

# MEMO

To: **Thomas Acker**  
From: Team 18: Hashem Bukhamsin, Angelo Edge, Roger Guiel, and Dan Verne  
Date: 12/11/2013  
Re: Solar Tracking Structure Design Proposal

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The attached proposal includes two designs that the team generated and analyzed for the solar tracking structure. The first design is the “Rotisserie” which is a single axis, cheap, and simple to build. The second design is the “TIE Fighter” which is dual axis, robust, and more complex to operate. After preliminary analysis and evaluation, the final design was selected to be the “Rotisserie” design. It was selected because of simplicity of the design and the low cost of one unit. We will be prototyping the “Rotisserie” design, which will include a motor and a tracking mechanism that is being designed by the electrical engineering team cooperating with the mechanical team. Also, this design was chosen because of the cost of one unit is lower than the cost of the second design. Detailed analysis for these designs can be found in the attached proposal.

## **Rotisserie Design:**

The design “Rotisserie” will utilize a motor along with a tracking method to rotate the panels.

## **TIE Fighter Design:**

The “TIE Fighter” design will utilize a motor, gears, and a tracking method to rotate the panels.

## **Estimated Prototype Cost:**

The bill of material shows that the cost of the parts of the system shown in Figure 1 is \$268.39.

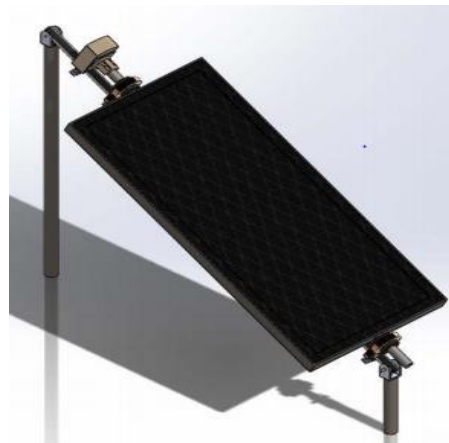


Figure 1: Rotisserie Design

# Solar Tracking Structure Design

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## Project Proposal Document

*Submitted towards partial fulfillment of the requirements for  
Mechanical Engineering Design I – Fall 2013*



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## Nomenclature

Table 1: Nomenclature

Nomenclature	Description	Nomenclature	Description
$w^t$	Transmitted Load	T	Torque
$K_s$	Overload Factor	F	Force
$K_v$	Size Factor	R	Radius
$P_d$	Pitch Diameter	T	Shear Stress
$d_f$	Face Width	A	Area
$K_m$	Load Distribution Factor	$\sigma_b$	Bending Stress
$K_b$	Rim Thickness	M	Moment
J	Geometry Factor	C	Distance to Centroid
\$	Unit Cost of Production	I	Moment of Inertia
$N/m^2$	Stress/Strain	A	Angular Acceleration
Days	Time	L	Panel Length
Amp/hr	Digital Screen	w	Snow Load
$^\circ$	Rotation Angle (Degree)	$\sigma$	Gear Stress

## **Abstract**

According to data collected by the Energy Information Administration, the United States is the 2<sup>nd</sup> largest energy consumer in the world with the majority of this energy being obtained from fossil fuels. Because the world's fossil fuel resources are limited, the use of renewable energy is being widely encouraged. The team was tasked with designing and building a solar tracking system that quantify the difference in power generation with and without the solar tracking device. Moreover, our design must conduct a lifecycle cost analysis of the solar system with and without the tracking device. The team has a limited budget of \$2000 to complete this project. Dr. Thomas Acker and the Consortium for Environmental Education and Technology Development (WEREC) are our clients for this project. The clients' needs were evaluated against a generated list of engineering requirements to evaluate the importance of each needs. To achieve the goal of this project and to satisfy our customer needs and requirements, our team generated a list of engineering requirements to evaluate against the customer needs and prioritize them accordingly. Then, five initial concepts were generated by the team members. Our five concepts consists of single and dual axis of rotation designs. Preliminary analysis were performed to evaluate the five concepts generated so that the best design can be selected. The final design selected based on the decision matrix is the Rotisserie design. This design is a single tracker with fixed second axis which provides an efficient yet simple and cost effective design.

After concept generation and design selection, full engineering analysis were performed for the best two designs. The engineering analysis helped choose the best design that would satisfy the customer needs and requirements. Both designs were reliable and efficient but the Rotisserie was cheaper. The power consumption needed to operate the Rotisserie design is estimated at 0.4615 kWh/year. Based on the engineering analysis, all the parts needed to build this design will cost a total of \$268.39. The team will move on to the building stage after the client approval of this design next semester.

## **Introduction**

Solar energy is increasing in popularity throughout the world. Germany continues to lead the world in solar power production while breaking its own records year after year [1], despite the nation's perpetual cloud cover, and Saudi Arabia has pledged to reach a solar energy capacity of 41 gigawatts within the next 20 years [2]. There is an excellent potential for solar power production in many locations throughout the United States, and there are a number of means of application.

Solar power production is usually accomplished using one of two methods. The first method utilizes Photovoltaic (PV) cells to convert sunlight into an electric current by the means of the photoelectric effect, in which a material absorbs electrons after receiving energy from a light source. A photovoltaic cell takes advantage of this effect by harnessing the electron flow in the form of direct current electricity. The second method of solar energy power production is the Concentrated Solar Power (CSP) method. CSP generation uses mirrors to concentrate sunlight into a specific spot. Unlike the PV method, the goal of the CSP method is to produce heat in order to drive a heat engine. Electricity is produced via a generator connected to the heat engine. This project will be focusing on the use of PV cells.

## **Needs Statement**

While solar panels are an effective means of collecting energy, their efficiency at doing so is directly related to their angle with the sun. Because PV cells get the most energy from facing the sun, a stationary solar panel collects less sunlight one that follows the sun across the sky. The problem that this project addresses is the inefficiency associated with fixed solar panels. Meaning, panels that do not track the sun across the sky. Two axis, as well as single axis solar panels allow for a better output from the PV cells, but they can be very expensive and require a lot of maintenance.

