Herbert Wertheim College of Engineering
UNIVERSITY of FLORIDA

Compact Tilted Heliostat

ARX Thermal

Section 13335, Group 3

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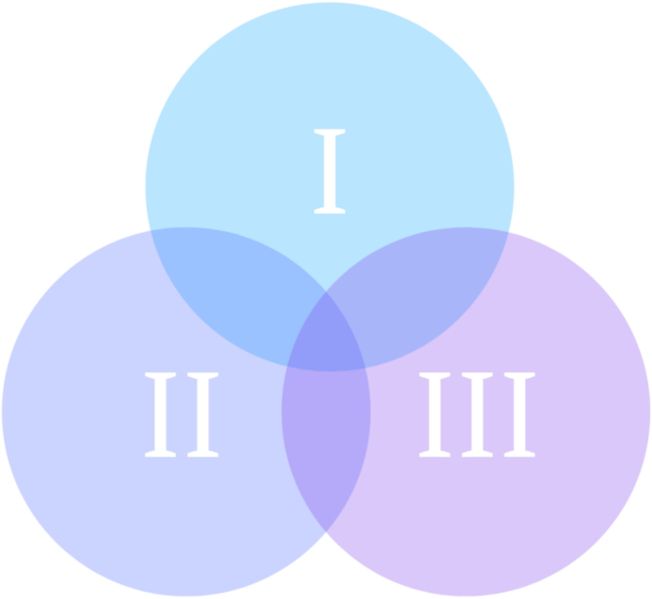
Product Motivations

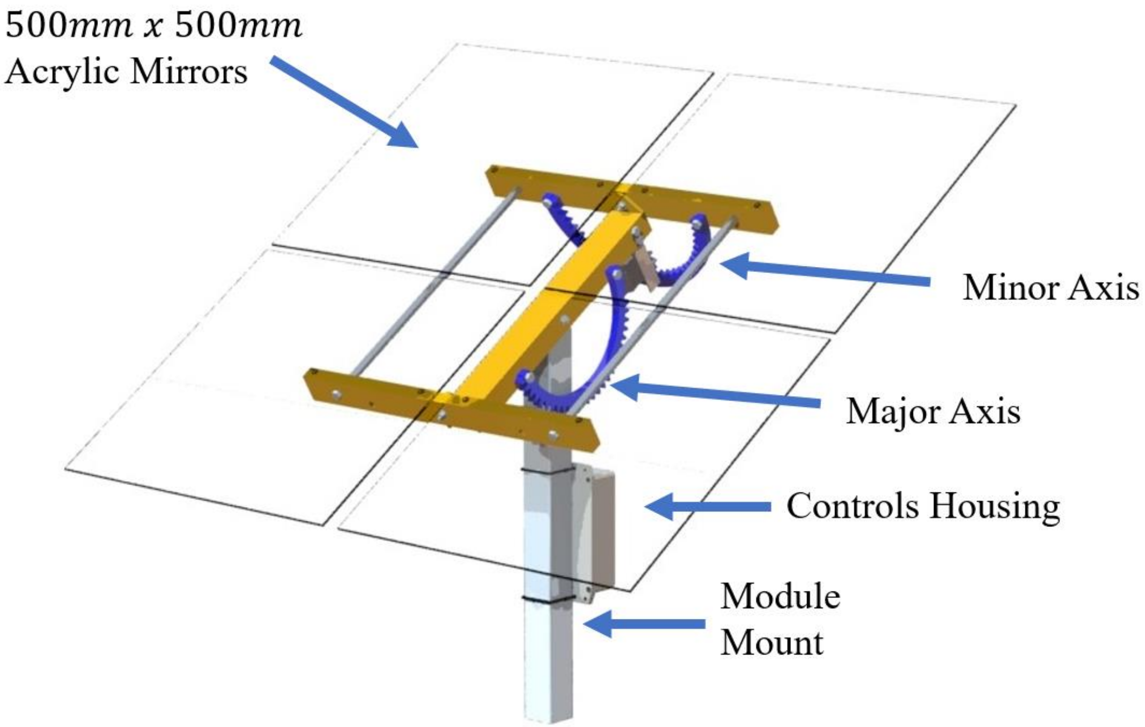
ARX Thermal is:

I. Passionate about sustainability
II. Best at minimizing number of motors
III. Increasing profit/concentration decreasing cost/module

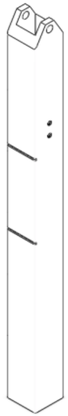
∴ Focus on a durable, power-efficient and cost-efficient to maximize solar concentration.



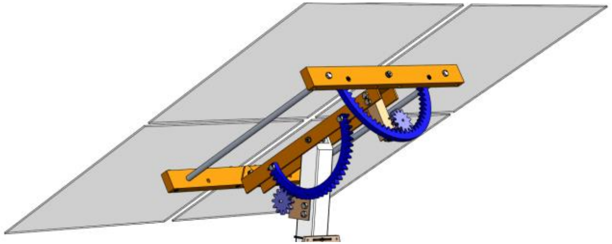
Product Overview



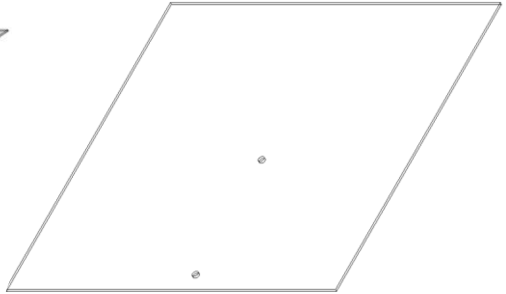
Identification of Subsystems



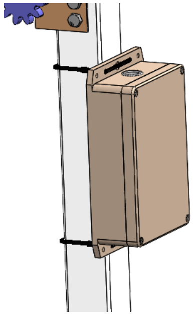
Module Mount



Drive Train



Mirror



Controls

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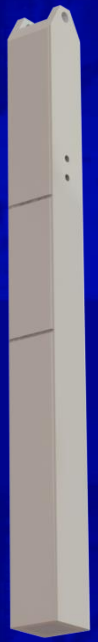
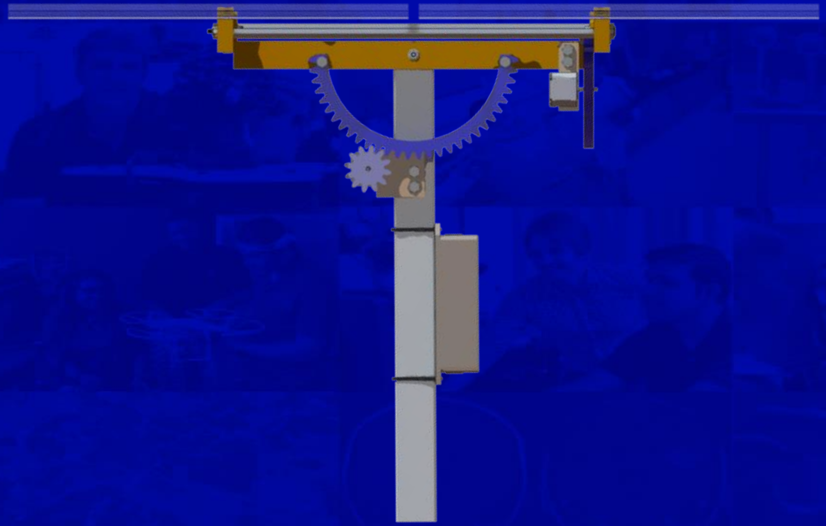
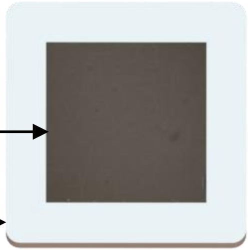
Module Mount

