# Solar Tracking Structure Design

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Team 07

# Project Analysis

Document

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## Contents

# 1. Introduction

Last report we came up with seven different concepts to solve the need of our client Dr. Acker. We narrowed it down to three concepts the Angled tracker, Hydraulic tracker, and the Solar Array tracker. Having chosen these three designs we modeled them in SolidWorks to better understand what parts of the designs should be analyzed. While modeling them in SolidWorks both the Angled tracker design and the Hydraulic tracker designs changed.  Based on the way the designs were modeled in SolidWorks we split our group into three groups of two to analyze each design. We also realized while modeling in SolidWorks that we would need certain angles for the slope of the panels in the designs so we did analysis of the solar tracking systems based upon the book provided to us by Dr. Acker.

# 2. Analysis

In this portion of the report our team did static structural analysis on all three of designs selected from the concept generation. With this information we selected some material and motors for each design. In addition to the structural analysis we also did analysis of the angles required to track sun.

## 2.1 Angled Solar Tracker

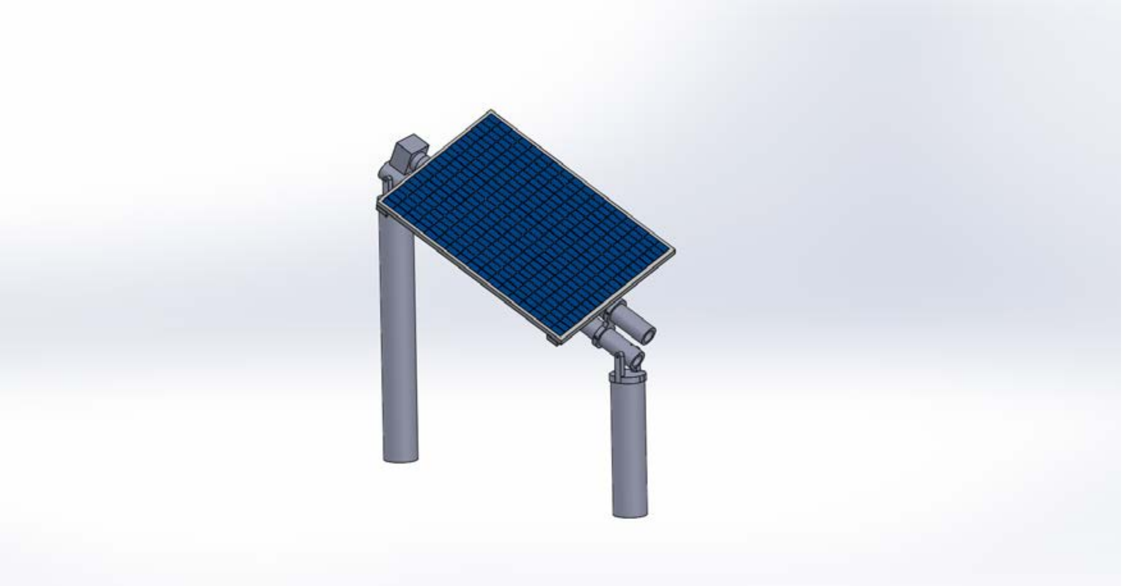


Figure 1: Isometric view of Angled tracker

Figure 2: Side view of Angled tracker

In the last report of concept generation this design originally consisted of one support with the upper part of the solar panel resting on a triangular support of two shafts. However, to save space and to make the analysis of the design easier we decided to go with only one support on the back.

The Angled Solar Tracker frame using statistical equations. The frame was broken up into segments and analyzed. Starting with Component A seen in Figure 3, the component that is attached directly to the solar panel experiences a distributed load over the width of the solar panel. The general equation is listed below.

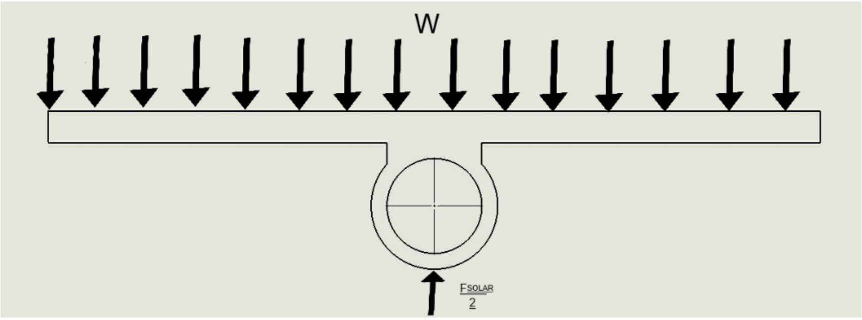


Figure 3: Component A

$\sum F_y = 0 = F_{solar} - F*W$

$\sum F_x = 0 = A_{1x}$

Where A1 is the reaction at the A joint, W is the width of the solar panel and $F_{solar}$ is the normal force exerted to the solar panel. F is the force of the whole solar panel.

For Component B, seen in Figure 4. The general equations come out to be

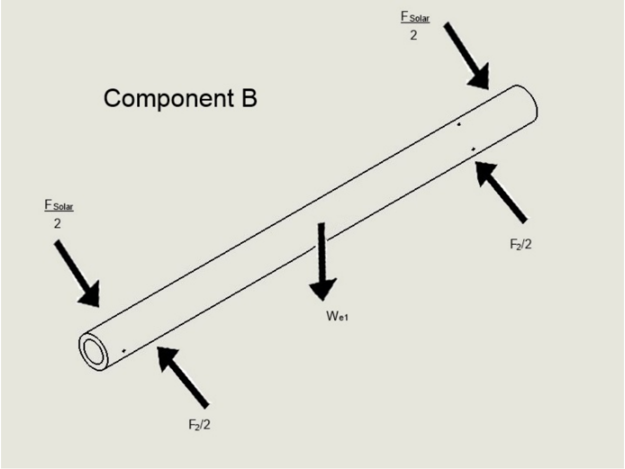


Figure 4: Component B

$\sum F_y = 0 = -F_{solar} + F_2 – W_{e1} * \sin(\theta_1)$

$\sum F_x = 0 = -W_{e1} * \cos(\theta_1)$

Where $W_{e1}$ is the weight of the component B bar. Component B is attached to Component C. Calculating the force in Component C seen in Figure 5 the general equations are shown below.

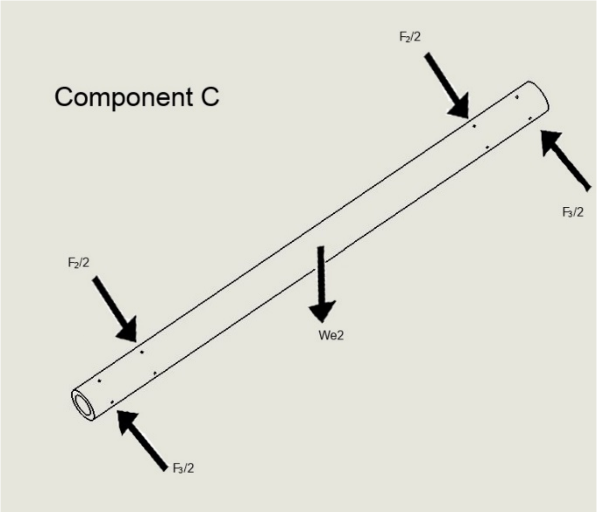


Figure 5: Component C

$\sum F_y = 0 = - F_2 + F_3 – W_{e2} * \sin(\theta_1)$

$\sum F_x = 0 = - W_{e2} * \cos(\theta_1)$

Component C rest upon two bars that are perpendicular to the ground, which have been labeled Component D seen in Figure 6 and Component E seen in Figure 7. Calculating the forces in each component the general equations become.

