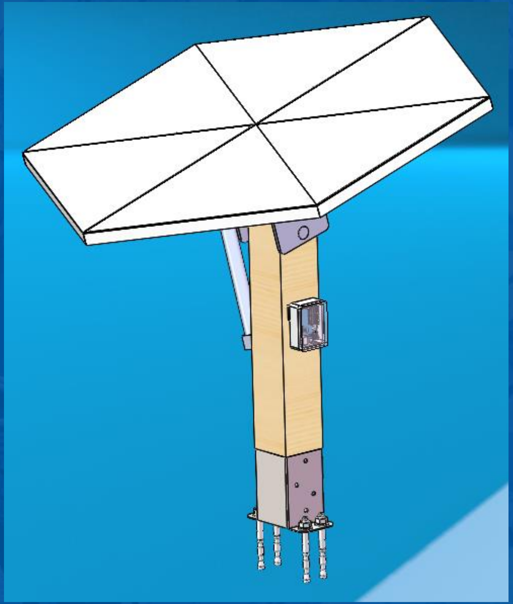
UF Herbert Wertheim College of Engineering
UNIVERSITY *of* FLORIDA

The Hive-Stat

Small-Scale Modular Tracking Heliostat



Group 13

Jake Anderer, Charles Datko, Kevin Diaz, Erika Joa, Joseph Miller, Akshay Ramakrishnan, Dari Samson

POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE

Meet the Team!