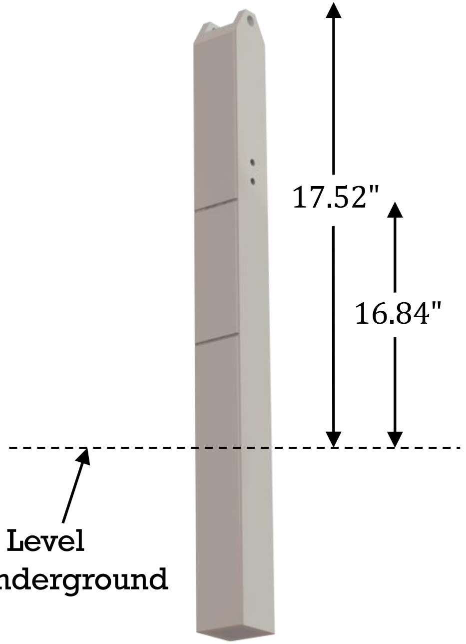




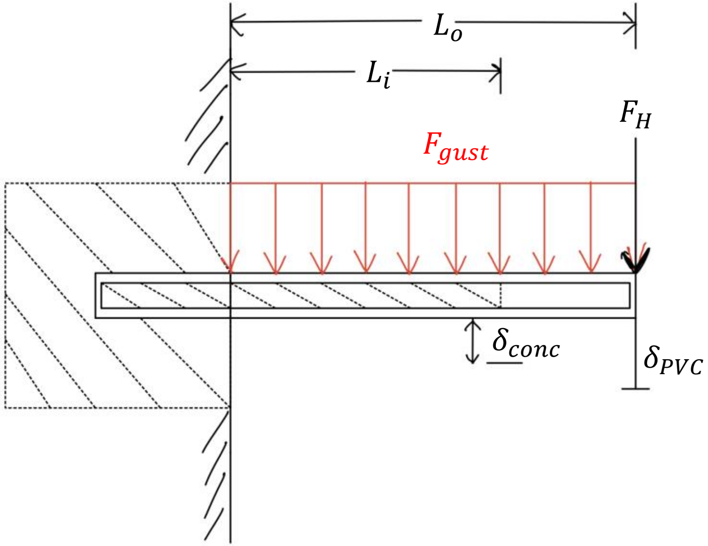
Module Mount - Design Innovations

- Mount features a tubular PVC design with an inner concrete pour
- Design Advantages
  - Increases structural strength and rigidity by minimizing post deflection
  - Minimizes post deflection
  - Prevents bending failure by maximizing the mount's section modulus





Module Mount - Mechanical Analyses



- **Max Wind Force (60.62 MPH)**
  - Weight of Heliostat: $F_H = 23.141\ lbs = 103.19\ N$
  - $F_{gust} = p_d A_p = \left(\frac{1}{2}\rho_{air} v^2\right)(bt)$

    → $F_{gust} = 10.17\ N$

- **Deflection**
  - Geometric Tranformation (Concrete Portion):

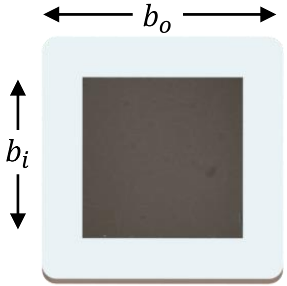
$$b_{i,new} = \left(\frac{E_{conc}}{E_{PVC}}\right) b_i = 0.206\ m$$

  - Moment of Inertia (Concrete Portion):

$$I_{total} = I_{x,PVC} + I_{x,conc} = 1.11 \times 10^{-6}\ m^4$$

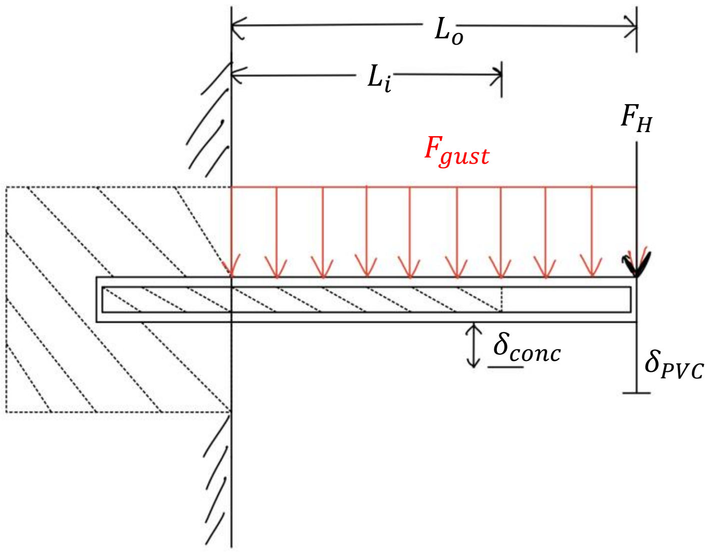
  - Deflection:

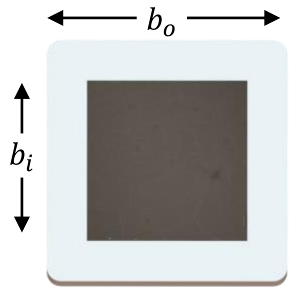
$$\delta_{max} = \delta_{F_{gust,conc}} + \delta_{F_{H,conc}} + \delta_{F_{gust,PVC}} + \delta_{F_{H,PVC}} = 0.003604 \text{ m} = 0.1419 \text{ in}$$



Module Mount - Mechanical Analyses

- **Bending Stress**
  - Max Bending Moment: $M_{max} = \frac{F_{gust} L_o}{2} + F_H L_o = 48.18\ Nm$
  - Bending Stress: $\sigma_b = \frac{M_{max}}{S} = 2.21\ MPa$
  - Factor of Safety: $FOS = \frac{S_U}{\sigma_b} = \frac{7.23\ MPa}{2.21\ MPa} = 3.28 > 2$ ←
- **Buckling**
  - Critical Load: $P_{cr} = \frac{\pi^2 (E_{PVC})(I_{x,conc})}{(L_o)^2} = 98{,}303.13$ N
  - Factor of Safety: $FOS = \frac{P_{cr}}{P_{applied}} = 952.66 > 2$ ←
- **Compression**
  - Factor of Safety: $FOS = \frac{S_{U,conc}}{\sigma_{applied}} = 48.78 > 2$ ←

