UF Herbert Wertheim College of Engineering
UNIVERSITY of FLORIDA

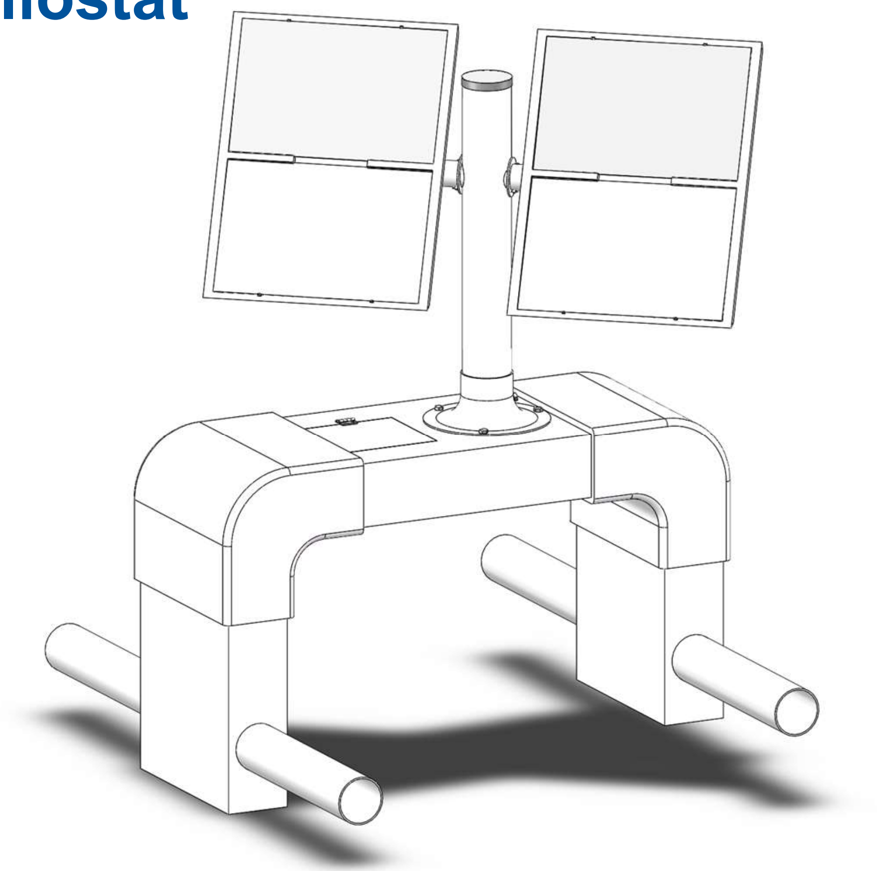
Dual-wing Heliostat

Section 13337, Group 8

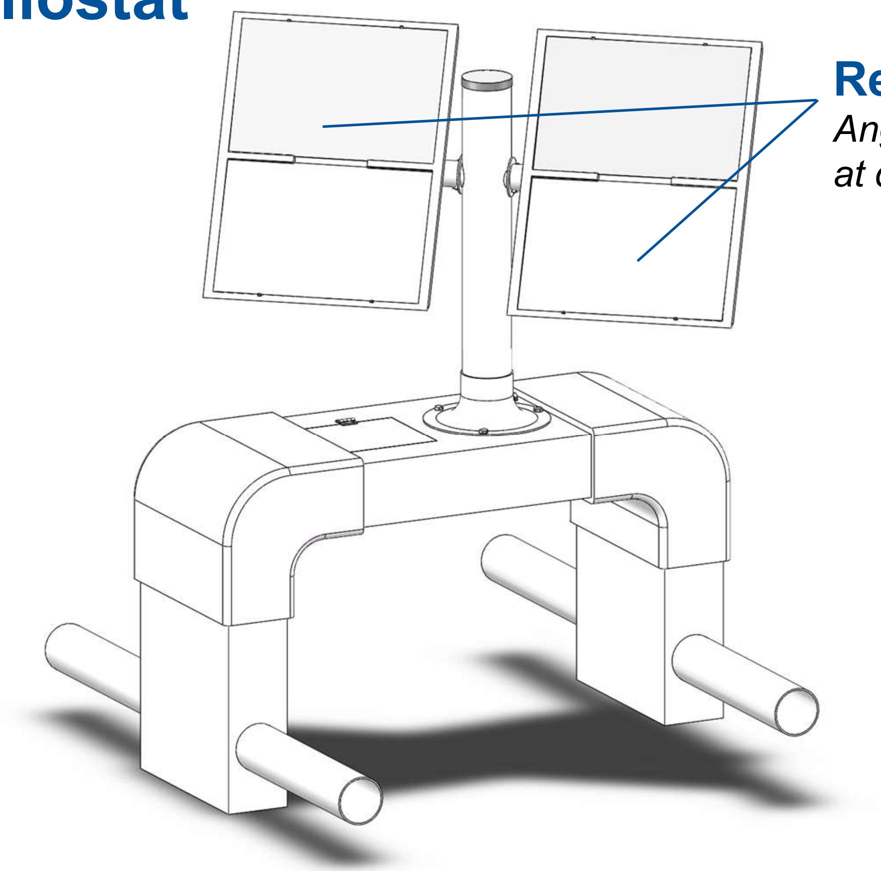
Nathan Brett, Kateland Hutt, Karl Jusino-Ortiz, Trevor Perez, Joseph Rios, Samantha Scholl, Devon Yon

POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE

Dual-wing Heliostat



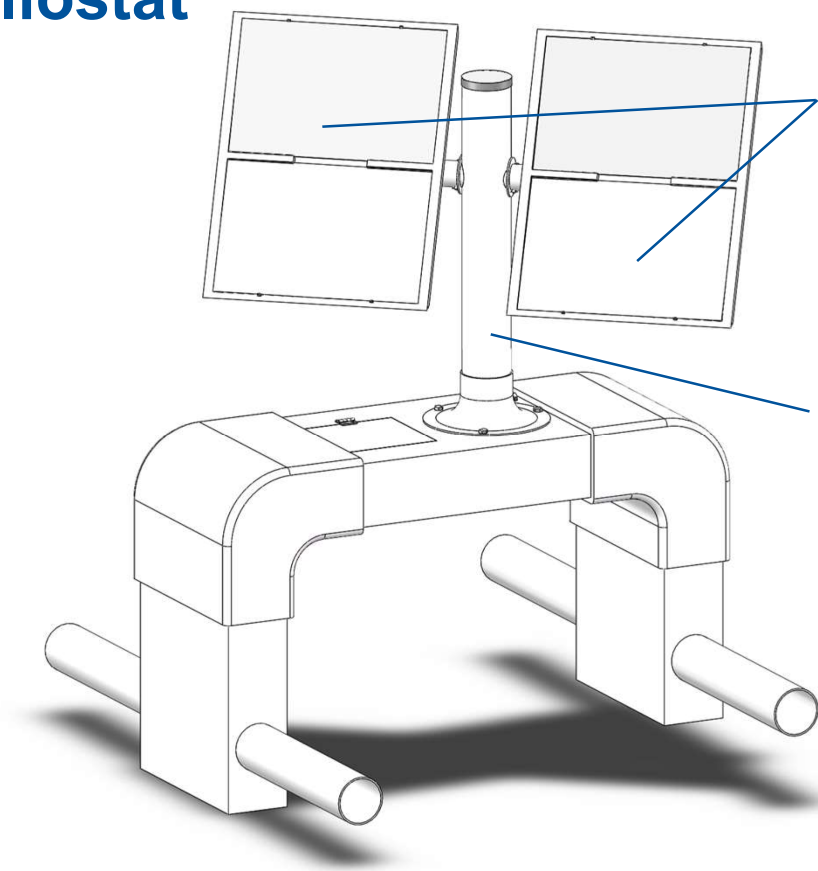
Dual-wing Heliostat



Reflector

Angled mirrors focus light at distance

Dual-wing Heliostat



Reflector

Angled mirrors focus light at distance

Actuation

Tracks sun 350° along both axes

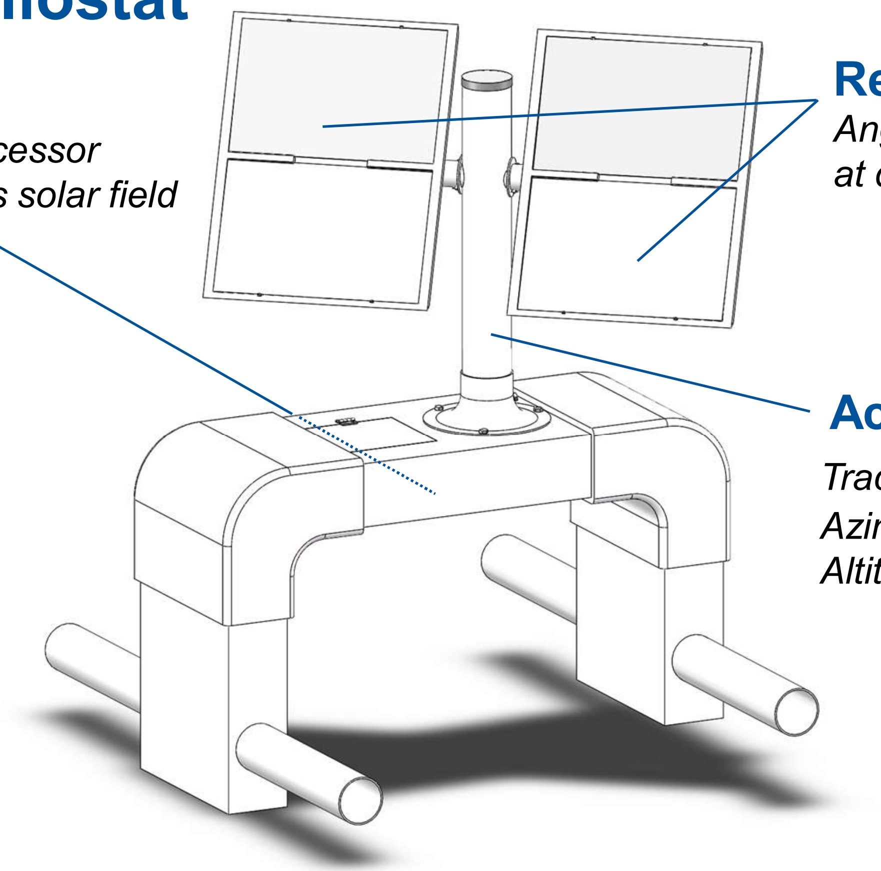
Azimuth axis – DC Gear Motor

Altitude axis – Servo/Stepper Hybrid Motor

Dual-wing Heliostat

Controls

Module-specific microprocessor allows optimization across solar field



Reflector

Angled mirrors focus light at distance

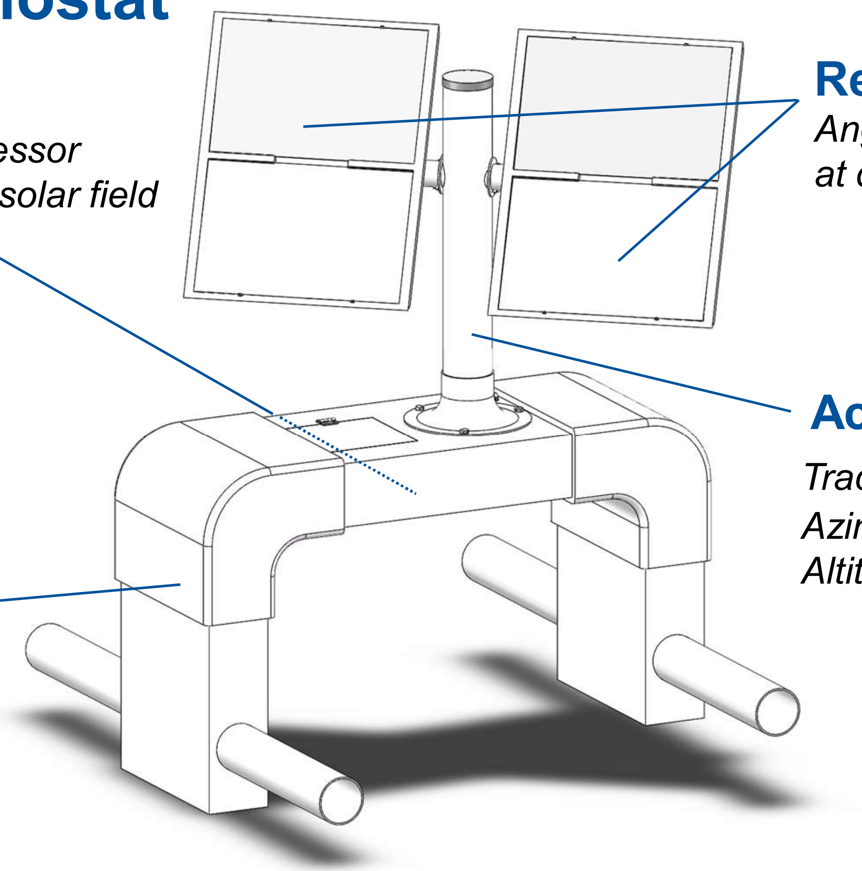
Actuation

Tracks sun 350° along both axes

Azimuth axis – DC Gear Motor

Altitude axis – Servo/Stepper Hybrid Motor

Dual-wing Heliostat



Controls
Module-specific microprocessor allows optimization across solar field

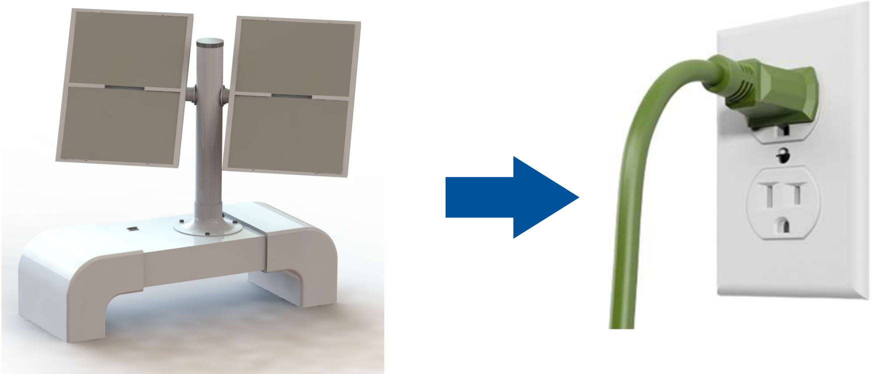
Reflector
Angled mirrors focus light at distance

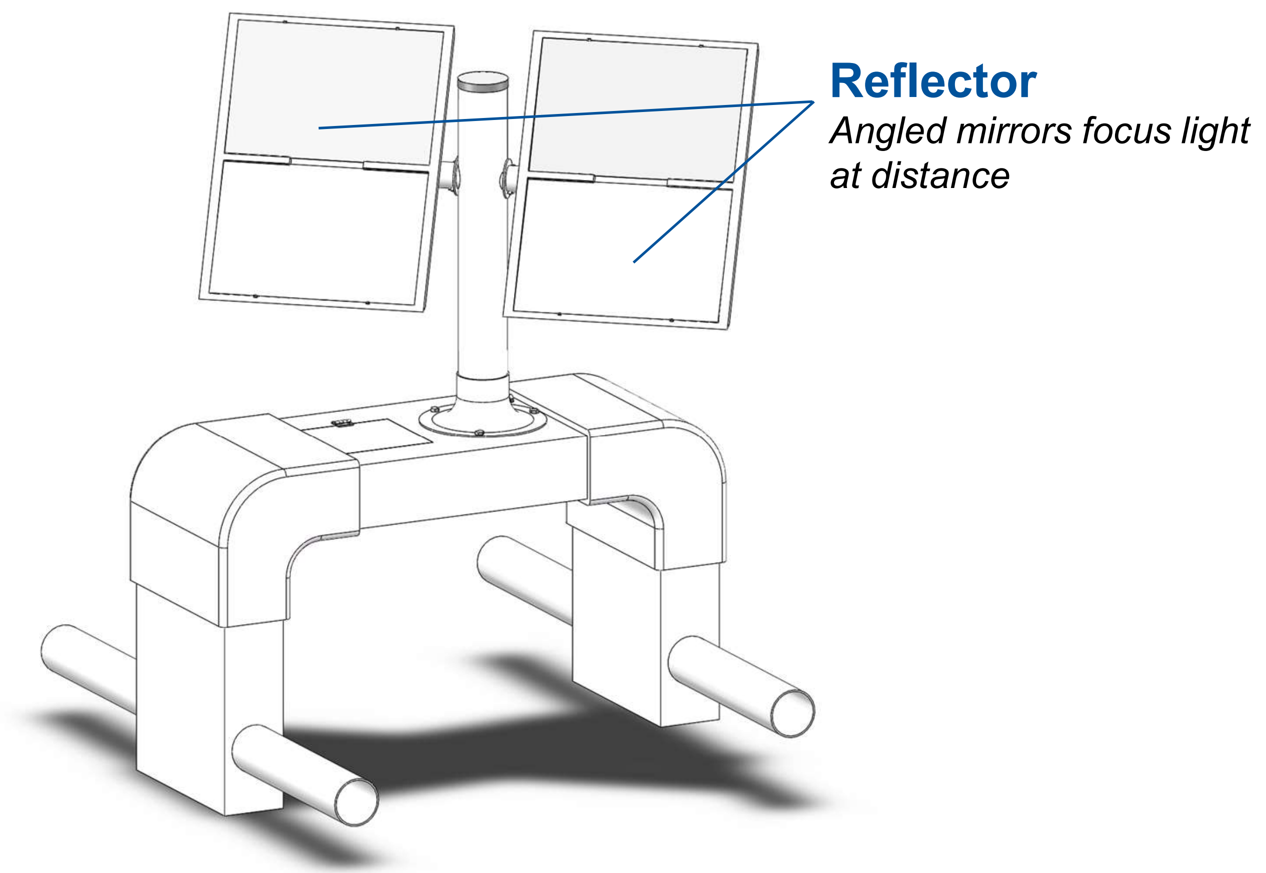
Actuation
Tracks sun 350° along both axes
Azimuth axis – DC Gear Motor
Altitude axis – Servo/Stepper Hybrid Motor

Base
Cost-efficient
Easily-assembled

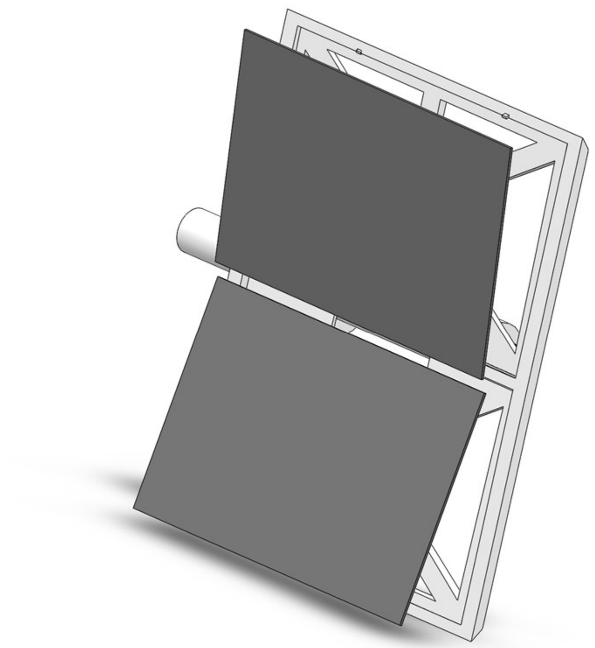
Product Motivations

- Efficiency
- Cost-effective
- Efficient Light/heat delivery
  - Control optimization
  - Angled reflectors to focus light
- Easily scaled-up

