Herbert Wertheim College of Engineering
UNIVERSITY *of* FLORIDA

MIRLAR

The Mylar Mirror Heliostat

Section 13335, Group 1

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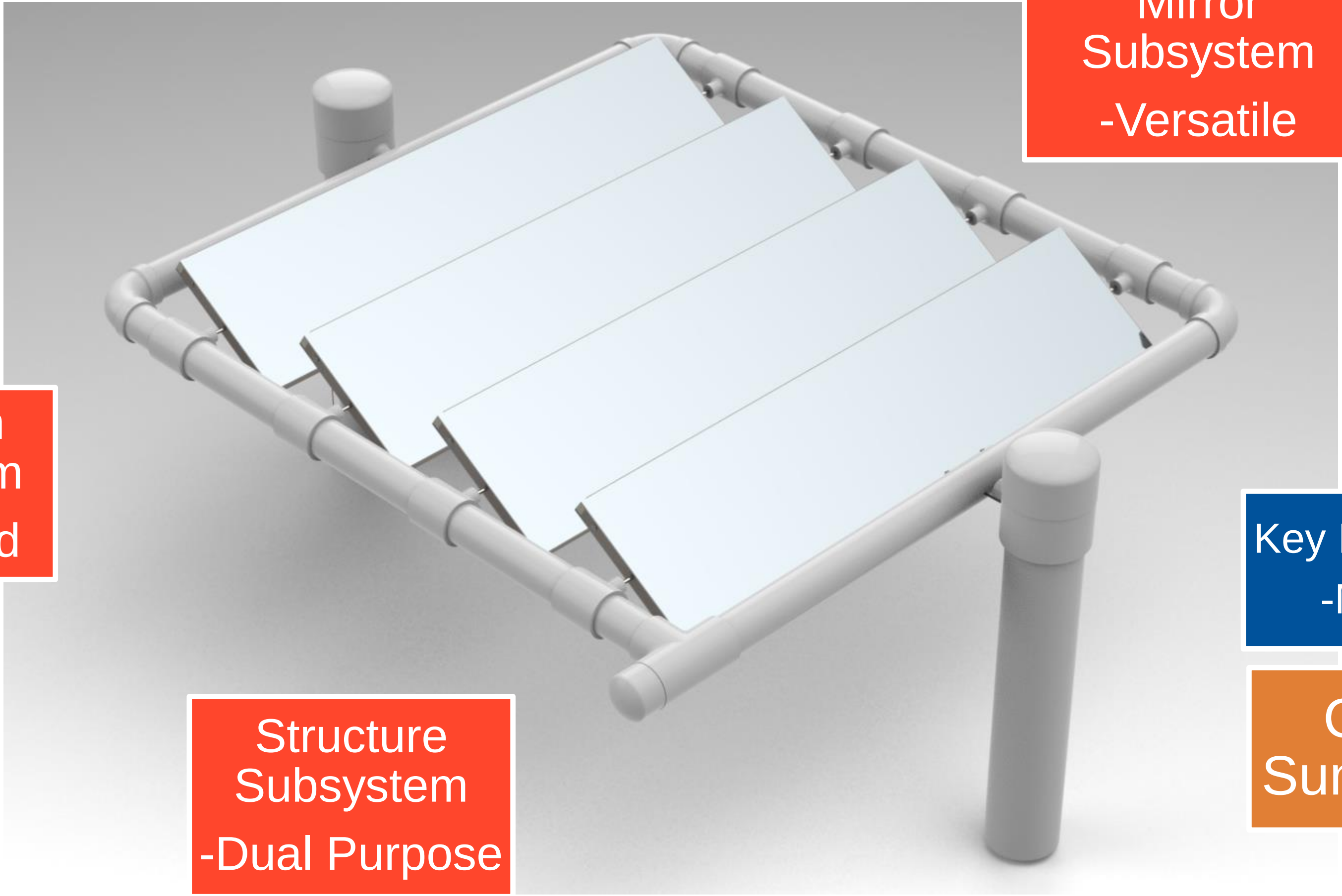
POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE

