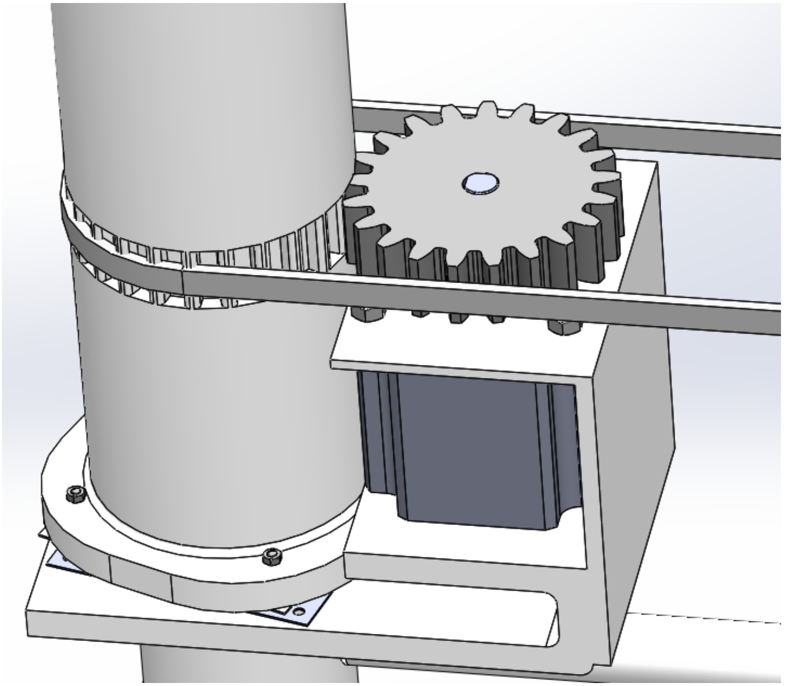
Actuation Subsystem Design Analyses

Motor Torque, $T_1 = 4.8\ \mathrm{N \cdot m}$

Available torque due to gear ratio:

$$\frac{d_1}{d_2} = \frac{T_1}{T_2}, \text{where } d_1 = 8.89\ \mathrm{cm};\ d_2 = 10.16\ \mathrm{cm}$$

$$T_2 = 5.486\ \mathrm{N \cdot m}$$



Actuation Subsystem Design Analyses

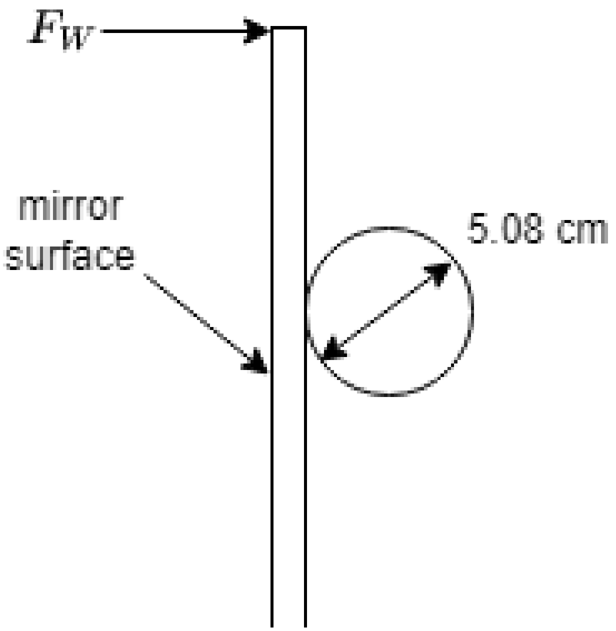
- Required torque for tilt axis (against wind force)

Wind force for average wind speed: $F_w = 2.997N$

Torque: $T = F_w r = (2.997\ \mathrm{N})(0.25\ \mathrm{m}) = 0.749\ \mathrm{N \cdot m}$

Torque produced by drive gears:

$$\frac{d_1}{d_2} = \frac{T_1}{T_2} \rightarrow \frac{3.175\ \mathrm{cm}}{5.08\ \mathrm{cm}} = \frac{1.96\ \mathrm{N \cdot m}}{T_2} \rightarrow \boxed{3.14\ \mathrm{N \cdot m}}$$