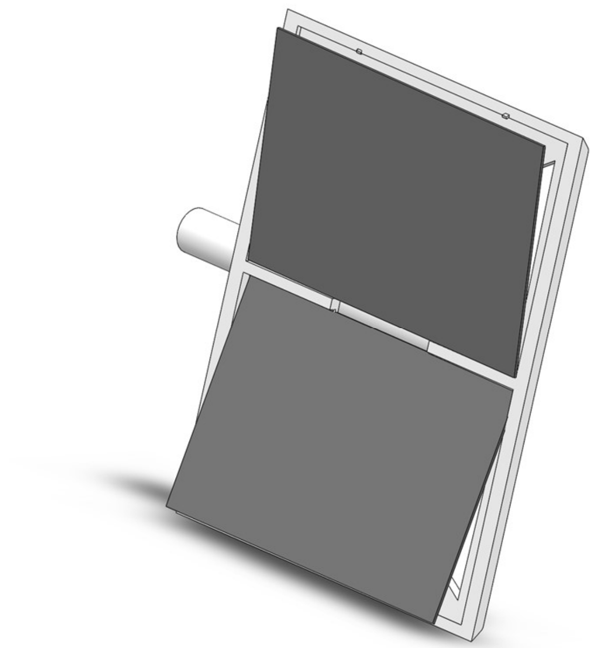



Reflector
Angled mirrors focus light at distance

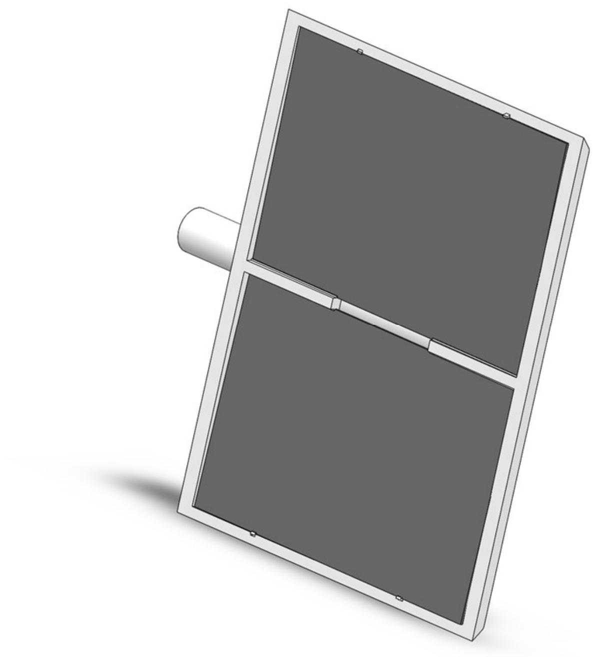
Reflector



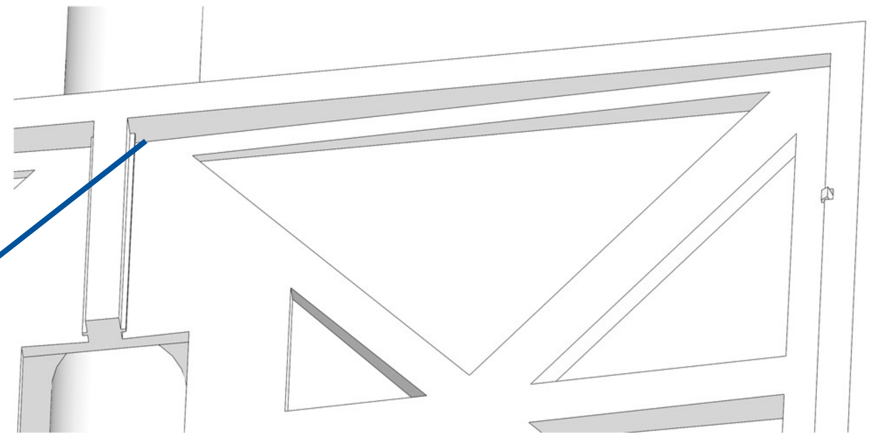
Reflector



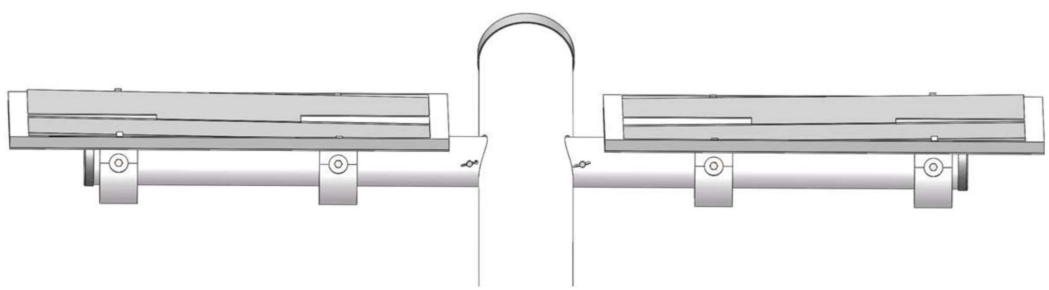
Reflector



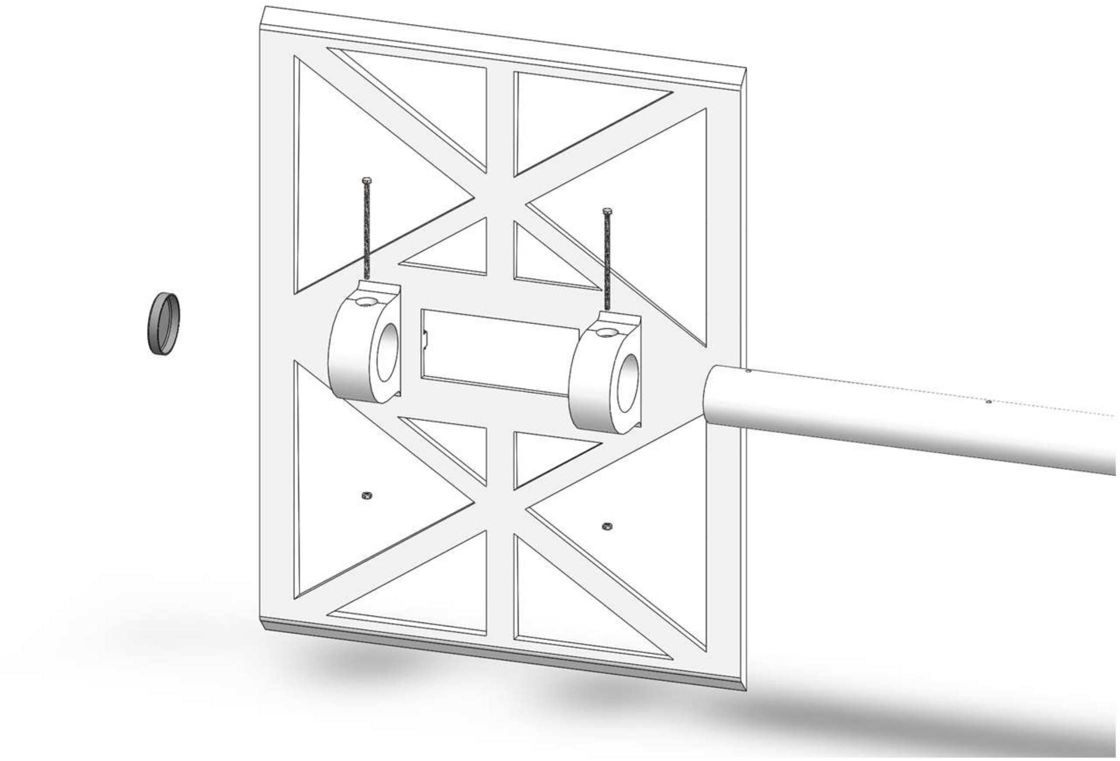
Reflector



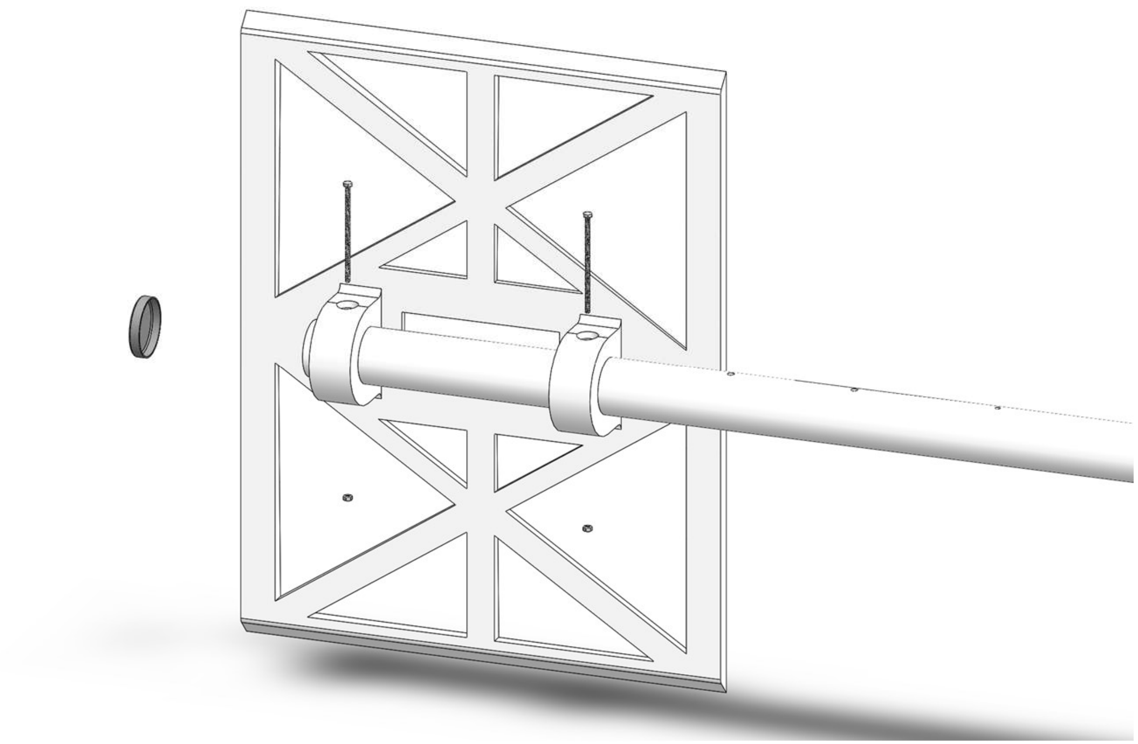
1° angle toward center



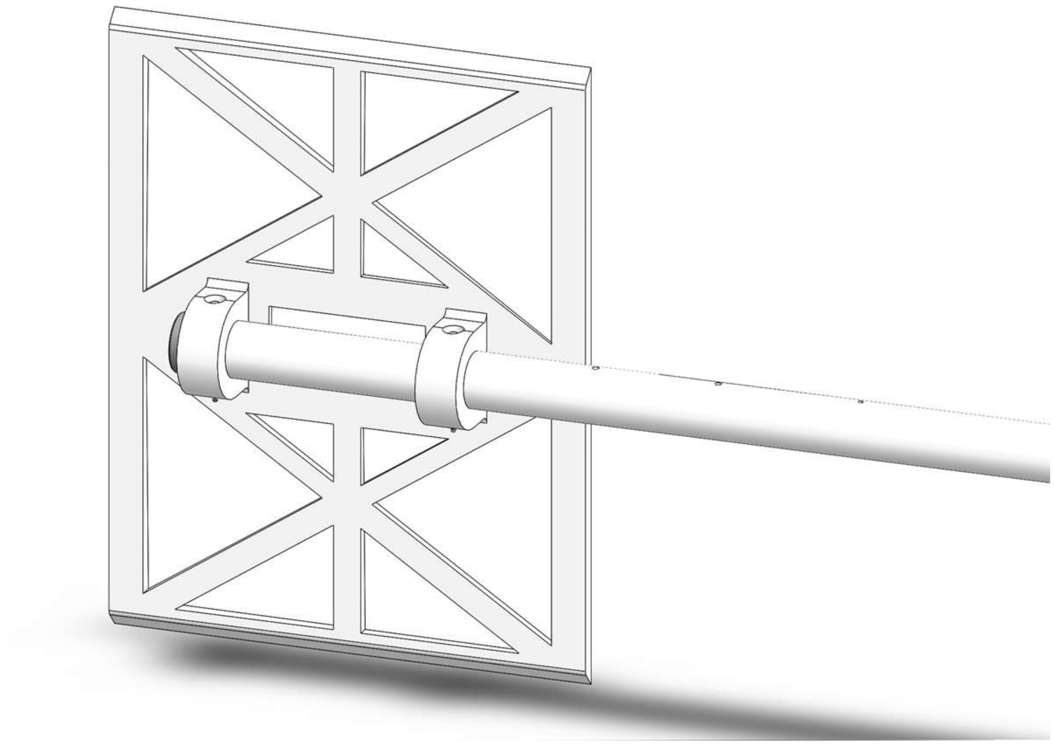
Mounting

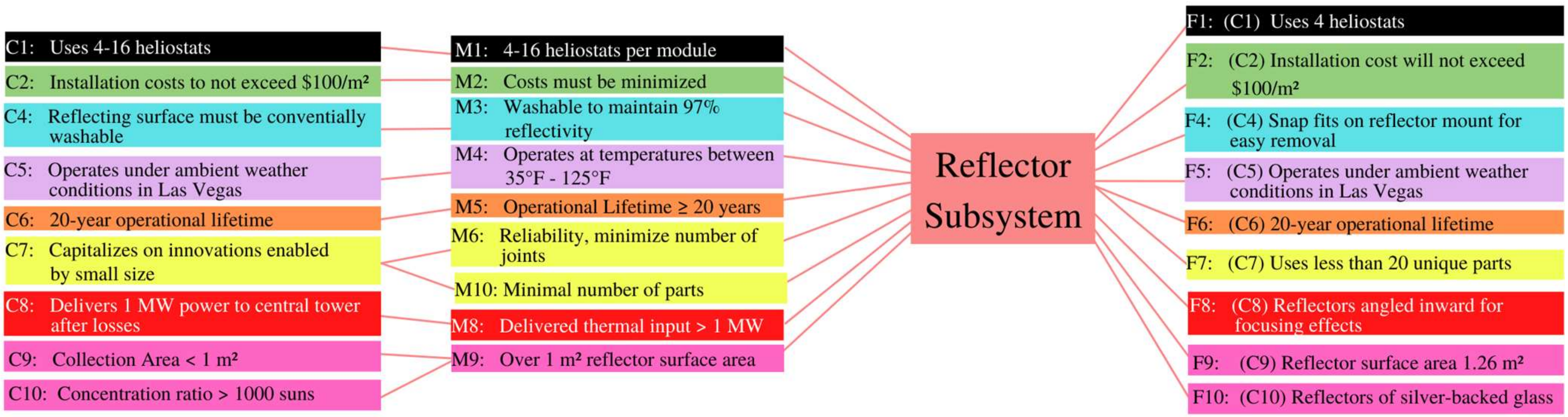


Mounting

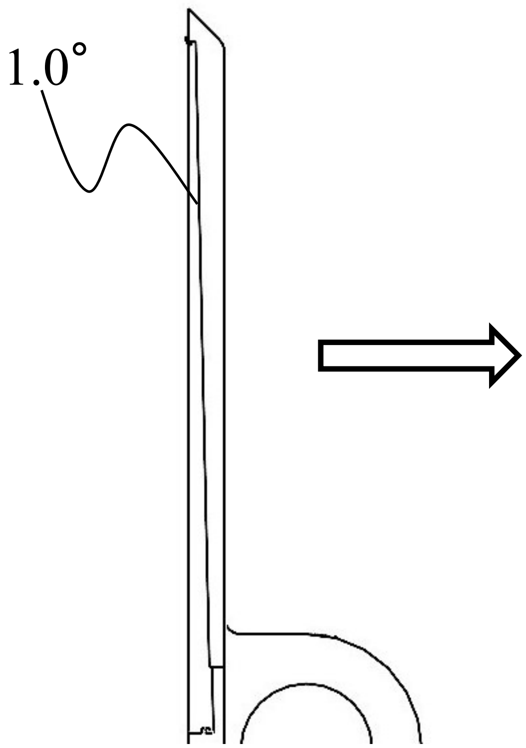


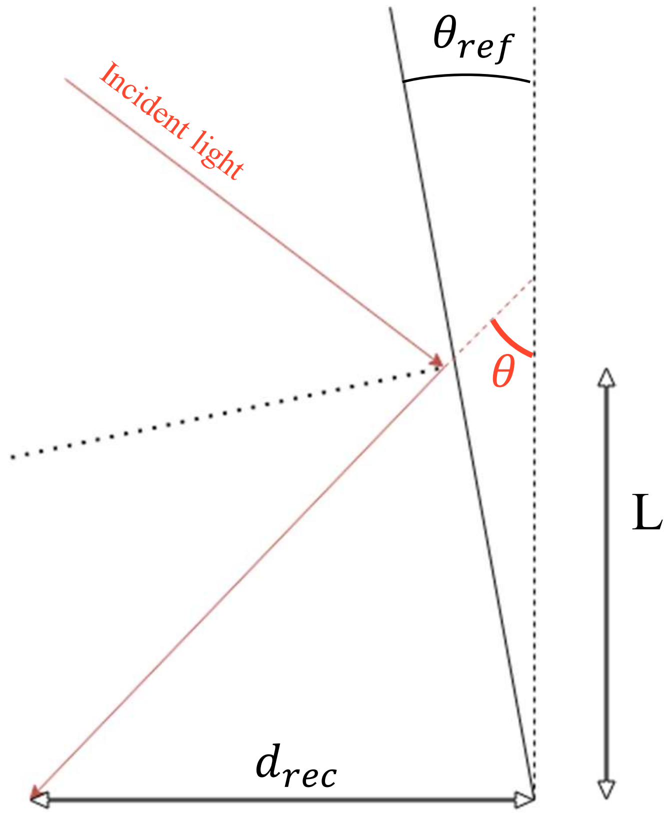
Mounting




C1: Uses 4-16 heliostats
C2: Installation costs to not exceed $100/m²
C4: Reflecting surface must be conventially washable
C5: Operates under ambient weather conditions in Las Vegas
C6: 20-year operational lifetime
C7: Capitalizes on innovations enabled by small size
C8: Delivers 1 MW power to central tower after losses
C9: Collection Area < 1 m²
C10: Concentration ratio > 1000 suns
M1: 4-16 heliostats per module
M2: Costs must be minimized
M3: Washable to maintain 97% reflectivity
M4: Operates at temperatures between 35°F - 125°F
M5: Operational Lifetime ≥ 20 years
M6: Reliability, minimize number of joints
M10: Minimal number of parts
M8: Delivered thermal input > 1 MW
M9: Over 1 m² reflector surface area
Reflector Subsystem
F1: (C1) Uses 4 heliostats
F2: (C2) Installation cost will not exceed $100/m²
F4: (C4) Snap fits on reflector mount for easy removal
F5: (C5) Operates under ambient weather conditions in Las Vegas
F6: (C6) 20-year operational lifetime
F7: (C7) Uses less than 20 unique parts
F8: (C8) Reflectors angled inward for focusing effects
F9: (C9) Reflector surface area 1.26 m²
F10: (C10) Reflectors of silver-backed glass