Agenda



Mirror Subsystem
-Versatile

Actuation Subsystem
-Integrated

Structure Subsystem
-Dual Purpose

Key Features
-Mylar

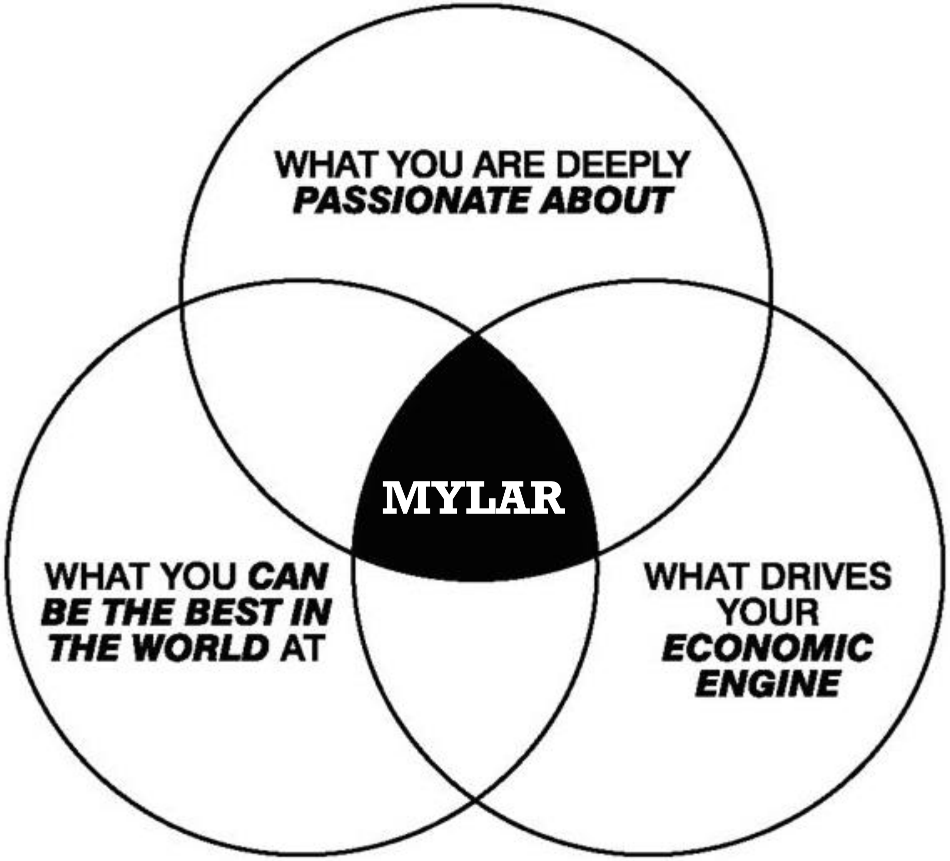
Cost Summary

Main Design Focus

Unique Resources

Creative Ideation

Lower Manufacturing Cost



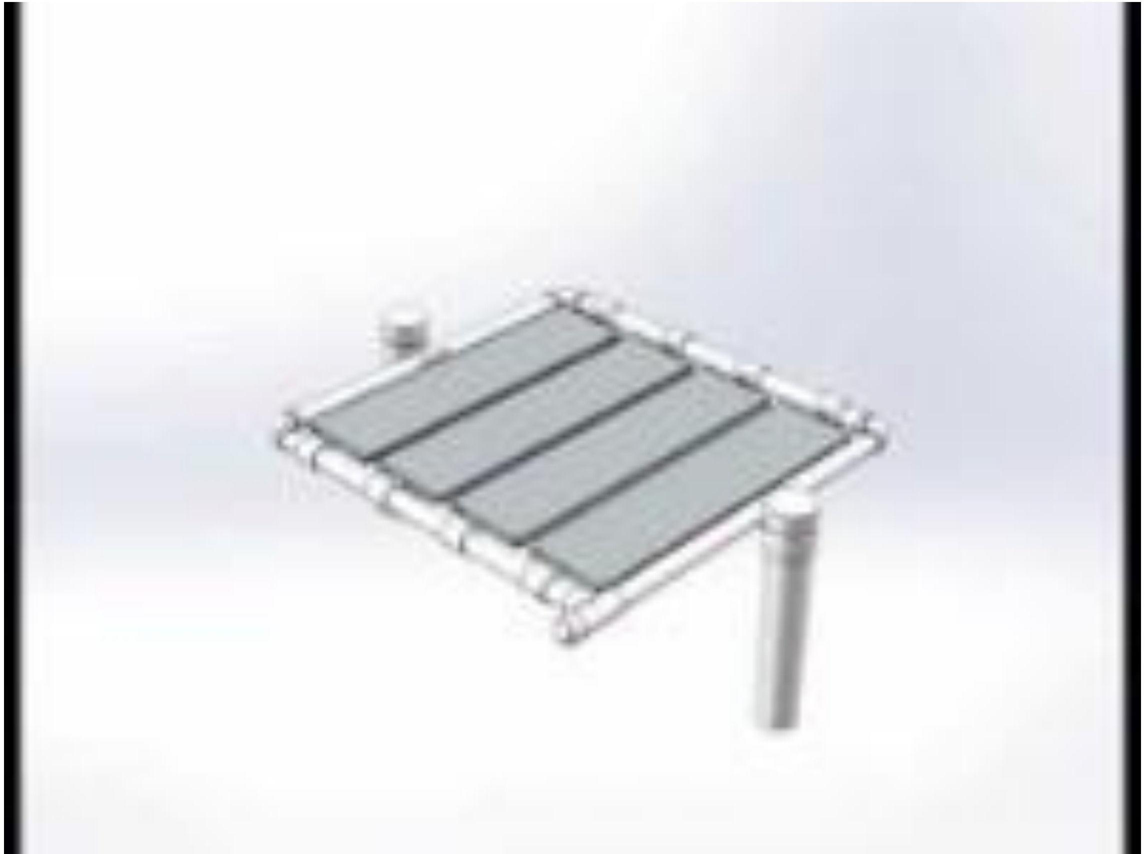
MYLAR

What?
Polyester Film
95% Reflectivity
High Modularity

Why?
Low Cost
Lightweight/Portable
Flexible

Where?
Dance Studios
Food Packaging
Greenhouses

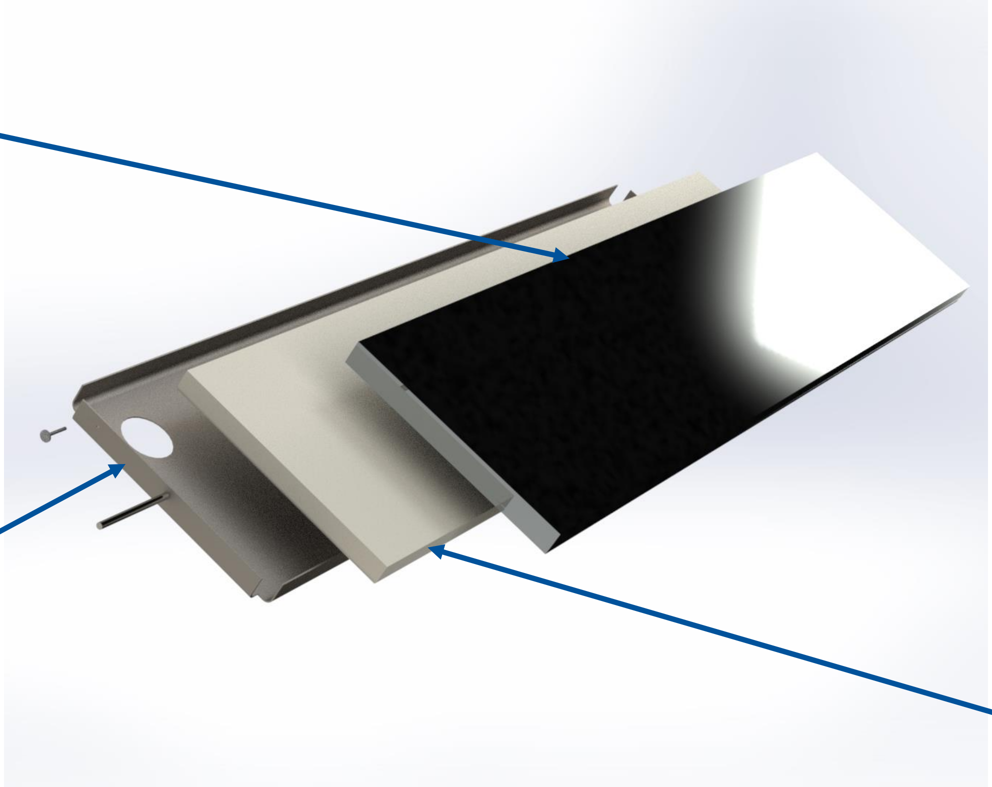
Product Overview



Mirror Subsystem

Reflective Surface

- Mylar film
- Heat shrunk
- UV-resistant aluminum coating
- 5-year lifespan
- $0.94/block



Key Features

- 4 heliostats
- 0.25 m x 1 m
- Replaceable mirror blocks

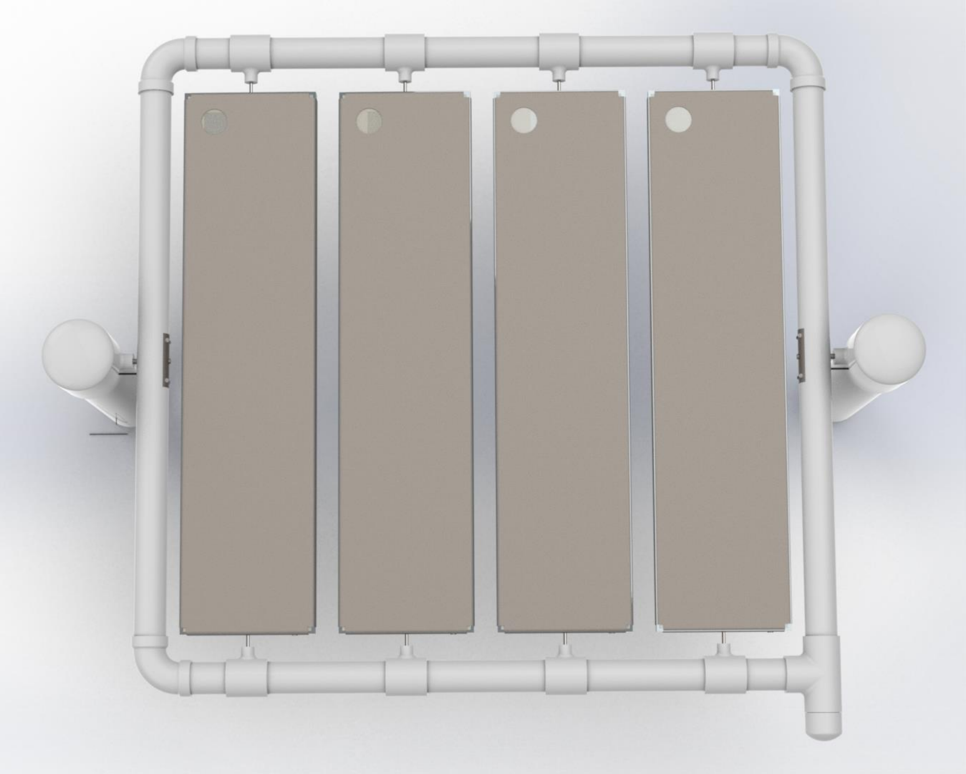
Mirror Frame

- Carbon steel axles welded to the box
- 16 GA steel sheet metal
- Lift-resistant nails

Foam Block

- PVC foam
- Rigid
- Moisture-resistant
- $0.17/block

Mirror Subsystem



Replacing Foam Mirror Blocks

1. Flip mirrors 180°
2. Remove all 8 nails
3. Use dowel to push blocks out
4. Press new blocks in
5. Push new nails in

Mirror Customer Needs

C2) Collection area ≤ 1 m2
C15) Ambient conditions in Las Vegas, NV
C12) Reflecting surface must be washable
C16) Thermal input power of 1 MW
C17) Solar concentration ratio > 1000 suns
C3) 4-16 heliostats
C6) No shading of other heliostats
C10) Module area relative to reflecting area is small
C18) Account for light dispersion

M2) A ≤ 1 m^2
M15) Coefficient of thermal expansion ≤ 2 x 10^{-4}
M12.1) Days before rinse ≥ 3 days
M12.2) Weeks before soap and rinse ≥ 2 weeks
M16) Area of Mirror ≥ 0.0625 m^2
M17) Geometric Concentration Ratio ≤ 1
M3) 4 ≤ Heliostats ≤ 16
M6) Mirror distance from ground ≤ 2 m
M10) Ratio ≤ 1.5
M18) Reflectivity ≥ 50%

F2) The total collection area is 1 m^2
F15) α = 1.7 × 10^{-5} in/in/°C
F12.1) 4 days before needing the next rinse
F12.2) Rinse with soap every 2 weeks
F16) Surface area of single mirror = 0.25 m^2
F17) Geometric concentration ratio = 1
F3) The number of heliostats is 4
F6) Mirror distance from the ground = 0.48 m
F10) Ratio = 1.48
F18) The reflectivity of the Mylar mirrors is 95%

Thermal Input Power

$$P = C_r N_{heliostats} A_{mirror} \eta_{opt}$$

$$C_r = 1000 \frac{W}{m^2}$$

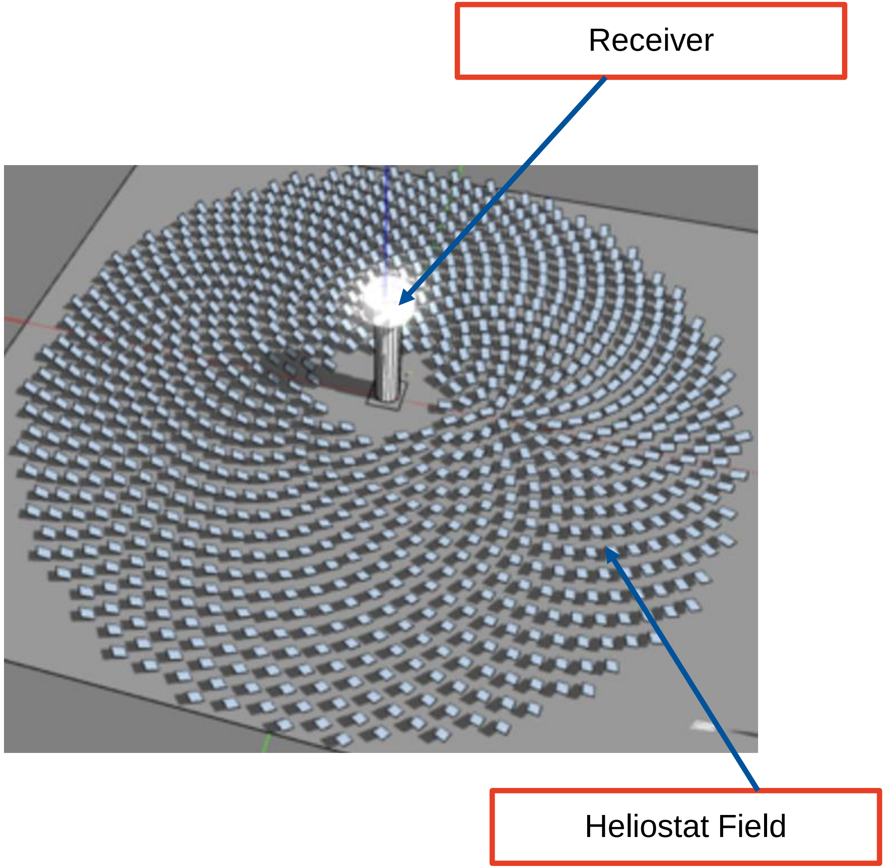
$$N_{heliostats} = 4$$

$$A_{mirror} = 0.25\ m^2$$

$$\eta_{opt} = 0.5$$

$$P_{module} = 500\ W$$

$$\frac{1\ MW}{500\ W} = \boxed{2000\ modules}$$



Solar Concentration Ratio

$$q_{solar} = G_{bn} C_{geo} \eta_{opt}$$

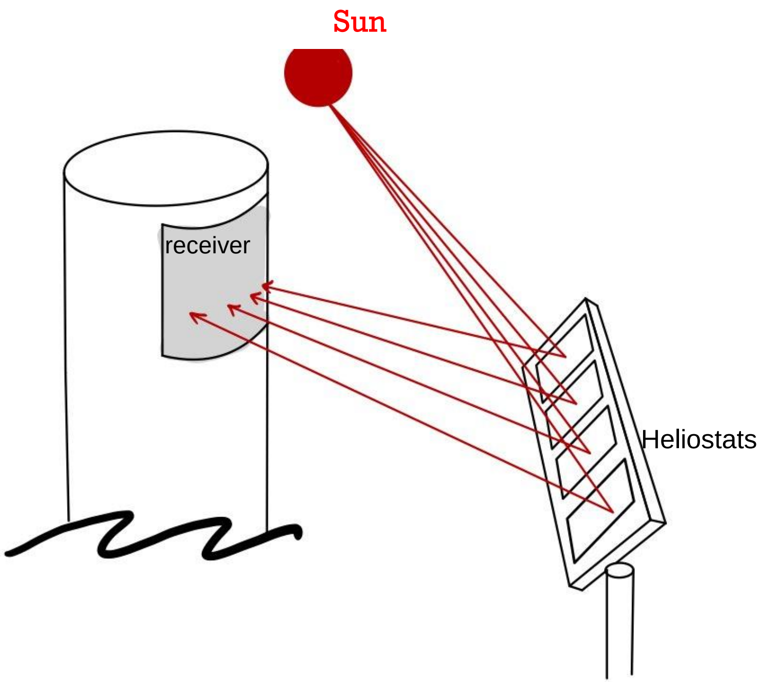
$$1000\frac{kW}{m^2} = 1\frac{kW}{m^2} * C_{geo} * 0.5$$

$$C_{geo} = 2000$$

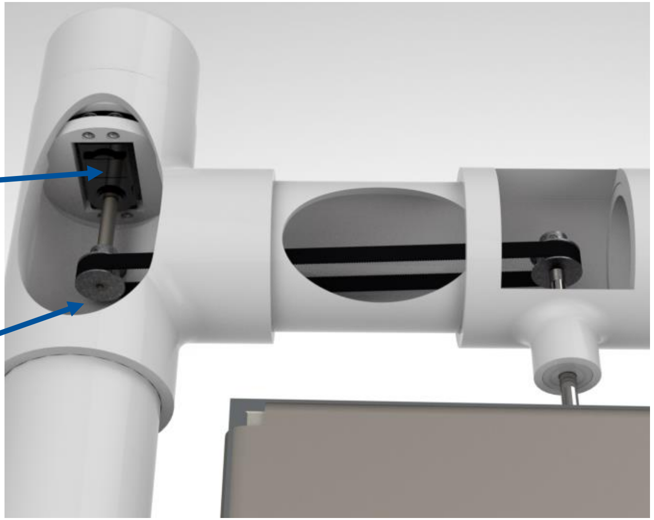
$$C_{geo} = \frac{A_h}{A_r} = \frac{x}{1m^2}$$

