Herbert Wertheim College of Engineering
UNIVERSITY of FLORIDA

Makeup Mirror Heliostat

Section 27096, Group 12

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POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE

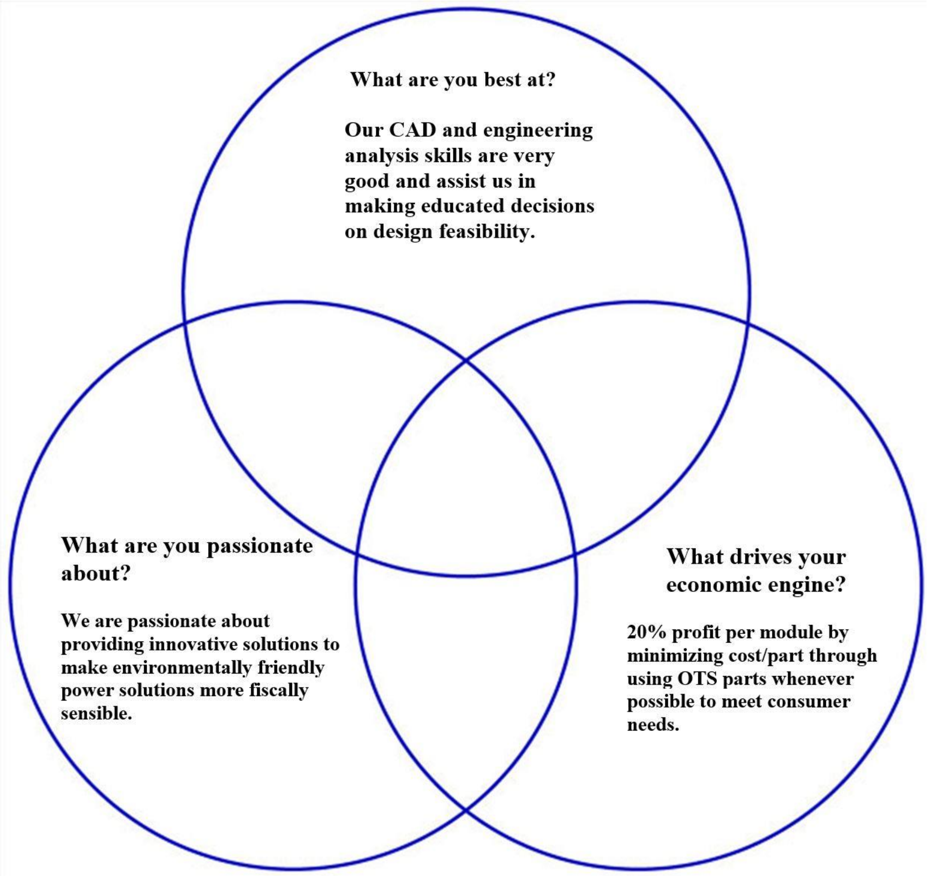
Presentation Outline

- Hedgehog Concept
- Product Overview
- Subsystem Identification
- Subsystem Descriptions
- Subsystem Analyses
- Key Features
- Cost Breakdown
- Technology Readiness Level
- Summary/Conclusion

Hedgehog Concept:

To use our CAD and engineering analysis skills to make heliostat fields more fiscally sensible and meet consumer needs by mini mizing cost and maintaining quality.

