# Solar Tracking Structure Design

By
Hashem Bukhamsin, Angelo Edge,
Roger Guiel, Dan Verne
Team 18

# Engineering Analysis

Document

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Department of Mechanical Engineering
Northern Arizona University
Flagstaff, AZ 86011

# Table of Contents

## 1.0 Introduction:

There are two solstices and two equinoxes every year. The solstice occurs as the sun reaches its highest or lowest point relative to the celestial equator. The equinox occurs when the plane of the Earth’s equator passes the center of the sun. During the June Solstice the sun’s circular path in Flagstaff is positioned North, above the horizon at 78.2°N. During December Solstice the sun’s circular in path in Flagstaff is positioned South, below the horizon at 31.4°S. The solstices and the equinoxes together make up the seasons. For each season the sun rises in the east and sets in the west at different angles. Solar panels adjust to these angles to optimize the amount of sunlight absorbed by the photovoltaic cells. The dual axis solar tracker is a more efficient machine, however, its efficiency compared to the single axis tracker is minimal, a mere 3-8% increase in efficiency. Engineering Analysis was performed on two different solar tracking designs. The solar tracking designs considered were the “Rotisserie”, a single axis solar tracker, and the “TIE Fighter”, a dual axis solar tracker. The dimensions of the solar panels are 56.1in. X 25.7in. X 2.3in. and each individual panel weighs 28lbs. The stresses considered for the engineering analysis were located where the design would most notably fail. Each design was analyzed under two different maximum loads. A maximum snow weight of 198lbs and a maximum wind drag of 210lbs were used to study the stresses acting on the solar trackers.

## 2.0 Design 1: Rotisserie

The Rotisserie design, a single axis solar tracker, is depicted below as Figure 1.

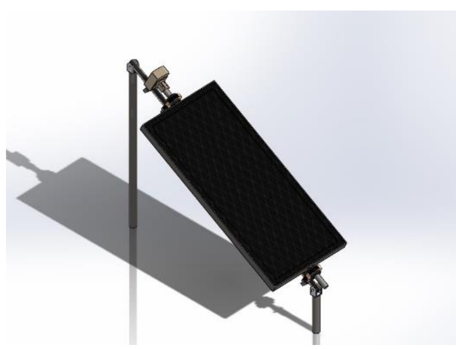

Figure 1: Rotisserie Design

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 deign, 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.

## 2.1Static and Dynamic Analysis:

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 1: Static and Dynamic Analysis

| 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:

$$T=F*r \qquad [1]$$

Where:

T = Compression due to Torque

F = Force

r = Radius

Where:

The equation for shear:

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

Where:

τ = 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 bending moment:

$$\sigma_B = \frac{M * c}{I} \quad [3]$$

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

α = Angular Acceleration

I = Mass Moment of Inertia

Having the required power, a motor with the proper specifications was selected. The motor would run in 1 second increments at 5° per increment totaling 70 seconds per day.

## 2.2 Material Selection:

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 7.7-8.3 $(x10^3)\frac{kg}{m^3}$. 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 5.14degrees/second. This amount of movement accumulates to a running time of roughly 70seconds per day needed to follow the sun.

## 2.3 Cost:

Table 2, located below, is a breakdown of the materials selected for the Rotisserie design.

Table 2: Cost Analysis

| Material | Units | Comment | Cost/unit | Cost |
|---|---|---|---|---|
| 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.

## 3.0Design 2: TIE Fighter

Figure 2, located below is the TIE Fighter Design.

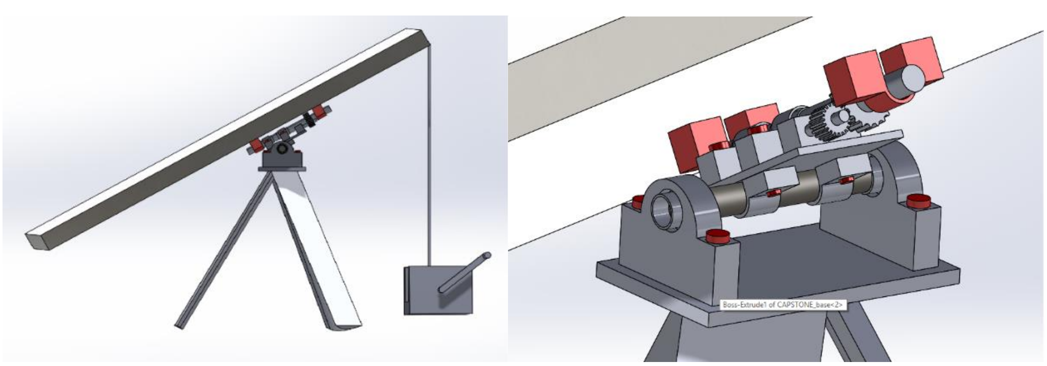

Figure 2: TIE Fighter Design

The TIE Fighter design is a dual axis solar tracking design. East to West tracking is motorized, and North to South tracking is manual. It is 3-8% more efficient than the Rotisserie solar tracking design.

## 3.1 Static and Dynamic Analysis:

Based on the environmental loads, 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 3: Static and Dynamic Analysis-Design 2

| 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$^2$, and the contact surface area of the U-component is 0.0625 in$^2$. 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.

$$\sum Fy = 0 = -T - 0.66(w * L) \qquad [5]$$

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.

$$\sigma = w^t k_\circ k_s k_v \frac{pd}{F} \frac{k_m k_b}{J} \qquad [6]$$

Where:

$\sigma$ = Stress experienced by the gear

$w^t$ = Transmitted Load

$K_0$ = Overload Factor

Ks = Size Factor

$K_v$ = Dynamic Factor

$P_d$ = Pitch diameter

F = Face Width

$K_m$ = Load Distribution Factor

$K_b$ = Rim thickness factor

J = Geometry factor

## 3.2 Material Selection:

For the majority of components, AISI 1010 steel will be sufficient. This material is inexpensive and readily available while providing high factors of safety and minimal cost. Galvanized steel aircraft cable will be used for the manual axis control cable, due to the high performance to cost ratio. Polyoxymethlyne plastic will be sufficient for the gears, providing a factor of safety of five while being less expensive than similar steel gears.

