TEAM 7 EDUCATION SOLAR TRACKING SYSTEM FINAL REPORT

TO: DR. ACKER
FROM: JOSHUA BELSHEIM, TRAVIS FRANCIS,
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SUBJECT: SOLAR TRACKING SYSTEM PROPOSAL
DATE: APRIL 25, 2014

Dr. Acker in the pages below is all the work we have done that led up to the completion of the Educational solar tracking system that you requested we should build for you. In this report is a description of our final design along with the analysis did on final design.

Since the solar tracking system is for the educational purposes, the final proposed design includes two different mechanisms to rotate two solar panels separately in order to provide an efficiency comparison. The overall design consists of one solar panel that can rotate automatically in East-West direction with a stepper motor and control system. The other solar panel can only be rotated in East-West axis with a hand crank. Both solar panels are sitting on the steel base frame and can be adjusted in North-South axis with the pin-sliding mechanism seasonally. The analysis covers stress analysis in the frame as well as torque analysis and solar tracking angles analysis. The report also covers the steps we took to build the prototype. The fabrication of our design all took place in the machine shop located here on campus was split up into 4 parts. The base frame, angle supports, frame connections and motor housing/manual crank assembly. The exact process of the building the prototype is covered in the report below.

For the testing of this prototype we moved the panels in the North-South axis through each of the 18 holes. For the best results to track the sun, we change the hole position by adjusting the pin location forward/backward every 10 to 15 days, increasing the angle as the days grow shorter and decreasing the angle as the days grow longer. For the single motor we have written a program for the motor has been downloaded into the Arduino board, it will send 5 V digital signals to the STR 8 control system in direction **+** pin every 15 minutes. Once the control system receives the signal, the step motor will rotate a full cycle clockwise. The program executes 48 times within 12 hours and then sends 5 V digital signals to the SRT 8 control system in direction **–** pin every 15 minutes, the stepper motor will rotate a full cycle counterclockwise. The solar panel will reverse back to the original position on next day at 7am and start rotation all over again.

Cost wise since we cancelled the order of the second motor and control system the total cost comes out to $1,532.64. More detailed breakdown of the cost for the prototype is available in the report. There no labor costs associated with this prototype because all of the work was done in the shop and they do not charge for welding services.

Solar Tracking Structure Design

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Team 07

Final Report

Document

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Nomenclature Table

	Symbol
Area	A
The minimum space of two solar panel	L(ft)
The total load of each single solar panel	W(Ib)
Friction factor	μ
Torque required	τ (Ib-in)
force act on the shaft	Fc (Ib)
diameter of the shaft	D(in)
House power	HP
Angular velocity: Revelation per minute	*rpm*

Abstract

Photovoltaic solar panels are used as alternative energy source that is separate from the electrical grid. Using a solar tracking system allows for solar panels to maximize the amount of energy captured. The goal of this project is to provide mechanical engineering students a solar tracking systems and hands on learning experience for renewable energy courses. The primary objective is to build a tracking system that is manual in North-South direction and automatic motor assisted tracking in East-West direction, but can be shifter to manual when desired. The final prototype of our design has a solar tracking array with two solar panels, perched on a square frame. The design is angled by flat steel rods that can be adjusted North-South. The East-West tracking is accomplished by the panels being on a metal shaft and using a step motor and hand crank connected to a worm gear to move the panels.

Chapter 1. Introduction

1.1 Client introduction and problem description and state of the art research

Solar tracking systems on today's market are intimidating to students. In order to help rectify the situation, the team has been tasked with designing and constructing a solar tracking system that is capable of effectively tracking the sun. The design must be a system that can be operated both manually and with an electronic motor. The constraints of this task are as outlined below:

- The team must stay within a reasonable budget.
- Limited space available for testing and solar tracking system operation.
- Unpredictable weather in Flagstaff, AZ.
- Good but limited building abilities and processes available to the team.

The team's objectives include the following:

- The system must be inexpensive to produce.
- System must have a relatively good efficiency.
- Design must be low maintenance with
- System must have a good build quality with relatively easy manufacturability
- Must be low in weight to be transportable.

This design is not only for demonstration and testing purposes, but it is also to function as an educational tool. Since future students will be using this system to learn the various components of a solar tracking system, it must be of a relatively simple design and user friendly. The system is to be controlled both manually and with the use of an electronic motor.

1.1 State of the art research

In order to correctly address the problem, the team performed some state of the art research on this subject. The team researched different designs that were available on the market. The team also used this step to formulate different designs on their own. During this step, the team found the following designs:

Table 1: Research

Manufacturer	***Model Number***	**List Price ($)**	**Panels Included**
Zomeworks [5]	*ZOMUTRH-072*	$1775.46	No
Suntura [6]	*WNN-S400*	$4995.95	Yes
Wattsun [7]	*AZ-225 WSUNTECH STP240*	$7175.00	No
Sonnen Systems [8]	*Sonnen_System_3_40*	$10725.00	No

The above results illustrated just how expensive these systems can get. So therefore, the team decided to have cost and reliability the two focal points that the team will mainly focus on. From this point, the team managed to generate a few concepts. The concepts that the team originally drew up were then put through a decision matrix to select the final design.

Chapter 2. Problem Formulation

2.1 Identification of Need, Project Goal, Objectives, Operating Environment, Constraints and QFD

This section defines the problem need, goal, objectives and the operating environment.

2.1.1 NEEDS

During the meeting with Dr. Acker he spoke about why he wanted us to design a solar tracking system for the solar panels up at the shack. What we gathered is that Dr. Acker wants us to design a more reliable solar tracking apparatus then is currently available.

Some of the reasons to build a more reliable solar tracking system are:

- Current solar tracking systems are too expensive for the school to purchase.
- Unreliable because the often break down.
- Since they break down often they are hard to maintain.
- Over by the student family housing there is currently a broken solar array tracking system that could possibly use our design.

2.1.2 Project Goals

The team is to design a reliable solar tracking device. This device will track the sun. The tracking device is to capture solar rays utilizing the solar panels. After the solar rays are captured, it will be converted into useable power in the shack between the Engineering Building and Forestry Building.