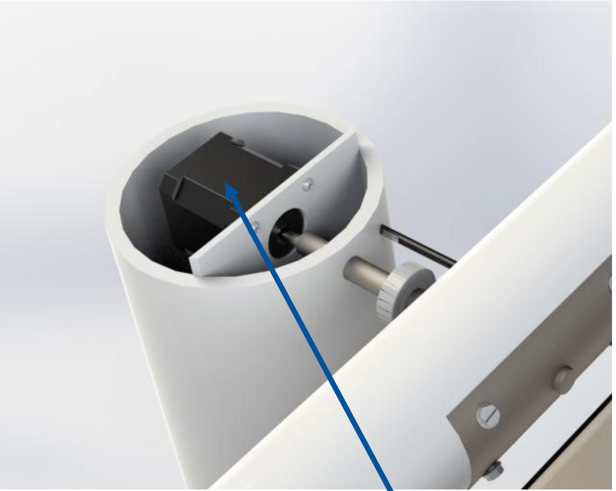
$$A_h = 2000m^2$$

$$\boxed{N_{module} = 2000}$$



Actuation Subsystem





MG995 Servo Motor

- Torque: 7.4 lb-in
- Operation Voltage: 4.8V-7.2V
- Operating Speed: 0.17 s/ 60°
- Controls azimuth (360°)

Belt and Pulley

- 4 GT2 Timing Belts
- 8 GT2 6 mm Timing Pulleys
- Belt service life: 100,000 miles
- Belt static tension: 2 lbf
- Synchronous movement
- Rubber cement glue

Key Features

- Fits within PVC piping
- Withstands ambient temperature
- Both motors can be wired directly to the controller

Nema 17 Stepper Motor

- Torque: 3.9 lb-in
- Operation Voltage: 5.3 V
- Rated Current/phase: 0.85 A
- Step Angle: 1.8°
- Controls altitude (113.2°)

Actuation Customer Needs

C8) Cost below $100/m2
C7) Redirect sunlight up to 100 m tall
C4) Optical losses not to exceed 40%
C5) Track sun throughout the day
C9) Sun tracking computer controlled

M8) Actuation cost ≤ $60/m^2$
M7) Range of motion in degrees ≥ 90°
M4) θ accuracy ≤ 0.9°
M5) Independent axis of motion ≥ 1
M9) Number of unique signals ≤ 4

F8) Cost = $26.90/m^2$
F7) Azimuth = 360°; Altitude = 113.2°
F4) θ = 0.9°
F5) Independent axes of motion = 2
F9) 2 signals: Servo motor and stepper motor

Required Motor Torque

Driving Torque Quantification

MG995 Servo

$$\tau_{servo} = 0.08745\ lb\ in$$
$$\tau_{MG995\ stall} = 7.4\ lb\ in$$

μ = coefficient of friction

N = normal load

F_{os} = factor of safety

r = distance to point of rotation

$$F_{friction} = \mu N = \frac{\mu M}{2}$$

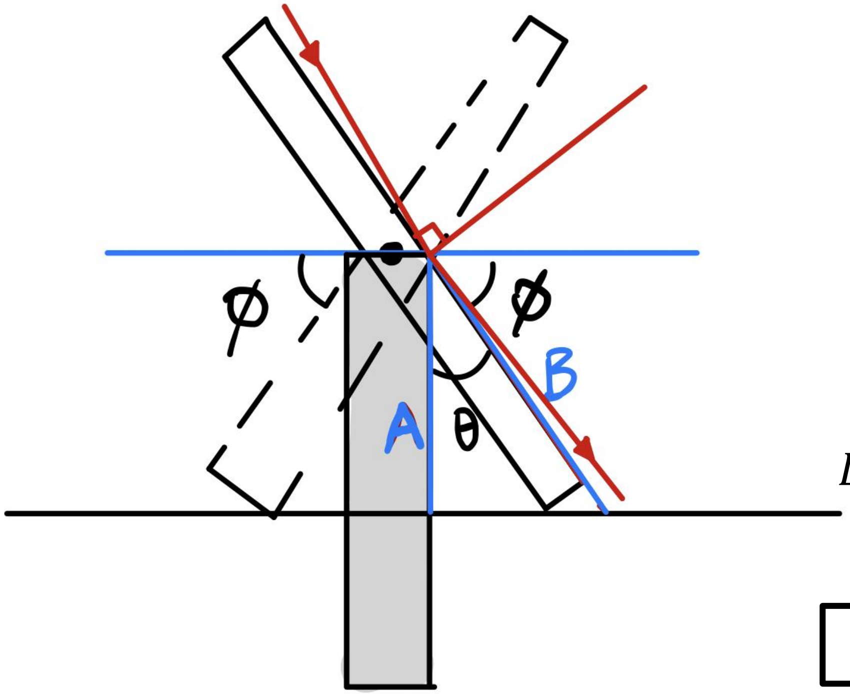
$$F_{friction} * F_{os} = \mu M$$

$$\tau = F_{friction} r$$

Nema 17 Stepper

$$\tau_{stepper} = 2.38\ lb\ in$$
$$\tau_{Nema\ 17\ stall} = 3.9\ lb\ in$$

Altitude Range Quantification



$$\theta = \cos^{-1}\left(\frac{A}{B}\right)$$

$$Frame\ Height: A = 19.2\ in$$

$$Frame\ Edge\ to\ Ground: B = 23\ in$$

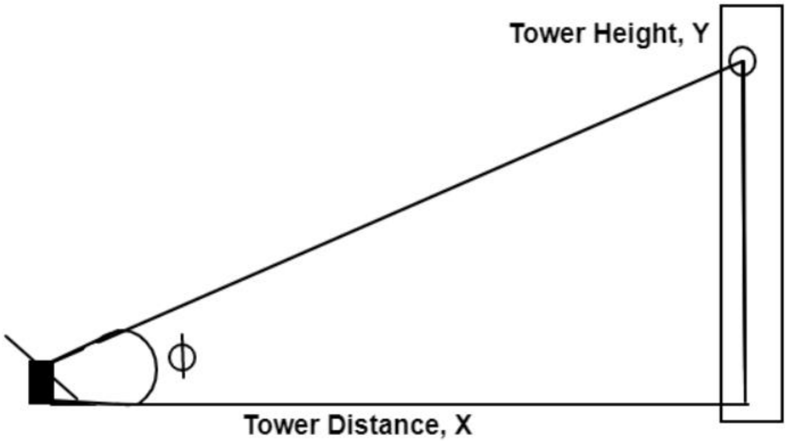
$$\theta = 33.4°$$

$$Lowest\ altitude\ under\ horizon\ line:$$

$$\varphi = 90° - \theta = 56.6°$$

$$\boxed{Total\ altitude: 180° + 2\varphi = 293.2°}$$

Maximum Distance from Tower Quantification



$$X = \frac{Y}{tan\varphi}$$

$$Receiver\ Height: Y = 100\ m$$

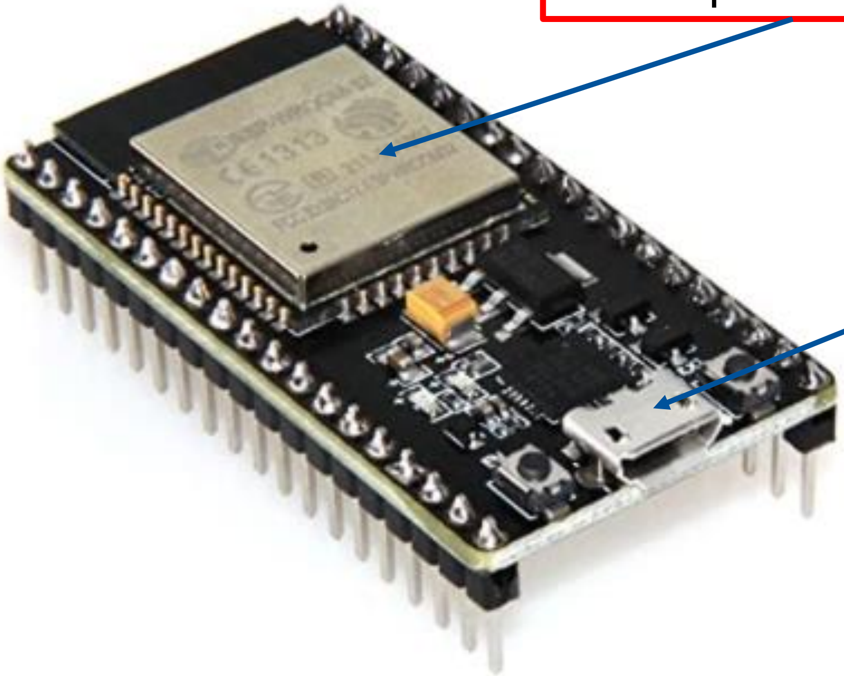
$$\varphi = 56.6°$$

$$\boxed{Tower\ Distance: X = 66\ m}$$

Control Board: HiLetgo ESP-32

Antenna RF AMP Filter to cancel undesired signals

CPU Speed: 2.4 GHz

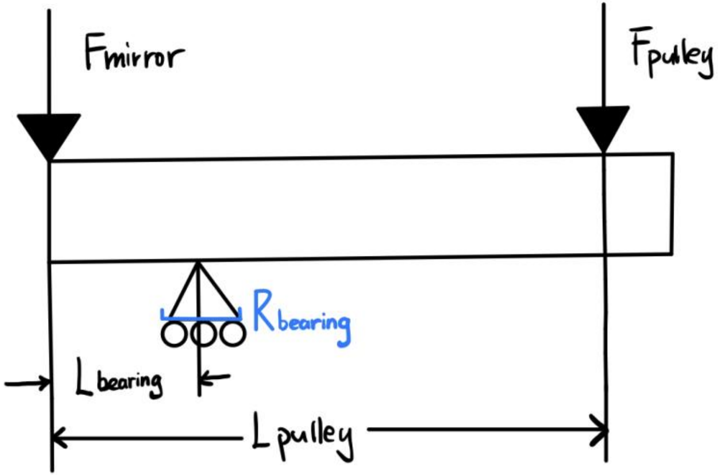


5V Output

Other Features

- Dual-Mode Wi-Fi and Bluetooth Capabilities
- Operating Temperature: −40℃ to 124℃

