Herbert Wertheim College of Engineering
UNIVERSITY of FLORIDA

TSAR

Tri-beam Solar Automated Reflector

Section 16669, Group 4

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POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE

TSAR

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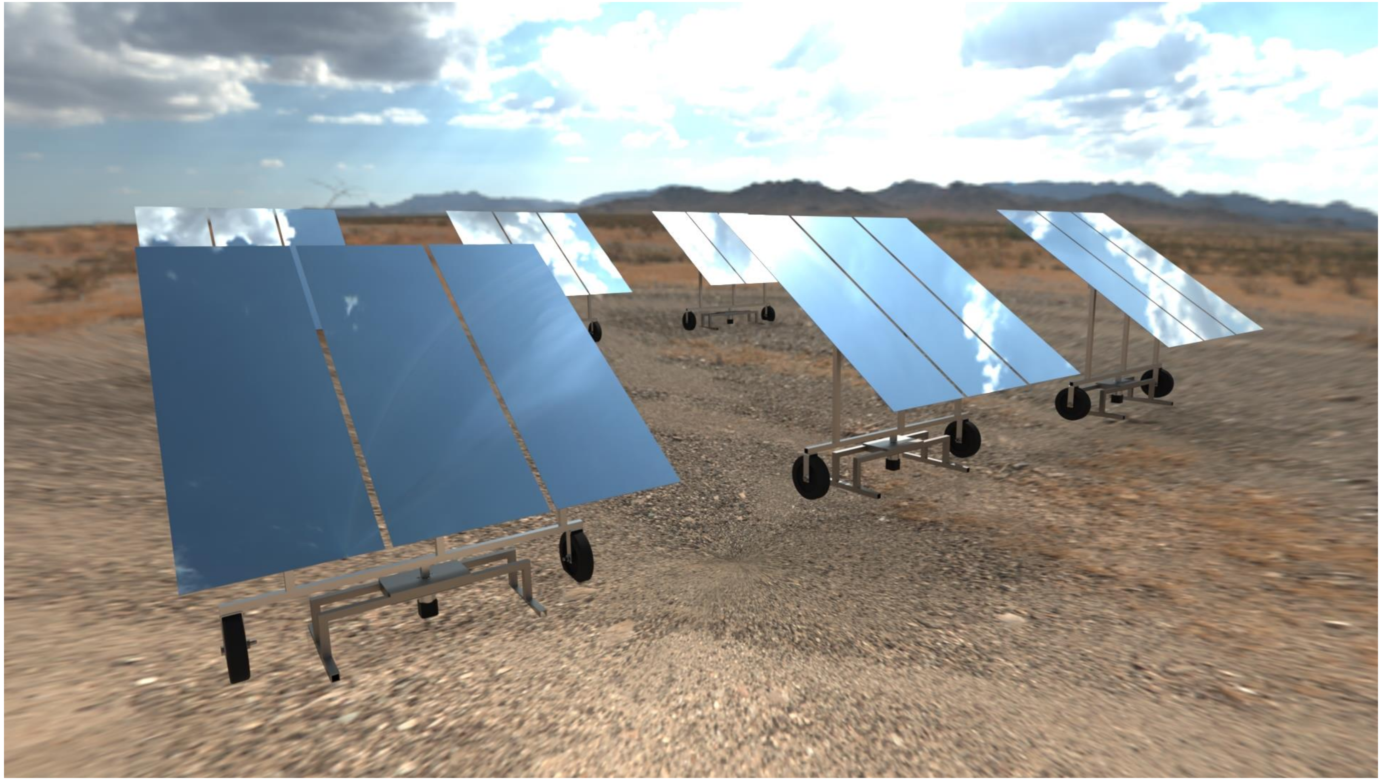
Reflection Platform
Heliostat Motors
Control System
Support Wheels
Frame
Central Motor