## **Goals**

Northern Arizona University offers several classes on renewable energies, and has its own area behind the Engineering building where several solar panels and wind turbines are stored. This project is going to be given access to four photovoltaic panels to fit the tracking system to. Along with the tracking station, this project also incorporates an educational component. The tracking system should have a manual override so the instructor can direct the solar panels in whichever direction they desire. The system should also display the power output of each individual photovoltaic cell, to show the efficiency at each angle.

## **Concept Generation and Selection**

The Solar Tracking Structure Team generated five preliminary concepts that address the needs of the customer while adhering to the project constraints. The customer requires a reliable, efficient, and inexpensive tracking system capable of moving a number of solar panels. Using weighted design criteria and a decision matrix, each design was scored based on its performance in the specified areas. As a result of the evaluation the team has decided to utilize a Nickel-Titanium wire based, single axis tracker. The design eliminates the need for motorized tracking through the creative use of a shape memory alloy. The team has also been informed that a separate Electrical Engineering team is responsible for any programming tasks. The team schedule has been updated in order to reflect this change in engineering requirements, and this new schedule is provided at the end of the report.

## Design 1 - Nitinol

This design focuses on maximizing the efficiency of the East and West movement. The panel's North and South axis is set to the maximum efficiency angle, while nitinol is used to track the daily movement of the sun. A half ellipse shape, shown in Figure 1 is fixed to the axis of the structure.

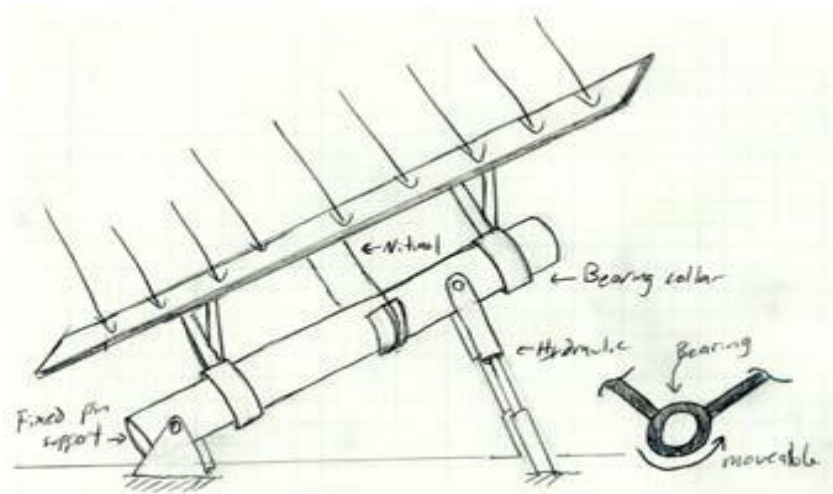


Figure 1-Nickel Titanium Design

The nitinol is wrapped around the half ellipse, causing a rotational movement of the panel when the nitinol is heated. This heat would be due to a small current, around 2.2 amps for a 0.015" in diameter wire [1]. Using a nitinol cable on both sides of the solar panel would allow for movement in both directions. The full design is shown in Figure 2.

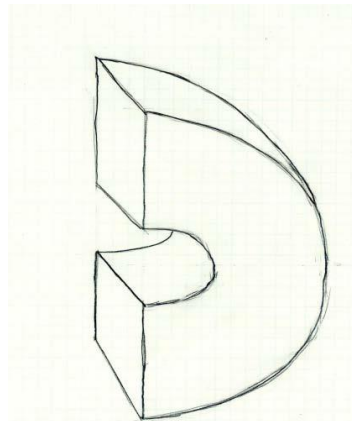


Figure 2: Half Ellipse Component

## Design 2- Tabletop

Having individual tracking systems for each solar panel is not cost efficient. This design focus on having a single tracking system that adjusts all of the solar panels in the system at the same time. Tabletop tracker design is shown in Figure 3 below. The panels are to be placed on the main shaft by attaching the panels to a support axis. The support axis is welded to the main



shaft. This will allow the panels to rotate when the main shaft rotates. The main shaft rotates using gears powered by a motor. Figure 3, below, shows the connection between the main shaft and the motor. The connection between the motor and the shaft is a gear box, which consists of a set of spur gears that are known for their rigidity, and ability to handle heavy torques. Since all solar panels in the system have the same motion, only one sensor and motor is needed to pivot all of the solar panels. The solar panels for this tracking device move from East to West. North to South orientation needs to be specified when setting up the frame. North to South rotation is not necessary because of the additional costs associated with adding a second axis.

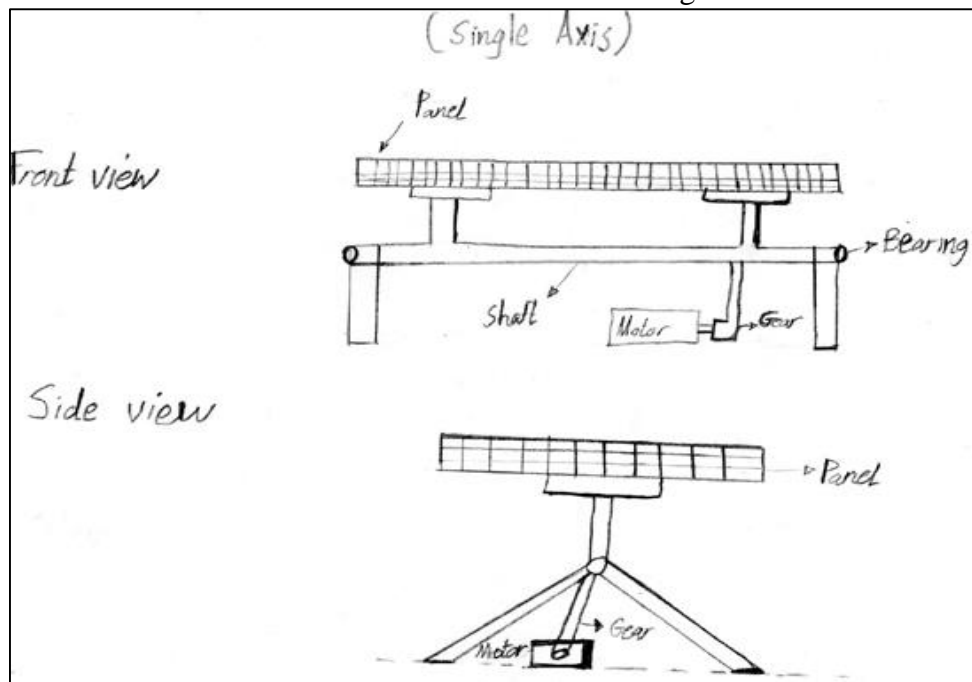


Figure 3: Tabletop Design

An advantage of the system is that the structure can hold multiple solar panels, instead of having several systems for different panels. Another advantage is that the system is very reliable. This is because the system contains fewer moving parts. The last advantage of the design is ease of maintenance and manufacturability. The Tabletop design is made so that the parts are easily accessible. Nevertheless the system has some disadvantages. The first disadvantage is that the system only has one moving axis. The single axis produces less of energy than a dual axis design. The second disadvantage is that the design has a poor space usage aspect, where having all the panels aligned next to each other occupies a lot of space. The last disadvantage is that the design requires a powerful motor since only one motor is used to rotate all of the panels in the system.