Maximum Mirror Axle Deflection: GT2 Timing Pulley



$$\sum F = 0 = F_{mirror} + R_{bearing} + F_{pulley}$$

$$F_{mirror} = 6\ lbf$$

$$F_{pulley} = 2\ lbf$$

$$F_{bearing} = 8\ lbf$$

$$EI\frac{d^2y}{dx^2} = M$$

$$\frac{dM}{dx} = V = F_{mirror} + R_{bearing} < x - L_{bearing} >^0 - F_{pulley} < x - L_{pulley} >^0$$

$$BC's: Integration\ constants = 0$$

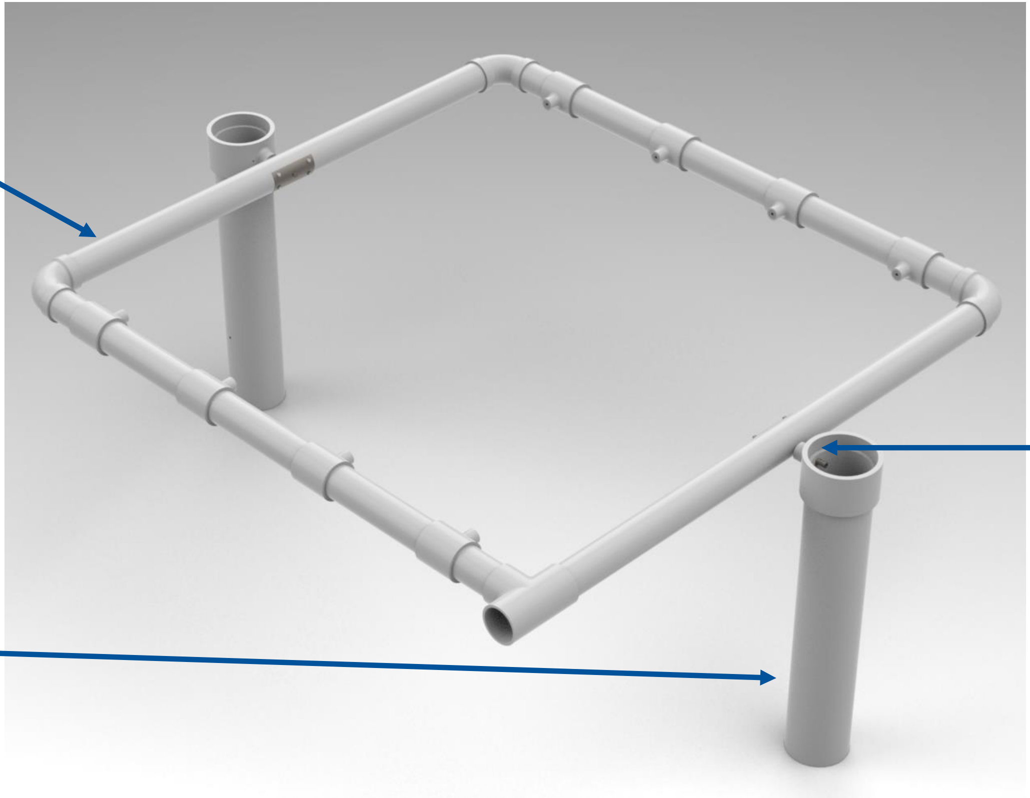
$$y(x) = \frac{1}{EI}\left(\frac{1}{6}F_{mirror}x^3 + \frac{1}{6}R_{bearing} < x - L_{bearing} >^3 - \frac{1}{6}F_{pulley} < x - L_{pulley} >^3\right)$$

$$\boxed{y(L_{shaft}) = y(3.5\ in) = 0.0009\ in}$$

Structure Subsystem

2-inch PVC
- Elbow & Tee joints
- PVC cement glue
- Lifetime 100 years

4-inch PVC
- 2 supports
- Concrete base grounded with rod
- Wires



Key Features
- Sealed from environment
- Houses actuation

Cradle Mechanism
- Carbon Steel Axles (10 mm dia.)
- Motor in 4-inch rotates
- Welded and hex head screws secured 16 GA plate

Structure Customer Needs

C13) Factor of Safety ≥ 2
C10) Module area relative to reflecting area is small
C14) Lifetime > 20 years

→

M13) FOS ≥ 2
M10) Ratio ≤ 1.5
M14) Lifetime ≥ 20yrs

→

F13) N = 2 at 91 mph
F10) Ratio = 1.48
F14) The service life of PVC = 100 years

Bending Deflection of Cradle Due to Weight

$$F_M = 46.64lb = 207.47N$$

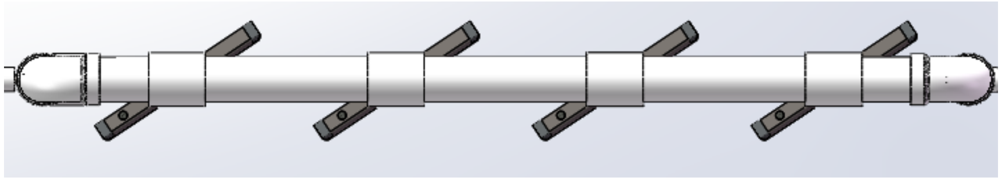
$$L = 1.5494\ m$$

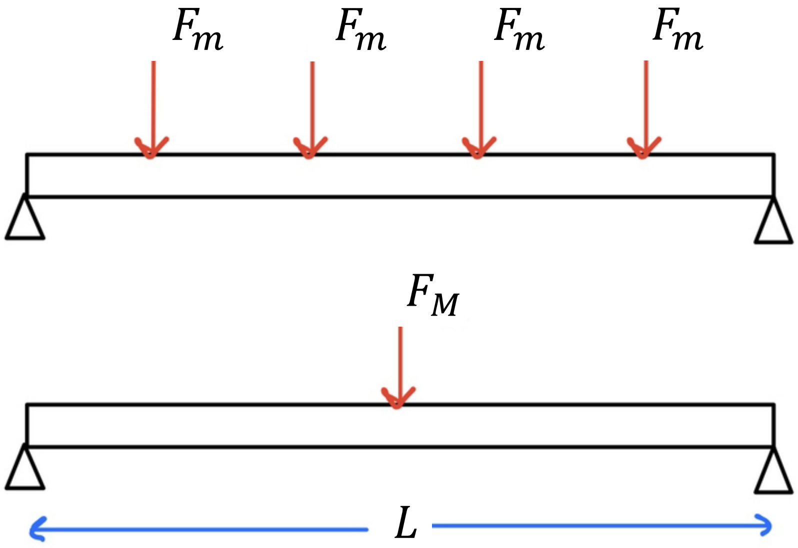
$$E = 3{,}275\ MPa\ for\ PVC$$

$$I = \frac{\pi}{4}\left(r_o^4 - r_i^4\right) = 5170.58\ m$$

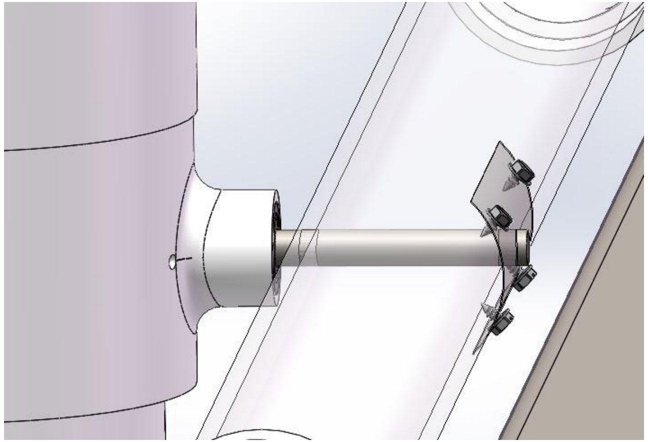
$$a = b = 0.7747\ m$$

$$\delta = \frac{Fa^3b^3}{3L^3EI} = \boxed{0.237mm}$$





FOS for shafts from 4-inch PVC to cradle



$$P_{wind} = 0.00256V^2$$

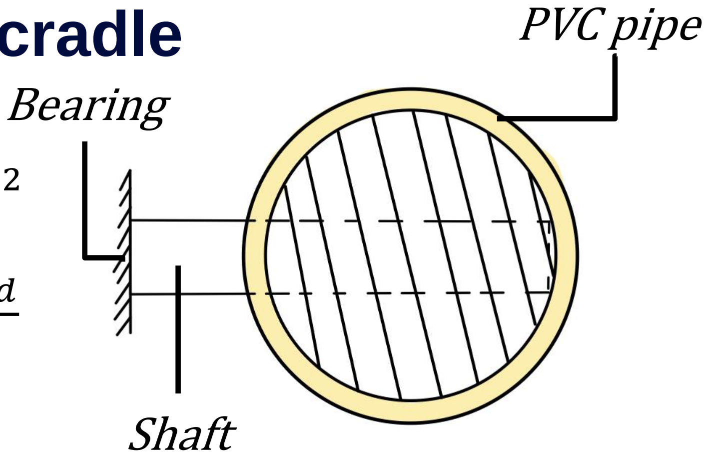
$$F_{wind} = \frac{A_r P_{wind} C_d}{2}$$

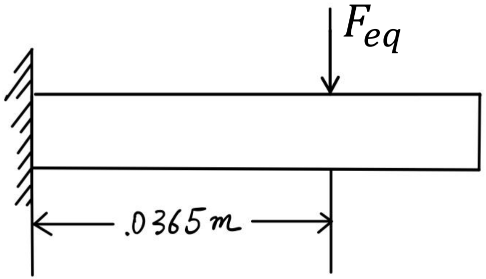
$$M = F_{eq} l$$

$$I = \frac{\pi}{64} \cdot D^4$$

$$\sigma_{ultimate} = 420\ MPa$$

$$C_d = 1.28$$





FOS for shafts from 4-inch PVC to cradle

$$F_{wind} = A_{projected} \cdot P \cdot C_d = 0.131V^2 (N)$$

$$F_{cradle} = 261N$$

$$F_{eq} = \sqrt{F_{wind}^2 + F_{cradle}^2} = \sqrt{0.131V^2 + 261^2}\ (N)$$

$$\sigma = \frac{Mc}{I} = \frac{\sqrt{0.131V^2 + 261^2} N \cdot 0.0365m \cdot 0.005m}{\frac{\pi}{64} \cdot 0.01016m^4}\ (Pa)$$

$$n = \frac{\sigma_{ultimate}}{|\sigma|}$$

$$\boxed{V = 91mph\ for\ N = 2}$$

Lifting Force on Mirror Units

$$L = C_l \frac{\rho V^2}{2} A \ \ (N)$$

$$C_l = sin(\alpha)cos(\alpha)\left(K_p cos(\alpha) + \pi sin(\alpha)\right)$$

$$(\alpha) = 13° \ \ K_p = 2.59$$

$$\rho_{air,Las\,Vegas} = 1.1423 \frac{kg}{m^3} \ (97°\text{F})$$

$$V_{avg} = 4\ m/s$$

$$L_{avg} = 6.47\ N$$

$$\sigma_{side\ of\ hole} = \frac{L_{avg}}{A_{connection}}$$

$$\sigma_{side\ of\ hole} = 0.126\ MPa < \sigma_{ultimate} = 55MPa$$

Parameters for flat plate lift and drag from Torres and Mueller

AR	α_m (°)	K_p	K
0.5	35	0.831	0.67
0.75	33	1.26	0.565
1.0	28	1.59	0.53
1.25	20	1.85	0.483
1.5	15	2.10	0.417
1.75	14	2.35	0.409
2.0	13	2.59	0.374