Actuation Subsystem Design Analyses

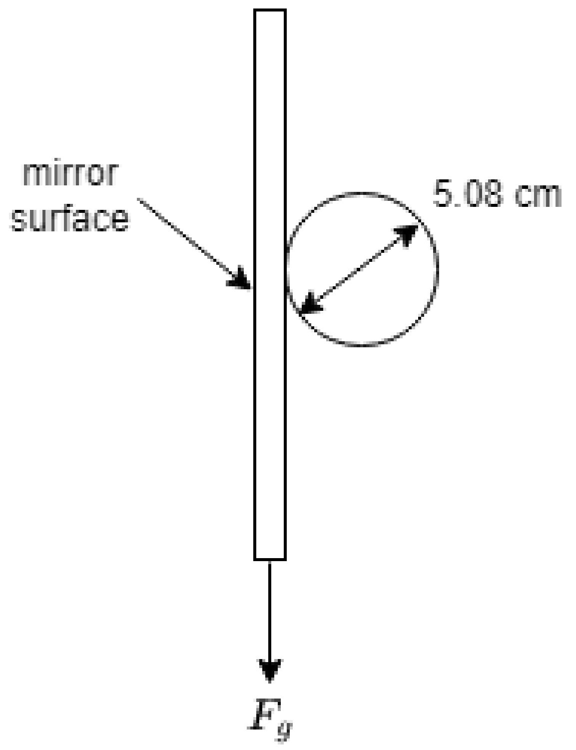
- Required torque for tilt axis (against gravity)

Weight of two mirrors: 6.95 kg $\rightarrow F_g = 68.18\ \text{N}$

Torque: $T = F_w r = (68.18\ \text{N})(0.0254\ \text{m}) = 1.73\ \text{N} \cdot \text{m}$

