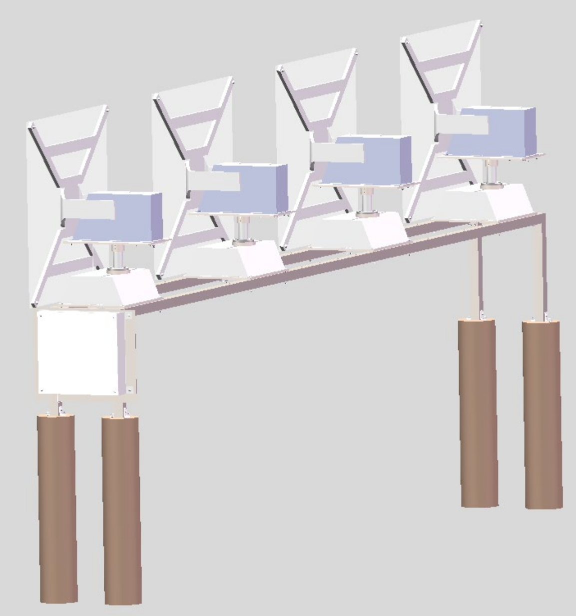
Herbert Wertheim College of Engineering
UNIVERSITY of FLORIDA

SOLR

Self Orienting Light Reflector



Section 27096, Group 11

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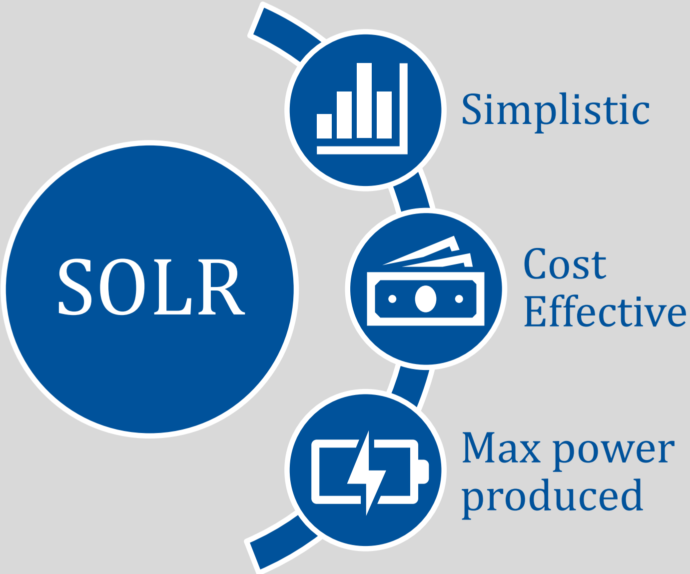
POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE

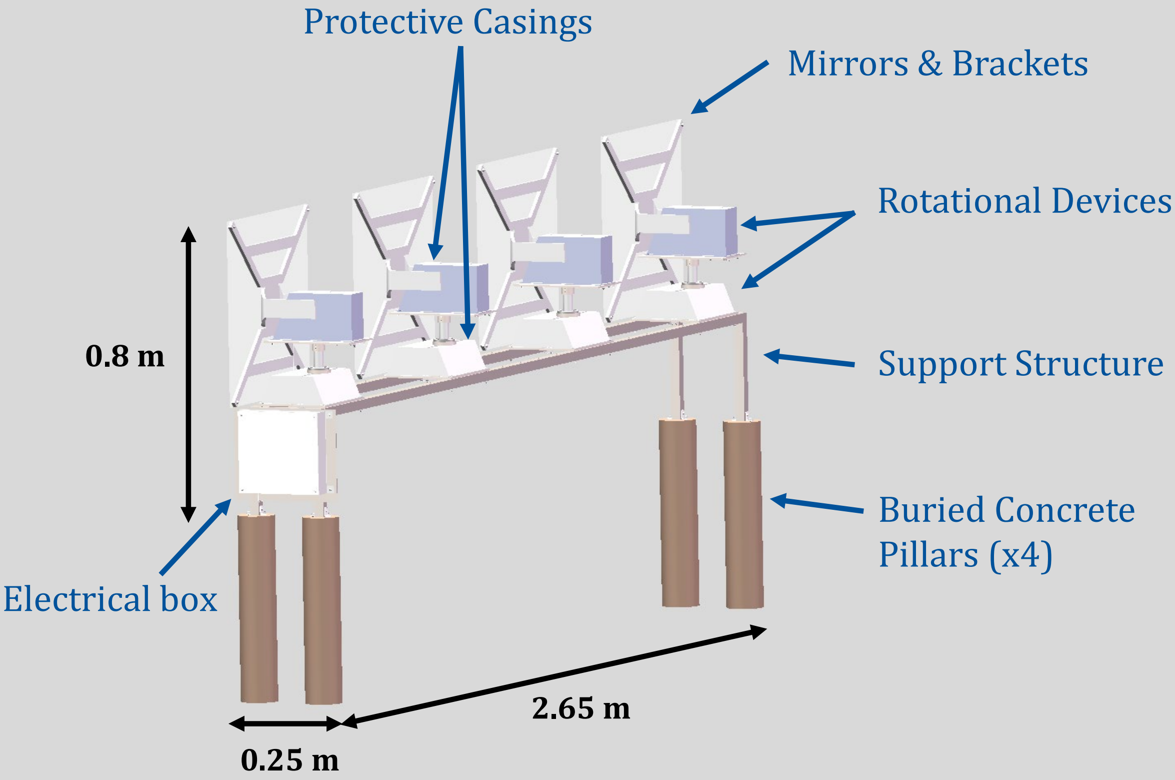
Team Motivation

Our team's passion, greatest skills, and financial drive guided us towards a design:



Overview of SOLR

- **Elevated, strong, secure, steel frame**
- **Four independent, identical heliostats**
- **Single, all-encompassing electrical box**
- **Precise elevation and azimuth tracking**
- **Ease of modularity (repairs/replacements)**



Protective Casings (x8)