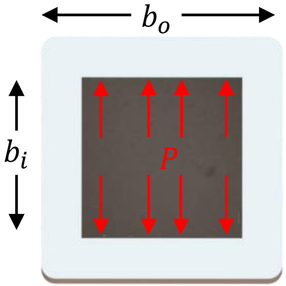




Module Mount - Thermal Analyses

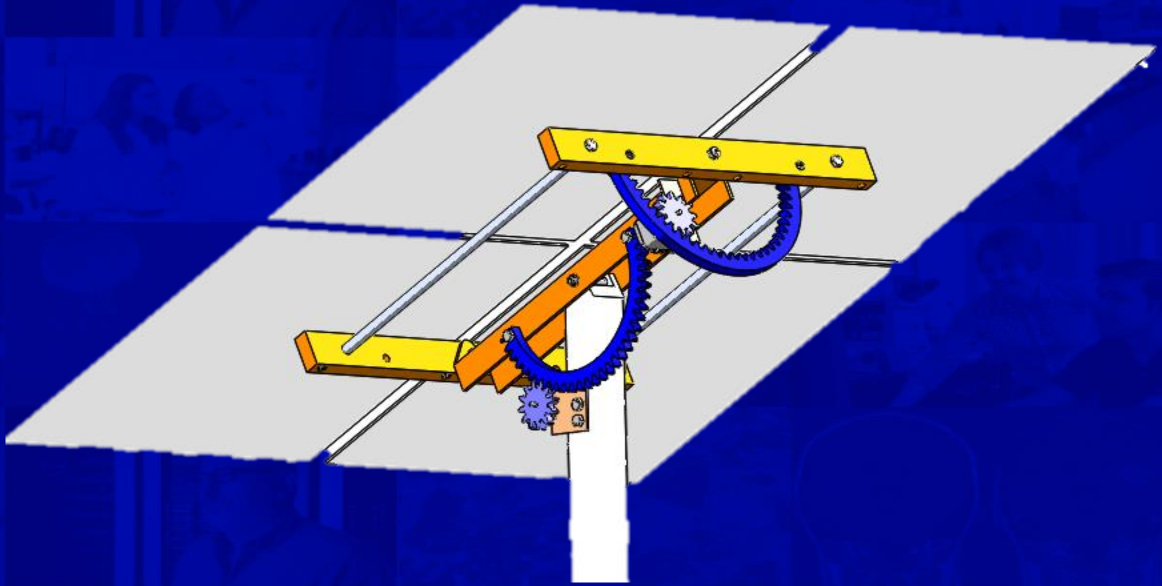
- **Concrete Volumetric Thermal Expansion**
  - Concrete can expand due to temperature change (expressed by thermal expansion coefficient)
  - Largest daily temperature swing in Nevada
    - $T_{high} = 105\ °F$
    - $T_{low} = 80\ °F$
  - Change in volume: $\Delta V = 3\alpha V_o\left(T_{high} - T_{low}\right) = 6.88 \times 10^{-4}\ m^4$

- **Internal Pressure**
  - Hoop stress was found to see if concrete expansion would crack through the PVC
  - Concrete Pressure (using bulk modulus): $P = B\left(\frac{\Delta V}{V_o}\right) = 497.8\ \text{kPa}$
  - $\sigma_{hoop} = \frac{Pr}{t} = 24.7\ MPa$
  - Factor of Safety: $FOS = \frac{S_{U,conc}}{\sigma_{hoop}} = 2.01 > 2$



Drive Train

Major & Minor Axis Design



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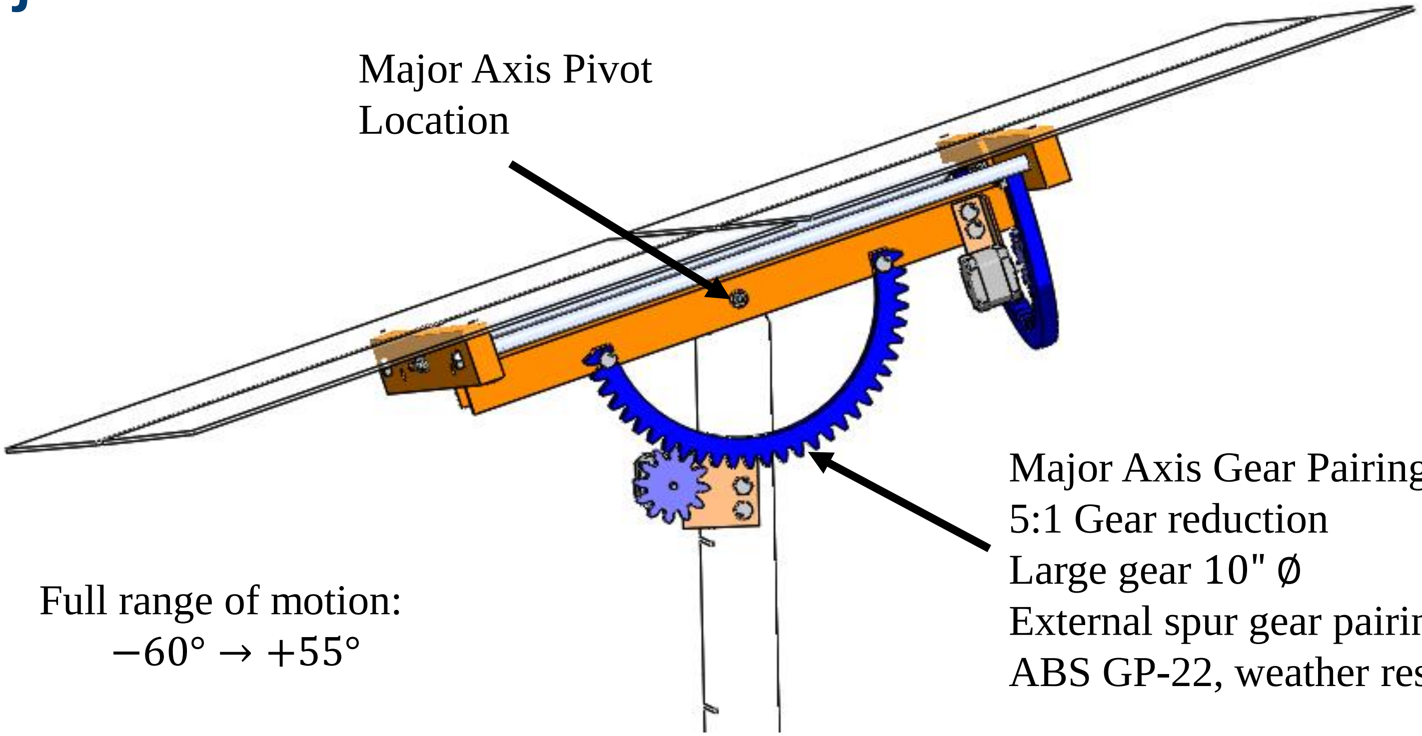
Major Axis of Rotation

Major Axis Pivot Location



Major Axis Gear Pairing:
5:1 Gear reduction
Large gear 10" Ø
External spur gear pairing
ABS GP-22, weather resistant poly

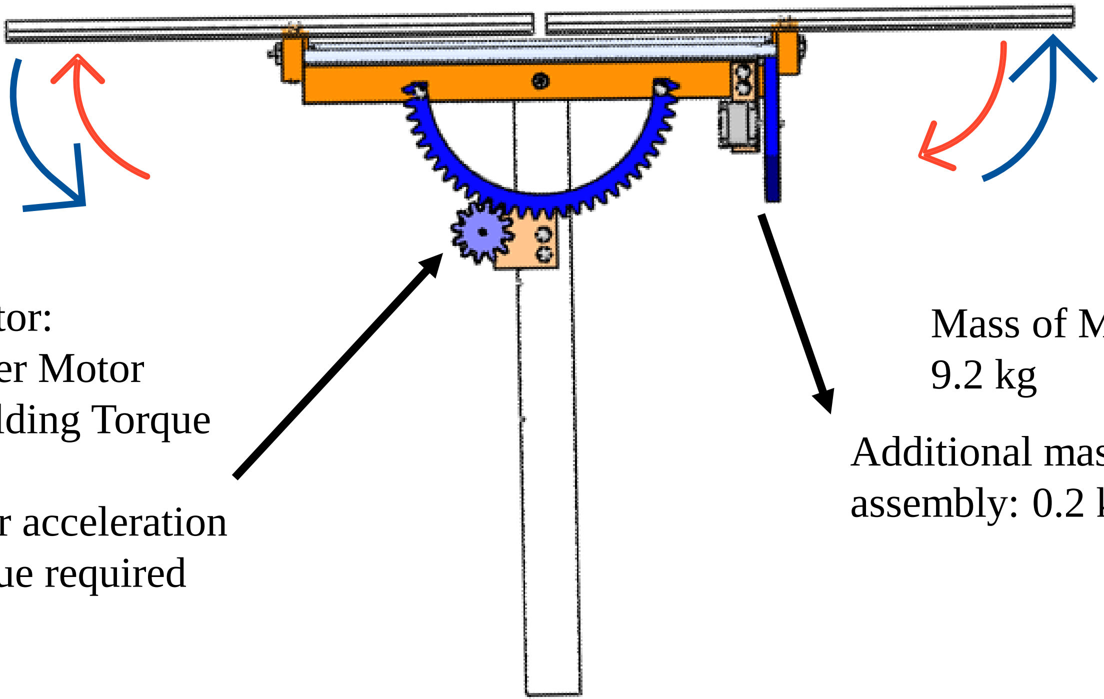
Full range of motion:
$-60° \rightarrow +55°$