TSAR

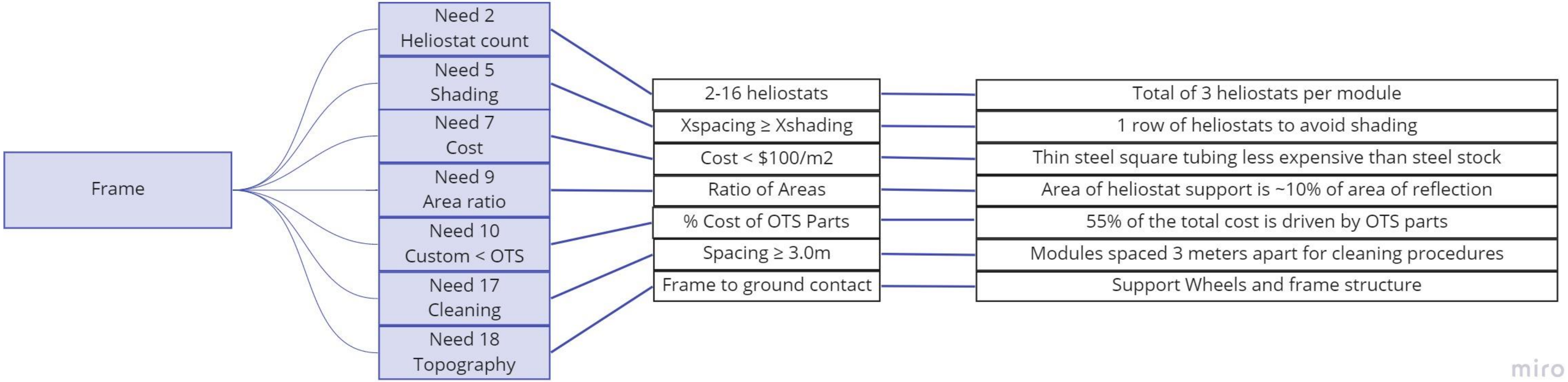
- Projection of heliostat field



Design Motivations

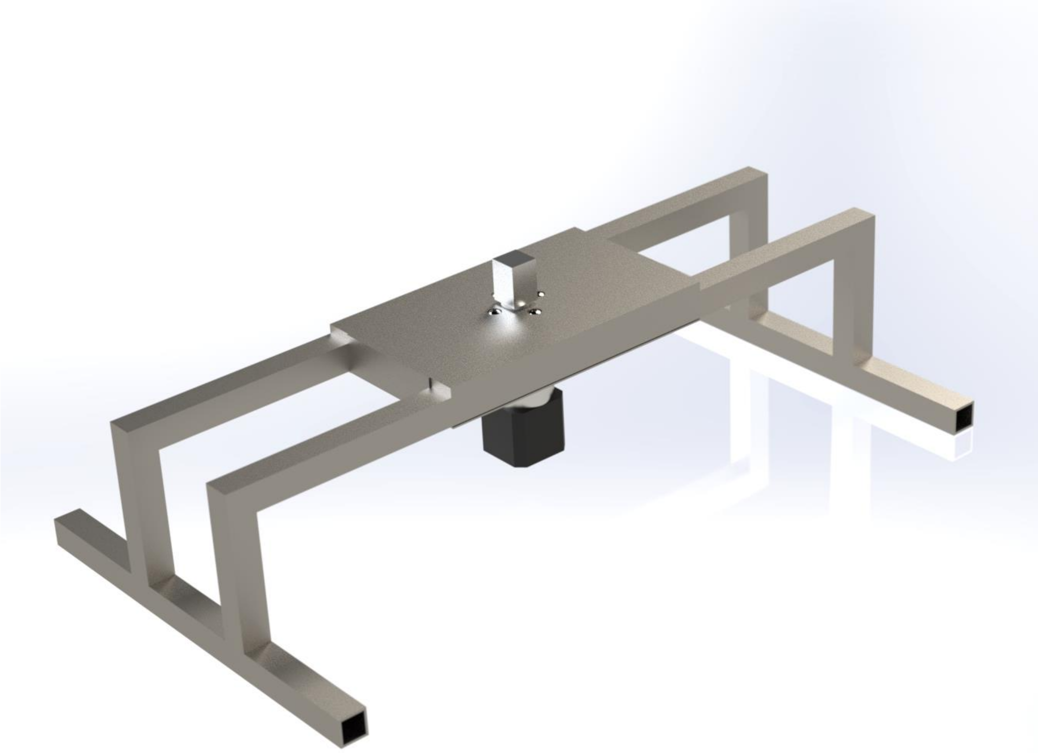
Our main design goal for this project was to create a heliostat module that used the least number of motors per individual reflective surface. Using as few motors as possible while still allowing independent rotation of each reflective surface strikes the perfect balance between simplicity and functionality. Having less motors reduces the cost as well as the potential risk of failure of the system and allows the system to be more easily repaired and maintained in the future.