Torque produced by drive gears: $T_2 = 3.14\ \text{N} \cdot \text{m}$

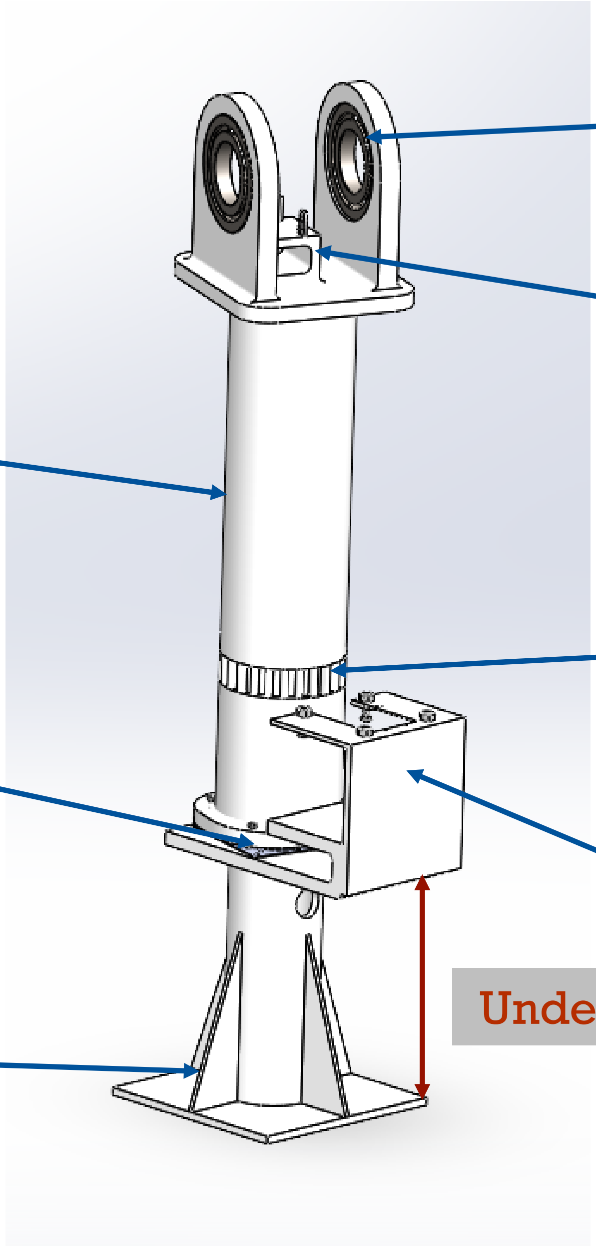
Motors can support load



Structure Subsystem

Need	Metric	Solution
3	$4 \leq$ No. Heliostats ≤ 16	4 reflective surfaces
6	No shading from other heliostats	Minimum spacing =1.07 m
8	Overall cost $\leq \$100/m^2$	Hollow PVC tubing
10	Total area ratio ≈ 1	Proportional structure
13	Factor of safety = 2	Set standard for analysis
14	Operational lifetime $\geq$ 20 years	20+ years with maintenance

Structure Design



Subsystem Design Analyses

- Structure - Bending stress on the poles

Typical wind force on each mirror:

$$F_w = \frac{1}{2}\rho v^2 A = \frac{1}{2}(1.2\ \mathrm{kg/m^2})(4.47\ \mathrm{m/s})^2(0.25\ \mathrm{m^2}) = \boxed{3.0\ \mathrm{N}}$$

Bending moment (per pole):

$$M = Fa = (6\ \mathrm{N})(0.446\ \mathrm{m}) = \boxed{2.67\ \mathrm{N \cdot m}}$$

Structure Subsystem Design Analyses

Second moment of area:

$$I = \frac{\pi}{4}(r_2^4 - r_1^4) = \frac{\pi}{4}[(50.8\text{ mm})^4 - (38.1\text{ mm})^4] = 3.58\text{x}10^{-6}\ m^4$$

Bending stress: $\sigma = \frac{My}{I} = \frac{(2.67\text{ N}\cdot\text{m})(0.0508\text{ m})}{3.58\times10^{-6}\text{ m}^4} = 37.8\text{ KPa}$

Maximum bending stress at 90 mph: $\sigma = 3.07\text{ MPa}$

Yield strength of PVC: 51.7 MPa

Structure Subsystem Design Analyses

- Torsional shear stress due to wind

$$\tau = \frac{Tc}{J}, where\ J = \frac{\pi({d_o}^4 - {d_i}^4)}{64}$$

$$\tau = \frac{(2.127\ \mathrm{N \cdot m})(0.0508\ \mathrm{m})}{\frac{\pi(0.1016^4 - 0.0762^4)}{64}\mathrm{m}^4} = \boxed{30.35\ \mathrm{KPa}}$$