Dari Samson

Akshay Ramakrishnan

Jake Anderer

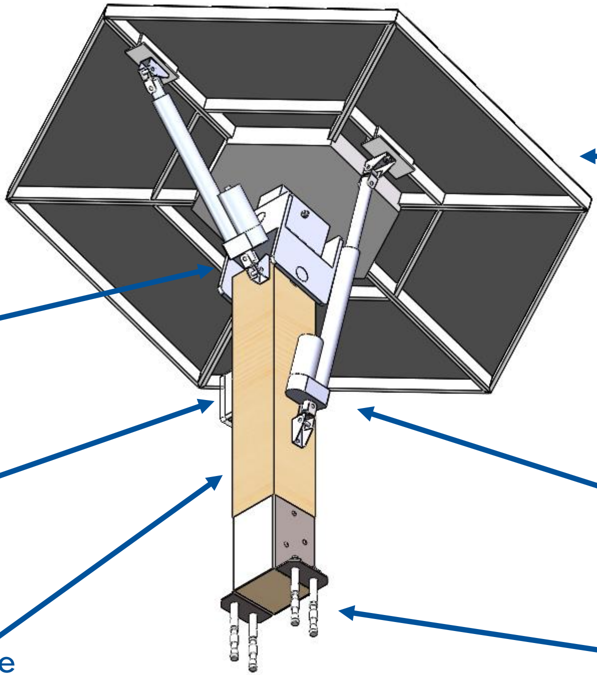
Joseph Miller

Kevin Diaz

Erika Joa

Charles Datko

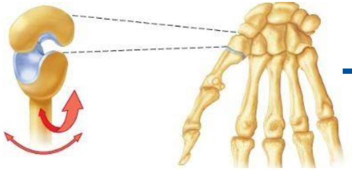
Design Problem

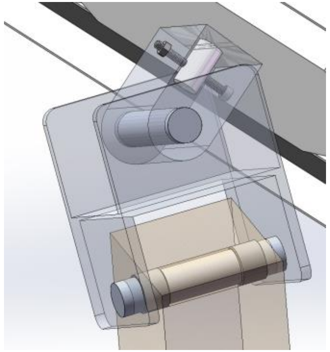


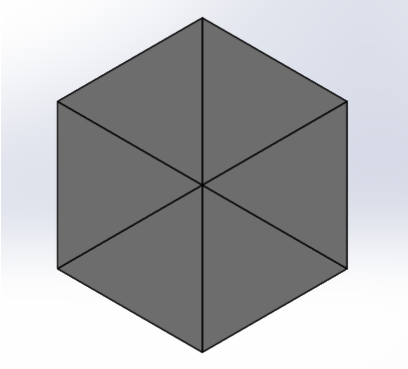
Total Mirror Area: 0.6 m^2

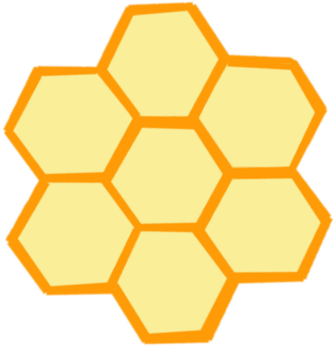
Height at Neutral Position: 0.8 m

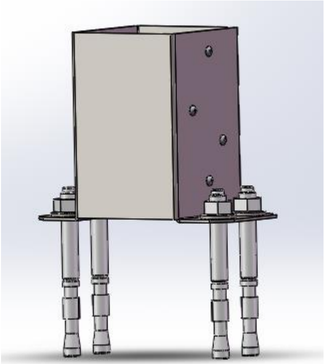
Inspiration from Nature