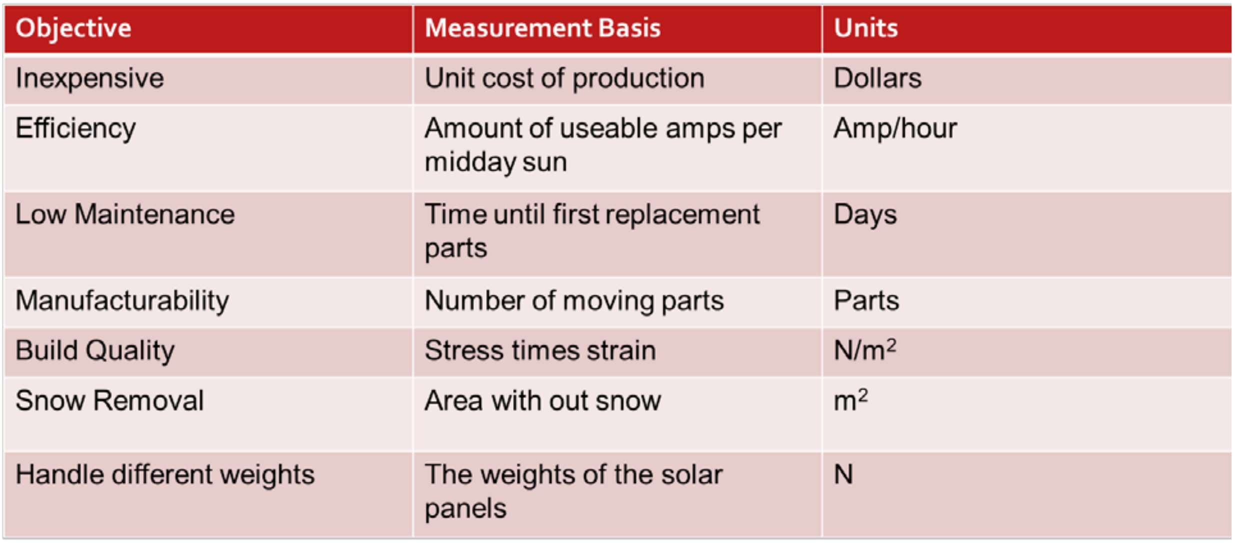
2.1.3 Operating Environment

Presently, there are a number of solar tracking designs on the market with different methods of tracking the sun. Our design will use either sensors or a timing device. Our system will be stationed at the shack that is located between the Engineering Building and the Forestry Building. The location currently has plenty of trees that surround the place. This location will be shady in the mornings and evenings, but there is an ample amount of sunshine during the day.

2.1.4 Objectives

The objectives of solar tracking system are for the construction to be inexpensive, require low maintenance, efficiency, manufacturability and a high build quality. If the system is inexpensive it will be available to more groups and organizations to purchase. Low maintenance equates to less part replacement, less repairs, less time spent on maintenance and overall more cost efficient. The whole point of using a tracking system is to make the solar panels more efficient. If the tracking system took more energy than produced by the system it would be useless and counterproductive, so one of our objectives is to have an efficient tracking system. The design of the tracking system should include the ability to be mass produced if in the future we decide to market the system. A high build quality will help insure the longevity of the system. The secondary objectives include removal of snow and the ability to handle the weights of different solar panels. By meeting these objectives, it will help make the tracking system be successful. The objectives as well as how they will be measured are shown in Table 1 below.

Table 2: Objectives and Their Measurement



Objective	Measurement Basis	Units
Inexpensive	Unit cost of production	Dollars
Efficiency	Amount of useable amps per midday sun	Amp/hour
Low Maintenance	Time until first replacement parts	Days
Manufacturability	Number of moving parts	Parts
Build Quality	Stress times strain	N/m^2
Snow Removal	Area with out snow	m^2
Handle different weights	The weights of the solar panels	N

2.1.5 Constraints:

Constrains indicate the non-permissible conditions of the solar tracking system and the non-permissible range of the design and performance parameters. The first constraint is the system weight. Since the light weight will reduce the cost of the material as well as the power needed for tracking system itself. The weight of the tracking system should be in a reasonable range. Another important constraint is the budget. There are some commercial solar tracking systems on the market, but the costs are usually high. So the new solar tracker needs to be built with a small budget in mind. Since the working space is fairly small, the solar panels will be placed close to each other. In order to have higher efficiency, the panels should not shade each other after adjusting. Considering the weather in Flagstaff, the solar tracking system must be able to work during winter as well as survive strong winds.

Chapter 3. Proposed Design

3.1 Final Concept

Since the solar tracking system is for the educational purposes, the final proposed design includes two different mechanisms to rotate two solar panels separately in order to provide an efficiency comparison. The overall design is shown in Figure 1. One solar panel can rotate automatically in East-West direction with a stepper motor and control system. The other solar panel can only be rotated in East-West axis with a hand crank. Both solar panels are sitting on the steel base frame and can be adjusted in North-South axis with the pin-sliding mechanism seasonally.

Figure 1: Isotropic view of the proposed design

The stepper motor provides the precise control over the East-West angle of rotation during the day. It is connected to the shaft through the worm-gear set. The advantage of using the worm-gear set is that it can stop the solar panel from rotating without using extra power to hold the stepper motor. Figure 2 shows the automatic system in detail.

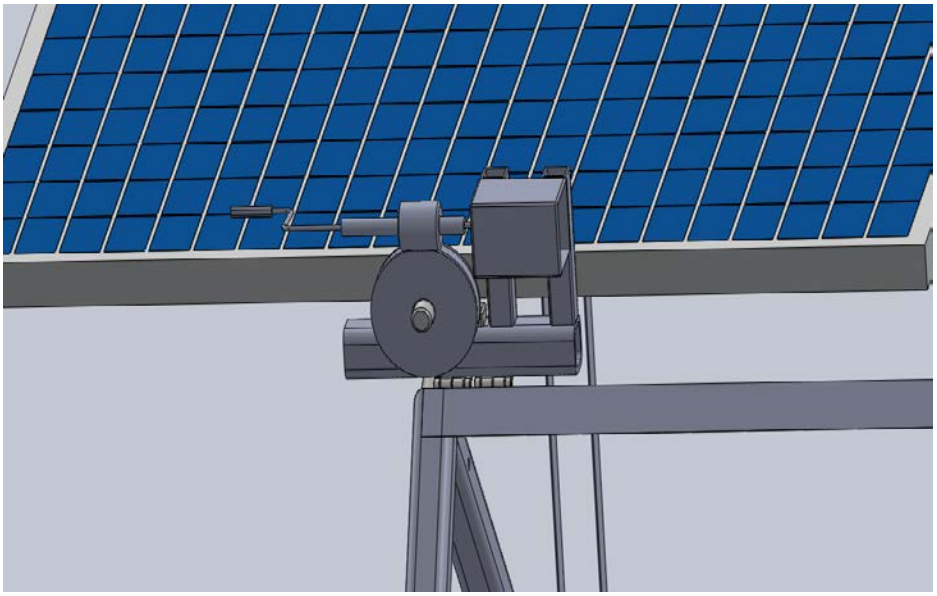


Figure 2: The Automatic Tracking System

3.2 Engineering Analysis

The team decided that there needed to be structural analysis performed on the frame of the system because that will ultimately support the entire panel configuration. The team utilized SolidWorks to perform this analysis.

The first thing that was to be done was to make a part in the program. Originally, the team decided to have 36 holes horizontally through the beam, but after reviewing the design, the team decided to move to 19 holes. It was changed from 36 to 19 holes because the tracking system only needed to be moved every 20 days instead of 10 days. This design change helps with keeping the strength of the material and ultimately making a safer design. In doing this, it will also help cut down on maintenance time, since it will be moved every 20 days instead of every 10 days.

