Final Design Review

Cal Poly Micro-grid Fixed PV Array

SUNS OF SOLAR

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Statement of Disclaimer

Abstract

The Mechanical Engineering Department at California Polytechnic State University of San Luis Obispo would like an adjustable, fixed angle solar panel mount to help educate students on basic solar energy principles. Our team has developed a unique sawhorse design utilizing ideation techniques and design selection tools. The selected design allows for multiple panel adjustability and control of both azimuth and tilt angle. Safety concerns are addressed with action plans to mitigate risk. Concept prototypes to justify gearbox functionality and subsystem cohesion were utilized to reduce manufacturing issues. Manufacturing began upon completion of CDR and was expected to proceed through the end of the year. The manufacturing of the mount was halted due to COVID-19, forcing the design to end strictly in a what if manufacturing procedure to allow the construction of it to be done in future time.

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1.0 Introduction

Our team consists of Chris Ewert, Jason Kehl, Donald Syracuse, and Justin Syracuse. We are four mechanical engineering students at California Polytechnic State University (Cal Poly) working on a project to benefit the Mechanical Engineering Department (ME). The intent is to design and construct an adjustable solar panel mount that demonstrates solar energy production and efficiency for the new Energy Resources concentration. This project will serve as both an educational tool for student engineers and help in the ongoing solar energy research performed at Cal Poly.

The sponsors for this project are two engineering professors, Dr. Andrew Davol and Dr. Jacques Belanger. Their intent for the design is to have a simple system that will be manually operated so they can move and/or angle the cells to a desired location and position. Their hope for this project is to utilize this system to demonstrate efficiency and output of photovoltaic systems to students in the new Energy Resources concentration.

The current panel mount consists of four solar thermal collectors mounted to a rigid system on top of the civil and mechanical engineering building located on the northwest corner of Cal Poly's campus (we will refer to it as Engineering 13). The collectors are non-operational, cumbersome, and cannot be adjusted. Dr. Davol and Dr. Belanger need a new system that is adjustable and can accommodate different sized photovoltaic panels. The mount will be located on the solar balcony of Engineering 13 and implemented into the renewable energy micro-grid.

The background addresses the current mount for the solar panels on Engineering 13, along with market designs and technical literature pertaining to solar panel mounts. The objectives section begins with the sponsor's desired needs, wants, and the engineering specifications set as a result. The most important specifications are described in detail to ensure that the solution meets these requirements.

The design will consist of four components, each one being necessary to ensure a successful design. The ideation process for each component is described in detail and initial concept models are provided to present various solution paths. Utilizing a morph matrix, we constructed six completed, feasible designs. These six designs were then analyzed against a weighted decision matrix to arrive at the selected sawhorse design.

Preliminary calculations using known panel weights and predicted wind provide proof of concept. Also, potential challenges and safety concerns moving forward were mitigated using failure modes and effects analysis. A manufacturing plan was created to provide clarity for unfamiliar technicians to assist in the assembly of the design. Each subassembly was broken down to allow for a consistent purchasing of parts in our cost analysis.

Unfortunately, due to the breakout of COVID-19 we were unable to complete the project as planned. The last few sections and appendices include the Manufacturing Plan, Testing Plan, and the Operators Manual. The manufacturing plan contains all the manufacturing that was performed before COVID-19 along with all the manufacturing that still needs to be done which will be performed by the professors and shop technicians. A test plan explicitly describing how to confirm that the specifications list will be met in the design. Lastly, an operator's manual which will allow for the ability to assemble or dissemble the mount safely and efficiently to transport or relocate it to a desired location.

2.0 Background

This section consists of sponsor meetings, interviews, existing designs, relevant journal articles, and building codes/regulations to provide references to previous material and requirements to ensure our design is up to industry standards and regulations. Initially, it was mentioned that we would be looking into processing and displaying the output of the panels, we have now narrowed down our project to just building and designing the solar panel mount.

2.1 Sponsor Meetings

Two meetings were conducted with Dr. Davol, it was concluded that the purpose of this project is to design an adjustable fixed angle mount that can hold multiple photovoltaic[1] (PV) panels of different sizes for research purposes in the Cal Poly ME department. The mount must have the means to hold two large Sunmodule Plus SWA 295 mono photovoltaic cells and should have the ability to adjust to hold three medium sized panels. The panels will be interchangeable depending on the research or demonstration that our sponsors will be conducting. A single person must be able to change out the solar panels without the assistance of a second party. Wheels will be implemented on the mount so that it can be relocated to a different location but will remain on the solar balcony of Engineering 13. This has changed from the initial Scope of Work due to a lack of clarity in the design. Initially, it was interpreted that an electronic display system was required for the project but was later concluded that the focus will be geared towards the mount primarily.

2.2 Problems with Existing Design

The current mount locating on the Engineering 13 balcony is non-operational and mounted on a very large and rigid system. This mount cannot be adjusted nor can be moved in any direction. Most of the time, fixed solar panels are efficient enough that they do not need to be angled toward the sun; however, the current system has the face of the panels pointing slightly east of due south. In the northern hemisphere, it is optimal to face your solar panels south as it orients the sun’s rays more perpendicular to the surface of the panel (the closer the sun rays are to perpendicular, the higher the efficiency). Furthermore, the panels themselves are in a very poor location as there is a large eucalyptus tree that shades the panels during most of the day.

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[1] These are your standard solar panels that produce electricity when two substances are exposed to light.

2.3 Existing Designs of Mounting Systems and Methods

Figure 1 is the pre-existing fixed solar mount located on top of Engineering 13. The system has never been used over a 25+ year time span. The old mount holds four large 8’ x 3’ PV thermal panels that cannot be replaced easily or relocated. The location of the fixed structure can only be used with the approval of Cal Poly because there are giant eucalyptus trees that shadow the panels at the peak times of the day. Currently, it seems more reasonable to rebuild/purchase a new mount that is not already fixed because Cal Poly may not approve of the tree's removal. For these reasons the existing system was not used.

Figure 1: Pre-existing mount on top of Engineering 13.

Figure 2 shows a side pole mounting system that can support a wide range of heavy-duty side pole solar structures. The design could hold 1-4 module panels depending on the required application. It can withstand wind speeds of up to 130 mph and the material of the mount is made of high strength stainless steel band clamps, U-bolts, and custom parts that can fasten the panels to the mounts. The tilt angles of this structure range from 30 to 90 degrees and support up to 1000W on a single structure [1]. This is an optimal structure design that could help us with adjustability for the angle portion of the design.

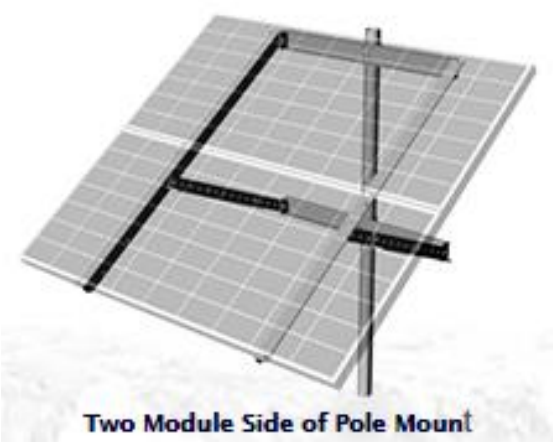

Figure 2: Side pole mount design with dual panels [2].

Figure 3 consists of a top pole mounting system that holds between 1-24 module panels. Depending on the location of assembly, the total area of these panels can add up to 260 ft^2. Installation of these panels is considerably easier than other mount frames, but it does not have the ability to hold universal panels. The tilt angle for this design ranges from 15-60 degrees, can sustain wind loads up to 90 mph, and can support a power output of 4.1kW on a single pole mount [2]. This structure is optimal for a similar design, if more power output was necessary for the device.

Figure 3: Top pole mount with multiple panels fastened to it [2].

Figure 4 is an image of an adjustable solar panel mounting bracket made from rust free aluminum with stainless steel hardware. This design can tilt with small holes and peg application along rail lines for single person adjustability. The mounts maximum panel application width is 500-550mm with most mounted panels being 100W and 12V output. The tilt angle ranges from 0-90 degrees [3]. The mechanism used to adjust the angle is a common application used for positioning purposes.

Figure 4: Adjustable solar panel mounting bracket [3].

2.4 Relevant Technical literature

While extensive research into panel efficiency has been conducted, technical research into panel mounting systems is relatively unexplored. Many dual-axis mounts commercially available have built in tracking mechanisms, which is outside the scope of this project. However, the mechanical design of the tracking mounts can be reverse engineered to gain a better understanding of the rotation methods utilized. Nader Barsoum of Curtin University fabricated a dual axis tracking system in 2011 [8]. Sections three and four of the articles discuss the physical mounting system and moments associated with the panel mass and wind forces. We have utilized this analysis and conducted similar calculations of our design. Further, Barsoum explains the use of pillow block bearings for both azimuth[2] and tilt[3] adjustability. This is a proven solution that we can utilize in our design. Our second relevant academic article comes from the Saddam University for Engineering and Science [9]. Al-Naima and Yaghobian designed a dual-axis tracking system for research purposes in 1990. The article offers great insights into solar coordinate systems, mounting design, and steel frame analysis. Sections two, three, and four all pertain to our scope while later sections detailing the automated tracking system do not. We have adapted their coordinate system and utilized it when designing for azimuth and tilt adjustability.

2.5 Industry Codes, Standards, and Regulations

Given our design will be used in primarily one location, the industry codes and standards will not significantly limit this design. Design safety is still a priority for the mounting system and current codes are implemented to ensure user safety. Three codes were considered in our design: the first is Title 24, Part 2.5: California Residential Code [10]. This ensures that the mount does not exceed building height limits. Second, is Title 24, Part 4: California Mechanical Codes [10] Part 4 requires safety from bodily injury while operating on and replacing solar panels on the mount. Finally, Title 24, Part 9: California Fire Code Regulation [10]. Part 9 mandates that the mount does not block fire exits or emergency evacuation routes.

3.0 Objectives

The objectives section of this report outlines the problem statement and design requirements. These are derived from sponsor meetings, the Quality Function Deployment process, and engineering judgement. Since Preliminary Design Review, we have re-evaluated a few of our engineering specifications. The main specification altered was the overall weight of the design, increased from 100 lbs. to 350 lbs.

3.1 Problem Statement

Cal Poly’s new Energy Resources concentration needs a way to inspire and educate students about various renewable energy sources through their micro-grid. We aim to design and build a new solar panel mount capable of holding multiple photovoltaic panels that can be interchanged, so that the instructors can demonstrate efficiency and power output of an adjustable system. This mount will also allow for expanded solar energy research to be done at Cal Poly.

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[2] Angle of the panel along the horizon. i.e. North, South, East, West

[3] The angle of the panel either up or down.

3.2 Boundary Diagram

Figure 5 shows the current boundary diagram. Boundary diagrams illustrate the systems assembly and components within the project that will be implemented into the final design. We have selectively chosen the base of the photovoltaic panels as it will be an important sizing factor to how the panels will be attached to the mount. The base of the mount has been incorporated along with the mount and the information needed to properly secure the system to the surface.

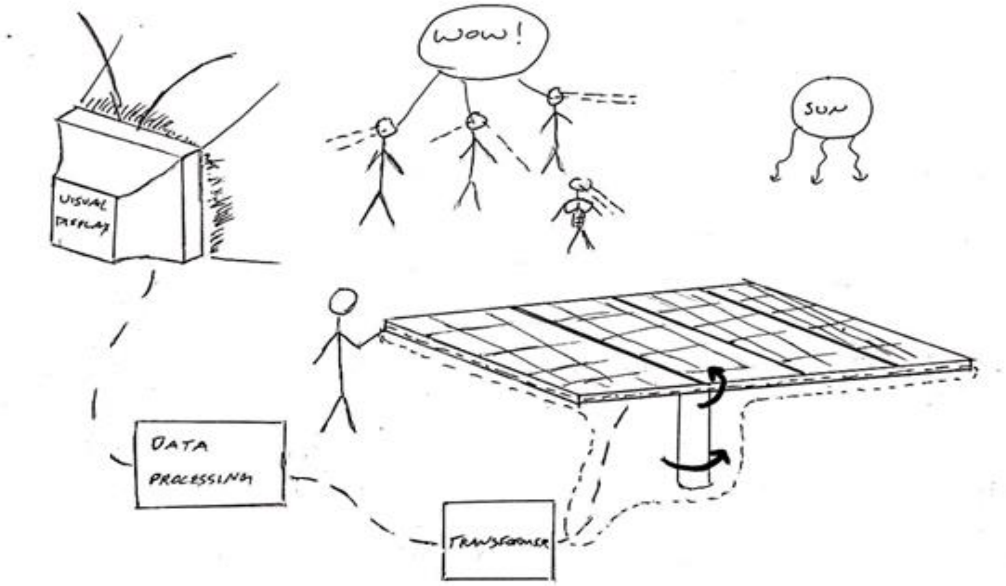


Figure 5: Boundary Diagram

3.3 Customer Wants and Needs

Through meetings with ME faculty and understanding Cal Poly ME students, a list of wants and needs was determined. Needs are classified as necessary requirements for basic mounting function. Wants are classified as stretch goals, but not required within our scope.

Table 1: Customer Wants and Needs

Wants	Needs
• Ability to mount multiple panels on a singular mount frame • Moveable • Relocation ability on the roof of Engineering 13 • Adjustable to 1° • Fit in Engineering 13 elevator • Fit in Micro-grid room above Engineering 13	• Safe to operate • Tilt adjustability - 15° to 90° off vertical • Azimuth adjustability - 360° • Durable, able to withstand outdoor environment (I.e. wind/dust/sun/rain) • Adjustable to different size panels • Student operable • Ability to monitor azimuth and tilt angles of panel • Wheels

Note: Tilt and Azimuth angle specifications have been added to the needs for the project. Size constraints due to the Engineering 13 elevator and the Engineering 13 micro-grid room have been added to the wants. Wheels have been moved from a want to a need as they provide azimuth adjustability and general relocation convenience.

3.4 Quality Function Deployment (QFD) Process

The Quality Function Deployment (QFD) process allows for a deeper understanding of the customer's problem. This method was developed to help determine specifications based upon the customers concerns and input. By spending time and energy in empathizing with the customer and getting to the root of the problem, we are better prepared to design a solution that will satisfy their need. We utilized a house of quality worksheet (Appendix A) to turn customer needs into engineering specifications. This helped prioritize customer needs, conduct market research into existing solutions, and set design goals for later in the design process.

From the QFD, safety and ease of use were established as top priorities when it came to operation of the device. As ethical engineers the design selected must consider all safety constraints. Safety concerns will be a top priority since there will be large swinging panels. Ease of use is necessary because the instructors would appreciate the ability to change the parameters of the system without the help of another person. Complete adjustment of the solar panels should take no longer than five minutes.

3.5 Engineering Specifications

The Engineering Specifications Table, shown in Table 2, quantifies specific qualifications to meet design requirements. These specifications are derived from needs by the customer. The requirement or target is derived using engineering judgement and the QFD process.

Table 2: Engineering Specifications Table

Spec. #	Specification Description	Requirement or Target	Tolerance	Risk	Compliance
1	Weight	350 lbs. (Excludes Panels)	Max	L	A, I
2	Production Cost	$1500	Max	L	A
3	Time to Clean	20 min	Max	L	T
4	Maintenance Time	60 min	Max	L	T
5	Forces/Loads	90 mph winds	Max	H	A
6	Demo Survey	Operable by untrained student		L	I
7	Time to adjust	2 min	Max	H	T, A
8	Range of tilt	15°- 90°	Range	L	A

Note: Table 2 shows our various requirements with their tolerance, risk (L = Low, M = Medium, H = High), and compliance (A = Analysis, T = Test, S = Similarity, I = Inspection).

Note: Range of tilt has been added to the specifications for further clarity in tilt adjustability. Overall Weight specification has been modified from 100 lbs. to 350 lbs.

The requirement or target is further explained for clarity purposes:

1. Weight

   The overall weight of the solar mount is important to consider because of possible tipping hazards and ensuring the mount can be moved or relocated when needed. The weight test will be conducted by taking the final model and placing the mount on the large blue digital scale that has a capacity of 1000 lbs. located in the Cal Poly Engines Lab. The weight requirement of the system has been changed to a maximum of 350 lbs. due to the size requirement and the necessity to support various loads without damaging the design. It was also concluded that weight is of lesser importance since the system will not be moved while in full assembly.

2. Production Cost

   Our Bill of Materials has outlined the price per component for all purchased and machined part. This allows us to keep close track of the budget and ensure efficient spending of resources. The assembly of this mount will be conducted in the Cal Poly shops to significantly reduce labor costs.

3. Time to Clean

   The user will be timed while wiping off the mount and solar panels after the design has been exposed to the outdoor conditions. It must not take this individual longer than 20 minutes to clean the entire project. This will be tested after completion of manufacturing.

4. Maintenance Time

   The amount of time it takes to replace one of the panels on the mount without the use of a second party. Upon user feedback, it was reasonable to expect a team of two or three people to perform panel replacement. This task should take no longer than 60 minutes to conduct. This will be tested after completion of manufacturing.

5. Forces/Loads

   Hand calculations and finite element analysis (FEA) have predicted how the mount will react under certain forces, loads, and design constraints. The most extreme case predicted was a maximum wind speed of 90 mph. It was shown that while not ideal for accurate operation, the mount and panels will remain upright and deflections will not permanently damage any component. Engineering analysis will be confirmed with inspection upon completion of manufacturing.

6. Demo Survey

   Upon completion of manufacturing, our group will provide a short demo on how to assemble and operate the mount. Then three students will be expected to test out our design to ensure that it can be used by an inexperienced individual.

7. Time to Adjust

   This specification is strictly for the user to make sure that it doesn't take them to long to change the position of the panels. Both azimuth and tilt angles were considered to capture multiple different data values at different times of day. This will be tested upon completion of manufacturing.

8. Range of Tilt

   This specification is the amount of rotation that the panel will point toward the sun to allow the mount to capture the maximum amount of sunlight. This will be tested after completion of manufacturing.

The engineering specifications deemed as "high risk" are specifications which will be most difficult to accomplish. These specifications were the primary focus during the design phase of the project.

1. Forces/Loads

   Force and load requirement are considered a high-risk specification due to our design's safety and dependability need. Safety is our highest priority, reflected in our house of quality QFD process. Through both engineering analysis during the design process and visual inspection upon completion of manufacturing, we can ensure a safe solution.

2. Time to Adjust

   Another highly weighted need for the design is the ability to easily and quickly adjust the azimuth and tilt of the panels. Our gear box will allow the user to rapidly and accurately adjust tilt while caster wheels allow for azimuth angle adjustment.

4.0 Concept Design

To proceed with a chosen solution, many design selection tools were utilized, such as functional decomposition, Pugh matrices, and a weighted decision matrix. These tools provide justification for the chosen design path and ensure consideration of all design ideas.

4.1 Ideation Process and Initial Ideas

The ideation process began by specifying exactly what was needed to meet our requirements. After analyzing basic needs and wants provided by the user, four basic components were established that when combined would create a successful design. The four main components consist of a structural frame, a method to adjust azimuth angle, a method to adjust tilt angle, and a system that would adjust to hold various panel sizes.

Brainwriting and Brainstorming were the first techniques used during the iteration process. During brainwriting, each group member independently sketched and described solutions to each of the basic components and after two minutes passed their paper to the next individual. This process was repeated until all members added to each paper. Appendix B provides an example of the brainwriting process for the panel mounting feature. Brainstorming is a common ideation method where team members rapidly contribute ideas through open dialogue. These two ideation techniques were repeated for each function and resulted in the initial list of ideas referenced in Appendix B.

After reviewing our initial ideas, a few designs were selected from each component pool based on what was deemed feasible and effective. These designs were put through a Pugh matrix (Appendix B) to determine the best couple designs for the given function. Pugh matrices compare ideas generated in brainstorming to a datum. We chose to compare our ideas to the current stationary mount located on the solar balcony of Engineering 13. After selecting the best few designs for each function, a morph matrix (Appendix B) was utilized to generate six completed designs. The morph matrix allows functional ideas generated in brainstorming to be combined in various ways. This allows the best features to be applied across different designs.

The top six designs advanced into the final selection process. Figure 6 provides a visual representation of the process exercised to reach our top six concept solutions.

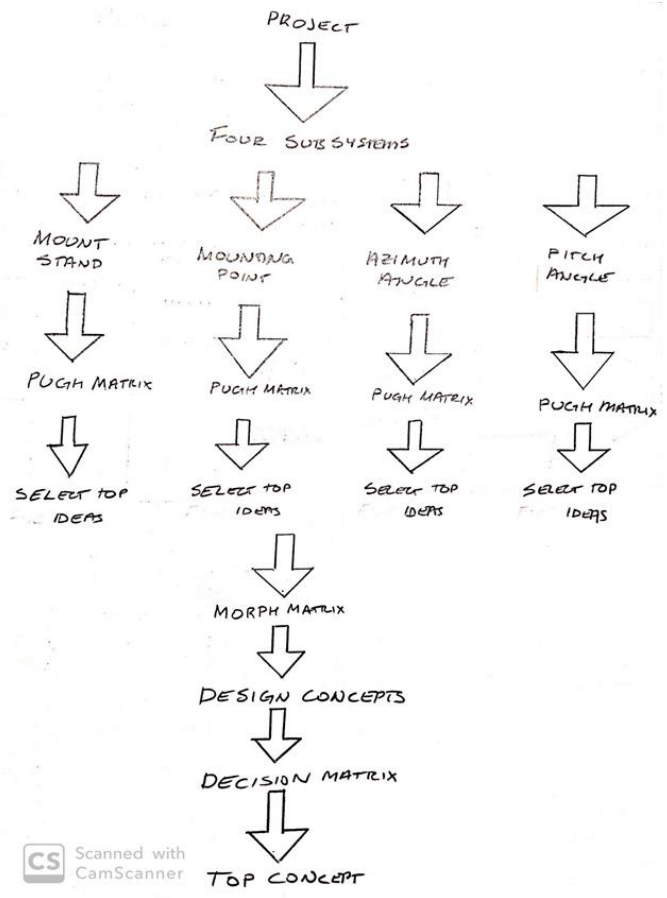
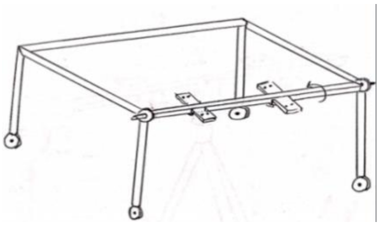
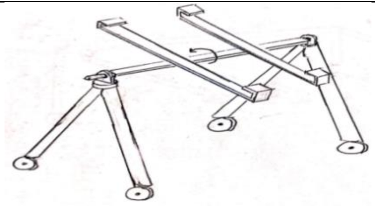
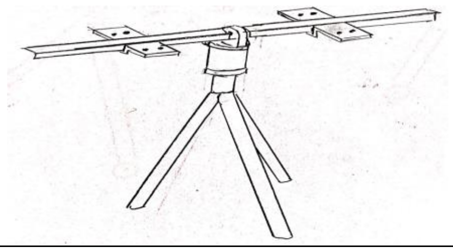
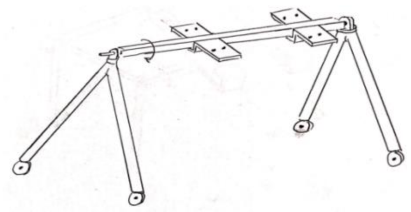
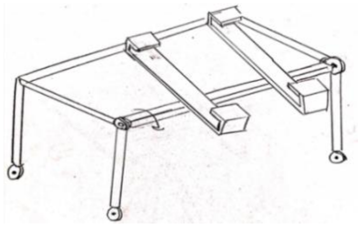
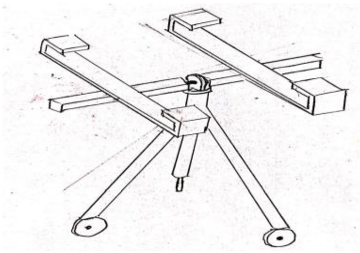


Figure 6. The step by step process taken to reach the final design concept.

4.2 Final Design Selection

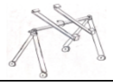
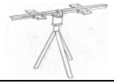
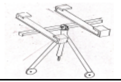
The top six designs shown in Table 3 were constructed based upon the top designs that came out of our Pugh matrices. Nine total components were selected from the Pugh matrices. Three stands, two changes in tilt angle, two changes in azimuth angle and two methods of mounting.

Table 3. Top Six Final Design Ideas

Design 1: This design utilized a large rectangular base with a rotating bar in the front for tilt, and wheels to adjust azimuth. The panels would be secured in place by several brackets that would mount to the back of the panels.	
Design 2: This design has an A-frame base that ensures stability, resembles a sawhorse design, and large clamps to fasten the panel to.	
Design 3: This design is a single tripod for a base. The legs are stationary, and the azimuth adjustment uses a large bearing as opposed to wheels. The mount bracket is the same from Design 2.	
Design 4: The design to the right has the same configuration as Design 2 being that it contains an A-frame base and rotating bar. The change from Design 2 is the connecting application from the system to the panel.	
Design 5: The frame design resembles Design 1 with the panels being secured in place by large clamps that allow for adjustability. The system has incorporated design ideas from Design 1 and Design 2.	
Design 6: The tripod base is used again; the bearing has been swapped for wheels and the panel fastening utilizes a clamping system.	

The six designs were then put through a decision matrix to establish a final design. We chose 11 factors referencing the House of Quality and Pugh matrices as they were still important to consider. Ease of use, ease of adjustment, and range of motion has been added at this stage since the Scope of Work. The weighted scale represents how important each factor is with one being least important and five being very important. Next, each design is ranked from 1-3, three being the design accomplishes the factor very well, and a one being the design doesn't accomplish the factor at all. Once ranked, the score is multiplied by the weight, then added together to determine the top design.

Table 4. Final decision matrix used to select final design concept

Decision Matrix							
Factors	**Weighted Scale**						
Cost	1	1	1	2	2	1	1
Reliability	4	2	1	2	3	1	2
Manufacture	3	1	2	1	2	1	1
Weight	3	2	1	3	2	1	2
Aesthetic	2	2	1	3	3	2	3
Ease of Assembly	4	2	2	1	2	2	1
Ease of Adjustment	5	3	2	3	3	2	2
Range of Motion	5	3	1	2	3	1	2
Durability	3	2	3	1	2	3	1
Mobility	5	3	2	1	2	2	3
Total		81	58	65	86	57	66

Our team agrees with the decision matrix that the sawhorse design would best fit the project requirements. This design scored well across all factors and can be manufactured within the timeframe of this project. A simplified CAD model was created for better understanding of design size and shape shown in Figure 7. The model also provides an idea of panel size relative to the mounting mechanism. The mounting system has been broken-down into four critical subsystems: the support frame, the rotating bar, the brackets and the gearbox/crank system.

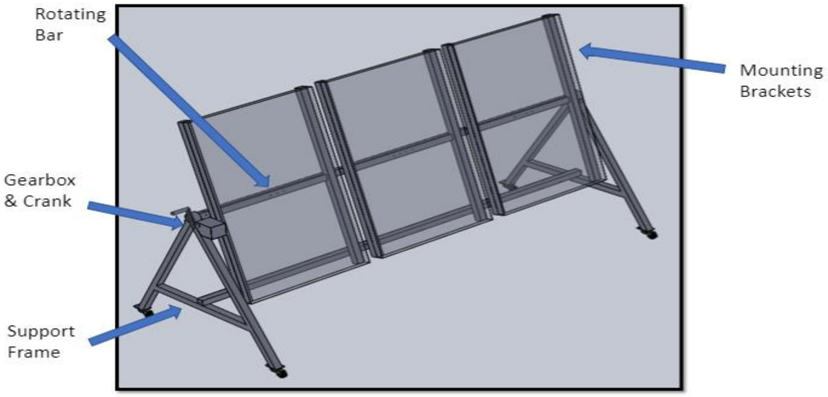


Figure 7. Isometric CAD of Initial Design Concept.

4.3 Support Frame

From the Pugh matrix and design matrix, the best support frame mimicked that of a sawhorse. This helped us limit material usage as the top converges at a single point where the panels rotate about. As shown in Figure 7, the support frame consists of two A-frame designs with a connecting bar in the middle. Although the system would stand without the long bar connecting the two, it was found during prototyping that it gave necessary support while moving the design, as the rotating bar would deflect without it. To rotate and move the system, caster wheels[4] will be placed on the bottom of the A-frame. This will also be the mechanism to rotate the azimuth. To mount the rotating bar, two bearing holders will be manufactured and mounted at the tip of each A-frame.

Size: It was established that the height would need to be a minimum of 3.3 feet off the ground to clear the largest panels. For stability reasons a large base was desired, and an interior angle of 60° was chosen. This required that the leg of the A-frame be at least 3.8 feet. For clearance and the sake of working in round numbers, a final length of four feet was decided upon.

Material: We have decided that Aluminum bar would be the best material to construct the support. Although it has less strength than steel, the maximum weight of the system will be considerably lower with aluminum. As well, since the design will be outside much of its life, the aluminum will corrode at a much slower rate than other materials.

Manufacturing: The aluminum bars will be cut to length and welded together, the bearing holders will be machined, and then welded to the top of the A-frame.

Concerns: Aluminum is very difficult to weld and would either require significant practice or professional assistance. We will consider asking Kevin Williams, the Cal Poly welding instructor, to help us with this task. Furthermore, the bearing holder will take significant time to manufacture and some form of protection from the elements will need to be designed for the bearings.

4.4 Rotating Bar

The rotating bar provides a method of adjusting the tilt of the panels. It will be supported on both ends by bearings with a few inches extruding through one of the bearings to provide a location for the gearing/crank system used, which will be explained in greater detail in section 4.6.