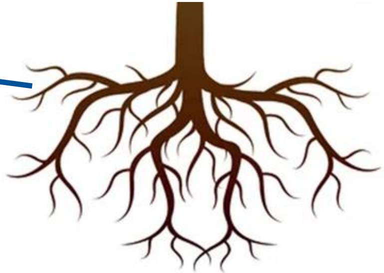








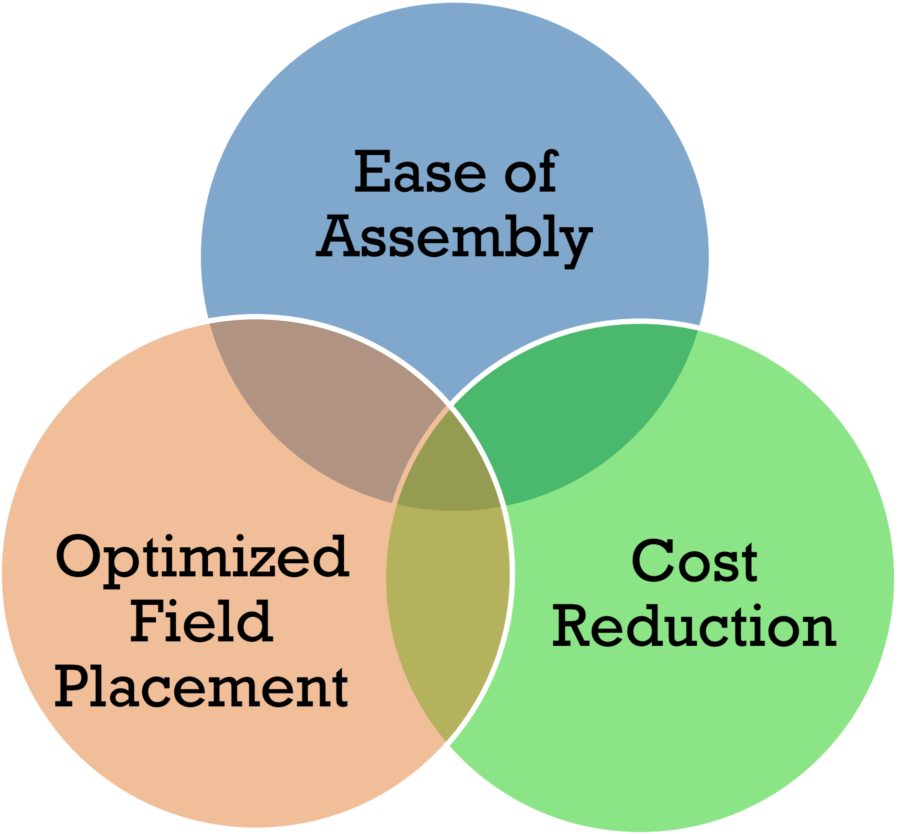


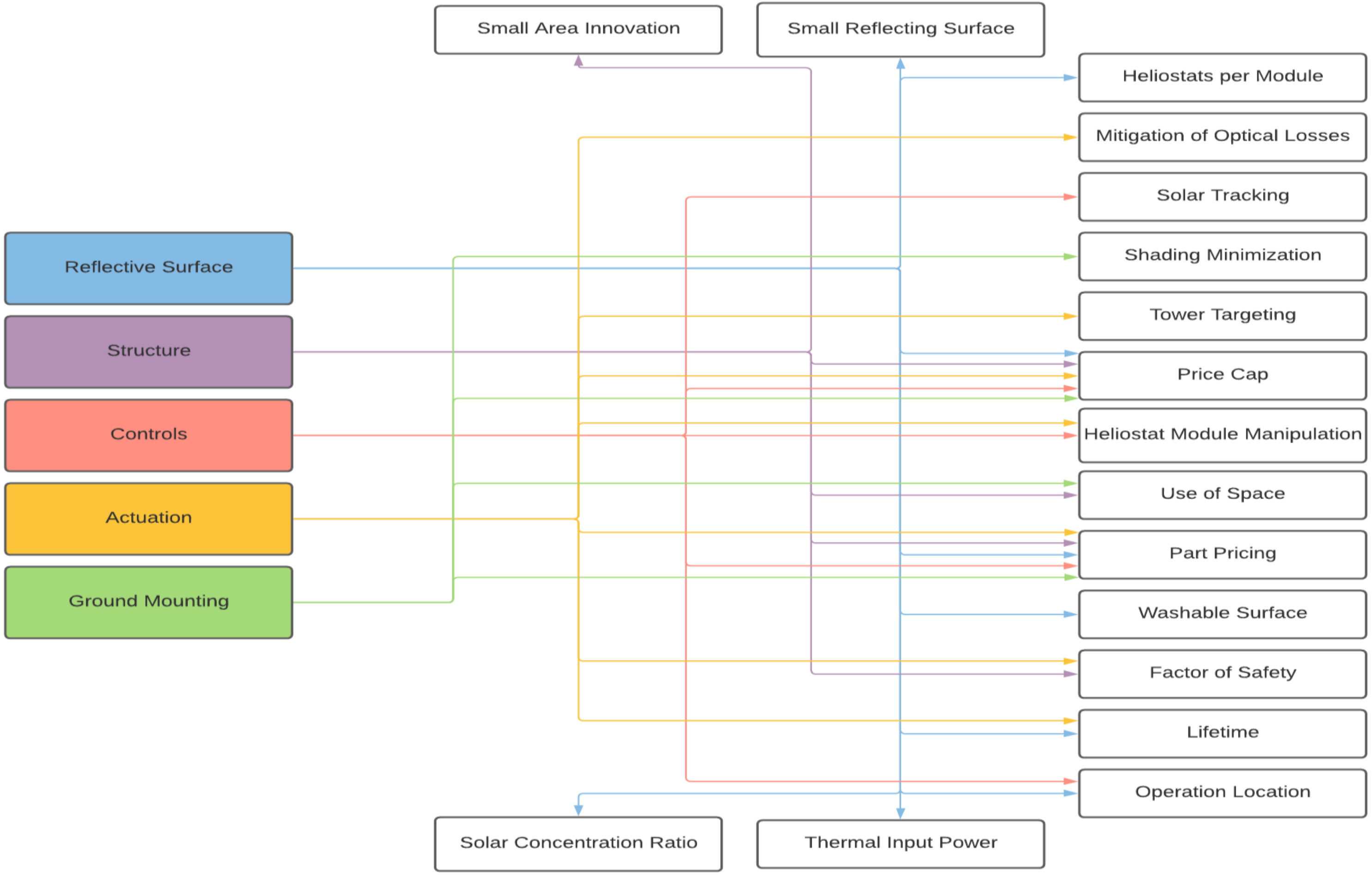


Ease of Assembly- Straightforward assembly for a faster setup time

Optimized Field Placement- The design is optimized to deliver efficiency in a multitude of positions

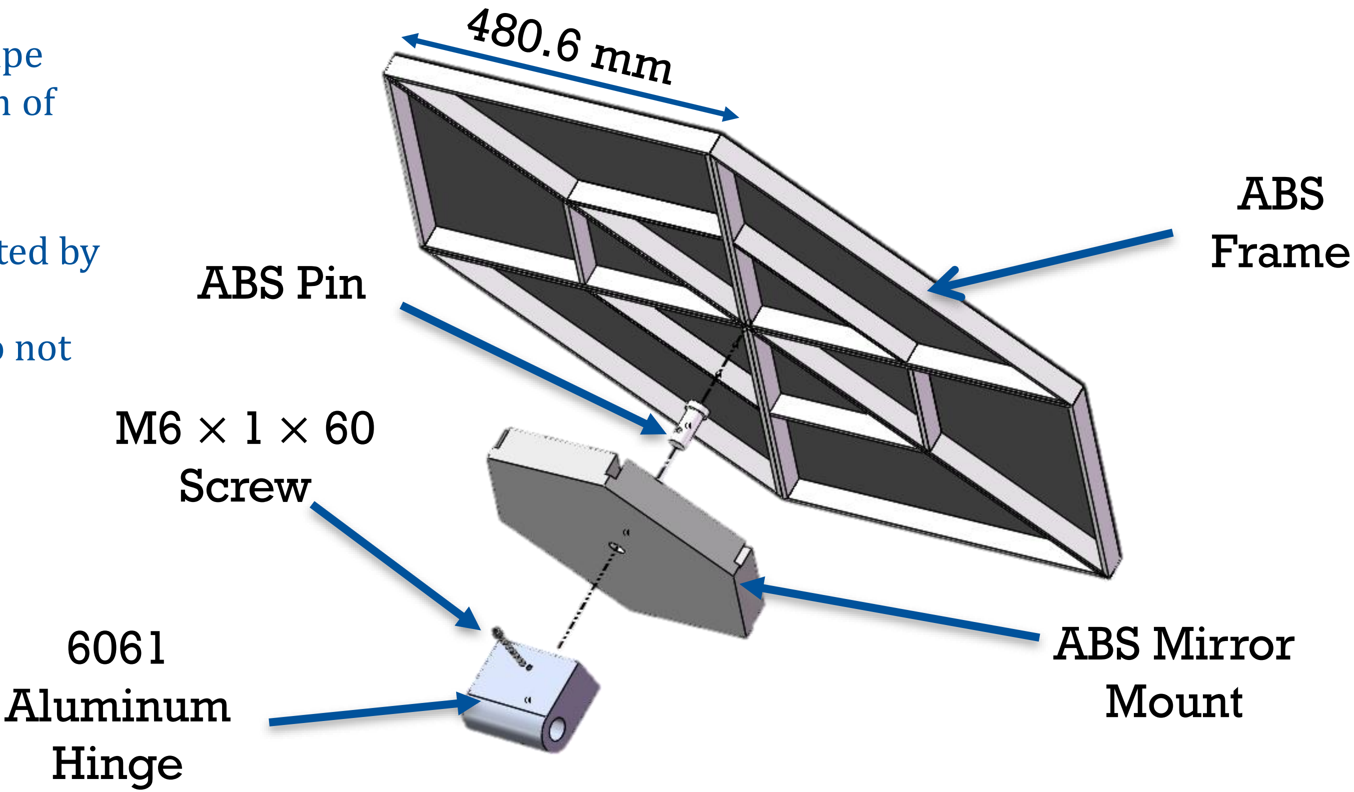
Cost Reduction- Cost reduced by using more common materials and off the shelf parts