Structure Breached with Water

$$q'_{conv} = \frac{T_m - T_\infty}{R'_t}$$

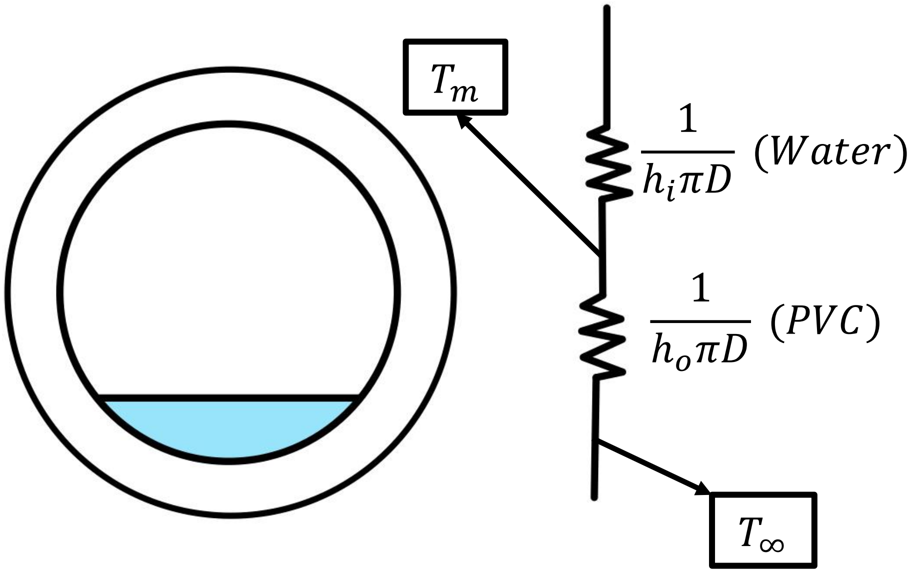
$$T_\infty = 93.8°F$$
$$T_m = 68.8°F$$

$$R'_t = 0.8534\,\frac{hr\ ft\ °F}{btu}$$

$$q'_{conv} = -29.2946\,\frac{btu}{hr\ ft}$$

$$\frac{8092\ btu}{1\ gal}\left(\frac{hr}{29.2946\ btu}\right) = \frac{276\ hr}{gal}$$

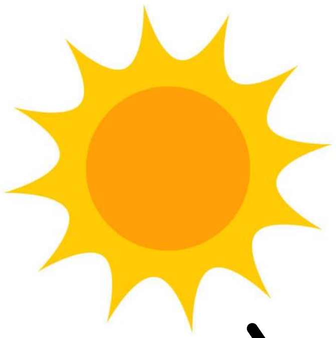
$$\frac{276\ hr}{gal} = \frac{11.5\ days}{gal} = \boxed{\frac{0.72\ days}{cup}}$$

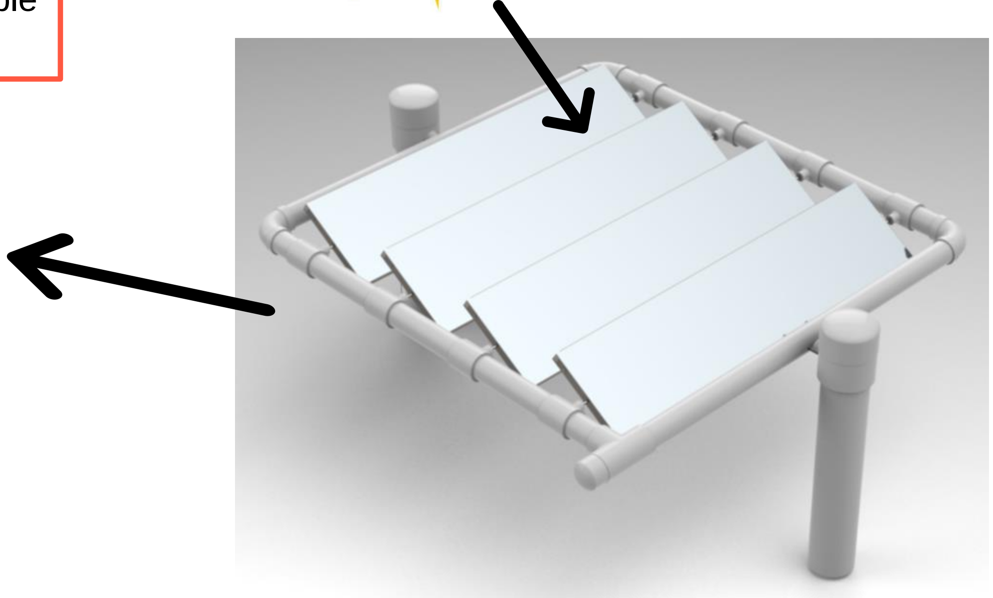


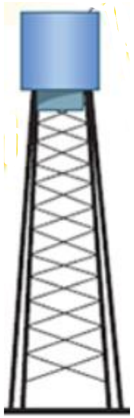
All Subsystems

Key Features

- Module area to reflecting = 1.48
- Easy access to attach/ assemble pieces







Sealed from Environment

- Sealed ball bearings
- Epoxy to close holes with wires
- Caps over PVC to protect motors

Tower Location

- Receiver is 1 m^2
- Tower is 100 m tall
- Last row of modules is 66 meters from tower
- Tower located on short side of module
- Long side of the heliostat is along the East to West axis

All Subsystems Customer Needs

C11) Custom part price ≤ OTS part price

C1) Capitalizes on innovations from small size

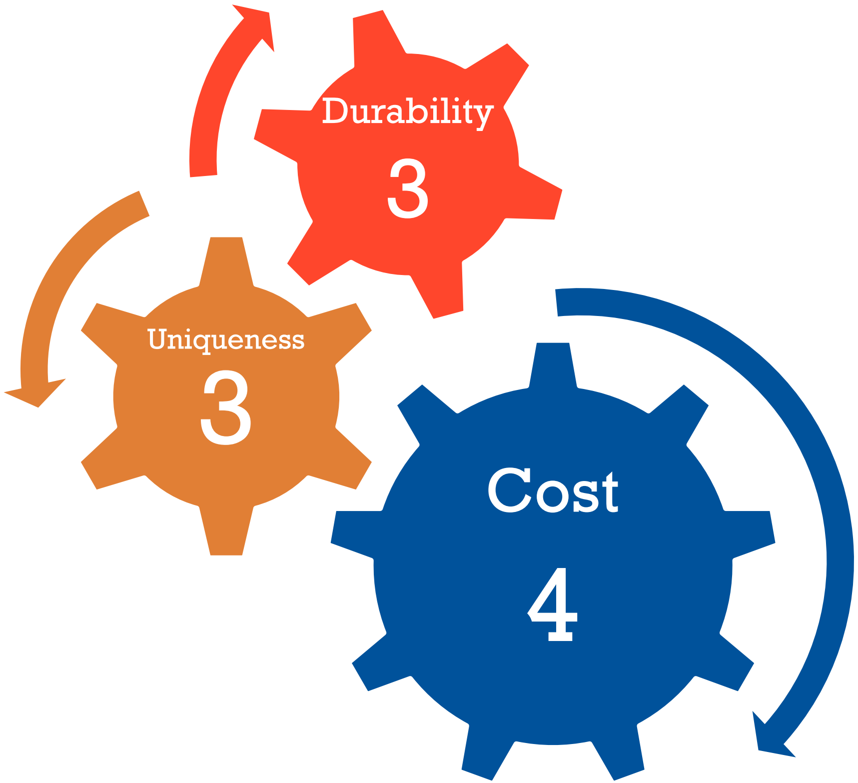
M11) Part cost ≤ OTS part

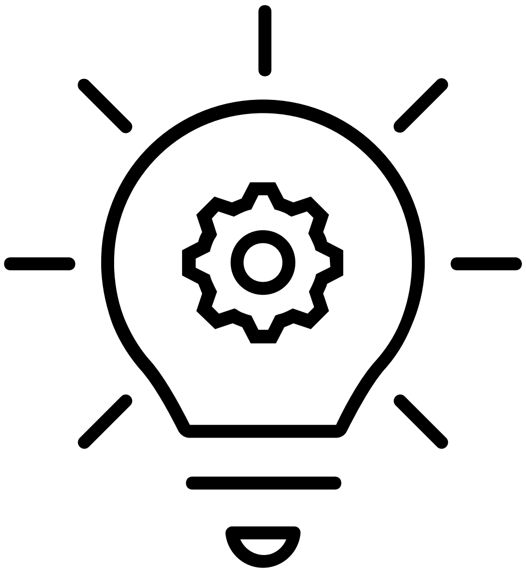
M1) Top 3 customer rated innovation questions score ≥ 3 on a 1-5 scale rating from instructor

F11) All custom parts price < OTS price

F1) Cost: 4 Durability: 3 Uniqueness: 3

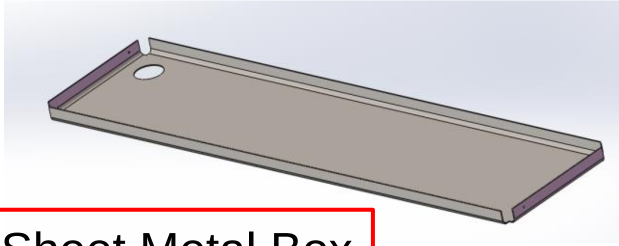
Questionnaire to EML 4501 Instructor



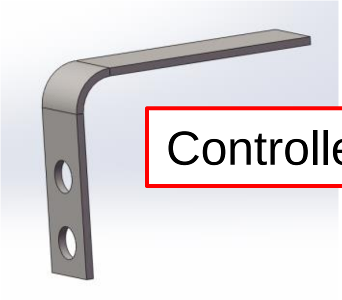


Cost of Parts is Equal to or Less than OTS Parts

Custom Parts: Machined OTS Parts

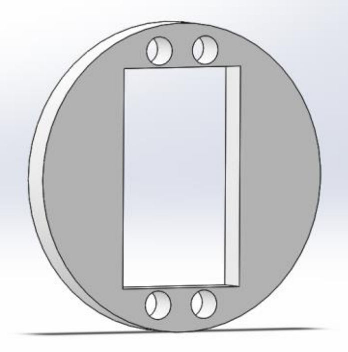


Sheet Metal Box

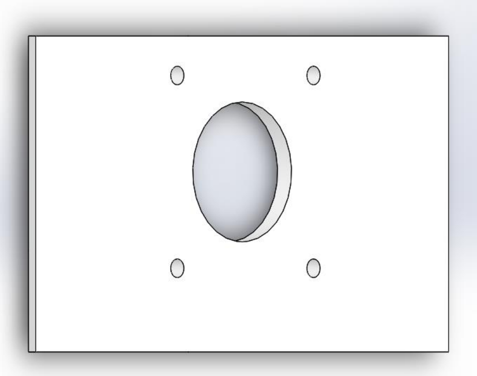


Controller Bracket

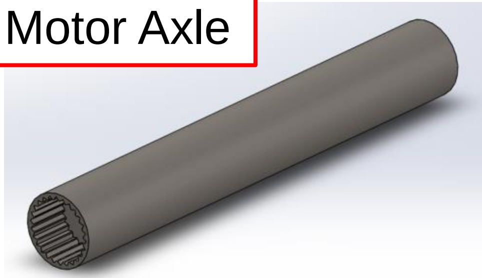
Stepper Motor Axle



Servo Motor Bracket



Stepper Motor Bracket



Servo Motor Axle

Exterior Module Maintenance

Cleaning

- Structure
  - Sealed from environment
  - Exterior materials are waterproof
  - Not crucial to clean structure
- Mylar Mirrors
  - Cleaned every 3 days with compressed air
  - Cleaned every 2 weeks with cleaning solution and rag
  - Heat shrunk back to its original form