Before the analysis was even started, the team needed to make some assumptions. The assumptions required a collaboration of the main components weight’s with the other team members. After consulting with the team, the component weights were used as forces. The weights of the components are as follows:

- Solar panel – 50 lbf (each)
- Frame of solar panel, motor and bracing steel – 10 lbf

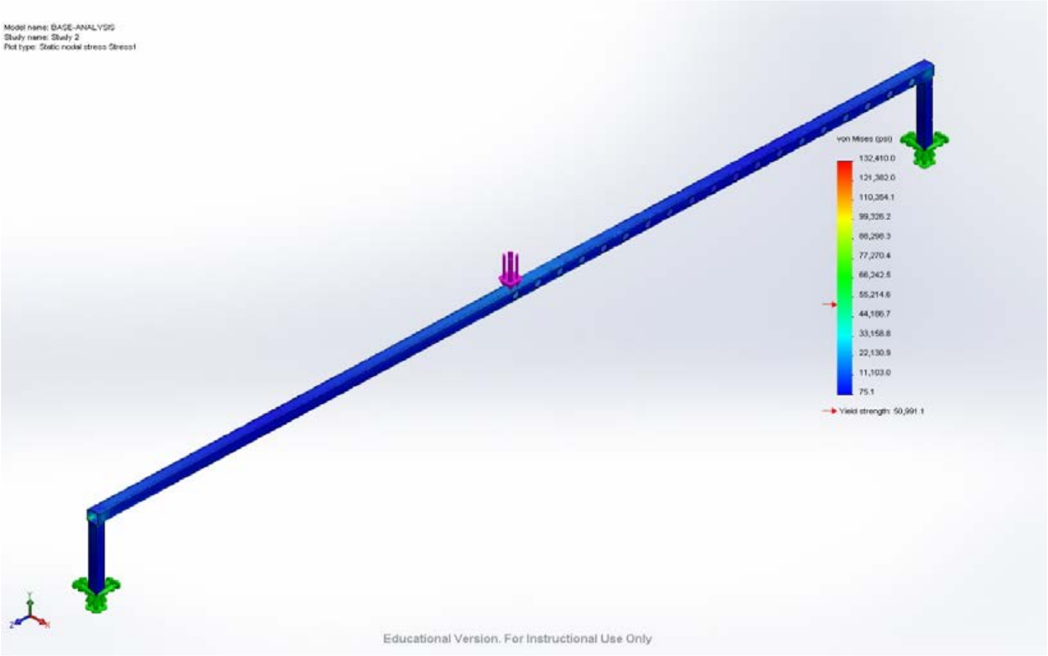
Another parameter that needed to be predetermined was to choose what material to use for our design. Since this design is to be made with materials that not need to be special ordered, we chose to use AISI 1020 Steel. We chose this material due to the fact that this material is readily available, inexpensive and relatively strong. So with this, the team will use this material in the construction phase.

The following steps were used to input the parameters and complete the structural analysis of our support beams using Solidworks:

1. Open up *Solidworks* program.
   a. Locate and open the part that is to be analyzed.
2. At the top menu, go to *Tool* tab, select Add-ins.
   a. Check left box of Solidworks Simulation, then select ok.
   b. Accept license agreement.
3. At the top menu, select *Simulation* tab.
4. Select drop down menu from Study Advisor and select New Study
   a. In the left column, select Static then the green check mark.
5. In the top menu, click Apply Material.
   a. In left column, select material (AISI 1020 Steel), click Apply, and then close.
6. In left column, right click Fixtures.
   a. Select Fixed Geometry, highlight face box, and then using the part; select face 1 and 2 to be fixed (meaning where the part will be supported). Click green check mark.
7. In the left column, right click External Loads and select Force.
   a. Now, locate Selection tab in left column, but force placements on beams or joints must be predetermined. For this project, I chose to set forces directly in the center of the beam because that is where the biggest load is at. Select Beams box and using the 3-D model, select the small square at the center and on top of the beam.
   b. Under Units tab, choose English Units.

    c. Under Force tab, select Normal to button, and input value of the force to be used. Finally, select green check mark at top.

8. In left column right click Study and select Run. A series of plots will appear in the window.
    a. In left column, right click Stress 1 and select Edit Definition.
        i. Stress Plot appears; under Display tab, select psi. Then select green check mark.
    b. In left column, right click Displacement 1 and select Edit Definition.
        i. Displacement Plot appears, then under Display tab, select URES Resultant Displacement and set measurements to mm. After setting these parameters, select green check mark.
9. After making these changes, the maximum stresses and deflections could be found by associating the colors from the scale to the members/joints to the color scale on the right hand side of the part.
10. After running the program, the team found these results:
    a. Maximum Stress – 33,158.8 psi (**Fig. 3**)
    b. Maximum Displacement – 7.9 mm (**Fig. 4**)



Model name: BASE-ANALYSIS
Study name: Study 2
Plot type: Static nodal stress Stress1

Figure 3: Stress plot of base frame

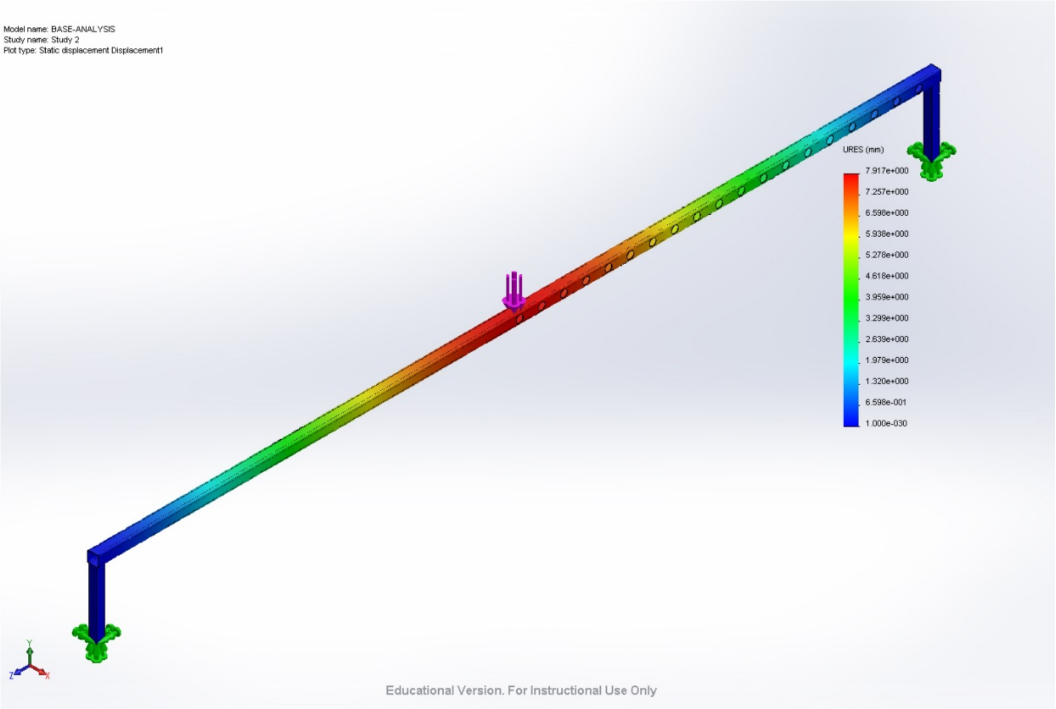


Figure 4: Displacement plot of base frame

The above analyses are only two completed out of a number of analysis carried out by the entire team. The requirement that I am addressing is that the frame is safe, reliable and able to hold the load. I found that the base frame would be safe because after using *Solidworks* to analyze it, we found that there is very little deformation and none of the structural members will fail during the loading of the solar panel system. We know that the frame is also cost efficient as well due to the fact that we are using steel that is locally and readily available.

Torque Analysis for the new design

The new design incorporates a motor for each solar panel thus requiring a new torque analysis. Given that each 4' x 6' solar panel weighed approximately 50lbs and that distance from the frame to the shaft is estimated to be 0.92 inches the torque is calculated below.

$$\tau = r \times F = 0.92in \ \times 50lbs = 46 \ lb - in$$

This gives us a maximum bending torque of 46 lb-in experienced by the shaft. Choosing a motor that is incorporates that torque requires an analysis of the gear reduction caused by the worm gear seen in figure 9 below.