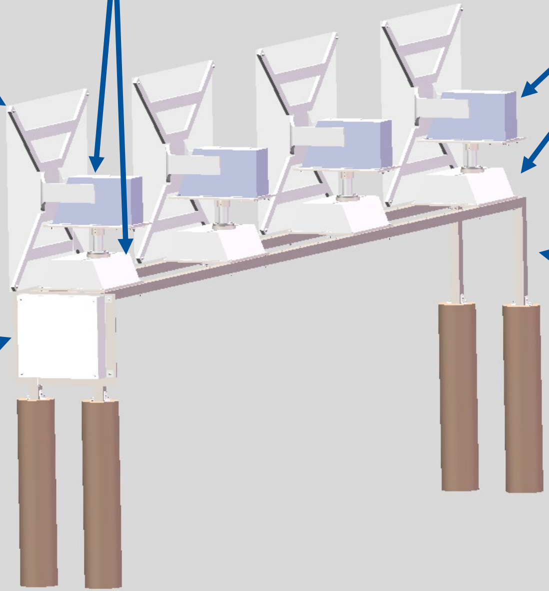
- Vacuum molded ABS plastic
- Seals off from environment for longer lifespan

Rotational Devices (x8)

- Worm gear driven by stepper motor
- Lower = azimuth
- Upper = elevation

Mirrors and Brackets (x4)

- Square plexiglass
- Solar reflective foil
- Area = 0.25 m^2



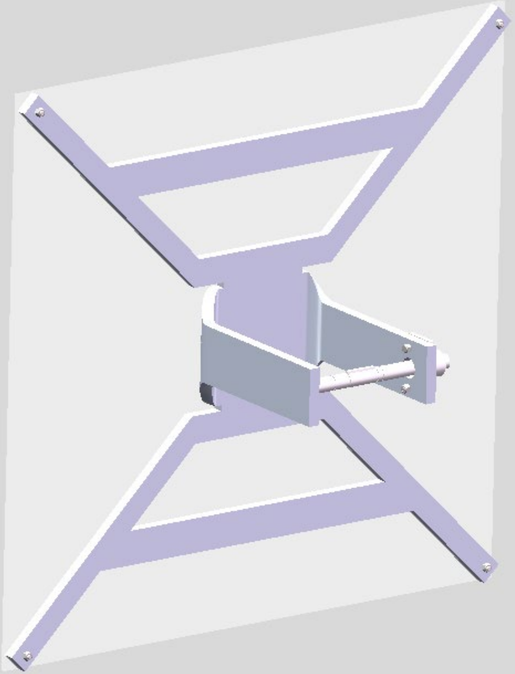
Support Structure

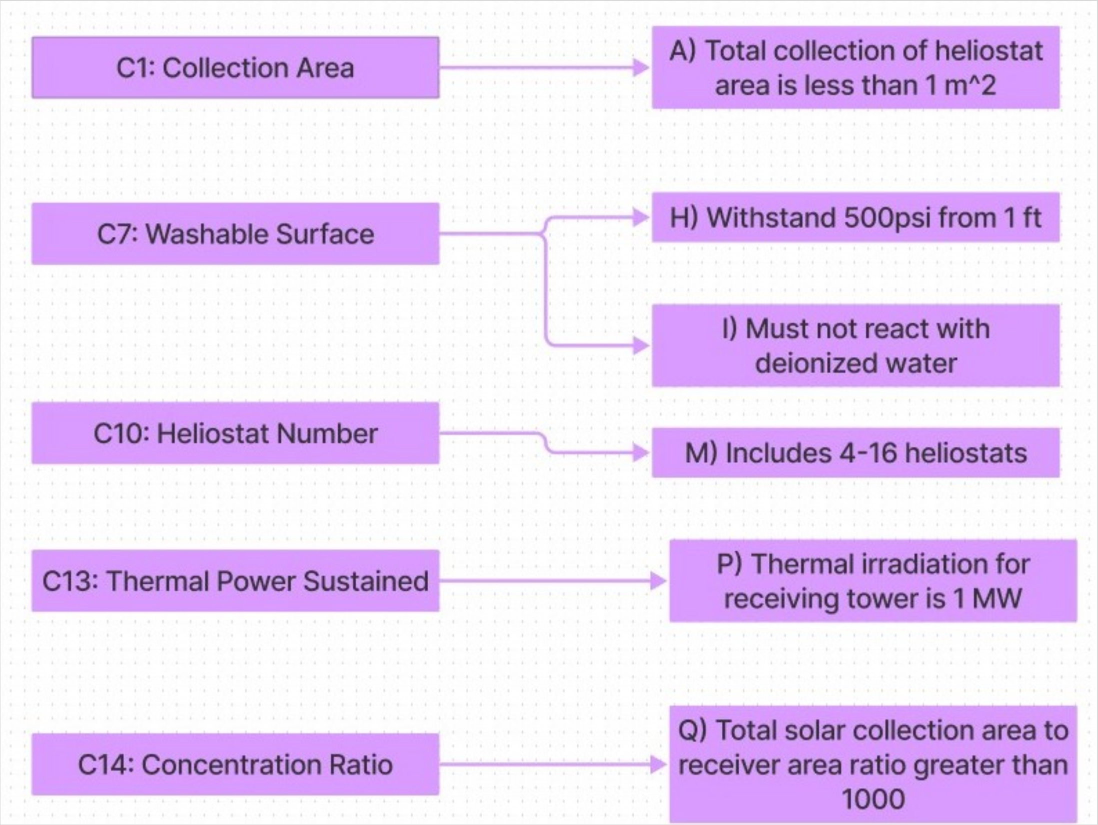
- Welded Steel frame
- Secured to ground via concrete anchors
- Heliostat baseplates bolted to frame

Electrical Box

- One Raspberry Pi
- 8 motor controllers

Mirror



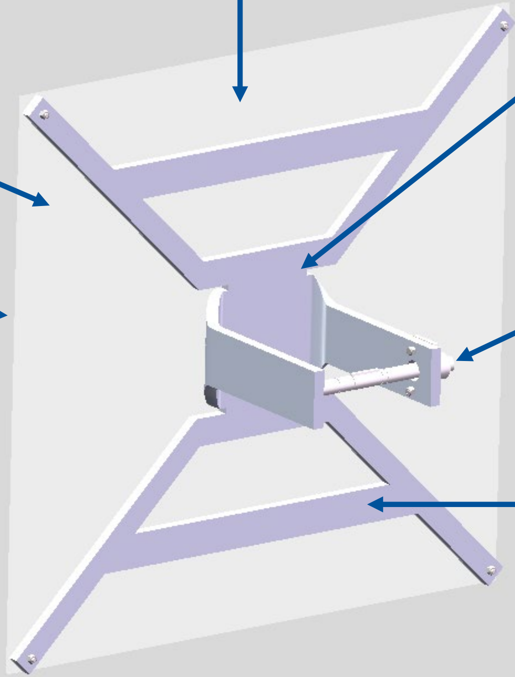

C1: Collection Area
A) Total collection of heliostat area is less than 1 m^2
C7: Washable Surface
H) Withstand 500psi from 1 ft
I) Must not react with deionized water
C10: Heliostat Number
M) Includes 4-16 heliostats
C13: Thermal Power Sustained
P) Thermal irradiation for receiving tower is 1 MW
C14: Concentration Ratio
Q) Total solar collection area to receiver area ratio greater than 1000