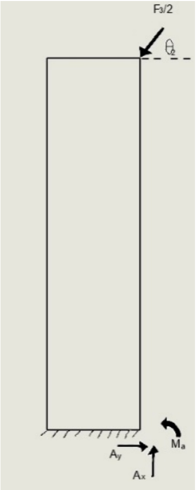


Figure 6: Component D

$\sum F_y = 0 = A_y – (F_3/2) * \sin(\theta_2)$

$\sum F_x = 0 = A_x – (F_3/2) * \cos(\theta_2)$

$\sum M_a = L * F_3/2 * \cos(\theta_2)$

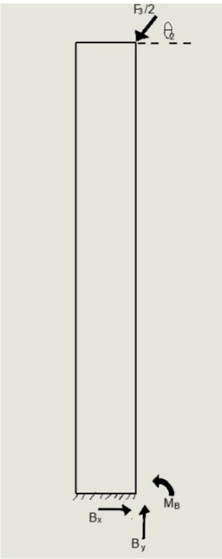


Figure 7: Component E

$\sum F_y = 0 = A_y - (F_3/2) * \sin(\theta_2)$

$\sum F_x = 0 = A_x - (F_3/2) * \cos(\theta_2)$

$\sum M_a = L * F_3/2 * \cos(\theta_2)$

## Torque

The Torque was calculated by taking the Force that the solar panels apply times a frictional coefficient of 0.48 times the radius of 2.54cm

$$T = (F \times 0.48) \times r$$

The Torque is calculated to be 3.254N*m. Then taking this Torque the ratio between horsepower (HP) and Revolutions per Minute (rpm) was found using the Full-load Torque equation.

$$T = (HP \times 5252) / rpm$$

The ratio of HP/rpm was found to be 0.0006196, using the DC Motor, NEMA 56 C-Face with Base, 12 VDC, 1/4 hp, 1800 rpm[1]

Solve the general equations using the givens shown in the Appendix A.

## Material Selection

The material that satisfies the stresses at these points is AISI 1020 steel. AISI 1020 steel has an Ultimate Tensile Strength (UTS) of 394.72 MPa and a modulus of Elasticity of 200 GPa which easily satisfies the design requirements. This steal was chosen over other grade steal since it is cheap and easy to manufacture.

## 2.2 Hydraulic Tracker

The team decided to design a light weight, yet reliable solar tracking system that not only meets the objectives and needs but is to perform in a safe and efficient manner. After applying the decision matrix, the team decided to pursue three potential designs since the tracking system will be utilized in an environment where there is plenty of sunshine during the midday and shady in the mornings and evenings. The team figured that in order to maximize the system’s efficiency, the system and its components would have to be designed and chosen with reliability in mind. The following is the analysis of the Hydraulic Tracker.

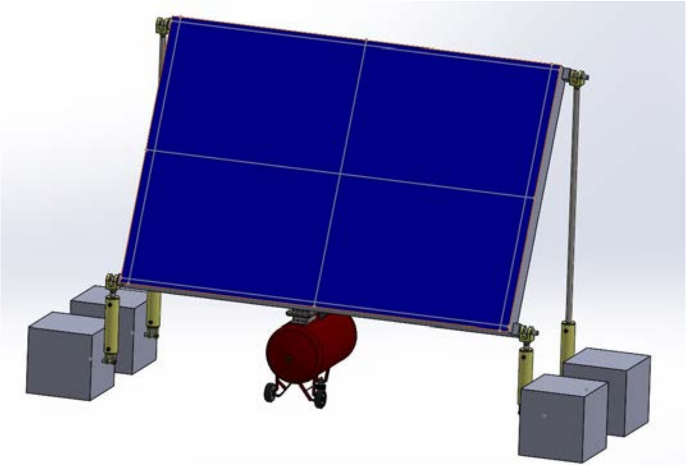


Figure 8. Isometric View of the Hydraulic Tracker

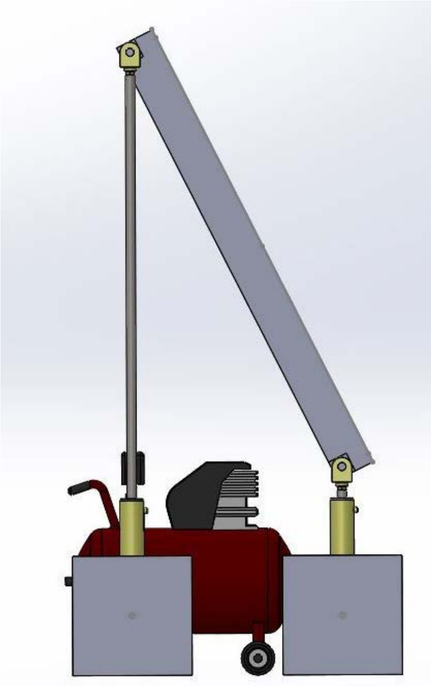


Figure 9. Side View of the Hydraulic Tracker

The original plan was for the design to include a ball joint in the center of each panel for support it also had magneto-rheological (MR) fluids in the hydraulics. Since the panels do not weigh as much as the team originally estimated, and it is hard to find a ball joint with our needed dimensions. The MR fluid is used in damper hydraulics and thus does not provide and lifting force. There has been a couple modifications done to the design due to the facts stated above. These modifications includes moving from MR hydraulic fluid to air and no ball joint.

So for this new design, the team decided to do a stress analysis of a few particular points. The stress analysis calculated on the system will be located at the points where the rods are inserted into the upper and lower eyelets of the hydraulic cylinder.

The weight of each solar panel is 266.9 Newton (N) and the weight of each hydraulic cylinder is approximately 22.24 N. The minimum length of the connecting rods should be 0.06 meters (m) to fit the eyelets of the hydraulic cylinder, nuts, and bolts used to secure it. The eyelets of the hydraulics have a diameter of 0.02 m.  The material that the team chose for the rods will be AISI 1020 Steel because it is relatively inexpensive and readily available. The Ultimate Tensile Strength (UTS) for the material chosen is 394.72 MPa.

The Modulus of Elasticity of AISI 1020 Steel is 200 GPa. With these known values and assumptions, the basic hand calculation of the prototype are as follows:

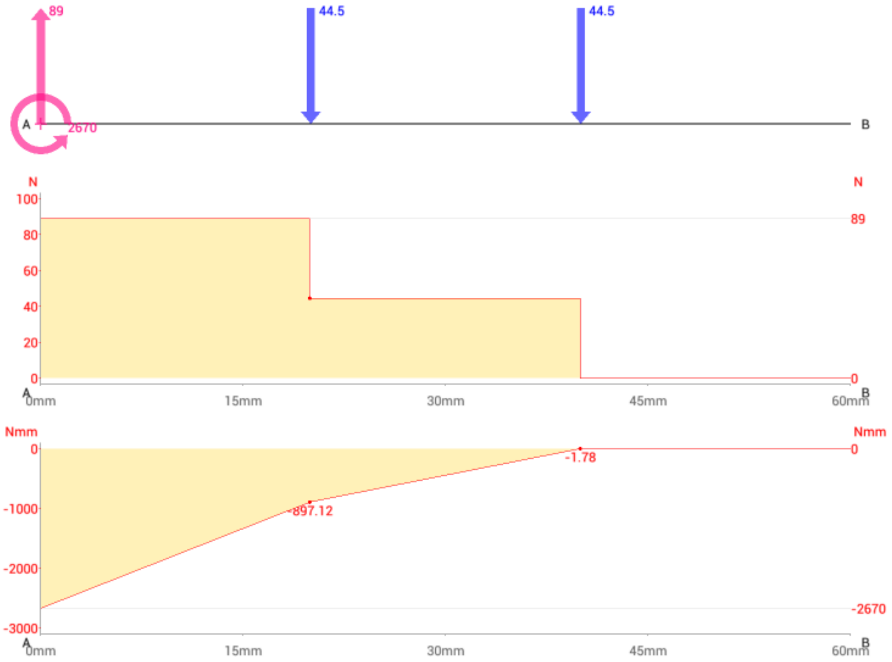


Figure 10. Shear and Bending Moment Diagram Section AB

This analysis is performed for the lower hydraulic eyelet. This location is to be connected to the cement blocks for support and stability. The reaction force acting on the connecting rods are the ¼ of the weight of each assembly, panel and 4 hydraulic cylinders, because there are four supports for each system. For this calculation, the team assumes static equilibrium because the acceleration of the panels will be slow. Thus, calculating at static equilibrium, the shear force is 88.97 N and the moment at Point A turned out to be 5.34 N-m. According to these values, the team did not calculate the forces that the hydraulic cylinders can withstand because each cylinder will have to withstand greater values of force due to the high internal pressures that each assembly must have to move each panel.