Cost Summary

Expense	Prototype Cost	Wholesale Cost
OTS Parts	$66.32	$37.16
Modified OTS	$38.56	$22.85
Raw Materials	$15.48	$7.74
Manufacturing Labor	$16.59	$16.59
Assembly Labor	$15.17	$15.17
Energy Consumption	$0.41	$0.41
Total	$152.53	$99.92

OTS Parts: Motors, HiLetgo, Pulleys, Wiring, Hardware, Bearings, PVC connectors

Modified OTS: PVC piping, Steel Rods, Belts, Sheet Metal, Mylar, PVC Sheets, Foam Sheets

Raw Materials: Epoxy, PVC cement, Rubber cement

Manufacturing Labor: Laser water jet cutting, Bending, Welding, Brush applying, Drilling, Cutting, Shearing

Assembly Labor: Gluing, Fastening, Heat shrinking, Soldering

Energy Consumption: Welding, Drilling, Laser water jet cutter, Band Saw

Cost Savings Summary

Prices since the Pandemic

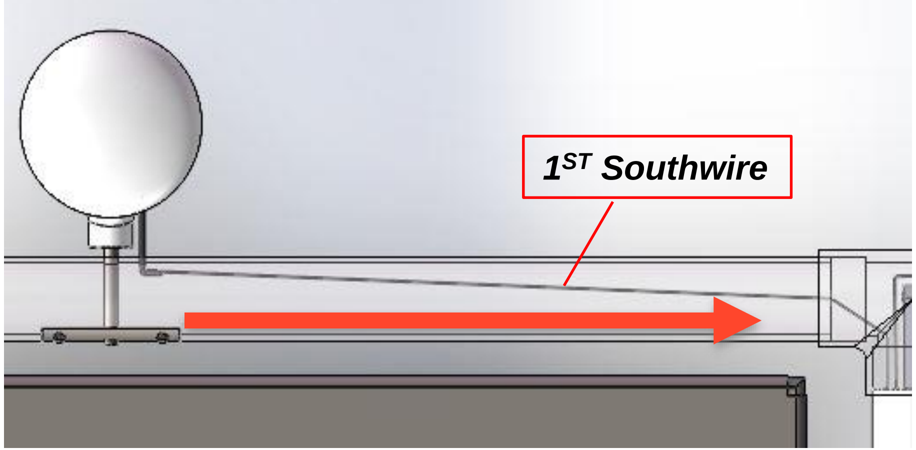
Raw Material & Inflation

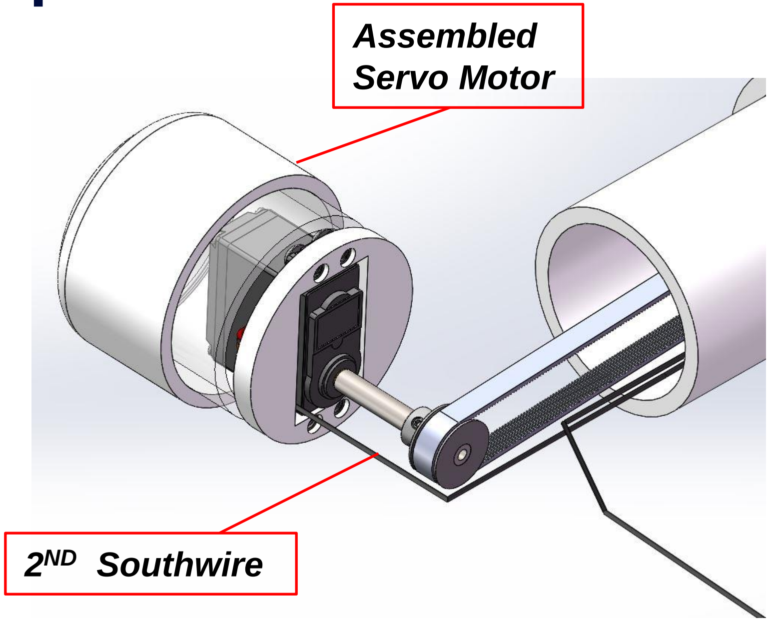
- PVC prices have approximately doubled
- Steel prices have risen 126%
- Foam prices have risen by 35%

Buying in Bulk & Shipping

- Avoided retail prices
- Prioritized purchasing from companies that offer free shipping

Assembly of Frame’s Inner Components

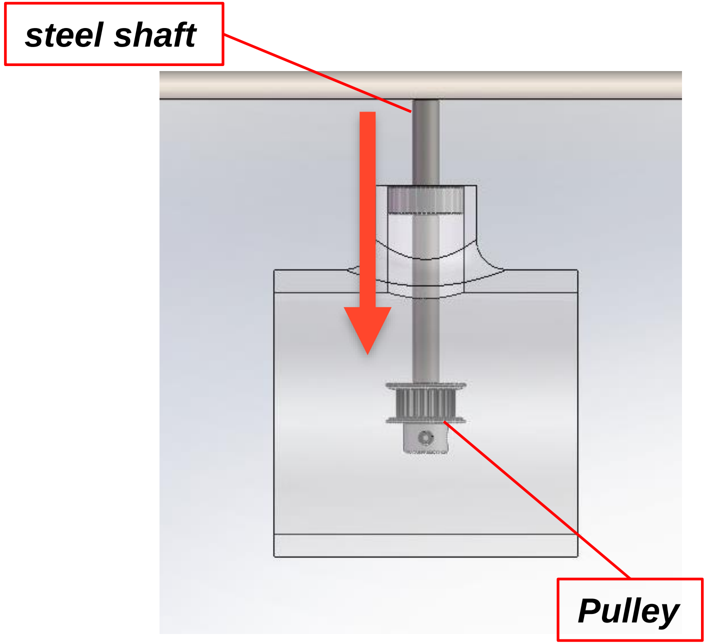


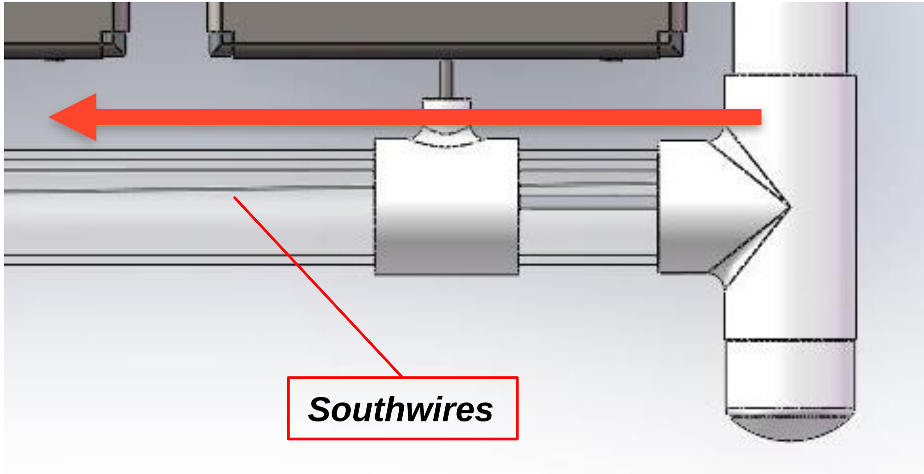


1st: Run Southwire from the stepper motor entrance to the servo motor through the 2-inch PVC pipe.

2nd: Attach servo motor to bracket and solder wiring for the second Southwire.

Assembly of Frame’s Inner Components

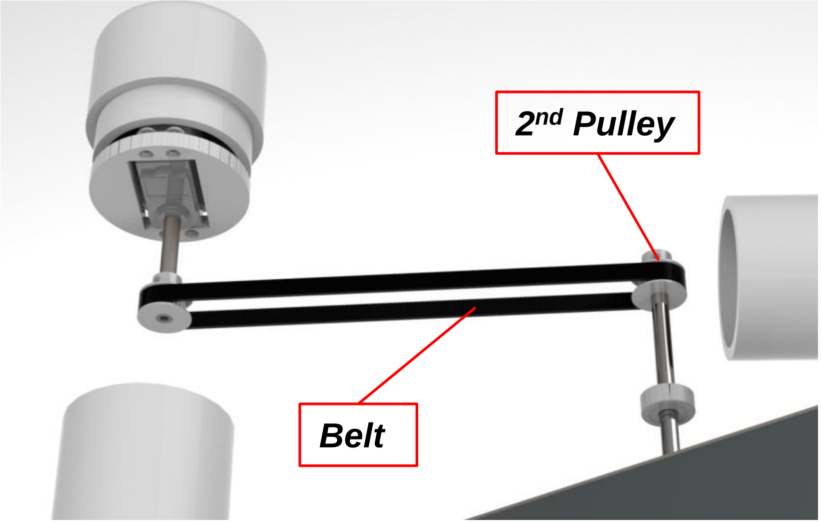




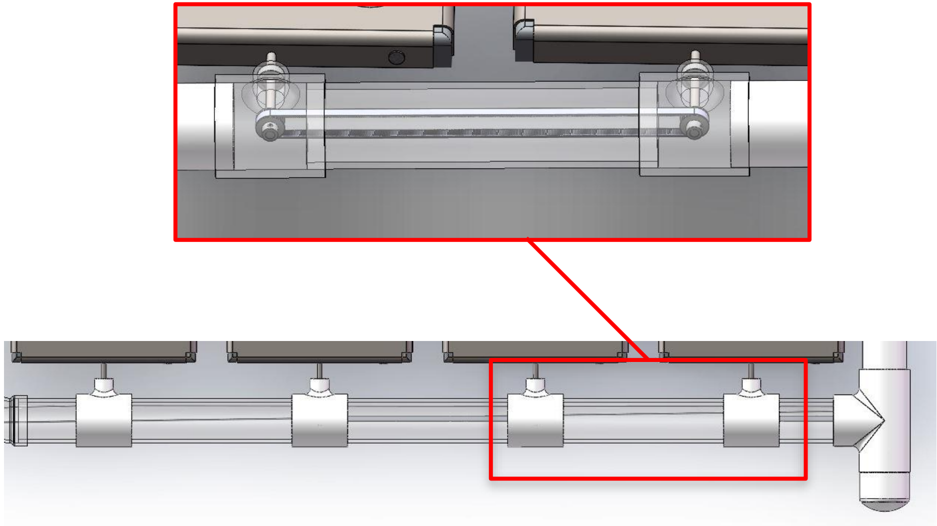
3rd: Insert ¼” steel shaft into bearing and secure pulley on it.