The Tabletop design is currently designed to support the maximum number of solar panels given to each team.. The solar panels sit on top of the main shaft that is connected to a gear train. The motor and the gear train should withstand the weight of the panels and rotate them in all weather conditions. For this, the design received a score of four for the supported weight in the decision matrix. The cost for this design received a three for two reasons. The first reason is that the Tabletop is designed to accommodate all of the available solar panels. The second reason is that the design operates with few moving parts. The efficiency of the Tabletop design received a score of two. Since Tabletop is a single axis tracker, it absorbs less sunlight

when compared to a dual axis design. The area allowed scored a two on the decision matrix because the design requires a lot of space to operate. There is one motor driven axis and a gear train that control the rotation. The system use little moving parts and little maintenance. For this, the design received a score of three.

### Design 3 - Sunflower

The design of the sunflower tracking system is that a single solar panel is mounted on a U shape beam. With the panel mounted, it will track the sun throughout the day. The panel in this design will be able to rotate freely in four directions. The panel is to be placed in the North to South direction using a manual gear. The manual gear consists of a circular gear called "the pinion." The pinion engages the teeth on a linear gear bar called "the rack." Rotational motion applied to the pinion causes the rack to move, thereby translating the rotational motion of the pinion into the linear motion of the rack [5]. The North to South adjustments will need to be performed every month. The panel is to be set on the East to West rotation by using an actuator motor. The actuator motor automatically sets the angle for the best efficiency. Figure 4 below is a rough sketch of the Sunflower design.

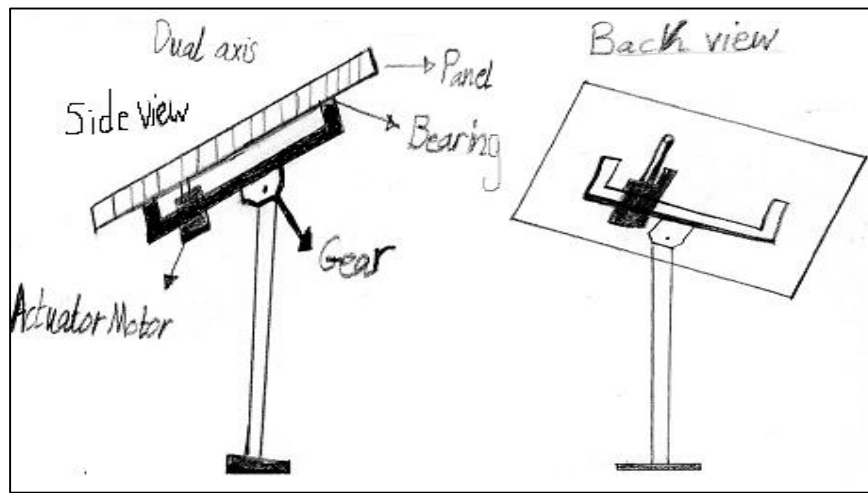


Figure 4: Sunflower Design

The U shape apparatus will be mounted to a universal joint. The universal joint is attached to a beam which is attached to a restricted base. The supporting base for the entire system is a wide square base that helps support the entire weight. The first advantages the system is that the structure requires little space to operate, due to each tracker using only one panel. Furthermore, the second advantage is the accuracy of the system. The Sunflower uses two axes to track the sun thus increasing its efficiency. A third advantage is that the structure is portable. On the other hand, the first disadvantage is that the system requires more maintenance as it uses more parts to track the sun. The second disadvantage is that the system only works for one solar panel, the limitation is due to having a single beam used to support the panel. The last disadvantage is that the structure cannot withstand severe weather conditions. A side view of the Sunflower is shown in Figure 5.

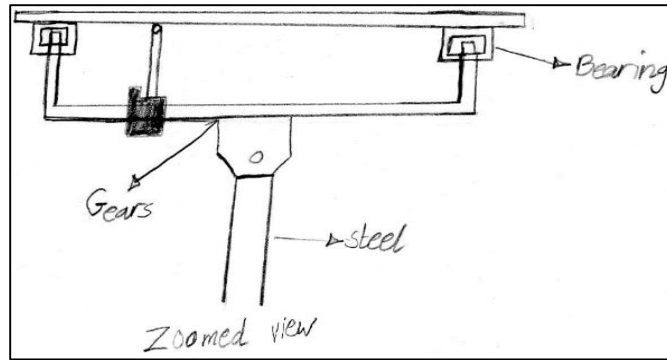


Figure 5: Sunflower Side View

The sun flower design is currently designed to only support a maximum of one solar panels per tracking device. The solar panel sits on top of U shape beam which then sit on top of the main beam. Because there is only one beam that connects the panel with the base of the structure, the stability of the panels is weak when facing severe weather condition such as wind or snow. Thus the stability of the structure received a score of one for the supported weight in the decision matrix. The cost for this design is one because it is relatively expensive for two reasons. The first is that we need four structures to operate the four panels the team was assigned to work with. The second reason is that there are several parts for axis movements in the structure, such as one actuator motor for one axes movement and a gear train for the second axis movement. For this the design cost received a score of one. The efficiency of the dual axis received the maximum score of four. Since Sunflower is a dual axis design, it can absorb more energy than a single axis solar tracker. The area allowed scored a four on the decision matrix because the design does not require a lot of space to operate. There is one motor driven axis and a gear driven axis that need to be changed and adjusted monthly. This makes it more complicated to maintain and thus the system is less reliable when compared to a design with two motor driven axes. For this, the design received a score of two.