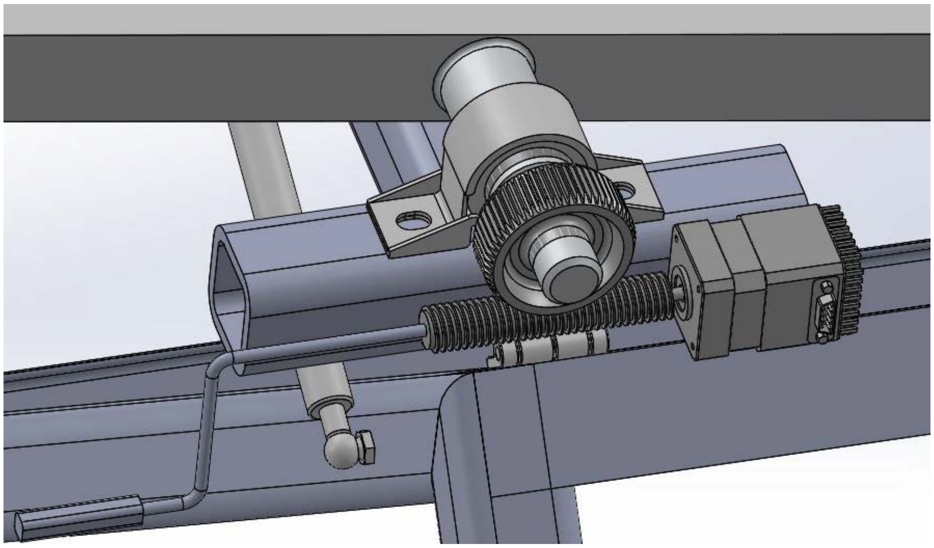


Figure 5: Worm gear assembly

The worm gear has a pitch of 6 and an outside diameter of 3.71inches, the worm that is attached to the motor has an outside diameter of 2.33 inches. So the gear reduction from the motor to the shaft is roughly 1.5922. Using the gear reduction the motor requires a torque of 73.3 lb-in.

Calculating the shear force experienced on the bolt

The new design incorporates an adjustable north to south direction using a series of holes in the frame and a pin to lock in the position seen in Figure 10 below.

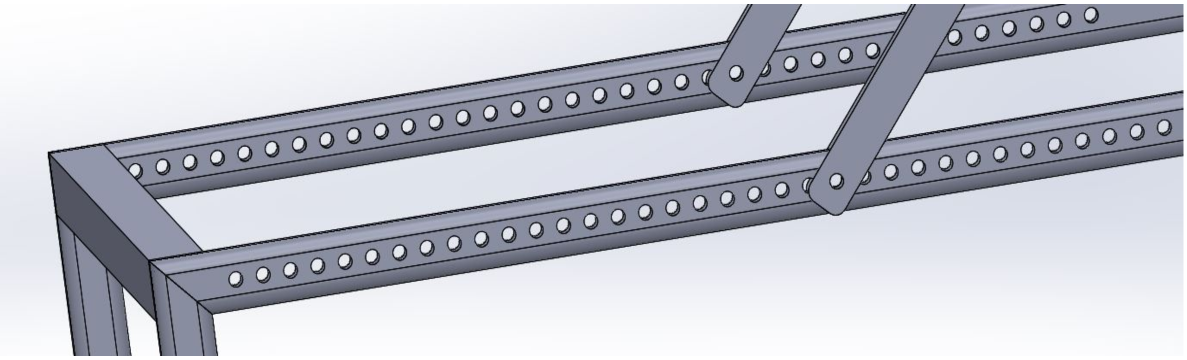


Figure 6: North to south pivot points

This pin expected to experience a shear force caused by the weight of the solar panel. Shear force was calculated by taking the maximum amount of force the bolt could experience roughly 50lbs then dividing it by the area.

$$Area = \pi D^2 = \pi \times 0.25^2 = 0.19635\ in^2$$

Then the bolt experiences the force along four points along the pin. Then the equation for shear force, ν, is shown below.

$$\nu = \frac{4 \times 50lbs}{0.19635\ in^2} = 1018.59\ {}^{lbs}/_{in^2}$$

From the shear force calculated 1020 ANSI steal would be an appropriate material for the pin to be made out of.

Chapter 4. Prototype Fabrication

4.1 Fabrication break down

The fabrication of our design all took place in the machine shop located here on campus using the various machines available at the shop. Our prototype was built using the help and expertise of the shop staff. The fabrication of the design was broken up into four main stages.

4.2 The Base Frame

The base frame consists of three 1”x1”x72” sections of square tubing along with two 1 ½”x1”x96” sections of angled bar. The first thing we did was cut the square tubing and angled bar down to the required dimensions above using a table grinder. The next step was to drill 18 holes into the square tubing with a diameter of ¼ inches, which was done on the end mill in the shop.

Figure 7: Holes for manual North-South tracking

With square tubing completed the next step was to weld the square tubing and angled bar sections together into a 8ft by 6ft rectangle with one 6ft section of square tubing in the middle to account for compression forces. Next we cut 1 ft long sections of 1”x1” square tubing to make 8 legs that would then be welded onto the frame. With the legs complete the final step was to create adjustable feet for the base frame to ensure that the system could sit level on uneven ground. The feet were made out of one quarter thick steel sheet metal with dimensions of 4”x4” a bolt was then welded to the feet as well as a 1”x1” square with a hole and nut welded to the bottom of each leg. The completed base frame can be seen below.

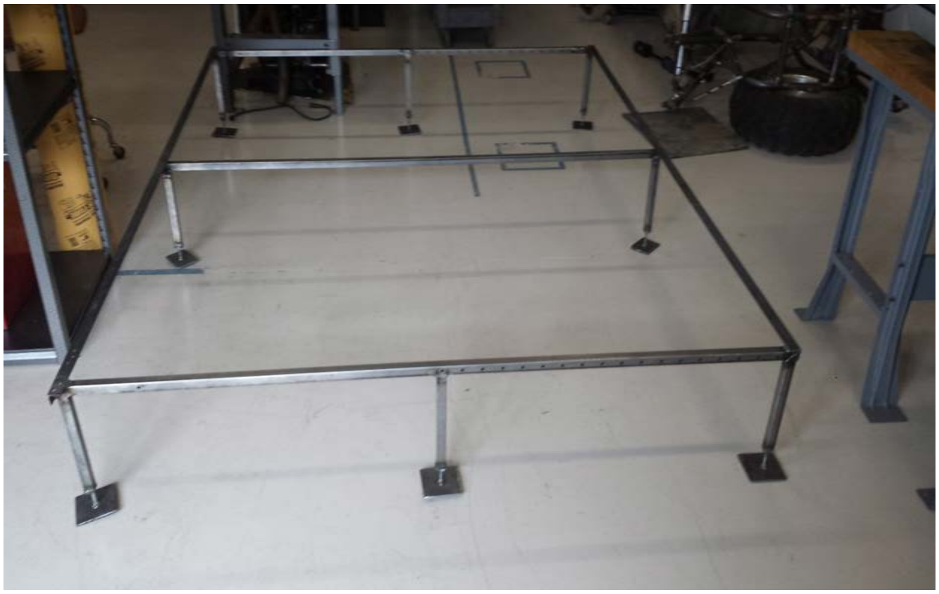


Figure 8: Completed base frame

4.3 The Angle Supports

The first thing we built for the top half the system were frames for the solar panels themselves which are 4ft by 6ft. The frames were made out of 1 ½”x1” angled bar with a section of flat steel bar in the middle for compression forces. The frame for the solar panels can be seen in the figure below.