Small Area Innovation
Small Reflecting Surface
Heliostats per Module
Mitigation of Optical Losses
Solar Tracking
Shading Minimization
Tower Targeting
Price Cap
Heliostat Module Manipulation
Use of Space
Part Pricing
Washable Surface
Factor of Safety
Lifetime
Operation Location
Reflective Surface
Structure
Controls
Actuation
Ground Mounting
Solar Concentration Ratio
Thermal Input Power

Reflective Surface

- Hexagonal compact shape allows close tessellation of heliostats
- Shading effects eliminated by spacing heliostats close together so shadows do not reach reflective surface



Reflective Surface Cont.

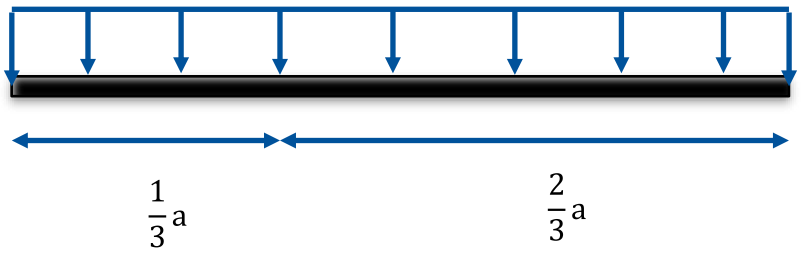
- Thermal Input Power, N = number of heliostats per module

$$TIP = 500 \cdot A_{helio} \cdot N = 500 \cdot 0.1m^2 \cdot 6 = 300\ W$$

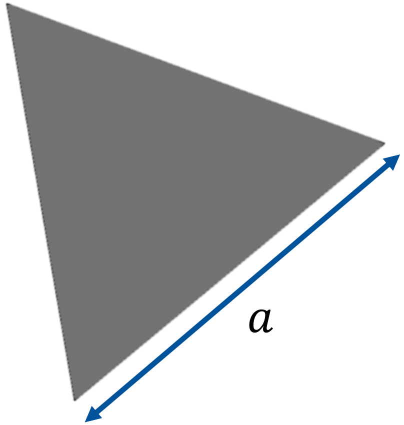
- Solar Concentration Ratio, assuming solar irradiance of $1000\text{W}/\text{m}^2$ and a collector area around the size of one heliostat

$$SCR = \frac{2000}{N} = \frac{2000}{6} = 333.33\ Suns$$

Reflective Surface Cont.



$$P = \frac{1}{2}\rho V^2 A C_d$$



$$u(x,y) = \frac{P}{64Da}\left(x^3 - x^2a - 3xy^2 - y^2a + \frac{4}{27}a^3\right)\left(\frac{4}{9}a^2 - x^2 - y^2\right)$$

$$D = \frac{Et^3}{12(1-\upsilon^2)} \qquad a = \frac{\sqrt{3}}{2}l$$

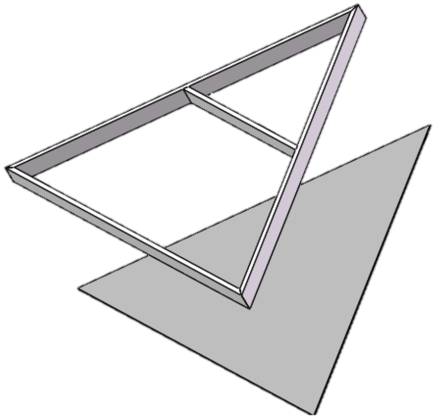
$$u_{max} = u(0,0) = \frac{Pl^4(1-\upsilon^2)}{144Et^3} = \frac{5.75\times0.48^4(1-0.22^2)}{144\times0.070\times0.002^3} = \boxed{7.5\ mm}$$