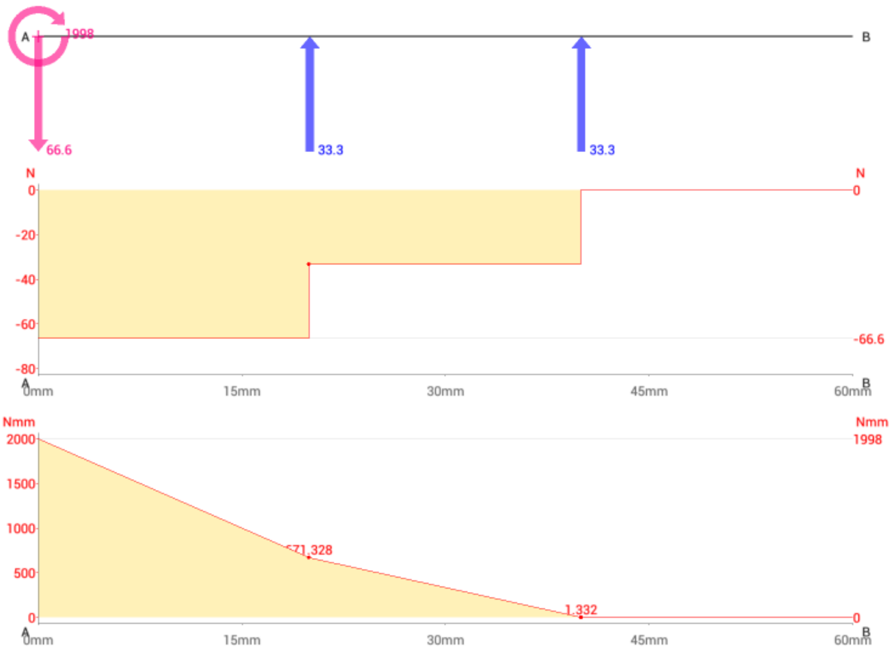


Figure 11. Shear and Bending Moment Diagram Section CD

The following analysis is of the connecting rods mounted to the solar panels. The weight applied to this area is ¼ of the weight of each panel. The team made the same assumptions for static equilibrium case. The shear force is 66.73 N and moment is 4 N-m. These values are less than the shear and moment in section AB. The driving values of this shear and moment diagram are 88.97 N and 5.34 N-m.

The determining factor of each connecting rod is the diameter or the cross sectional area of each rod so it can match the diameter of the hydraulic. We chose AISI 1020 steel because it is inexpensive and readily available. Using equation UTS=FL/EA the maximum length that each rod can withstand before failure is 11914 m. Since the length of the rod we are using is 0.06 m, there is no concern about the rods failing.

After doing some further research, the team found that using a Standard Double-Acting Hydraulic Cylinder. This system would be the best fit since it can deliver both, a pulling and pushing motion. These pistons are relatively cost-effective when compared to other systems such as Double-Rod Cylinders, Spring Return Single-Acting Cylinders, Tandem, Telescoping Cylinders and so forth.

The next set of analyses performed were on the hydraulic cylinders. The hydraulic cylinders were analyzed to determine the force needed to lift and lower the panel throughout the day. The hydraulic cylinders are permanently set on the North-South axis, but do move on the East-West axis. As a part of this analysis, the team did manage to calculate forces needed to move the panels to effectively track the sun. The following calculations were completed using Microsoft Excel program. The program was utilized to calculate forces required to successfully move the solar panels. There were some constant variables that were used, such as:

- Panel weight = 60 lbs or 266.9 N each (approximately)
- Number of Supports = 4
- Weight at each support = 15 lbs or 66.725 N

After determining the essential constants, the following equation was used to determine the pushing force that each double acting hydraulic piston would produce:

$$F = P * (\pi d^2 / 4)$$

Where

F = rod pull force (kN)
d = piston diameter (m)
P = inside cylinder pressure (piston side) (kPa) [1]

Using an excel spreadsheet, numerous iterations were performed of this equation. The program did supply a large quantity of possible combinations that would be sufficient for this application. In order to keep the energy consumption down to a minimum, the team decided to keep the air pressure as low as possible within the cylinder so that the air compressor would not have to be operating constantly.

After reviewing the calculations found within the spreadsheet (Table 2 in the Appendix) and comparing them to the options listed within the Parker Cylinder Catalog, the team found that the best option would be to utilize a cylinder with a piston diameter of 0.125 m [2]. The reason why we compared results to the catalog was to order an off-the-shelf part rather than a custom made one because this would lead to money saved. The team found an assembly that would allow us to use the least power possible and still have a functioning tracking system. This choice was made by assuming that when the hydraulics located on the east side would be pulling while the ones located on the west side would be pushing in the morning. Then the hydraulics would operate in an opposite manner in the afternoon. The reason why the team chose to perform the analysis in this manner is because it would keep the hydraulics from conflicting with each other and causing damage to the design. Plus, the hydraulics will be assisting each other in moving the solar panel. This in return would help save the power required to move each solar panel. In reference to this idea, the pressure needed to be re would have to be a pump included within each system that would need to produce and hold 80 bars of pressure. Therefore, when the system is not in operation, the pressure inside the hydraulic cylinders will be great enough to hold the solar panel in place until it is ready to move again. This will help cut down on the power consumption during operation.

In conclusion to the analysis of this design, the team concluded that it would be rather expensive to assemble this design. The original plan was to include a ball joint in the design. The ball joint idea was dismissed due to weight issues, because the panels do not weigh as much as the team thought. Also, the team chose to utilize a different fluid within the cylinders due to the cost constraint. Lastly, the team believes this design would rank closer to last than the other two designs.

## 2.3 SOLAR PANEL ARRAY

The solar panel array can adjust all the solar panels in the system simultaneously through a pulley and belt system. The design can efficiently reduce the cost and increase efficiency of the tracking system, since only one motor and one sensor are used in the system. The design consists of

- a frame made of 3”×3”×0.25” square hollow tube
- four 2” diameter partially keyed drive shafts
- several mounted bearings
- a pulley belt system
- a powerful DC motor
- a light sensor and control system

Most of the components are made from AISI 1020 carbon steel.

The overall system is shown in Figure 12. As mentioned in the next section, the angle between the shaft and the ground is 36 degree. Four solar panels are fixed on the rotating shafts. And a pulley-belt system is installed on the lower end of the shafts.

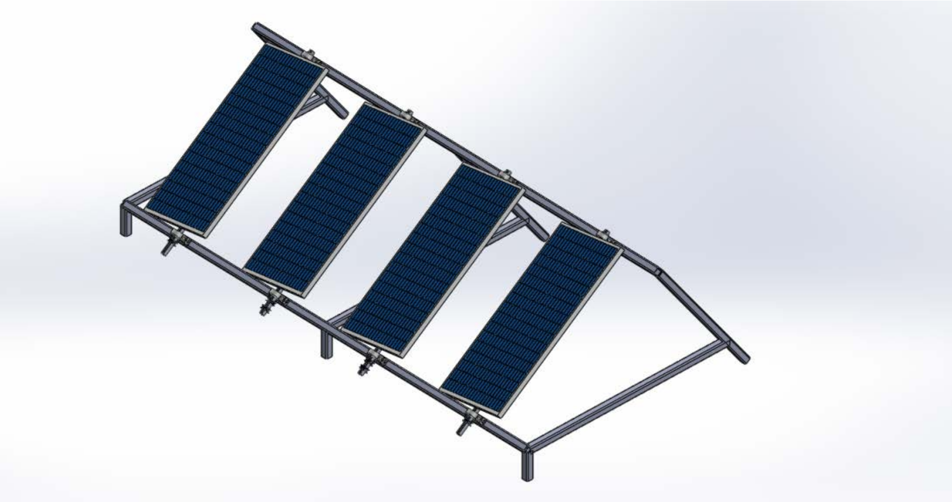


Figure 12: Isometric View of Solar Panel Array

Figure 13: Side View of the Solar Panel Array

The presented sketch is used to conduct the analysis on each member of the design. No sensor and motor is included since more calculations need to be done to determine the locations of the motor and the light sensor.