Hedgehog Concept



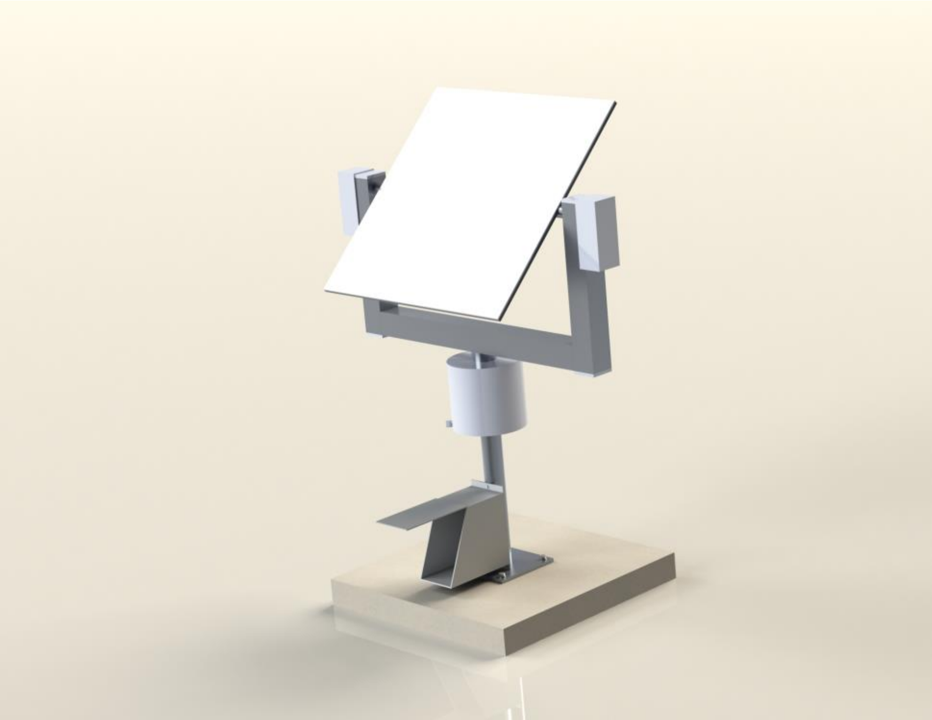
Product Overview

Objectives:

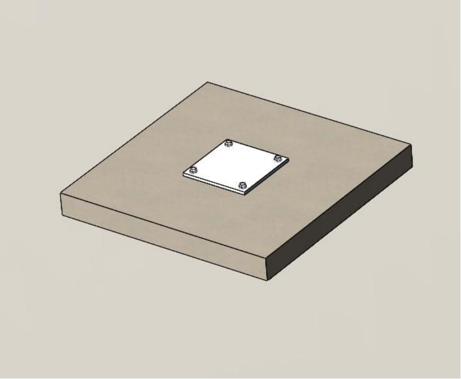
- Design a small-scale low-cost heliostat
- Maximize thermal efficiency
- Automated sun-tracking control

Overall dimensions:

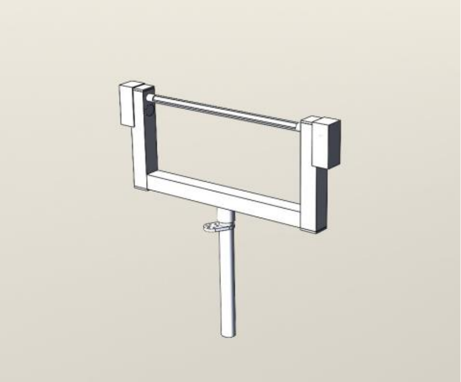
- 4 heliostats per module
- 360° rotation along two axes
- Max. size: 0.5 m × 0.73 m × 1.07 m
- Total mass: 33.6 kg