Reflector angle calculations





$$\theta = 90° - 2\theta_{ref}$$

$$\theta_{ref} = 180° - 2\tan^{-1}\left(\frac{d_{rec}}{L}\right)$$

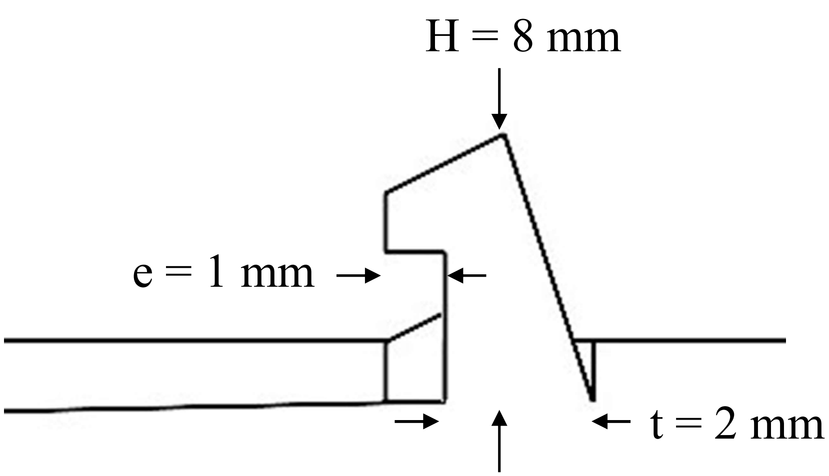
$$\theta_{ref} = f(d_{rec})$$

<u>Results:</u>

$$\theta_{ref}(40\ m) = 1.21°$$

$$\theta_{ref}(60\ m) = 0.81°$$

Reflector snap fit



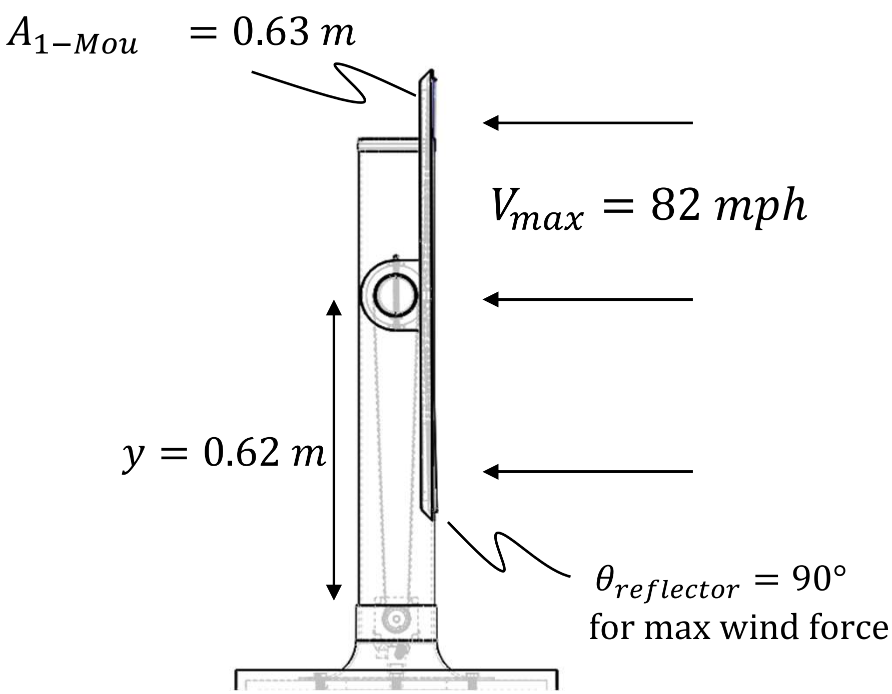
Width w out of page

$$\delta = e = \frac{FH^3}{3EI} \Longrightarrow F = \frac{3Eewt^3}{12H^3}$$

$$\sigma = \frac{Mc}{I} = \frac{FHt}{2I} = \frac{3Eet}{2H^2}$$

$$\sigma = 13.3\ MPa$$

Reflector mount



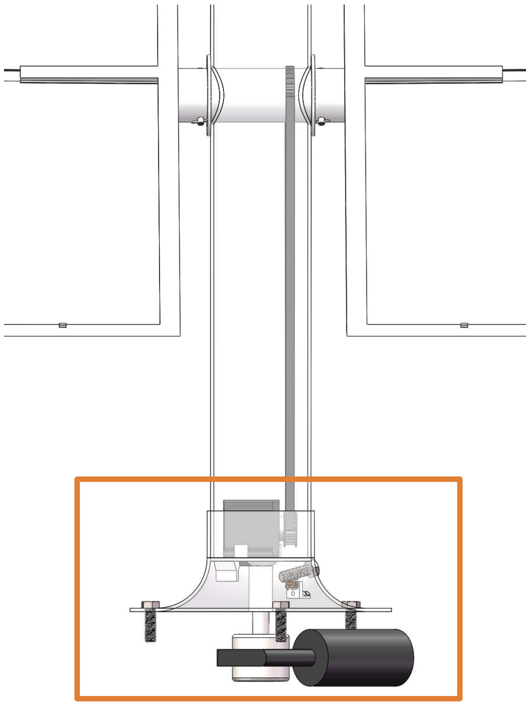
$$F_{wind} = \frac{1}{2}\rho_{air}(2A)V^2$$

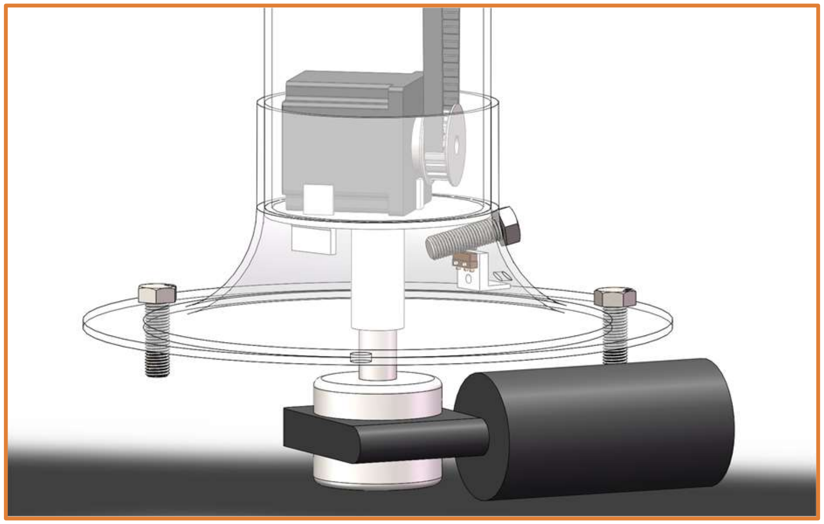
$$F_{wind} = 1037.4\ N$$

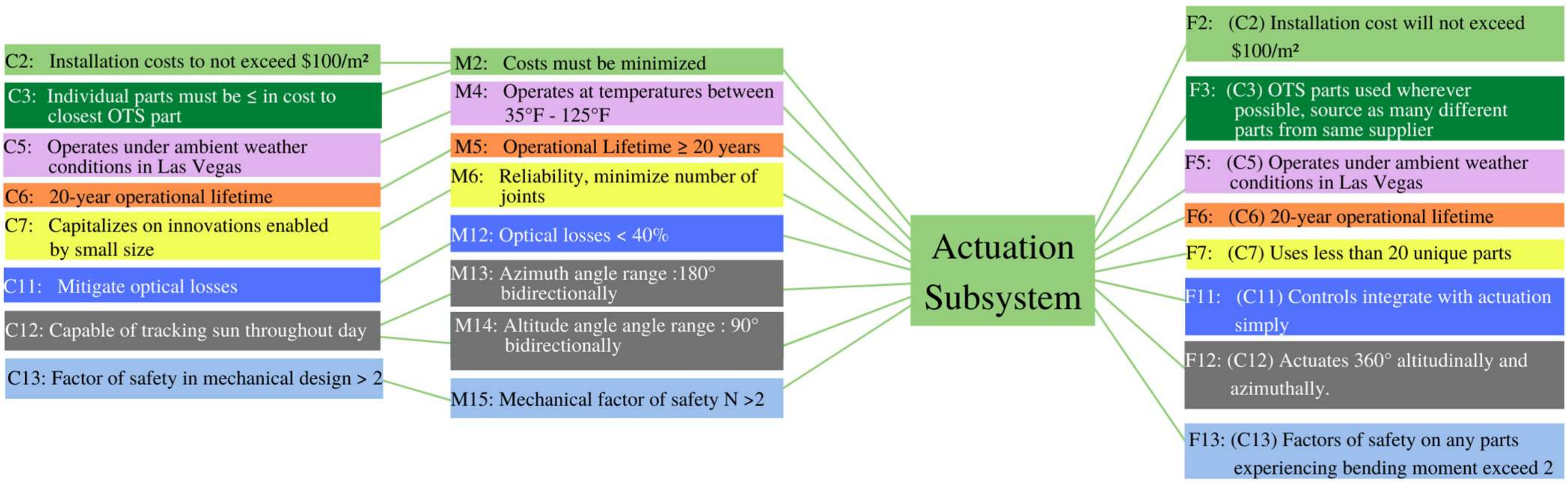
$$\sigma = \frac{F_{wind}yc}{0.25\pi({r_o}^4 + {r_i}^4)}$$

$$\sigma = 4.56\ MPa < \ \sigma_{y_{PVC}} = 24\ MPa$$

Actuation

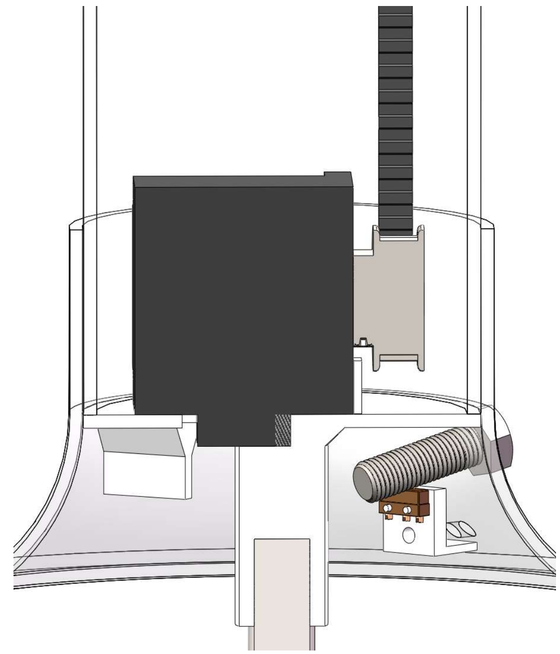





C2: Installation costs to not exceed $100/m²
C3: Individual parts must be ≤ in cost to closest OTS part
C5: Operates under ambient weather conditions in Las Vegas
C6: 20-year operational lifetime
C7: Capitalizes on innovations enabled by small size
C11: Mitigate optical losses
C12: Capable of tracking sun throughout day
C13: Factor of safety in mechanical design > 2
M2: Costs must be minimized
M4: Operates at temperatures between 35°F - 125°F
M5: Operational Lifetime ≥ 20 years
M6: Reliability, minimize number of joints
M12: Optical losses < 40%
M13: Azimuth angle range :180° bidirectionally
M14: Altitude angle angle range : 90° bidirectionally
M15: Mechanical factor of safety N >2
Actuation Subsystem
F2: (C2) Installation cost will not exceed $100/m²
F3: (C3) OTS parts used wherever possible, source as many different parts from same supplier
F5: (C5) Operates under ambient weather conditions in Las Vegas
F6: (C6) 20-year operational lifetime
F7: (C7) Uses less than 20 unique parts
F11: (C11) Controls integrate with actuation simply
F12: (C12) Actuates 360° altitudinally and azimuthally.
F13: (C13) Factors of safety on any parts experiencing bending moment exceed 2