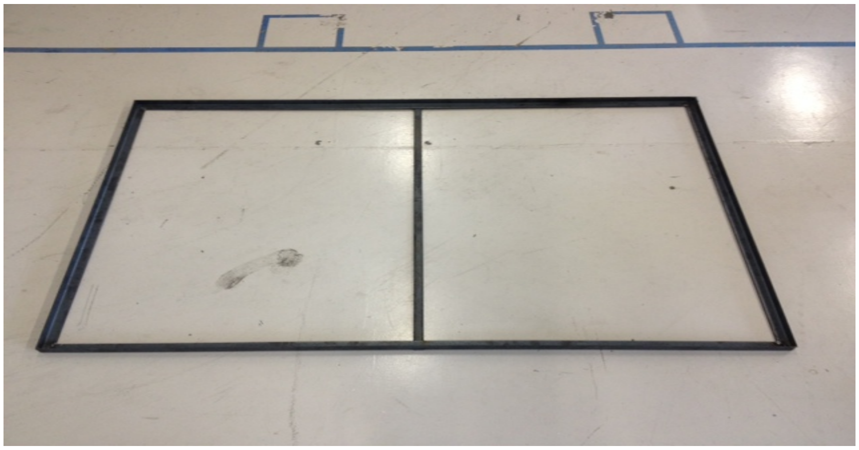


Figure 9: Solar panel frame

The solar panel frame then had two steel shafts welded on each side that go into the bearings which allow the system to move in the East-West axis. The solar panel frame sits on two

1”x1”x74” square steel tubing with welded smaller sections of square tubing to hold the bearings for the solar panel frame. For the bottom bearing where the gear is located the bolts had to be welded to the inside of the square tubing because if they had been bolted normally then they would interfere with the panel’s ability to lay flat horizontally.

Figure 10: Welded bolts to angle support

Two 1”x38” flat steel bars were cut and used for the manual North-South axis tracking system with a bolt hole drilled in the top, and middle of each to keep the parts together as well as pin hole drilled in the bottom. The completed angled supports can be seen in the figure below.

Figure 11: Side view of angle supports

4.4 Frame Connections

To connect the bottom frame to the angled supports and solar panel frames we decided to use two heavy duty door hinges on each side of the system. However due to the need for the ability to lay the solar panels flat bolts on the bottom of the bearing was not option because they would run into the base frame as well as be almost impossible to bolt on properly due to the small space inside the 1”x1” square tubing. Below is a picture of what the welded on door hinges look like.

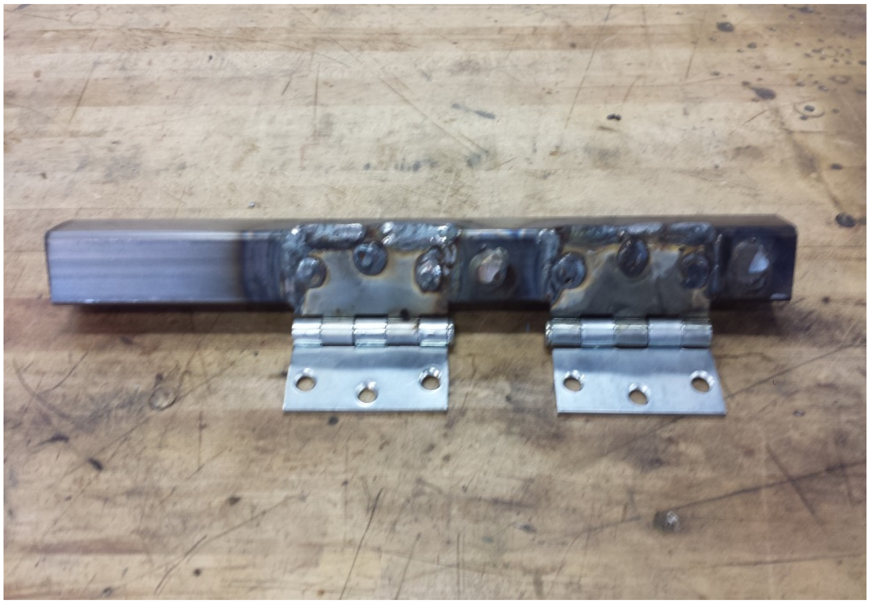


Figure 12: Welded on hinges

With the hinges welded on the angled supports we still wanted the frame to be able to be disassembled so we bolted the door hinges to the base frame. However, when we drilled the holes we discovered that one hole was not on the base frame at all so we had to weld a small piece of angled bar to the side of the base frame and drill a hole in that. We also found that one of the holes went into the top of the legs at the corners made out of square tubing which made bolting it impossible so instead we threaded that hole and made sure the bolts could be bolted on. Also we bought hydraulic stabilizers which are the same stabilizers that are on your car hood to make the manual changing of the North-South axis tracking easier. The connection between the base and angled supports can be seen below.

Figure 13: Frame connections

4.5 Motor Housing/Manual Crank

A case was built for our stepper motors in our design made out of 16 gauge steel sheet metal with dimensions that matched the size of the motor in the shape of an L bracket. The front of the housing has four 5mm holes drilled into as well as a 4 inch diameter hole for the shaft of the motor to stick through. Small spaces were cut into the walls of the L bracket to ensure that 5mm Allen bolts we bought could be tightened properly. The housing was built to ensure the motor does not fly off of our design because the torque it is creating. It was welded onto the angled support of our solar system to ensure that the worm gear could properly mesh with our gear on the shaft that is welded to the solar panel frame. To hold the L bracket up we used some spare sections of our 1”x1” square tubing that were welded to the L bracket and the angled supports of our system. As seen in the figure below.

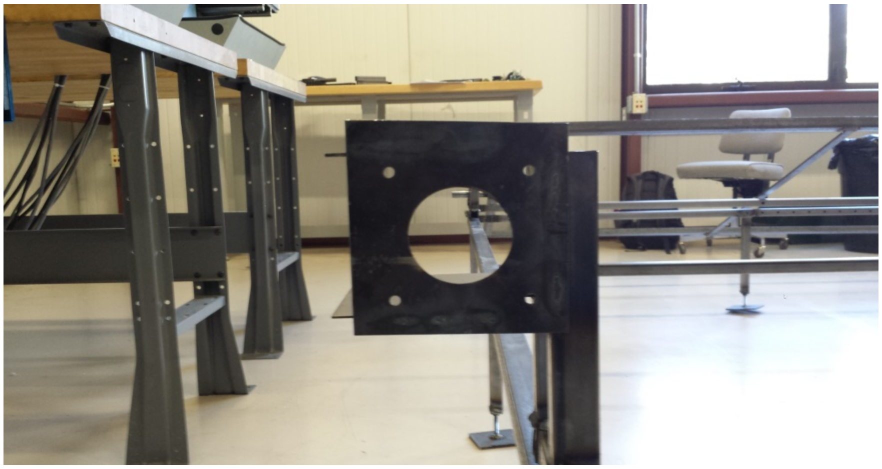


Figure 14: L bracket for motor

The shaft connects to our worm gear through a coupling because the diameter of the worm gear is 7/8 inches and the diameter of our shaft is only ½ inch. For the manually operated solar panel An L bracket was also created because initially we were designing for two motors however, that did not happen so we simply placed a bearing in the space for the motor shaft and then stuck a shaft through that with a keyway cut into it for the worm gear. Keyways were cut into the shafts on both the manual and motorized sides to keep the worm gears in place. Keyways were also cut into the gears and shafts on the solar panel frames to keep the gears in place while the gears are rotating. Below is a picture of some of the keyways and keys we made for our design.