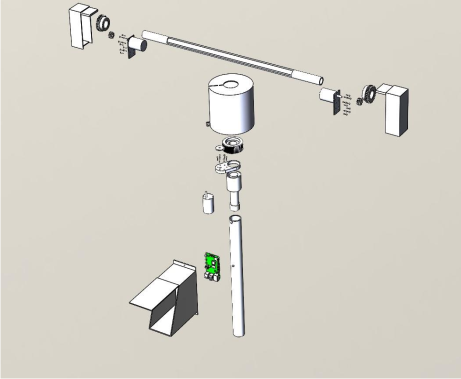
Subsystem Identification



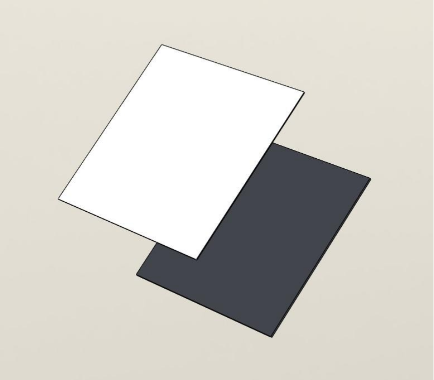
Foundation



Support



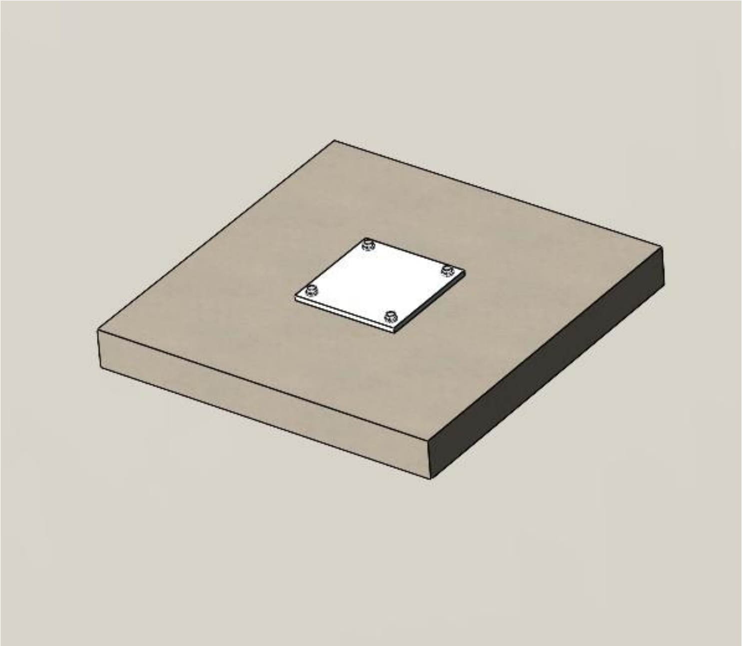
Sun-tracking Mechanics



Reflective Surface

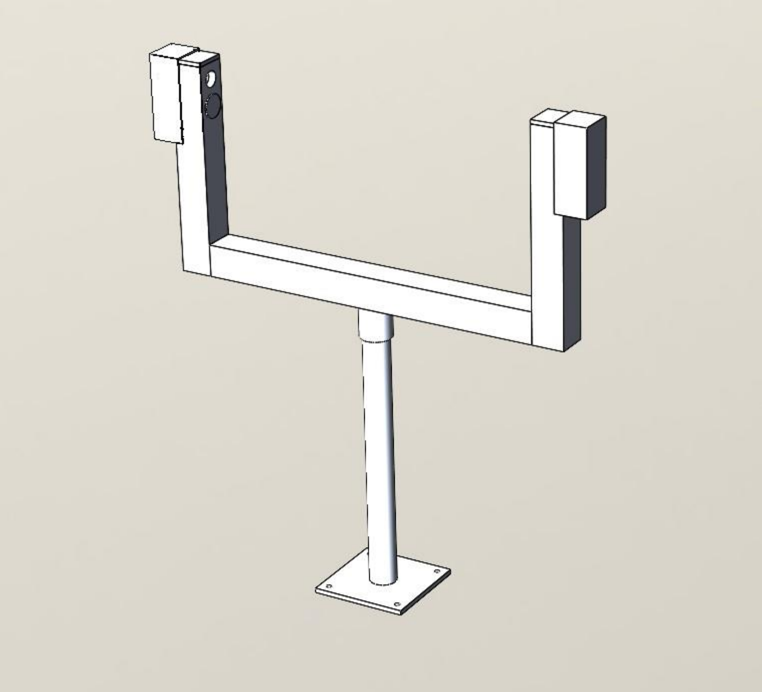
Foundation

- The concept chosen for the foundation was a plated concrete block.
- The plate is made of aluminum while the screws are made of zinc-plated-steel.
- This concept delivers good weight and stability to the system for a relatively low cost.
- It also resists corrosion from the ambient weather in Las Vegas, NV.
- This design benefits from low manufacturing cost and high manufacturability.



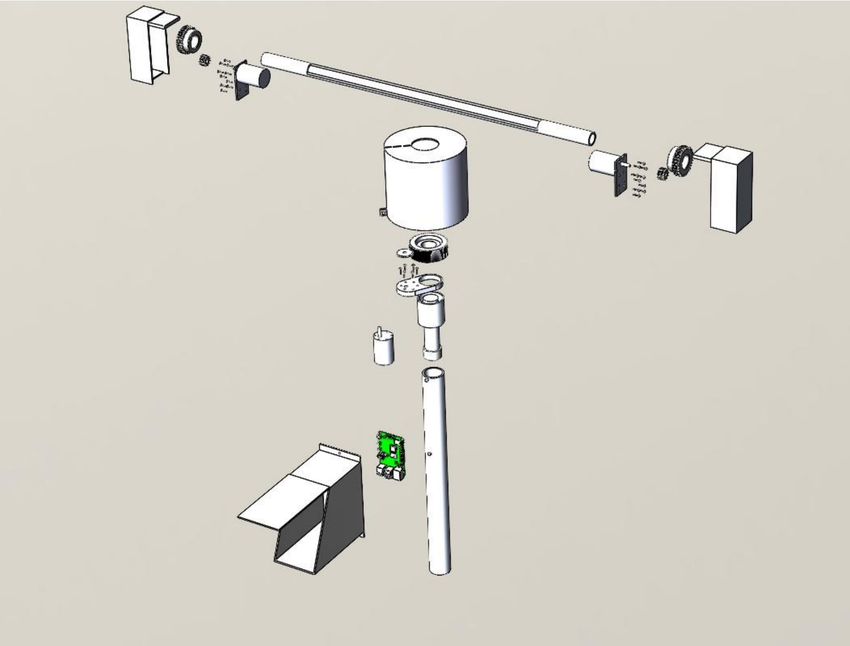
Support

- The concept chosen for the support was the 'Makeup Mirror'.
- The entire support system is made of either square or round aluminum tubing, ensuring corrosion resistance.
- The support rod is made of aluminum as well.
- The support and the sun-tracking-mechanics designs blend to avoid extra material cost.
- Worst case scenarios were simulated to achieve a factor of safety of well over N=2.