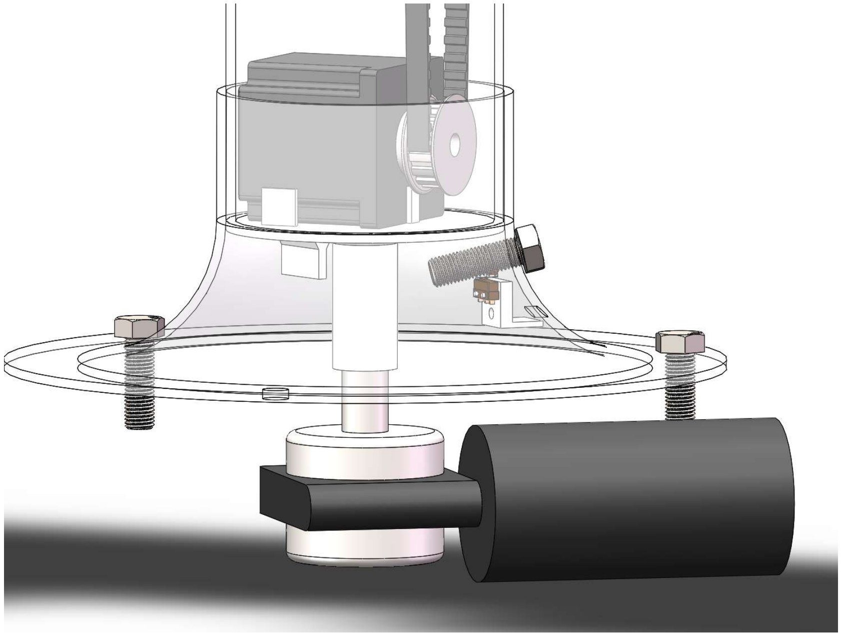
Altitude actuation

Closed-loop Stepper Servo Hybrid motor
2.7 V / 6.0 A
16.2 W delivered power
57 RPM
4.5 N·m torque



Azimuth actuation

Worm Gear DC motor
12 V / 25.0 A
300 W delivered power
65 RPM
11 N·m torque



Power delivered

GOAL: turn 94 N weight about 0.4 m lever-arm

P = 16.2 W T = 4.5 N·m ω = 57 RPM (217 deg/s)	*65% efficiency* →	P = 10.53 W T = 37.6 N·m ω = 16 deg/s max

GOAL: turn 80 kg structure with 0.3 m lever-arm

P = 300 W T = 11 N·m ω = 65 RPM (390 deg/s)	*60% efficiency* →	P = 195 W T = 235.44 N·m ω = 47 deg/s max