Figure 15: Keyways and key

Chapter 5. Testing and Results

5.1Testing procedures and environment, Results discussion

The solar panel in north-south direction tracking was tested by moving the panels in the North-South axis through each of the 18 holes. For the best results to track the sun, we change the hole position by adjusting the pin location forward/backward every 10 to 15 days, increasing the angle as the days grow shorter and decreasing the angle as the days grow longer.

For the East-West automated tracking system, the motor rotates a full rotation every 15 minutes, and the solar panel rotates 2.5 degrees in East-West axis correspondingly. The Solar panel rotates from 30 degree to 150 degree for 12 hours per day from 7 am to 7pm. The motor will rotate backwards for next 12 hours.

Once the program that we have written for the motor has been downloaded into the Arduino board, it will send 5 V digital signals to the STR 8 control system in direction **+** pin every 15 minutes. Once the control system receives the signal, the step motor will rotate a full cycle clockwise. The program executes 48 times within 12 hours and then sends 5 V digital signals to the SRT 8 control system in direction **–** pin every 15 minutes, the stepper motor will rotate a full cycle counterclockwise. The solar panel will reverse back to the original position on next day at 7am and start rotation all over again.

Chapter 6. Cost Analysis

For our design, we choose to minimize the cost as much as possible despite the client Dr. Acker not imposing a strict budget. The team managed to carry this out by utilizing materials that were readily and locally available. As shown in the following table 3, the resources used, relevant costs and their justifications are outlined.

Table 3: Bill of Materials

Resource	**Cost**	**Justification**
1.25” x 1.25” Angle Bar	$98.09	Steel used for framework of solar panel tray
1” x 1” Square Tubing	$180.00	Used for framework of tracking system base
1” Solid steel rod	$13.71	Connected to bearings to turn solar panel
Hardware	$20.00	Used in connections where welding will not work
Worm and Spur Gears	$311.92	Used to rotate solar panel
Motor and Control Panel	$597.00	Standalone system used to control tracking system
Bearings	$311.92	Solar panel shafts rotate on them
Total	$1,532.64	

All the hardware and square tubing were sourced from the local Home Depot. The bearings, motor, control panels, and gears were purchased from McMaster. The angle bar and the solid steel shaft were all purchased from Mayorga’s Welding, which is a local welding shop that also stocks various types of steel.

Chapter 7. Conclusions

7.1 Problem description

Solar tracking systems are intimidating to students in design complexity. The solar panels are limited to the set angle they are placed at. This project is educational with low maintenance requirements. The solar tracking system is designed to be operational in any weather condition. The solar tracking device will track the movement of the sun both manually and automatically via a step motor.

7.2 Concept Generation and Selection

Our group came up with seven different concepts for the design of the solar tracking system. Each concept ether used passive or active tracking systems. These include the angled tracker, ball joint, and solar panel array. The solar panel was chosen then constructed threw out the semester.

7.3 Engineering Analysis

The team performed a structural analysis of the power, torque, and motor required to move the solar panels to effectively track the sun. The AISI 1030 steal was the material chosen. To determine the north and south tracking pivot points a Matlab Programming code was created given Flagstaff's latitudinal coordinate.

7.4 Cost Analysis

Through the cost analysis of the design a table that held the bill of materials which listed what each part was, the company that produced it, unit price of each part and the amount required to build our design. Our materials came from McMasters.com, Home Depot and Mayorga's Welding. The method of shipping the material was found to be ether USP ground or US Postal Service ground. The cost of labor was not added to the final cost since we did all of the labor using equipment provided by Northern Arizona University