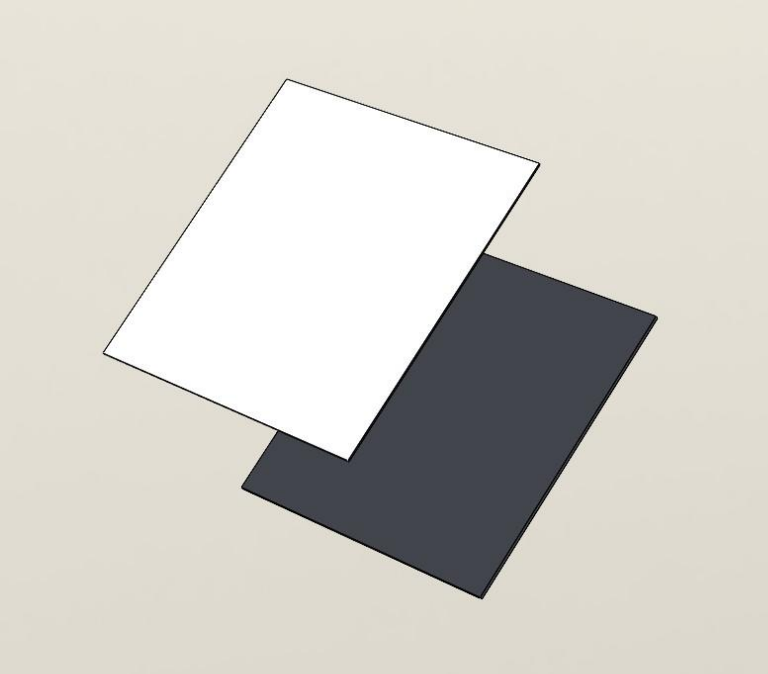
Sun-tracking Mechanics

- Raspberry PI 4 Pico
- Two 24V DC motors allow the mirror to rotate vertically
- A system of two gears inside an aluminum casing provides azimuthal rotation
- The gears are custom-made and 3D-printed using Thermoplastic-blend filament
- Closed-loop control



Reflective Surface

- Flat rectangular glass
- Silver coating for high reflectivity: 90%
- Area of each mirror is $0.25\ m^2$
- Aluminum frame adhesively attached to the reflective surface
    - Master Bond Supreme 10HT
- All parts are commercially available
- All components operate well under high temperatures



Design Subsystem Analyses

Foundation: Bolt Analysis

Objective: Avoid shear failure in bolt due to wind induced drag force.

Assumptions:

- $C_D = 1.17$
- $A_{refl} = 0.25m^2$
- $V_{wind} = 40.2\frac{m}{s}$
- $A_{bolt} = 3.16 * 10^{-5}\ m^2$
- $USS_{bolt} = 0.75 * \sigma_{UTS} = 315MPa.$
- $H_{mirror} = 0.745m$
- $L_{pole\ to\ polt} = 0.15m$

Calculations:

- $F_D = \frac{C_D A_{refl} V_{wind}^2}{2} = \frac{1.17*0.25*40.2^2}{2} = 236.346N.$
- $M_{base} = F_D * H_{mirror} = 236.346\ * 0.745 = 176.077\ Nm$
- $F_{bolts} = \frac{M_{base}}{L_{pole\ to\ bolt}} = \frac{176.077}{0.15} = 1173.8518\ N$
- $F_{bolt} = \frac{F_{bolts}}{2} = \frac{1173.8518}{2} = 586.93\ N$
- $\tau_{bolt} = \frac{F_D}{A_{bolt}} = \frac{586.93N}{3.16*10^{-5}m^2} = 18.574MPa < 315MPa.$

Design Subsystem Analyses

Support: Support beam failure

Objective: Avoid damage to the support beam from wind induced force.

Assumptions:

- $C_D = 1.17$
- $A_{refl} = 0.25m^2$
- $V_{wind} = 40.2\frac{m}{s}$
- $A_{supp} = 0.589m^2$
- $\sigma_{UTS} = 276MPa$
- Entirety of drag force applied as bending stress to the support beam.