Customer Needs Map

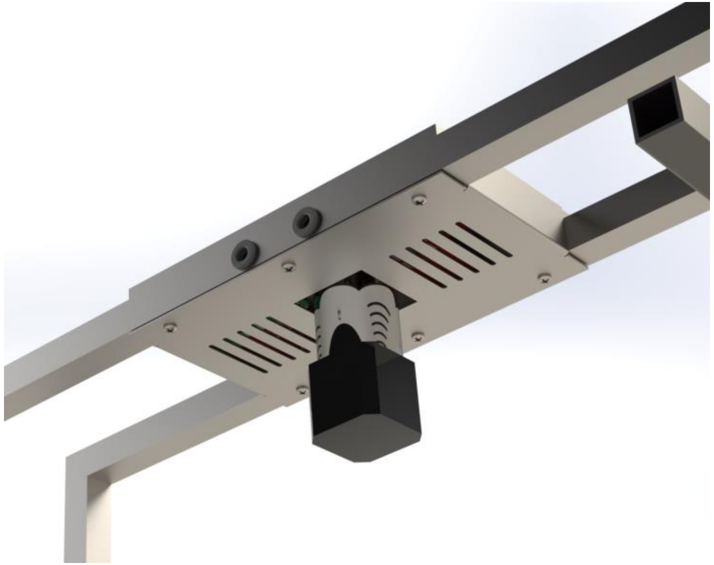


Frame

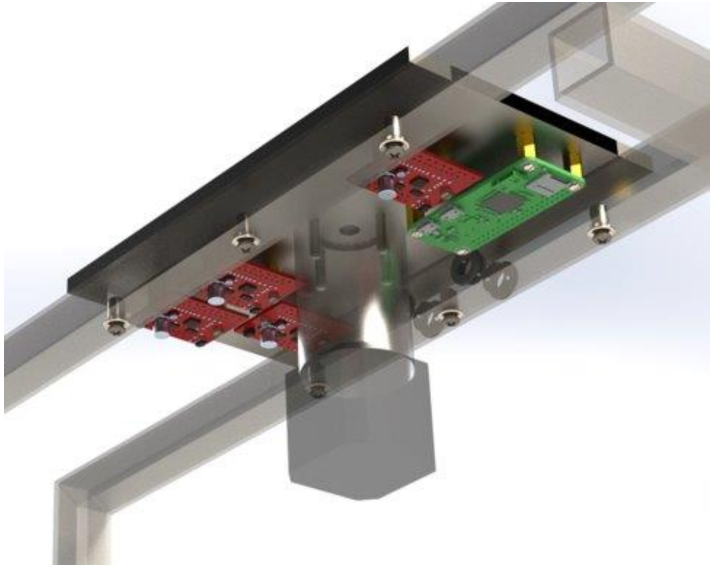
- ¾ inch steel frame structure
- Nema 17 central motor
- Raspberry Pi Zero W microcontroller and Big Easy motor drivers
- Shaft coupler