Resolution of 0.36°

Major Axis of Rotation

Major Axis Motor:
Nema 17 Stepper Motor
550 $N \cdot cm$ Holding Torque

$1°/sec^2$ angular acceleration
8.5 $N \cdot cm$ torque required



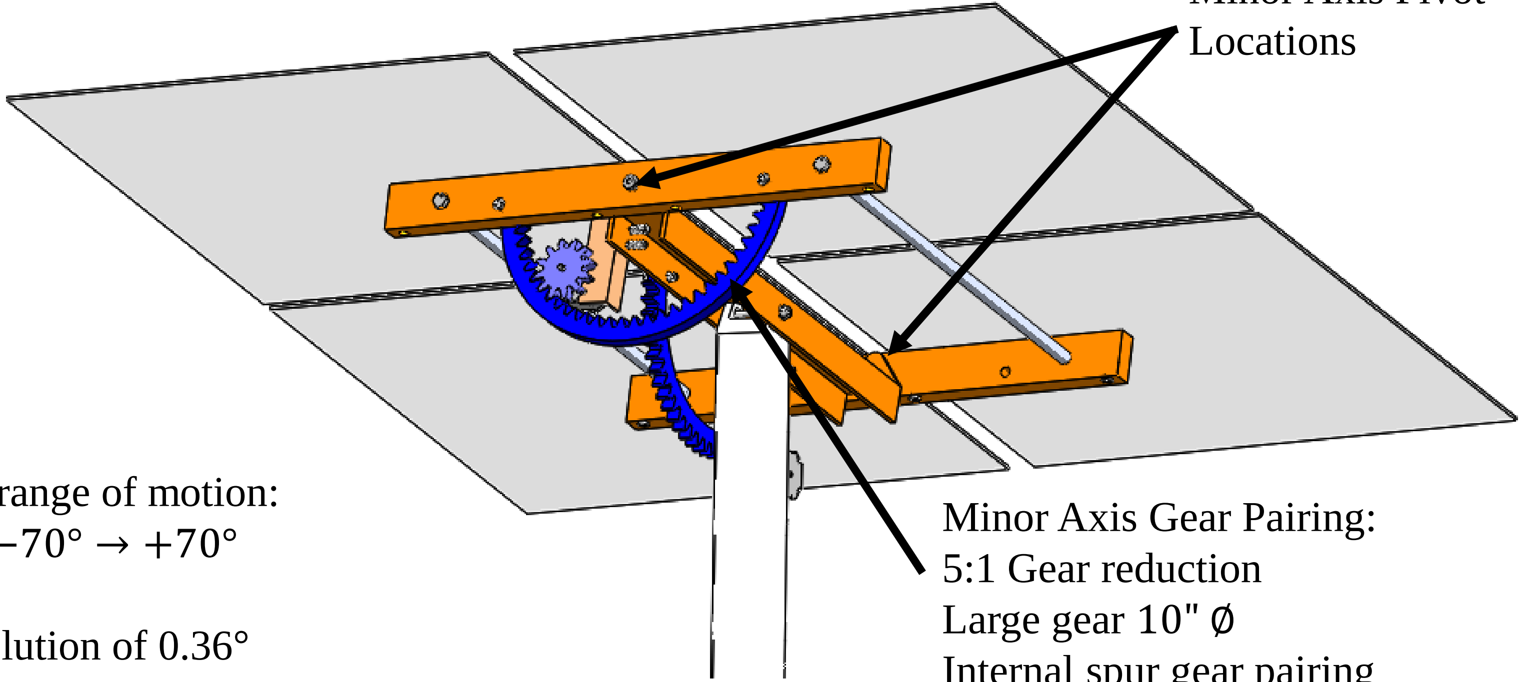
Mass of Mirror and Frame:
9.2 kg

Additional mass due to minor axis assembly: 0.2 kg

Side View of Module

Minor Axis of Rotation

Minor Axis Pivot Locations



Full range of motion:
$-70° \rightarrow +70°$

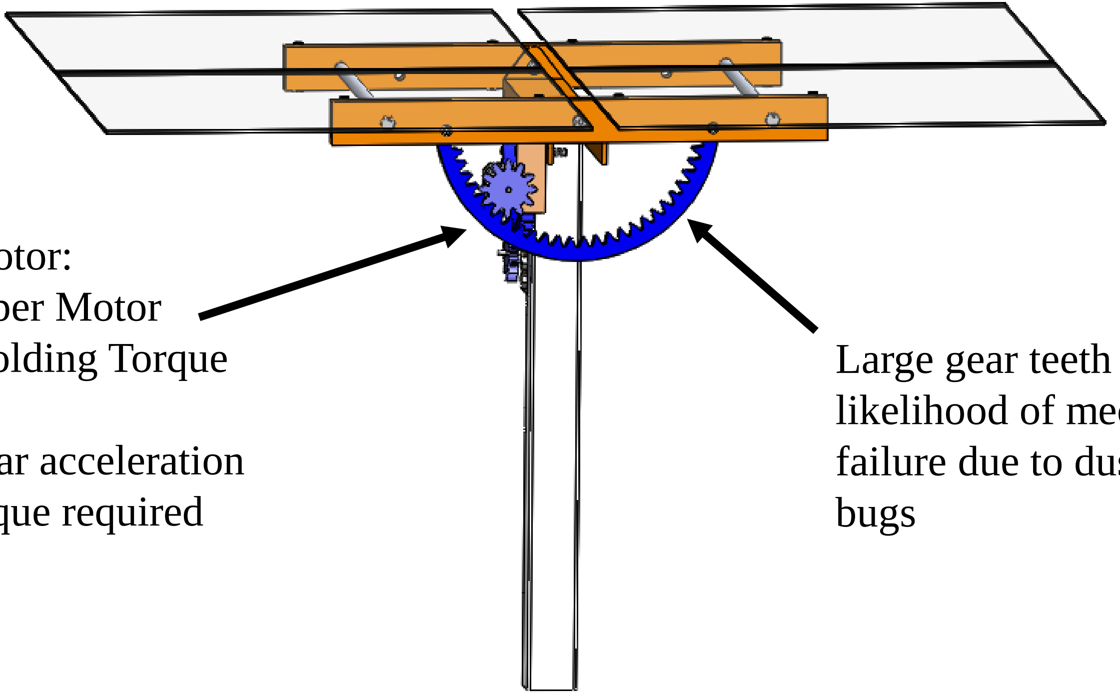
Resolution of 0.36°

Minor Axis Gear Pairing:
5:1 Gear reduction
Large gear 10" Ø
Internal spur gear pairing
ABS GP-22, weather resistant poly