Shear strength of PVC: 5 MPa

Structure Subsystem Design Analyses

- Maximum deflection at wind speed of 90 mph

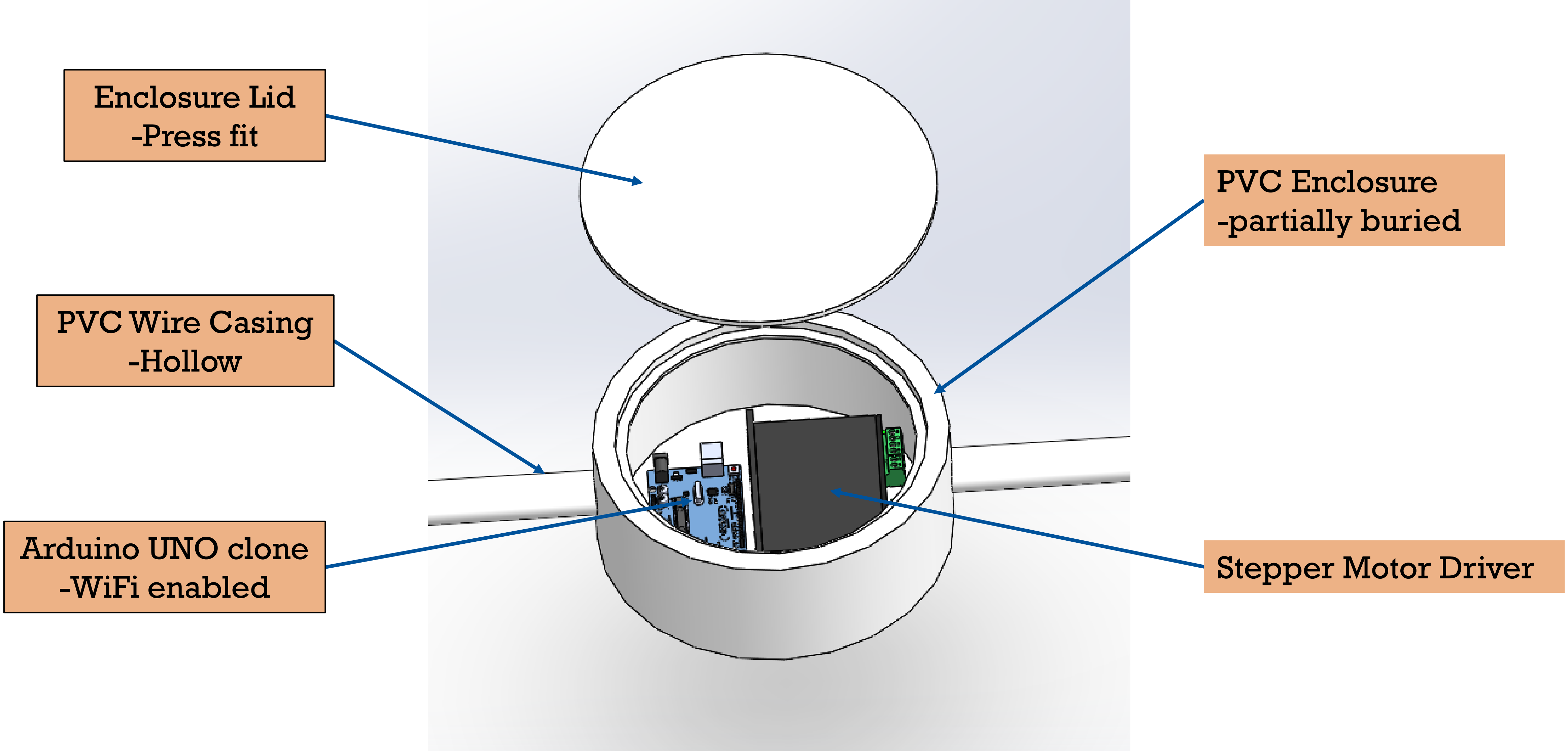
$$\delta = \frac{FL^3}{3EI}$$

$$\delta = \frac{(480\ \mathrm{N})(0.4445\mathrm{m})^3}{3(2.8x10^9\mathrm{m})(3.58x10^{-6}\mathrm{m}^4)} = \boxed{1.403\ \mathrm{mm}}$$

Controller Subsystem

Need	Metric	Solution
5	Minimum refresh rate = 13.9 Hz	1 kHz refresh rate
8	Overall cost ≤ $100/m^2$	Comparable Arduino UNO clone
9	Automated and computer controlled	WiFi capabilities
14	Operational lifetime ≥ 20 years	20+ years with maintenance

Controller Design



Controller Subsystem Design Analyses

Controller & Driver – Heat Load (H) in Enclosure

$$h_{in} = \frac{P}{10} = \frac{194\ W}{10} = 19.4W$$

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$$\Delta T = T_{max\ in\ Vegas} - T_{target} = 46 - 40 = 6^{\circ}C.$$

This temperature difference correlates to a constant in W/ m^2 $(Table\ 1)$.

$$H = (SA_{box} * 11.3\ W/m^2) + h_{in} = (0.055918\ m^2 * 11.3) + 0.14 = 0.771873\ W$$

Temperature Difference in Deg F	BTU/hr./sq. ft.	Temperature Difference in Deg C	Watts/sq.m
5	1.5	3	5.2
10	3.3	6	11.3
15	5.1	9	17.6
20	7.1	12	24.4