Reflective Surface Cont.

$$\alpha Q_{sun} - \varepsilon\sigma\left(T^4 - T_{sky}^4\right) - \mathrm{h}(T - T_{air}) = MC_p \frac{dT}{dt}$$

$$\alpha = \frac{1}{Q_{sun}}\left[MC_p\frac{dT}{dt} + \varepsilon\sigma(T^4 - T_{sky}^4)\right]$$

$$Q_{sun}\alpha = \varepsilon\sigma\left(T^4 - T_{sky}^4\right) - \mathrm{h}(T - T_{air})$$



$$7.62\left[\frac{kW}{m^2}\right] \times 0.09 = 0.03 \times (5.67 \times 10^{-8})\left[\frac{W}{m^2K^4}\right] \times (T^4 - 300^4)[K] + 2\left[\frac{W}{m^2K}\right] \times (T - 313.15)[K]$$

$$\boxed{T = 285.49°\ C}$$

Structure

$q = \frac{1}{2} \rho v^2$

$v = 12.38$ m/s
$\rho = 1.225$ kg/m^3

$q = 93.874$ N/m^2

$F = qA$

$A = 0.6$ m^2
$q = 93.874$ N/m^2

$F = 56.325$ N

$Mmax = Fr$

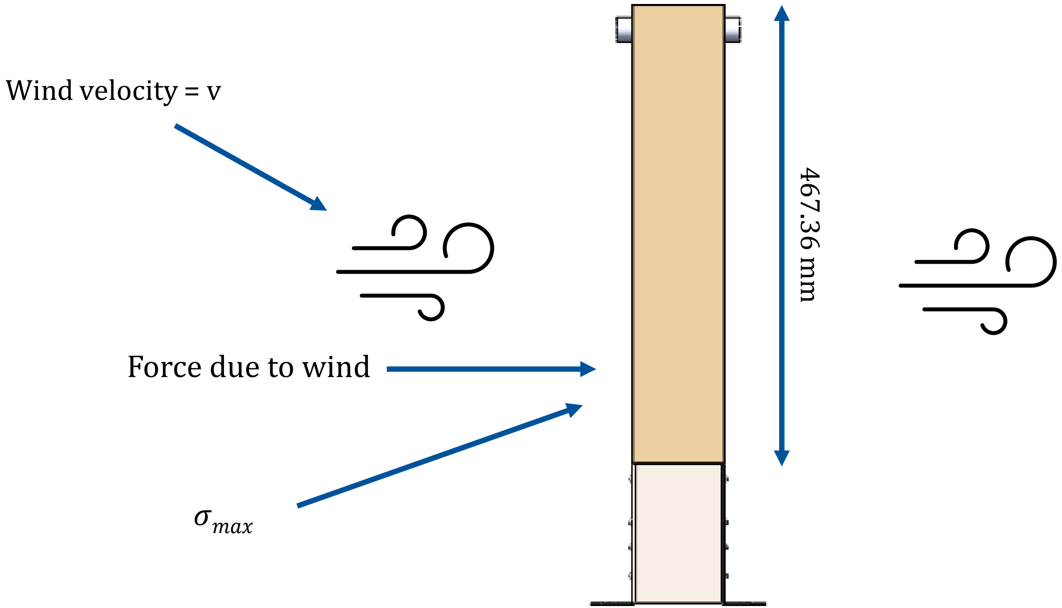
$F = 56.325$ N
$r = 609.6$ mm

$M_{max} = 34.335$ N-M

$I = (a_1^4 / 12)$

$a_1 = 13.54$ in^2

$I = 2{,}800.872$ in^4



$\sigma_{max} = y{*}Mmax / I$

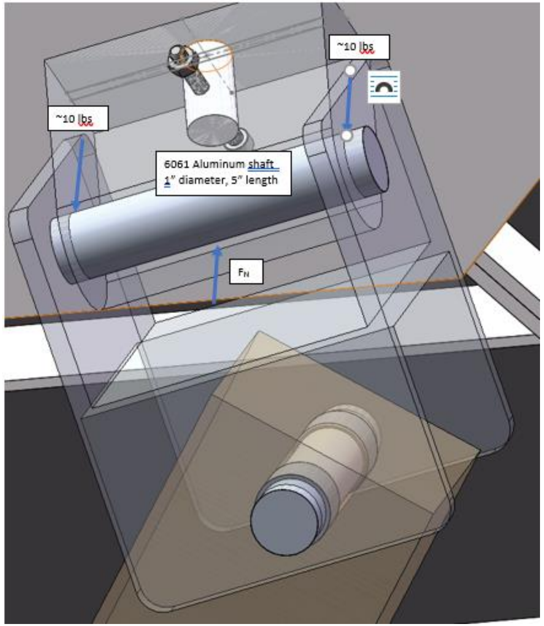
$Mmax = 34.335$ N-M
$y = 6.77$ in^2
$I = 2{,}800.872$ in^4

$\sigma_{max} = 82.99$ kPa

Yield strength of wood (2.1mPa) > σ_{max}

Structure Cont.