Minor Axis of Rotation

Minor Axis Motor:
Nema 17 Stepper Motor
550 $N \cdot cm$ Holding Torque

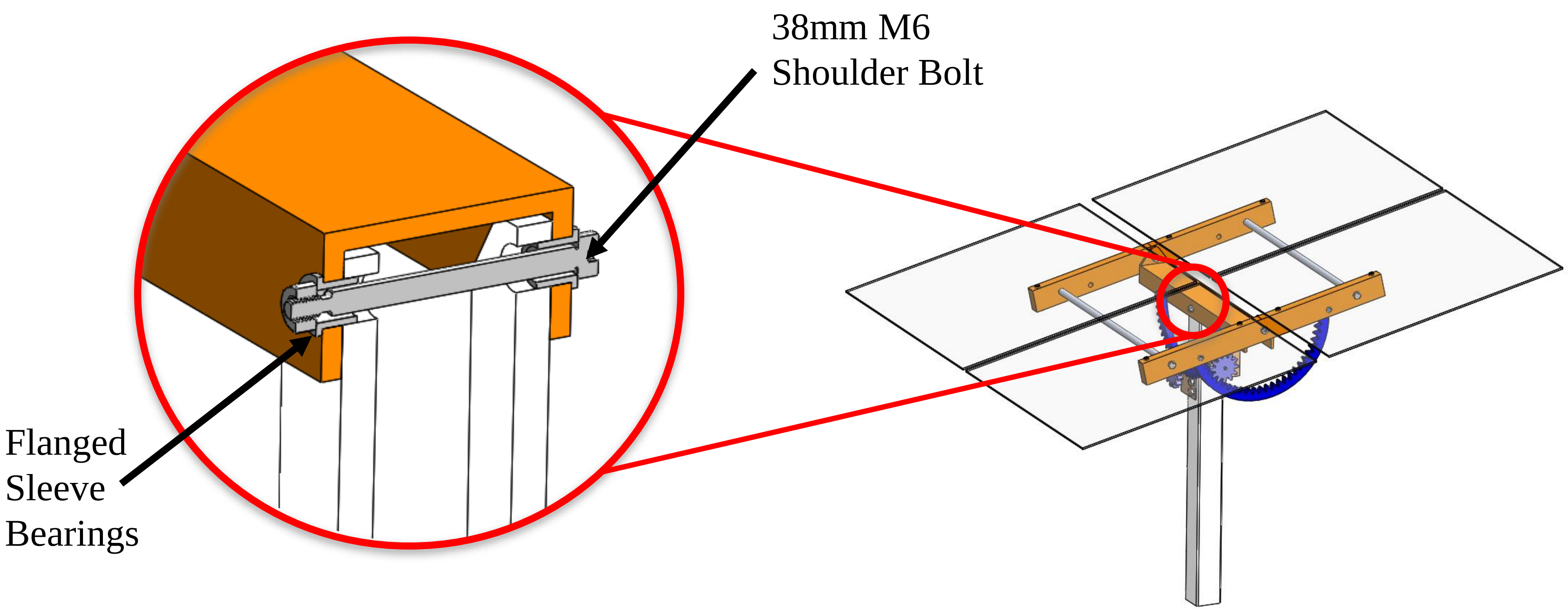
$1°/sec^2$ angular acceleration
2.7 $N \cdot cm$ torque required



Large gear teeth reduce likelihood of mechanical failure due to dust, sand, and bugs

Front View of Module

Low Cost, Simplistic Pivot Design



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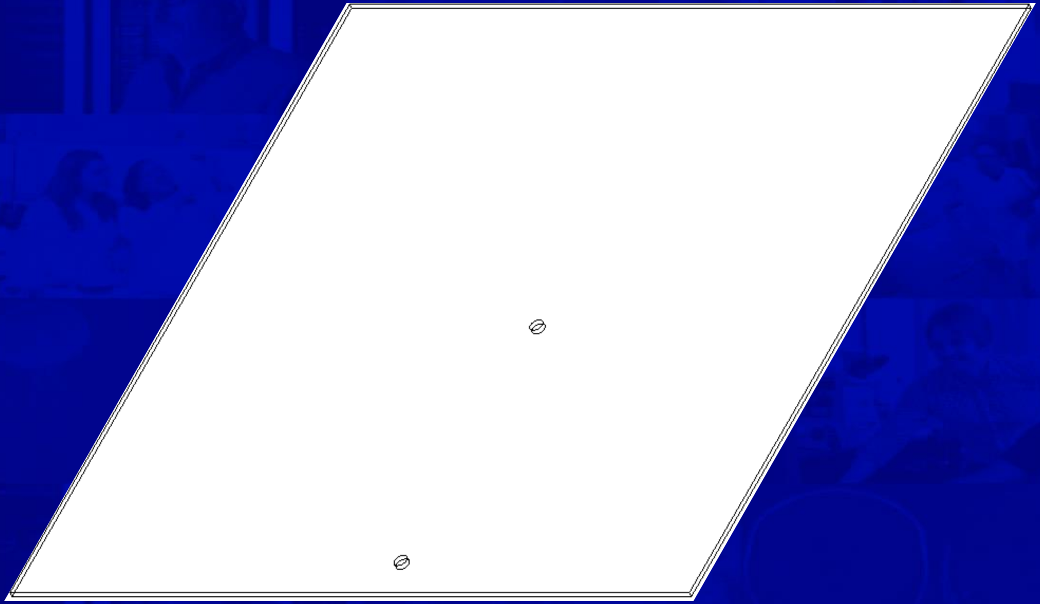
Mirror



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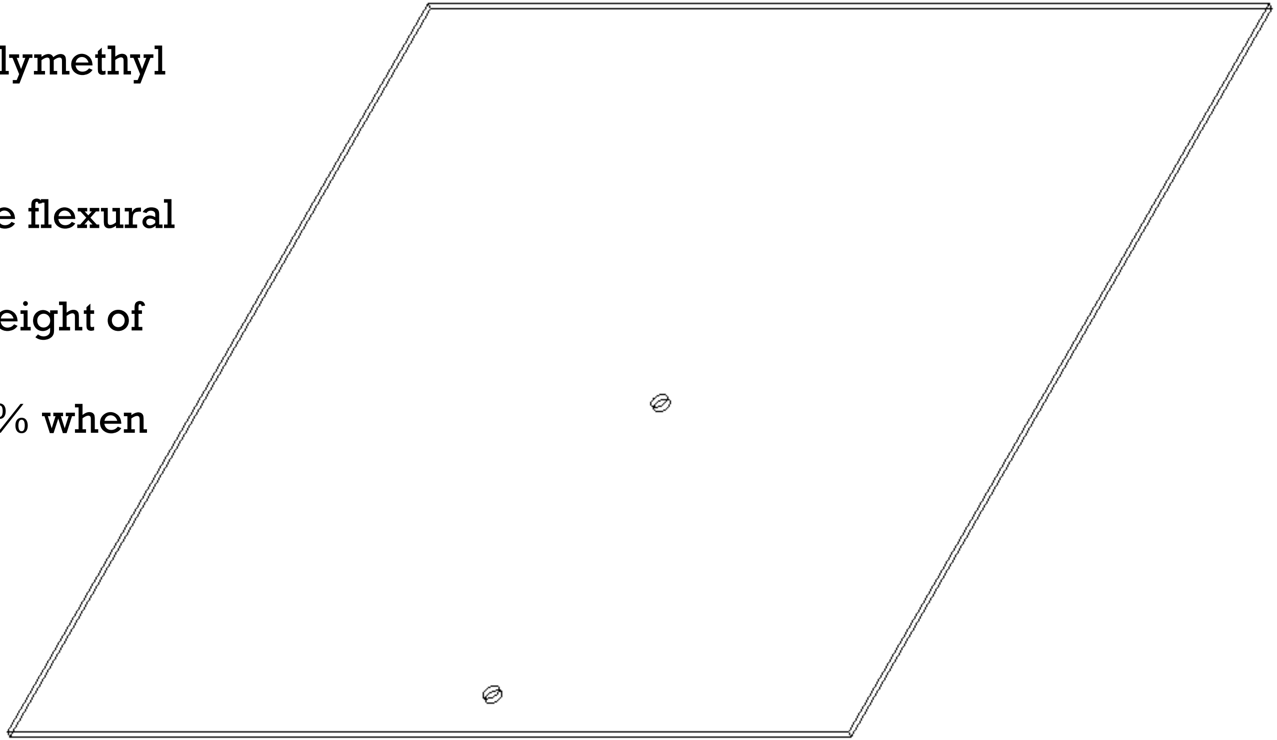
Mirror Material