Frame

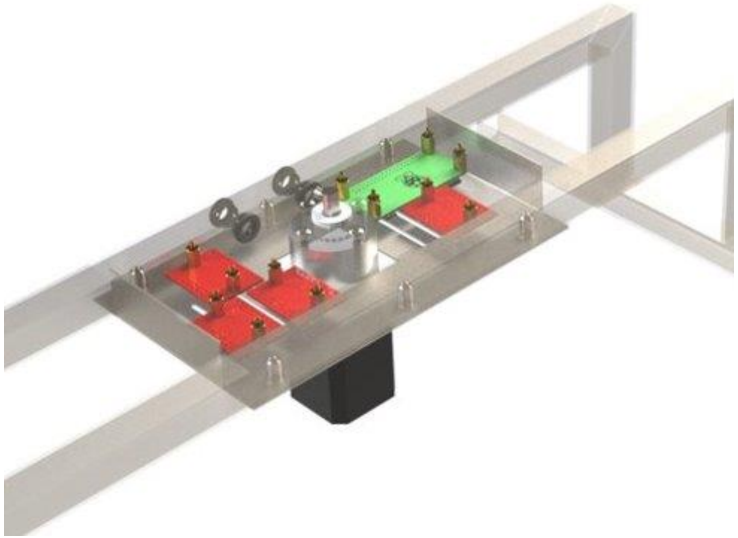


Electronics with shielding

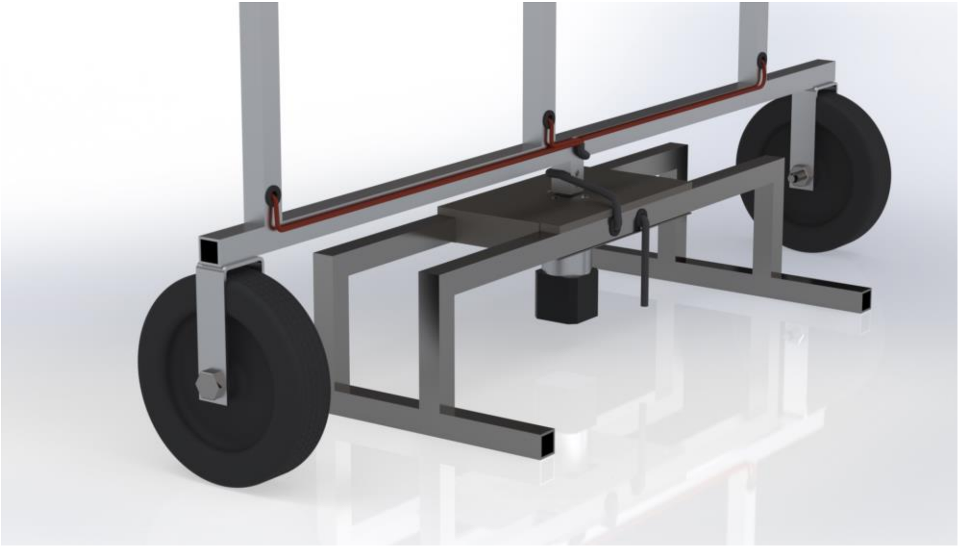


Electronics without shielding

Frame

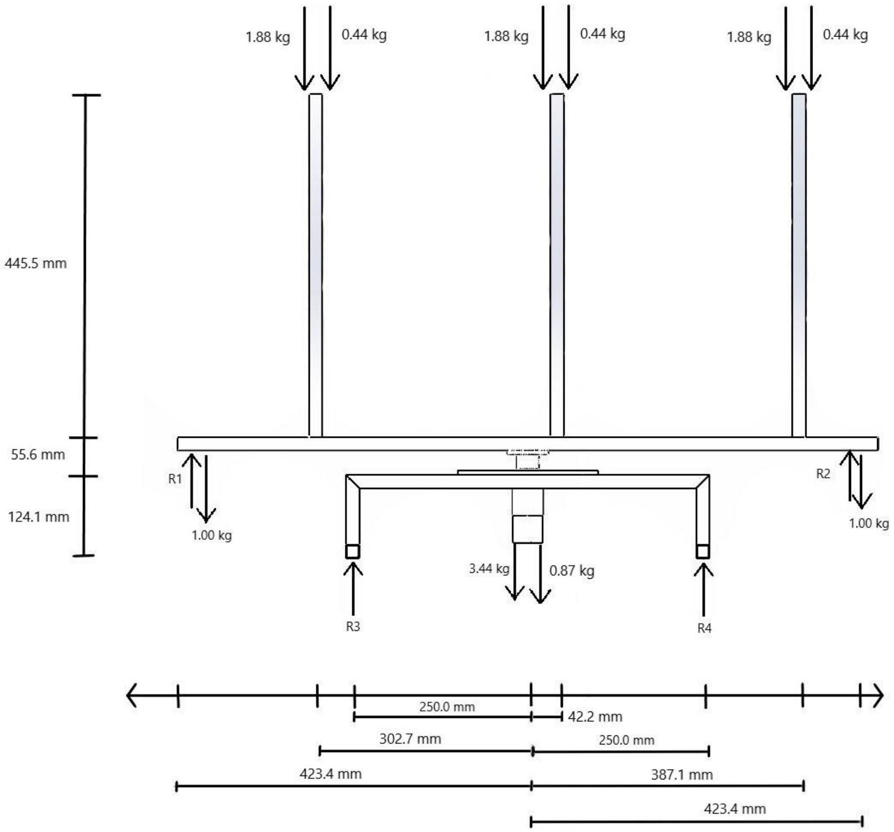


View of electronics from above



View of wiring layout

Frame


1.88 kg
0.44 kg
1.88 kg
0.44 kg
1.88 kg
0.44 kg
445.5 mm
55.6 mm
124.1 mm
R1
1.00 kg
R2
1.00 kg
3.44 kg
0.87 kg
R3
R4
250.0 mm
42.2 mm
302.7 mm
250.0 mm
423.4 mm
387.1 mm
423.4 mm

Frame

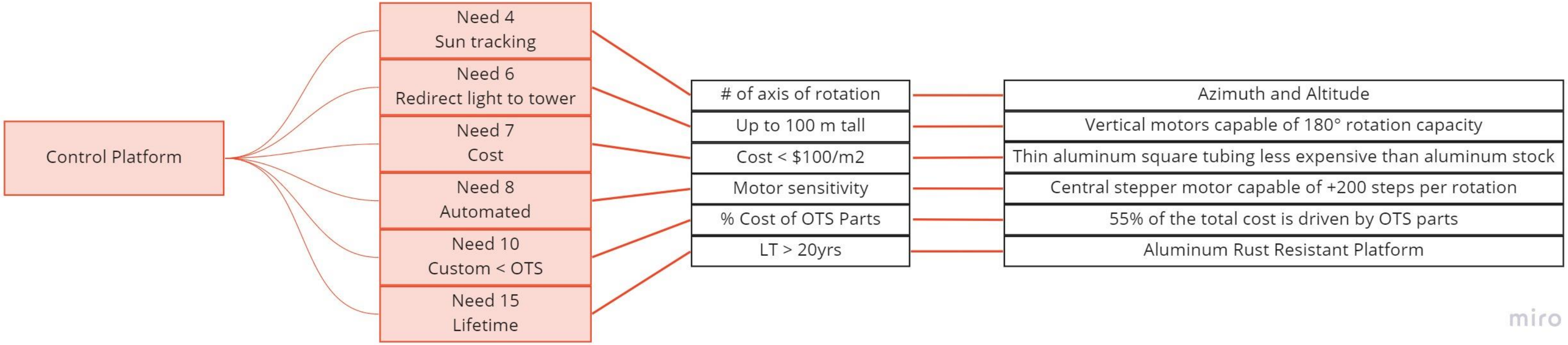
Central motor torque calculation:

$$\tau = \sum(F_i * d_i)\ \textit{where F is the Force (N) and d is the distance in (m)}$$