#### Design 4-TIE Fighter

The TIE Fighter tracking structure is a dual axis design that utilizes motorized East to West tracking and manual North to South tracking. The solar panel is mounted on three rectangular pieces arranged in an “H”-like configuration, with the connecting crossbeam raised above the centers of the two vertical beams. Longitudinal movement is made possible using two bearings that sit on raised platform with a shaft running between them. The shaft itself is connected to a plate using two brackets, and the plate itself is welded to the crossbeam. Two cables are connected to the upper portions of the vertical beams and converge at a single ring. A third cable runs directly to a hand-operated winch, allowing the user to change the North to South angle of the panel by turning the handle. Since the sun’s elevation changes with each month, markers will be placed on the winch cable to denote the length needed for maximum efficiency. The structure sits on a rotating platform powered by an electric motor that will allow tracking from East to West, supported by a rectangular stand. The entire design can be seen in the Figure 6 below.

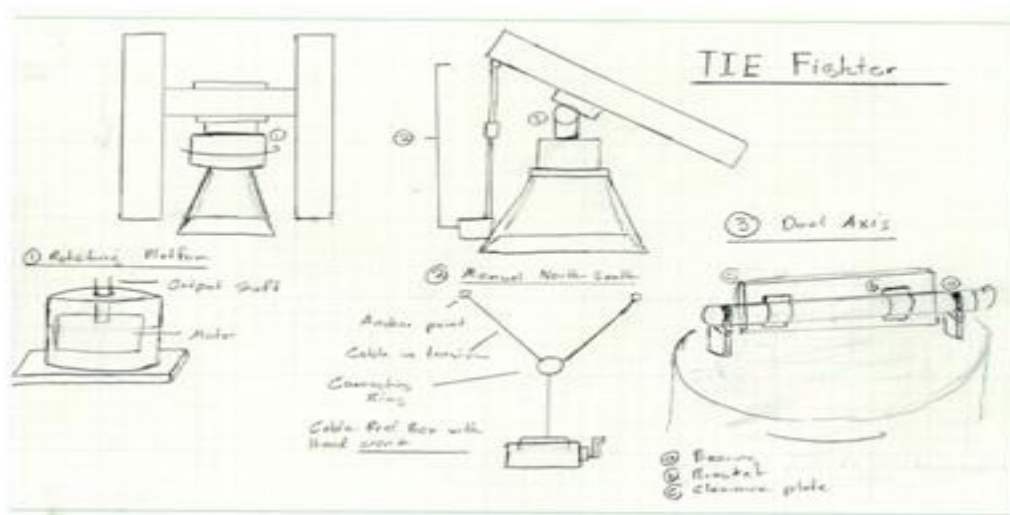


Figure 6: TIE Fighter Design

In theory, the TIE Fighter design is relatively inexpensive to implement. The components required for the structure itself are fairly easy to acquire or manufacture, with the most expensive component being the electric motor. The dual axis design allows for greater tracking efficiency, and by manually controlling one of the axes the design receives the benefits of a dual tracker at a greatly reduced cost. However, dual axis systems are not as reliable as single axis or fixed systems due to the greater number of moving parts. While the TIE Fighter tracker achieves these capabilities through simple means, the inherent disadvantages of dual axis trackers cannot be ignored. This structure itself is also larger than other trackers, requiring more space in the limited area that the team is allotted. Furthermore, the system has potential vulnerabilities with regards to environmental factors. The panels are free to rotate in the North to South direction, and placing the axis of rotation higher on the structure should prevent the panels from tipping backwards on their own, and anchoring the top of the structure to the ground will prevent the panels from tilting forward. However, a very top heavy snow load or forces from significant winds at the bottom of the panels could also cause the structure to tip about its North to South axis.

## Design 5 - Direct Rotation

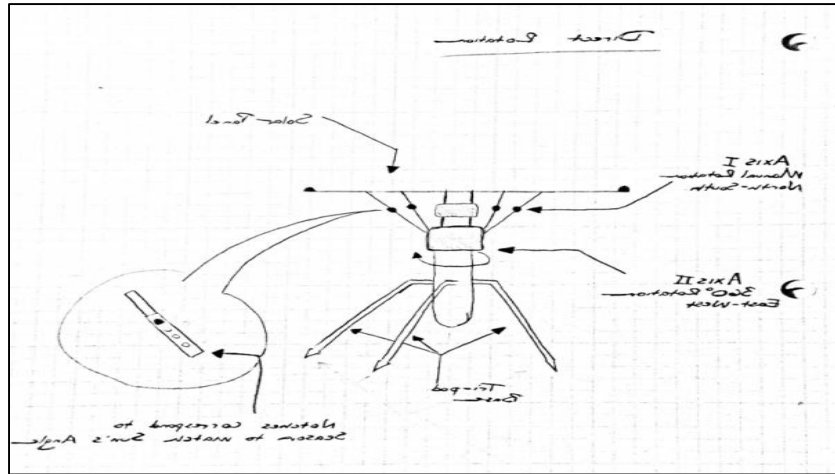


Figure 7: Direct Rotation Design

The direct rotation design is a dual axis design. The primary axis operates by use of a notch system. There are four pegs that extend out from the shaft of the solar tracker to the solar panel. Each peg is equipped with notches that correspond to a specific angle of the sun. These notches only need to be adjusted a few times a year. These angles are useful when tracking the sun from north to south. The secondary axis operates through the use of a motor. The motor rotates the panel three hundred sixty degrees. The secondary axis tracks the sun from east to west. The base for the Direct Rotation design is a tripod equipped with sharp legs for penetrating the soil. The base of the tripod can be altered to operate on a concrete surface. The tripod design for the base distributes the weight evenly thus increasing the systems stability. Advantages for this design are that it is cost effective, because one of the axes requires manual intervention, and it is relatively easy to manufacture. A disadvantage for the design is that it does require manual intervention to maximize the amount of sun absorbed by the PV cells.