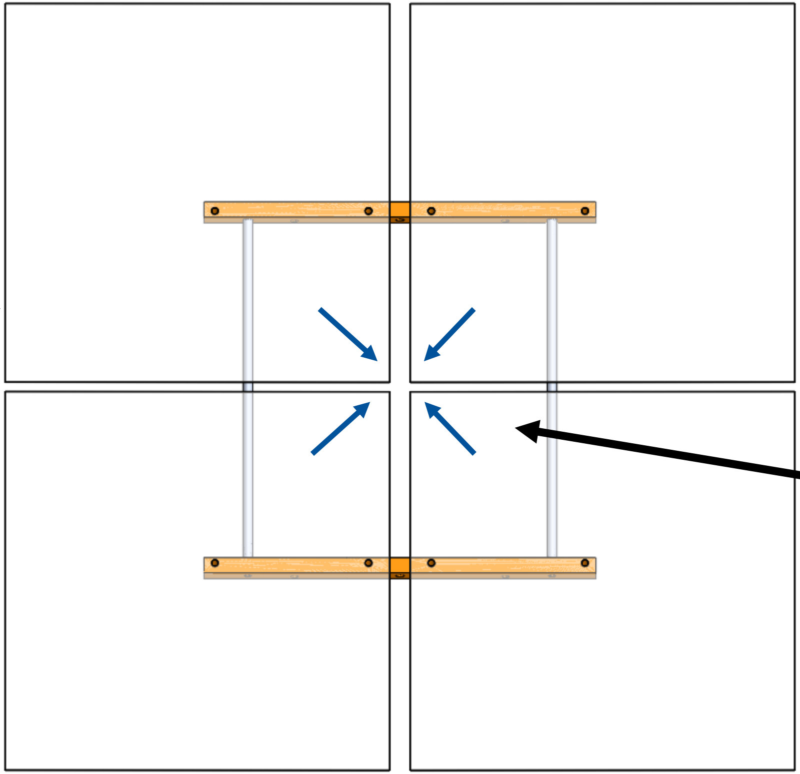
Acrylic – PMMA (polymethyl methacrylate)

- More than 10x the flexural strength of glass
- Nearly half the weight of glass
- Reflectivity of 90% when polished
- Does not yellow



Mirror Arrangement

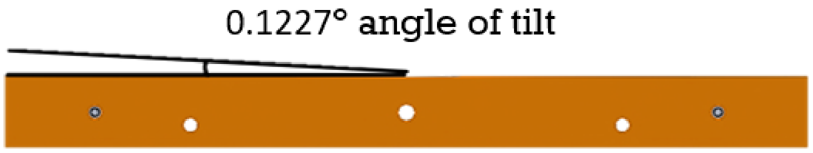
Four 500mm x 500mm mirrors arranged in a square

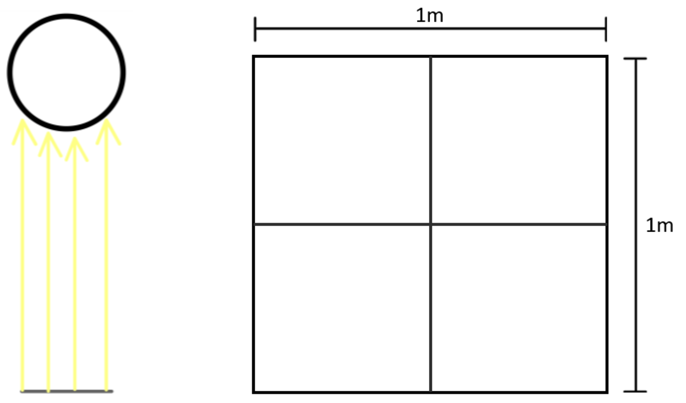


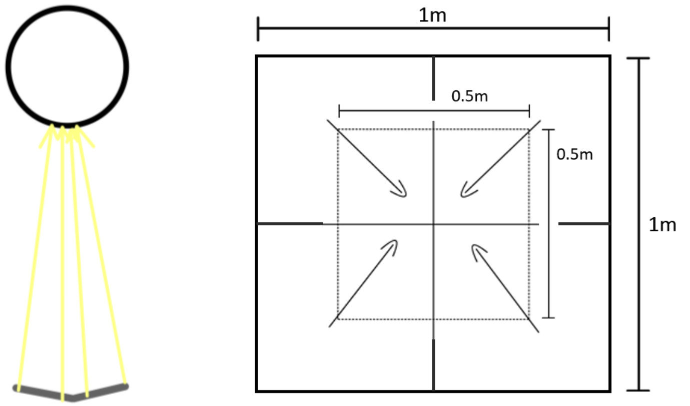
All angled at 0.1227 degrees along the diagonal

Mirror Tilt

- Mirror overlap was the focus of our design
- 75% reduction in tower projection area
- Tilt angle of 0.1227 degrees

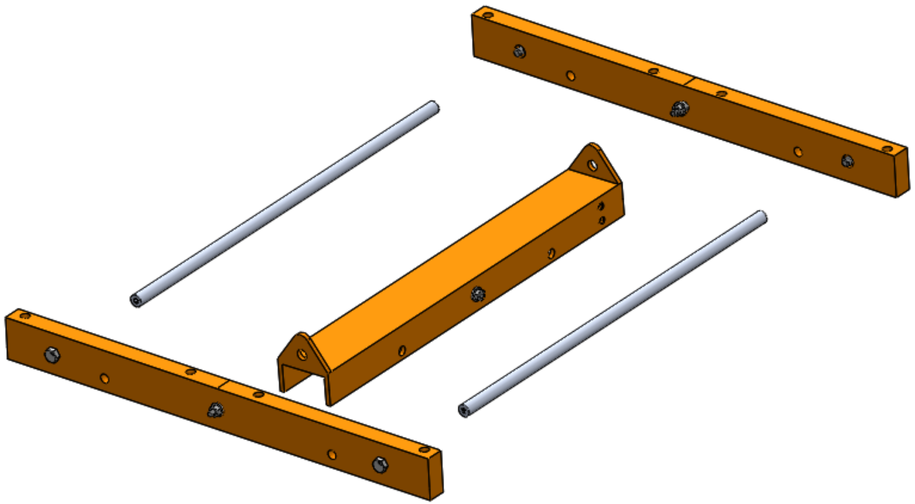






Mirror Fixture

- Injection molding allows for unique high tolerance angles
- Made from weather resistant injection molded ABS
- Most cost-efficient assembly orientation
- Connected with M6 hex bolts by a torque wrench



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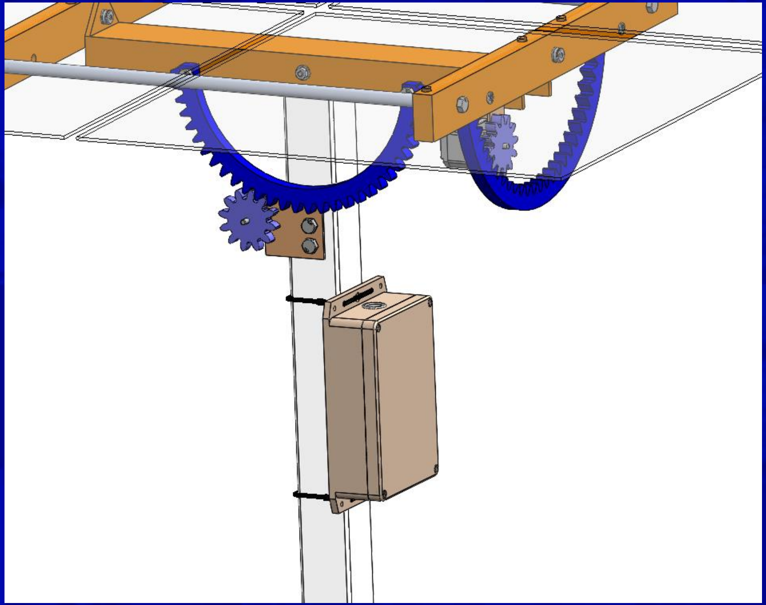
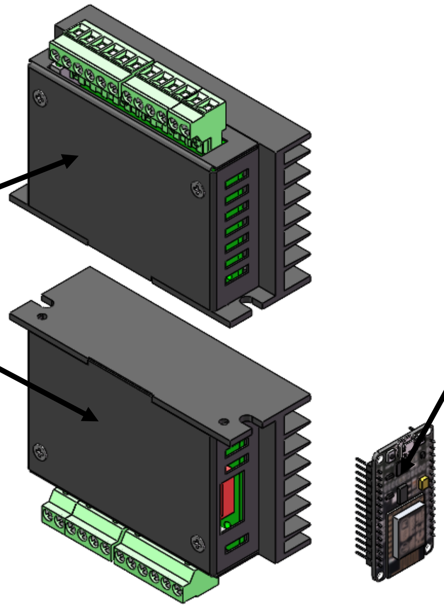
Controls