## 3.3 Cost:

Table 4, located below, lists the estimated cost of construction for the Modified TIE Fighter.

Table 4: Modified TIE Fighter Cost Analysis

| Material | Units | Comment | Cost/unit | Cost |
|---|---|---|---|---|
| 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 | Still shopping | | |
| Tripod | 1 | Still shopping | | |
| | | | Total | $316.39 |

## 4.0 Gantt Chart:

The team has completed phase two of the design process by completing the engineering analysis. The team has moved forward but has not adhered to the deadlines outlined on the Gant Chart. Specifically, the engineering analysis had taken additional time to complete. Figure 4, below, is the teams scheduler for completing the engineering design process.

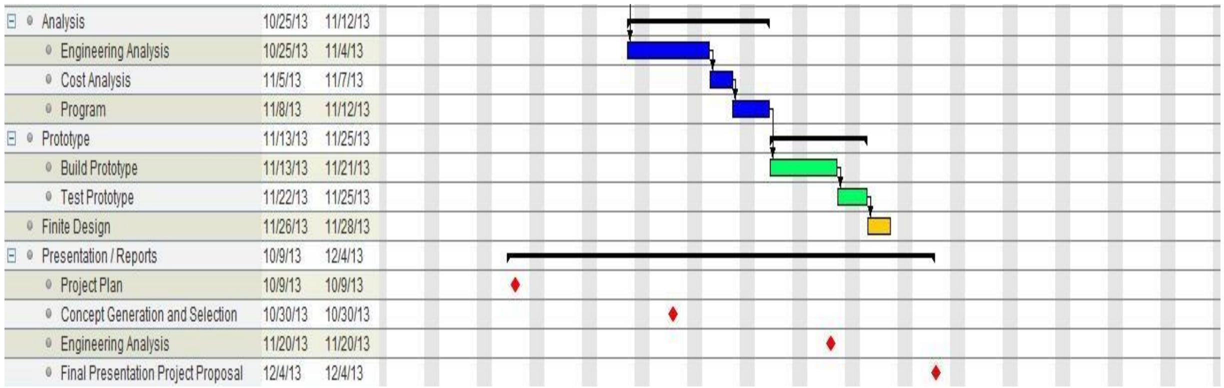


Figure 4: Gantt Chart

The team has now entered into the prototype phase. The prototype design will facilitate the location of any additional engineering design problems. The final prototype will be model using CAD drawings and will be presented during the Project Proposal. Figure 5 is the current updated version of the Gantt Chart.

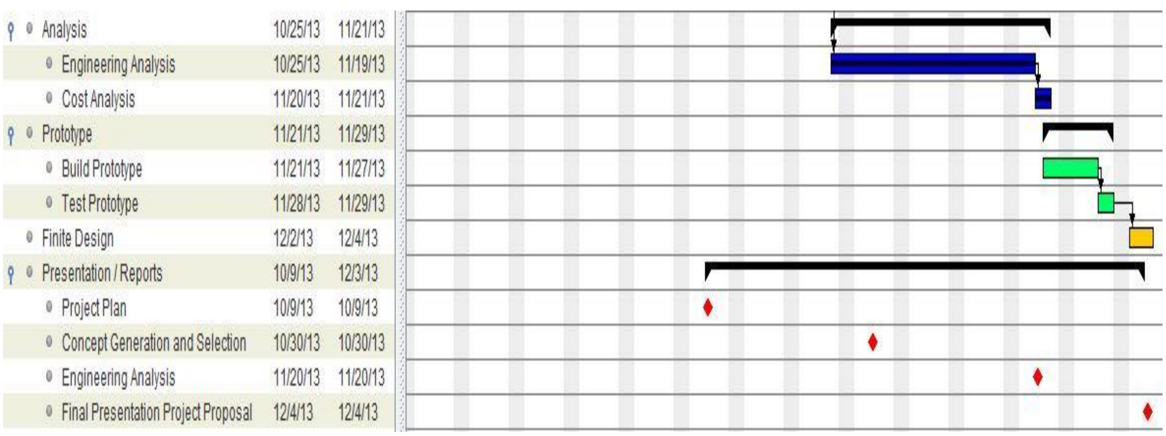

Figure 5: Updated Gantt Chart

## 5. 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 cheap 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 deign. 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 design was analyzed at the East-West shaft bolts, the panel bed welds, the manual axis control cable, and the solar panel rotation gears. The minimum factor of safety for this design was 4, which was associated with the control cable. This design is sturdier than the Rotisserie design but it is also more expensive. More analysis is required in order to determine if the dual axis capabilities justify the costs. 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 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.

## 6. Resources:

[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&skwcid&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)

[5]Hibbeler, *Engineering Mechanics Dynamics*, 13th ed. Upper Saddle River, New Jersey: Pearson Prentice Hall, 2013, pp.1-736.

[6]Philpot, *Mechanics of Materials*, 2nd ed. Rolla Missouri, 2011, pp.1-767.

[7]McGraw-Hill, *Shingley's Mechanical Engineering Design,* 8$^{th}$ ed. United States, 2006, pp.1-1059