Shading analysis:

The solar panels will be installed on the frame as shown in Figure 14. To avoid the solar panel shading each other, the distance between two adjacent solar panels needs to be at least 8 ft. The calculation is shown below. Usually, solar panels absorb the sun light from 7:00 am to 6:00 pm. and the sun light has the incident angle about 30 degrees and the solar panel will always perpendicular to the sun light. The minimum space of the solar panel L can be calculated as the follow function:

$$L = \frac{0.5 * a}{\sin 30} * 2$$

Where:

L: the minimum space between solar panel;

$a$: short side length of the solar panel;

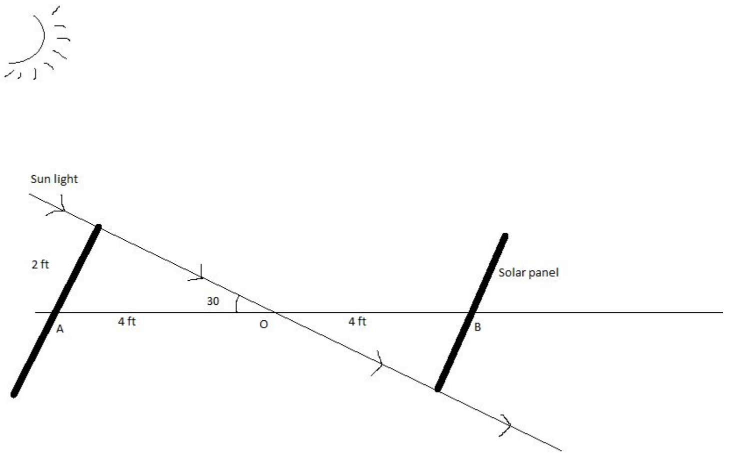


Figure 14: the geometric sketch of the space analysis

Structure Analysis:

As showing above in Figure 15, the shaft will be welded with a solar panel at two points and the distances between each point are same, assuming the weight of each solar panel is 60-Ibs, the maximum snow load is 127-Ibs, and the maximum wind load is about 75-Ibs, and self-weight of the steel bar is 10-Ibs, the total load can be regard as the concentrated load is 272-Ibs of each single solar panel.  The reactioin forces and shear moment diagram will be provide below.

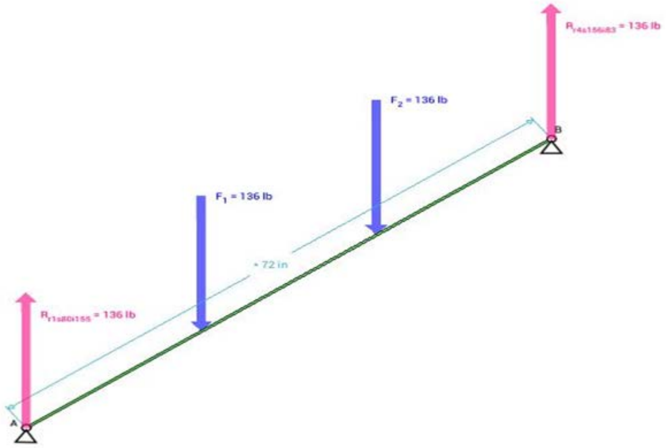


Figure 15: Free body diagram for shaft

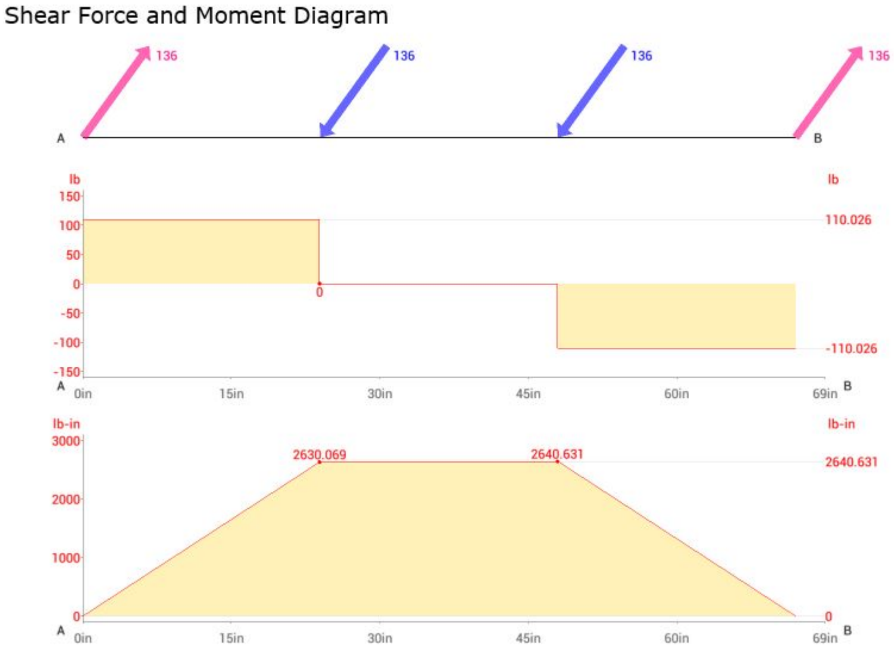


Figure 16: Shear moment diagram for the shaft

Based on the shear moment diagram above, the maximum moment occurred between two supports, where is the most likely region of failure. The maximum shear force is 110 lbs. The diameter of the shaft is 2 in. equation below is used to calculate the shear stress of the shaft:

$$\text{Shear Stress} = \frac{Forces}{Area}$$

Area=1/4*π*D^2

Raw data:

Maximum shear forces: 110 Ib;

Maximum moment: 2640 Ib-in;

Maximum shear stress: 35 Ib/in^2

There are four shafts which will be connected and supported by two parallel beams. The distances between each shaft are equally. The free body diagram and shear moment diagram are provided below:

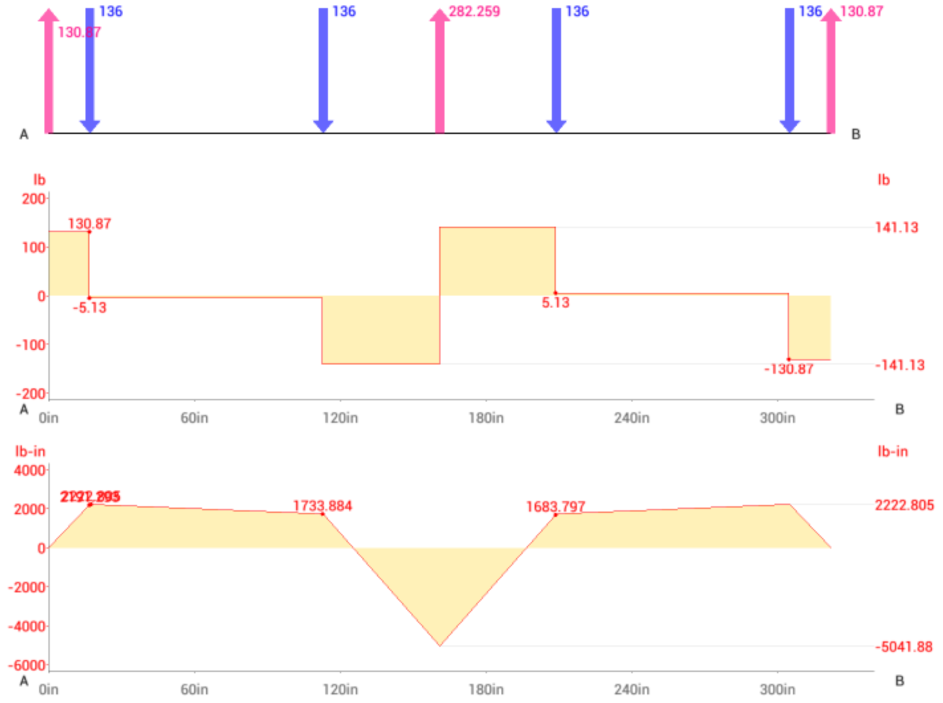


Figure 17: Shear moment diagram for the beam

Based on the shear moment diagram above, the maximum moment occurred at the mid-point of the beam between the two supports, which is the most likely region of failure. The maximum shear force is 116 lb on the beam made of 3”×3”×0.25” square hollow tube. The equations below are used to calculate the shear stress of the shaft:

$$\text{Shear Stress} = \frac{Forces}{Area}$$

Area=L^2-(L-2t)^2

$$A = L^2 - (L - 2 * t)^2$$

Raw data:

Maximum shear forces: 141 Ib;

Maximum moment: 5041 Ib-in;

Maximum shear stress: 51.273Ib/in^2

The shear moment diagrams indicate the possible failure point and region so that group can choose the appropriate material for the solar tracker to avoid fracture.

Torque

Assuming that the forces calculated above are used to drive a single shaft of 300lb, and the shaft diameter is 2 in, The Torque can be calculated by using the equation below:

$$\tau = Fc*D/2$$

Where:

$\tau$: the torque required to drive the shaft for rotating solar panel.
Fc: forcing act on the shaft.
D: diameter of the shaft.