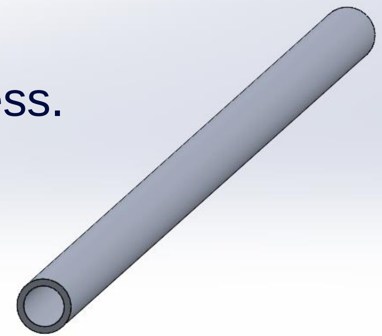
- $USS_{bolt} = 0.75 * \sigma_{UTS} = 315MPa.$
- $H_{mirror} = 0.745m$
- $L_{pole\ to\ polt} = 0.15m$
- $D = 0.0422m,\ y = .02108m$
- $I = 8.104 * 10^{-8}m^4$

Calculations:

- $F_D = \frac{C_D A_{refl} V_{wind}^2}{2} = \frac{1.17*0.25*40.2^2}{2} = 236.346N.$
- $M_{base} = F_D * H_{mirror} = 236.346 * 0.745 = 176.077\ Nm$
- $\sigma_{supp} = \frac{M_{base}*y}{I} = \frac{176.078*.02108N}{8.104*10^{-8}m^4} = 45.8MPa < 276MPa.$

Design Sub-system Analyses

Sun-tracking Mechanics: Shaft Failure



Objective: Ensure that the shaft does not fail under excess stress.

Assumptions:

- Shear failure – Tresca Criterion: $\tau_{max} = 0.5S_y$
- Yield strength of aluminum: 276 MPa
- Polar moment of inertia for hollow tube: $\frac{\pi(R_i^4+R_o^4)}{2} = 5.3658 \cdot 10^{-8}\, m^4$
- Maximum torque provided by motors: 1.471 N-m

Calculations: the maximum shear stress at a radial distance $R_o = 25.4\, mm$ and motor torque T is found as:

$$\tau = \frac{TR_o}{J} = 348.165\, kPa$$

This results in a factory of safety of 396.

Design Sub-system Analyses

Reflective Surface: Solar Concentration Ratio

Objective: Provide a solar concentration ratio greater than 1000 suns

Assumptions:

- Optical loss $\eta_o = 0.4$
- Receiver area $A_r = 1\ m^2$
- Area of each reflective surface $A_{refl} = 0.25\ m^2$
- A heliostat field consisting of 1900 heliostat modules, resulting in $N_h = 7600$ heliostats

Calculations: the solar concentration ratio, c, was found as

$$c = (1 - \eta_o) \cdot \frac{A_{refl} N_h}{A_r} = 1140\ suns$$

Design Sub-system Analyses

Reflective Surface: Thermal Input Power

Objective: Provide a thermal input power of 1 MW after losses.

Assumptions:

- Incidence angle, θ, optimized to have a cosine value of 0.9-1.0
- Direct normal irradiance, G_{bn}, provided from: https://midcdmz.nrel.gov/apps/sitehome.pl?site=NPC

Calculations: beam irradiance on a tilted surface is found as:

$$G_{bt} = G_{bn} cos\theta$$

Therefore, the thermal input, $\dot{Q}$, can be expressed as follows:

$$\dot{Q} = (1 - \eta_o)\eta_{cos} G_{bn} A_{refl} N_h$$

For $G_{bn} \geq 1000\ W/m^2$, the thermal input is equal to 1.03 MW.

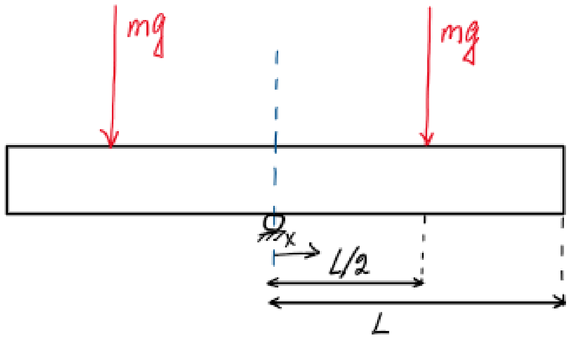
Design Sub-system Analyses

Reflective Surface: Aluminum Frame Failure

Objective: Ensure that the aluminum frame does not fail under bending

Assumptions:

- Frame modeled as a rectangular beam fixed at its center
- Maximum bending stress occurs at a slope angle $\beta = 0°$
- Flexural strength of aluminum: 299 MPa



- Due to symmetry, one half of the beam can be considered for analysis

Design Sub-system Analyses

Reflective Surface: Aluminum Frame Failure

Calculations:

- Bending stress, $\sigma_{bend} = \frac{My}{I}$
- The loads are concentrated at a length $L/2 = 0.125\ m$, where L is half of the frame length
- The moment, M, is found as: $M = \frac{mgL}{2}$, where m the sum of the masses of the frame and the reflective surface, divided by two.
    - $m = \frac{1}{2}(m_{frame} + m_{glass}) = \frac{1}{2}(4.29 + 1.84) = 3.065kg$
- The moment of inertia, I, is equal to $5.3343 \cdot 10^{-9}\ m^4$
- Distance y is equal to half of the frame's thickness
- Therefore, the maximum bending stress was equal to 2.24 MPa
    - The resulting factor of safety is 133.5