Size: A square bar approximately 10 feet in length will be needed to hold the panels. The length was determined by the width of each of the panels (three feet a piece). The clearance between each panel and the bearing holders will be approximately one inch. The square cross-section was determined by the mounting method. A bracket on a circular cross-section rod may not provide enough clamping force to keep the panel from slipping on the rotating bar. The square bar design eliminates that possibility.

Material: The optimal material will likely be steel as it is weather resistance and has high strength.

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[4] Undriven, multidirectional wheel, similar to those on the front of shopping carts.

Manufacturing: Stock material will include a 10-foot square hollow bar, and two 10-inch solid rectangular bars. The solid bars can be turned down on one side into a circular cross section. The square end can be inserted into the hollow square bar, and then welded together to act as an adaptor piece with the circular end being inserted into the bearing.

Concerns: Using a steel bar will be very heavy. A 1”x1”x10’, 1/8” thick bar weighs about 35lb. This, along with the weight of the panels, will add to the deflection of the bar. The more the bar deflects, the more difficult it will be to change the tilt angle leading to a shorter lifespan on the bar.

4.5 Mounting Brackets

Separate brackets will be machined to configure with residential and commercial panels. The bracket will be fastened to the panel using the preexisting bolts in the corners of the panel. Then four holes on the horizontal member of the bracket will line up with holes on the rotating bar to complete the mounting system.

Material: The bracket will be made of aluminum.

Manufacturing: The bracket dimensions will correspond with panel dimensions. Then, the vertical components of the bracket will be welded to the horizontal components. Finally, four holes in the horizontal and four holes in the corners need to be drilled.

Concerns: Bolt shearing will be analyzed and tested; however, this is not expected to be an issue with the panels being loaded on the rotating bar at their center of mass.

4.6 Gearbox and Crank

A gear system will be implemented to precisely adjust the tilt of the panels. It will require a high gearing ratio such that the bar moves in small increments for each turn of the hand crank. The hand crank will be able to lock at several points using a pin on the crank and hole on the frame, thus locking the entire mechanism. The hand crank will be locked every quarter turn which will correspond to a single degree change on the panel.

Size: The ratio will be very large and could consist of two or three gears. This will allow for accurate tilt angles. Gear size will dictate the overall configuration of the gearbox housing.

Materials: Premade steel gears will be used with aluminum housing.

Manufacturing: Components will be purchased off the shelf and then assembled.

Concerns: We are now adding a system that will need to be lubricated and requires high tolerance fitting. It will be time consuming and difficult to manufacture.

4.7 Analysis and Testing

To prototype our design, we constructed the supports and bearing holders out of 2” x 4” wood beams. The rotating cross bar was modeled as a PVC pipe. Figure 8 shows the completed sawhorse prototype.

Figure 8: Structural Prototype

As stated in section 4.3, when moving the mount, the supports would separate from each other and the PVC pipe would deflect. To solve this, we added the connecting bar at the base. This solved the deflection issue but now limits our range of motion. Fortunately, our tilt angle requirements were between 15°-90° and the added bar now limits it from 5° to 175°. Furthermore, it was discovered that the bearing holders and our method of mounting them would act as a weak point in our system. To correct for this, we decided that manufacturing our own holder and welding it to the final design will be our best option.

To better understand the loads we are working with, a free body diagram was drawn of the support to obtain a better understand how the loads would be distributed, for reference see Appendix C. Given the size of the panels, each leg of the system will not need to hold greater than 100 lbs. This calculation will also dictate the size of caster wheels necessary.

Under full loading, strain analysis determined the beam would deflect 1.75” at the center of the rotating bar if it is made of solid 1” x 1” steel. This is unacceptable, so we looked at increasing the size of the beam to 1.5” x 1.5”. This reduced the deflection to .88”, which is still far too great. At 2” x 2”, the deflection is only .43”, which is more acceptable, but the weight of the bar would be considerably large at that point. We will continue to look for a proper medium. Calculations can be viewed in Appendix C.

4.8 Safety Concerns

The greatest concerns for the system are large rotating masses and pinch points. Since the system will support large rotating panels, it is imperative that a certain perimeter is set. This acts as a restriction zone to prevent any user or viewer from obtaining bodily harm during operational use. Pinch point concerns are factored in because of the rotating gears and panels at the point of the A-frame intersection. The gears will be encased in a box to meet that concern, but the user must be aware that the panels can pinch or crush body parts when entering the interior frame of the system. Appendix D assesses significant design hazards and our plan for corrective action.

5.0 Final Design

The final design incorporates pre-existing solutions, sponsor feedback, and stress calculations of critical components in the system. For simplicity purposes, the design was intentionally driven away from electrical circuitry and complex software programs. The solution uses proven mechanical concepts and an array of mechanical components such as gears, bearings, fastening methods and simple beams. All beam components will be made up of carbon steel and stainless steel, while the gear assembly is a combination of iron and carbon steel. All custom components and assemblies have been included in the drawing package (Appendix F).

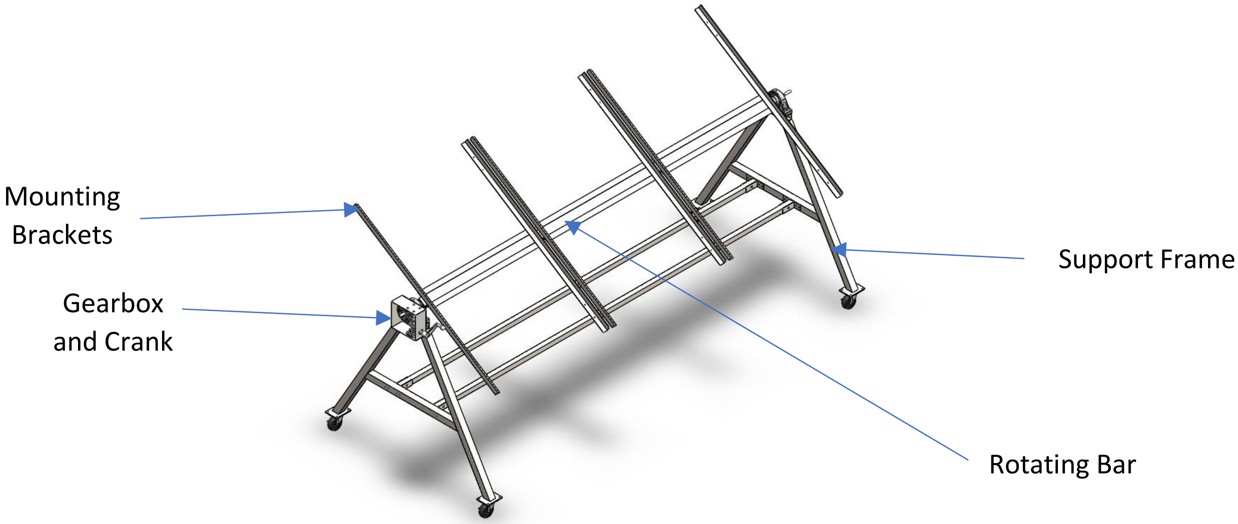


Figure 9: Isometric CAD Final Design

As previously mentioned, the design is broken into four critical subsystems: the support frame, the rotating bar, the mounting brackets, and the gearbox/crank system.

5.1 Support Frame

The support frame has remained largely unchanged since the conceptual design phase. Minor changes include the addition of a second support beam spanning the bottom of the frame and a short rectangular tube on top of each A-frame to fasten the pillow bearings too.

Figure 10: Isometric CAD Frame

The second support beam was deemed necessary to reduce twisting of the frame if a large impulse was applied to one side of the frame. The 1.5” x 1.5” horizontal bars will be fastened to the interior faces of the A-frame using T-joints. The A-frames are assembled from 2” X 2” x 1/8” carbon steel square tubing. The weight applied at the top of each A-frame is well under the tensile strength for carbon steel and is not a critical failure component of the system. After consulting with our sponsors, Dr. Belanger and Dr. Davol, a conclusion was reached that it was not required to conduct any further deflection or stress analysis on the A-frame assembly. At the top of each A-frame, a 6” long hollow rectangular tube made of 2” x 2” x 1/8” steel will be mounted which will allow the pillow bearings to be bolted on top. The hollow tubing will be capped on each side using 2” x 2” plastic end caps to enclose the fastening system in the tube. This portion of the A-frame was changed from the initial design of a flat plate due to an interference with the bolts and the legs of the A-frame. The interior angle of each A-frame will be positioned at a 60-degree resulting in a base length of approximately 4’. The overall purpose of the frame is to support the rotating bar and give the design durability.

5.2 Rotating Bar

The rotating bar remains largely unchanged as well. The main difference is an increase in size from 1” to 2-½" carbon steel square tubing and a wall thickness from 1/8”. With the tube steel increasing from 1” to 2-½", the interior bar that connects the end of the tube steel to the bearing was increased from 3/4" to 2-¼" to allow the interior bar to fit snug on the interior wall of the 2-½" x 2-½" steel tubing.

Figure 11: Isometric CAD Rotating Bar

After multiple discussions with faculty in both the Mechanical Engineering Department and Industrial Manufacturing Department, it was agreed that the beam required an increase of both thickness and width. Preliminary designs only considered the weight of the panels and panel fixtures without the addition of any wind loads. We now conclude any deflections during high wind loads will be manageable as shown in our hand calculations located in Appendix G. Significant deflection of the rotating bar for long periods of time may move the bearings out of eccentricity and would thus need to be replaced. The performance of the system is driven by the rotating bar, so the total weight was increased in order to allow for the load performance and safety to increase. The bar will have nine through holes, 3/8" diameter drilled along the top and bottom to interface with the mounting brackets to allow the panels to be fastened to the bar.

5.3 Mounting Brackets

The mounting brackets have been significantly modified to better interface with the rotating bar. The new design incorporates “angle iron” carbon steel to slide over the rotating bar and provide two points of contact. This was done to reduce the moment on the bolts when the panels were in the upright position.

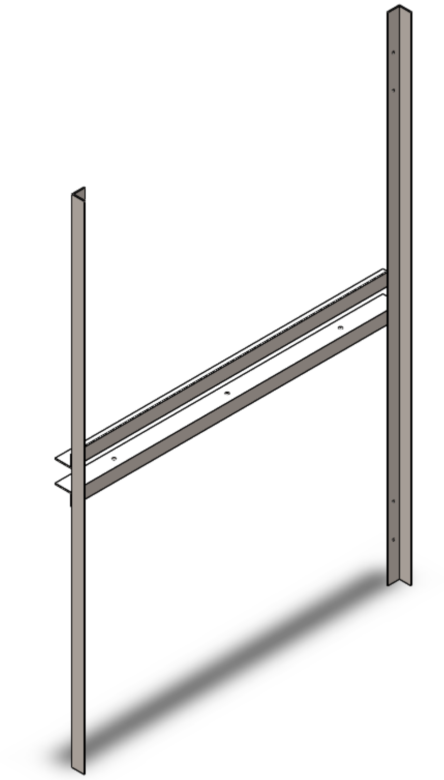


Figure 12: Isometric CAD Mounting Brackets

These two angle iron beams are welded to 1” x 1” x 1/8” square tube steel which span the vertical distance of the solar panel. The 1” tube steel is then bolted to the panel using the pre-existing holes in the back of the panel.

5.4 Gearbox and Crank

The Gearbox is completely redesigned. Initially the gearbox used two spur gears with a large ratio to achieve the one-degree resolution that our sponsors desired. However, the larger gear would need a minimum of 120 teeth to get close to this ratio. This gear would be expensive and excessively large.

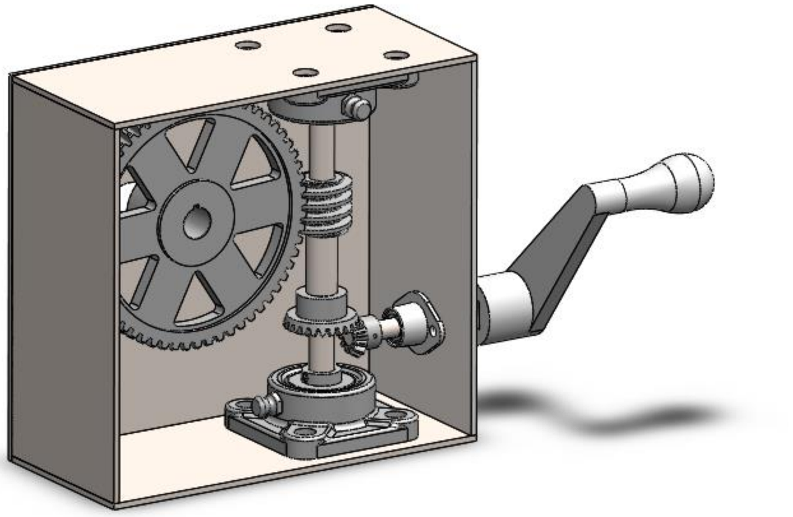


Figure 13: Isometric CAD Gearbox and Crank

As an alternative, a worm and spur gear were implemented. With this setup alone, we could achieve a 60:1 gear ratio in a space of roughly 6” x 6” x 2”. The worm gear would also be a self-locking system. Unfortunately, this would leave the hand crank needed to turn the gear at an awkward angle and would still only provide a one-degree resolution per sixth of a turn. To fix this a bevel gear was implemented with a 2:1 ratio. This lined up the hand crank shaft parallel to the rotating bar and would now give us an overall ratio of 120:1, a far more acceptable resolution. The box to hold the system will be 8” x 8” x 4” and all six sides will be laser cut from 1/8” thick sheet metal. The worm gear and the large bevel will be mounted on the same shaft. This shaft will be supported by two face bearings on each end that will be bolted into the top and bottom plate of the frame. The shaft will be driven by the bevel pinion connected to the hand crank. This shaft will be supported by two roller bearings bolted to the side of the box. A hole will be drilled in the back plate to allow the shaft from the rotating bar to enter the gear box. The spur gear will be mounted to this shaft and will be driven by the worm gear. During prototyping we found that press fitting on the gears would not provide enough friction force to drive the system. As a solution, it was decided that each gear would need to have a keyway and each shaft a keyset, and a set screw when necessary. For a detailed explanation of keyway and set screw connections refer to the Manufacturing Plan, Appendix I.

5.5 Maintenance and Repair

The system has been designed for easy disassembly and reassembly. This was essential considering the size and weight of each component within the design. Each component can be taken off the assembly and routinely inspected to ensure proper function and safety. Exterior components will be coated in an anti-corrosion epoxy, spray, or paint. Given our system will remain outdoors and the large amount of carbon steel, the potential for rust will be high. WD-40 Dry Lube PTFE spray coating is commercially available and easy to apply. We would recommend routinely reapplying when visual inspection shows the coating begin to wear. The FMEA and Design Hazard Checklist have been updated to reflect the final design as shown in Appendix H and Appendix D.

5.6 Cost Analysis

The total cost of the design is expected to be roughly $1500. The most expensive aspect of the design is the gear box as the gears alone account for almost half of the project budget.

Table 5. Estimated Cost per Subsystem

Subsystem	Estimated cost
A-frame/Support Bar	$558.84
Rotating Bar	$292.28
Mounting Brackets	$152.07
Gear and Crank	$487.06
Total	$1490.26

The pillow bearings and casters were both among the most expensive parts given their importance to the design and unique features. The total cost of the design was roughly 15% under our budget of $1800 set during the initial design phase. Full analysis of each part and its associated price can be found in the Bill of Materials, Appendix E.

6.0 Manufacturing Plan

Our team has chosen to manufacture a prototype of the gearbox and crank for the concept prototype as shown in Figure 14. This section serves as a brief overview detailing where we chose to source components and any expected complications. Detailed manufacturing plans for all four subsystems can be found in Appendix I.

6.1 Procurement

The gear box components will be purchased from a variety of different companies. The bevel gears, worm gear, worm specific spur gear and all bearings will be purchased from McMaster Carr since the company's components are all dimensioned out and can be input directly into our modeling programs to verify workability. Metals Depot is the company where we will be purchasing the sheet steel for the frame of the gear box because of their ability to order specific dimensioned material at an affordable price. All the hollow tube steel, solid steel, and angle iron steel will also be purchased from Metals Depot since they have all the necessary steel we need and prevent increase cost due to shipping and lead time. For convenience, all nuts, washers, bolts, and screws will be purchased from a local hardware store.

6.2 Manufacturing

Each steel member will be cut and have the holes drilled out inside of the Hanger or Machine shop at Cal Poly to ensure safety, time management, and guarantee that each necessary blade/machine will be available during the process. Using these shops also ensures that there is the proper cutting fluid to lower the risk of damaging the steel parts. The vertical member that will be placed on the inside of the gear box that have the worm and bevel gear fastened to them need to have a keyseat input on the outer diameter of the shaft. With so many shafts rotating that have gears fastened on them, it requires that each gear (excluding the worm since it already has one) have a keyway broached to the same desired thickness as the keyseats to ensure the gears do not slip on the shafts while in operation. This process will be done inside of the Industrial Manufacturing Building (Grant Brown Building) because of the required machinery that is needed. It has already been verified through Professor Trian that he possesses each vital broach size for the gears. Our only portion of the design that will be outsourced is the welding portion. It will be outsourced to a friend of two group members that has 10+ years of experience in welding and does it for a living. The welded components will include the support frames, mounting brackets, rotating bar inserts, and gear box frame as all are major components that cannot afford to be poorly welded by an inexperienced group member. The gear box welds are the most important part of the design to ensure the box is completely square for the gearing and the welds are sealed entirely to prevent the outdoor conditions from weathering the bearings and gears (see Appendix I for manufacturing plan).

6.3 Assembly

The assembly of the design will be systematic to ensure the proper fitting of all necessary components, fittings, and mating components. Each A-frame has two wheels mounted to the bottom of the frame. With a rotating bar that will have turned down pegs inserted into the pillow bearings located on top of the A-frame assembly. Next, it is critical that two support beams are pinned into the horizontal portion of the A-frames spanning from frame to frame to improve the structural integrity of the design and remove the possibility of the design racking or twisting while in use or during relocation. Bolt, washer, and nut assemblies will be used for these pinpoint locations to provide an easy method for fastening, removing, and tightening these intersections. The support bars will also eliminate the A-frames from flaring when loading the panels onto the rotating bar. Then, the gear box will be placed over the end of the rotating bar that has a smaller turned down peg sticking out of the bearing to allow for the rotating bar to be controlled by the gearing assembly on the interior of the gear box. Each solar panel will have their own mounting bracket fasten to the back of each panel to act as a mounting mechanism from panel to rotating bar.

7.0 Design Verification Plan

When weighing the importance of each subsystem, the gearbox and crank were deemed most essential to project success. This also allows us to verify three of the eight design specifications mentioned earlier. An accurate and reliable gearing system not only ensures functional success, but also significantly reduces risk of injury.

Figure 14: Structural Prototype – Gearbox Subsystem

The gearbox prototype can verify three of the original eight design specifications,

6. Demo survey - design must be operable by an untrained student
7. Time to adjust - tilt angle adjustment must be completed less than two minutes
8. Range of tilt – panels must tilt from 15° from vertical to 90° or horizontal.

For the demo survey specification, freshman from Dr. Davol's introductory course will be asked to rotate the dummy rotating bar to various angles during one of their lectures. Given the simplicity of the crank interface, untrained students should have no issues determining the correct crank rotation to panel rotation relationship.

The time to adjust will be tested by both our team and the primary users of the system, Dr. Davol and Dr. Belanger. We will test the time it takes to change the angle using a stopwatch and verify the time to rotate falls within our required two minutes specification. This is important because if the system cannot be rotated in a certain amount of time, then the system will not be able to capture the desired angle of the sun at given times of the day.

The last specification requires the gearing system to allow rotation from 15° to 90° with respect to a line normal to the ground. The gearing system allows for a full 360° of rotation but with frame constraints, the panels have adjustability of 330° from -15° to 15°. This was proven by visual inspections, hand calculations, and testing (Appendix J).

The other five specifications will be tested upon completion of the final design. This is because the other 5 specifications are highly dependent on the full assembly being built. Detailed verification plans for each specification to be confirmed after assembly can be found in the Design Verification Plan, Appendix K.

A list of design “wants” were also provided during the initial design phase. While not required, many of them can be verified with the gearbox prototype assembled. These include tilt angle adjustability by 1°, the ability for students to visually inspect gearbox functionality during use, and complete containment of rotating gears within the box. The gear ratio of 120:1 allows for 1° adjustability for every 1/3 turn of the crank (Appendix J). By keeping the front face of the gearbox transparent, faculty can ensure proper gear interactions and students can learn fundamental spur, worm, and bevel gear theory. Lastly, by housing all gear elements within the gearbox, pinch points and potential hazards are eliminated. The gear and crank subsystem are the primary use interface, so safety is especially critical.

8.0 Project Management

Upon submission of the Final Design Review (FDR), we have provided detailed manufacturing plans and an operators manual. These will assist our sponsors in manufacturing the design during Fall 2020. Figure 15 shows the ideal steps performed before FDR, however this timeline was altered due to social distancing restrictions. Manufacturing, assembly, and full system testing are all planned for Fall 2020 to be performed by our sponsors.

With the main parts already ordered for the design, the manufacturing process will begin in Fall 2020. The components that were used for the structural prototype gearbox are the same components that will be used in the final design. This decreases manufacturing lead time and reduces cost. Furthermore, using the same components for each design will ensure that our system functions properly by verifying dimension accuracy and ensure unforeseen safety hazards are dealt with accordingly.

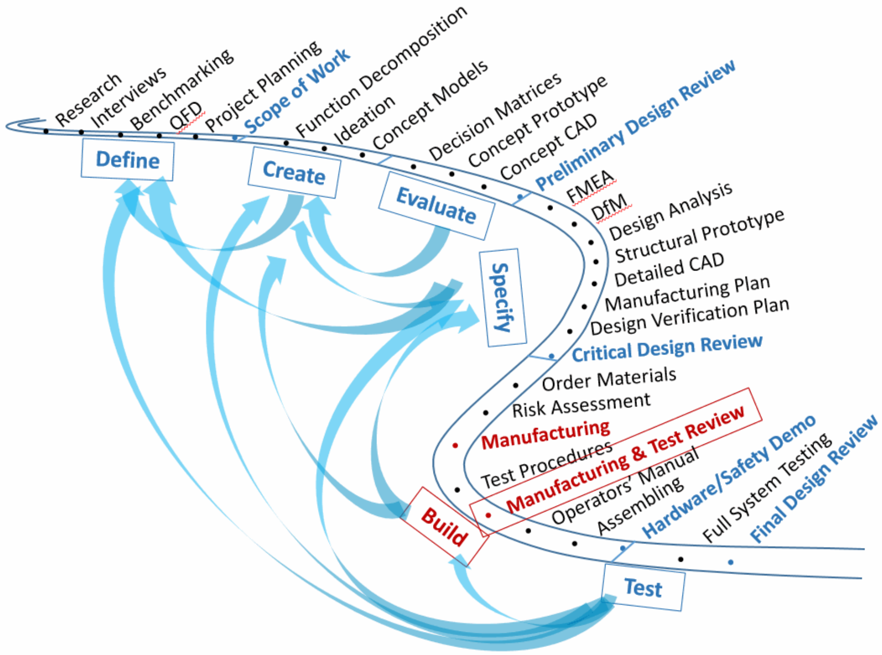


Figure 15: Design Process Timeline [11].

8.1 Key Deliverables and Timeline

To ensure the project was kept on track, the Cal Poly Senior Project program outlined several deliverables that were met in Table 6. Our final report presents the final assembly plans and test plans to our sponsors, students, and faculty.

Table 6: Key Deliverables and Timeline

Key Deliverables	Date
Critical Design Review Presentation	2/6/2020
Critical Design Review	2/7/2020
Manufacturing/Test Review	3/12/2020
Virtual Design Expo	5/29/2020
Final Design Report	6/4/2020

These deliverables are reflected in our Gantt chart, Appendix L. The next step is to begin the manufacturing phase of our design and verify that the design meets all desired requirements to meet the sponsor's requests. These will be supported with the use of Cal Poly shops and the assistant of outside sources.

9.0 Manufacturing

Due to COVID-19 and the stay-at-home orders from the state of California, our project timeline and ultimate goals of the project have been altered. Instead of completing manufacturing on site, this step of the process will be outsourced when it is deemed safe to do so. Testing is postponed until manufacturing is completed and the Cal Poly University is reopened.

9.1 A-Frame Work Done

The hollow tube stock of the frame support that came in at a length of 24' was cut down to two 12' members and the A-frame hollow tubing were cut to the correct lengths using a portable band saw, as seen in Figure 16. The 30-degree angle cuts to place the caster wheelbase plates and the 30-degree base for the tubing support for the bearing were cut using an abrasive cutting saw located in mustang 60 for the leg of the frame, part #210, as seen in Figure17. The horizontal tubing support of the frame were cut to length and angled at the necessary 30-degree cut to run flush with the horizontal support bar tubing, part #220. A hand file was used to remove the burrs on the edges of the tubing after using the abrasive cutting saw to eliminate the chances of obtaining a metal splinter or obstructing the proper connection between parts #210 and #220. The plates used to mount the caster wheels to the frame, part #241, were cut using a water jet after inputting the 3D model into a digital program to produce the base plate on the steel plate in Figure 18.

Figure 16. Cutting the Hollow Steel Tubing for the A-frame Legs Using A Portable Band Saw.

Figure 17. Cutting the Angles for the A-frame Leg Using an Abrasive Cutting Saw.

9.2 Rotating Bar Work Done

The only manufacturing step that was achieved in this step of our process was that we cut the solid square block of steel that are our inserts, part #311. The part was cut into two halves. This cutting process was done using a band saw.

9.3 Mounting Brackets Work Done

Using the abrasive cutting saw, the angle iron/L-bar steel, was cut to the length of 40”, part #410, which still allows for enough room for the user to be able to fit their fingers in between each panel when mounting the entire fixture to the rotating bar. This slight increase in size will not change the overall function of the system. The L-bar used to mount the panels, part #420, was cut to a length of 60” using the abrasive saw and had the ends of the sharp edges hand filed down to the safety of the user.

9.4 Gearbox Work Done

All components of the gearbox, parts #620-#623 were manufactured using a waterjet by transferring our drawing models into a program that executed the cut for our desired dimensions. The large spur gear, part #312, had a keyway broached into the inner circle of the gear with a dimension of 1/8” to allow for a key to be placed inside of the gear and required two shims to increase the depth of the keyway. Without the keyway, the large rotating bar would slip and not rotate upon applied force. A keyway was broached into the bevel gear that was 3/32” but will need to be improved in the depth of the broach because of the amount of force that will be applied to it when the gears are in motion. This bevel gear was part #632 and requires a shim to improve the depth to 1/16”.

Figure 18. Water Jet on Gear Box Frame and Base Plates for the Caster Wheels.

9.5 Support Beams Work Done

The T-joints, part #510, had four ¼" holes drilled in each joint using a drill press to widen the hole diameters that will be fastened to the horizontal members of the A-frame and prevent the system from racking. A ½" hole was drilled into each T-joint that runs perpendicular to the ¼" holes that fasten the supporting bars that span from one A-frame to the other A-frame.

Figure 19. Drill Press Widening the Holes on the T-joints For Larger Bolts to Fasten the Support Bars to the A-frame.

9.6 A-frame Work to be Done

The A-Frame support bar, part #220 requires the eight ¼" through holes to be drilled on both cross-bar members. View Appendix F to obtain proper hole positioning. These holes should be drilled using a drill press to ensure concentricity of the holes for the bolts to be fastened through them. The tube that is holding the bearing, part #232, requires the use of the abrasive cutting saw to cut the part to length and a drill press to input the holes for the bearings to be fastened to the frame, view Appendix F for more detailed information. **Note:** Hand file down any burrs that are produced from the material removal process to eliminate possible injure or interference.

9.7 Rotating Bar Work to be Done

The rotating bar, part #310, requires the use of the abrasive cutting saw to drop the length down from 12’ to 10’4”. Using a drill press, put the nine 3/8” through holes in the rotating bar that will have the mounting brackets fastened to them, see Appendix F for hole positioning. Mill the insert width, part #311, to the desired thickness to fit on the interior walls of the rotating bar so that the insert can fit flush against the walls. Be sure to rotate the inserts continuously after each pass on the mill to ensure that the part remains completely square or else it will have issues fitting flush inside of the rotating bar. After the piece has been milled down to the proper thickness, a lathe is required with a four-jaw chuck, to turn down the inserts to the desired diameter in Appendix F. Once the inserts are manufactured to the desired dimensions, mill out a keyseat to a depth of 1/16”, 1/16” wide, and a length of 1.25” on the smallest diameter cylinder of the insert that will be responsible for holding the spur gear. Cut the 1/8” x 1/16” key stock to a length of 1.25” so that it will fit flush into the milled-out keyseat. The key stock must be 1/8” in thickness to make sure that it fits into the 1/16” keyway and the 1/16” keyseat. If the dimensions of the keyway and keyseat need to be altered, it will be at the discretion of the sponsors because the necessary dimensions cannot be tested at the time of the final design.

9.8 Mounting Brackets Work to be Done

Using a drill press, four ¼" holes need to be drilled into all six pieces of part #420 for the solar panels to be able to be fastened to them, refer to Appendix F for hole positioning. Three 3/8” holes need to be drilled into each of the six pieces of part #410 to allow the mounting brackets to be fastened to the rotating bar, refer to Appendix F for hole positioning.