Controller Subsystem Design Analyses

- Max Enclosure Operating Temperature

$$\dot{q}_{control} = 19.4\ W$$

$$\dot{q}_{sun} = 32.45\ W$$

$$L = 0.00397\ m^2$$

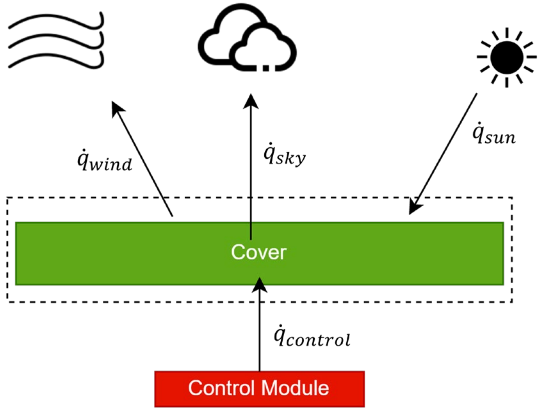
$$A = 0.0324\ m^2$$

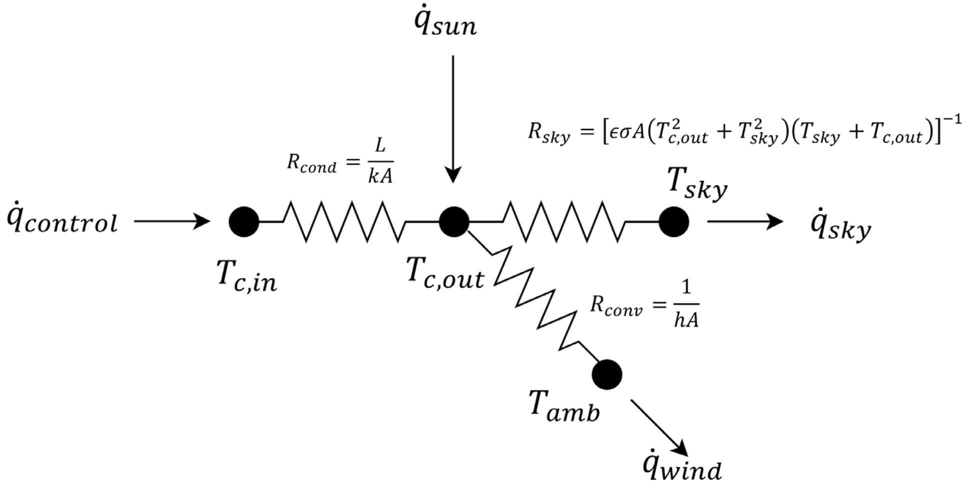
$$h = h_{wind} = 18.02\frac{W}{m^2K}$$

$$k = k_{cover} = 0.2\frac{W}{mK}$$

$$T_{amb} = 320.37\ K$$

$$T_{sky} = 318.10\ K$$





$$\sum \dot{q} = \dot{q}_{sun} + \dot{q}_{control} - \dot{q}_{sky} - \dot{q}_{wind} = 0$$

$$\dot{q}_{sky} = \frac{T_{c,out} - T_{sky}}{R_{sky}}$$

$$\dot{q}_{wind} = \frac{T_{c,out} - T_{amb}}{R_{conv}}$$

$$T_{c,out} = 379.23\ K$$

$$\dot{q}_{control} = \frac{T_{c,in} - T_{c,out}}{R_{cond}}$$

$$T_{c,in} = 391.06\ K = 117.91℃$$

Cost Breakdown

Expense	Prototype Cost	Mass Production Cost
OTS Parts	$139.97	$97.98
Raw Materials	$52.35	$36.65
Manufacturing	$19.26	$16.05
Assembly Labor	$4.20	$4.20
Energy Consumption	$0.67	$0.67
TOTAL:	$216.45	$155.55

Full-scale plant production is expected to result in a 30% cost savings for bulk purchases.

Summary

Thank you for your interest in HelioSmart

WE STRIVE TO MEET EVERY CUSTOMER NEED TO THE BEST OF OUR ABILITY.

WE PROVIDE A COMPACT, INNOVATIVE MULTI-UNIT MODULE DESIGN.

UTILIZES EFFECTIVE COST REDUCTION TECHNIQUES WHILE PROVIDING EFFECTIVE OPTICAL EFFICIENCY AND TRACKING ACCURACY.

PLEASE CONTACT US WITH ANY ADDITIONAL QUESTIONS OR CONCERNS.