The Torque for a single shaft is calculated to be 300Ib-in. Once the torque for a single shaft is known, the sum of the torque for 4 shafts is 1200Ib-in. we can select the appropriate motor by using equation

$$T = (HP \times 5252 \times 8.851)/rpm$$

$$HP/rpm = 0.026$$

The ratio of HP/rpm is 0.026, using the DC Parallel Shaft Gear motor, 1/2 hp, 18 rpm. It needs to be mounted a base or flat plate, the figure below is the motor we choose to power the solar tractor which was chosen from the McMaster website. [5]

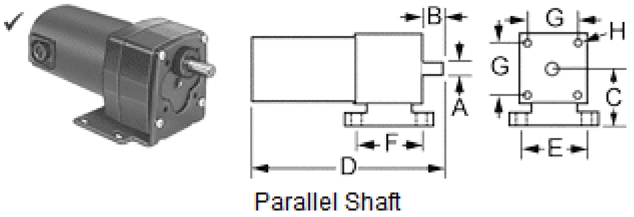


Figure18: Motor Chose for Solar Panel Array Design

## 2.4 Tracking Angle Analysis

To understand the analysis we did for the tracking angles of our design some basic solar engineering concepts must be introduced. The first being beam radiation which is defined as the solar radiation received from the sun without having been scattered by the atmosphere, also referred to as direct radiation. [1] There are two parts of the total solar radiation that solar panels receive the first being beam radiation the second being diffuse radiation. Diffuse radiation is defined as the solar radiation received from the sun that is scattered by the atmosphere. For the purpose of our analysis however regarding angles of tracking for our solar panels all calculations are done with respect only to beam radiation due to the nature of diffuse radiation being a value that requires extensive modeling outside of what is necessary to get the tracking angles for a solar panel. The next important term is Irradiance, which is defined as the rate which radiant energy is incident on a surface per unit area of the surface. [1] This term is relevant to the irradiance angle which will be covered later. The last term to go over is the Solar time which is the time based on the apparent angular motion of the sun across the sky, with solar noon being the time that the sun crosses the meridian of the observer.

In sections 1.6 and 1.7 of the Solar Engineering of Thermal Processes book provided to our team by Dr. Acker the topic of “Direction of beam radiation” and “Angles for Tracking surfaces” the concepts required to analyze the angles of tracking for our designs is gone over. The goal of any solar tracking system is to minimize the angle of incidence of beam radiation and thus maximize the incident beam radiation on the surface of you tracking system which should increase the amount of energy collected by the tracking system. The book goes over methodology of analysis for North-South and East-West solar tracking in these sections as well. However, due to the location of Flagstaff not being in the Arctic Circle the variation of the sun in the North-South axis is very small our team has decided that all three designs should be fixed in North-South direction, the slope angle between the solar panel and the ground needs to be calculated to maximize the energy absorption. As shown in Figure 19, the slope angle (h) in North-South direction is related to the solar elevation angle.

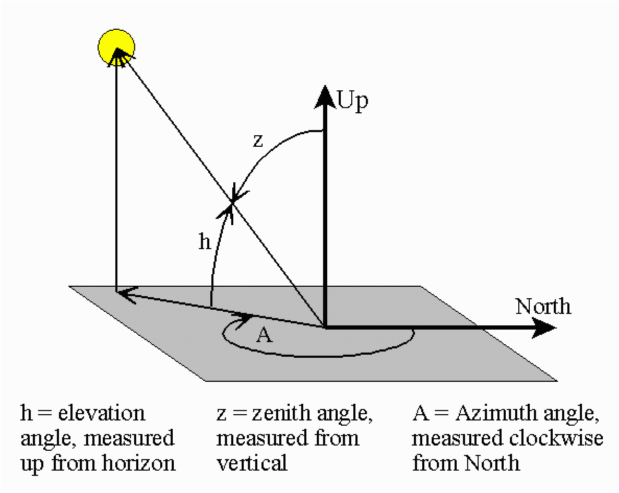


Figure 19: Solar Angle Diagram

The maximum solar elevation angle in Flagstaff occurs at 12:30pm on June 21 (Summer solstice), which is about 78 degrees above the ground. The minimum solar elevation angle in Flagstaff occurs at 12:27pm on December 21 (Winter solstice), which is about 31 degrees. Azimuth angles are 180° for both cases. The average of the maximum angle and the minimum angle is 54 degree, which is the average angle between the sunlight and the ground in North-South direction over a year. Therefore, the angle between the frame and the ground is 36 degree (without considering the shading), which is shown in Figure 20.

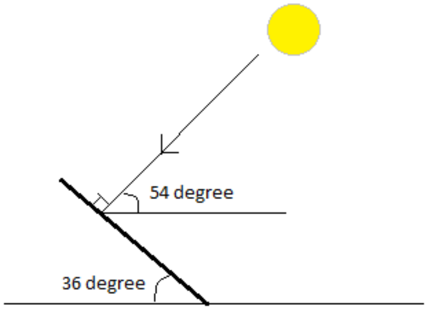


Figure 20: Angle between the Ground and the Solar Panel

So the main focus of our analysis relates to the angles required to accurately track the sun east-west with figures 22 and 23 below from the book you get an accurate picture of what angles are needed to properly analyze our tracking angles as well as what the variables mean.

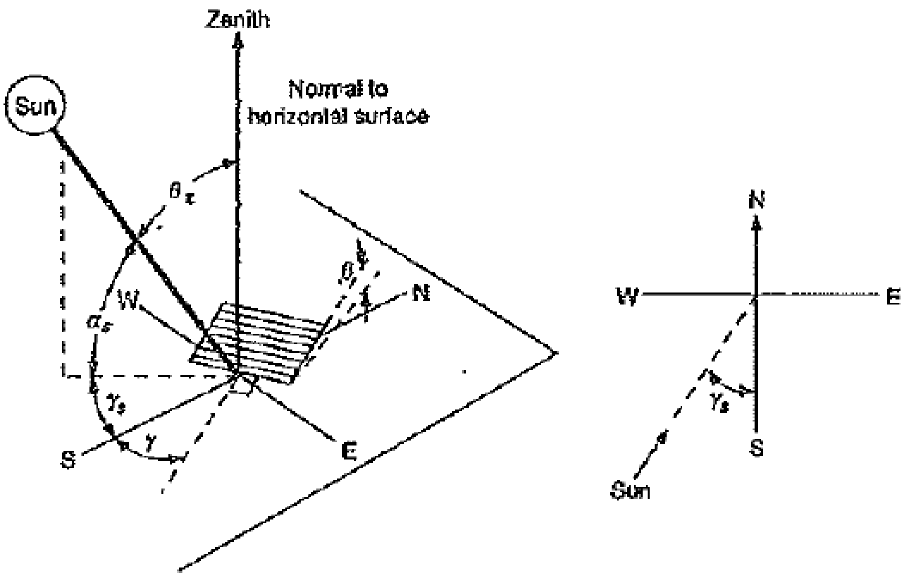
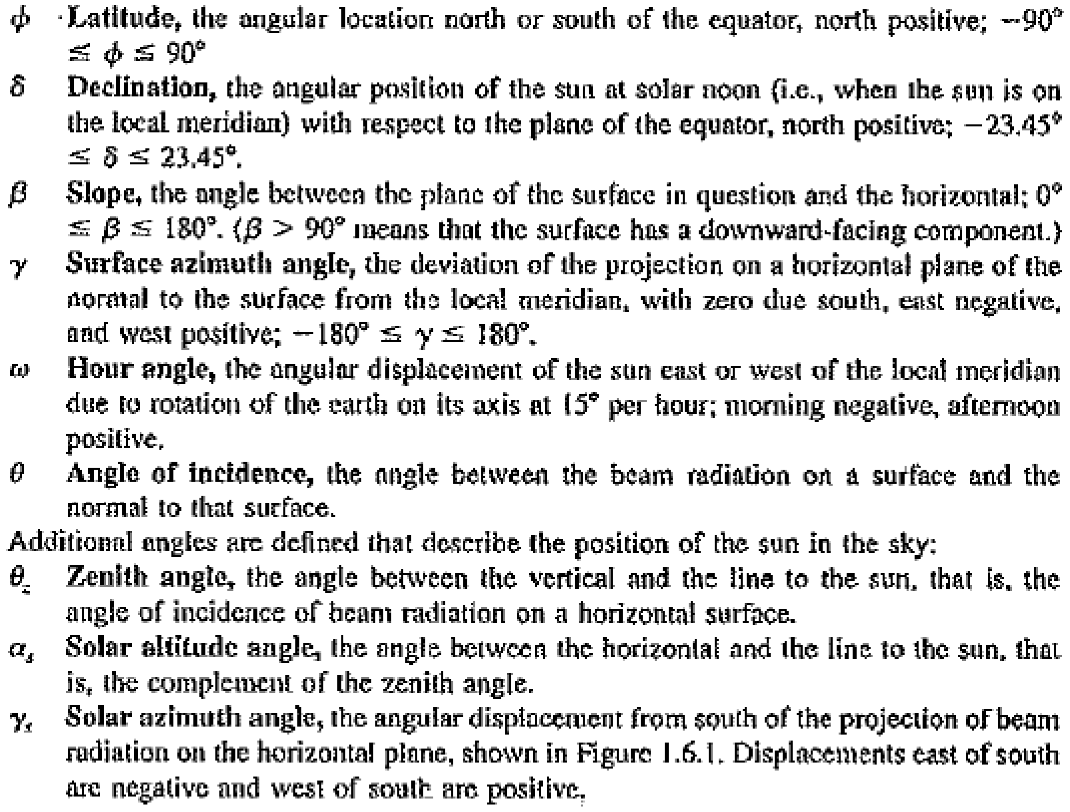