$$\tau = [(1.88 + 0.44) * (9.81)] * \left[\frac{302.7+42.2+387.1}{1000}\right]$$

$$\tau = 16.7\ Nm$$

Customer Needs Map

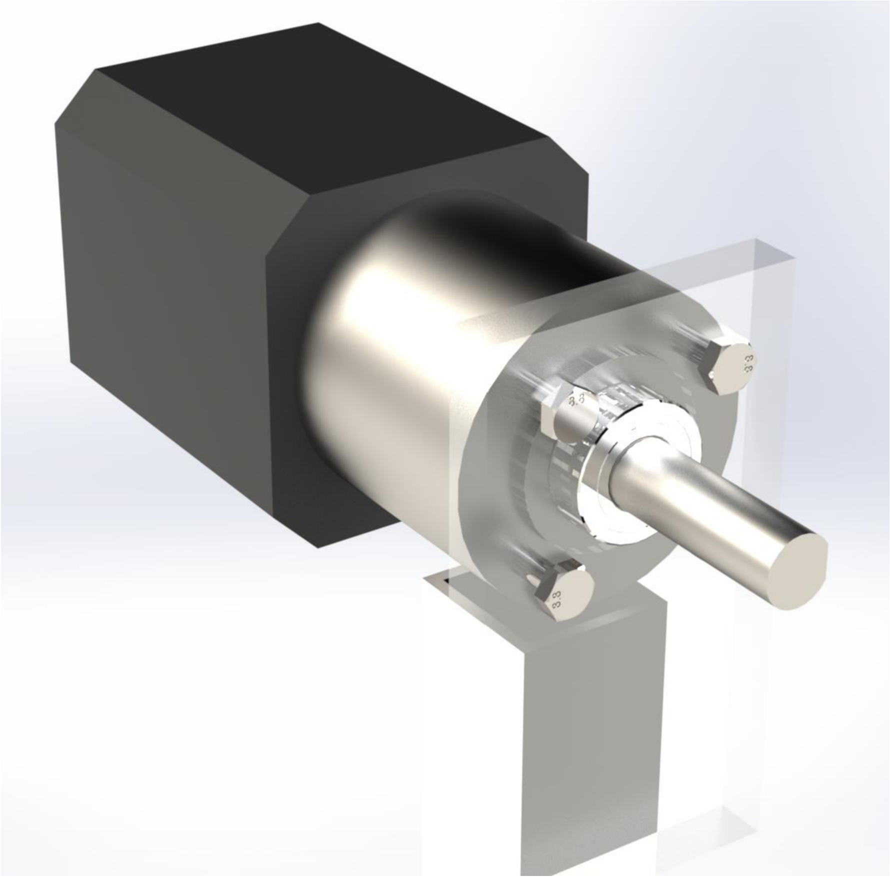


Control Platform

- Support wheels to alleviate load on central motor
- ¾ inch aluminum control frame
- Tri-beam design for individual mirror rotation

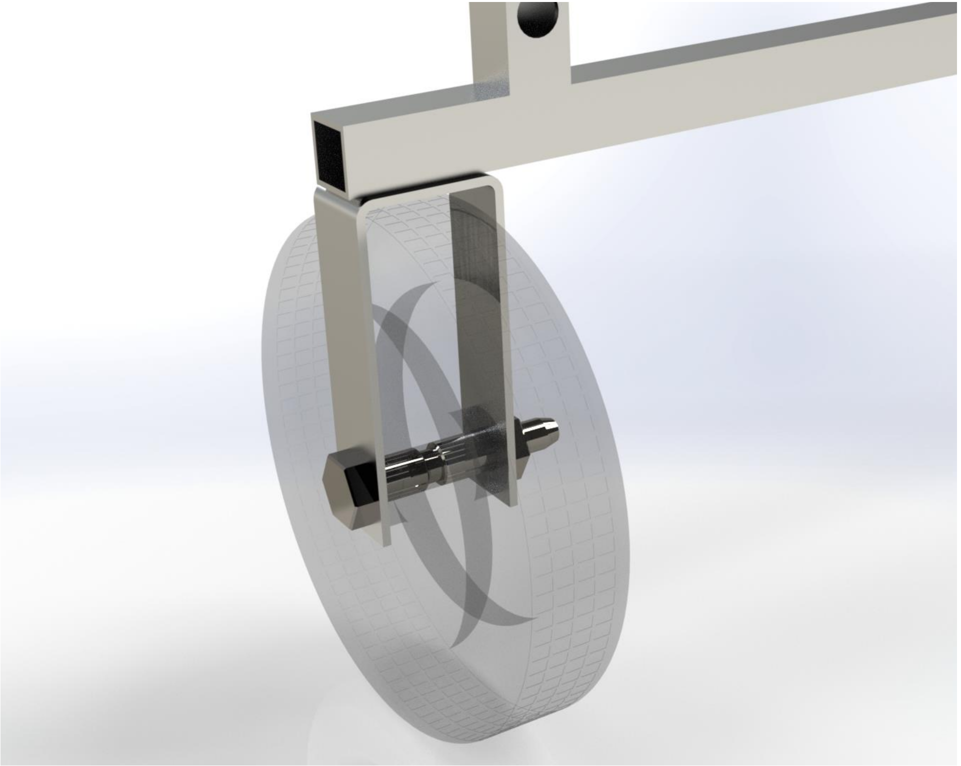
Control Platform

- Stepper motor with planetary gearbox
- ¼ inch aluminum motor bracket
- Axial support ball bearing



Control Platform

- 10-gauge aluminum wheel bracket
- 6-inch hard rubber all-terrain wheels



Control Platform

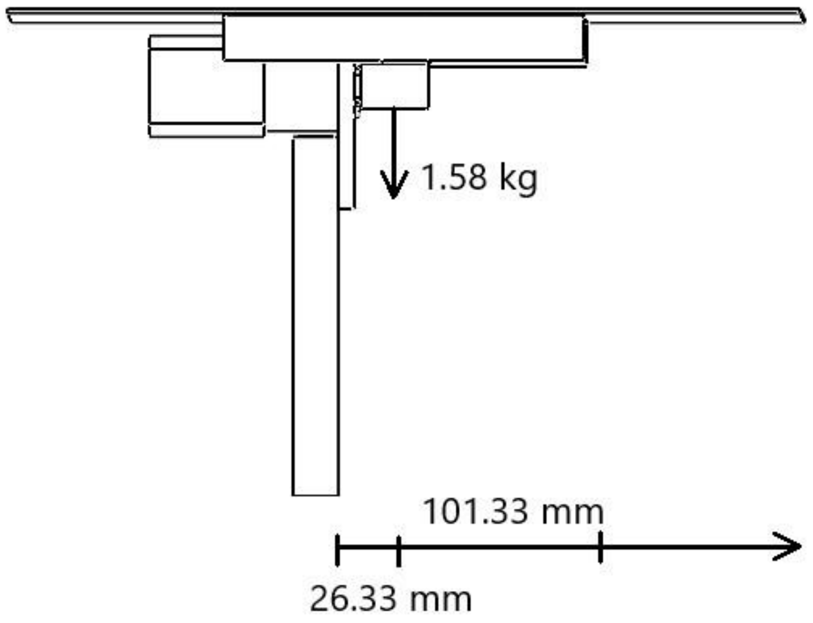
Upper motor torque calculation:

$$\tau = \sum(F_i * d_i)$$

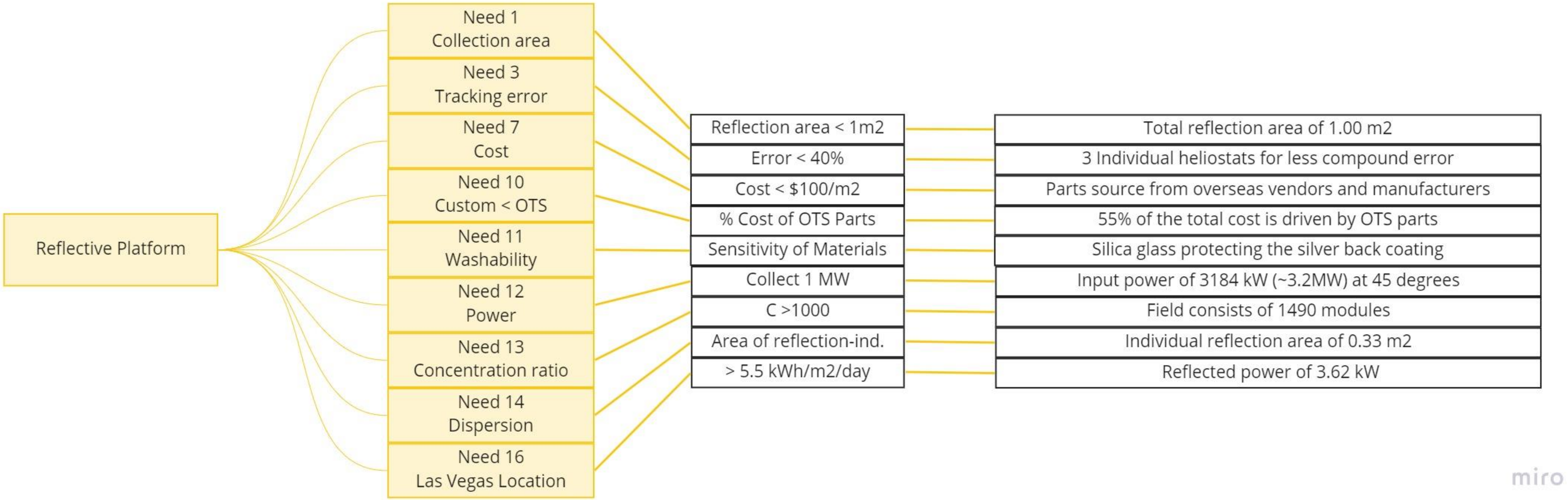
$$where\ F\ is\ the\ Force\ (N)$$
$$and\ d\ is\ the\ distance\ in\ (m)$$

$$\tau = [(1.58) * (9.81)] * \left[\frac{26.33}{1000}\right]$$

$$\tau = 0.41\ Nm$$

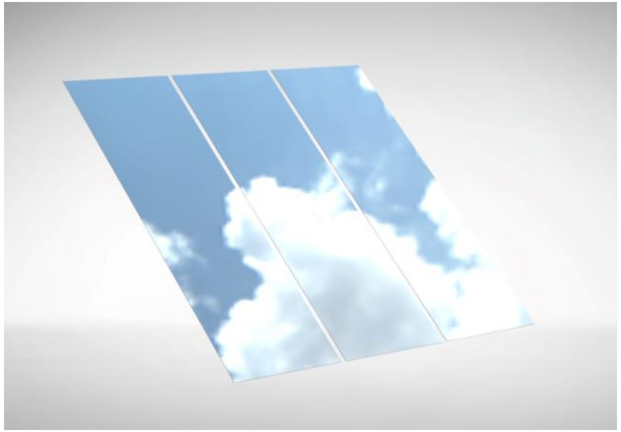


Customer Needs Map



Reflection Platform

- Glass surface backed by reflective mirror coat
- ¾ inch aluminum I-beam support



Reflection Platform

Reflection area:

$$SA_{Reflection} = \sum_{i=1}^{n} SA_{Mirror,i}$$

$$SA_{Reflection} = \sum_{i=1}^{3} 0.335 = 3(0.335) = 1.00\ m^2$$

Total reflection area for 1 module: 1.00 m^2

Reflection Platform

Receiver area:

$$Y = 100\sin(0.5°) = 0.8727\ m$$

$$Y_{Receiver} = 0.6 \times Y_{Reflection} + 0.8727$$

$$Y_{Receiver} = 0.6 \times 0.9906 + 0.8727 = 1.467\ m$$

$$A_{Receiver} = Y_{Receiver} \times X_{Reflection}$$

$$A_{Receiver} = 1.467 \times 1.016 = 1.49\ m^2$$

The minimum required receiver area is 1.49 m^2

Reflection Platform

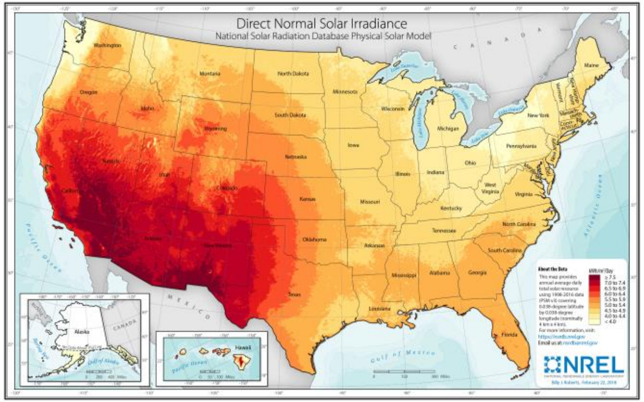
Number of modules required to achieve a concentration ratio of 1000 suns:

$$N = \frac{A_{Receiver} \times C}{SA_{Reflection}}$$

$$N = \frac{1.49 \times 1000}{1.00} = 1490$$

For this module design and receiver area, 1490 modules are required in the field.

Reflection Platform



Source: https://www.nrel.gov/gis/solar-resource-maps.html

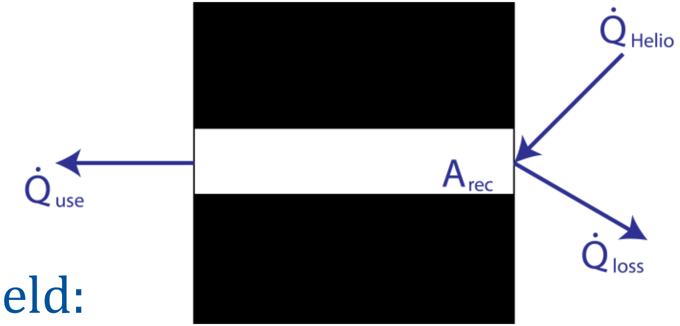
Reflected power of a single module:

$$\dot{Q}_{Mod} = G_{bn} cos\theta \times SA_{Reflection} \times \zeta_R$$

$$\dot{Q}_{Mod} = (5.5)\cos(45) \times 1 \times 0.93 = 3.62\ kW$$

The reflected power reflected by a single module in the Las Vegas environment at an incidence angle of 45 degrees is 3.62 kW

Reflection Platform



Useful thermal input power of all modules in the field:

$$\dot{Q}_{use} = \dot{Q}_{Helio}\eta_{opt}N - A_{rec}\sigma T_{rec}^4$$

$$\dot{Q}_{use} = (3.62)(0.6)(1490) - (1.49)(5.67 \times 10^{-11})(873)^4$$

$$\dot{Q}_{use} = 3187\ kW$$

The useful thermal input power for all modules is 3.2 MW

Wind Force Calculations

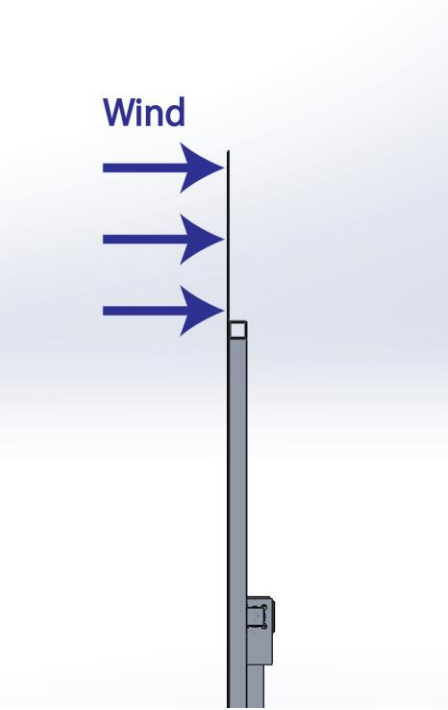
Average Weight of US Gallon : 8.3 lbf

7.00in x 13.3in mirror: 0.648 ft^2

Max Wind Speed: 52 MPH

Wind Speed Source:

http://lumber.soundcedar.com/calculators/force.wind2014.php?



Wind Force Calculations

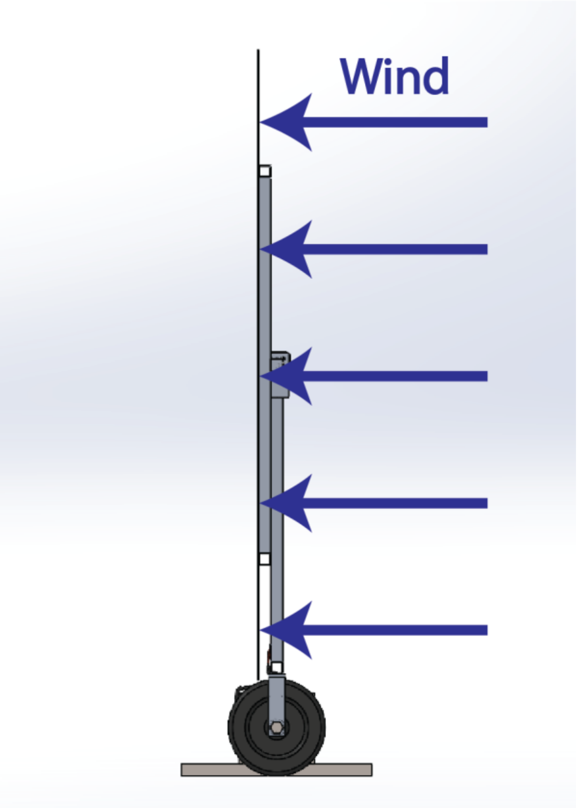
J-B Weld™ Tensile Strength: 5020 PSI (34.6 MPa)

Area of I beam: 0.0170 m2

Tensile Failure Force: 588 kN (132 kips)

Area of Mirror: 13.33in x 39in = 3.52 ft

Maximum Wind Speed: 200 MPH+



Wind Speed Source: http://lumber.soundcedar.com/calculators/force.wind2014.php?