9.9 Gearbox Work to be Done

With the implementation of a lathe, part #641 needs to be turned down to the desired dimensions that are shown in Appendix F. A four-jaw chuck will be required to execute this manufacturing because of the bar stock having four flat surfaces. A setscrew is required in the small pinion gear, part # 642, because it is too small to broach without damaging the gear. Using a drill press, a hole with a diameter of 5mm will be drilled through to the center of the gear and then a tap will be needed to input a thread on the internal surface of the gear. There will also need to be a flat surface on the cylindrical face of part #641 to allow for the set screw to flush up against it, which will use a mill to do so. Use a cold saw to shorten the steel shaft to the desired length. After it is cut to length, use a lathe to turn down the shaft to the desired diameters that will allow for the worm gear, part #631, and bevel gear, part #632, to fit tight on it. There should be no tolerance on the shaft to the gears so that the gears do not slip vertically while the gears are in motion. Once the shaft has been turned down to the proper diameter, use a mill to plunge a keyseat into the shaft to allow for a key to be inserted into the seat that will lock the worm gear to the rotating shaft, refer to Appendix F for proper dimensions. The keys that will be cut out of the bar stock need to match the length of the keyways that have been plunged into the shaft. The last necessary step is to grind down the sharp edge of the front panel of the gear box, part #623, to reduce the chance of the user cutting or injuring themselves when they go to alter the inside of the gear box or if they accidentally slip while rotating the crank.

9.10 Supporting Beams Work to be Done

Cut the 24’ x 1.5” x 1.5” bar into two pieces at a length of 10’6” using an abrasive cutting saw. Once cut, this turns into part #520 and needs to have two ½" through holes drilled out using a drill press at the ends of each tube, see Appendix F for positioning. Drill a corresponding ½" hole in the tube fitting, part #510.

9.11 Welding Steps

Refer to drawing #200 for welding schematic and weld types

1. Part #220 to part #210, must be done twice because there are two legs and one on each side for the frame.
2. Part #232 to part #210, must be done twice because there is one on each A-frame.
3. Part #241 to part #210, four welds are necessary to place one on each leg.

Refer to drawing #300 for welding schematic and weld types

1. Part #311 to part #310 on both sides of the rotating bar

Refer to drawing #400 for welding schematic and weld types

1. Part #410 to part #400, there are six pieces for part #410 and #400, so it will need to be done at each point of connection for the H-frame.

Refer to drawing #610 for welding schematic and weld types

1. Part #621 to part #622, do the bottom plate to each side plate first, and then weld the top plate to the side plates.
2. Part #620 to part #621 and #622, important to place the backing plate on the box first to allow for the internal components of the gear box to be assembled.
3. Part #623 to part #621 and #622, the front plate is the last part of the gear box that needs to be welded on the box to ensure that the internal components of the box will fit properly.

10.0 Testing Plans

The testing plans that were expected to be conducted from the Design Verification Plan & Report for the PV Solar Array System before COVID-19 shutdown Cal Poly consisted of four different specifications being analyzed. The four tests that were selected are Time to Clean, Maintenance Time, Forces and Loads, and Time to Adjust. An updated Engineering Specification Table can be seen in Table 7 below.

Table 7. Updated Engineering Specification Table for the Final Design

Spec. #	Specification Description	Requirement or Target	Tolerance	Risk	Compliance
1	Weight	350 lbs. (Excludes Panels)	Max	L	A, I
2	Production Cost	$2000	Max	L	A
3	Time to Clean	20 min	Max	L	T
4	Maintenance Time	60 min	Max	L	T
5	Forces/Loads	90 mph winds	Max	H	T, A
6	Demo Survey	Operable by untrained student		L	I
7	Time to adjust	2 min	Max	H	T, A
8	Range of tilt	15°- 90°	Range	L	A

Specification 3: Time to Clean

Test Setup: Upon completion of the final assembly, the user will be asked to perform a routine cleaning of the mount. This cleaning will not require the user to disassemble the mount. The user will be given chemical resistant cleaning solution and cotton rags. Our team will use a stopwatch to time the process and verify the absence of fingerprints, smudges, and other residues on all steel parts. Estimated time to test is 1 hour.

Test Procedure:

1. Supply 1st team member with multipurpose steel cleaning solution
2. Have a 2nd team member ready with a stopwatch and tell the 1st team member to begin.
3. 1st team member will apply cleaning solution to all exposed surfaces on the mount
4. When completed, the 2nd team member will stop the stopwatch and verify cleaning

Equipment Needed:

1. Multipurpose steel cleaning solution
2. Cotton rags
3. Stopwatch

Specification 4: Maintenance Time

Test Setup: Upon completion of the final assembly we will verify the time to swap a panel is under the required 60 minutes. The user will be asked to dismount a singular panel and remove it from the mount fixture and rotating bar. Once completed, the user will remount the panel to the fixture and then mount the fixture back on the rotating bar. Once remounted it will signify the end of the test and the timer will be stopped. Estimated time to test is 2 hours.

Test Procedure:

1. Supply 1st team member with assembly procedure for mounting and dismounting panels
2. Have a 2nd team member ready with a stopwatch and tell the 1st team member to begin.
3. 1st team member will be required to dismount the fixture from the bar
4. Once completed, the 1st team member must also disassemble the fixture from the panel.

5. The 2nd team member will verify all components have been disassembled and allow the 1st team member to proceed.
6. 1st team member must reattach the panel to the fixture and then attach the fixture to the rotating bar.
7. When completed, the 2nd team member will stop the stopwatch and verify proper assembly.

Equipment Needed:

1. Assembly procedure for mounting/dismounting panels
2. Stopwatch

Specification 5: Forces/Loads

Test Setup: Once the final design for each subsystem is assembled into the final assembly then we will test for the deflection of our system. The process will consist of assembling the mounting system regarding each subsection. We will place each panel that the system was designed for on the rotating bar. Estimated test time is 4 hours.

Test Procedure:

1. *Place the final design* on the solar balcony of Cal Poly's campus fully assembled
2. Fasten the panels to the designate area on the rotating bar
3. Place four 45 lb weight plates on the rotating bar to simulate wind loads
    a. Separation between each plate will be 32" to simulate a distributed load
4. The plate will be held on the rotating bar using ropes spanning from each plate
5. A dial indicator will be used to measure the displacement of the entire system while accounting for the wind load
6. This test will be run with all four team members present to confirm the process
7. The maximum deflection that will be expected for the test will be a ¼" from the point of origin

Data Collection*:* Data will be collected for no wind conditions using only the 3 panels and no additional plates. The data will be collected in 3 runs, resetting the dial indicator after each measurement. This process will be repeated 2 more times at additional loads of 90lbs (2 plates) and 180lbs (4 plates) for a total of 9 data points in 3 scenarios. This is to mimic heavy wind loads and extreme wind loads.

Uncertainty Analysis: Uncertainty analysis was conducted using equation (1-1) to determine the reproducibility and validity of our data. The Bias is assumed negligible due to the simplicity of the test design. The precision was determined using the resolution of the dial indicator which will be ±.0005. Repeatability will be determined using the variability between our three tests. The total uncertainty will be the root sum square of these three variables.

$$u_{xm} = \sqrt{(B^2 + P^2 + R^2)} \qquad (1\text{-}1)$$

Equipment Needed:

1. 4 – 45 lb plate weights
2. 1 – dial indicator
3. 4 – pieces of rope

Specification 7: Time to Adjust

Test Setup: The concept prototype of the gearbox will be used to verify the panel tilt can be modified in under 2 minutes. Using the prototype gearbox, we will determine how long it takes to rotate the dummy bar from the minimum value of 15° to the maximum value of 90°. Estimated Time to test is 1 hour.

Test Procedure:

1. Instruct 1st team member on how to rotate crank.
2. Have a 2nd team member ready with a stopwatch and tell the 1st team member to begin.
3. 1st team member will begin gradually rotating the bar from its initial value of 15° and told to continue until the panel is horizontal.
4. When completed, the 2nd team member will stop the stopwatch and verify cleaning

Equipment Needed:

1. Stopwatch

10.1 Operators Manual

Once each component has been constructed, they will need to be properly and safely assembled. The processes we believe to be most optimal to assemble the system is outlined in Appendix N along with safety precautions when operating.

11.0 Conclusion

Our final design is the product of ideation, design selection tools, and engineering evaluation. A weighted decision matrix was used to emphasize important factors. The sawhorse design incorporated user feedback and satisfied design requirements most effectively. The problem statement and project scope are both considered and satisfied. The final design consists of steel framing, cast iron and steel gearing, and stainless-steel screws to ensure durability and prevent corrosion from damaging the integrity of the design. A structural prototype of the gearing mechanism was built to ensure functionality of this subsystem. Manufacturing has been delayed to Fall 2020 due to Covid-19. A detailed manufacturing plan and operator's manual were provided to our sponsors for when the project resumes. Lastly, the project was added to the Mechanical Engineering expo website for public review.

References

[1] Solar Electric Supply Inc., “Solar Panel Pole Mounts – Side Pole Mounting,” [Online]. Available: https://www.solarelectricsupply.com/solar-panel-mounts/pole-mounts. [Accessed: Oct. 6, 2019].

[2] Solar Electric Supply Inc., “Solar Panel Pole Mounts – Top Pole Mounting,” [Online]. Available: https://www.solarelectricsupply.com/solar-panel-mounts/pole-mounts. [Accessed: Oct. 8, 2019].

[3] Link Solar. “Solar Brackets Solar Panel Mounts,” [Online]. Available: https://www.flexible-solar-panel.com/solar-brackets/. [Accessed: Oct. 2, 2019].

[4] Harris, G. , Stephan, E. K. (2017). *Mounting Assemblies for Solar Panel Systems and Methods for using the same. United States Patent No. US 20170093327*. Retrieved from https://patents.google.com/patent/US20170093327A1/en?q=solar+energy&q=mounting&oq=solar+energy+mounting

[5] Chen, C. , (2007). *Double-Jointed Mounting for Solar Panel. United States Patent No. 20070084500*. Retrieved from https://patents.google.com/patent/US20070084500A1/en?q=solar+energy&q=mounting&oq=solar+energy+mounting&page=1

[6] Miros, Robert H. J. , Birmingham, M. , (2010). *Solar Array Mounting System. United States Patent No. US 20100089390.* Retrieved from https://patents.google.com/patent/US20100089390A1/en?q=solar+energy&q=mounting&oq=solar+energy+mounting&page=2

[7] Whipple, et al. (2010). *Balanced Support and Solar Tracking System for Panels of Photovoltaic Cells. United States Patent No. US 20100139645A1*. Retrieved from https://patents.google.com/patent/US20100139645A1/en?q=solar+energy&q=mounting&oq=solar+eneene+mounting&page=7

[8] Barsoum, Nader. “Fabrication of Dual-Axis Solar Tracking Controller Project.” Intelligent Control and Automation, vol. 02, no. 02, 2011, pp. 57–68., doi:10.4236/ica.2011.22007.

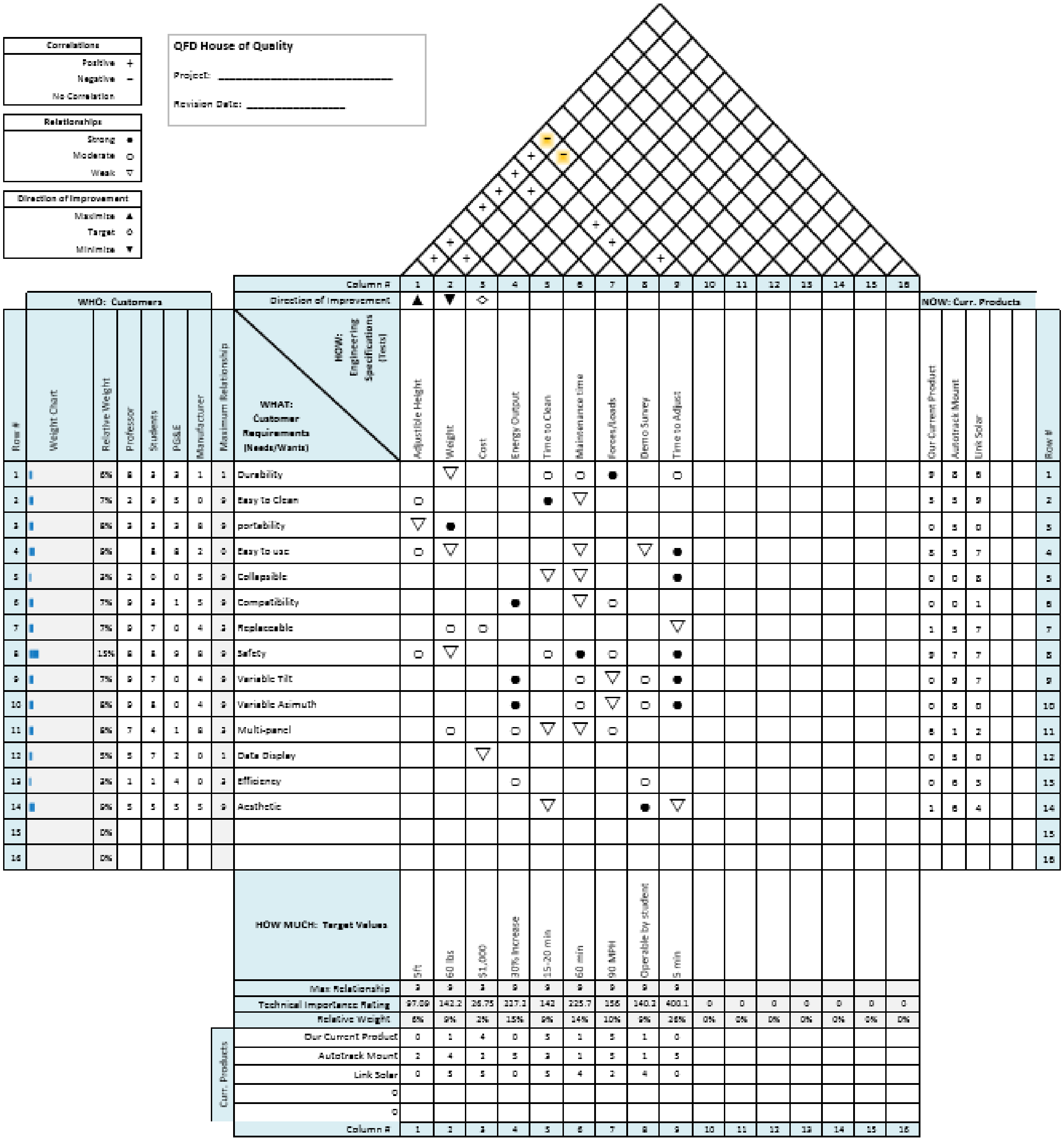
[9] Al-Naima, F.m., and N.a. Yaghobian. “Design and Construction of a Solar Tracking System.” Solar & Wind Technology, vol. 7, no. 5, 1990, pp. 611–617., doi:10.1016/0741-983x(90)90072-a.

[10] *California Building Standards Commission. California Building Standard Codes.* : Available: https://www.dgs.ca.gov/BSC/Codes. [Accessed: Oct. 1, 2019].

[11] Department of Mechanical Engineering. “ME Senior Design Project Student Success Guide” 2019. PDF file

Appendices

Appendix A: QFD House of Quality Table



Correlations	
Positive	+
Negative	−
No Correlation	

Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼

QFD House of Quality

Project: ______________________________

Revision Date: ________________

WHO: Customers

NOW: Curr. Products

Row #	Weight Chart	Relative Weight	Professor	Students	PG&E	Manufacturer	Maximum Relationship	WHAT: Customer Requirements (Needs/Wants) / HOW: Engineering Specifications (Tests)	Adjustible Height	Weight	Cost	Energy Output	Time to Clean	Maintenance time	Forces/loads	Demo Survey	Time to Adjust								Our Current Product	Autotrack Mount	Link Solar			Row #
								Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16						
								Direction of Improvement	▲	▼	◇																			
1		6%	8	3	3	1	1	Durability		▽			○	○	●		○								9	8	8			1
2		7%	2	9	5	0	9	Easy to Clean	○				●	▽											5	5	9			2
3		8%	3	3	3	8	9	portability	▽	●															0	5	0			3
4		9%		8	8	2	0	Easy to use	○	▽				▽		▽	●								8	5	7			4
5		3%	2	0	0	5	9	Collapsible					▽	▽			●								0	0	8			5
6		7%	9	3	1	5	9	Compatibility				●		▽	○										0	0	1			6
7		7%	9	7	0	4	3	Replaceable		○	○						▽								1	5	7			7
8		15%	8	8	9	8	9	Safety	○	▽			○	●	○		●								9	7	7			8
9		7%	9	7	0	4	9	Variable Tilt				●		○	▽	○	●								0	9	7			9
10		8%	9	8	0	4	9	Variable Azimuth				●		○	▽	○	●								0	8	8			10
11		8%	7	4	1	8	3	Multi-panel		○		○	▽	▽	○										8	1	2			11
12		5%	5	7	2	0	1	Data Display			▽														0	5	0			12
13		3%	1	1	4	0	3	Efficiency				○				○									0	8	5			13
14		9%	5	5	5	5	9	Aesthetic					▽			●	▽								1	8	4			14
15		0%																												15
16		0%																												16

HOW MUCH: Target Values	5ft	60 lbs	$1,000	30% Increase	15-20 min	60 min	90 MPH	Operable by student	5 min							
Max Relationship	3	9	3	9	9	9	9	9	9							
Technical Importance Rating	97.09	142.2	26.75	227.1	142	225.7	156	140.2	400.1	0	0	0	0	0	0	0
Relative Weight	6%	9%	2%	15%	9%	14%	10%	9%	26%	0%	0%	0%	0%	0%	0%	0%
Curr. Products: Our Current Product	0	1	4	0	5	1	5	1	0							
AutoTrack Mount	2	4	1	5	3	1	5	1	5							
Link Solar	0	5	5	0	5	4	2	4	0							
0																
0																
Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

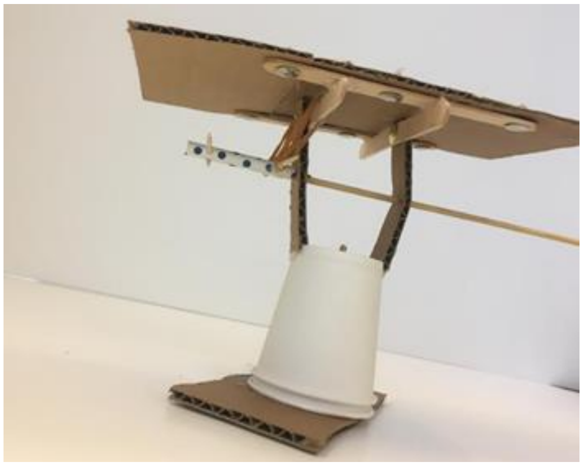
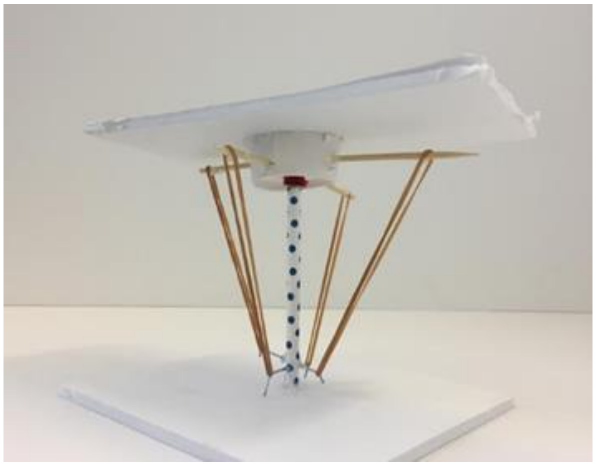
Appendix A references the House of Quality utilized in our QFD process

Appendix B: Ideation

Table 8. Concept Designs from Ideation

Mounting Stand	Azimuth Angle	Tilt Angle	Mounting System
• Tripod • Two Tripods • Rectangle • Sawhorse • Single rod in ground • Wide base with single rod	• Ball Socket • Gyroscope • Bearing • Wheels • Gearing system • Worm gear • Single point of rotation, rail going around • Motor on bottom • Build base like stepper motor	• Ball Socket • Knee Joint • Gyroscope • Piston on each corner • Rotating bar • Pretension system adjusted with string • Large spring • Something like bendy straws • Hinge • Suspended by adjustable cables • Foam that holds shape when pressed	• Zipper • Folded metal • Cables • Balance • Zip Ties • Claw Holder • Tie Downs • Belt • Adhesive • Magnets • Rope • Velcro • Press fit • Pins • Big Staples • Welding • Nuts and bolts • Spring • Rivet • Clamps

Table 9: Figures of Concept Designs from Ideation

 **Figure 20.** A concept model design for the tilt angle of the mount conducted during the concept prototyping. The panel rotates around the axial direction of the wooden stick with the rotation taking place at the straw/wooden intersection.	 **Figure 21.** A concept model design for azimuth angle. The wheel design allows the mount to rotate and eliminates the need of another axis.
 **Figure 22.** A concept model design showing a component for azimuth in the double cup design simulates a rotational axis, a mounting design that attaches the solar panel to the stand, and a tilt angle using the rubber band pulley system to adjust the tilt.	 **Figure 23.** The concept model design shows the tilt of the panels at the upper most point of the straw to allow the model to resemble a ball and socket joint.

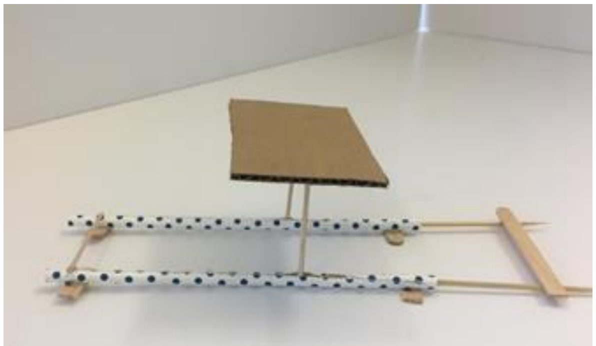


Figure 24. A model of the solar panel mounted on two sticks that simulate a panel angled directly parallel to the ground and pointed straight up toward the sun.

Figure 25. Fixed stand with three vertical bars and two horizontal bars holding three, same sized panels at a designated angle. This model only represents a way to fasten the panels down and does not solve the tilt issue.

Figure 26. A concept model that shows the bottom point of connection for the stand resembling a ball and socket joint that implements tilt and azimuth angle to the design.

Figure 27. A model of the solar panel mounted on two sticks that simulate a panel angled directly parallel to the ground and pointed straight up toward the sun.

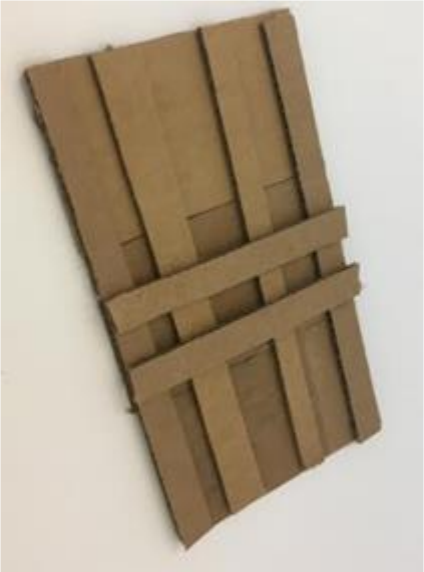


Figure 28. A concept model that shows one possible way to fasten multiple panels together with the cross bar acting as the mounting point to the stand.

Figure 29. A concept model mount that has an azimuth angle adjuster at the top perpendicular joint, the two-stick member inside the vertical straw allowing for rotational adjustment, and the double prong stick to fasten the solar panels to.

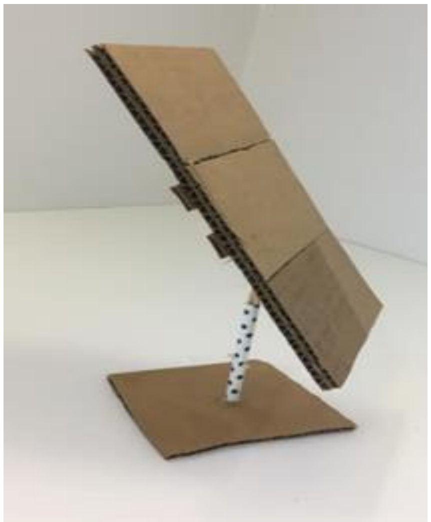
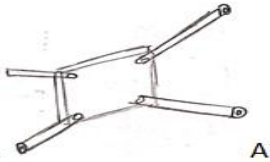


Figure 30. A concept model that shows the solar panels fixed on the mount.

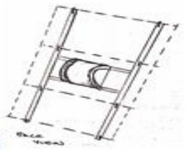
Figure 31. A concept model for the mount that has an azimuth angle adjuster at the top joint where the cork and tooth picks intersect, the two vertical stick members connected at each end with the bottom connection allowing for rotational adjustment, and the double prong stick to fasten the solar panels to.

Table 10. Concept Design Pugh Matrix for Mounting System Application.

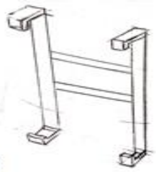
Design/Criterion	A1	A2	A3	A4	A5
Cost	+	+	+	-	-
Weight	+	s	+	+	+
Quality	s	+	s	-	+
Ease of Use	-	+	s	-	-
Maintenance	+	s	-	-	-
Durability	-	-	-	-	-
Safety	-	-	-	-	-
Mobility	+	+	+	+	+
Σ+	5	5	3	3	4
Σ-	2	1	3	5	4
Σs	1	2	2	0	0
Total	3	4	0	-2	0



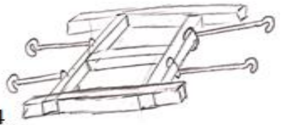
A1



A2



A3

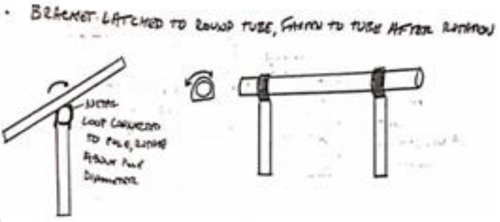


A4

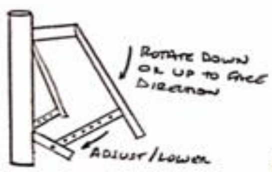
A5

Table 11. Concept Design Pugh Matrix for Tilt Angle Application.

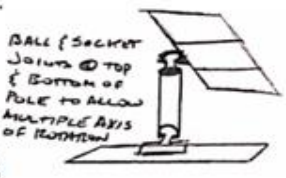
Design/Criterion	B1	B2	B3	B4	B5	B6
Cost	+	-	s	s	+	-
Weight	+	+	+	+	s	s
Quality	+	-	-	-	+	+
Ease of Use	-	-	-	-	-	-
Maintenance	-	+	-	-	+	-
Durability	+	+	+	+	+	+
Safety	+	s	-	-	s	+
Mobility	+	+	s	s	+	+
Σ+	6	4	2	2	5	4
Σ-	2	3	4	4	1	3
Σs	0	1	2	2	2	1
Total	4	1	-2	-2	4	1



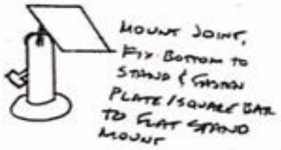
B1



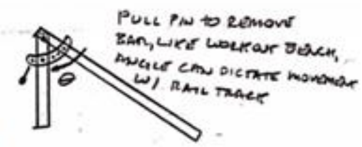
B2



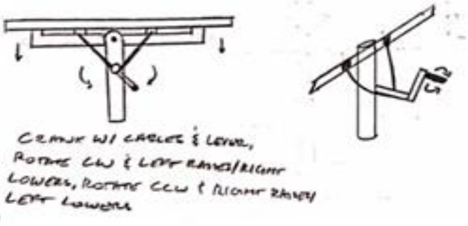
B3



B4



B5



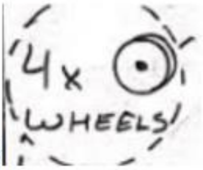
B6

Table 12. Concept Design Pugh Matrix for Azimuth Angle Application.

Design/Criterion	C1	C2	C3	C4
Ease of Use	+	-	+	s
Weight	+	+	+	+
Cost	s	-	+	-
Durability	-	+	+	s
Safety	s	+	s	-
Angle Adjustability	+	+	+	+
Mobility	+	-	-	+
Σ+	4	4	5	3
Σ-	1	3	1	2
Σs	2	0	1	1
Total	3	1	4	1

C1

C2

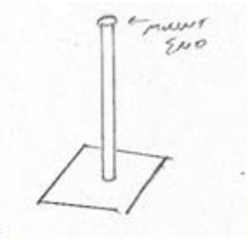


C3

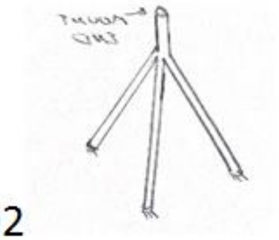
C4

Table 13. Concept Design Pugh Matrix for Mounting Stand Application.