4th: Connect PVC fittings and run both Southwires through the medium size 2-inch PVC pipe.

Assembly of Frame's Inner Components

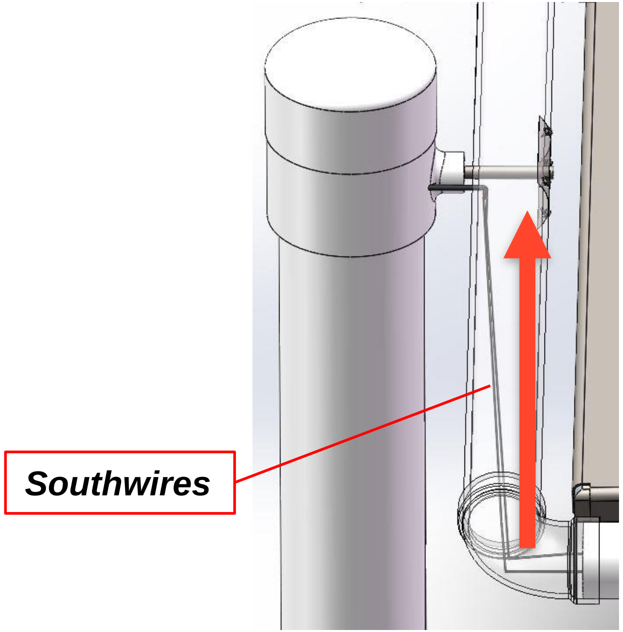


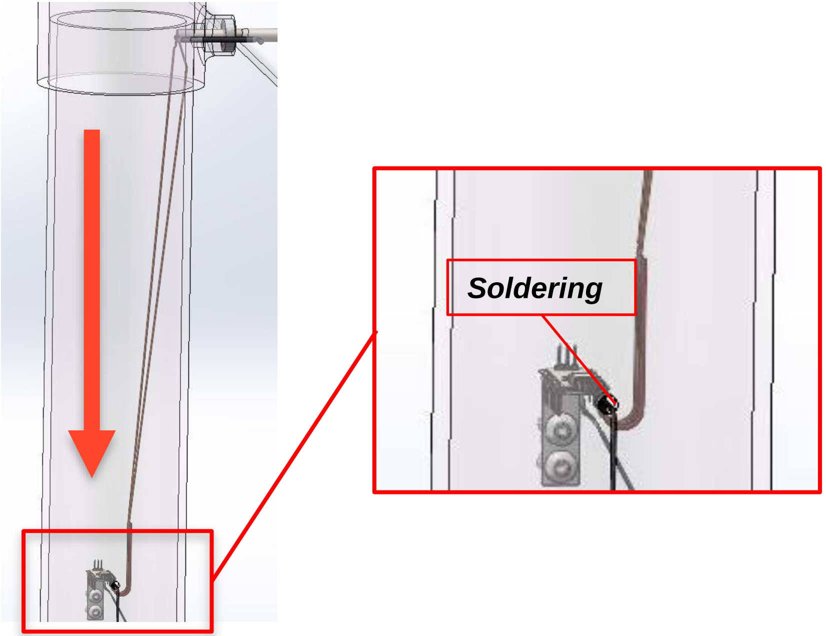
5th: Use a hook to stretch belt over the second pulley.



6th: Repeat the process of installing pulley system and pulling Southwires through the 2-inch PVC pipe frame until the elbow joint is reached.

Assembly of Frame's Inner Components

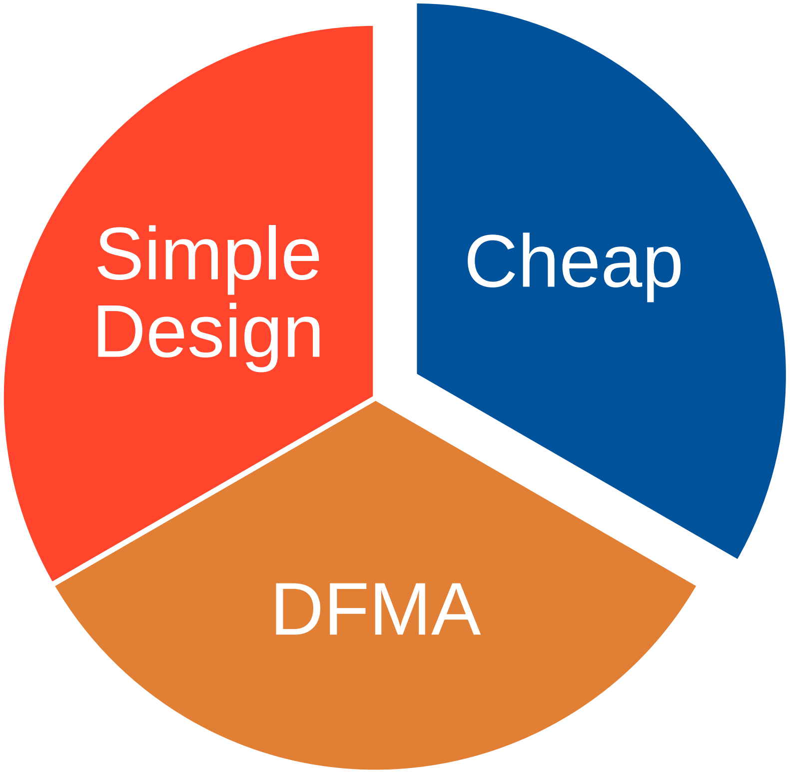




7th: Run Southwires from the elbow joint to the exit hole at the HiLetgo.

8th: Feed wiring into the housing for the HiLetgo and solder wires together. Then, seal any frame openings with epoxy.

Why prototype MIRLAR?



Additional Details - Initiative

Customer — Insight on importance level of differing needs

Jena Dolinar — Background research and experience with Mylar in Industry

Dr. Niemi — Additional feedback on early stages of design

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THANK YOU

Questions?

Cummins

NORTHROP GRUMMAN

Carrier®

aurigo®

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Backup Slides

POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE

Mech2_shaft.m*

```
clc;
clear;
V = 8;
while true
    V = V+1; %wind speed (mph)
    A = 0.835; %1*cos(33.4 degree) (m^2)
    P = 0.00256*V^2; %Wind pressure(psf)
    P = P*47.88; %Wind pressure(Pa)
    D = 0.01016; %Diameter of the shaft(m)
    Cd = 1.28; %drag coefficient
    Fw = A*P*Cd; %wind force (N)
    Fw = Fw/2; %Two shafts shares the force (N)
    L = 0.0365125;%shaft length to force (m)
    F2 = 261; %mirror weight and cradle (N)
    Ftot = sqrt(Fw^2 + F2^2); %Equivelant force (N)
    M = Ftot*L; %bending moment on shaft (N.m)
    c = 0.00508; %distance to central axis (m)
    I = (pi/64)*(D^4); %Moment of inertia for the shaft(m^4)
    sigma = M*c/I; %Bending stress(Pa)
    sigmau = 420e6; %Ultimate strength(Pa)
    n = sigmau/sigma; %Factor of safety
    if n <= 2
        fprintf('Wind speed is %d mph when n is 2!',V);
        break;
    end
end

```

Command Window

```
fx Wind speed is 91 mph when n is 2!>>
```

Buckling of 4 in PVC pillars

$$Euler's\ Buckling\ Formula: P_{CR} = \frac{\pi^2 EI}{(KL)^2}$$

$$Elastic\ modulus\ PVC: E = 400ksi$$

Moment of inertia: I = 0.184 in^4

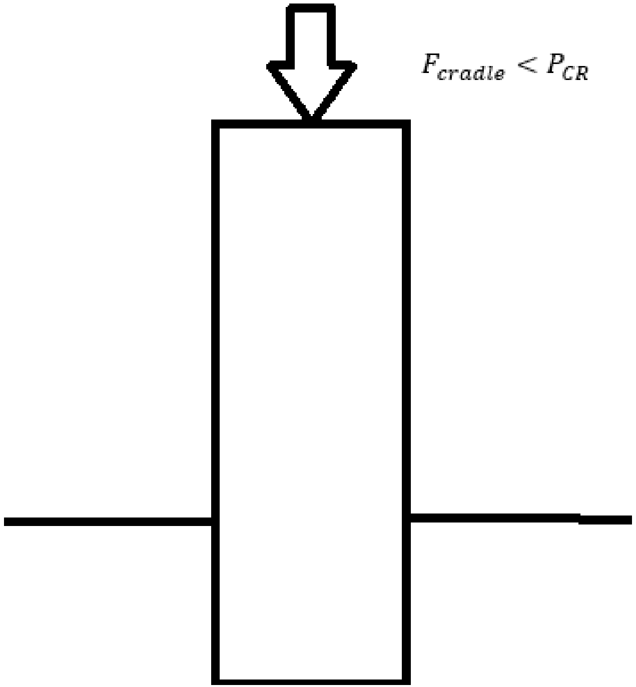
$$Effective\ \ length\ factor: K = 2$$

$$Pole\ length\ above\ ground: L = 24\ in$$

$$Critical\ load\ for\ buckling:\ P_{CR} = 13000\ lbf$$

The cradle weights 58.64 lbf

The pillars will not fail under compression



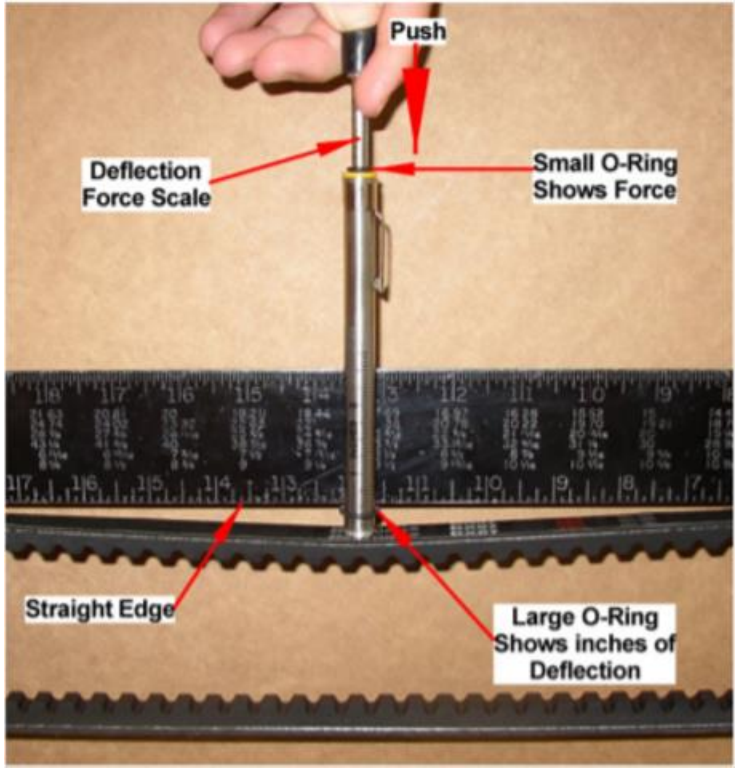
Interior Module Maintenance

Belts

- Timing belt tensioning
  - How to check for proper tensioning: compression gage
  - Static tension required: 2 lbf
- Infinite life span
  - GT2 belts last up to 100,000 miles
  - One means infinite liferevolution per day (<2 ft)