Key Features

Fully Aluminum Construction

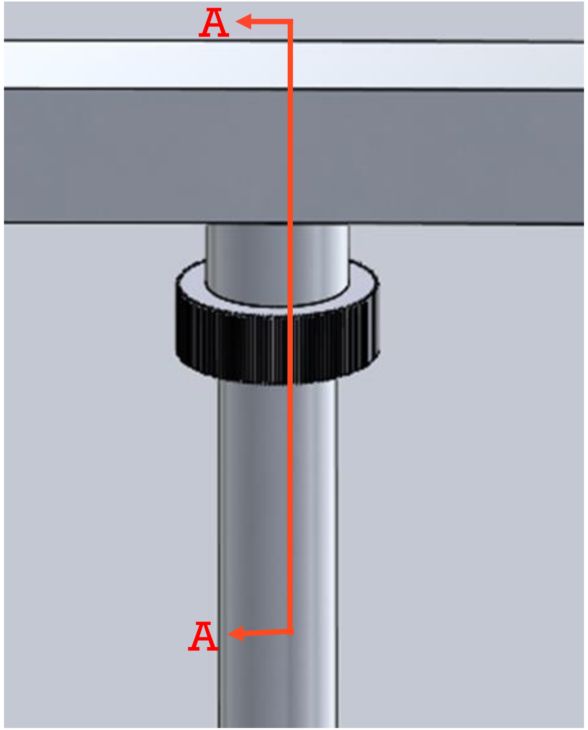
- Being constructed entirely of aluminum this heliostat has amazing strength and potential for longevity.
- The aluminum can easily be welded on site by a skilled welder making for a short assembly time.

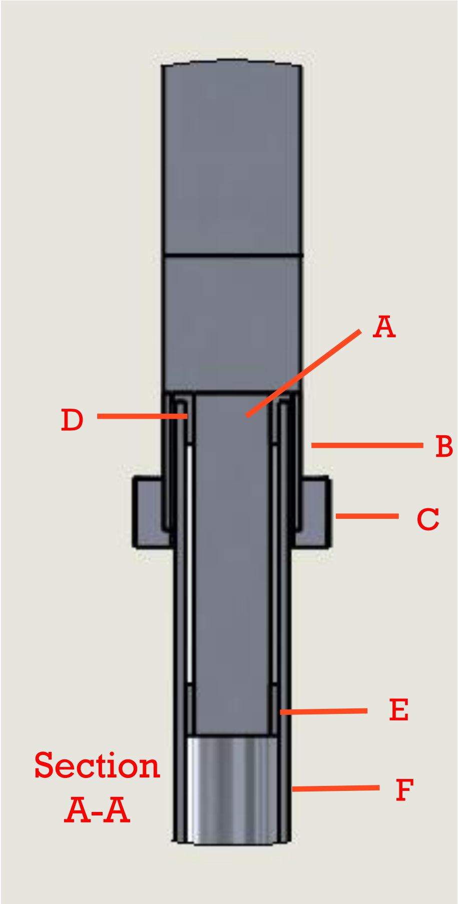
360º Azimuthal and Elevation Rotation

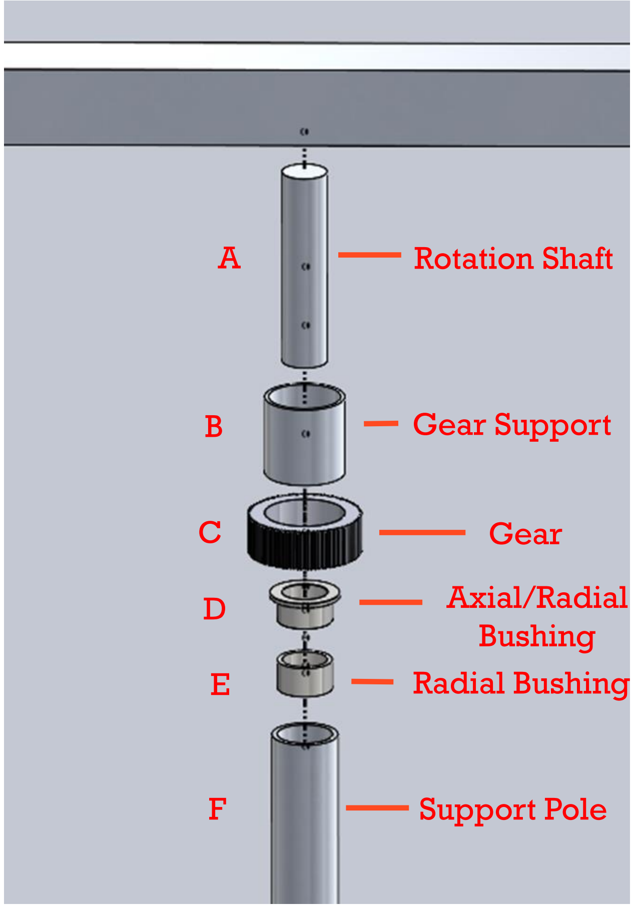
- The “Makeup Mirror” design style allows for easy implementation of 360 degree azimuthal and elevation rotation.
- Unlimited rotation allows the heliostats to be placed in field without any consideration of aim caused by limited rotation.