The Direct Rotation design is currently designed to only support a maximum of two solar panels per tracking device. The solar panels sits on top of axis two and the panels are reinforced with the four pegs that make up axis one. Because axis one reinforces the stability of the design it received a score of three for the supported weight in the decision matrix. The cost for this design is a three because it is relatively cheap as it only uses one motor for two axes. Since Direct Rotation is a dual axis design, it can absorb more energy than a single axis solar tracker. The efficiency of the dual axis received the maximum score of four. The area allowed scored a three on the decision matrix because it is relatively easy maneuver and the design does not require a lot of space to operate. There is only one motor driven axis. This is easier to maintain and thus more reliable when compared to a design with two motor driven axes. For this, the design received a score of three. The Direct Rotation is show below as Figure 7.

## Design 6 - Rotisserie

The Rotisserie design, a single axis solar tracker, is depicted below as Figure 8.

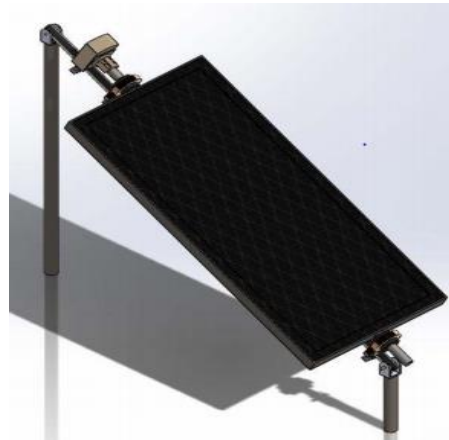


Figure 8: Rotisserie Design

## Weighting

Each criterion for the decision matrix was assigned a weighted value. To solve for this weighted value, each criterion was compared to one another. If a particular criterion was valued more important, it would receive a value of one. After each criterion was compared, the total number of one's assigned would be added up. The sum of each individual criterion is then divided by the sum of awarded points. This method yields the weighted value. Table 2, below, outlines the method used to weight each criterion.

Table 2: Weighted Criteria

Weight Criteria							
	Structure Weight (lbs)	Supported Weight (lbs)	Cost (\$)	Efficiency (%)	Area (ft*ft)	Reliability (%)	Criterion Weight
Structure Weight	<b>X</b>	0	0	0	0	0	0
Supported Weight	1	<b>X</b>	0	0	1	0	0.14
Cost	1	1	<b>X</b>	1	1	0	0.29
Efficiency	1	1	0	<b>X</b>	1	0	0.21
Area	1	0	0	0	<b>X</b>	0	0.07
Reliability	1	1	0	1	1	<b>X</b>	0.29

The criterion used in the decision matrix was supported weight, cost, efficiency, area, and reliability. Using the method above to weight each criterion, the team discovered that the structure weight was nonessential to the design process and thus it was removed from the decision matrix. The supported weight of the structure accounts for how much weight the tracking system can support without failing. The cost is essential to the design process as it pertains to the allowed budget for materials and assembly. The efficiency dictates how much energy is absorbed by the tracking system and the area pertains to how much space is needed for the system to operate. Reliability also incorporates maintenance and is responsible for ensuring that design requires little additional effort to maintain. The decision matrix is represented in Table 3.

Table 3: Decision Matrix

<b>Design Decision Matrix</b>						
Scale: 0-1-2-3-4	Criterion Weight	Nickel Titanium	Tie Fighter	Table Top	Direct Rotation	Sun Flower
Supported Weight (lbs)	0.14	3	2	4	3	1
Cost (\$)	0.29	4	3	3	3	1
Efficiency (%)	0.21	2	4	2	4	4
Area (ft*ft)	0.07	3	2	2	3	4
Reliability (%)	0.29	4	3	3	3	2
Total	1	3.37	3	2.86	3.21	2.13

### Engineering Analysis

The Rotisserie design is focused on absorbing the sun light from east to west. The team is considering adding a second manual axis to track the varying sun angles from season to season. The addition of a second axis is only a 3-8% increase in efficiency and installation of the second axis could significantly add to the overall cost of the project. At this point, the team does not have a cheap, reliable solution to this situation. However, the addition of a manual axis is still cheaper than implementing a second motor. The Rotisserie design, as it stands now, is a low cost design that is positioned directly south at an angle of 35.2°. The positioning of the solar panel is related to the angle of latitude, where Flagstaff sits 35.2° north of the equator. The hinge bolt, support bar, frame, and frame connection were determined to have the highest percentage rate of failure. Table 1 summarizes each locations material selection, yield stress, maximum stress, and factor of safety.

Table 4: Static and Dynamic Analysis-Rotisserie

Stresses	Material	Yield Stress (Ksi)	Maximum Stress (Ksi)	FOS
Hinge Bolt (0.5")	Steel	70	5.03	7.0
Support Bar (1.5")	AISI1020	60	5.261	11.4
Frame (1/8" thick)	AISI1020	60	30.57	4.0
Frame Connection	Weld	50	17.5	2.9

All locations operate with a factor of safety of at least 2.9. The lowest factor of safety was associated with the welds that connect the frame. Whereby, the welds would be the most notable location to fail.

- Hinge Bolt (0.5") :

The hinge bolt is located at the base of the solar panel. The hinge bolt located at the top of the solar panel was negated because more force will be experienced by the hinge bolt located at the base of the solar panel. The hinge bolt experiences shear due to torque caused by wind as well as shear due to vertical loads. The equation for torque is:

$$T = Fr \quad [1]$$

Where:

T = Compression due to Torque

F = Force

r = Radius

Where:

The equation for shear is:

$$\tau = \frac{F}{A} \quad [2]$$

Where:

$\tau$  = Shear

F = Force

A = Area

- Support Bar (1.5")

The support bar supports the weight of the solar panel. The support bar experiences a bending moment due to the collective load of the snow, solar panel, and frame. The equation for the bending moment is:

$$\sigma_B = \frac{Mc}{I} \quad [3]$$

Where:

$\sigma_B$  = Maximum Bending Moment

M = Applied Moment

c = Distance to Centroid

I = Moment of Inertia

- Frame (1/8" thick)

The frame holds the solar panel in place. The frame experiences a bending moment due to the weight of the snow and the solar panel. The bending moment was calculated using Equation 3, above.

- Frame Connection



The frame is welded to the rotating shaft. The weld experiences a bending moment due to the weight of the system. The bending moment was calculated using Equation 3, above.