Item	Weight
Mirror + mirror body	16 lbs
Hinge + pole + shaft	4.28 lbs

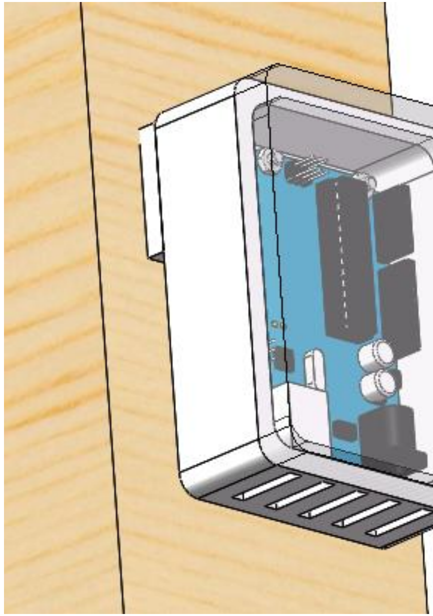


Using Shigley's 8th Ed. Shaft Bending Stress Eq. 7.3, assuming a well-rounded shaft for stress concentration:

$$\sigma = K_p \frac{32M_a}{\pi d^3} = 1.7 \frac{32(2 * 10\ lbs * 2")}{\pi * 1^3} = 1732psi$$

Assuming a shear stress for 6061 aluminum as 30000psi and a fatigue strength of 14000psi for 500 million cycles, the factor of safety for near infinite life is about 8 and for peak loads about 17.

Controls Hardware cont.



•Bidirectional control for two brushed DC motor (DC 4V to 16V).
•Control one unipolar/bipolar stepper motor.
•Maximum Motor Current: 3A continuous per channel, 5A peak.
•Buck-boost regulator to produce 5V output (200mA max).

Microcontroller	ATmega328P
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limit)	6-20V
Digital I/O Pins	14
PWM Digital I/O Pins	6
Analog Input Pins	6
DC Current per I/O Pin	20 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB
SRAM	2 KB
EEPROM	1 KB
Clock Speed	16 MHz

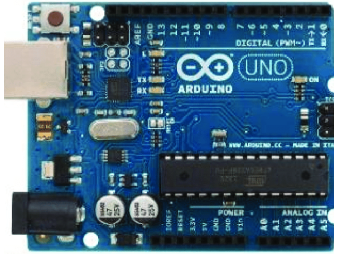


Figure. 1 Arduino Uno

Controls Hardware cont.