Hardware

TB6600 driver converts signals from controller to angular displacement in stepper motors



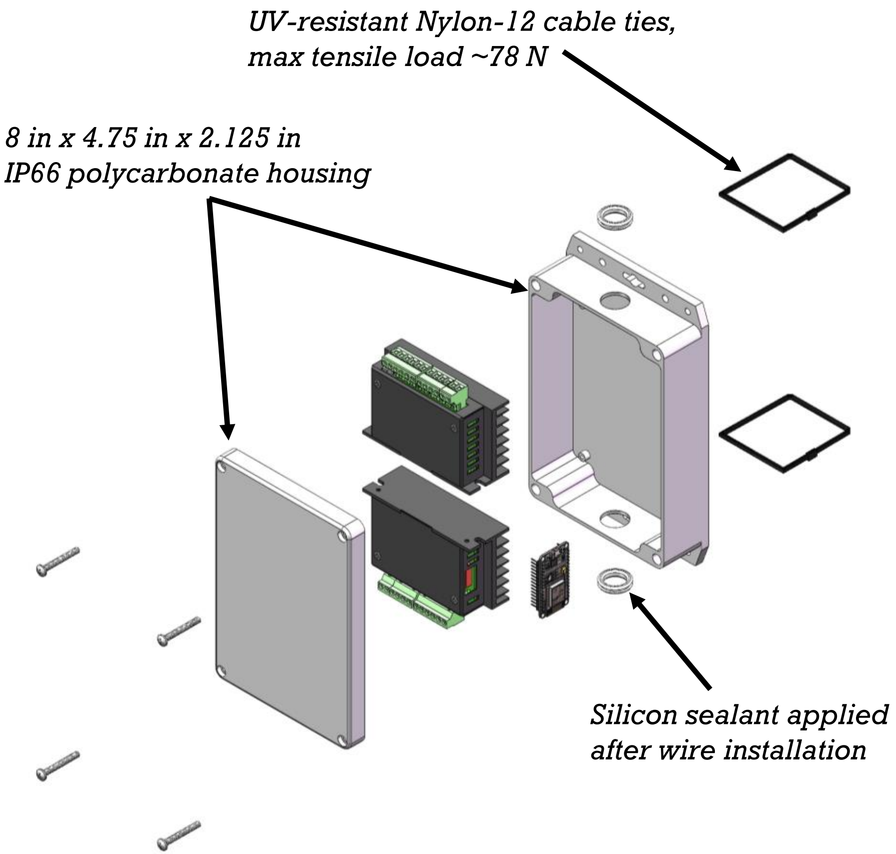
ESP8266 Wi-Fi enabled microcontroller to communicate between motors and logic system

Housing

[N9] Metal blocks WiFi signals. Plastic is more suitable

[N12, N14, N15] According to British Standard E EN 60529:1992, *IP 66* means "Protected from tot dust ingress and from high pressure water jets from any direction"

[N12, N14, N15] Polycarbonate vs. ABS: the former is more UV-resistant and melts at 260°C.