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7.2 Engineering Drawings

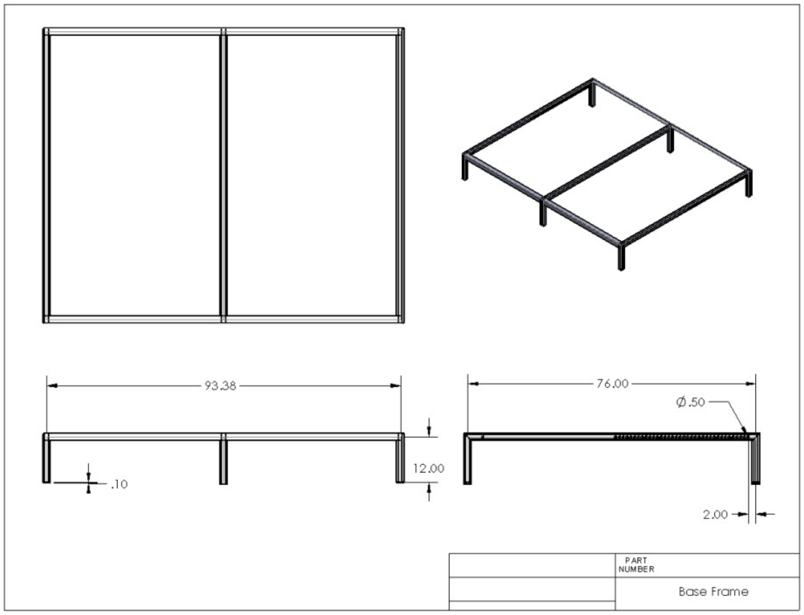

Figure 16: Base frame

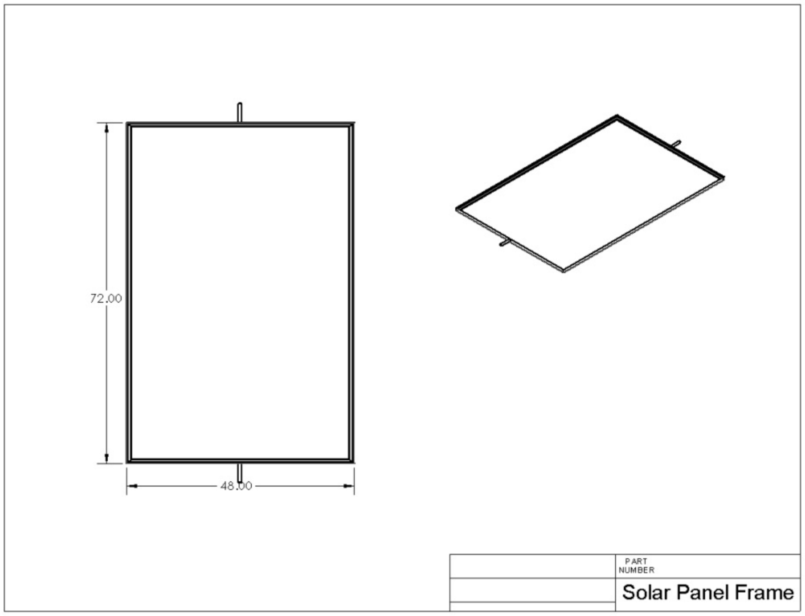

Figure 17: Solar panel frame

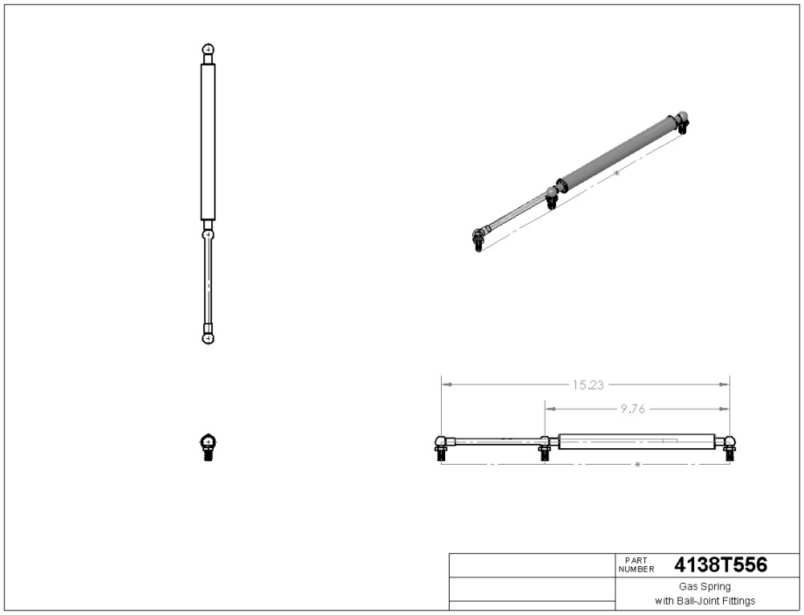

Figure 18: Hydraulic stabilizer

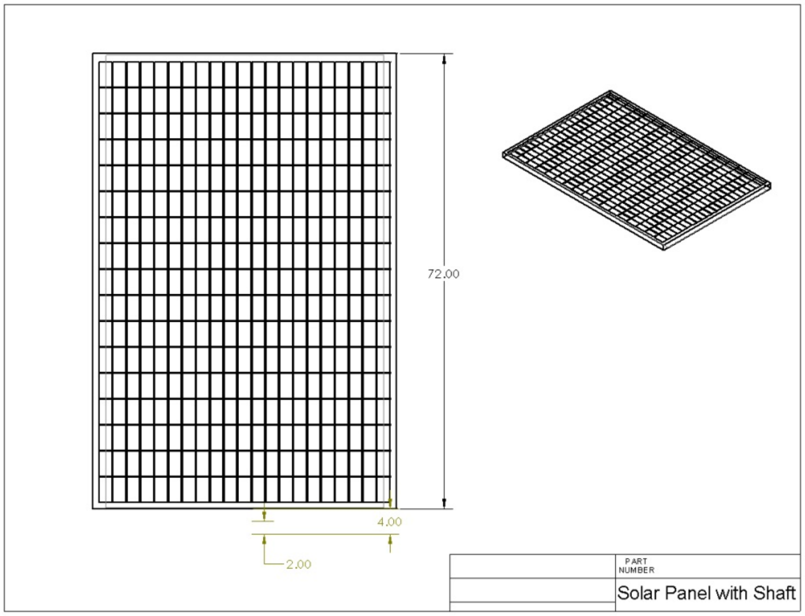

Figure 19: Solar panel

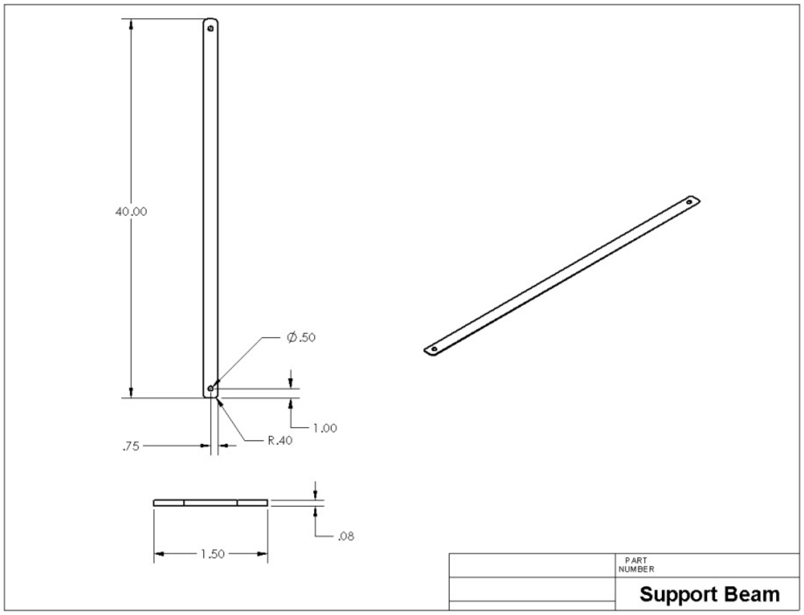

Figure 20: Angled support