Figure 21: important angles for analysis



$\phi$ **Latitude,** the angular location north or south of the equator, north positive; $-90^\circ \leq \phi \leq 90^\circ$

$\delta$ **Declination,** the angular position of the sun at solar noon (i.e., when the sun is on the local meridian) with respect to the plane of the equator, north positive; $-23.45^\circ \leq \delta \leq 23.45^\circ$.

$\beta$ **Slope,** the angle between the plane of the surface in question and the horizontal; $0^\circ \leq \beta \leq 180^\circ$. ($\beta > 90^\circ$ means that the surface has a downward-facing component.)

$\gamma$ **Surface azimuth angle,** the deviation of the projection on a horizontal plane of the normal to the surface from the local meridian, with zero due south, east negative, and west positive; $-180^\circ \leq \gamma \leq 180^\circ$.

$\omega$ **Hour angle,** the angular displacement of the sun east or west of the local meridian due to rotation of the earth on its axis at 15° per hour; morning negative, afternoon positive.

$\theta$ **Angle of incidence,** the angle between the beam radiation on a surface and the normal to that surface.

Additional angles are defined that describe the position of the sun in the sky:

$\theta_z$ **Zenith angle,** the angle between the vertical and the line to the sun, that is, the angle of incidence of beam radiation on a horizontal surface.

$\alpha_s$ **Solar altitude angle,** the angle between the horizontal and the line to the sun, that is, the complement of the zenith angle.

$\gamma_s$ **Solar azimuth angle,** the angular displacement from south of the projection of beam radiation on the horizontal plane, shown in Figure 1.6.1. Displacements east of south are negative and west of south are positive.

Figure 22: definitions of all variables required for analysis

Given that the latitude of Flagstaff is 35$^{o}$ and that slope of our solar panels does not change based on no North-South axis tracking the most important angles for analysis are the Angle of incidence ($\Theta$), the Zenith angle ($\Theta_z$), and the Solar azimuth angle (΄$\Upsilon_s$). The incidence angle is important because it should be minimized to increase the amount of beam radiation that the solar panel absorbs. The Zenith angle is important because it is the angle that should be maximized to allow for the most absorption of beam radiation. Finally the azimuth angle is important because it relates to rotation of panel from east to west to track the sun.

The first things needed for solar angle tracking calculations are the Solar hour angles (w) in either the North-South axis or East-West axis. Since our design focuses on East-West tracking in the table below contains the corresponding solar hour angles. One thing to keep in mind though is that for this analysis per the books recommendation as seen figure xx (w) must be in increments of 5° which means that the solar panel makes a tracking correction three times every solar hour.

Table 1: Solar Hour angle for east west tracking

| ***Solar hour angle (w) in degrees*** | ***True solar time*** |
|---|---|
| *-90* | *6 hours before solar noon* |
| *-75* | *5 hours before solar noon* |
| *-60* | *4 hours before solar noon* |
| *-45* | *3 hours before solar noon* |
| *-30* | *2 hours before solar noon* |
| *-15* | *1 hour before solar noon* |
| *0* | *Sun overhead ( Solar Noon)* |
| *15* | *1 hour after solar noon* |
| *30* | *2 hours after solar noon* |
| *45* | *3 hours after solar noon* |
| *60* | *4 hours after solar noon* |
| *75* | *5 hours after solar noon* |
| *90* | *6 hours after solar noon* |

The first equation needed to analyze these angles relates to the day of the year that you wish to analyze the angles for.

$$B = (n-1)\left(\frac{360}{365}\right)$$

Where:

n= day of the year 1-365

Once you have B you must calculate the angle of declination (δ) to be able to calculate the incidence angle, zenith angle, and the azimuth angle. The equation we used for calculating the declination is seen below

$$\delta = 23.45 sin\left[360\left(\frac{284+n}{365}\right)\right]$$

Where:

n= day of the year 1-365

With the variable B and declination (δ) calculated you can then calculate the angle of incidence for a plane about a horizontal east-west axis with continuous adjustment using the equation below

$$\theta = cos^{-1}[1 - cos^2(\delta) sin^2(w)]$$

Where:

δ= the declination angle

w=sun hour angle from -90° to 90° in increments of 5°

After calculating the angle of incidence (Θ) to see if the device minimizes the angle of incidence between 90 and -90 degrees. The zenith angle should be calculated using this equation

$$\theta_Z = cos^{-1}[cos(\emptyset)\cos(\delta)\cos(w) + \sin(\emptyset)\sin(\delta)]$$

Where:

Ø= Latitude
δ= the declination angle
w=sun hour angle from -90° to 90° in increments of 5°

Finally when rotating about the East-West axis it is necessary to know the azimuth angle to rotate the solar panel to properly track the sun which, can be done using the equation below

$$\gamma_s = sign(w)\left|cos^{-1}\left(\frac{\cos(\theta_z)\sin(\emptyset) - \sin(\delta)}{\sin(\theta_z)\cos(\emptyset)}\right)\right|$$

To effectively analyze the angle of incidence, zenith angle, and azimuth angle we wrote a Matlab code that calculates all of these angles for any day specified from 1-365. With the angles calculated for each day this will be useful for the eventual programming of sensor and tracking system to run on its own further down the line. To demonstrate how the program works we will display the data for the incidence angle, zenith angle, and azimuth angle for n=180 which is about half way through the year and about half way through the earth's rotation around the sun.

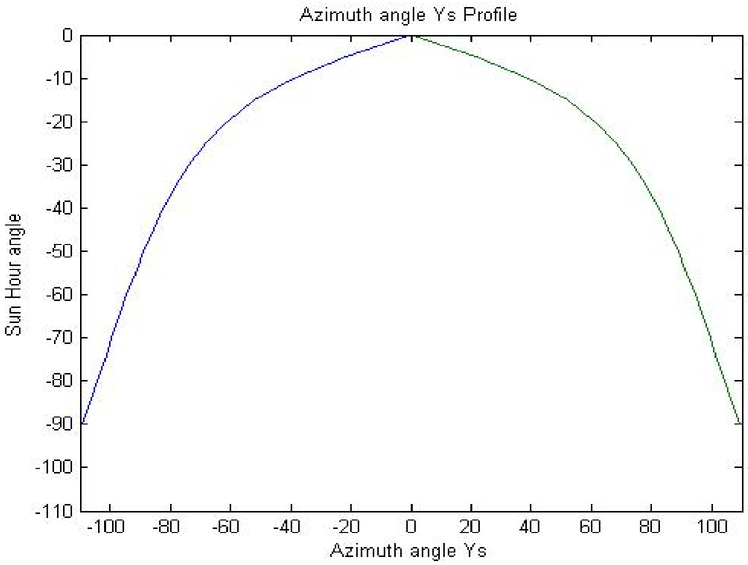


Figure 22: Azimuth angle profile for the 180th day of the year

What Figure 22 shows is the angle that the solar panel will rotate from East-West during the 180th day of the year. This angle is most important to East-West tracking due to the fact that our solar panel will only be tracking in the East-West axis.