The power needed to be able to rotate the shaft was equated for by using the Equation 4, below.

$$T = \alpha I \quad [4]$$

Where:

T = Torque of Rigid Body

$\alpha$  = Angular Acceleration

I = Mass Moment of Inertia

Having the required power, a motor with the proper specifications was selected. From the engineering analysis, the cheapest, readily available, and most applicable material for the support bar and frame is AISI 1020 Carbon Steel. AISI 1020 Carbon Steel has a yield Strength 60Ksi, a Modulus of Elasticity of roughly 190-210GPa, and a Density of  $7.7-8.3E3 \frac{kg}{m^3}$ . The properties of AISI 1020 Carbon Steel exceed the maximum forces exerted on the solar tracking design and will serve as a durable material for the structure. The Antennacraft TDP2 motor is capable of 8ft.\*lbs. of torque and a power input of 65W. The motor specifications will be more than sufficient to power the solar tracker design. The motor is relatively inexpensive, dial controlled, weather proof, and is capable of moving the panels at 5.14°/second. This amount of movement accumulates to a running time of roughly 70 seconds per day needed to follow the sun.

Based on the environmental loads for the TIE Fighter Design, it was determined that failure was most probable at two points: the bolts on the East-West shaft bearings and the welds that connect the panel frame to the East-West shaft brackets. The tension in the manual axis control cable and the stresses experienced by the gear were also considered. Due to the length of the shaft, bending stresses were not a concern. Table 3, located below, summarizes each locations material selection, yield stress, maximum stress, and factor of safety.

Table 5: Static and Dynamic Analysis-Modified TIE Fighter

Stress Analysis Points	Material	Yield Stress (Ksi)	Maximum stress(Ksi)	FOS
North and South bolts	AISI 1010	25.5	4.3	5.9
Welds on the panels box	AISI 1020	50	0.096	106
Cable	Galvanized Aircraft	2.6	.64	4
Gears	Polyoxymethylene	2	10	5

- East-West Shaft Bolts (0.25 in):

Four bolts connect the East-West shaft bearings to the East-West shaft brackets, with a 0.25 inch thick steel plate acting as a spacer between them. Assuming that the bolts will experience maximum stress due to max wind loads, they will most likely fail due to shear. For calculation purposes, each bolt was assumed to be made of steel. Therefore, the maximum shear stress experienced by each bolt was calculated using equation 2.

- Panel Bed Welds:

The panel bed, which holds the PV panel, is connected to the East-West rotation shaft using brackets and welds. In order to attach the manual axis control cable to the frame, a steel, U-shaped component is also welded to the top of the panel box. Assuming that the bracket welds experience max load when the panel is perpendicular to the ground and the U-component experiences max load when the cable experiences maximum tension, the likely failure mode for each weld is shear. The area of the contact surface for each bracket is 0.25 in<sup>2</sup>, and the contact surface area of the U-component is 0.0625 in<sup>2</sup>. The maximum shear stress experienced by each bracket contact point and each U-component contact point was calculated using equation 2.

- Cable (1/16 in):

The manual axis control cable connects the panel box to the winch, which will sit on the ground. The cable will experience maximum tension if the panel is experiencing maximum snow load. This was modeled by assuming that the panel is loaded from the North-South axis of rotation to the bottom of the panel. This distributed load was converted to a point load which was placed at the bottom of the panel. Since this force would be acting at an angle, the vertical component of the force was used for calculations. The equations used to determine the cable tension are shown below.

$$\sum F_y = 0 = -T - 0.66(wL) \quad [5]$$

Where:

T = Cable Tension

L = Panel length

w = snow load

- Gears (1 and 2 in):

To determine the appropriate gears, the amount of torque required to turn the panels was found using equation 1. Due to distance of the motor shaft from the primary axis shaft, a 2:1 gear ratio was assumed in order to account for the covered. Stress was analyzed on each gear using the following equation, with all factors assumed to be one. The stress experienced by the gears was determined using the following equation.

$$\sigma = w^t k_o k_s k_v \frac{P_d k_m k_b}{d_f J} \quad [6]$$

Where:

$\sigma$  = Stress experienced by the gear

$w^t$  = Transmitted Load

$K_0$  = Overload Factor

$K_s$  = Size Factor

$K_v$  = Dynamic Factor

$P_d$  = Pitch diameter

$d_f$  = Face Width

$K_m$  = Load Distribution Factor

$K_b$  = Rim thickness factor

$J$  = Geometry factor

## Cost Analysis

Table 5, located below, is a breakdown of the materials selected for the Rotisserie design.

Table 5: Rotisserie Cost Analysis

<u>Material</u>	<u>Units</u>	<u>Comment</u>	<u>Cost/unit</u>	<u>Cost</u>
Motor	1	Antennacraft TDP-2	\$62.99	\$62.99
Bearing	2	TB-105 Support	\$35.95	\$71.90
Axle Bolt	2	0.5" x 4"	\$2	\$4.00
1.5" Pipe Flange	2	Home Depot	\$2	\$4.00
2" Pipe Flange	2	Home Depot	\$2	\$4.00
Flange Bolt	16	Home Depot	\$0.75	\$12.00
Pipe Hinge	2	Still Shopping	\$10	\$20.00
2" Base Pipe	1	8ft., cut down	\$35	\$35.00
1.5" Support pipe	1	7ft.	\$35	\$35.00
1/8" x 2.5" Flat bar	1	13ft. at \$9/72"	\$19.50	\$19.50
			Total	\$268.39

The total cost for the Rotisserie solar tracker is \$268.39. Implementing this design for all four solar panels is well under budget, and leaves room for the possibility of adding a second

axis. The majority of the cost is dedicated to the motor, and bearings. Additionally, a majority of the materials can be purchased locally at Home Depot.

Table 6, located below, lists the estimated cost of construction for the Modified TIE Fighter.

Table 6: Modified TIE Fighter Cost Analysis

<u>Material</u>	<u>Units</u>	<u>Comment</u>	<u>Cost/unit</u>	<u>Cost</u>
Motor	1	Antennacraft TDP-2	\$62.99	\$62.99
Bearing	4	TB-105 Support	\$35.95	\$143.80
Bolts	8	Home Depot	\$0.16	\$1.28
1/8" Pipe Strap	2	Home Depot	\$2	\$4.00
Gears	2	Amazon	\$7	\$14.00
Winch	1	Amazon	\$20	\$20.00
1' Base Pipe	2	8ft., cut down	\$35	\$70.00
Cable	1	13ft. at \$9/72"	\$0.08	\$0.32
Plates	2	Grainger	\$10.23	\$20.46
Tripod	1	Steel pipe, cut and welded	\$35	\$35
			Total	\$371.85

The initial cost of construction for the Modified TIE Fighter is shown to be roughly 28% higher than the Rotisserie. When comparing this increased cost to the potential benefit of a dual axis system, the team was unable to justify dual axis implementation.