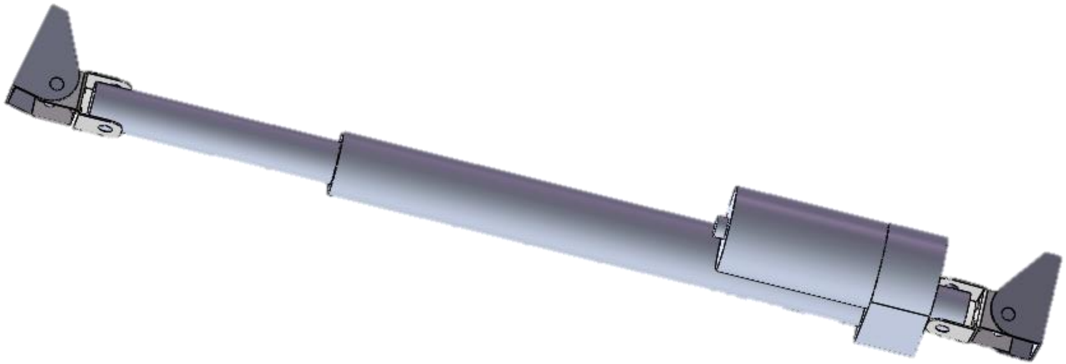
PRODUCT PARAMETERS

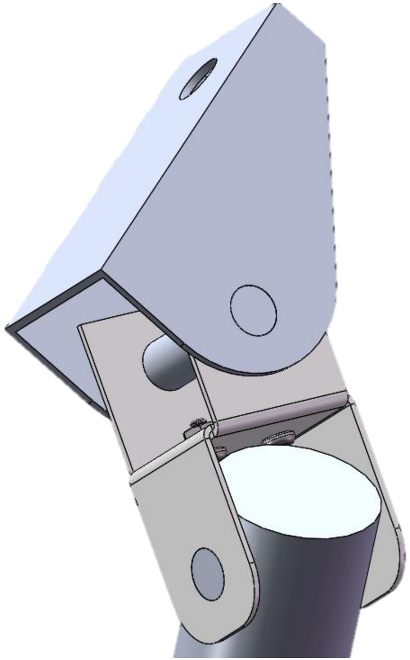
1500N Electric Putter	
Input Voltage:	12V DC
Max Push Load:	1500N/330lbs
Max load:	150KG/330lbs
Max Pull Load:	1000N/264lbs
Travel Speed:	0.39 in/sec
Duty Cycle:	20%
Material:	Aluminum alloy
Color:	Silver grey
Operation temperature:	-26~+65°C
Protection Class:	IP54
No-load current:	0.8A
Max load current:	3A

- With a speed of 10 mm/s, it would take about 35 seconds for the actuator to fully extend
- The actuator is more than fast enough to track the Sun as it travels
- Max power draw of 36 W for the actuator; 12.8V battery with 10aH
- Allows for 2 hours of full load continuous operation and 9 hours of low load continuous operation with a 20% reserve capacity

Actuation

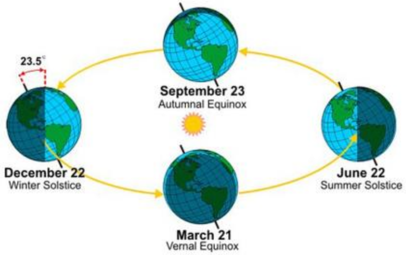
- Angle control using two linear actuators
- Actuators each have two 2-axis joints for independent movement
- Reduced risk of damage to mirror in case of malfunction





Actuation Cont.

- Heliostats to be installed near Las Vegas, Nevada at 36.1699° N
- Earth's tilt of 23.5° gives a range of solar angles of 36.1699±23.5°= 59.67° to 12.67° from vertical in the South
- The Sun also moves 180° from East to West, but most energy is available when the Sun is high in the sky, making angles near the horizon less desirable to reach



Actuation Cont.

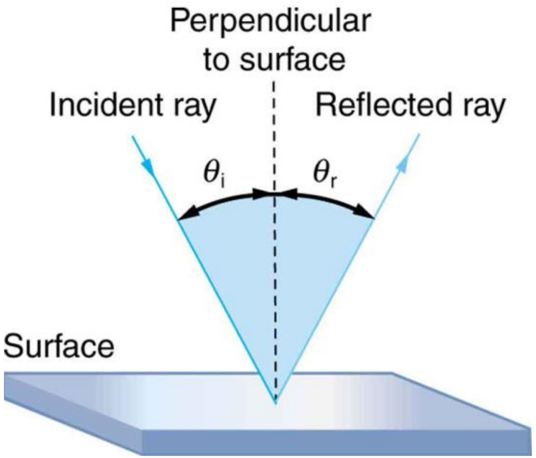
Assumption: Tower and heliostat field is North-South aligned with the tower in the South to minimize Sun-tower angle

Assumption: Heliostats are located between 50 and 100 meters from the tower

$$\theta_{min} = \tan^{-1}\frac{100m}{50m} = 63.43° \; above\ horizon = 26.57° \; from\ vertical$$

$$\theta_{max} = \tan^{-1}\frac{50m}{50m} = 45° \; above\ horizon = 45° \; from\ vertical$$

Actuation Cont.



- Heliostat works by reflecting light, so the Law of Reflection is used
- Angle of Incidence = Angle of Reflection
- Heliostat normal bisects angle between Sun and tower

Actuation Cont.

- Maximum heliostat angle North-South from vertical

$$Max = \max\left(solar\ angle - \frac{abs(Tower\ angle - solar\ angle)}{2}\right.$$

$$= 59.67 - \frac{59.67 - 45}{2} = 52.34° \text{ from vertical towards South}$$

- Minimum heliostat angle North-South from vertical

$$Min = \min\left(\frac{abs(Tower\ angle - solar\ angle)}{2} + solar\ angle\right)$$

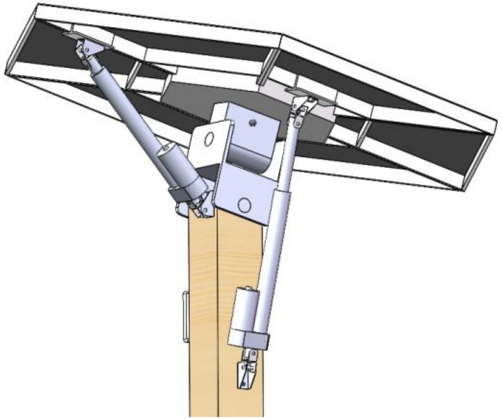
$$= \frac{26.57 - 12.67}{2} + 12.67 = 19.62° \text{ from vertical towards South}$$

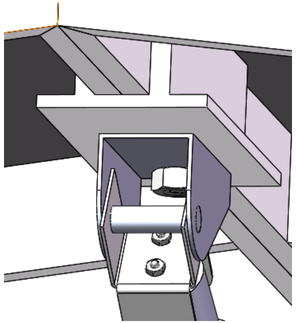
Actuation Cont.