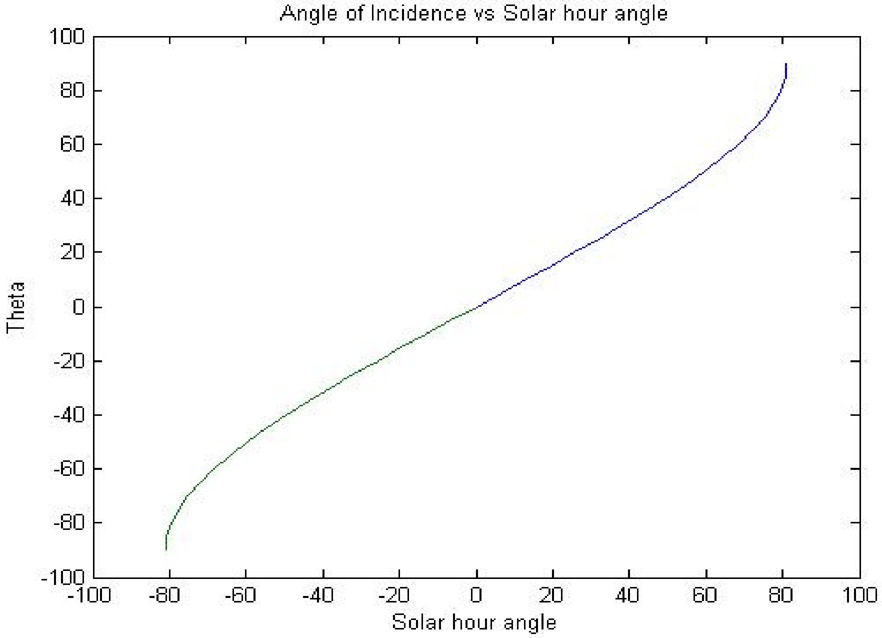


Figure 23: angle of incidence for 180th day of the year

What this graph shows for the 180th day of the year is that the angle of incidence will be not exceed -90° or 90° which is necessary for the solar panel to receive the most beam radiation during the day.

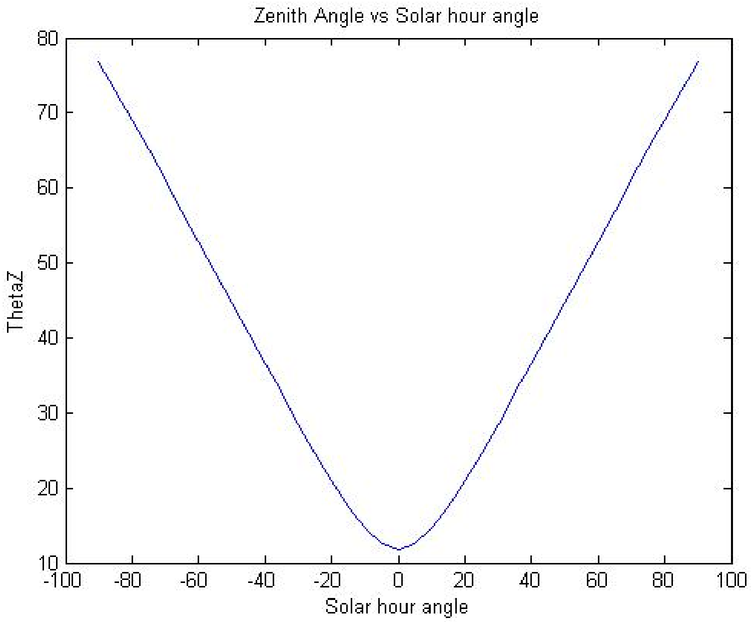


Figure 24: Zenith angle for the 180th day of the year

What this graph shows is the Zenith angle of panel which once again should not exceed $90^o$ to ensure that the solar panel receives the most beam radiation absorption.

The Matlab program also calculates the available hours of sunlight for the day specified by using this equation where N=number of daylight hours in a day which comes out most of the time to 12 hours of sunlight per day.

$$N = \left(\frac{2}{15}\right) cos^{-1}[-\tan(\emptyset)\tan(\delta)]$$

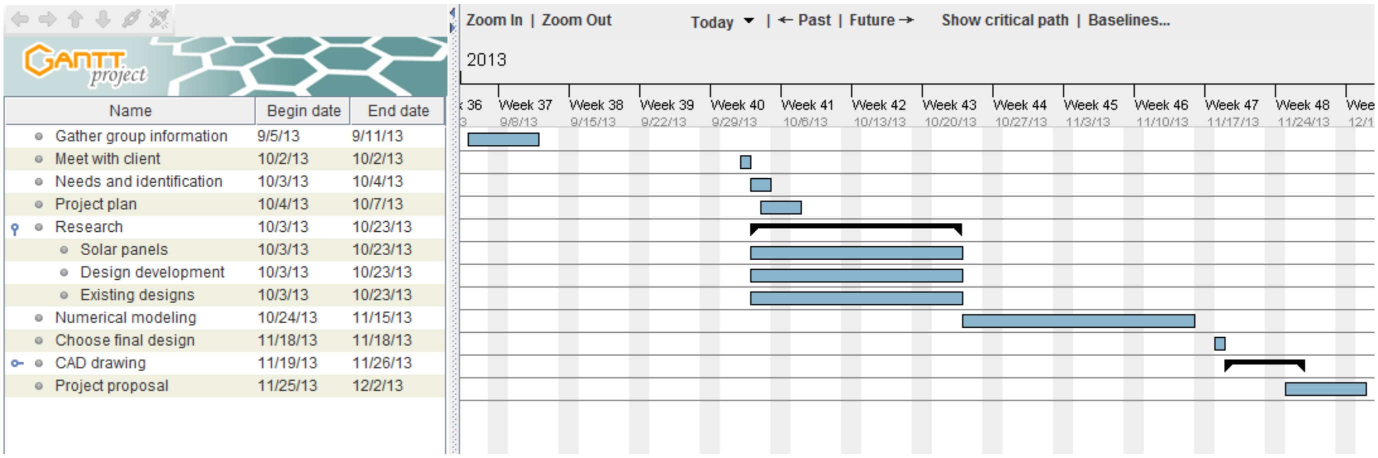
The last thing the Matlab program does is calculate the Geometric ratio ($R_b$) of a tilted solar panel to a horizontal solar panel using this equation which results in a number ranging from 0 to 2

$$R_b = \frac{\cos(\theta)}{cos(\theta_z)}$$

In conclusion for the solar angle tracking analysis the Matlab program, which is available in the appendix of this report, calculates the incidence angle, zenith angle, and azimuth angle based on the known variables for each day of the year from 1 to 365. The program itself only produces data for the day specified by the user. As the project nears completion this program will have to be changed to graph data for every day onto one graph but for this engineering analysis it is sufficient to only calculate the data based on the day of the year that you want to know about in question

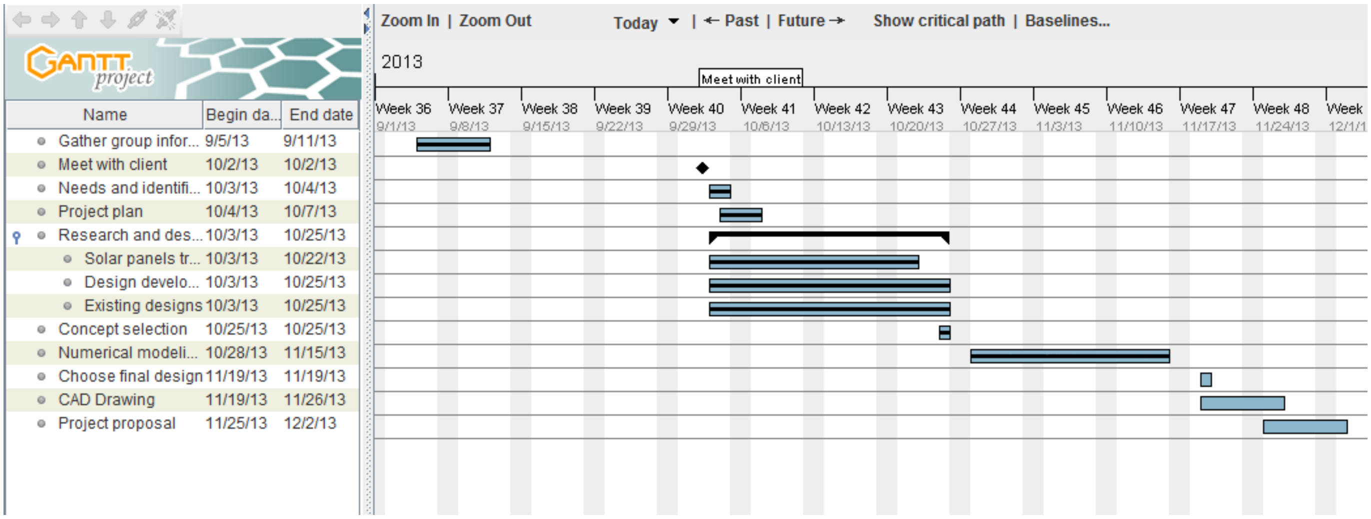
## **Gantt Chart Update**

The team has closely followed the timeline that was created in the beginning of semester. Since the last update, the team did manage to catch up with the schedule that was set forth in the beginning. The team has completed the numerical modeling task on Nov. 15th and is looking forward to choosing and starting the CAD drawings for the final design on Nov. 19th. The original and updated Gantt charts are shown in figures 28 and 29 below:



| Name | Begin date | End date |
|---|---|---|
| Gather group information | 9/5/13 | 9/11/13 |
| Meet with client | 10/2/13 | 10/2/13 |
| Needs and identification | 10/3/13 | 10/4/13 |
| Project plan | 10/4/13 | 10/7/13 |
| Research | 10/3/13 | 10/23/13 |
| Solar panels | 10/3/13 | 10/23/13 |
| Design development | 10/3/13 | 10/23/13 |
| Existing designs | 10/3/13 | 10/23/13 |
| Numerical modeling | 10/24/13 | 11/15/13 |
| Choose final design | 11/18/13 | 11/18/13 |
| CAD drawing | 11/19/13 | 11/26/13 |
| Project proposal | 11/25/13 | 12/2/13 |

Figure 25: Original Gantt chart



| Name | Begin da... | End date |
|---|---|---|
| Gather group infor... | 9/5/13 | 9/11/13 |
| Meet with client | 10/2/13 | 10/2/13 |
| Needs and identifi... | 10/3/13 | 10/4/13 |
| Project plan | 10/4/13 | 10/7/13 |
| Research and des... | 10/3/13 | 10/25/13 |
| Solar panels tr... | 10/3/13 | 10/22/13 |
| Design develo... | 10/3/13 | 10/25/13 |
| Existing designs | 10/3/13 | 10/25/13 |
| Concept selection | 10/25/13 | 10/25/13 |
| Numerical modeli... | 10/28/13 | 11/15/13 |
| Choose final design | 11/19/13 | 11/19/13 |
| CAD Drawing | 11/19/13 | 11/26/13 |
| Project proposal | 11/25/13 | 12/2/13 |

Figure 26: Updated Gantt chart

## Conclusion

For this report, the team did manage to evaluate and numerically analyze the top three designs that the team derived. Each of the designs were analyzed in their own manner. First, the team analyzed the Angled Tracker design. Here, the team performed a structural analysis of the design and the power, torque, and motor required to move the solar panels to effectively track the sun. The analyses were completed with the material already chosen. Second, the team analyzed the Hydraulic Tracker. For this design, the team found the stresses at various locations throughout the design. The pushing force that is required to move the solar panel was also calculated. Third, the last design, the Solar Array design was analyzed for shading, structurally, and for tracking. The analyses for the three designs were all completed using a combination of hand calculations, Matlab programming, and using Excel spreadsheets. Finally, the Gantt Chart was updated and we found that the team is on schedule.

## References

1. Beckman A., William, Duffle A. John, 2006, “Solar Engineering of Thermal Processes”, Third Edition, John Wiley & Sons, Hoboken, New Jersey

2. Budynas G., Richard, Nisbett J., Keith, 2011, “Shigley’s Mechanical Engineering Design”, Ninth Edition, McGraw-Hill, New York, New York

3. Hibbler C. R., 2010, “Engineering Mechanics Statics”, twelfth edition, Pearson Education Inc., Upper Saddle River, New Jersey

4. Hugh , M. (1995). *The design of hydraulic components and system* . London : Ellis Horwood

5. “Mc-Master-Carr”(Nov,2013) http://www.mcmaster.com/#electric-motors/=pfvl6a

6. Parker Cylinder. Hydraulic and Pneumatic Cylinder Appendix Application Engineering Data. http://www.parker.com/literature/Industrial%20Cylinder/cylinder/cat/english/0106c002.pdf

## Appendix A

Given

Width = 4’ = 1.2192m

Length of Component D = 1.9m

Length of Component E = 1m

Weight of Component B = 10lbs = 44.5 N

Weight of Component C = 10lbs = 44.5 N

$\Theta = 21.1$

Raw Data

$F_{solar} = 325.4$ N

$F_2 = 341.42$ N

$F_3 = 357.44$ N

$A_y = 64.34$

$A_x = 166.737$

$B_y = 64.34$

$B_x = 166.737$

## Appendix B

Table 2: Calculated Push Force

| Push Force generated by Standard Double-Acting Hydraulic Cylinder | | | | |
|---|---|---|---|---|
| | | | | |
| Piston Diameter (m) | Piston Area (m²) | Weight(kN) | Cylinder Pressure (kPa) | Cylinder Pressure (bar) |
| 0.025 | 0.00049 | 0.0334 | 68.00 | 0.680 |
| 0.035 | 0.00096 | 0.0334 | 34.69 | 0.347 |
| 0.040 | 0.00126 | 0.0334 | 26.56 | 0.266 |
| 0.045 | 0.00159 | 0.0334 | 20.99 | 0.210 |
| 0.050 | 0.00196 | 0.0334 | 17.00 | 0.170 |
| 0.055 | 0.00237 | 0.0334 | 14.05 | 0.140 |
| 0.060 | 0.00283 | 0.0334 | 11.81 | 0.118 |
| 0.065 | 0.00332 | 0.0334 | 10.06 | 0.101 |
| 0.070 | 0.00385 | 0.0334 | 8.67 | 0.087 |
| 0.075 | 0.00442 | 0.0334 | 7.56 | 0.076 |
| 0.080 | 0.00502 | 0.0334 | 6.64 | 0.066 |
| 0.085 | 0.00567 | 0.0334 | 5.88 | 0.059 |
| 0.090 | 0.00636 | 0.0334 | 5.25 | 0.052 |
| 0.095 | 0.00708 | 0.0334 | 4.71 | 0.047 |
| 0.100 | 0.00785 | 0.0334 | 4.25 | 0.043 |
| 0.105 | 0.00865 | 0.0334 | 3.85 | 0.039 |
| 0.110 | 0.00950 | 0.0334 | 3.51 | 0.035 |
| 0.115 | 0.01038 | 0.0334 | 3.21 | 0.032 |
| 0.120 | 0.01130 | 0.0334 | 2.95 | 0.030 |
| 0.125 | 0.01227 | 0.0334 | 2.72 | 0.027 |
| 0.130 | 0.01327 | 0.0334 | 2.51 | 0.025 |
| 0.135 | 0.01431 | 0.0334 | 2.33 | 0.023 |
| 0.140 | 0.01539 | 0.0334 | 2.17 | 0.022 |
| 0.145 | 0.01650 | 0.0334 | 2.02 | 0.020 |
| 0.150 | 0.01766 | 0.0334 | 1.89 | 0.019 |
| 0.155 | 0.01886 | 0.0334 | 1.77 | 0.018 |
| 0.160 | 0.02010 | 0.0334 | 1.66 | 0.017 |
| 0.165 | 0.02137 | 0.0334 | 1.56 | 0.016 |
| 0.170 | 0.02269 | 0.0334 | 1.47 | 0.015 |
| 0.175 | 0.02404 | 0.0334 | 1.39 | 0.014 |
| 0.180 | 0.02543 | 0.0334 | 1.31 | 0.013 |
| 0.185 | 0.02687 | 0.0334 | 1.24 | 0.012 |
| 0.190 | 0.02834 | 0.0334 | 1.18 | 0.012 |
| 0.195 | 0.02985 | 0.0334 | 1.12 | 0.011 |
| 0.200 | 0.03140 | 0.0334 | 1.06 | 0.011 |
| 0.205 | 0.03299 | 0.0334 | 1.01 | 0.010 |
| | | | | |