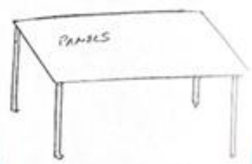
Design/Criterion	D1	D2	D3	D4
Stability	-	-	s	s
Weight	+	+	s	+
Durability	-	-	-	-
Mobility	+	+	+	+
Safety	-	-	s	s
Cost	+	+	+	+
Σ+	3	3	2	3
Σ-	3	3	1	1
Σs	0	0	3	2
Total	0	0	1	2



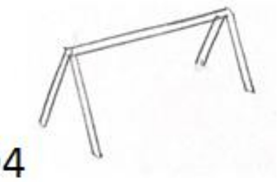
D1



D2

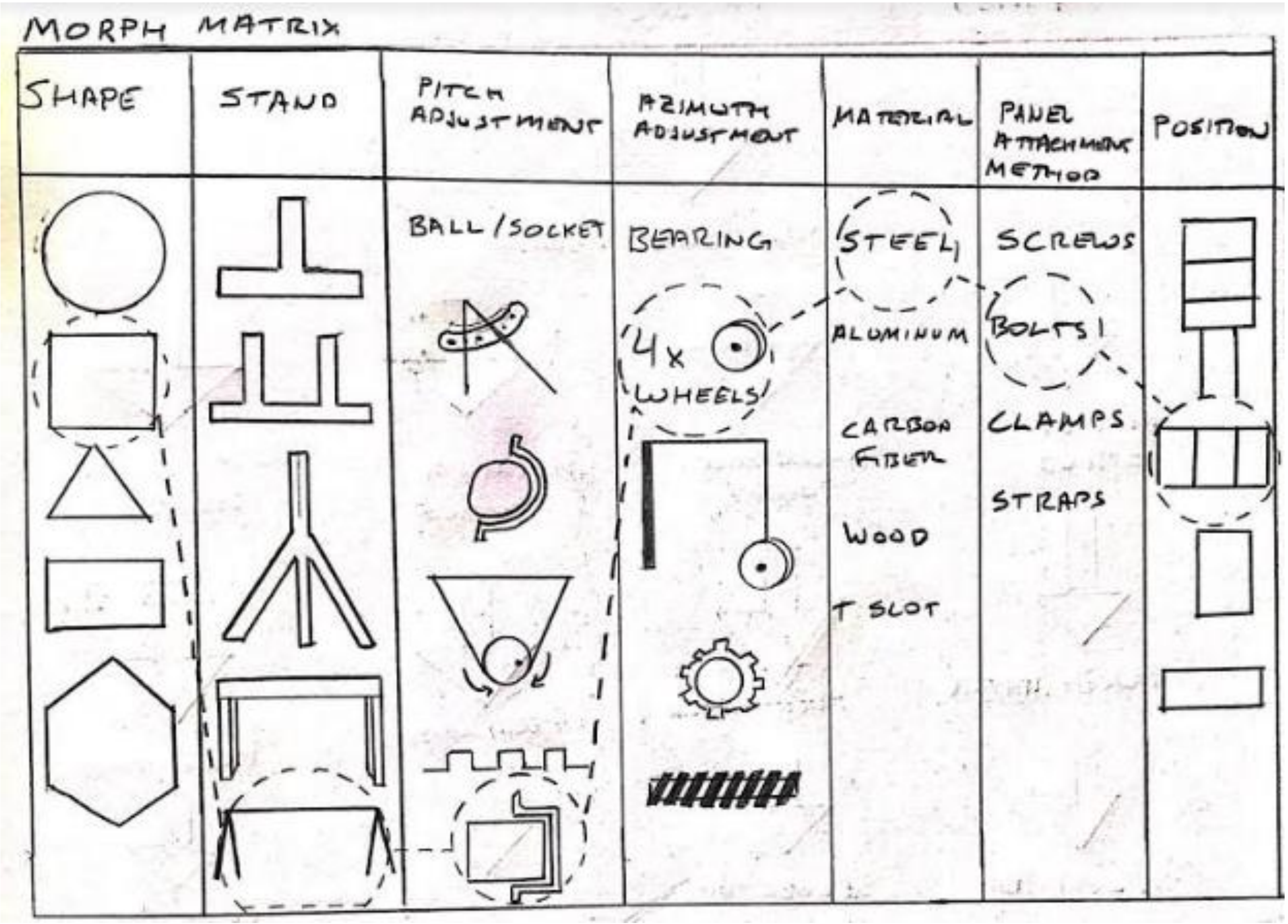


D3



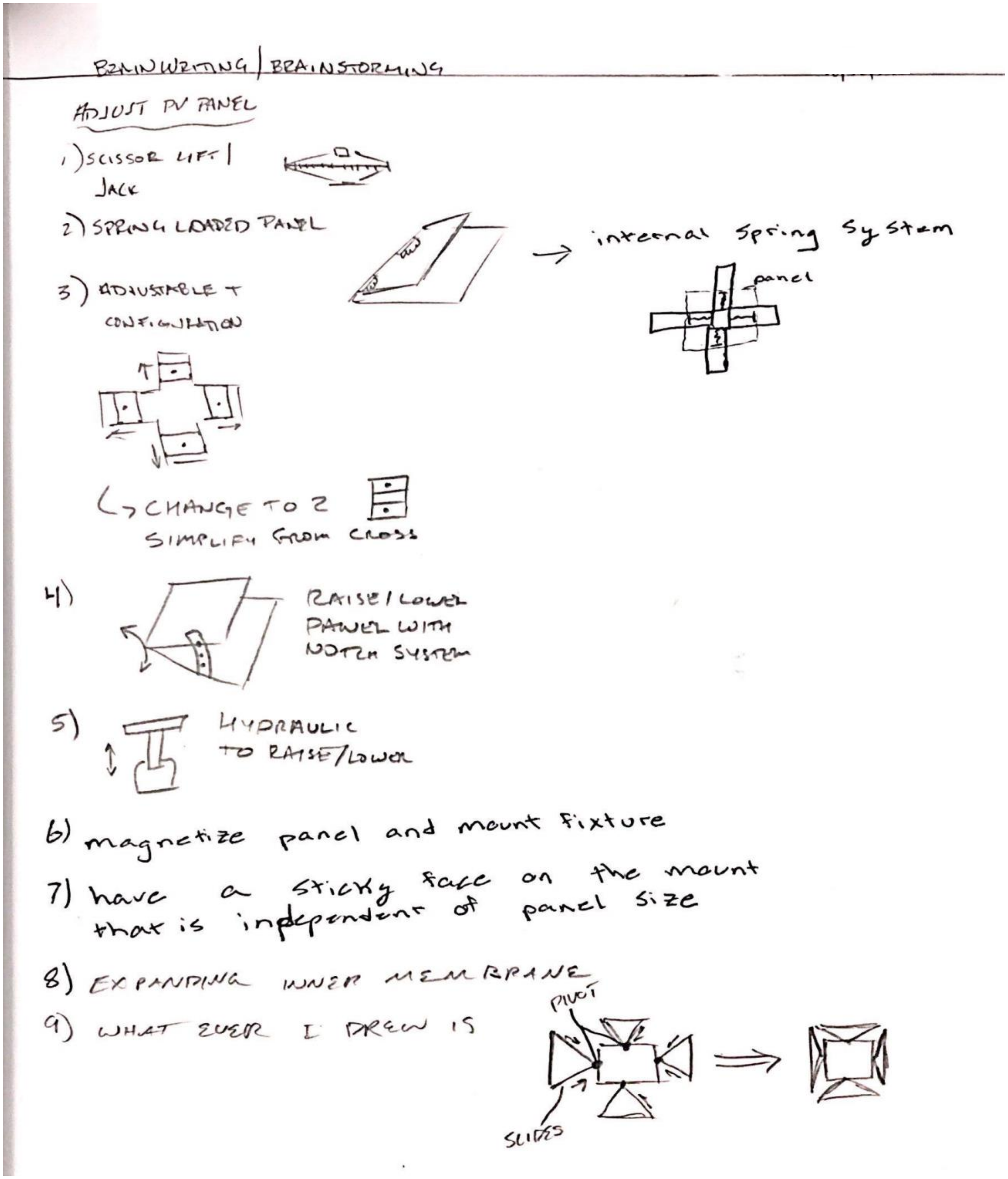
D4

Table 14. Morph Matrix



MORPH MATRIX

SHAPE	STAND	PITCH ADJUSTMENT	AZIMUTH ADJUSTMENT	MATERIAL	PANEL ATTACHMENT METHOD	POSITION
		BALL/SOCKET	BEARING	STEEL	SCREWS	
			4x WHEELS	ALUMINUM	BOLTS	
				CARBON FIBER	CLAMPS	
				WOOD	STRAPS	
				T SLOT		



BRAINWRITING | BRAINSTORMING

ADJUST PV PANEL

1) SCISSOR LIFT | JACK

2) SPRING LOADED PANEL → internal spring system

3) ADJUSTABLE T CONFIGURATION

↳ CHANGE TO 2 SIMPLIFY FROM CROSS

4) RAISE/LOWER PANEL WITH NOTCH SYSTEM

5) HYDRAULIC TO RAISE/LOWER

6) magnetize panel and mount fixture

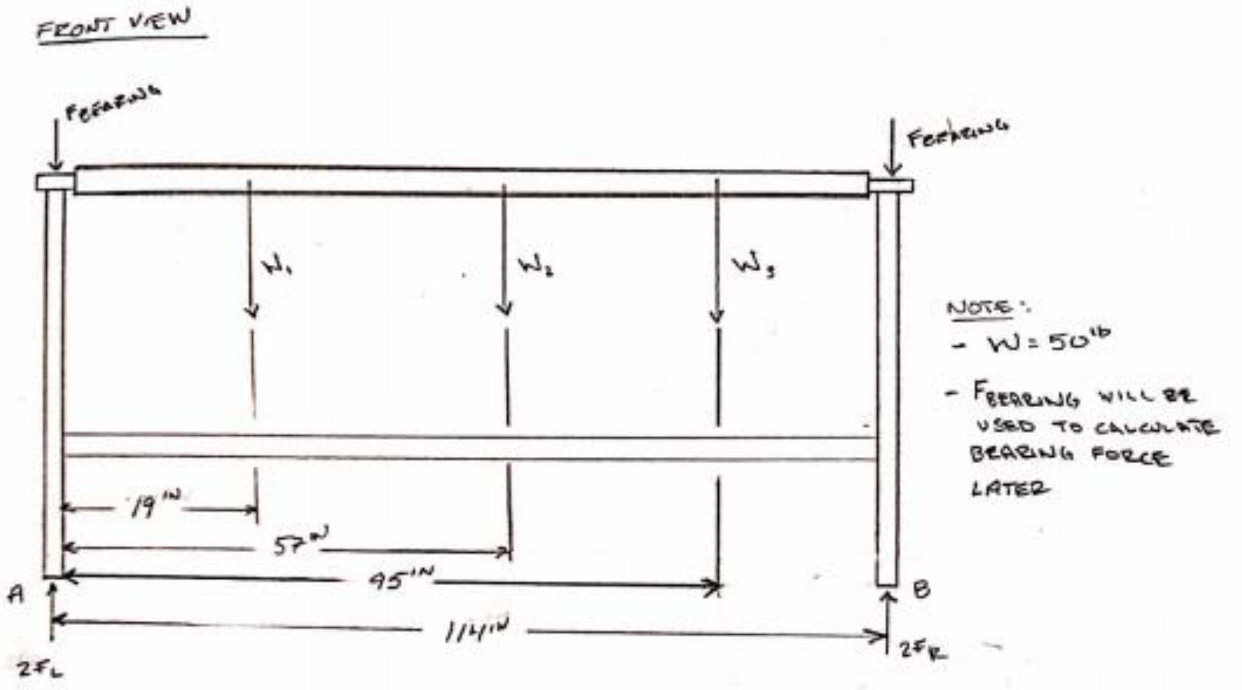
7) have a sticky face on the mount that is independent of panel size

8) EXPANDING INNER MEMBRANE

9) WHAT EVER I DREW IS

Figure 32. Brainwriting and brainstorming ideas

Appendix C: Free Body Diagram Analysis



ASSUME

1) MODEL AS RIGID BAR

2) $\Sigma M_A = 0$

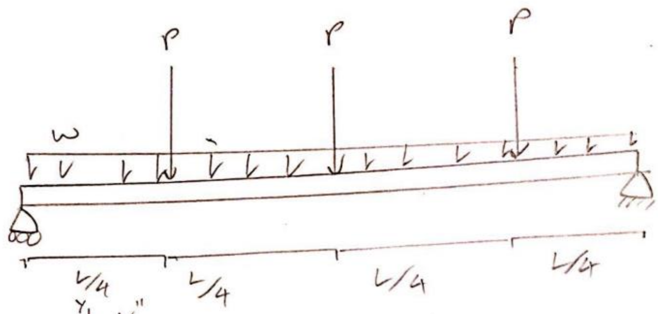
$$W_1(19") + W_2(57") + W_3(95^{IN}) - 2F_R(114") = 0$$

$$F_R = \frac{W_1(19") + W_2(57") + W_3(95")}{2(114")}$$

$F_R = 37.5^{lb}$ (EACH LEG WILL CONTAIN THIS FORCE)

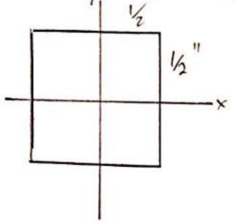
$F_R = F_L$ (4 LEGS)

Figure 33. Calculations for System Loading



$E_{STEEL} = 29\times10^6\ psi$
$E_{ALUM} = 10\times10^6\ psi$

$\rho_{STEEL} = 490\ lb/ft^3$
$\rho_{ALUM} = 173\ lb/ft^3$



$$I = \frac{bh^3}{12}$$
$$I = \frac{(0.042ft)^4}{12}$$
$$I = 4.0212\times10^{-6}\ ft^4$$

$L = 10ft$
$P = 40lbs$
$w_{STEEL} = 3.403\ lb\cdot ft$
$w_{ALUM} = 1.21\ lb\cdot ft$

FOR LOAD IN MIDDLE

$$Y = -\frac{PL^3}{48EI}$$

FOR DISTRIBUTED LOAD

$$Y = -\frac{5wL^4}{384EI}$$

FOR ASYMETRICAL LOADING

$$Y = -\frac{Pb(L^2-b^2)^{3/2}}{9\sqrt{3}\,EIL}$$

b is LENGTH FROM FAR END

BY SUPER POSITION

$$Y = -\frac{PL^3}{48EI} - \frac{5wL^4}{384EI} - \frac{2Pb(L^2-b^2)^{3/2}}{9\sqrt{3}\,EIL}$$

FOR STEEL

$$Y = -\frac{40lb\,(10ft)^3}{48\left(29\times10^6\frac{lb}{in^2}\left(\frac{12in^2}{1ft^2}\right)^2(2.512\times10^{-7}ft^4\right)} - \frac{5\left(3.403\frac{lb}{ft}\right)(10ft)^4}{384\left(29\times10^6\left(\frac{12in}{1ft}\right)^2(2.512\times10^{-7}\right)}$$

$$-\frac{40lb\left(\frac{10}{4}ft\right)(10ft^2-2.5ft^2)^{3/2}}{9\sqrt{3}\ 29\times10^6\frac{lb}{in^2}\left(\frac{12}{1}\right)^2(2.512\times10^{-7}ft^4)(10ft)}$$

$Y = -0.596in - 0.317in - .832in$

$Y = -1.745in$ FOR $b + h = 1"$

$Y = -0.88in$ FOR $b + h = 1.5"$

Figure 34. Calculations for Beam Deflection

Appendix D: Design Hazard Checklist

Table 15. Safety Issues Checklist

Y	N	
x		1. Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points?
	x	2. Can any part of the design undergo high accelerations/decelerations?
x		3. Will the system have any large moving masses or large forces?
	x	4. Will the system produce a projectile?
	x	5. Would it be possible for the system to fall under gravity creating injury?
	x	6. Will a user be exposed to overhanging weights as part of the design?
	x	7. Will the system have any sharp edges?
	x	8. Will any part of the electrical systems not be grounded?
	x	9. Will there be any large batteries or electrical voltage in the system above 40 V?
	x	10. Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?
	x	11. Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system?
	x	12. Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?
	x	13. Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
	x	14. Can the system generate high levels of noise?
x		15. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc?
x		16. Is it possible for the system to be used in an unsafe manner?
	x	17. Will there be any other potential hazards not listed above? If yes, please explain on reverse.

Table 16. Safety Hazard Description

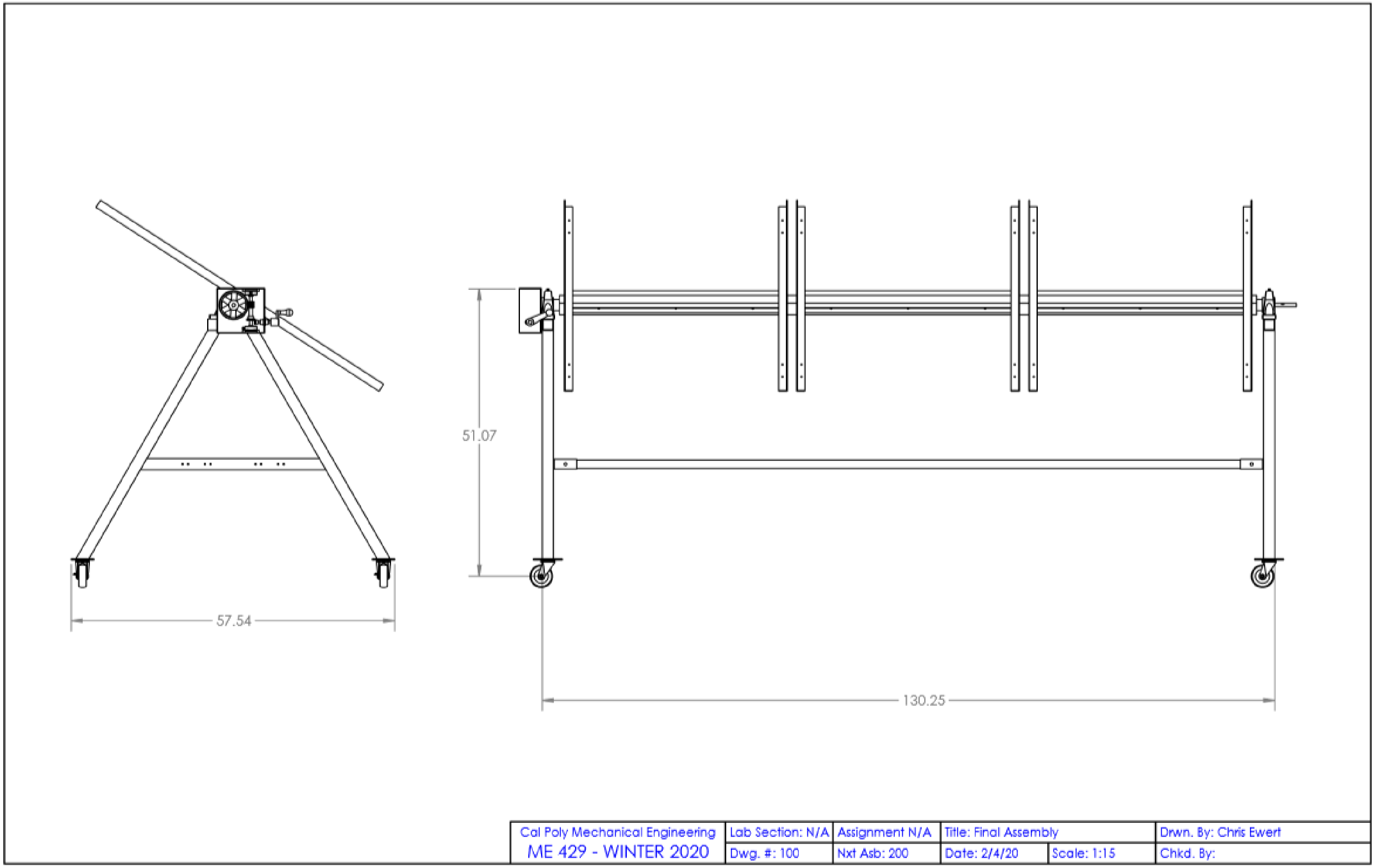
Description of Hazard	Planned Corrective Action	Planned Date	Actual Date
1. Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points?	The device may rotate quickly if rapid adjustment occurs. We will mandate 5 ft clearance from panels while adjusting. We will also utilize a gear safety and cover all moving gears to reduce pinch points.	Fabrication	
3. Will the system have any large moving masses or large forces?	We will adhere labels to the design stating the dangers associated with rapidly spinning the panels while they are attached to the roll bar.	Fabrication	
15. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc?	The solar panel mount will be permanently located outside. The design must withstand normal and abnormal wind and sun conditions.	none	

Appendix E: Indented Bill of Materials (iBOM)

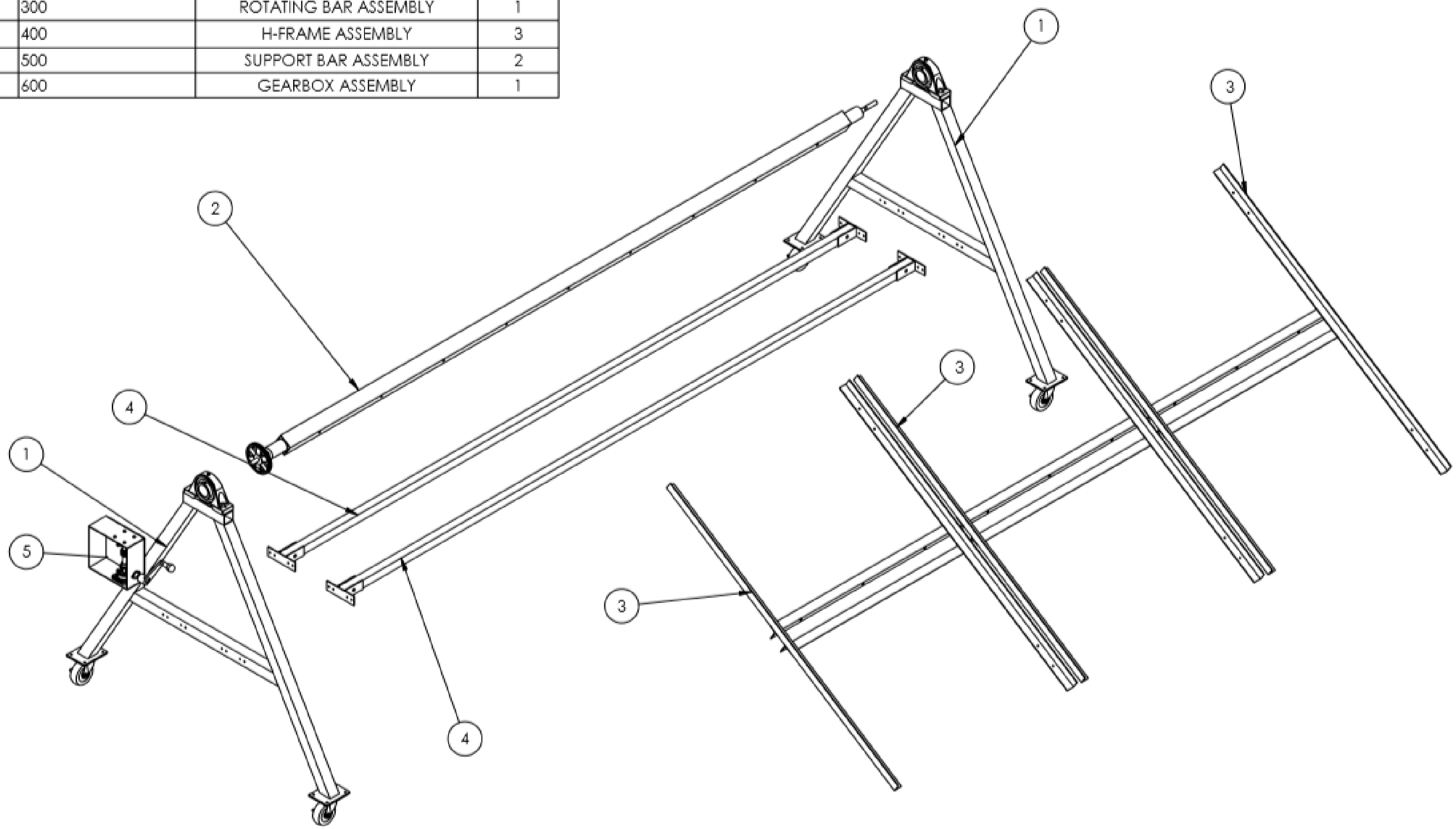
Assembly Level	Part Number	Indented Bill of Materials Description				Material	Dimension	Qty	Cost Per Piece	Ttl Cost	Source	More Info
		Lvl0	Lvl1	Lvl2	Lvl3							
0	100	Final Assembly									------	
0	101	Final Assembly (Exploded)									------	
1	200		A-Frame Assembly								------	
1	201		A-Frame Assembly (Exploded)								------	
2	210			Leg		1045 Carbon Steel	48" x 2" x 2"	4	10.25	44.18	MetalsDepot	30 Degree Cut
2	220			Crossbar		1045 Carbon Steel	30" x 2" x 2"	2	7.50	16.16	MetalsDepot	30 Degree Cut
2	230			Bearing Assembly							------	
3	231				Pillow Bearing	52100 Chrome Steel	5.51" x 1.5" x Ø 2"	2	113.35	244.27	Granger	Item #UCP205-16
3	232				Tube	1045 Carbon Steel	6" x 2" x 2"	2	4.50	9.70	MetalsDepot	30 Degree Cut
3	901-A				Hex Head Bolt	Stainless Steel	3/8-16 x 2-in	4	0.41	1.64	Home Depot	
3	902-A				Washer	Stainless Steel	3/8"	4	0.17	0.68	Home Depot	
3	903-A				Nut	Stainless Steel	3/8-16	4	0.15	0.60	Home Depot	
3	233				Cap	Rubber	2" x 2"	4	2.30	9.91	Amazon	Item #SQR-2-10-14
2	240			Wheel Assembly (Exploded)							------	
3	241				Plate	11-Gauge	5" x 4" x 1/8"	4	2.59	11.16	MetalsDepot	Cut Down from 12" x 24"
3	242				Caster	Rubber/Zinc-Steel	4"	4	24.30	104.73	McMaster Carr	Item #2407T75
3	901-B				Hex Head Bolt	Stainless Steel	3/8-16 x 3/4-in	16	0.22	3.52	Home Depot	
3	902-A				Washer	Stainless Steel	3/8"	16	0.17	2.72	Home Depot	
3	903-A				Nut	Stainless Steel	3/8-16	16	0.15	2.40	Home Depot	
1	300		Rotating Bar Assembly								------	
1	301		Rotating Bar Assembly (Exploded)								------	
2	310			Tube		1045 Carbon Steel	2-1/2" x 2-1/2" x 1/8"	1	71.64	77.19	MetalsDepot	10'4" Length
2	311			Insert		1018 Carbon Steel	9-1/2" x 2-1/4" x 2-1/4"	2	44.84	89.68	MetalsDepot	24" x 2-1/2" x 2-1/2" Bar Stock
2	312			Spur Gear		Iron	5" Pitch D	1	125.41	125.41	McMaster Carr	5/8" Shaft Diameter
1	400		H-Frame Assembly								------	
1	401		H-Frame Assembly (Exploded)								------	
2	410			L-Bar		1045 Carbon Steel	2" x 1-1/2" x 1/8"	6	13.88	89.73	MetalsDepot	39" Length Per Piece
3	901-C				Hex Head Bolt	Stainless Steel	3/8-16 x 4-in	9	0.64	5.76	Home Depot	
3	902-A				Washer	Stainless Steel	3/8"	9	0.17	1.53	Home Depot	
3	903-A				Nut	Stainless Steel	3/8-16	9	0.15	1.35	Home Depot	
2	420			L-Bar		1045 Carbon Steel	1-1/2" x 1-1/2" x 1/8"	6	7.31	43.86	MetalsDepot	5' Length
3	901-D				Hex Head Bolt	Stainless Steel	1/4-20 x 1-1/2 in	24	0.20	4.80	Home Depot	
3	902-D				Washer	Stainless Steel	1/4"	24	0.13	3.12	Home Depot	
3	903-D				Nut	Stainless Steel	1/4-20	24	0.08	1.92	Home Depot	

1	500	Support Bar Assembly (Exploded)					—		
2	510	Tube Fitting	Galvanized Steel	6" x 7/8" x 4"	4	7.25	31.25	Farm Tek	Item #104624
2	520	Tube	1045 Carbon Steel	1-1/2" x 1-1/2" x 1/8"	2	29.16	62.84	MetalsDepot	10' Length
3	901-E	Hex Head Bolt	Stainless Steel	1/4-20 x 3-in	16	0.27	4.32	Home Depot	
3	902-D	Washer	Stainless Steel	1/4"	16	0.13	2.08	Home Depot	
3	903-D	Nut	Stainless Steel	1/4-20	16	0.08	1.28	Home Depot	
3	901-F	Hex Head Bolt	Stainless Steel	1/2-13 x 2-1/2	4	0.86	3.44	Home Depot	
3	902-F	Washer	Stainless Steel	2-1/2"	4	0.25	1.00	Home Depot	
3	903-F	Nut	Stainless Steel	1/2-13	4	0.24	0.96	Home Depot	
1	600	GearBox Assembly					—		
1	601	GearBox Assembly (Exploded)					—		
2	610	Box Assembly					—		
2	611	Box Assembly (Exploded)					—		
3	620	Back Plate	11-Gauge	8-1/2" x 8" x 1/8"	1	10.20	10.20	MetalsDepot	Cut Down from 12" x 24"
3	621	Side Plate	11-Gauge	8" x 3-3/4" x 1/8"	1	3.35	3.35	MetalsDepot	Cut Down from 12" x 24"
3	622	Top/Bottom Plate	11-Gauge	8-1/2" x 3-3/4" x 1/8"	2	3.75	7.50	MetalsDepot	Cut Down from 12" x 24"
3	623	Mounting side plate	11-Gauge	8" x 3-3/4" x 1/8"	1	11.46	11.46	MetalsDepot	Cut Down from 12" x 24"
2	612	Shaft Assembly (Exploded)					—		
3	630	Shaft	1045 Carbon Steel	8" x Ø 1/2"	1	4.00	4.31	Metal Store	Keyseat in it
3	631	Worm Gear	1144 Carbon Steel	1-1/8" Pitch Ø 1-in	1	34.80	37.50	McMaster Carr	Item #57545K527
3	632	Bevel Gear	1144 Carbon Steel	2" Pitch D	1	56.24	60.60	McMaster Carr	Item #2515N11
3	633	Key	1018 Carbon Steel	1-1/8" x 1/8" x Ø 1/8"	1	3.04	3.28	McMaster Carr	Item #98491A100
3	634	Four Bolt Flange Mount	Cast Iron		2	57.29	123.46	McMaster Carr	Item #1434K25
3	901-G	Hex Head Bolt	Stainless Steel	3/8-16 x 1"	8	0.24	1.92	Home Depot	
3	902-A	Washer	Stainless Steel	3/8"	8	0.17	1.36	Home Depot	
3	903-A	Nut	Stainless Steel	3/8-16	8	0.15	1.20	Home Depot	
2	613	Hand Crank to Bevel Assembly (Exploded)					—		
3	640	Two Flange Roller Bearing	Steel	3/8" Diameter	2	18.64	37.28	McMaster Carr	Item #1434K25
3	641	Shaft	1045 Carbon Steel	9/16" x 9/16" x 3-5/8"	1	8.00	8.62	Metal Store	Bar Stock
3	642	Bevel Pinion	1144 Carbon Steel	1" Pitch D	1	33.80	36.42	McMaster Carr	Item #2515N14
3	643	Hand Crank	Chrome-Plated Steel	9/16" Hole	1	127.20	137.06	McMaster Carr	Item #6089K18
3	901-H	Hex Head Bolt	Stainless Steel	3/16-24 x 3/4-in	2	0.44	0.88	Home Depot	
3	902-H	Washer	Stainless Steel	3/16"	2	0.15	0.30	Home Depot	
3	903-H	Nut	Stainless Steel	3/16-24	2	0.19	0.38	Home Depot	
				Total	309		1490.26		