Electronics

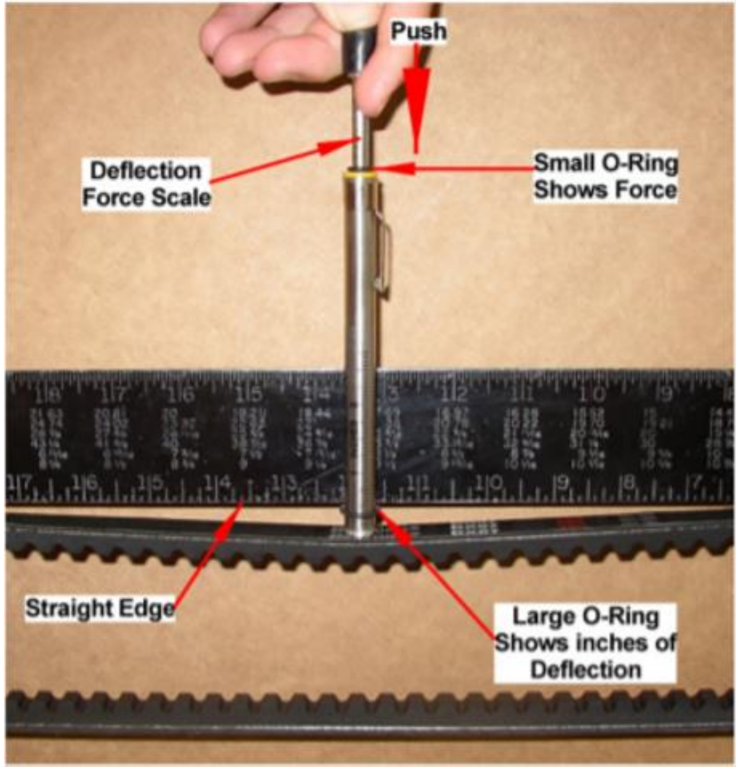
- Servo & Stepper Motor
  - Life span > 50 years
- HiLetgo
  - Life span > 20 years
  - Easily be rebooted



How to Use a Compression Gage (Bestorq)

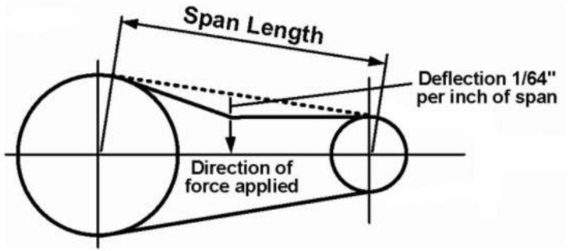
TENSION PENCIL (compression gage)

1. Measure the span length "P".
2. Set the large O-Ring on the number of inches obtained by dividing the span length "P" inches by 32 or 64 or 128 depending on what amount of deflection is the easier to read. For example, if the span was 32 inches the most convenient deflection amount to use would be 32/64 inches or 1/2 inch
3. Set the small O ring on the deflection force scale to zero.
4. Place the tension gage directly on one belt at the center of the span. Push down on the gage until the large O-Ring lines up with the straight edge laid across the back of the belt pulley-to-pulley.
5. Remove the tension gage and read the force applied by looking at the position of the small O-Ring. The force "F" you apply should be what is shown in the table. on the next page.



Force Required to Examine Proper Belt Tensioning

Belt	Belt Width	m	Y	Minimum T_{st} (lbf) Per Span
2 mm GT2	4 mm	0.026	1.37	1.3
	6 mm	0.039	2.05	2.0
	9 mm	0.058	3.08	3.0
	12 mm	0.077	4.10	4.0
3 mm GT2	6 mm	0.077	3.22	2.2
	9 mm	0.120	4.83	3.3
	12 mm	0.150	6.45	4.4
	15 mm	0.190	8.06	5.5
5 mm GT2	9 mm	0.170	14.9	8.4
	15 mm	0.280	24.9	14.1
	20 mm	0.380	33.2	18.7
	25 mm	0.470	41.5	23.4
3 mm HTD	6 mm	0.068	3.81	2.5
	9 mm	0.102	5.71	4.3
	15 mm	0.170	9.52	7.8
5 mm HTD	9 mm	0.163	14.9	6.3
	15 mm	0.272	24.9	12.0
	25 mm	0.453	41.5	21.3
MXL	1/8"	0.003	1.40	1.0
	3/16"	0.004	2.11	1.7
	1/4"	0.005	2.81	2.3
XL	1/4"	0.010	3.30	3.2
	3/8"	0.015	4.94	5.1
L	1/2"	0.19	10.00	13.0
	3/4"	0.29	18.00	19.0
	1"	0.38	25.00	25.0
T2.5	4 mm	*	0.3	0.2
	6 mm		0.55	0.45
	10 mm		1.05	0.92
T5	6 mm	*	7	2.25
	10 mm		17	5.62
	16 mm		27	8.99
T10	16 mm	*	73	24.73
	25 mm		133	44.96



In the force-deflection method, a specified force is used to create a given deflection in the belt.

$$F_{min} = \frac{T_{st} + \left(\frac{t}{L}\right) \cdot Y}{16}$$

$$F_{max} = \frac{1.1 \cdot T_{st} + \left(\frac{t}{L}\right) \cdot Y}{16}$$

F = Force to produce the specified deflection (N)

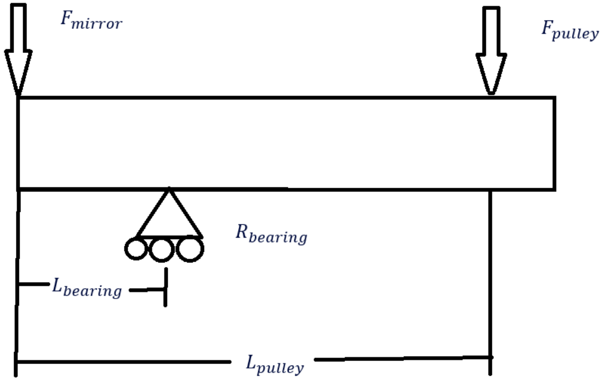
T_{st} = static tension (N)

t = belt span length (m)

L = belt pitch length (m)

Y = tensioning constant based on belt (provided by manufacturer)

Maximum Mirror Axle Deflection: GT2 Timing Pulley



$$\sum F = 0 = F_{mirror} + R_{bearing} + F_{pulley}$$

$$F_{mirror} = 6\ lbf$$

$$F_{pulley} = 2\ lbf\ \ L_{pulley} =$$

$$F_{bearing} = 8\ lbf$$

$$EI\frac{d^2y}{dx^2} = M$$

$$\frac{dM}{dx} = V = F_{mirror} + R_{bearing} < x - L_{bearing} >^0 - F_{pulley} < x - L_{pulley} >^0$$

$$M = F_{mirror}x + R_{bearing} < x - L_{bearing} >^1 - F_{pulley} < x - L_{pulley} >^1$$

$$EI\frac{dy}{dx} = \frac{1}{2}F_{mirror}x^2 + \frac{1}{2}R_{bearing} < x - L_{bearing} >^2 - \frac{1}{2}F_{pulley} < x - L_{pulley} >^2 + C_1$$

$$EIy = \frac{1}{6}F_{mirror}x^3 + \frac{1}{6}R_{bearing} < x - L_{bearing} >^3 - \frac{1}{6}F_{pulley} < x - L_{pulley} >^3 + C_1x + C_2$$

$$BC's:\ Integration\ constants = 0$$

$$y(x) = \frac{1}{EI}\left(\frac{1}{6}F_{mirror}x^3 + \frac{1}{6}R_{bearing} < x - L_{bearing} >^3 - \frac{1}{6}F_{pulley} < x - L_{pulley} >^3\right)$$

$$\boxed{y(L_{shaft}) = y(3.5\ in) = 0.0009\ in}$$

Structure Breached with Water (Thermal Resistance)

Laminar Flow: $N_{uD} = 3.66$

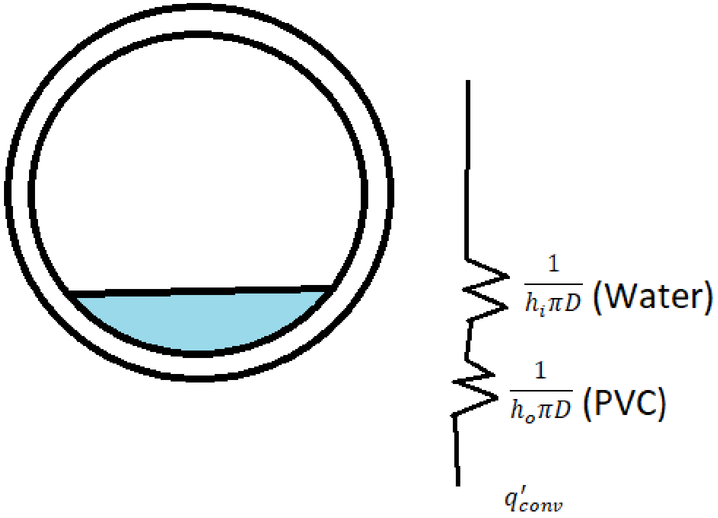
$$R'_t = \frac{1}{h_i \pi D} + \frac{1}{h_o \pi D}$$

$$h_i = \frac{N_{uD} k_w}{D_{pipe}} = 7.5916 \frac{Btu}{hr\ ft^2 °F}$$

$$h_o = \frac{N_{uD} k_{PVC}}{D_{pipe}} = 3.1732 \frac{Btu}{hr\ ft^2 °F}$$

$$\frac{8092\ btu}{1\ gal}\left(\frac{hr}{29.2946\ btu}\right) = \frac{276\ hr}{gal}$$

$$\frac{276\ hr}{gal} = \frac{11.5\ days}{gal} = \boxed{\frac{0.72\ days}{cup}}$$



DFMA Principles

Design for Assembly (DFA)

DFA involves design for a product's ease of assembly. It is concerned with reducing the product assembly cost and minimising the number of assembly operations.

Both DFM and DFA seek to reduce material, overhead, and labour costs.

DfMA principles

In a similar approach to lean construction, applying DfMA enables the identification, quantification and elimination of waste or inefficiency in product manufacture and assembly. It can also be used as a benchmarking tool to study the products of competitors.

The main principles of DfMA are:

- Minimise the number of components: Thereby reducing assembly and ordering costs, reducing work-in-process, and simplifying automation.
- Design for ease of part-fabrication: The geometry of parts is simplified and unnecessary features are avoided.
- Tolerances of parts: Part should be designed to be within process capability.
- Clarity: Components should be designed so they can only be assembled one way.
- Minimise the use of flexible components: Parts made of rubber, gaskets, cables and so on, should be limited as handling and assembly is generally more difficult.
- Design for ease of assembly: For example, the use of snap-fits and adhesive bonding rather than threaded fasteners such as nuts and bolts. Where possible a product should be designed with a base component for locating other components quickly and accurately.
- Eliminate or reduce required adjustments: Designing adjustments into a product means there are more opportunities for out-of-adjustment conditions to arise.