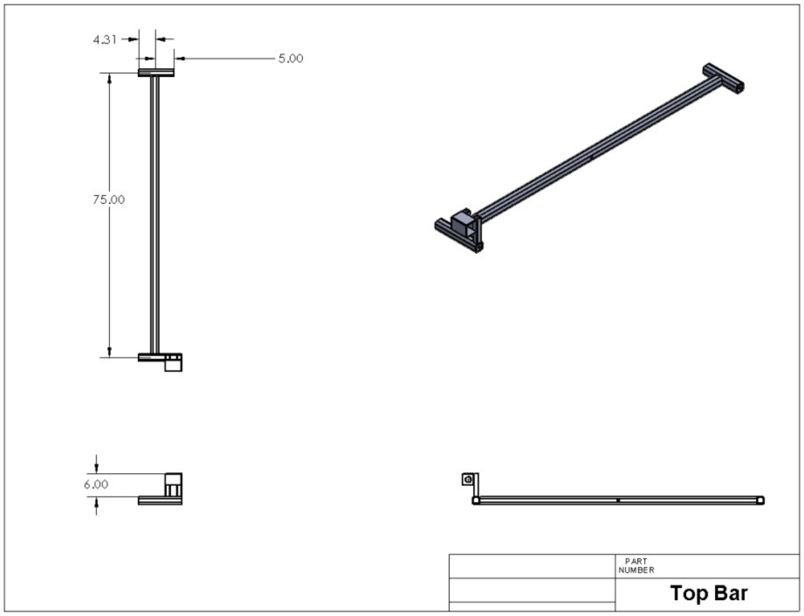

Figure 21: Top angled support

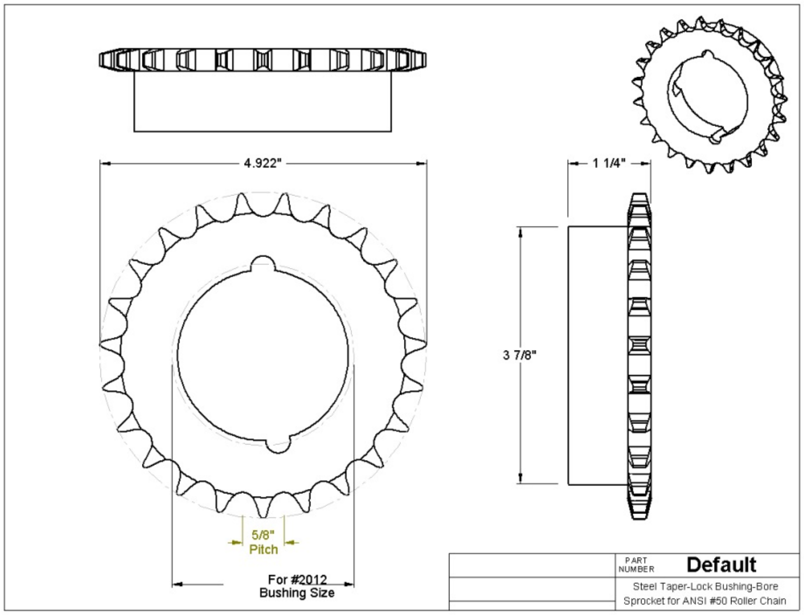

Figure 22: Spur Gear

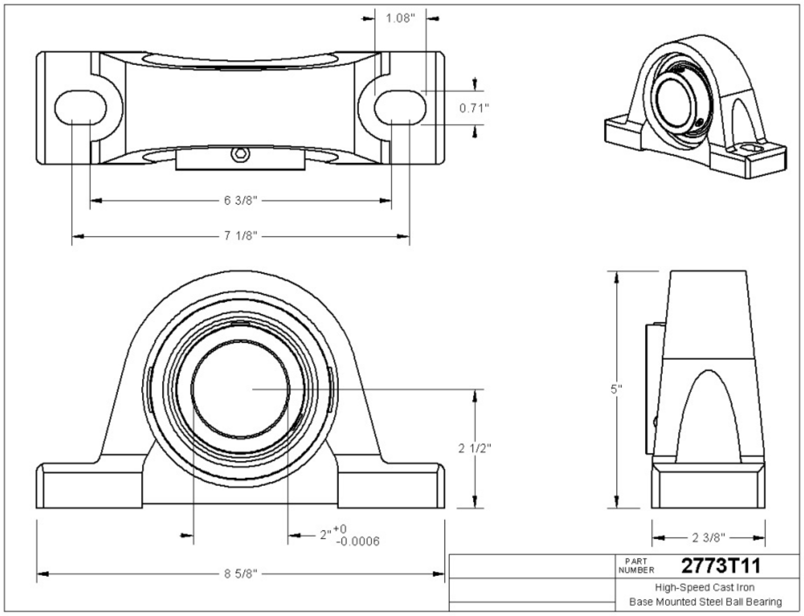

Figure 23: Bearings

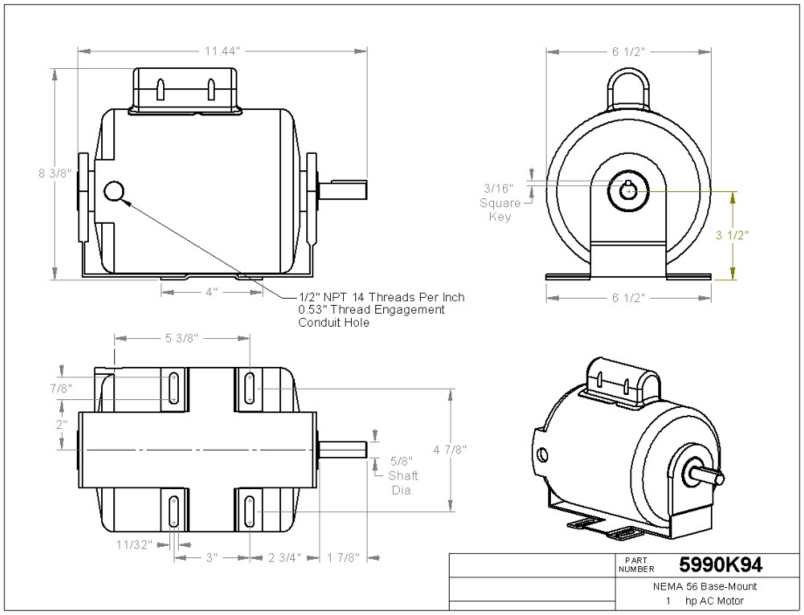

Figure 24: Motor dimensions

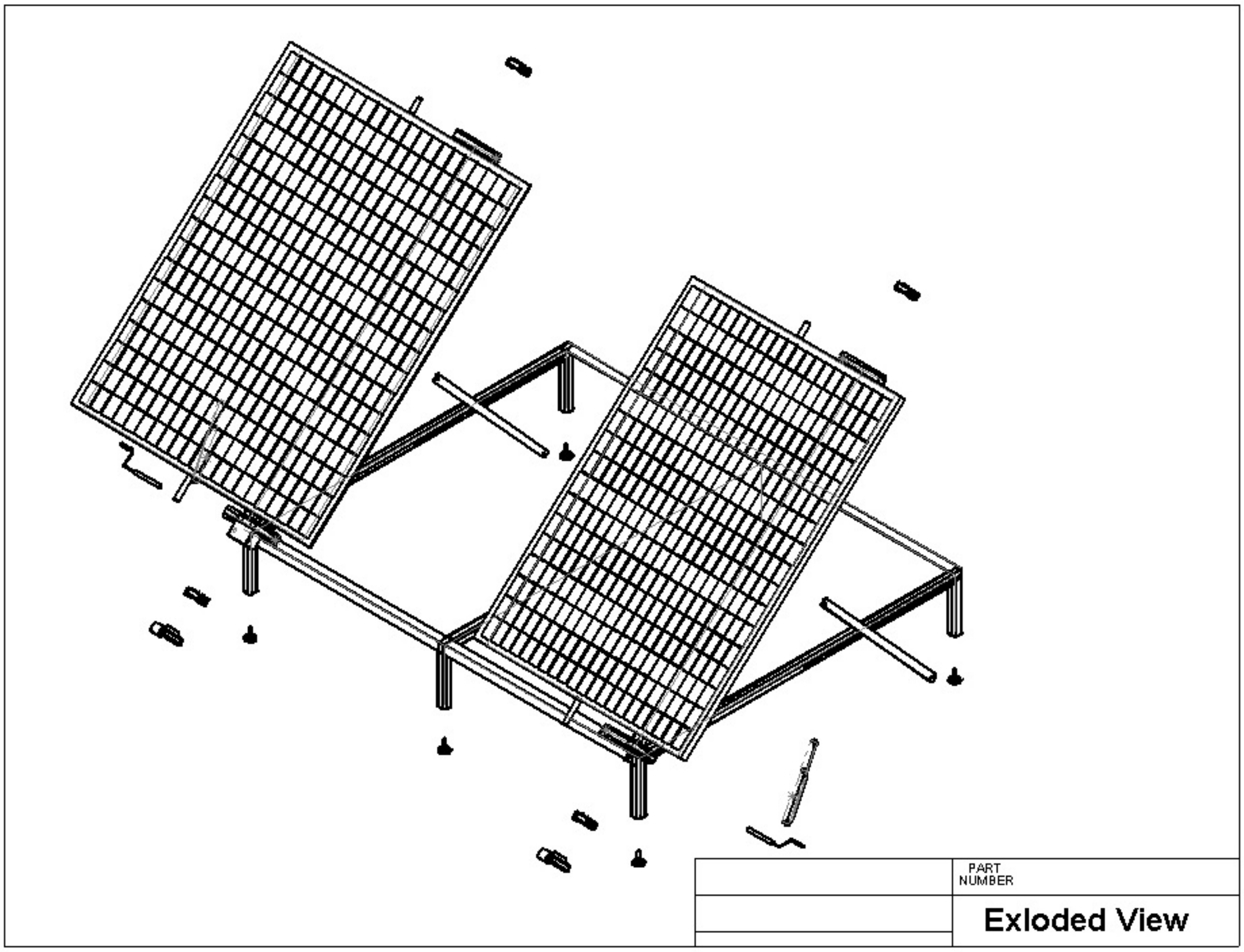

Figure 25: Exploded View

7.3 Acknowledgements

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