Structural concerns

Bending Factor of Safety, $n = \frac{\sigma_{y,PVC}}{\sigma_b}$

$\sigma_{y,PVC} = 24\ MPa$

$$I = \frac{\pi}{64}\left(D^4 - d^4\right)$$

$$I = 8.32 \times 10^{-7}\ m^4$$

$$W_H = 94\ N$$

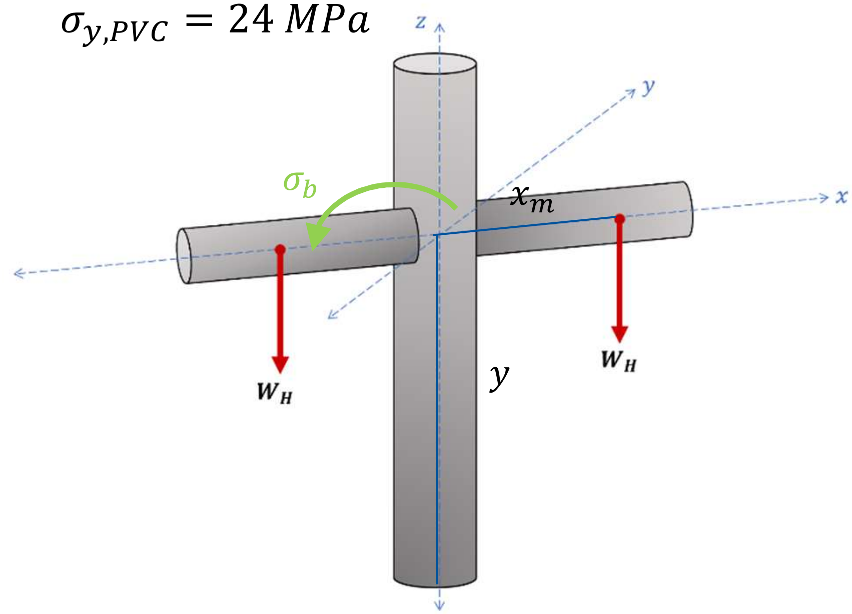
$$x_m = 0.3\ m$$

$$M = W_H x_m$$

$$\sigma_b = \frac{My}{I}$$

$$n = \frac{2I}{W_H x_m D}\sigma_{y,PVC}$$

$$n = 9.44 \gg 1$$



D = 150 mm
d = 140 mm

Structural concerns

Shearing Factor of Safety, $n = \frac{\sigma_{y,PVC}}{2\tau_{max}}$

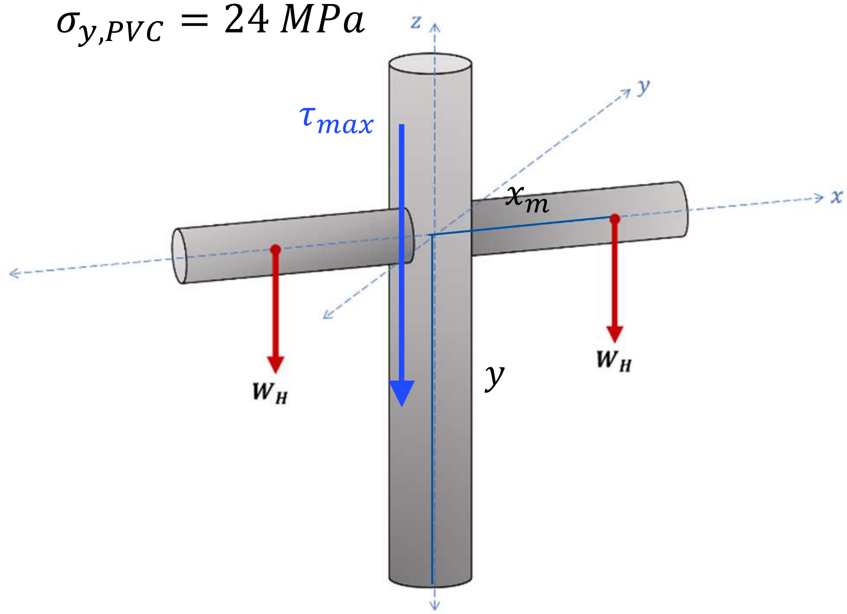
$$\sigma_{y,PVC} = 24\ MPa$$

$$\tau_{max} = \frac{4V}{3A}\left(1 + \frac{Dd}{D^2 + d^2}\right)$$

$$V = W_H = 94\ N$$

$$A = \frac{\pi}{4}\left(D^2 - d^2\right)$$

$$A = 3.77 \times 10^{-3}\ m^2$$

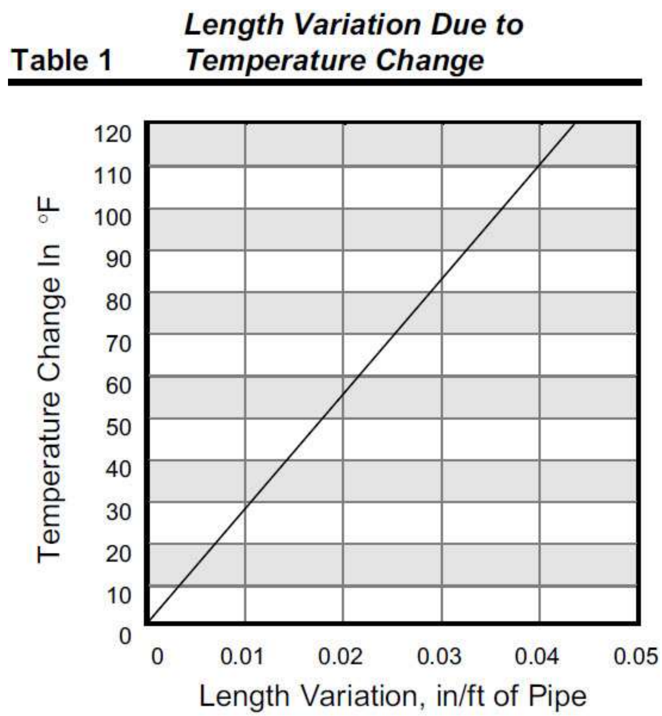


$$n = \frac{3A}{8V}\left(1 + \frac{Dd}{D^2 + d^2}\right)^{-1} \sigma_{y,PVC}$$

$$n = 240 \gg 1$$

OD = 150 mm
ID = 140 mm

Thermal expansion



Pillar height: L = 1.5 m = 4.92 ft

Max. Variation: $\delta = 0.045$ in/ft

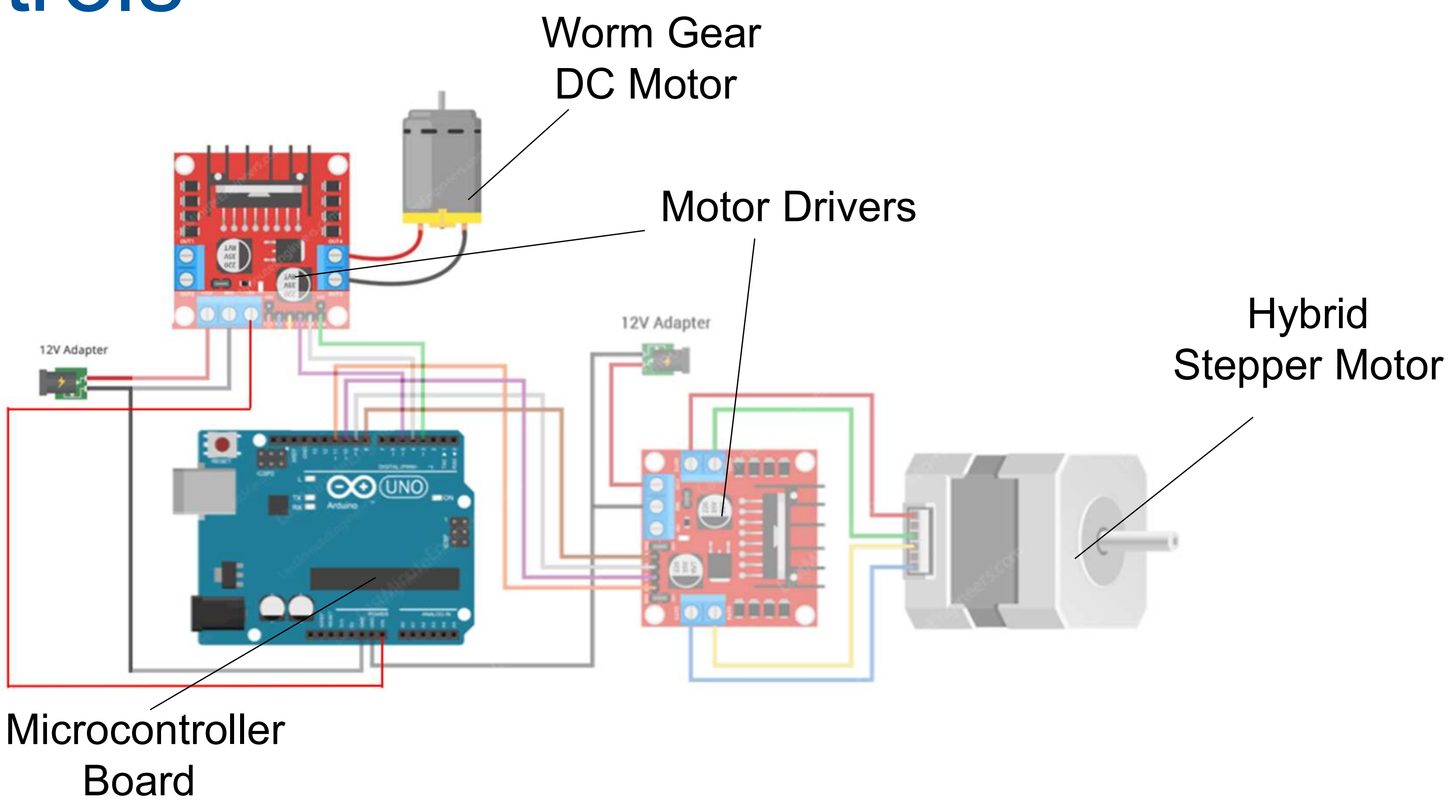
Max. Extension: $\delta L = 0.22$ in = 5.58 mm

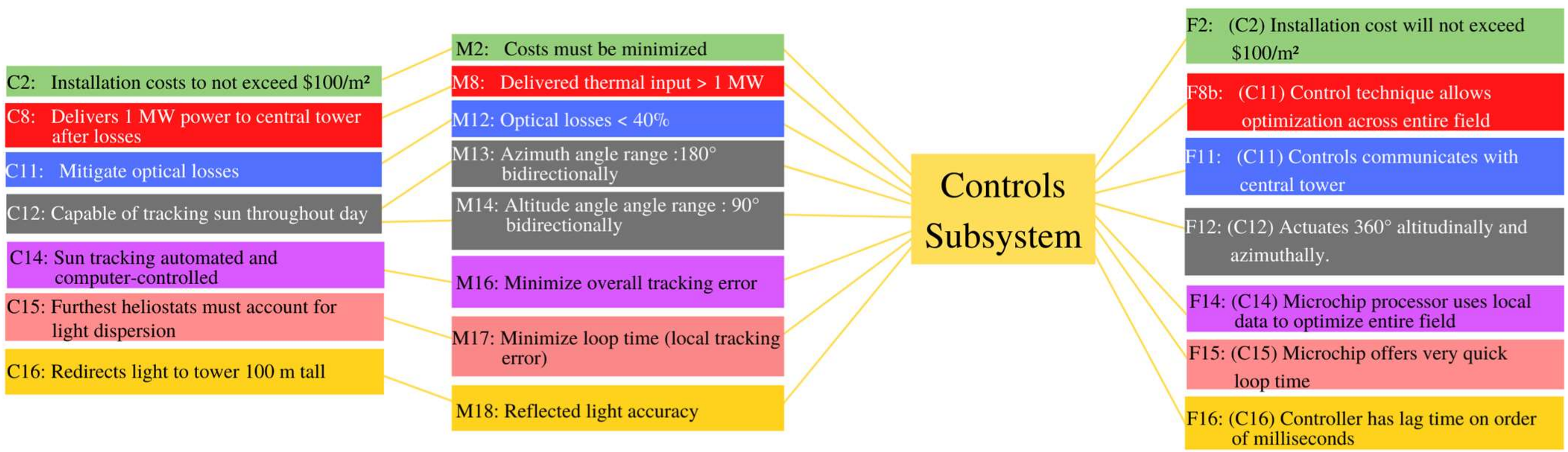
$$E_{neoprene} = 4.2\ MPa \qquad A = 2 \times 10^{-5}\ m^2$$
$$F = 100\ N \qquad L = 0.646\ m$$

Functional stretch of neoprene:

$$\delta = \frac{FL}{AE} = 76.9 \text{ mm}$$

Controls


Worm Gear
DC Motor
Motor Drivers
12V Adapter
12V Adapter
Hybrid
Stepper Motor
UNO
Microcontroller
Board


C2: Installation costs to not exceed $100/m²
C8: Delivers 1 MW power to central tower after losses
C11: Mitigate optical losses
C12: Capable of tracking sun throughout day
C14: Sun tracking automated and computer-controlled
C15: Furthest heliostats must account for light dispersion
C16: Redirects light to tower 100 m tall
M2: Costs must be minimized
M8: Delivered thermal input > 1 MW
M12: Optical losses < 40%
M13: Azimuth angle range :180° bidirectionally
M14: Altitude angle angle range : 90° bidirectionally
M16: Minimize overall tracking error
M17: Minimize loop time (local tracking error)
M18: Reflected light accuracy
Controls Subsystem
F2: (C2) Installation cost will not exceed $100/m²
F8b: (C11) Control technique allows optimization across entire field
F11: (C11) Controls communicates with central tower
F12: (C12) Actuates 360° altitudinally and azimuthally.
F14: (C14) Microchip processor uses local data to optimize entire field
F15: (C15) Microchip offers very quick loop time
F16: (C16) Controller has lag time on order of milliseconds

Controls governing equations

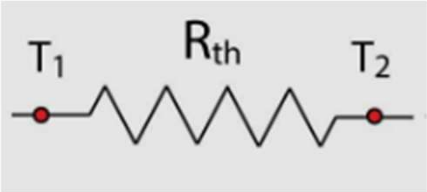
- Goal: Sun Tracking Error < 0.5 degrees

$$H_{E\Theta_i} = \frac{E(s)}{\Theta_i(s)} = \frac{1}{1+C(s)P(s)} < 0.5$$

- Goal: Sun Tracking Error < 0.5 degrees

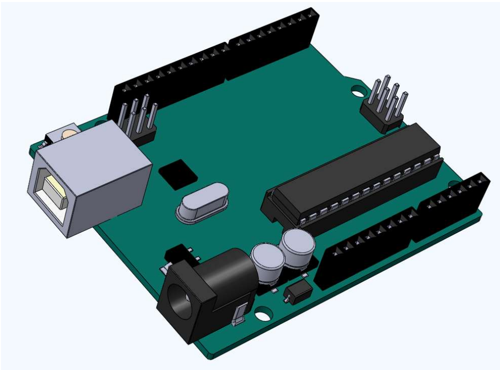
$$H_{\mathrm{E}\Theta_r} = \frac{E(s)}{\Theta_r(s)} = \frac{1}{1 + C(s)P(s)} \leq 10\%$$

Thermal concerns

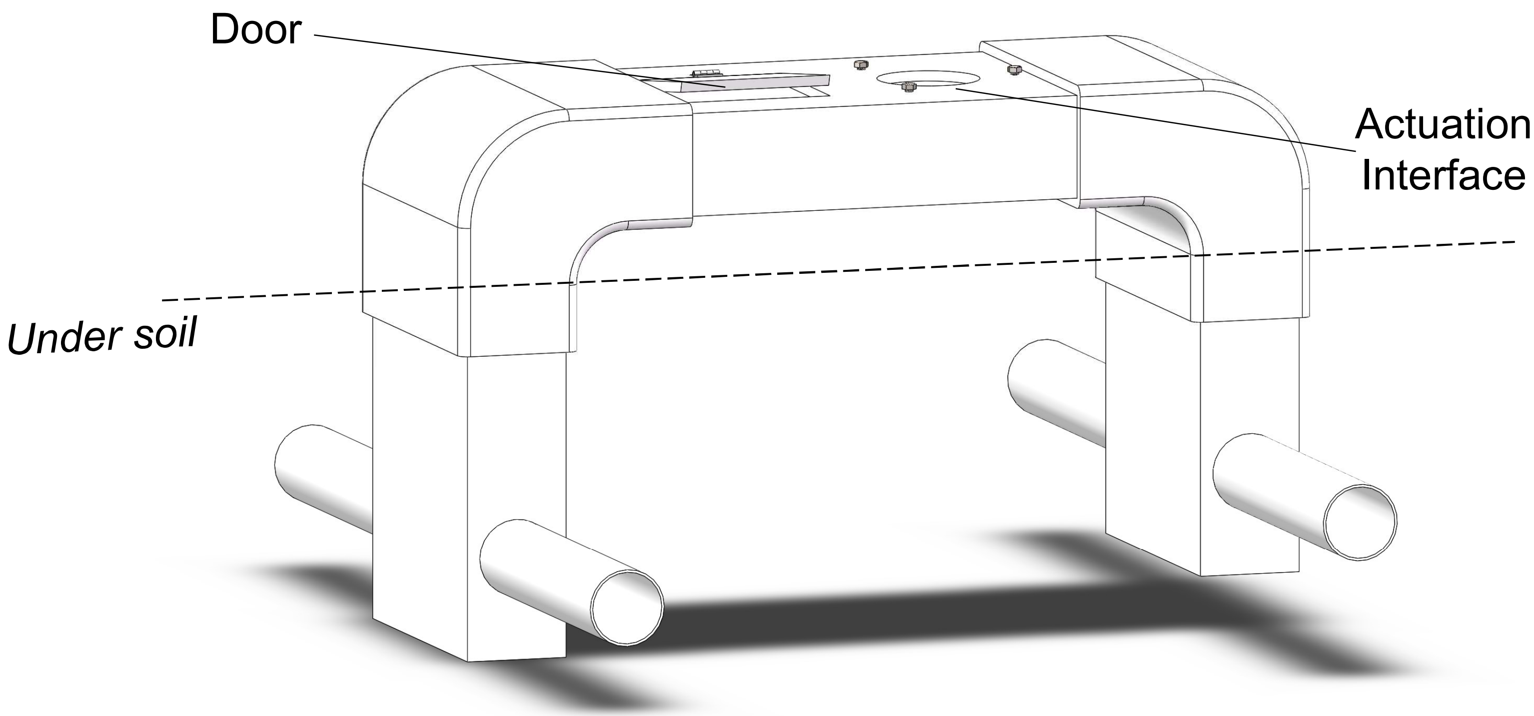


- $\dot{Q}_{max} = \frac{(T_{max} - T_{ambient})}{R_{th}}$
- $R_{th} = \frac{L}{kA}$ $\quad \dot{Q}_{max} = P = (VI)_{max}$
- $T_{max} = T_{ambient} + (VI)_{max} R_{th}$
- $T_{max} = 56.35°C$