Key Features

Azimuthal Rotation

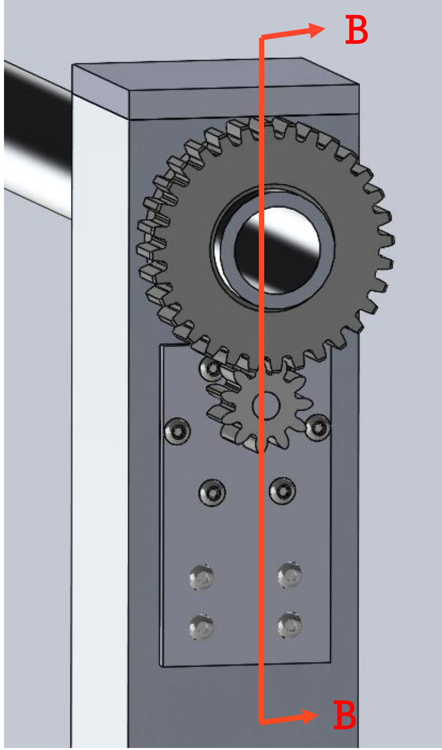


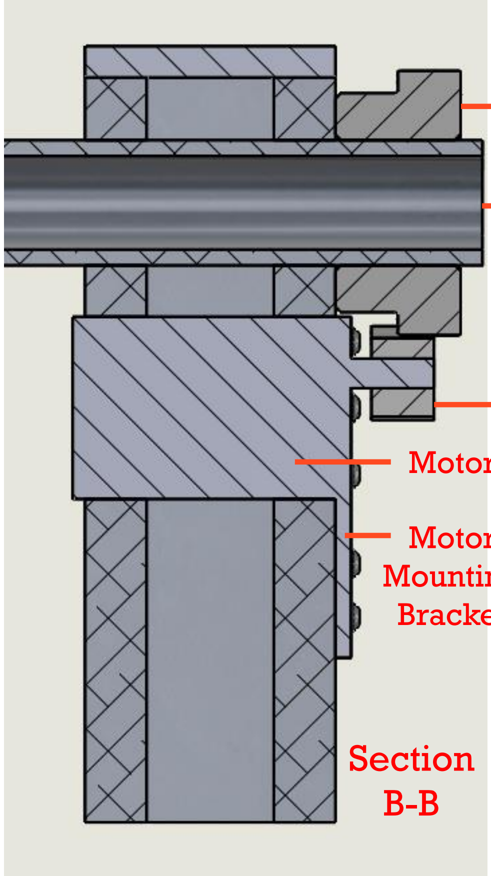




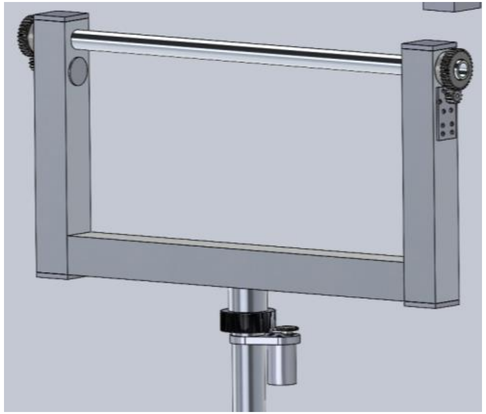
Key Features

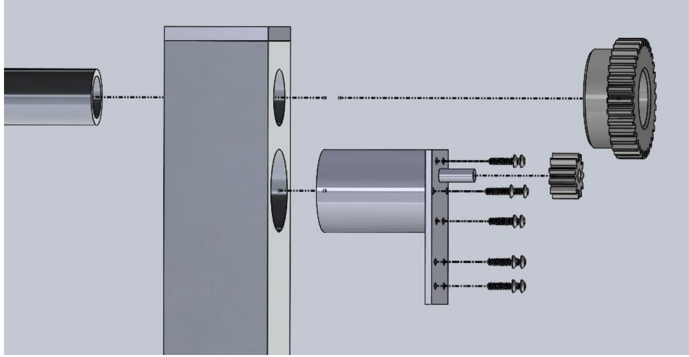
Elevation Rotation





Section B-B





Explosion of Elevation Rotation System (one side only)