## Conclusion

The team analyzed two solar tracking designs. The areas considered for analysis were located where the material would most notably fail. The estimated maximum loads were calculated for variable snow and wind conditions. The designed maximum weight of the snow was 198lbs., and the maximum wind force, when the panel is perpendicular to the wind, was 210lbs. Both solar tracking designs selected materials that were relatively inexpensive and surpassed the variable loads each design could experience.

The Rotisserie design was analyzed along the bottom hinge bolt, support bar, frame, and frame connection. Each section considered for analysis operated with a factor of safety of at least

2.9. The lowest factor of safety was associated with the welds that connects the frame. The Rotisserie design is the cheapest design. The team will continue analysis on the Rotisserie design in order to implement a secondary manual axis for seasonal angle changes of the sun.

The TIE Fighter designed was analyzed along both axes of rotation, the winch system used to control the secondary axis, the gearing mechanism used to rotate the solar tracker, and the welds that connect the panel bed to the primary axis bearings. The most likely failure point of the system was found to be the manual axis control cable. However, the actual factor of safety at this point was still 4. While this design is very robust, the team did not believe that the efficiency increase of a dual axis system justified the cost.

The sources used to analyze the designs was most notably the “Mechanics of Materials” text book. Additional sources such as the “Engineering Dynamics” text book, and “Shingley’s Mechanical Engineering Design” text book were used to further analyze the forces acting on the solar tracking designs. The Gantt Chart in Figure 12 located in Appendix B has been updated to show the actual time that it had taken to complete previous tasks. The Gantt Chart deadlines will be treated with more urgency than in previous phases of the design process. Also, Figure 13 is located in Appendix B, which is a Gantt Chart that illustrates the team plan for next semester.

## References

- [1]<http://www.timeanddate.com/worldclock/astronomy.html?n=1945&month=12&year=2013&obj=sun&afl=-11&day=1>
- [2]<http://www.dynalloy.com/TechDataWire.php>
- [3][http://www.homedepot.com/p/Unbranded-1-1-4-in-x-48-in-Plain-Steel-Flat-Bar-with-1-8-in-Thick-42180/100337615?cm\\_mmc=shopping--googleads--pla--100337615&skwid=&kwd=&ci\\_sku=100337615&ci\\_kw=&ci\\_gpa=pla&ci\\_src=17588969#product\\_description](http://www.homedepot.com/p/Unbranded-1-1-4-in-x-48-in-Plain-Steel-Flat-Bar-with-1-8-in-Thick-42180/100337615?cm_mmc=shopping--googleads--pla--100337615&skwid=&kwd=&ci_sku=100337615&ci_kw=&ci_gpa=pla&ci_src=17588969#product_description)
- [4][http://www.solidsignal.com/pview.asp?p=tdp2&d=antennacraft-by-radioshack-tdp2-tv%2Ffm-tv-antenna-rotator-\(tdp-2\)](http://www.solidsignal.com/pview.asp?p=tdp2&d=antennacraft-by-radioshack-tdp2-tv%2Ffm-tv-antenna-rotator-(tdp-2))
- [5] Hibbeler, *Engineering Mechanics Dynamics*, 13th ed. Upper Saddle River, New Jersey: Pearson Prentice Hall, 2013, pp.1-736.
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- [7] McGraw-Hill, *Shingley's Mechanical Engineering Design*, 8<sup>th</sup> ed. United States, 2006, pp.1-1059
- [8] U.S. Energy Information Administration, "Average Revenue per kWh by State", (2013, September). [online], pp1. Available: [http://www.eia.gov/electricity/monthly/update/end\\_use.cfm#tabs\\_prices-3](http://www.eia.gov/electricity/monthly/update/end_use.cfm#tabs_prices-3)