Surface Area = 0.25 m^2

Solar Reflex Foil
- Irradiation: 1094.19 W
- 95% Reflective

E6000 Adhesive
Working Temp. -40 to 180°F

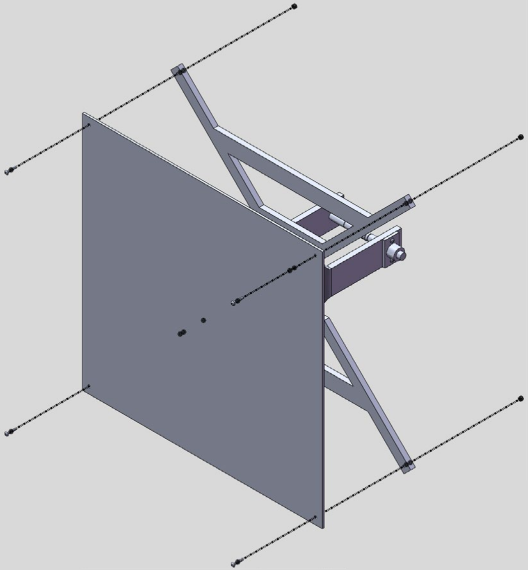
Plexiglass
- Strength = 20.39 MPa
- Moh's Hardness: 3.5<H<4
- Heat expansion $4.1x10^{-5}\frac{in°F}{in}$

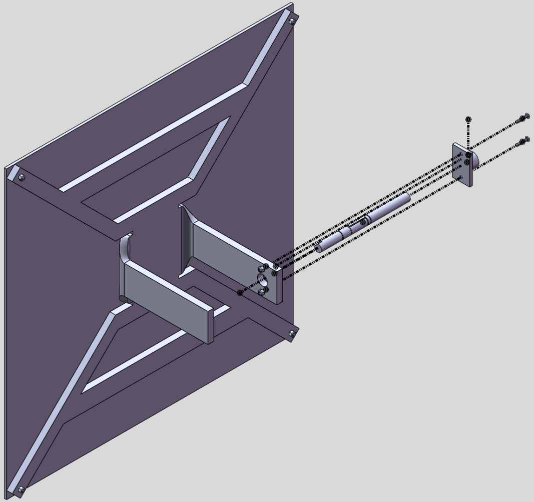


ABS Plastic
- Heat expansion $4.1x10^{-5}\frac{in°F}{in}$
- Max working temp $= 220°F$

Rotational Lock Shaft
- Easy insert shaft with lock by set screw and collar

X Bracket Design
- Structural integrity
- 4 anchor points
- lightweight





Thermal Irradiance on the central tower from 1 module

$$P = \phi A \eta_f (\eta_p)^2 = \left(\frac{1360.8\ W}{m^2}\right)(1\ m^2)(0.95)(0.92)^2$$

$$P = 1094.19\ W$$

Strength using fracture toughness

$$\sigma = \frac{K_{IC}}{\beta\sqrt{\pi a}} = \frac{1.15\ MPa\sqrt{m}}{1.5\sqrt{\pi 450\ nm}}$$

$$\sigma = 20.39\ MPa$$

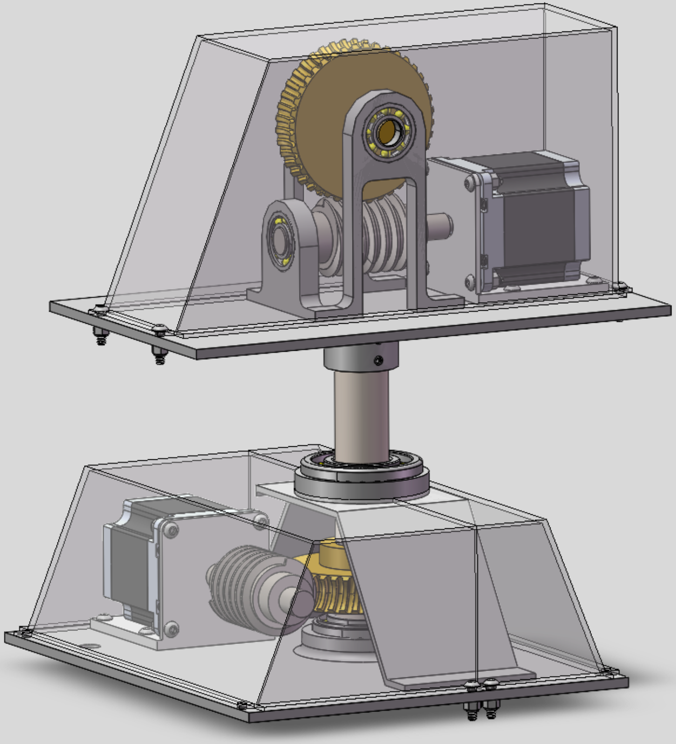
Brinell Hardness of acrylic: Between 3.5 and 4