Cost $$$

Raw Materials

- Aluminum, 3D Printing Filament, Concrete

OTS Parts

- Motors, Fasteners and Gears

Manufacturing Labor

- Custom Gears, Aluminum End Caps, Motor/Gear Housings, Shafts, Mirror, and Concrete Foundation

Expenses Breakdown:

- **Materials:** $373.82
- **OTS Parts:** $307.39
- **Manufacturing Labor:** $80
- **Assembly Labor:** $158
- **Energy Consumption:** $0

Total: $919.21

Cost $$$

Assembly Labor

- Welding at $65/hour for about 2 hours
- Motor/gear/housing assembly at $14/hour for about 2 hours

Energy Consumption

- No cost since power is supplied by the energy the heliostats generate.

Expenses Breakdown:

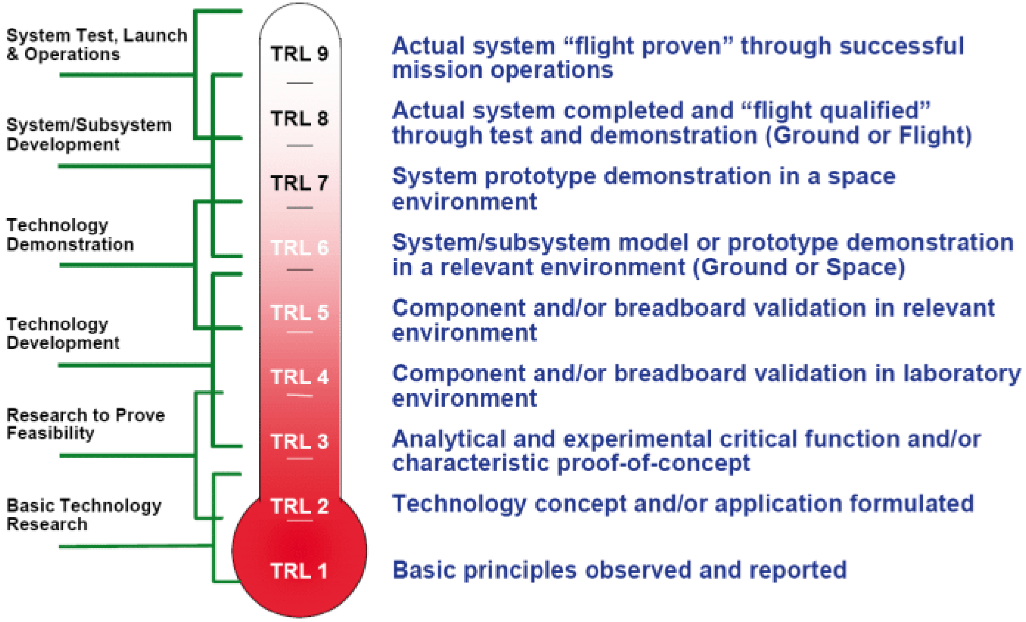
Materials: $373.82
OTS Parts: $307.39
Manufacturing Labor: $80
Assembly Labor: $158
Energy Consumption: $0

Total: $919.21

Technology Readiness Level

Level 3

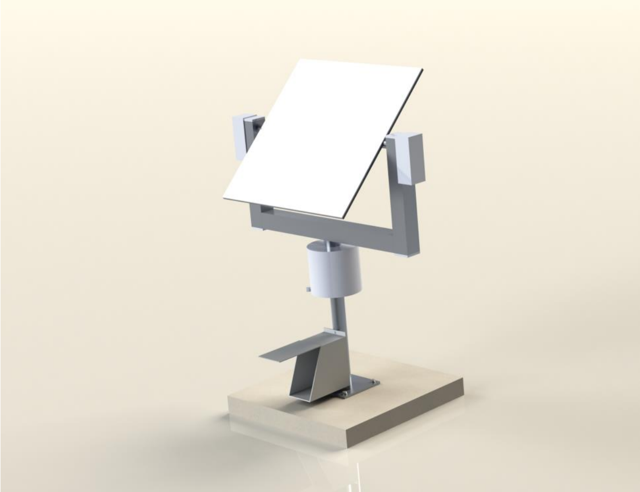
- The Makeup-Mirror heliostat is currently rated at a level 3.
- Upon further development and prototyping its level will increase



Summary

Makeup Mirror Heliostat

- Group 12 believes that the Makeup Mirror Heliostat should be chosen as a prototype for EML4502.
- This is due to:
  - Its innovative design combining a support subsystem and the sun-tracking mechanics subsystem.
  - Prototyping this system will allow for unique insight into the engineering design process.



Conclusion

- ***Thank you*** for attending our presentation!
- The Makeup Mirror Heliostat opens the door to sustainable, affordable power solutions and we are happy to take any questions.