K = 130 W/mK
A =0.00010973 m^2
L = 0.05334 m
V=5V
I=0.5 A
T_amb = 47 ℃



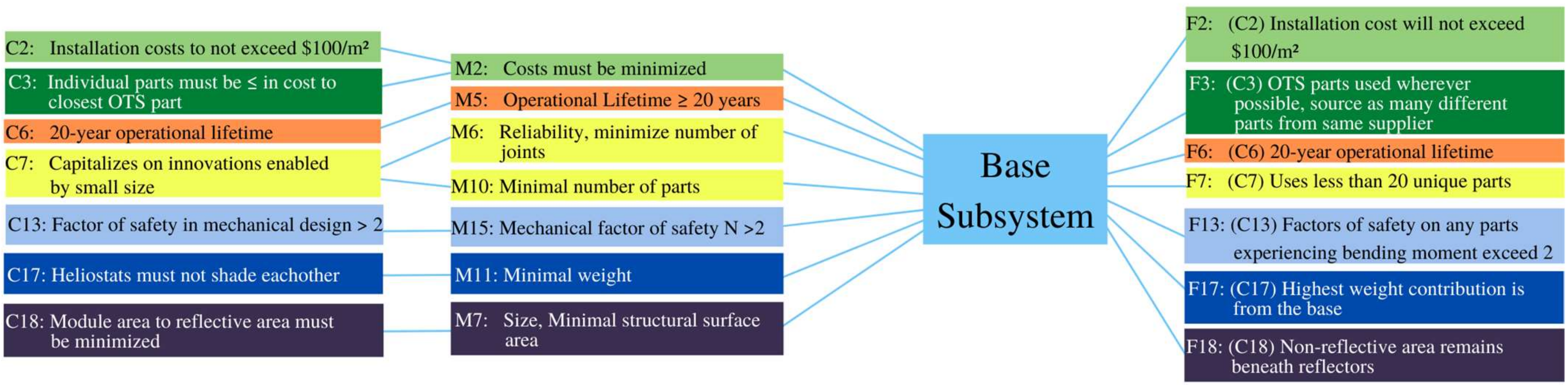
Base



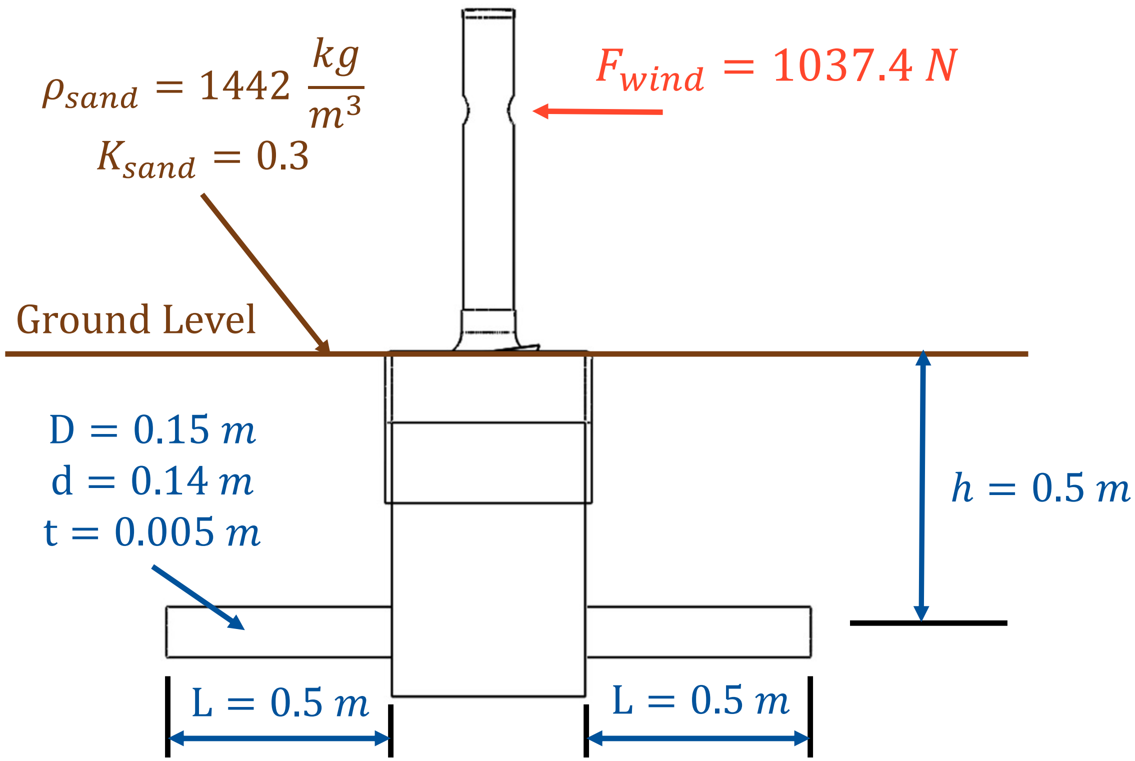
Herbert Wertheim College of Engineering

POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE

Department of Mechanical & Aerospace Engineering



Soil force



ρ_{sand} = 1442 kg/m^3

K_{sand} = 0.3

$$A_r = 2\pi LD = 0.4172\ m^2$$

$$F_{sand} = \rho_{sand} K_{sand} \frac{h}{2} = 108.2\ \text{N}$$

$$P_{sand} = \frac{F_{sand}}{A_r} = 229.6\ \text{Pa}$$

$$\sigma_{h,sand} = \frac{P_{sand} D}{2t} = 3444\ Pa$$

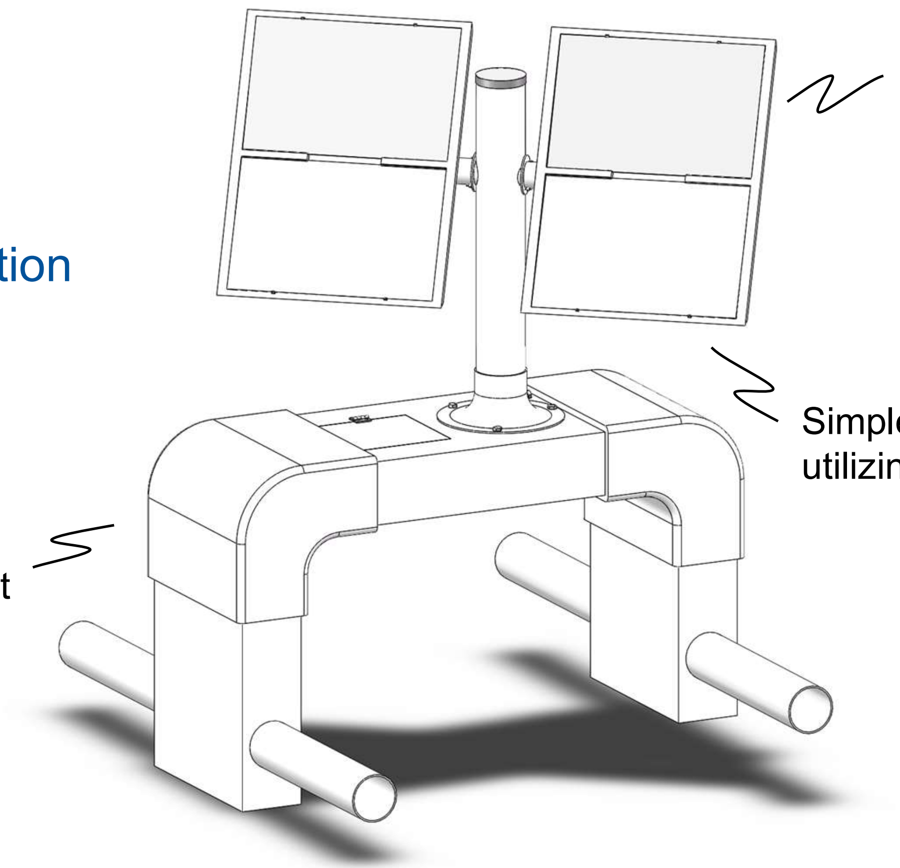
$$n = \frac{\sigma_{y,PVC}}{\sigma_{h,sand}} = 6968 \gg 2$$

Cost analysis

Category	Prototype	Production
OTS parts	$236.48	$98.29
Modified OTS parts	$34.19	$8.23
Raw materials	$48.20	$10.23
Manufacturing labor	$0.00	$4.32
Assembly labor	$0.00	$5.66
Energy consumption	$0.45	$0.45
TOTAL	$319.32	$127.18

Summary

- Cost-effective
- Controls optimization
- Scalability



UF Herbert Wertheim College of Engineering
POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE
Department of Mechanical & Aerospace Engineering

Conclusion

Kateland Hutt
k.hutt@ufl.edu

Samantha Scholl
samanthascholl@ufl.edu

Trevor Perez
trevorperez@ufl.edu

Nathan Brett
nbrett@ufl.edu

Karl Jusino-Ortiz
Karljusino453@ufl.edu

Devon Yon
dyon@ufl.edu

Joseph Rios
josephrios@ufl.edu