Weight of Acrylic

$$W = \rho V g = \left(1180\ \frac{kg}{m^3}\right)(0.25\ m^2 * 0.004\ m)\left(9.81\frac{m}{s^2}\right)$$

$$W = 11.58\ N$$

Rotational Device

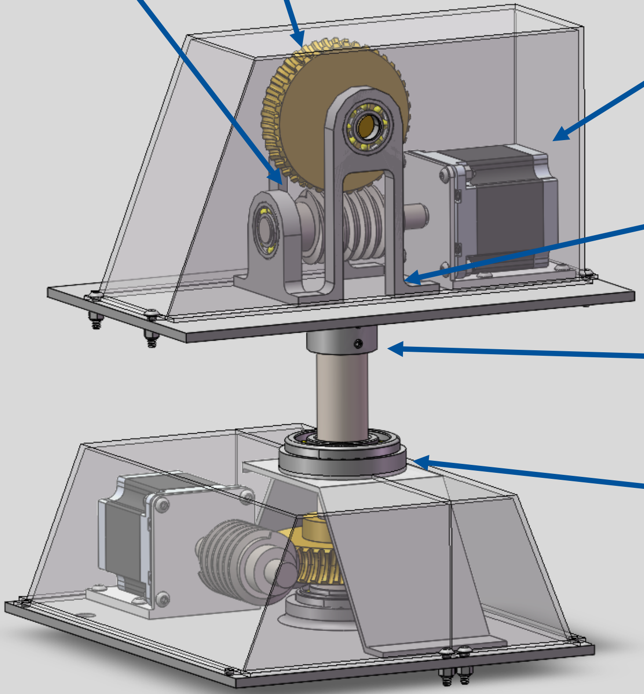


Brass Worm Wheel

Steel Worm Shaft

Elevation Tracking Device

Azimuth Tracking Device



NEMA Stepper Motor
- 360° azimuth rotation
- 180° elevation rotation

Welded Supports
- Long lasting strength

Welded Collar
- Easy on-site assembly

Bearings and Snap-Ring
- Rotational and distance lock

Tracking Accuracy of Rotational Drive with 1/4th Micro-stepping

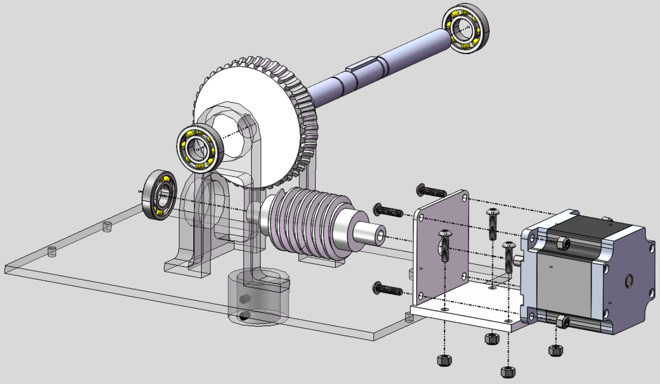
$$Motor\ Resolution = \frac{200\frac{steps}{rev}}{{}^{1}/_{4}\frac{microsteps}{step}} = 800\frac{steps}{rev}$$

$$Output\ Resolution = Motor\ Resolution * Worm\ Drive\ Ratio$$

$$Output\ Resolution = 800\frac{steps}{rev} * \left(\frac{40}{1}\right) = 32000\frac{steps}{rev}$$

$$Tracking\ Accuracy = \frac{360\frac{degrees}{rev}}{32000\frac{steps}{rev}}$$

$$Tracking\ Accuracy = 0.0225°\ per\ step$$



Efficiency of Worm Gear Drive

$$\eta = \frac{W^t(without\ friction)}{W^t(with\ friction)}$$

$$\eta = \frac{cos\phi sin\lambda}{f cos\lambda + cos\phi sin\lambda} * 100$$

$$\eta = \frac{cos14.5° sin17.1°}{0.1 cos17.1° + cos14.5° sin17.1°} * 100$$

$$\eta = 75\%$$

Worm Gear Design Factor of Safety

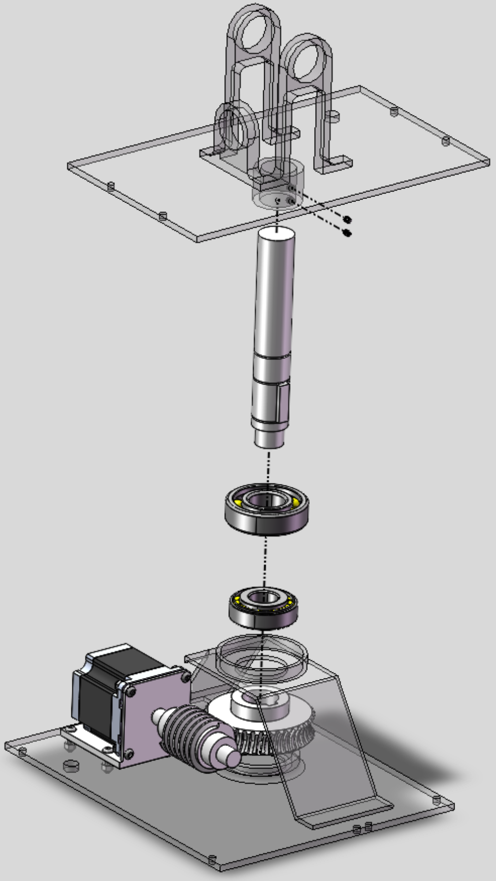
$$\sigma_{allow} = \frac{W^t}{F\left({}^{d}/_{N}\right)Y}$$