**Appendix A**

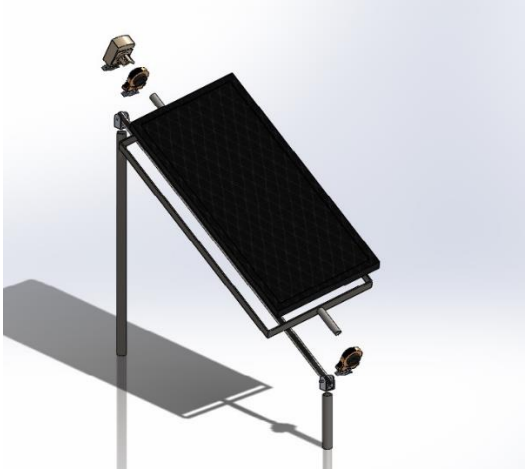


Figure 9: Exploded View Final Design

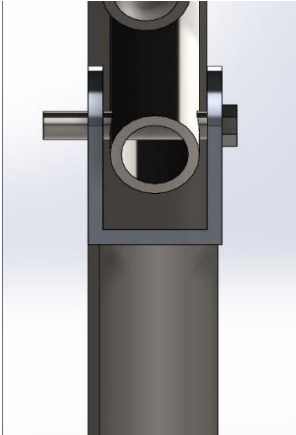


Figure 10: Hinge Joint - Final Design\

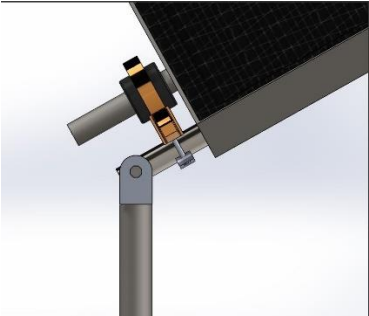


Figure 11: Weld - Final Design

# Appendix B

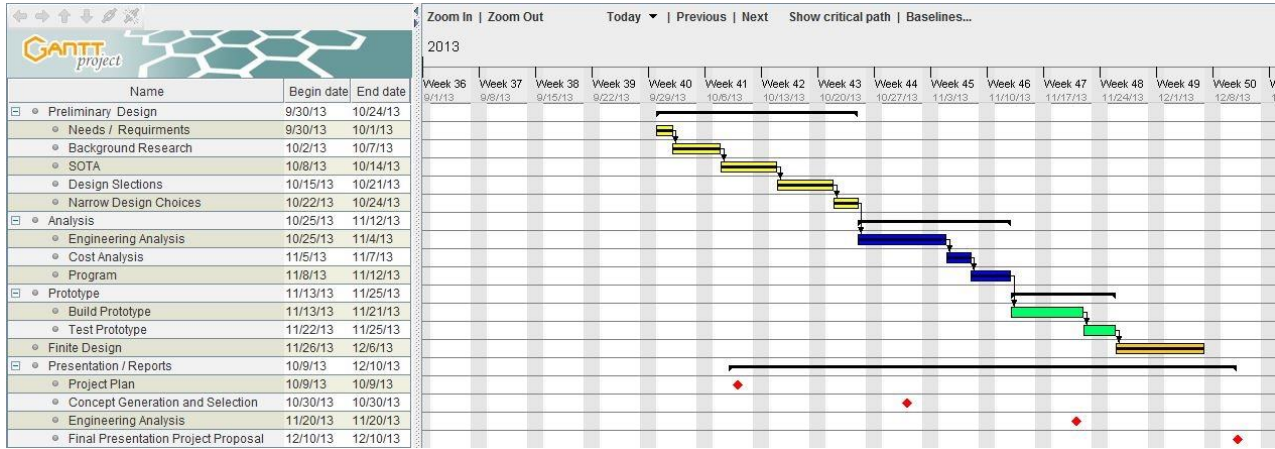


Figure 12: Fall Semester Gantt Chart

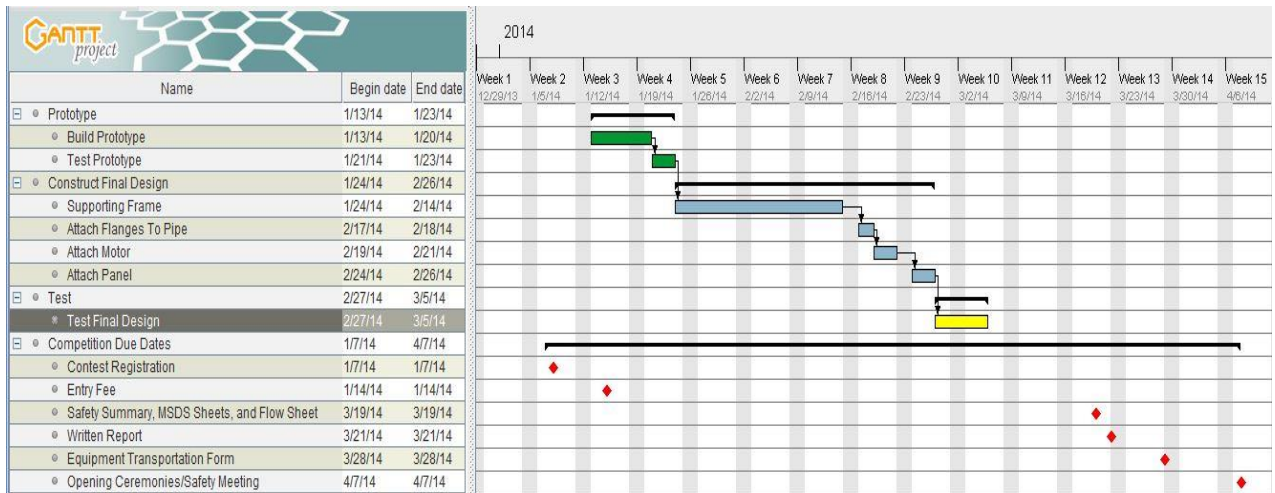


Figure 13: Projected Spring Semester Gantt Chart



Appendix C

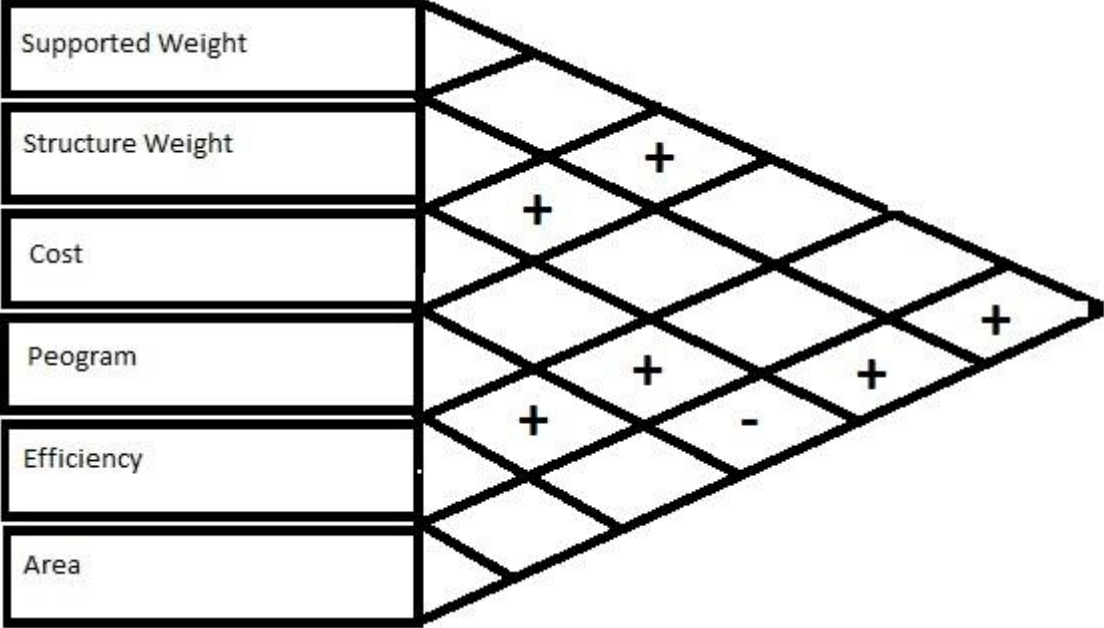


Figure 14: House of Quality