J-B Weld: https://www.jbweld.com/product/j-b-weld-professional-size

Wind Force Calculations

Axial force on upper motors:

Max Radial Force of Motor Shafts: 80 N

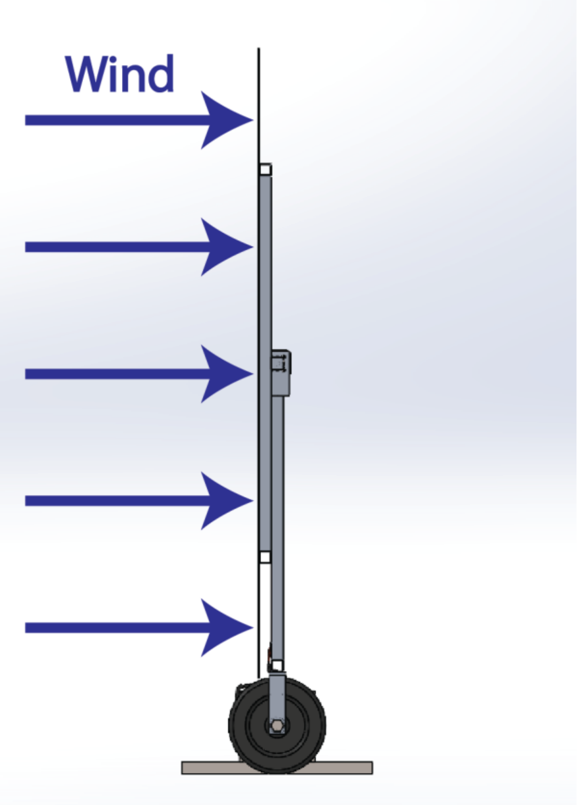
Max Wind Speed: 34 MPH

New Bearing Design: 588 N

Max Wind Speed: 90 MPH

Bearing Cost: $5.39

Wind Speed Source: http://lumber.soundcedar.com/calculators/force.wind2014.php?



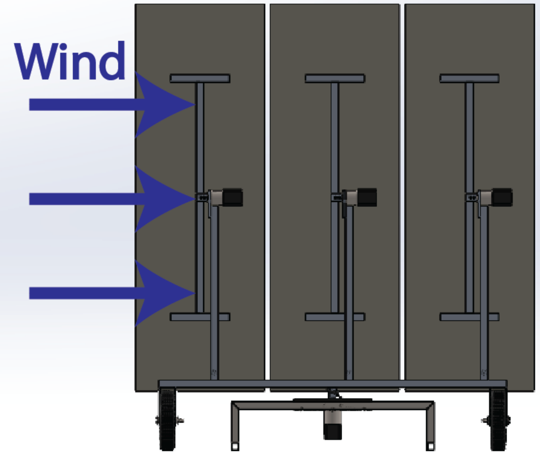
Wind Force Calculations

Natural frequency:

$$f = \frac{1.732}{2\pi}\sqrt{\frac{EIg}{FL^3 + 0.236WL^4}}$$

Minimum f allowed: 1 hz

f decreases as F increases: 200 MPH+



Roark's Formula for Stress and Strain 7th ed., Chapter 16, Table 16.1, page 765.

Wind Speed Source: http://lumber.soundcedar.com/calculators/force.wind2014.php?

https://www.cppwind.com/wp-content/uploads/2020/12/WindLoadsDynamicResponses-Boggs2006.pdf

Wind Force Calculations

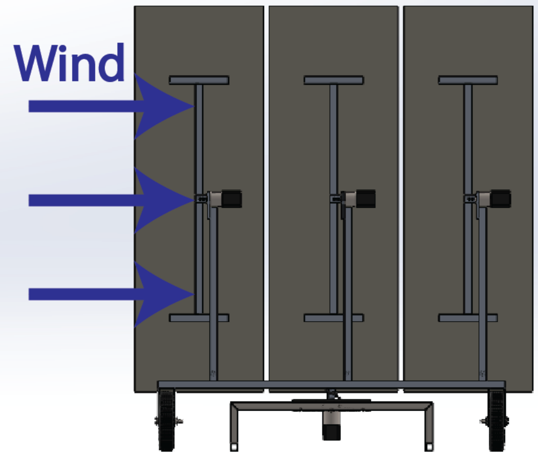
Deflection:

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

Distance between Mirrors: 14.1 mm

Max F: 105 N or 23.6 lbf

Max Wind Speed: 175 MPH



Wind Speed Source: http://lumber.soundcedar.com/calculators/force.wind2014.php?

Cost Discussion

- Material cost: $ 253.45
- Material cost (w surplus fasteners): $ 321.94
- Material cost (w shipping): $ 592.67

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