$$\sigma_{allow} = \frac{0.2805}{(0.0018)\left(\frac{72.2}{40}\right)(0.336)}$$

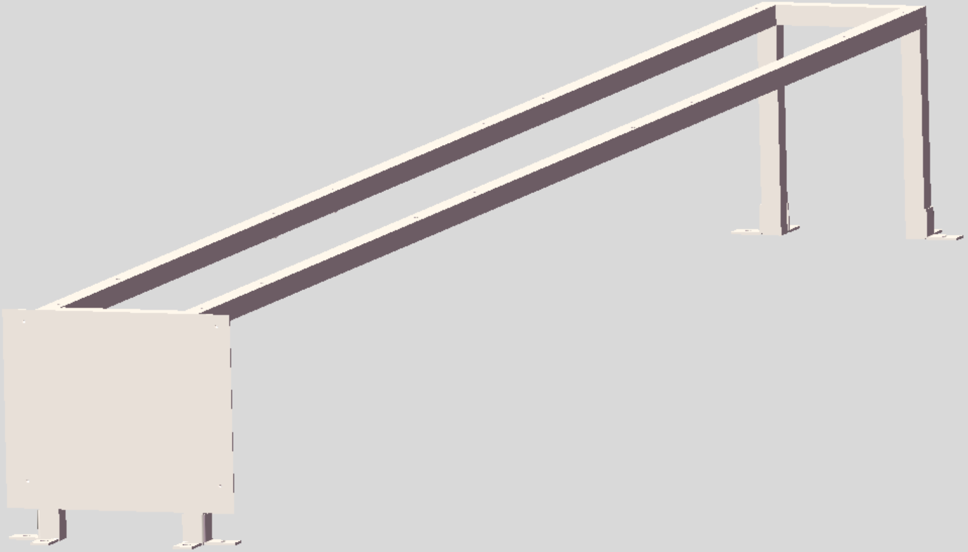
$$\sigma_{allow} = 256.94MPa$$

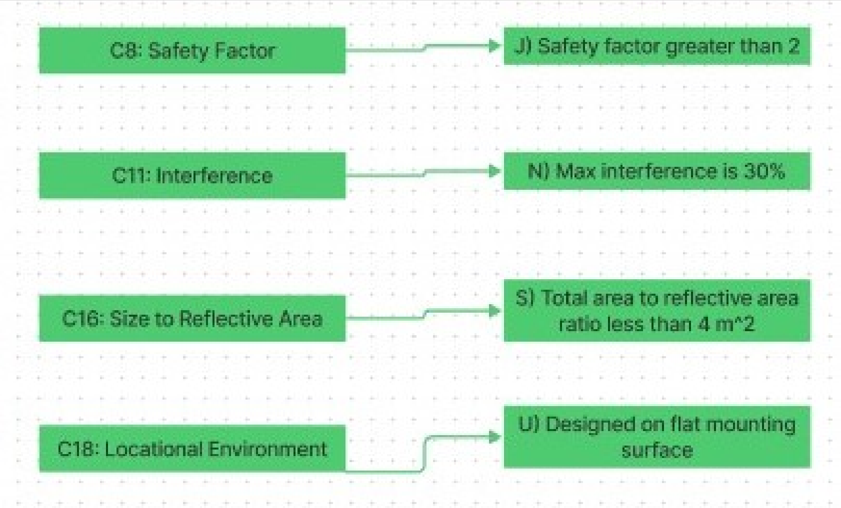
$$\eta_d = \frac{350MPa}{256.94MPa}$$

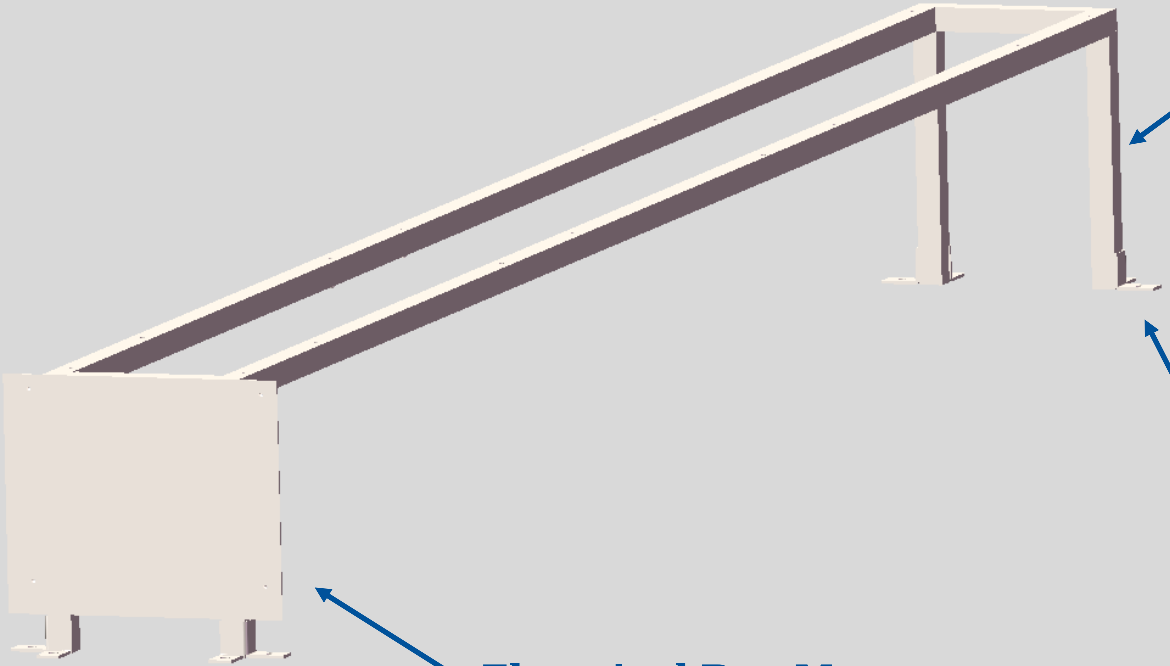
$$\eta_d = 1.36$$



Modular Support Structure







Welded Steel Frame

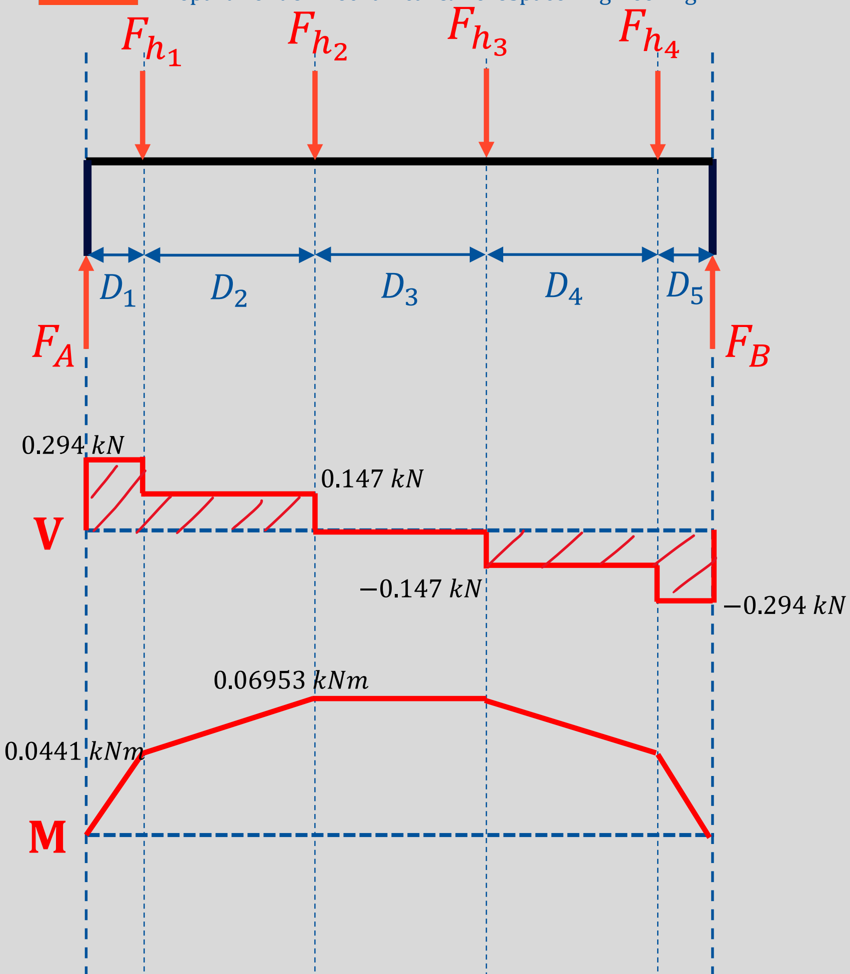
- Moderate cost
- High strength
- Ease of manufacture
- Ease of on-site assembly