- Maximum heliostat angle East-West from vertical
- Sun reaches fully West and fully East, 90° from tower in each direction

$$Min = Max = \frac{90 + 0}{2} = 45° \text{ from vertical in both directions}$$

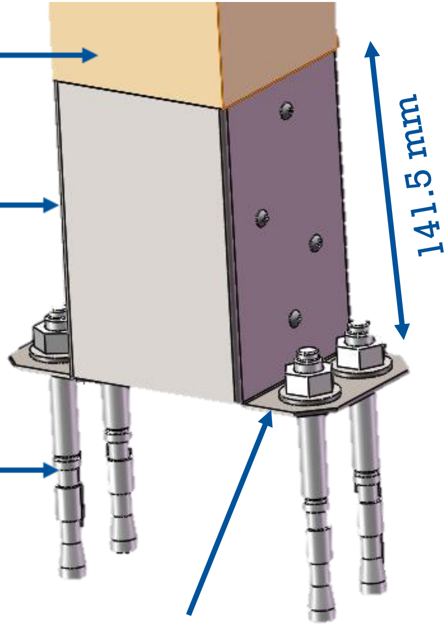
Actuation Cont.

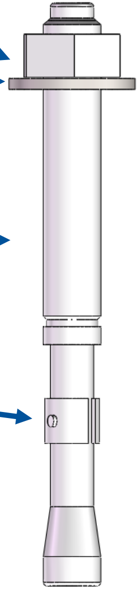




- North-South angle achieved by actuator mounted high on pillar, lowest angle needed is 0° for neutral position in storms
- East-West angle controlled by lower-mounted actuator for equal control in either direction
- Attached to plastic support by clips screwed onto connector

Ground mounting





Ground Mounting Cont.

Parallel Axis Theorem

$$I = 4\left(\frac{\pi d^4}{64} + \frac{\pi d^2}{4} L^2\right)$$

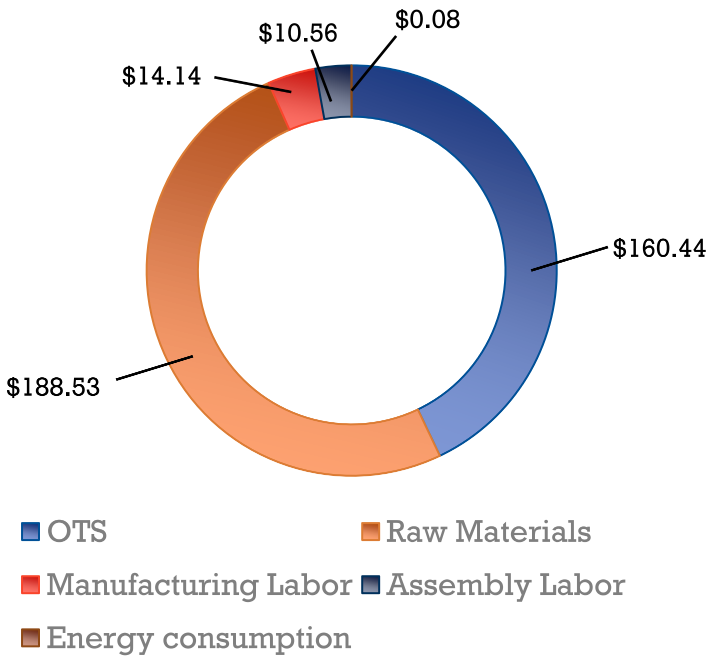
$$I = 4\left(\frac{\pi(0.032\ m)^4}{64} + \frac{\pi(0.032\ m)^2}{4} 0.1299\ ^2\right) = 0.209\ m^4$$

Failure Mode

$$\sigma_{max} = \frac{yM_{max}}{I}$$

$$\sigma_{max} = \frac{(0.1299\ m)(23.45\ N\ m)}{0.209\ m^4} = 14.57$$

Cost Table Summary



Total Cost: $373.75

*Retail pricing for prototyping is higher than for commercial/bulk quantities.

Why this design?

- Budget Friendly
- Unique & Modern Look
- Seamless Assembly
- Innovative
- Autonomous

Conclusion

- The Hive-Stat meets the standards for a 1 MW thermal-solar power plant using the reflected light of the Sun off heliostat surfaces
- The Hive-Stat is a unique and innovative design that accomplishes this, while also addressing the need for a small-scale easily deployable heliostat