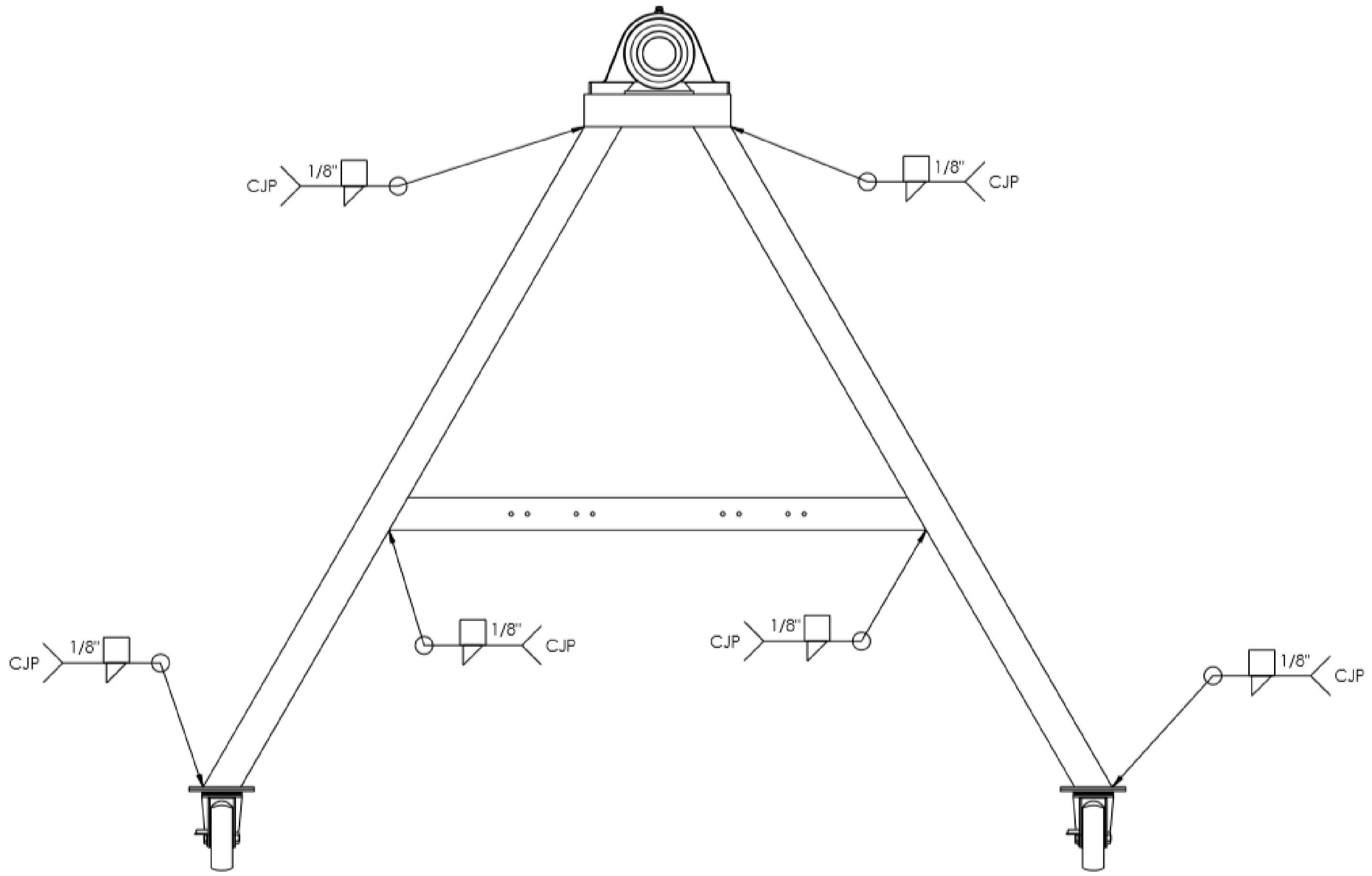
Appendix F: Drawing Package



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	200	A-FRAME ASSEMBLY	2
2	300	ROTATING BAR ASSEMBLY	1
3	400	H-FRAME ASSEMBLY	3
4	500	SUPPORT BAR ASSEMBLY	2
5	600	GEARBOX ASSEMBLY	1

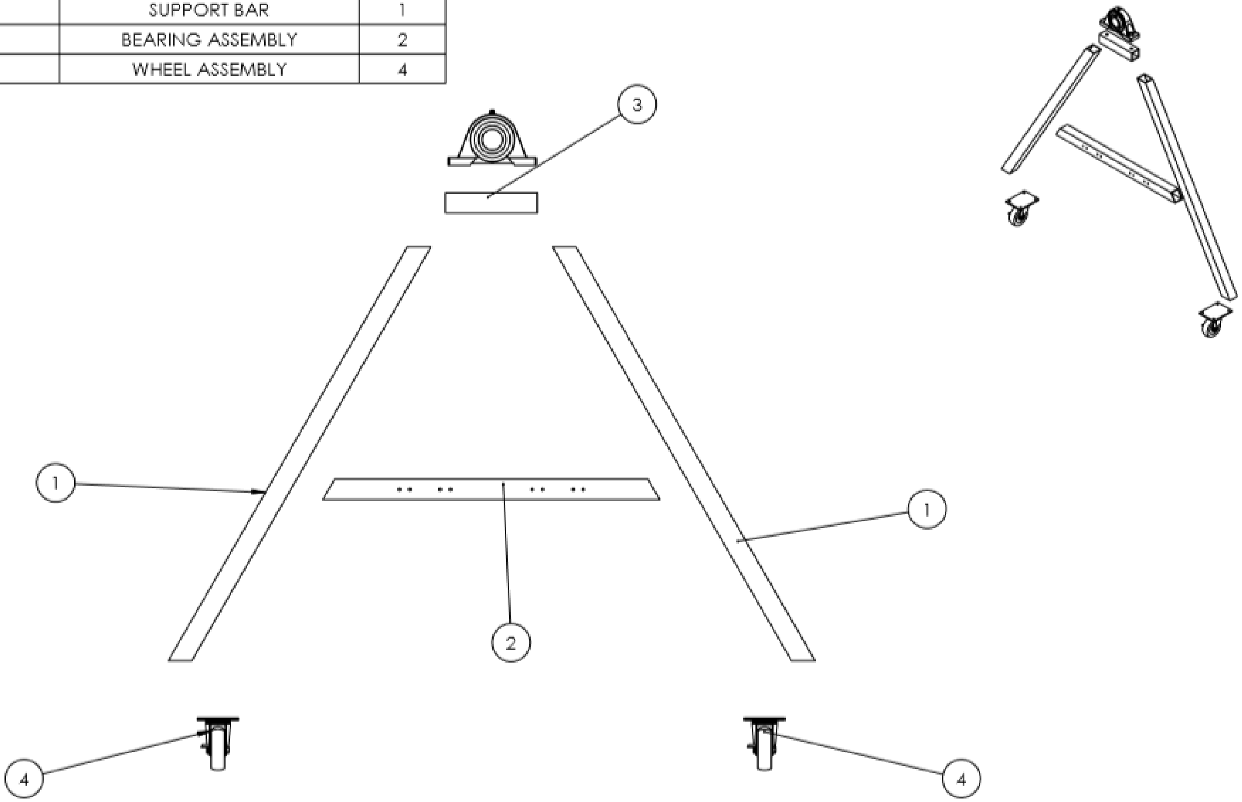


Cal Poly Mechanical Engineering	Lab Section: N/A	Assignment N/A	Title: Final Assembly (exp)	Drwn. By: Chris Ewert
ME 429 - WINTER 2020	Part #: 101	Nxt Asb: N/A	Date: 2/4/20 Scale: 1:15	Chkd. By:

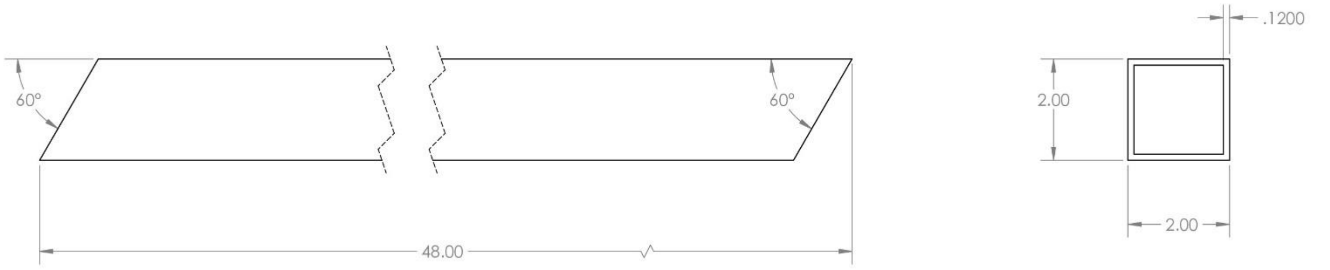


Cal Poly Mechanical Engineering	Lab Section: N/A	Assignment N/A	Title: A-Frame Assembly		Drwn. By: Chris Ewert
ME 429 - WINTER 2020	Part #: 200	Nxt Asb: 210	Date: 2/4/20	Scale: 1:5	Chkd. By:

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	210	LEG	2
2	220	SUPPORT BAR	1
3	230	BEARING ASSEMBLY	2
4	240	WHEEL ASSEMBLY	4



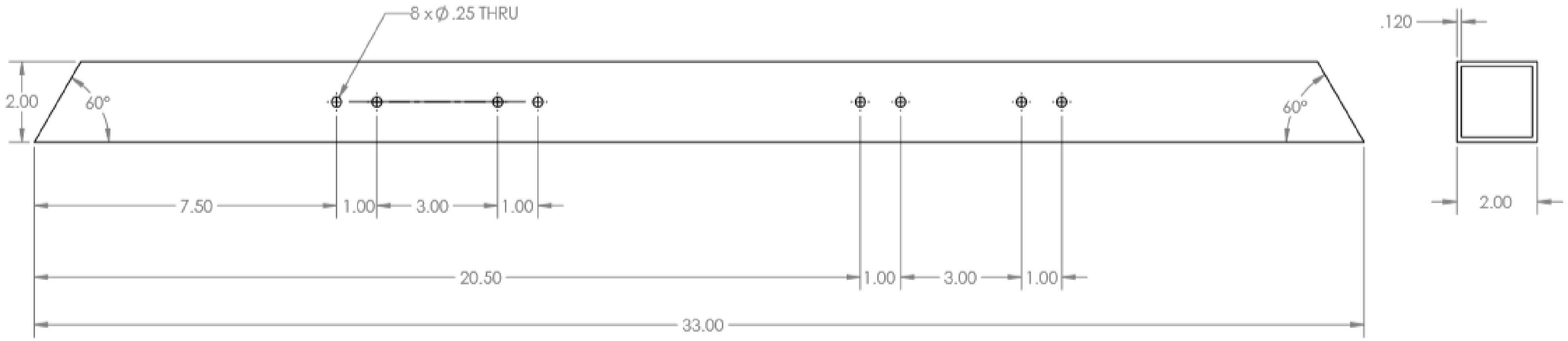
Cal Poly Mechanical Engineering	Lab Section: N/A	Assignment N/A	Title: A-FRAME EXPLODED		Drwn. By: Chris Ewert
ME 429 - WINTER 2020	Dwg. #: 201	Nxt Asb: N/A	Date: 2/5/20	Scale: 1:1	Chkd. By:



NOTES

UNLESS OTHERWISE SPECIFIED:
1. ALL DIMENSIONS IN INCHES
2. TOLERANCES:
   X.XX = ±0.01
   X.XXX = ±0.005
   ANGLES = ±1°
3. 1/8" THICK STEEL TUBING
4. BREAK SHARP EDGES 0.005 MAX
5. MATERIAL: 1045 CARBON STEEL
6. 1.6 √FAO

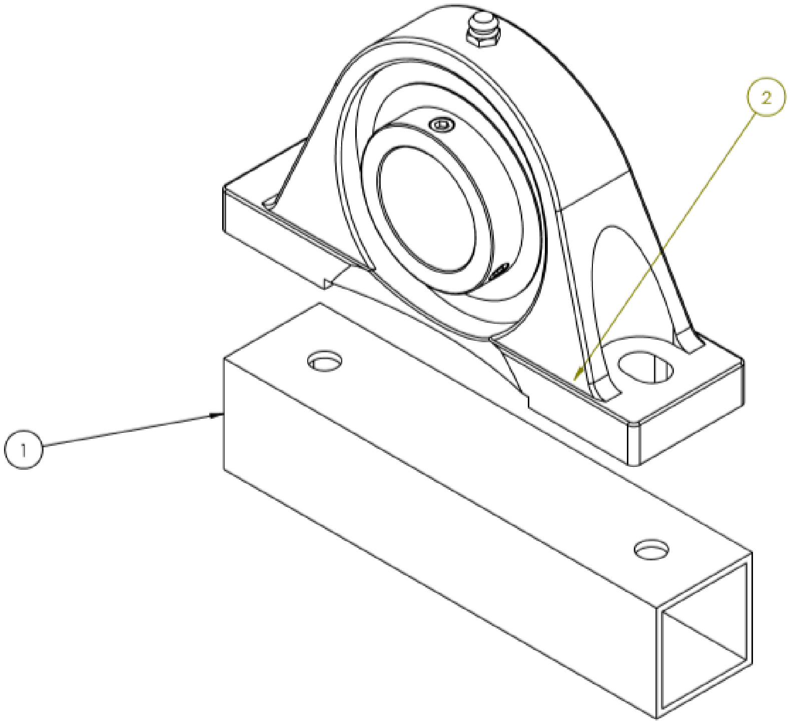
Cal Poly Mechanical Engineering	Lab Section: N/A	Assignment N/A	Title: Leg		Drwn. By: Chris Ewert
ME 429 - WINTER 2020	Part #: 210	Nxt Asb: 220	Date: 2/4/20	Scale: 1:2	Chkd. By:



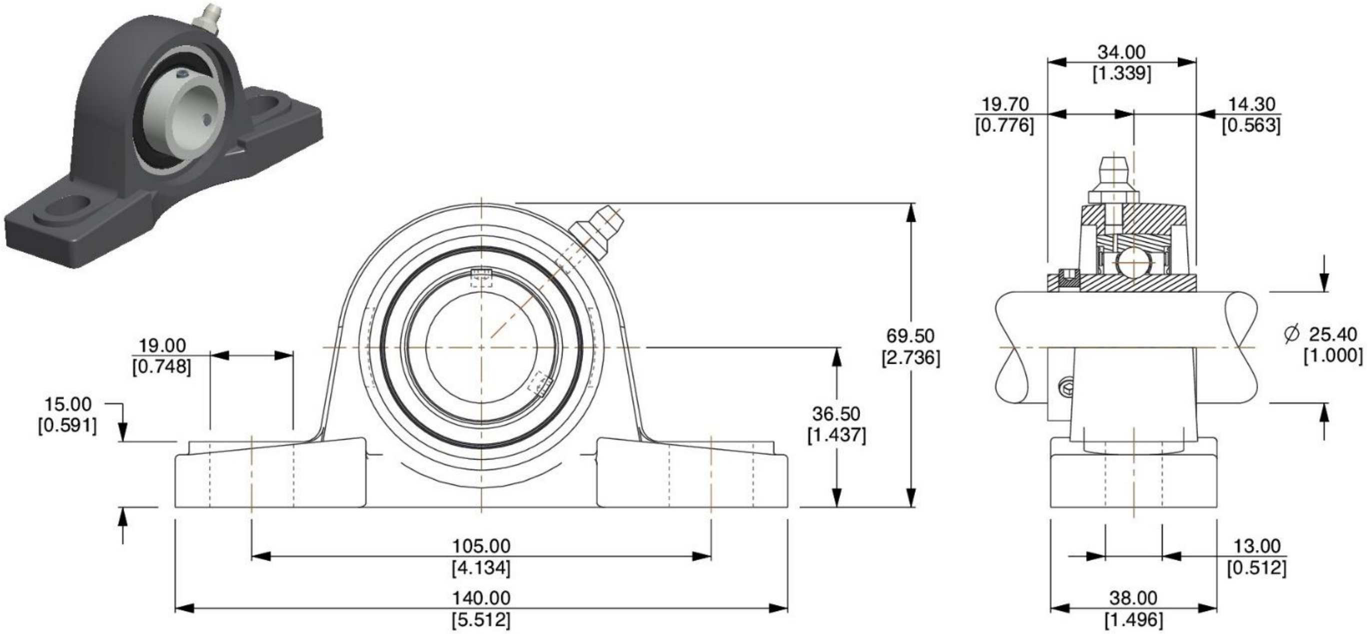
NOTES
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMENSIONS IN INCHES
2. TOLERANCES:
X.XX = ±0.01
X.XXX = ±0.005
ANGLES = ±1°
3. 1/8" THICK STEEL TUBING
1045 CARBON STEEL
4. BREAK SHARP EDGES 0.005 MAX

Cal Poly Mechanical Engineering	Lab Section: N/A	Assignment N/A	Title: Crossbar		Drwn. By: Chris Ewert
ME 429 - WINTER 2020	Part #: 220	Nxt Asb: 230	Date: 2/4/20	Scale: 1:2.5	Chkd. By:

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	232	TUBE	2
2	231	PILLOW BEARING	2



Cal Poly Mechanical Engineering	Lab Section: N/A	Assignment N/A	Title: Bearing Assembly		Drwn. By: Chris Ewert
ME 429 - WINTER 2020	Part #: 230	Nxt Asb: 231	Date: 2/4/20	Scale: 2:3	Chkd. By:



NOTES:

1. SERIES: UCP
2. FINISH: Painted
3. NUMBER OF BOLTS: 2
4. STANDARDS: ISO, AFBMA
5. BEARING INSERT TYPE: Ball
6. TEMP. RANGE: -40 °F to 250 °F
7. SHAFT LOCKING TYPE: Set Screw
8. LOAD CAPACITY: Static - 1765 Lb. / Dynamic - 3147 Lb.
9. BEARING LUBRICATION: Shell Alvania RL2 or NLGI #2 Equivalent
10. BEARING MATERIAL: Housing - Cast Iron / Insert - 52100 Chrome Steel

COMPONENT Pillow Block Bearing

GRAINGER

100 Grainger Parkway, Lake Forest, Illinois 60045-5201
1-(800) GRAINGER, 1-(800) 472-4643, (847) 535-1000
www.grainger.com

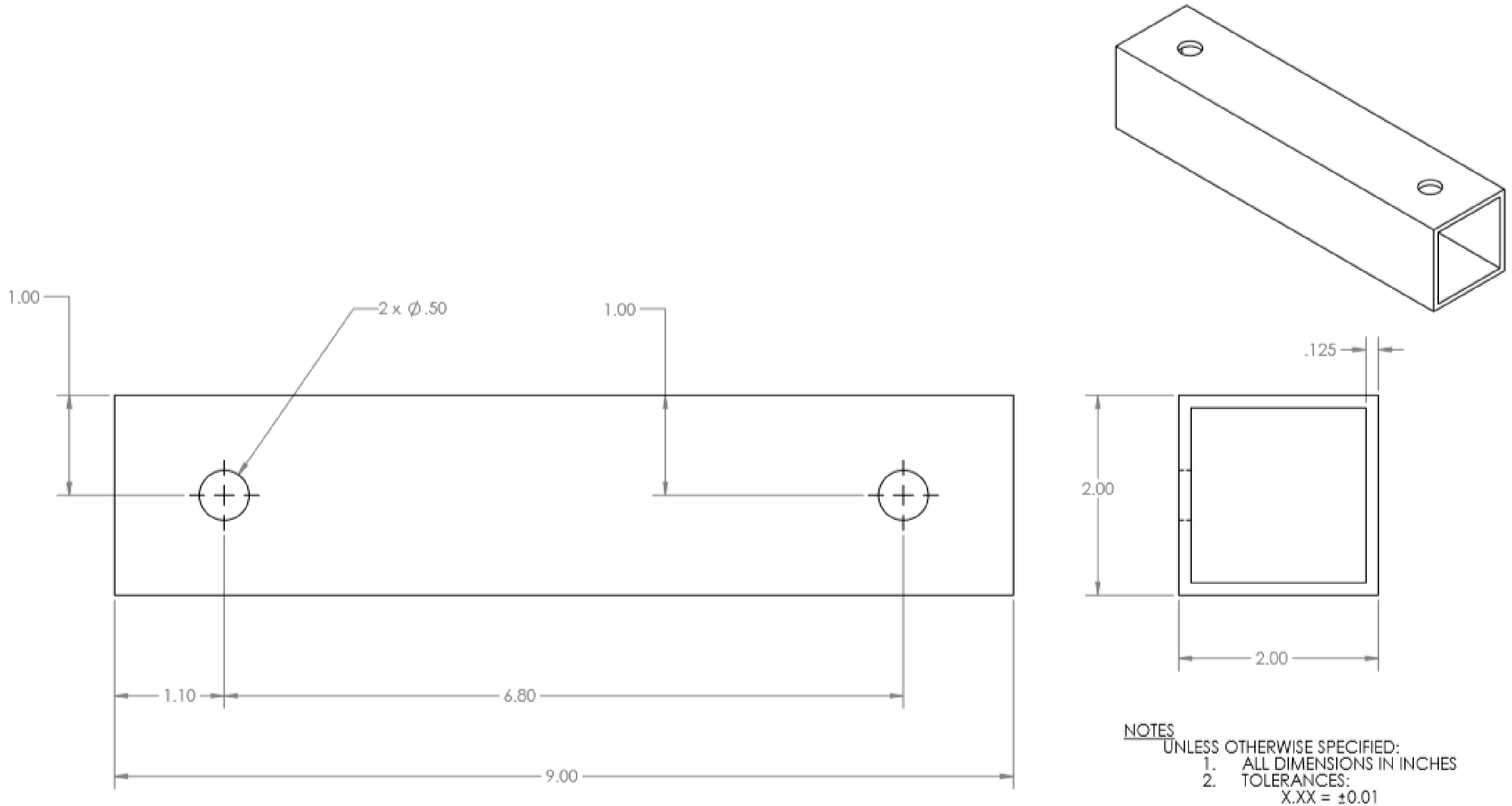
SCALE 0.75

231

Pillow Block Bearing, Ball, 1" Bore

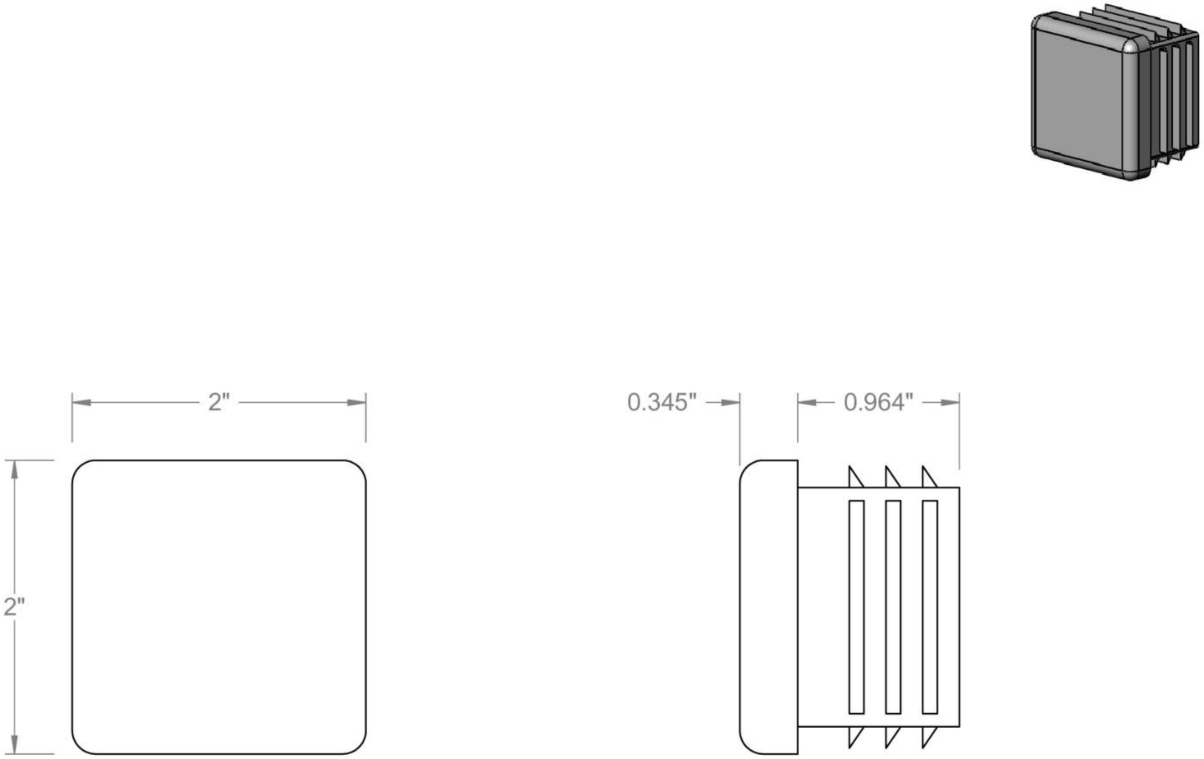
UNIT MM

SHEET 1 of 1



NOTES
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMENSIONS IN INCHES
2. TOLERANCES:
    X.XX = ±0.01
    X.XXX = ±0.005
    ANGLES = ±1°
3. 1/8" THICK STEEL TUBING
    1045 CARBON STEEL
4. BREAK SHARP EDGES 0.005 MAX

Cal Poly Mechanical Engineering	Lab Section: N/A	Assignment N/A	Title: Tube		Drwn. By: Chris Ewert
ME 429 - WINTER 2020	Dwg. #: 232	Nxt Asb: N/A	Date: 1/23/20	Scale: 1:1	Chkd. By:



McMASTER-CARR® CAD

PART NUMBER **233**

http://www.mcmaster.com

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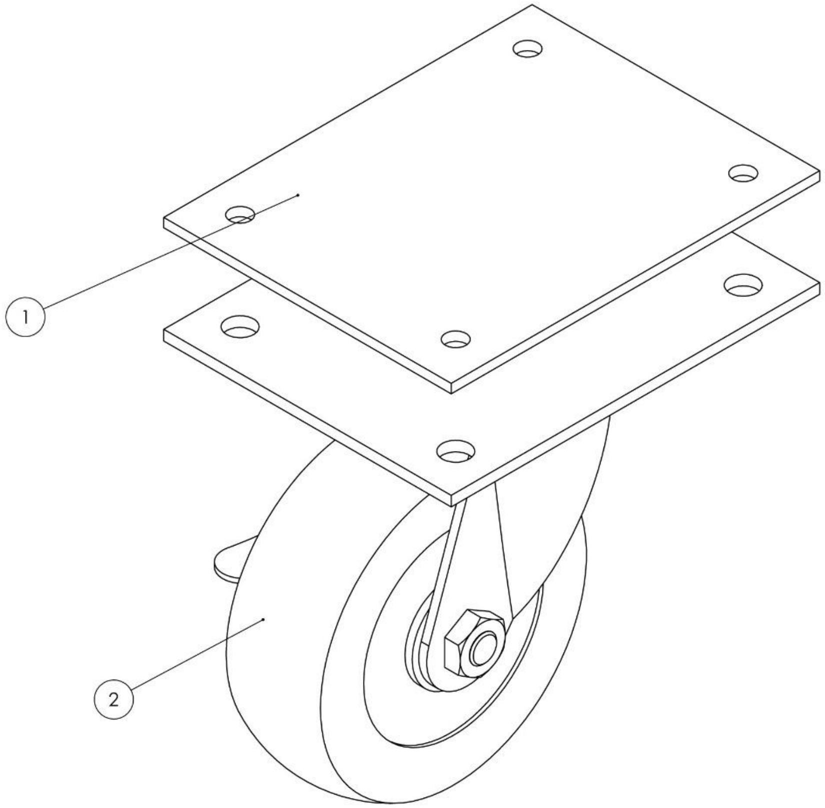
Information in this drawing is provided for reference only.