Concrete Wedge Anchors

- Ease of on-site assembly
- Secure anchoring under loads

Electrical Box Mount

- Easy access for maintenance
- Low cost
- Secures electrical box and components



Each heliostat module is approximately 33 lbs.

$$F_{h_1} = F_{h_2} = F_{h_3} = F_{h_4} = 33\ lbs \sim .147\ kN$$

Summing the forces and solving for the reaction forces yields,

$$\Sigma F_y = 0 = F_A - F_{h_1} - F_{h_2} - F_{h_3} - F_{h_4} + F_B$$

$$F_A = F_B = 0.294\ kN$$

Therefore, the maximum shear force experienced is approximately 0.3 kN.

$$D_1 = D_5 = 0.15\ m\ \ \&\ \ D_2 = D_3 = D_4 = 0.79$$

Normal stress, $\sigma_A = \frac{My}{I}$

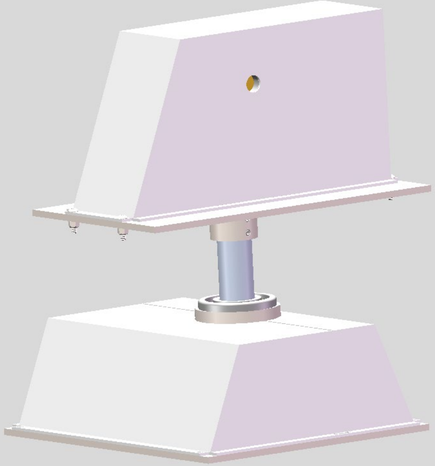
$$M = 0.07\ kNm$$

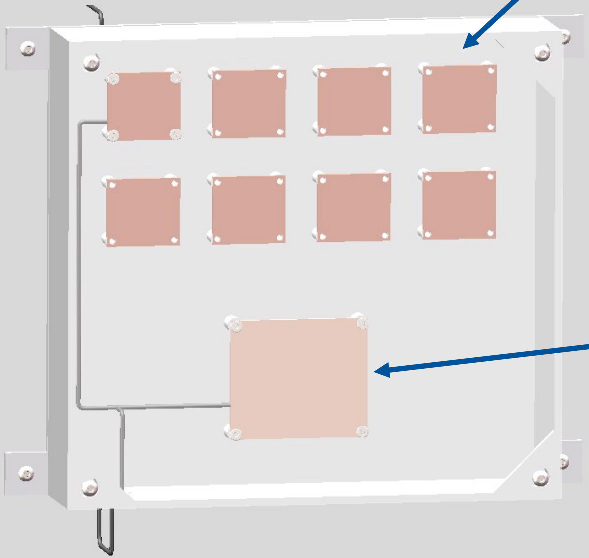
The resulting stress on the frame is <u>60 MPa.</u>

$$60\ MPa \ll 80\ GPa$$

Electronics

Limit Switches for motor location





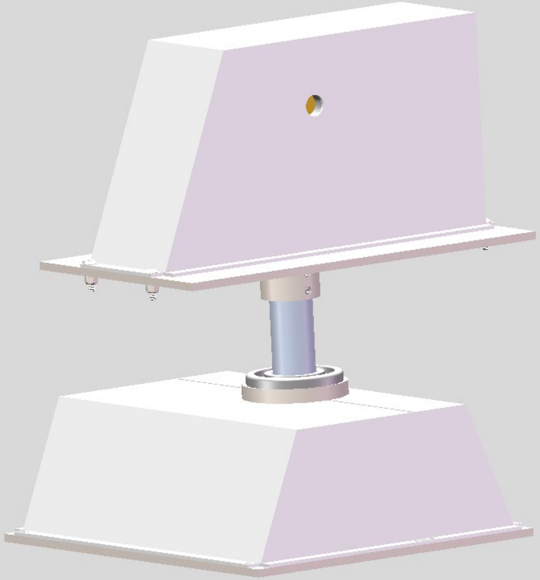
Motor Drivers (x8)

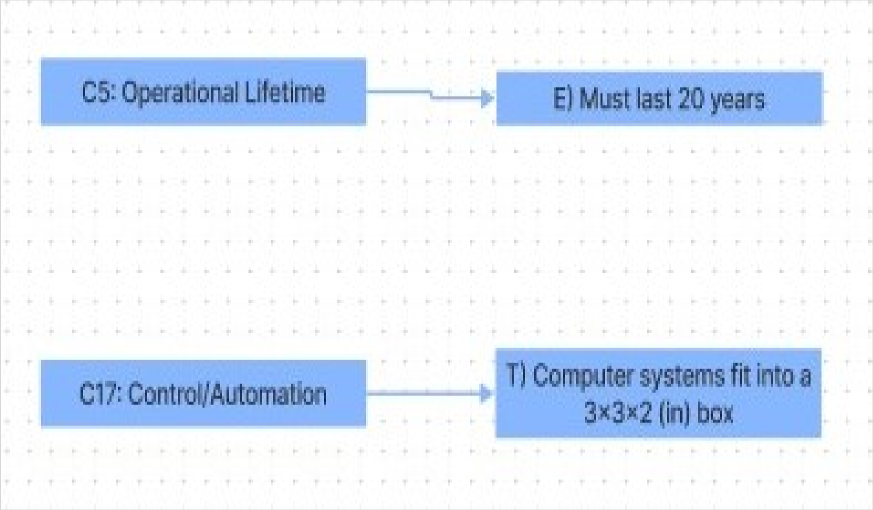
- ULN2003 – stepper motor driver
- Built in controller
- Converts pulse signals to motor motion to achieve precise positioning