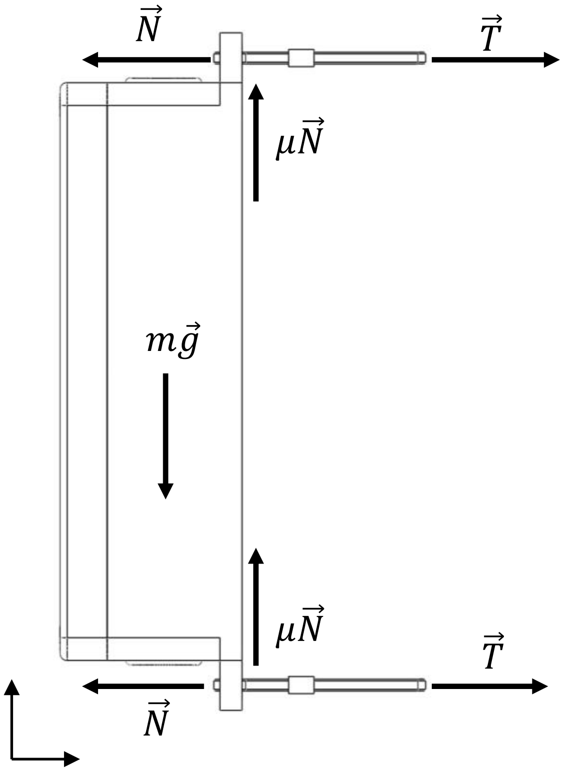
Housing

$$T = \frac{mg}{2\mu}$$

where μ is the friction coefficient between polycarbonate and steel

$$T = \frac{0.641\ kg * 9.81 \frac{m}{s^2}}{2 * 0.38} = 8.3\ N$$

$$\therefore n = \frac{T_{max}}{T} = \frac{78\ N}{8.3\ N} = 9.4$$



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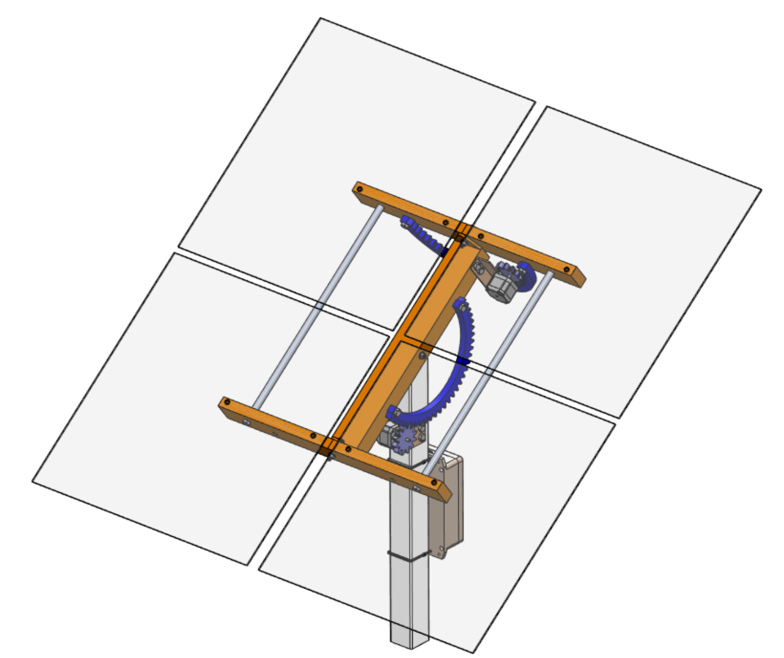
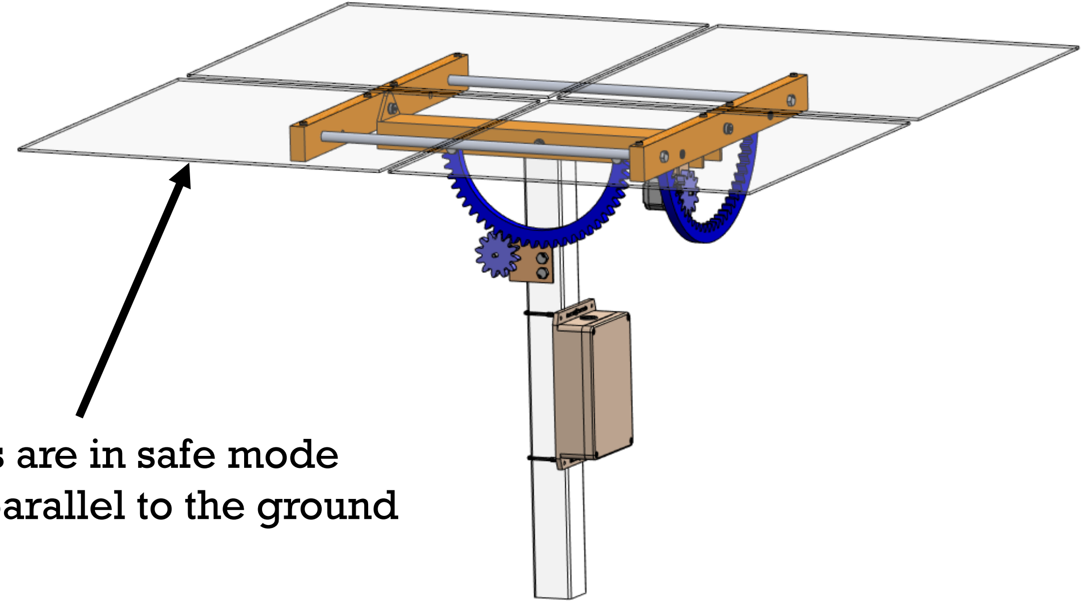
Full Heliostat



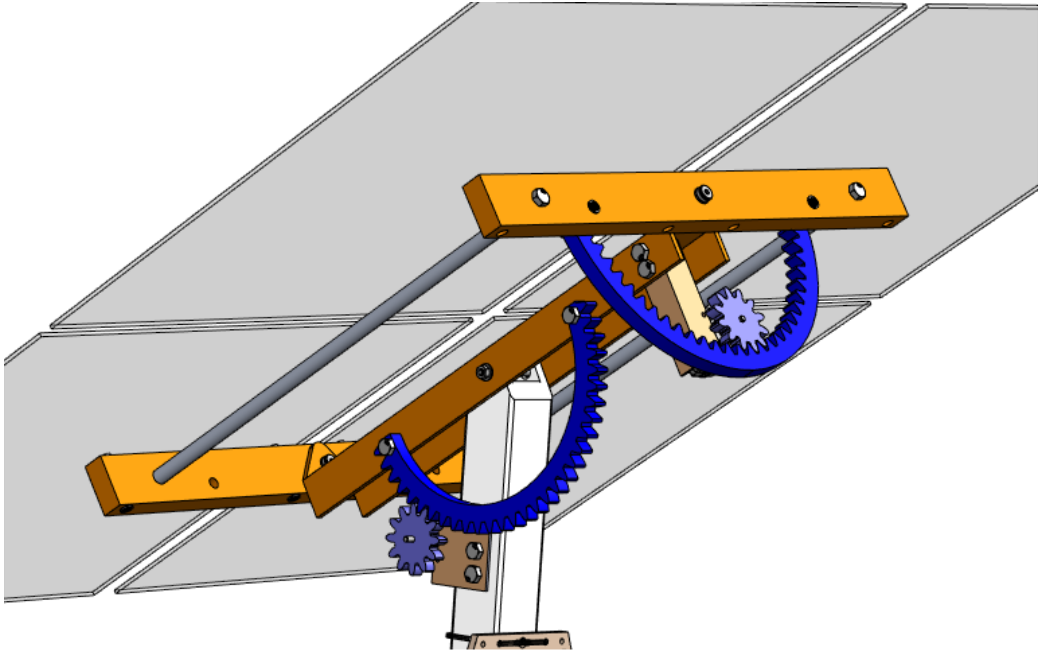
Safe Mode Position for High-Speed Winds

- Heliostat enters safe mode when windspeed is predicted to exceed 60.62 mph.



Mirrors are in safe mode when parallel to the ground

Use of Injection Molded Polymers



- Orange and Blue parts are injection molded ABS BASF Terluran GP-22 poly
- Low density at $1.04 \frac{g}{cm^3}$
- Rigid, and highly resistant to impact and heat

Cleaning and Maintenance Protocols*

- Rinse acrylic mirror faces and gear teeth with water every 4 days to remove surface dirt
- Wash acrylic mirror faces with ammonia free detergent every 2 weeks to avoid heavier build up

*According to Heliostat Dust Build Up and Cleaning studies conducted in New Mexico

Heliostat Thermal Energy and Efficiency

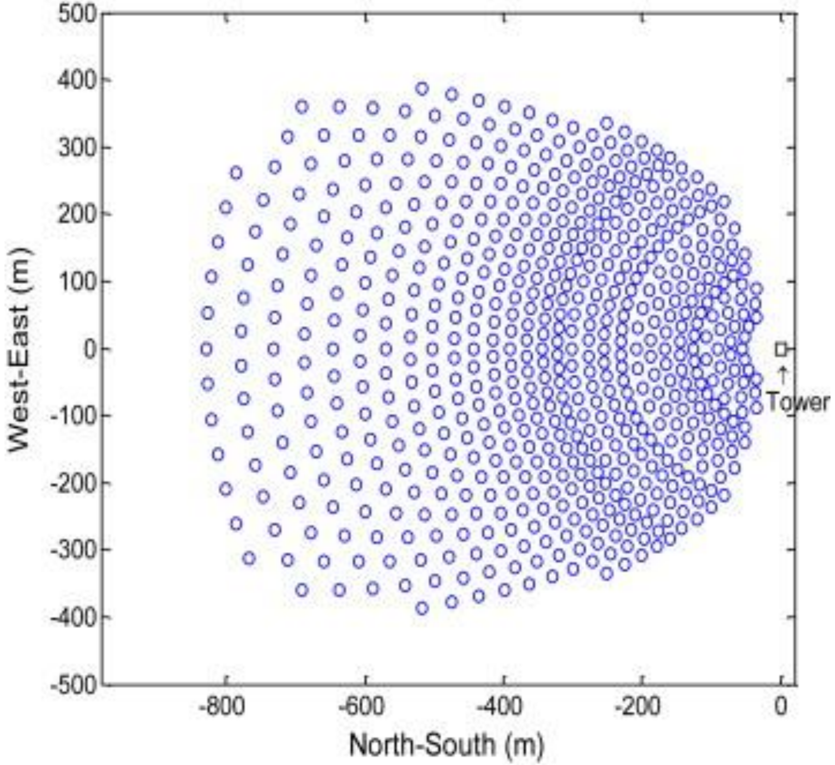
At Solar Noon:

- Summer Solstice: $\sim 1.2\ \frac{kW}{m^2}$
- Winter Solstice: $\sim 0.4\ \frac{kW}{m^2}$

Operating from solar noon ± 3 hours

Roughly 70% efficient

Field size of 2000 heliostats



Cost Breakdown

$20.63
OTS Parts
Fasteners, motors, controls

$19.90
Modified OTS Parts
Mirrors

$27.60
Raw Material
PVC Post, injection molded plastic

$33.44
Manufacturing Labor
Injection molds

$0.05
Monthly Energy Consumption

$3.84
Assembly Labor
14.2-minute assembly time

Total Full Scale Production Cost: $105.46

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