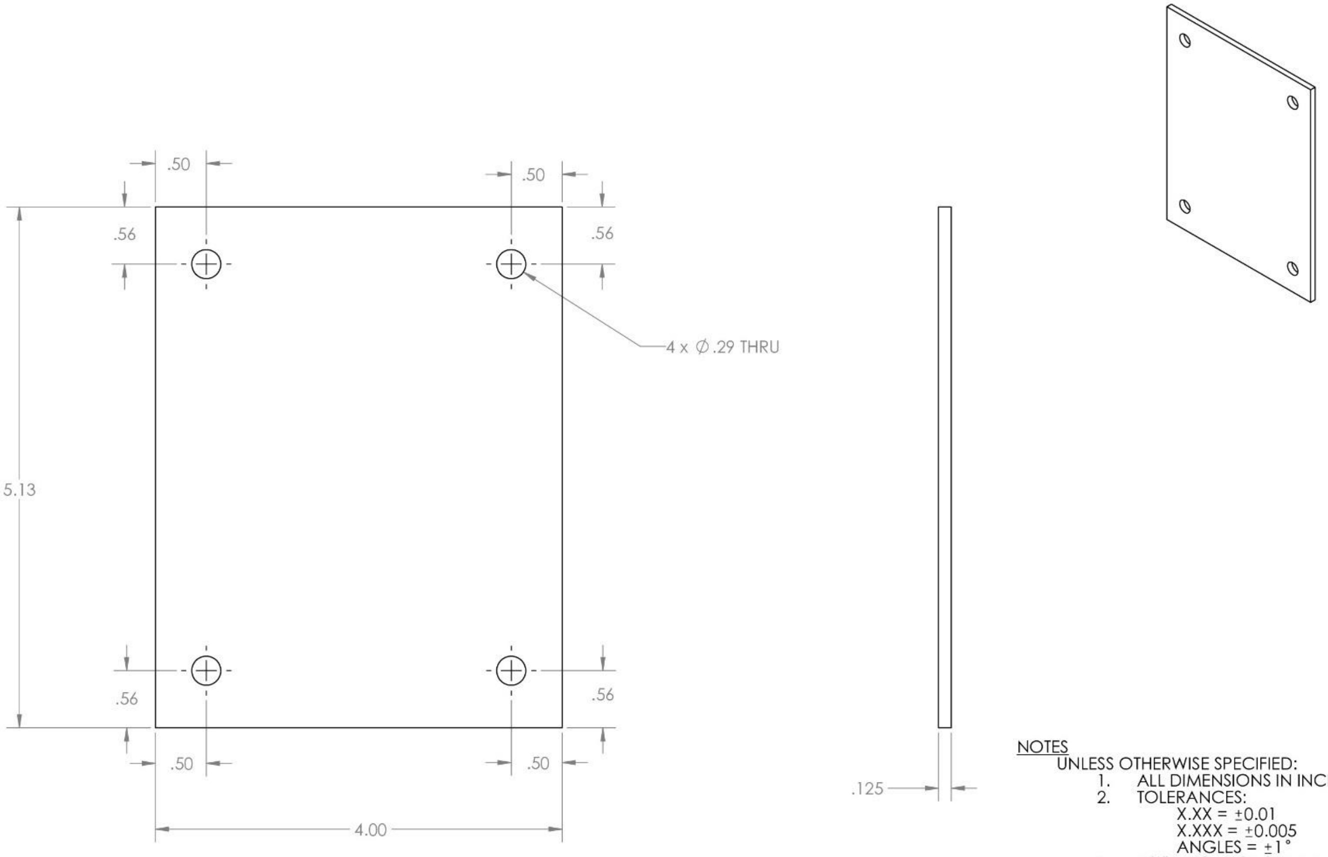
End Cap for
Friction-Grip Framing Fittings

SOLIDWORKS Educational Product. For Instructional Use Only.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	241	PLATE	4
2	242	CASTER	4

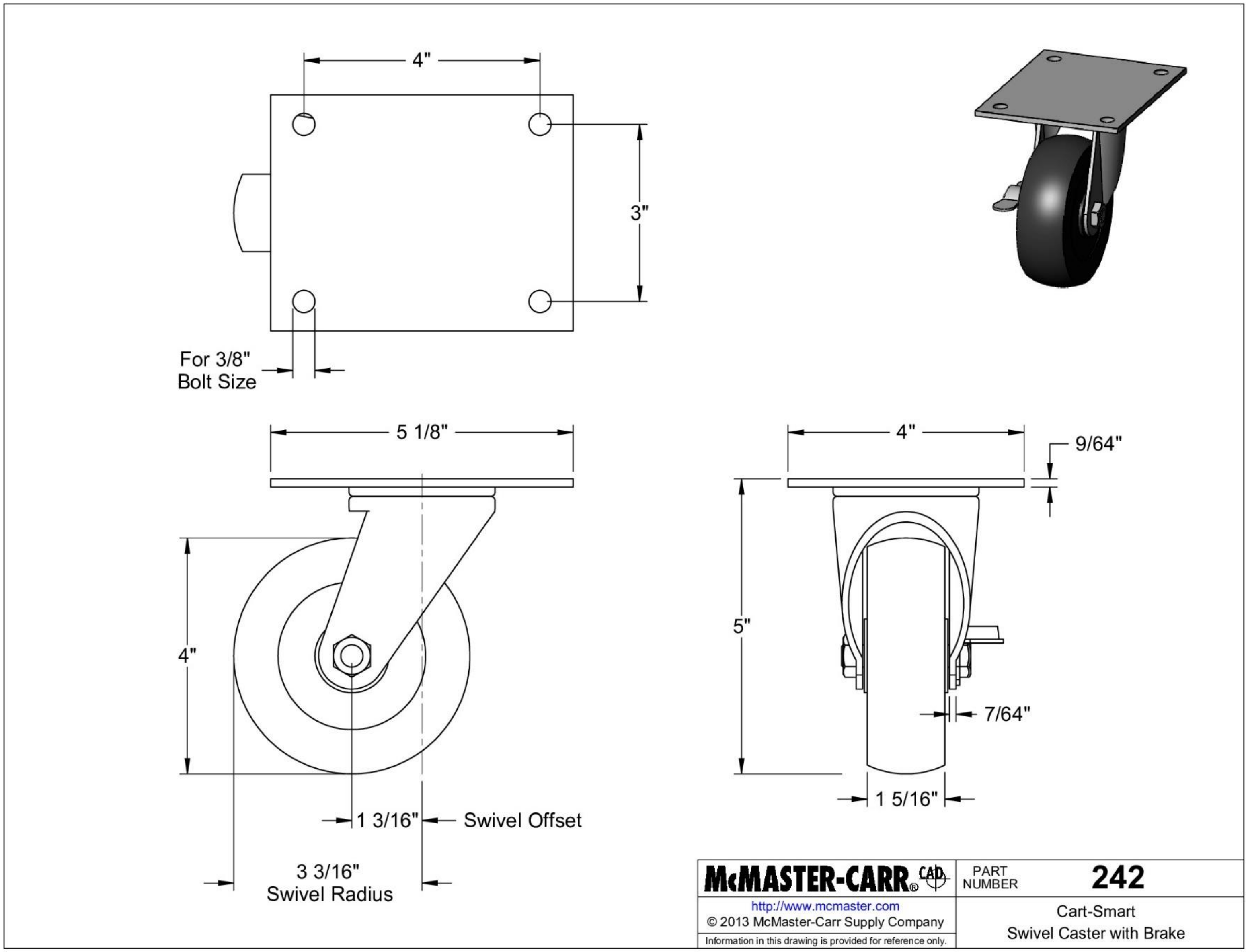


Cal Poly Mechanical Engineering	Lab Section: N/A	Assignment N/A	Title: Wheel Assembly		Drwn. By: Chris Ewert
ME 429 - WINTER 2020	Part #: 240	Nxt Asb: 241	Date: 2/4/20	Scale: 1:1	Chkd. By:



NOTES
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMENSIONS IN INCHES
2. TOLERANCES:
    X.XX = ±0.01
    X.XXX = ±0.005
    ANGLES = ±1°
3. 1/8" 11-GAUGE STEEL PLATE
4. BREAK SHARP EDGES 0.005 MAX

Cal Poly Mechanical Engineering	Lab Section: N/A	Assignment N/A	Title: Plate		Drwn. By: Chris Ewert
ME 429 - WINTER 2020	Part #: 241	Nxt Asb: 242	Date: 2/4/20	Scale: 1:1	Chkd. By:

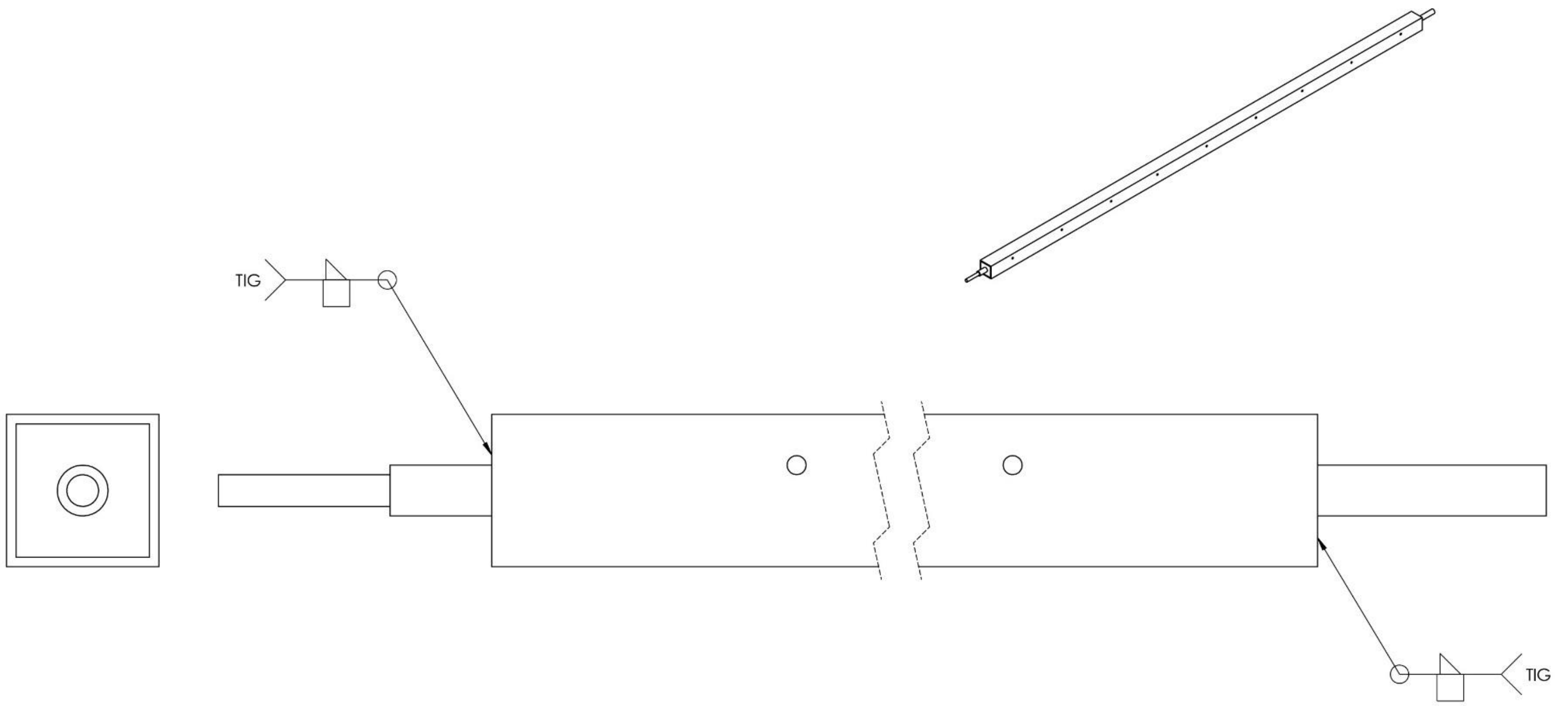


McMASTER-CARR® CAD

PART NUMBER **242**

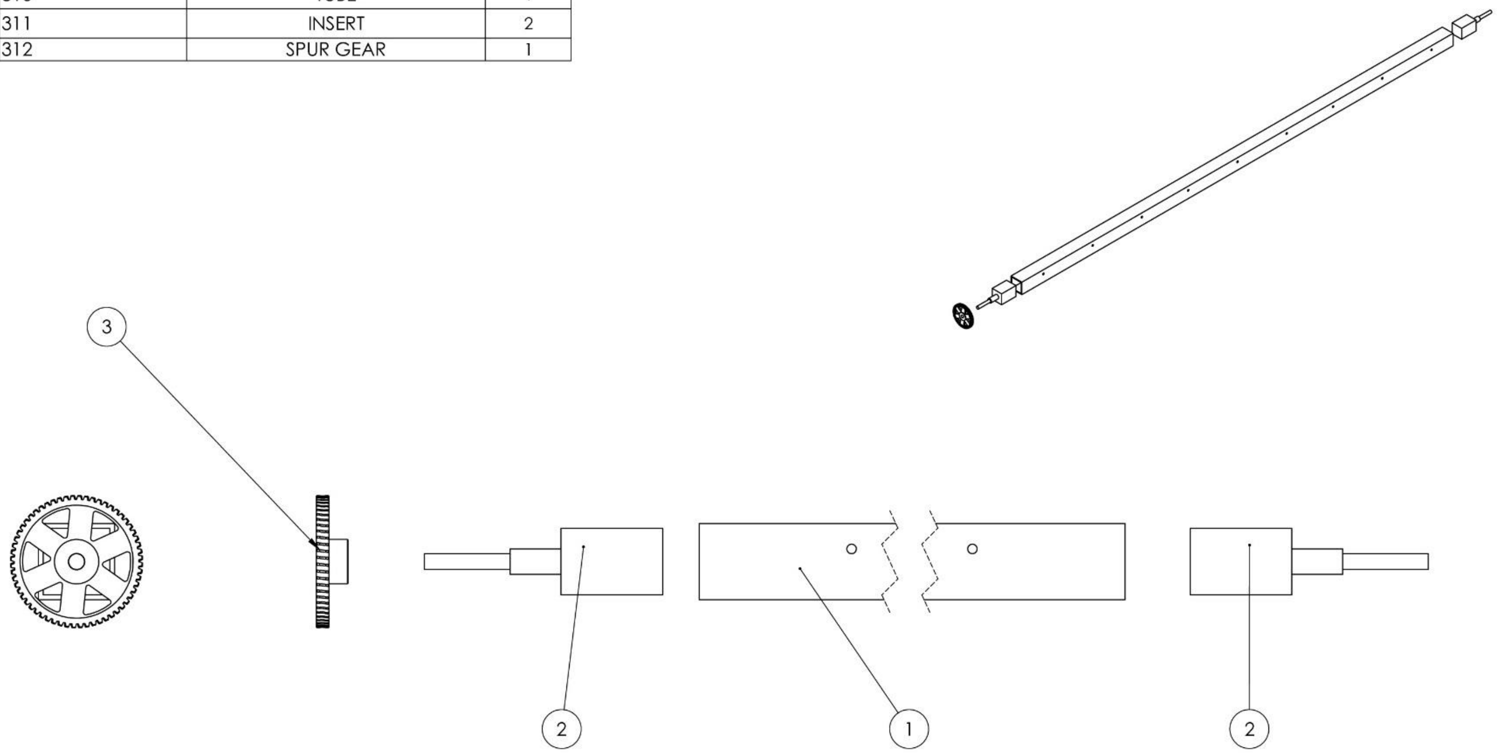
http://www.mcmaster.com

Cart-Smart
Swivel Caster with Brake

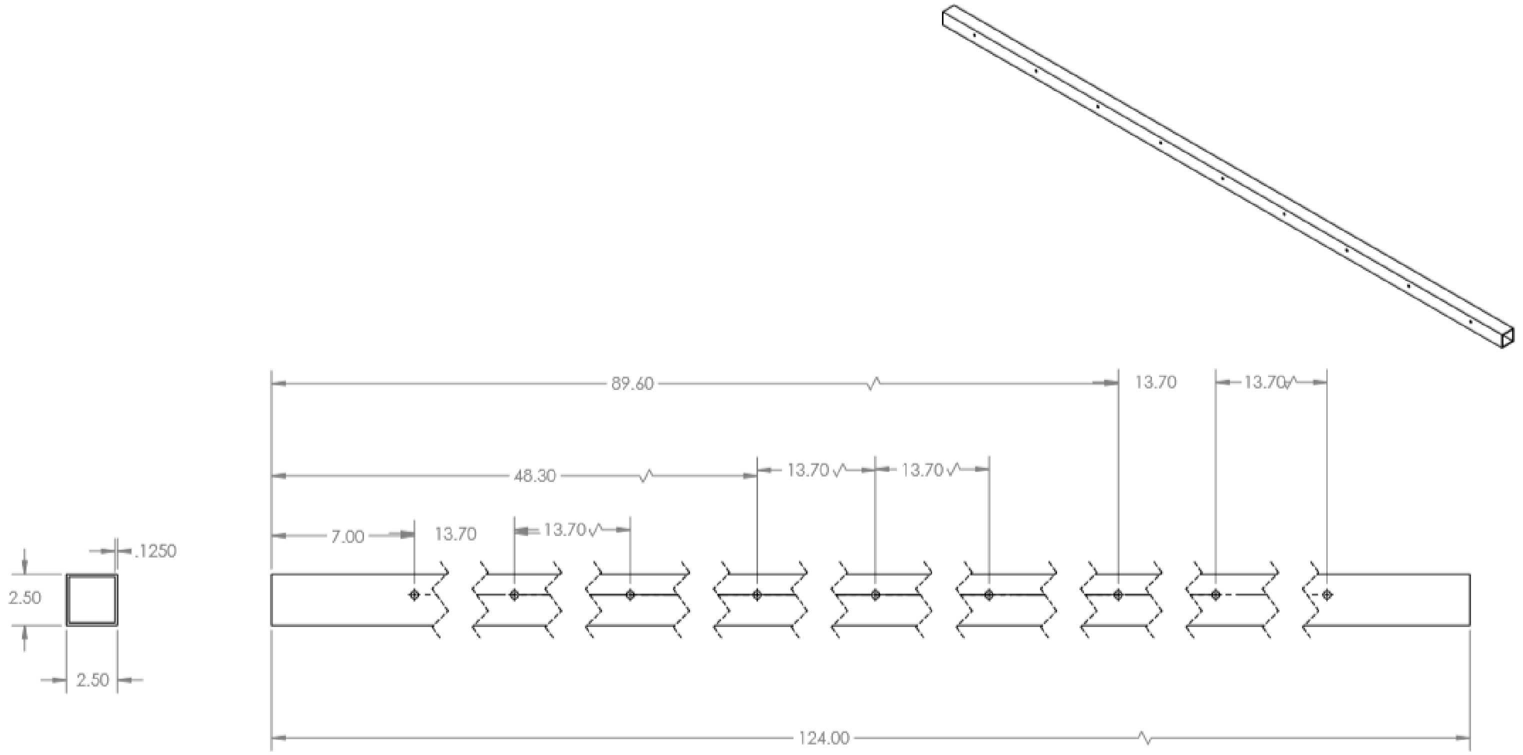


Cal Poly Mechanical Engineering	Lab Section: N/A	Assignment N/A	Title: Box Siding		Drwn. By: Chris Ewert
ME 429 - WINTER 2020	Dwg. #: 300	Nxt Asb: 301	Date: 2/4/20	Scale: 1:1	Chkd. By:

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	310	TUBE	1
2	311	INSERT	2
3	312	SPUR GEAR	1

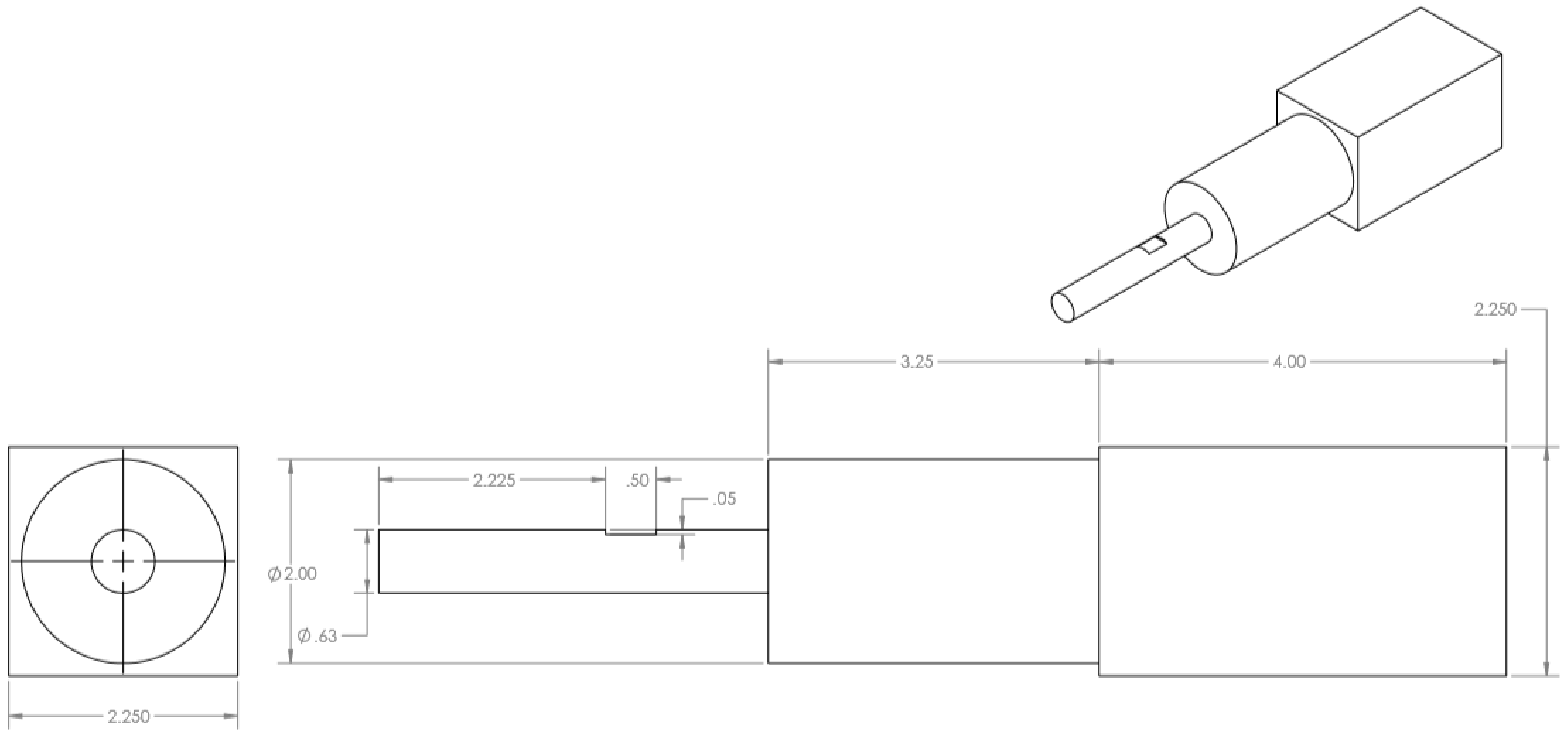


Cal Poly Mechanical Engineering
ME 429 - WINTER 2020
Lab Section: N/A
Part #: 301
Assignment N/A
Nxt Asb: 310
Title: Rotating Bar Assembly (exp)
Date: 2/5/20
Scale: 1:4
Drwn. By: Chris Ewert
Chkd. By:



NOTES
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMENSIONS IN INCHES
2. TOLERANCES:
X.XX = ±0.01
X.XXX = ±0.005
ANGLES = ±1°
3. 3/16" THICK STEEL TUBING
1045 CARBON STEEL
4. BREAK SHARP EDGES 0.005 MAX

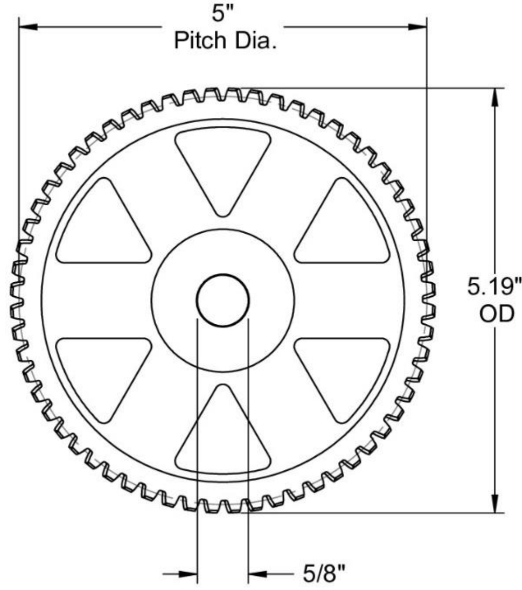
Cal Poly Mechanical Engineering	Lab Section: N/A	Assignment N/A	Title: Tube		Drwn. By: Chris Ewert
ME 429 - WINTER 2020	Part #: 310	Nxt Asb: N/A	Date: 2/4/20	Scale: 1:5	Chkd. By:

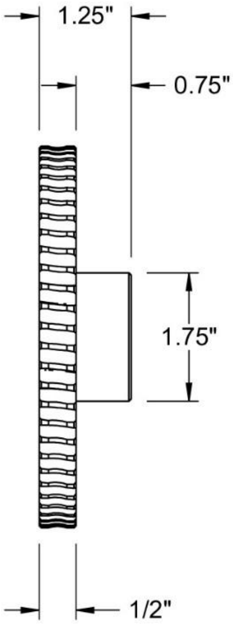


NOTES
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMENSIONS IN INCHES
2. TOLERANCES:
X.XX = ±0.01
X.XXX = ±0.005
ANGLES = ±1°
3. MATERIAL: 1018 CARBON STEEL
4. BREAK SHARP EDGES 0.005 MAX

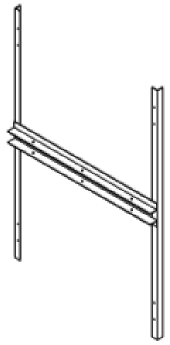
Cal Poly Mechanical Engineering	Lab Section: N/A	Assignment N/A	Title: Insert		Drwn. By: Chris Ewert
ME 429 - WINTER 2020	Part #: 311	Nxt Asb: N/A	Date: 2/4/20	Scale: 1:1	Chkd. By:

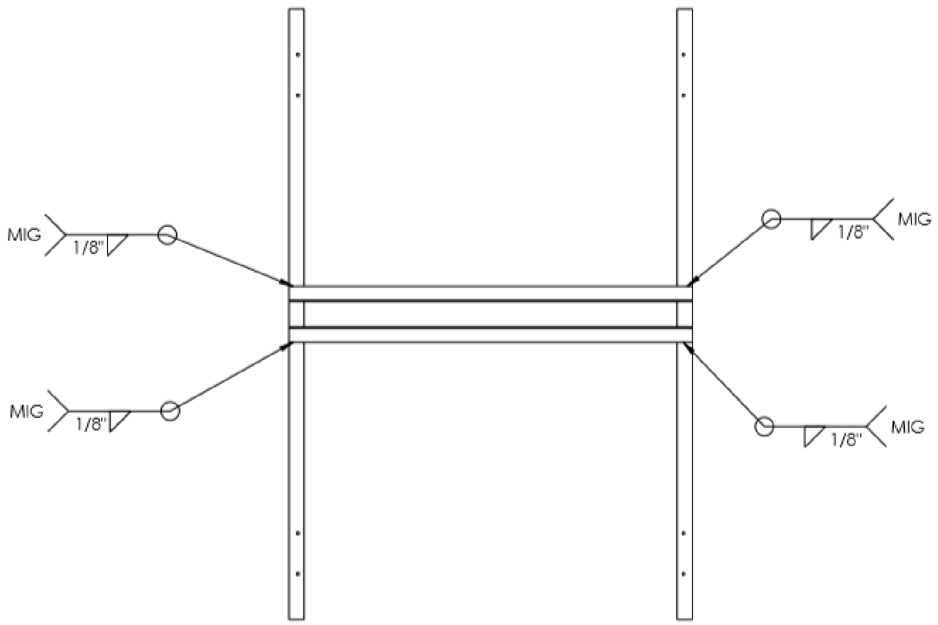
Pitch: 12
Number of Teeth: 60





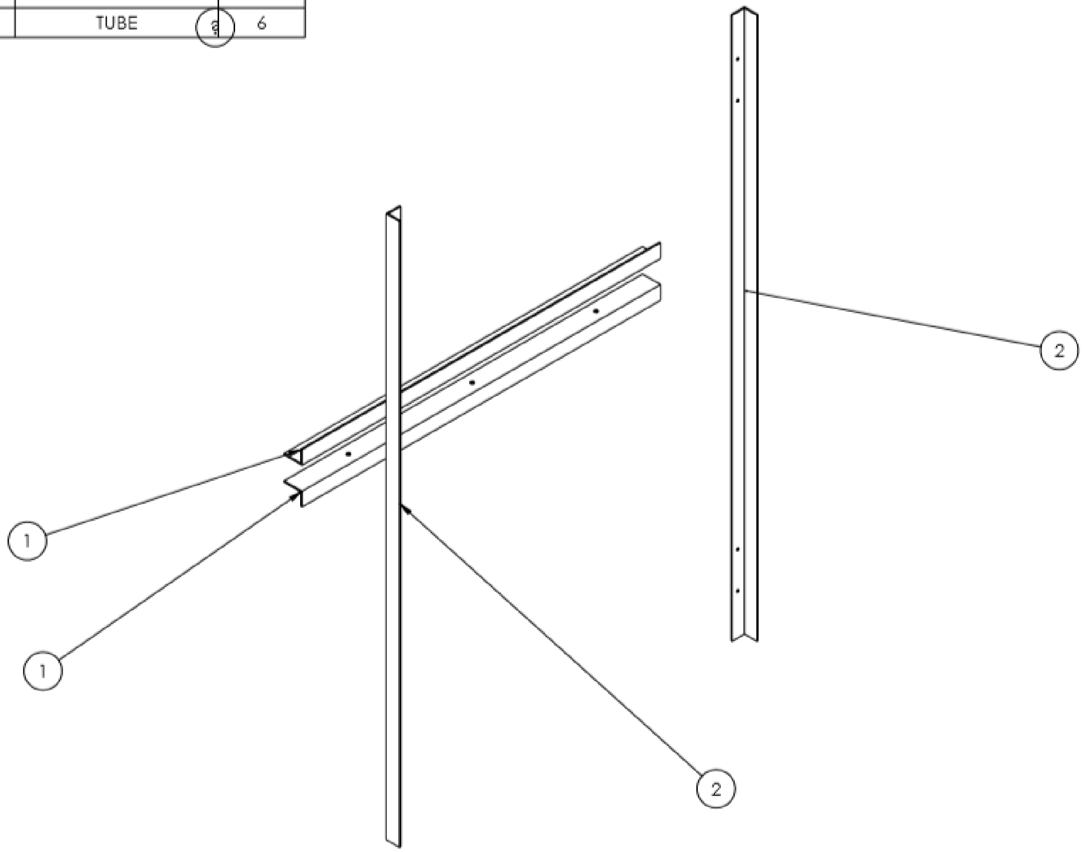
McMASTER-CARR®	PART NUMBER	312
http://www.mcmaster.com © 2017 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	Speed-Reducing Worm Gear for 90° Angle Motion Transfer - 14 1/2° Pressure Angle	