Espressif ESP8266

- Cost effective
- 2.4 GHz WiFi
- Bluetooth 4.3
- 5V DC power

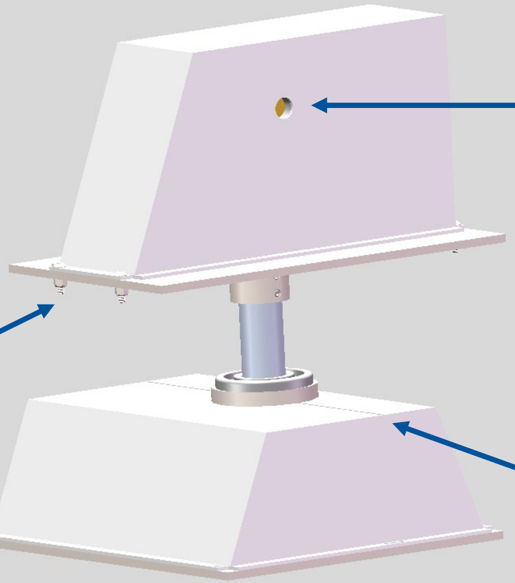
Protective Casing





Angled casings

- ABS plastic
- Max working temp = $220°F$
- UV resistant pigment
- 35+ year lifetime

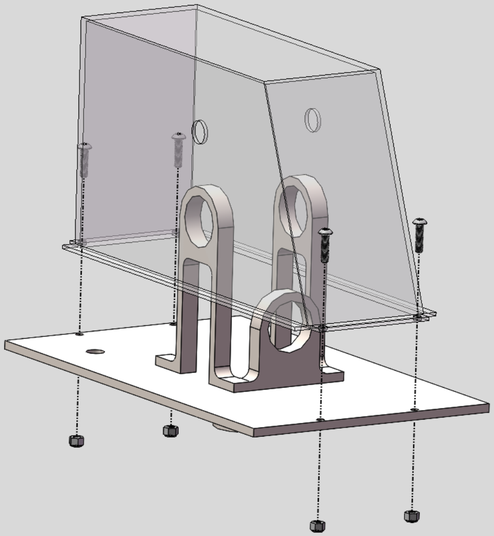


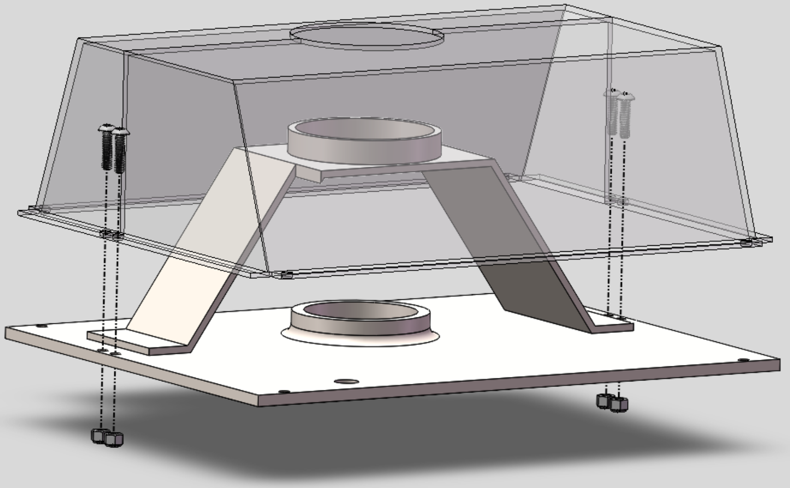
Top casing slides over top and has holes for the mirror bracket to mount to

Standard bolt fastening

- M4 x 0.7 mm

Bottom casing splits in half for easy access to the motor and gear systems





Heat Transfer Calculations for motors

- The maximum surrounding temperature to ensure the motor remains functional is 212°F
- The hottest recorded temperature ever in the United States was recorded to be 134°F

$$-q_s = h(T - T_0)$$
$$-q_s = 0.175(212°\text{F} - 134°\text{F})$$
$$-q_s = 13.65\ W/m^2$$

$$q_s = hA(\Delta T)$$
$$-13.65\ W/m^2 = (0.175)(0.0431\ m^2)(\Delta T)$$
$$\Delta T = 18.11\ °\text{F}$$

- The change in temperature inside the protective structure would meet the motor standards

High Wind Safety Mode

- Holding Torque
  - $H_T = MotorH_T * G_R = 1.26\ Nm * 40 = 50.4\ Nm$
- Lift on flat plate @ 90 mph
  - $C_L = 2\pi \sin\alpha = 2\pi \sin 12 = 1.31$
  - $F_D = \frac{1}{2}\rho v^2 C_D A$
  - $T = d * F_D = 0.125m * \frac{1}{2} * \frac{1.225kg}{m^3} * \left(\frac{40.23m}{s}\right)^2 * 1.31 * 0.25m^2 = 40.47\ Nm$

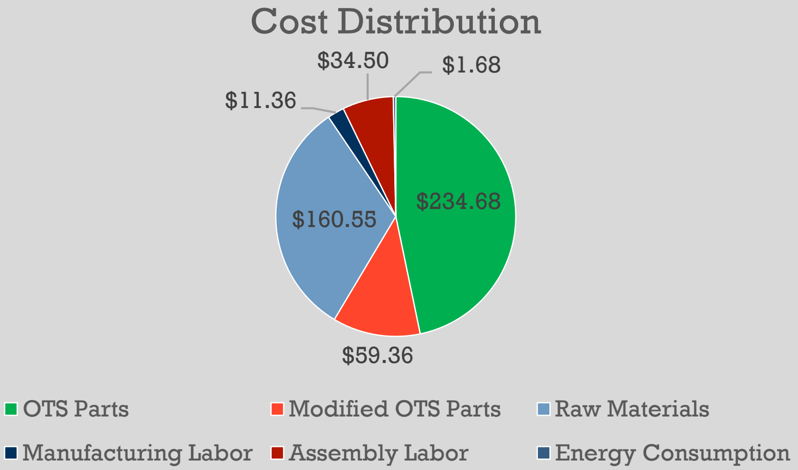
$$40.47\ Nm < 50.4\ \text{Nm}$$

Cost of SOLR

Manufacturing Labor				
Subsystem	Discription	Cost	Quantity	Total
Mirror	Making Mirror	$ 12.00	0.02	$ 0.20
Mirror	Coating the Mirror	$ 12.00	0.04	$ 0.48
Mirror	Making Bracket	$ 12.00	0.02	$ 0.24
Rotational Device	Cutting Stock	$ 12.00	0.1	$ 1.20
Rotational Device	Modifiying Gears	$ 12.00	0.1	$ 1.20
Rotational Device	Making Platforms	$ 12.00	0.02	$ 0.24
Rotational Device	Printing Motor Mount	$ 12.00	0.07	$ 0.80
Protective Structure	Vacume Cover	$ 12.00	0.17	$ 2.00
Module Support Structure	Welding Frame	$ 20.00	0.25	$ 5.00
Total				$ 11.36

Assembly Labor				
Subsystem	Discription	Cost	Quantity	Total
Mirror	Attach to Bracket	$ 15.00	0.2	$ 3.00
Rotational Device	Assemble	$ 15.00	1	$ 15.00
Protective Structure	Bolts	$ 15.00	0.1	$ 1.50
Module Support Structure	Attach Heilostats, set frame	$ 15.00	1	$ 15.00
Total				$ 34.50

Energy Consumption				
Subsystem	Discription	Cost	Quantity	Total
Fuel Charge		$ 0.04	2.5	$ 0.10
Non-Fuel Charge		$ 0.02	5	$ 0.08
Demand Charge		$ 5.00	0.3	$ 1.50
Total				$ 1.68

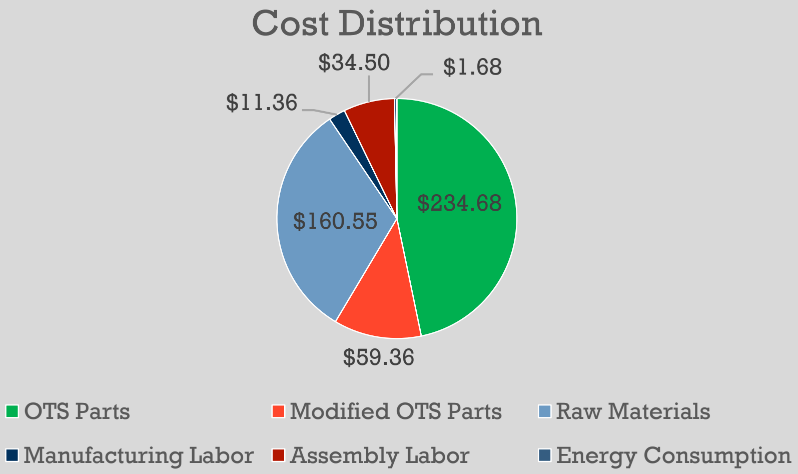


Cost of SOLR (cont.)

OTS Parts				
Subsystem	Discription	Cost	Quantity	Total
Rotational Device	Motors	$ 14.24	8	$ 113.92
Rotational Device	Spur Gear	$ 4.78	8	$ 38.24
Rotational Device	Bearings	$ 1.39	16	$ 22.24
Rotational Device	Rasberry Pi	$ 25.00	1	$ 25.00
Rotational Device	Motor Driver	$ 16.08	1	$ 16.08
All	Nuts and Bolts	$ 0.05	300	$ 15.00
Rotational Device	Snap Rings	$ 0.15	28	$ 4.20
Total				$ 234.68

Modified OTS Parts				
Subsystem	Discription	Cost	Quantity	Total
Rotational Device	Worm Gear	$ 7.42	8	$ 59.36
Total				$ 59.36

Raw Materials				
Subsystem	Discription	Cost	Quantity	Total
Mirror	ABS Plastic	$ 5.21	4	$ 20.84
Mirror	Mirror Bracket	$ 4.21	4	$ 16.84
Rotational Device	Round Stock	$ 3.30	4	$ 13.20
Rotational Device	Motor Platforms (steel)	$ 4.68	8	$ 37.44
Rotational Device	3-D Filiment	$ 31.49	0.2	$ 6.30
Protective Structure	ABS Plastic	$ 2.13	8	$ 17.04
Protective Structure	PVC for Casing	$ 2.40	1	$ 2.40
Module Support Structure	Steel Stock	$ 1.65	23	$ 37.95
Module Support Structure	Weld Stick	$ 0.002	52	$ 0.10
Module Support Structure	Concrete	$ 4.22	2	$ 8.44
Total				$ 160.55



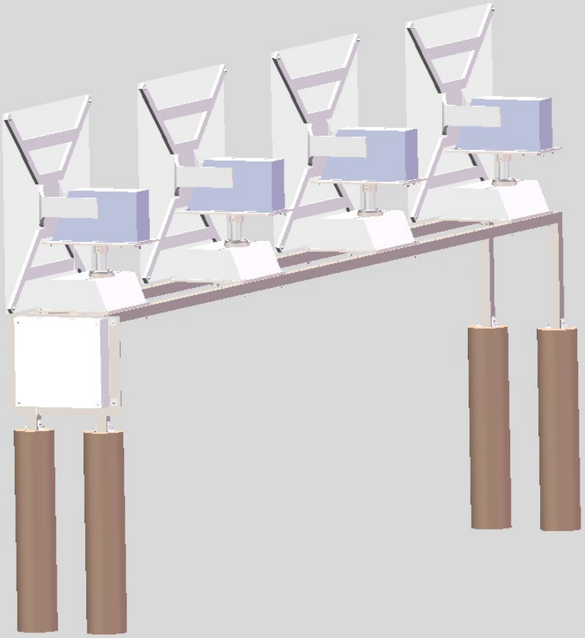
Summary of design

Modularity

- Ease of manufacture
- Ease of assembly
- Ease of access to parts for repair/replacement
- 4 identical heliostats on each module

Zero interference

- Heliostats in line, with same rotation



Lifetime (>20 years)

- Durable parts
- Safety modes
  - High wind
  - Electrical/mechanical failure

Quick Assembly

- Same screw heads used throughout
- Screws are easily accessed
- Limited on-site equipment necessary

Questions?