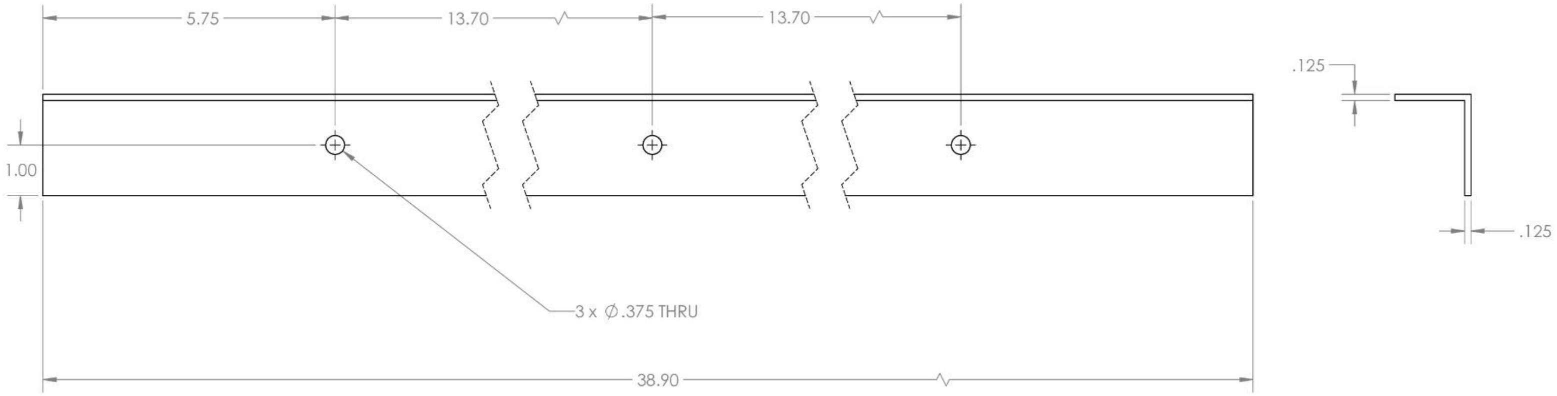


Cal Poly Mechanical Engineering	Lab Section: N/A	Assignment N/A	Title: H-Frame Assembly		Drwn. By: Chris Ewert
ME 429 - WINTER 2020	Part #: 400	Nxt Asb: 410	Date: 2/4/20	Scale: 1:1	Chkd. By:

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	410	L-BAR	6
2	420	TUBE	6

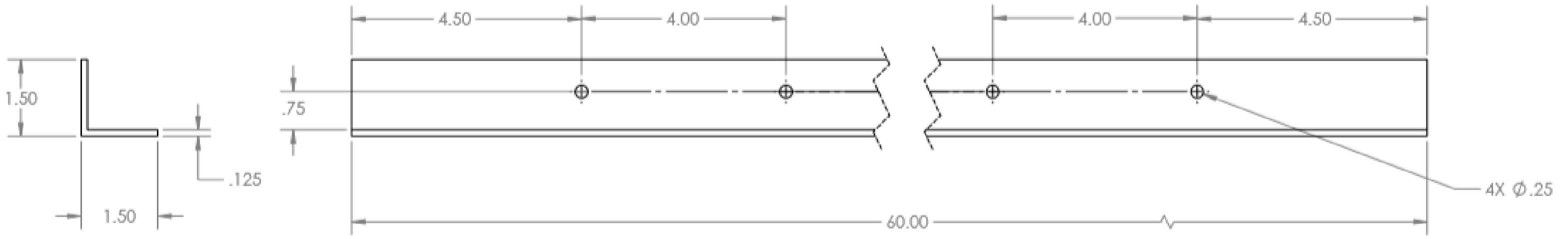


Cal Poly Mechanical Engineering	Lab Section: N/A	Assignment N/A	Title: H-Frame Assembly (exp)		Drwn. By: Chris Ewert
ME 429 - WINTER 2020	Dwg. #: 401	Nxt Asb: N/A	Date: 2/5/20	Scale: 1:8	Chkd. By:



NOTES
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMENSIONS IN INCHES
2. TOLERANCES:
X.XX = ±0.01
X.XXX = ±0.005
ANGLES = ±1°
3. 1/8" THICK STEEL L-BEAM
1045 CARBON STEEL
4. BREAK SHARP EDGES 0.005 MAX

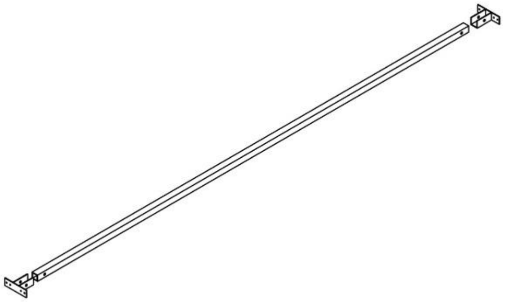
Cal Poly Mechanical Engineering	Lab Section: N/A	Assignment N/A	Title: L-bar		Drwn. By: Chris Ewert
ME 429 - WINTER 2020	Part #: 410	Nxt Asb: N/A	Date: 2/4/20	Scale: 1:2	Chkd. By:

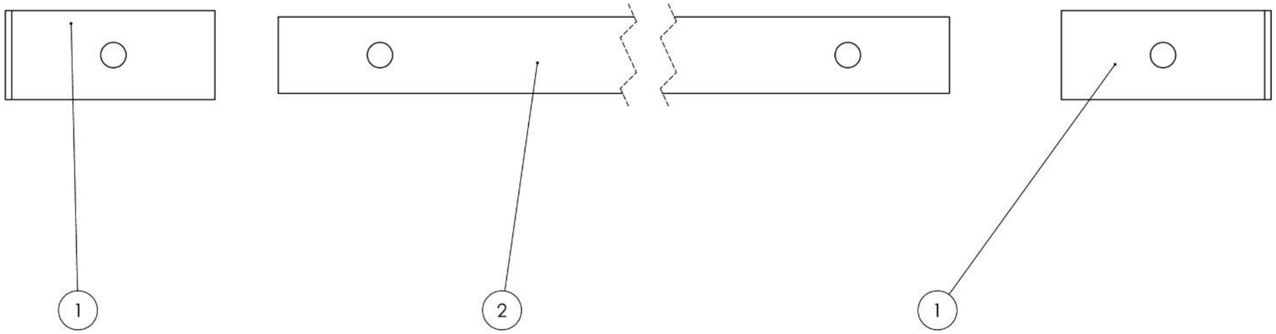


NOTES
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMENSIONS IN INCHES
2. TOLERANCES:
   X.XX = ±0.01
   X.XXX = ±0.005
   ANGLES = ±1°
3. 1/8" THICK STEEL TUBING
   1045 CARBON STEEL
4. BREAK SHARP EDGES 0.005 MAX

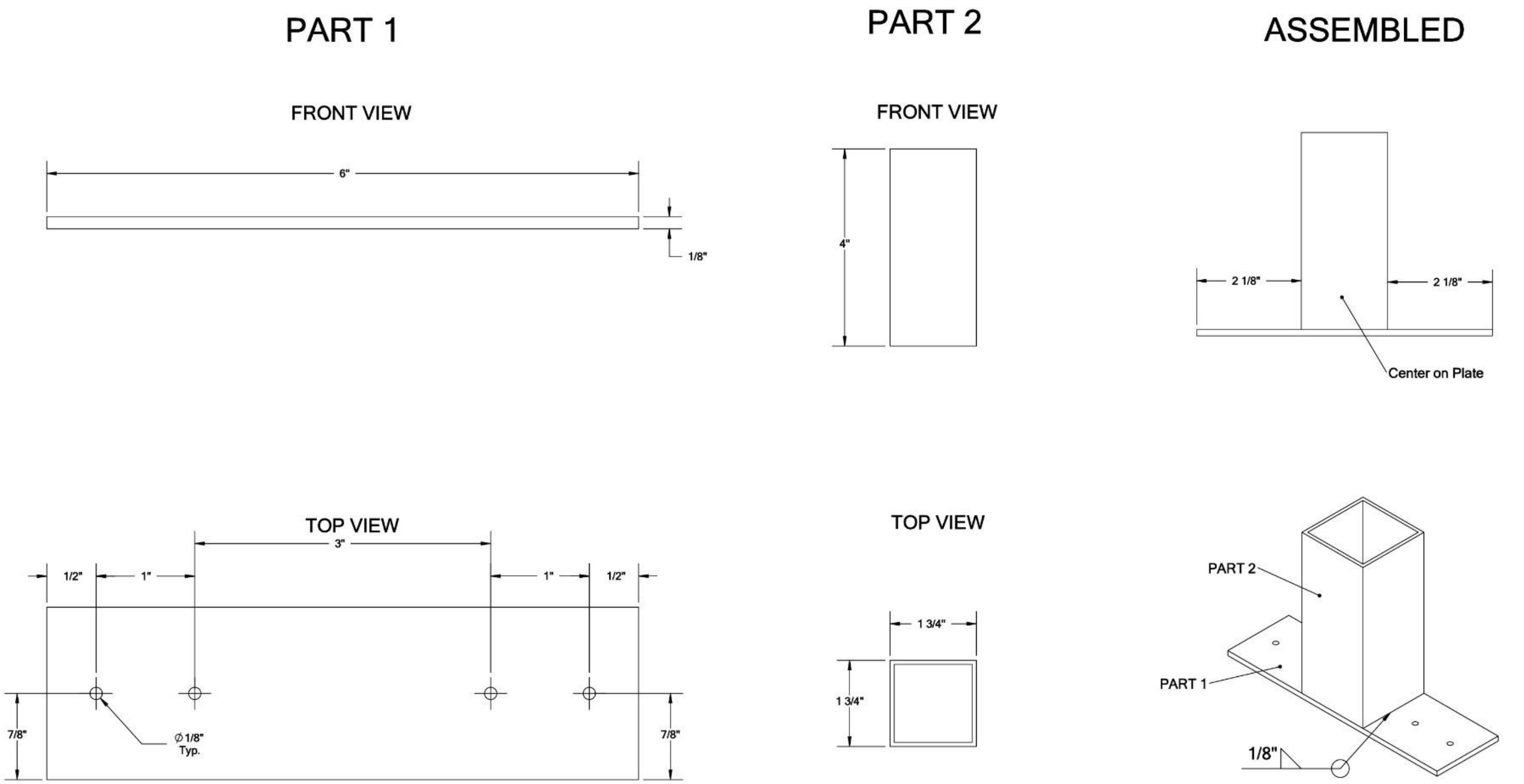
Cal Poly Mechanical Engineering	Lab Section: N/A	Assignment N/A	Title: Tube		Drwn. By: Chris Ewert
ME 429 - WINTER 2020	Part #: 420	Nxt Asb: N/A	Date: 2/4/20	Scale: 1: 2	Chkd. By:

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	510	TUBE FITTING	4
2	520	TUBE	4





Cal Poly Mechanical Engineering	Lab Section: N/A	Assignment N/A	Title: Support Bar Assembly (exp)		Drwn. By: Chris Ewert
ME 429 - WINTER 2020	Part #: 500	Nxt Asb: N/A	Date: 2/4/20	Scale: 1:2	Chkd. By:



SKU/MATERIAL	QTY.	SUPPLIED BY ESAPCO
PART 1 (1/8")	1	NO
PART 2 (14GA)	1	YES

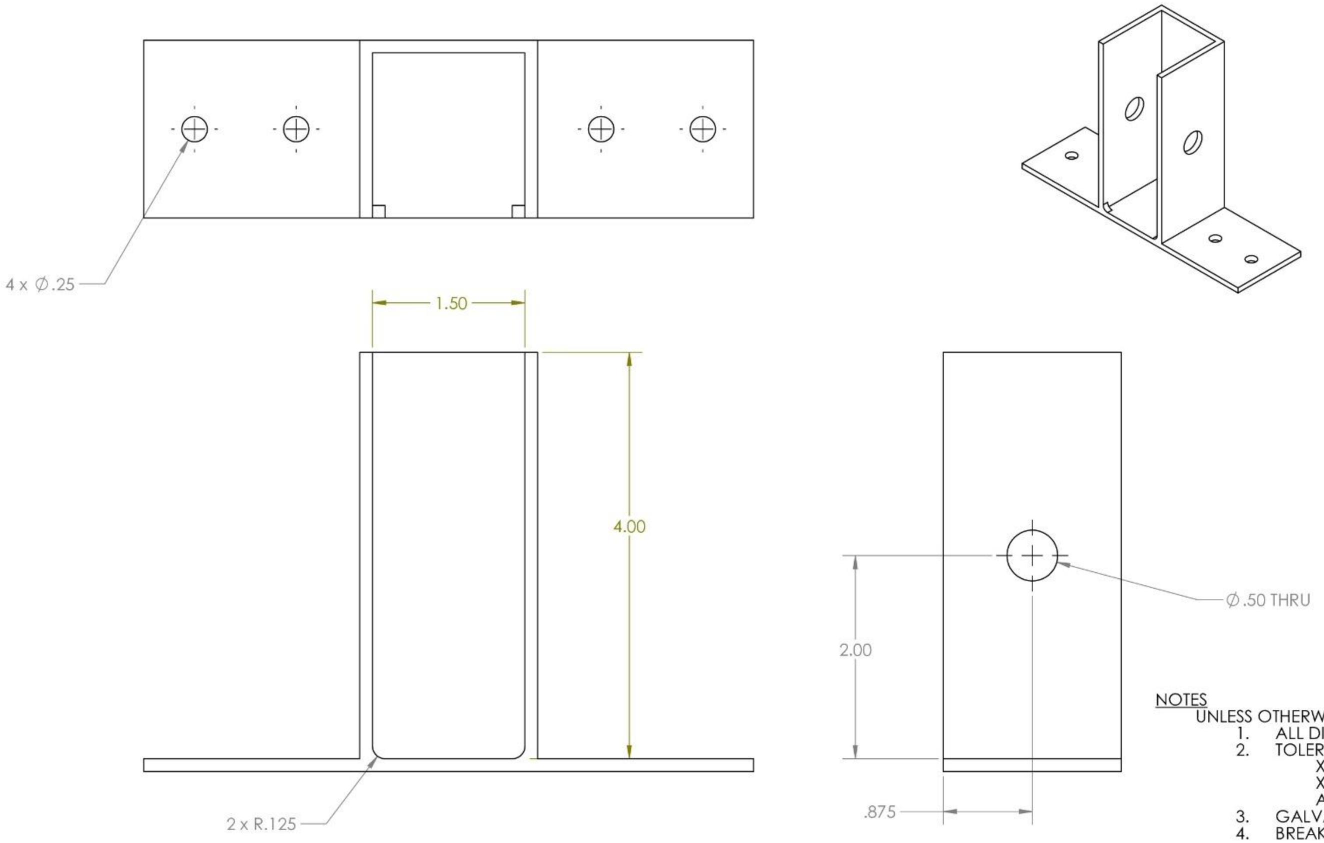
UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR ± .5° ONE PLACE DECIMAL ± .06 TWO PLACE DECIMAL ± .03 THREE PLACE DECIMAL ± .01	DRAWN	TS	12/23/2004
	CHECKED	JG	12/23/2004
	ENG APPR.		
	MFG APPR.		
GUAGE: TABLE	Q.A.		
MATERIAL: GALV	COMMENTS:		
DO NOT SCALE DRAWING			

PART NUMBER
510

PDMWorks Project: SQ. TUBE CONNECTORS

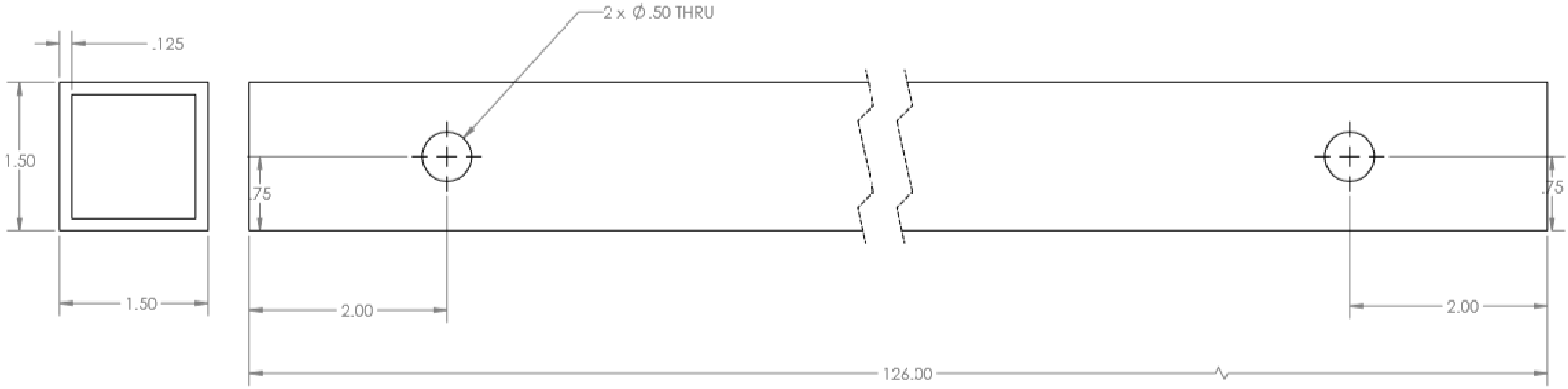
Rev. By: CJO

Last Rev. Date: 3/9/2006



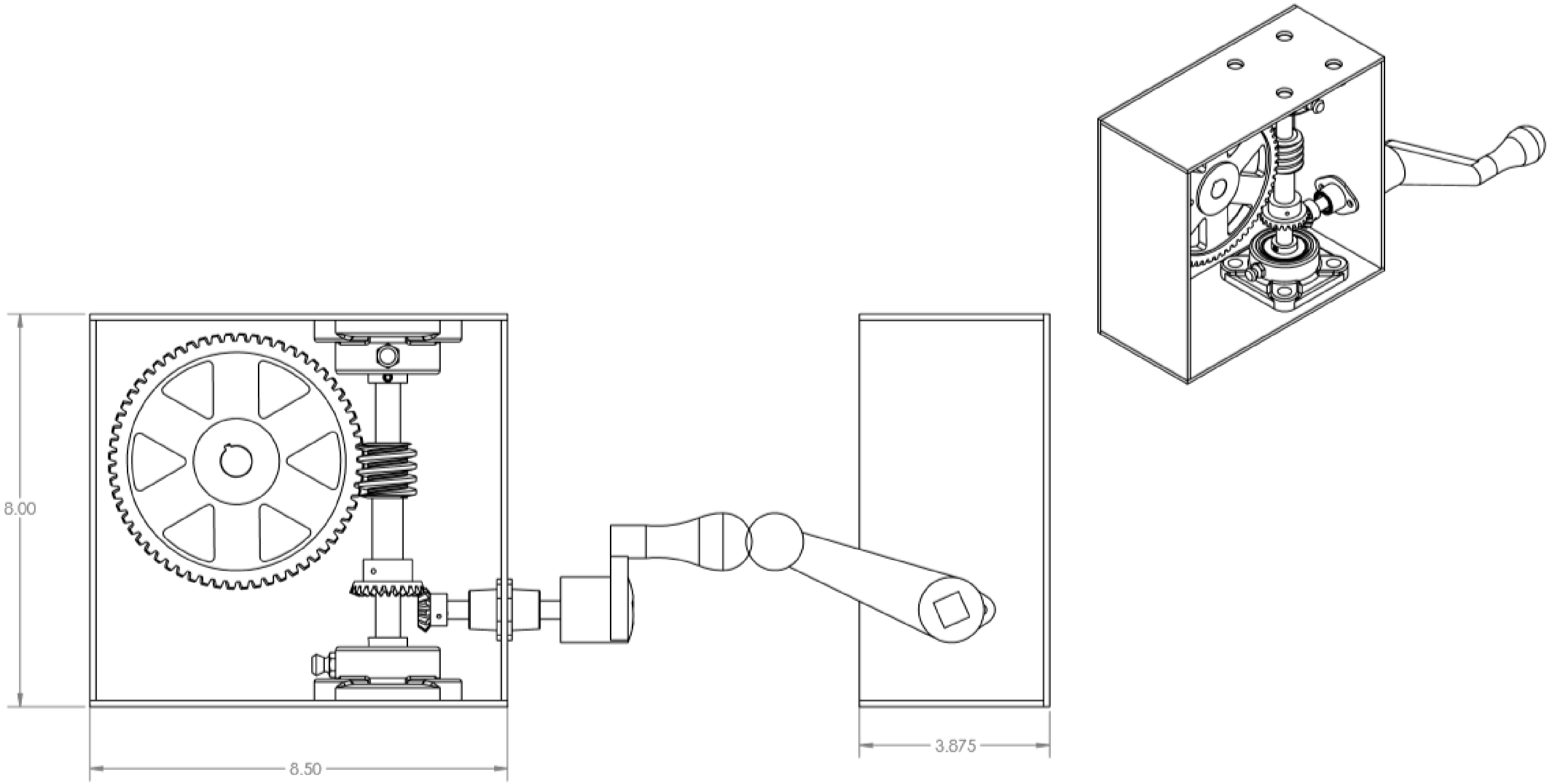
NOTES
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMENSIONS IN INCHES
2. TOLERANCES:
X.XX = ±0.01
X.XXX = ±0.005
ANGLES = ±1°
3. GALVANIZED STEEL TUBE FITTING
4. BREAK SHARP EDGES 0.005 MAX

Cal Poly Mechanical Engineering	Lab Section: N/A	Assignment N/A	Title: Tube Fitting		Drwn. By: Chris Ewert
ME 429 - WINTER 2020	Part #: 510	Nxt Asb: 520	Date: 2/4/20	Scale: 1:1	Chkd. By:



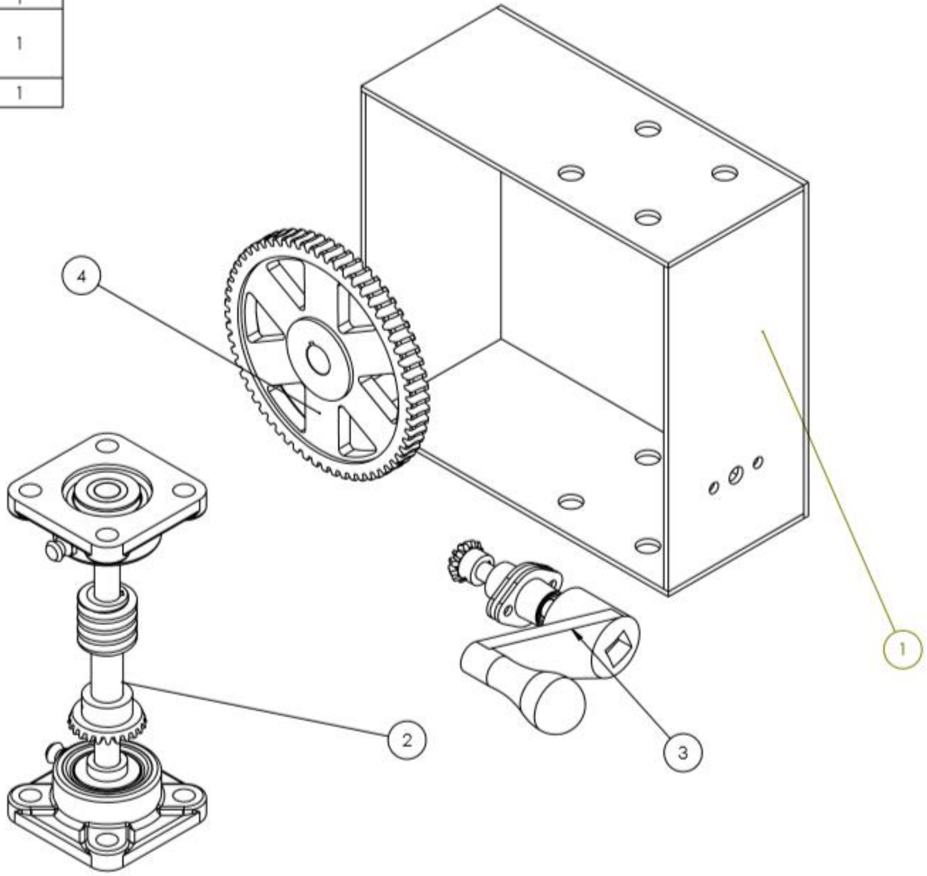
NOTES
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMENSIONS IN INCHES
2. TOLERANCES:
    X.XX = ±0.01
    X.XXX = ±0.005
    ANGLES = ±1°
3. 1/8" THICK STEEL TUBING
   1045 CARBON STEEL
4. BREAK SHARP EDGES 0.005 MAX

Cal Poly Mechanical Engineering	Lab Section: N/A	Assignment N/A	Title: Tube		Drwn. By: Chris Ewert
ME 429 - WINTER 2020	Part #: 520	Nxt Asb: N/A	Date: 2/4/20	Scale: 1:1	Chkd. By:

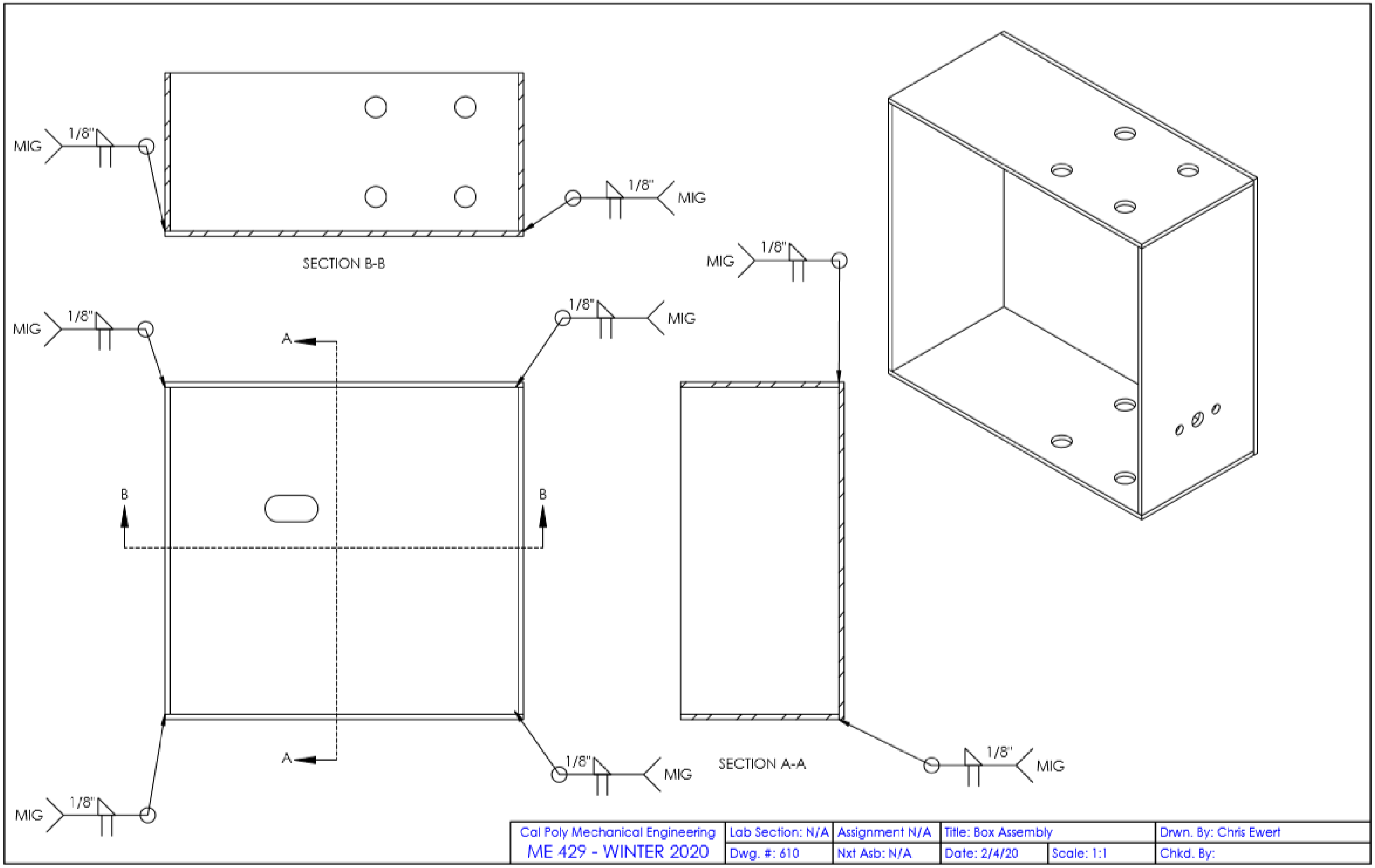


Cal Poly Mechanical Engineering	Lab Section: N/A	Assignment N/A	Title: GearBox Assembly		Drwn. By: Chris Ewert
ME 429 - WINTER 2020	Part #: 600	Nxt Asb: N/A	Date: 2/5/20	Scale: 1:2	Chkd. By:

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	610	BOX ASSEMBLY	1
2	612	SHAFT ASSEMBLY	1
3	613	HAND CRANK TO BEVEL ASSEMBLY	1
4	312	SPUR GEAR	1

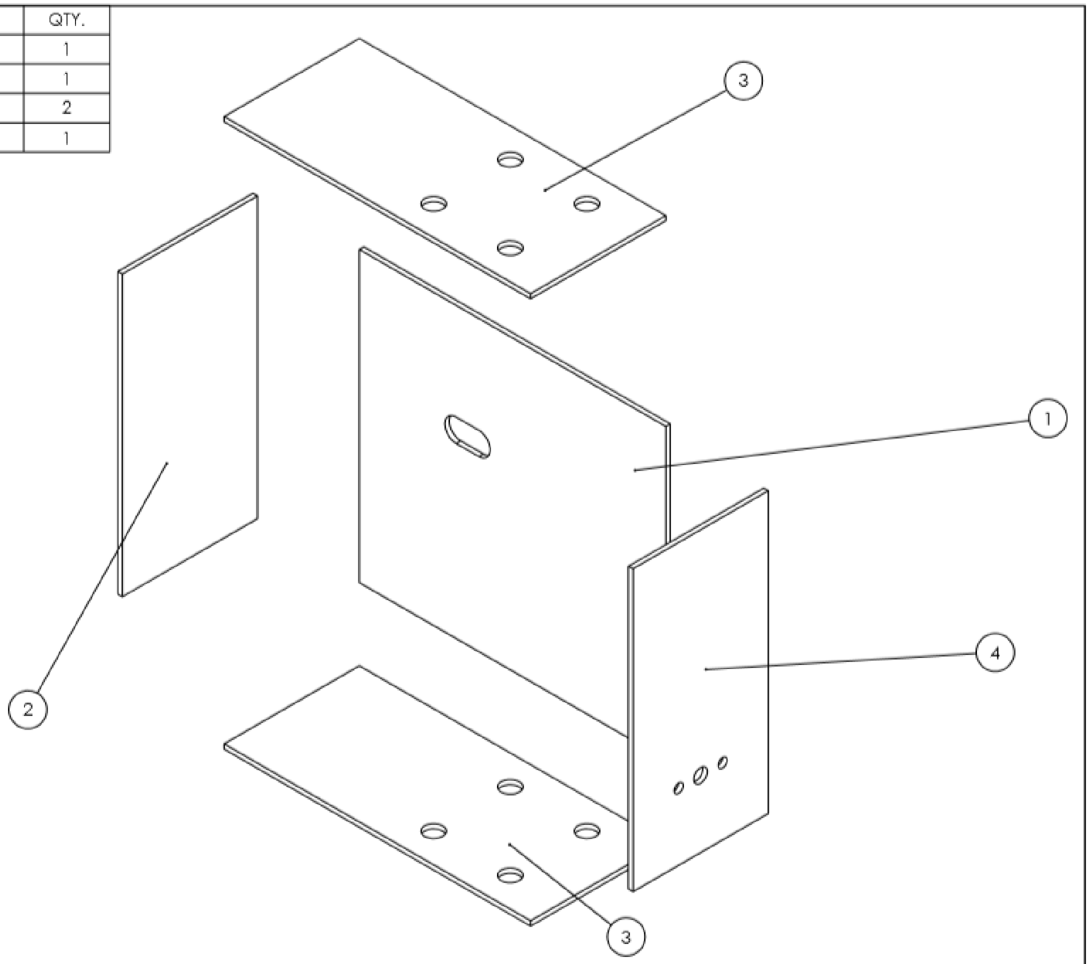


Cal Poly Mechanical Engineering	Lab Section: N/A	Assignment N/A	Title: GearBox Assembly (exp)	Drwn. By: Chris Ewert
ME 429 - WINTER 2020	Dwg. #: 601	Nxt Asb: N/A	Date: 2/5/20 Scale: 1:2	Chkd. By:

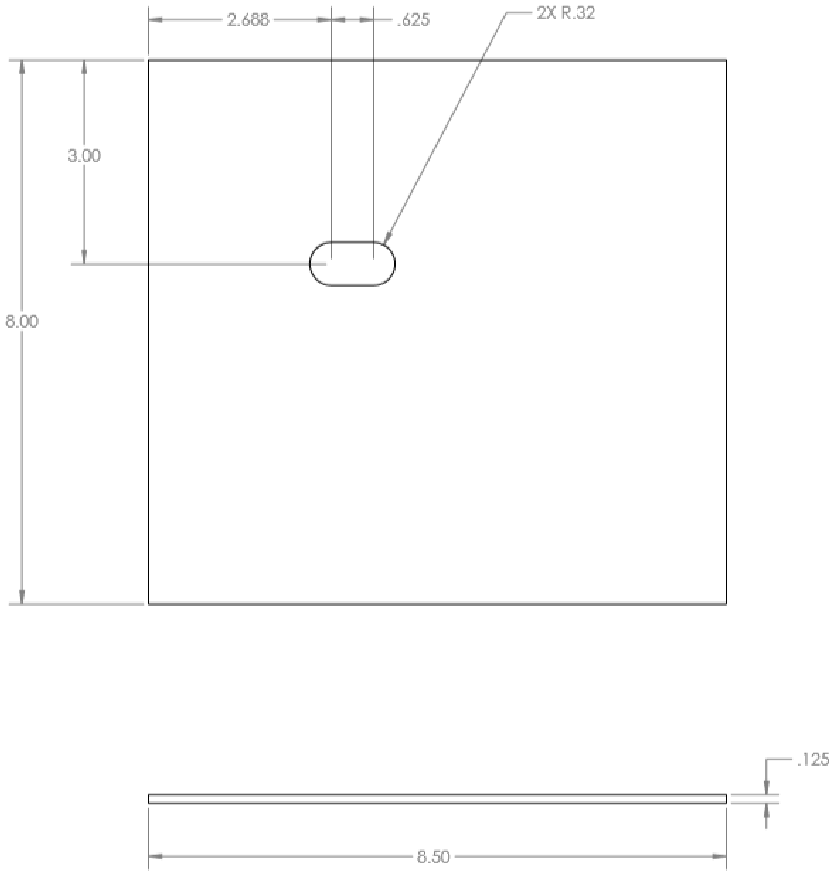


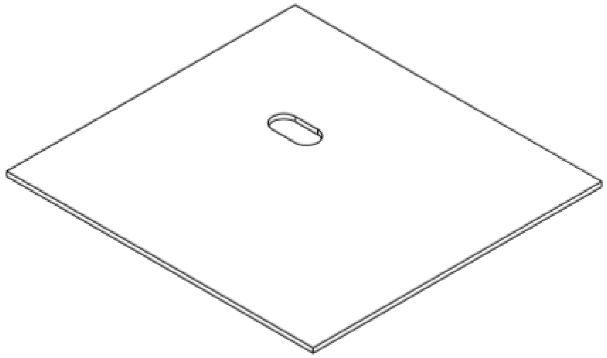
Cal Poly Mechanical Engineering	Lab Section: N/A	Assignment N/A	Title: Box Assembly		Drwn. By: Chris Ewert
ME 429 - WINTER 2020	Dwg. #: 610	Nxt Asb: N/A	Date: 2/4/20	Scale: 1:1	Chkd. By:

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	620	BACK PLATE	1
2	621	7.75 BOX SIDING	1
3	622	TOP/BOTTOM PLATE	2
4	623	7.75 BOX SIDING 2	1



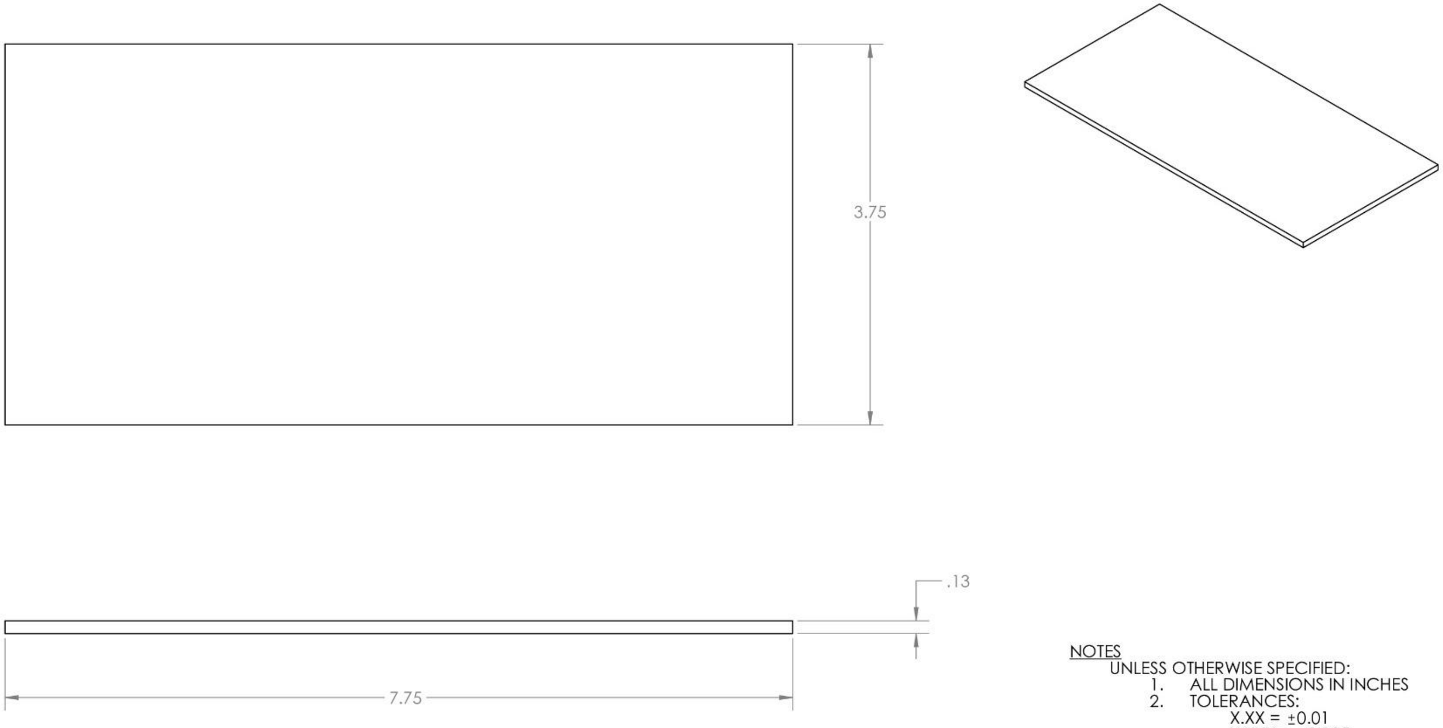
Cal Poly Mechanical Engineering	Lab Section: N/A	Assignment N/A	Title: Box Assembly (exp)		Drwn. By: Chris Ewert
ME 429 - WINTER 2020	Dwg. #: 611	Nxt Asb: N/A	Date: 2/4/20	Scale: 1:2	Chkd. By:





NOTES
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMENSIONS IN INCHES
2. TOLERANCES:
    X.XX = ±0.01
    X.XXX = ±0.005
    ANGLES = ±1°
3. 1/8" 11-GAUGE STEEL PLATE
4. BREAK SHARP EDGES 0.005 MAX

Cal Poly Mechanical Engineering	Lab Section: N/A	Assignment N/A	Title: Back Plating		Drwn. By: Chris Ewert
ME 429 - WINTER 2020	Part #: 620	Nxt Asb: N/A	Date: 2/4/20	Scale: 2:3	Chkd. By:

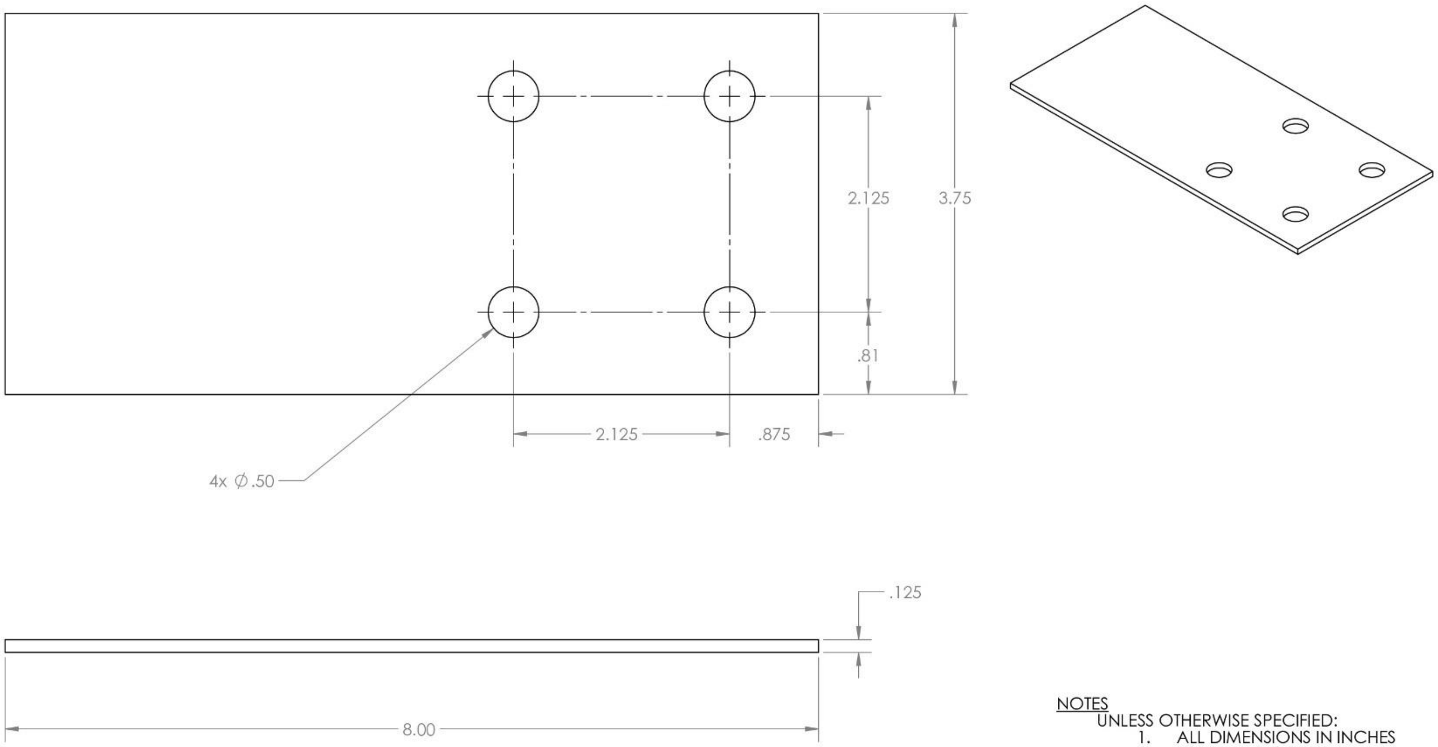


NOTES

UNLESS OTHERWISE SPECIFIED:

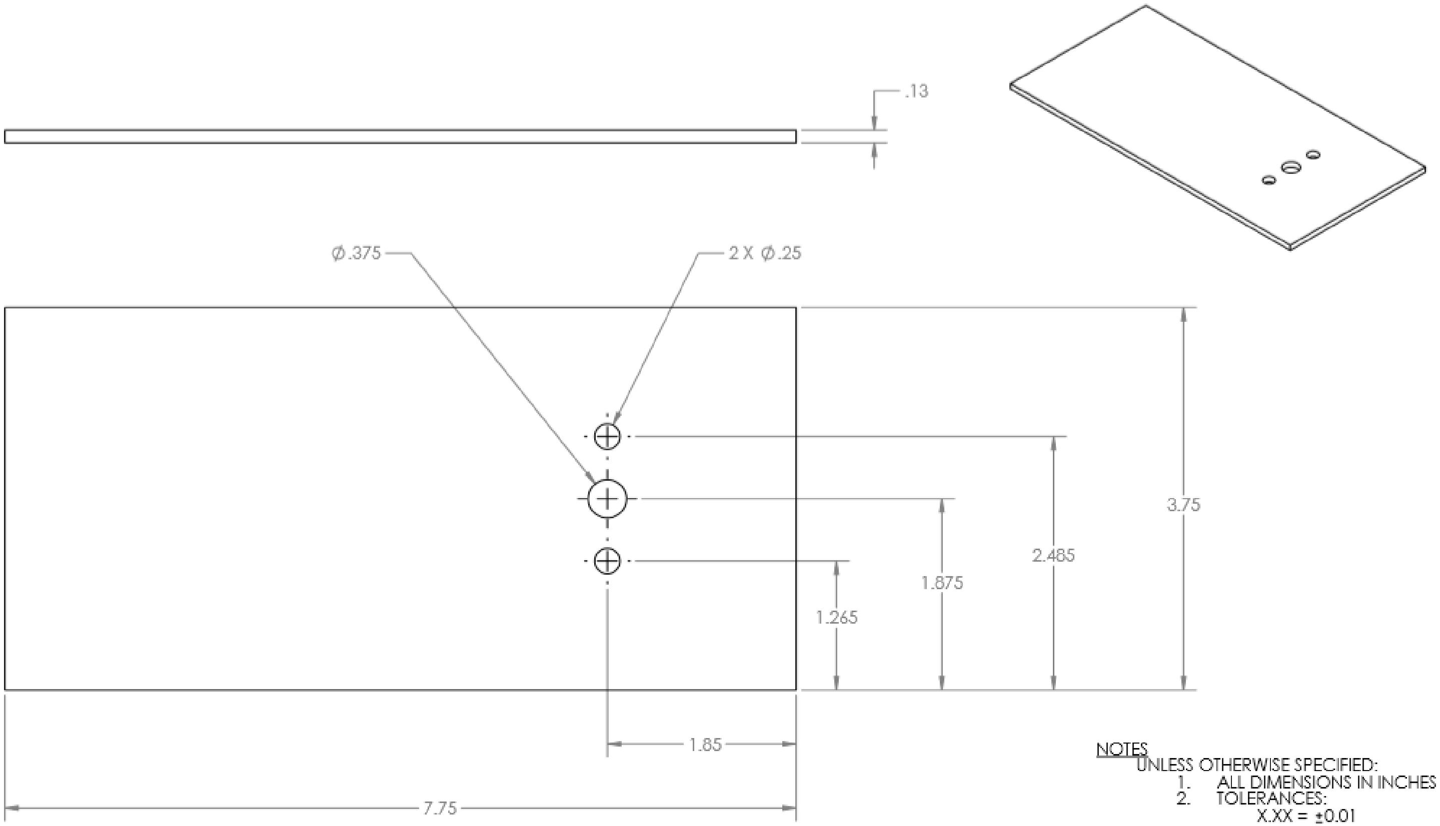
1. ALL DIMENSIONS IN INCHES
2. TOLERANCES:
   X.XX = ±0.01
   X.XXX = ±0.005
   ANGLES = ±1°
3. 1/8" 11- GAUGE STEEL PLATE
4. BREAK SHARP EDGES 0.005 MAX

Cal Poly Mechanical Engineering	Lab Section: N/A	Assignment N/A	Title: Side Plate		Drwn. By: Chris Ewert
ME 429 - WINTER 2020	Part #: 621	Nxt Asb: N/A	Date: 2/4/20	Scale: 1:1	Chkd. By:



NOTES
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMENSIONS IN INCHES
2. TOLERANCES:
   X.XX = ±0.01
   X.XXX = ±0.005
   ANGLES = ±1°
3. 1/8" 11-GAUGE STEEL PLATE
4. BREAK SHARP EDGES 0.005 MAX

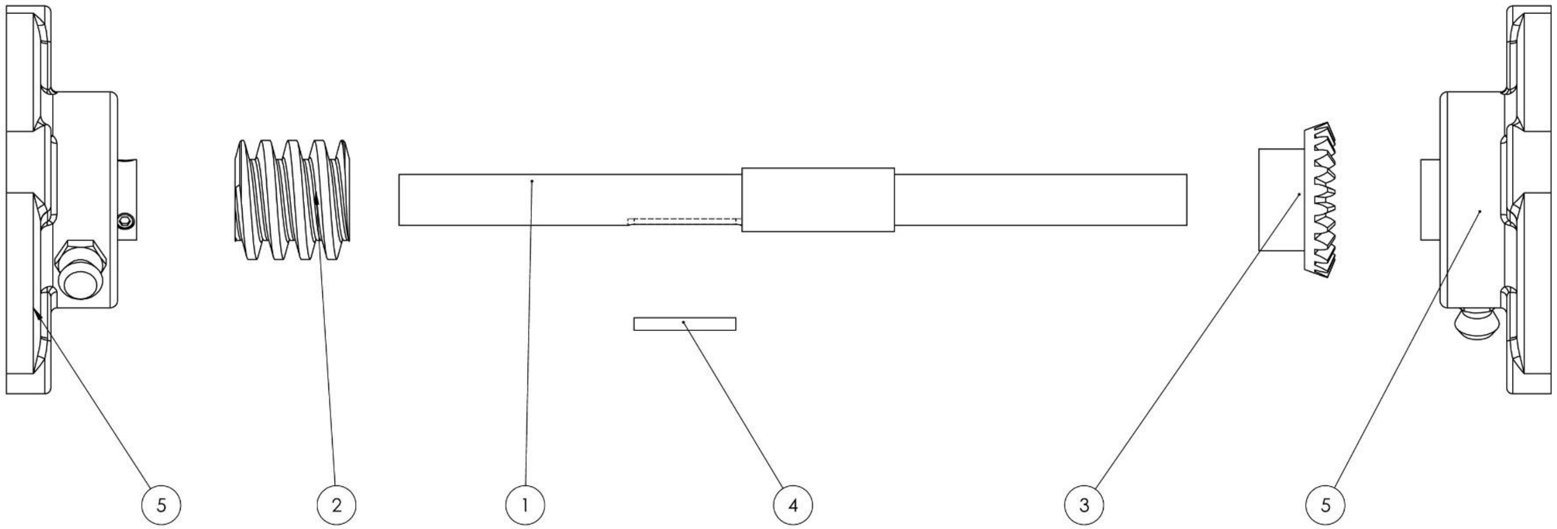
Cal Poly Mechanical Engineering	Lab Section: N/A	Assignment N/A	Title: Top/Bottom Plate		Drwn. By: Chris Ewert
ME 429 - Winter 2020	Part #: 622	Nxt Asb: N/A	Date:2/4/20	Scale: 1:1	Chkd. By:



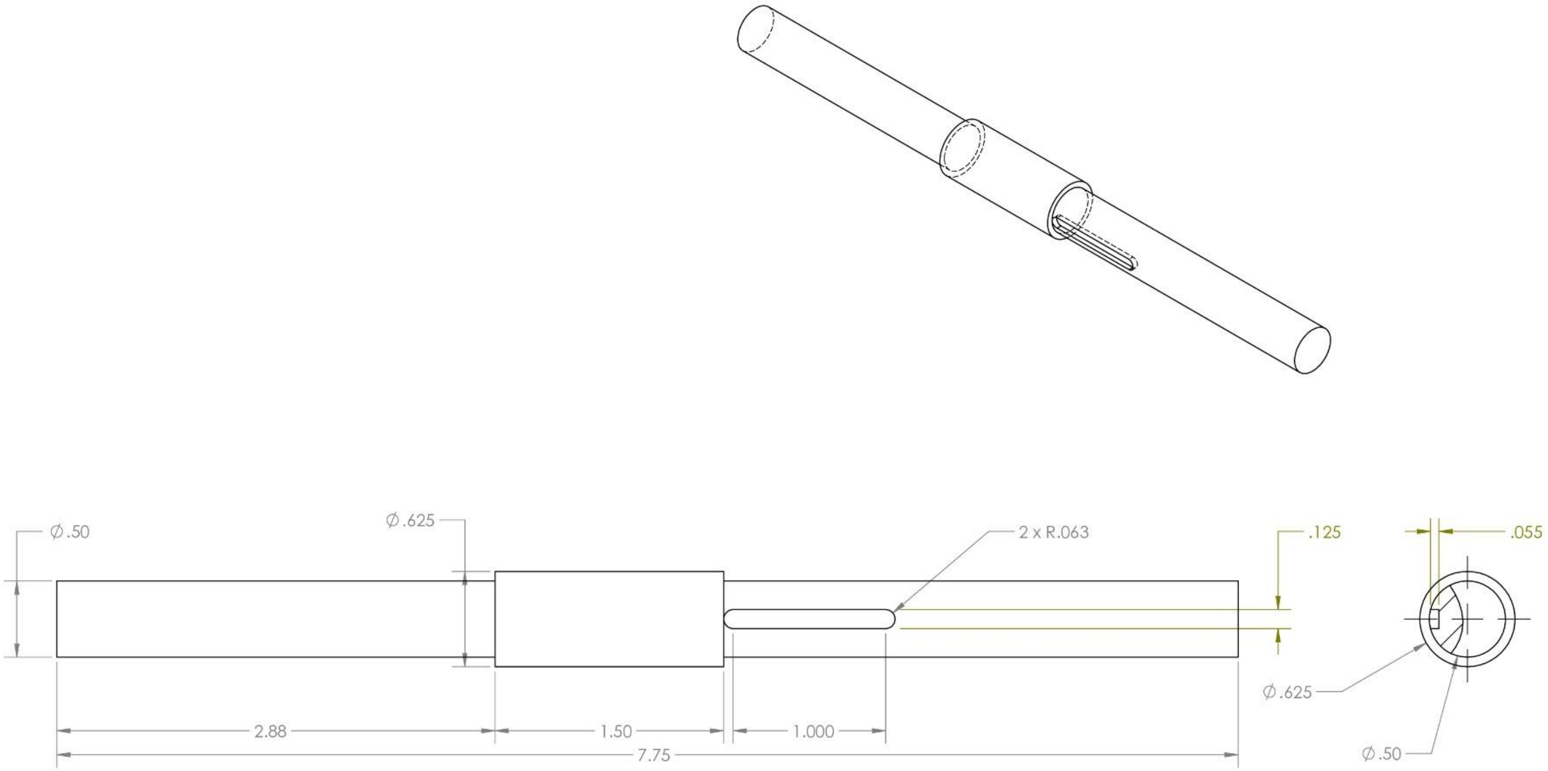
NOTES
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMENSIONS IN INCHES
2. TOLERANCES:
X.XX = ±0.01
X.XXX = ±0.005
ANGLES = ±1°
3. 1/8" 11- GAUGE STEEL PLATE
4. BREAK SHARP EDGES 0.005 MAX

Cal Poly Mechanical Engineering	Lab Section: N/A	Assignment N/A	Title: Box Siding 2		Drwn. By: Chris Ewert
ME 429 - WINTER 2020	Dwg. #: 623	Nxt Asb: N/A	Date: 3/3/20	Scale: 1:1	Chkd. By: N/A

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	630	SHAFT	1
2	631	WORM GEAR	1
3	632	BEVEL GEAR	1
4	633	KEY	1
5	634	FOUR BOLT FLANGE MOUNT	2

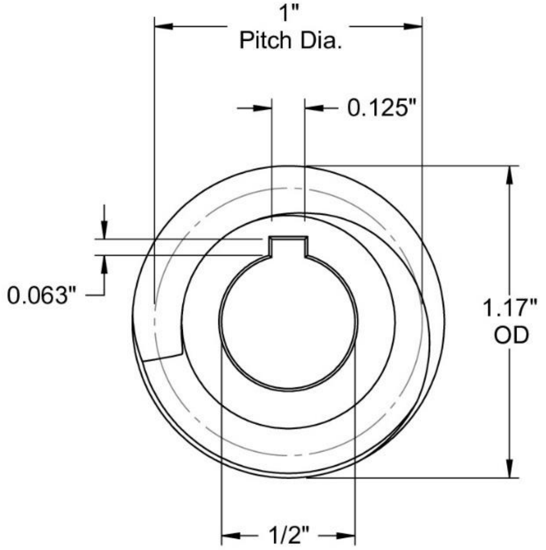


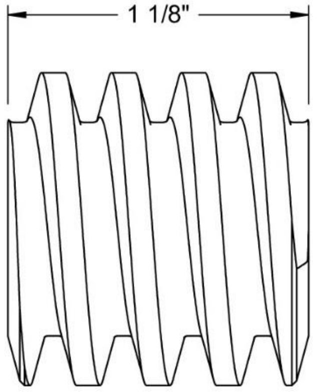
Cal Poly Mechanical Engineering	Lab Section: N/A	Assignment N/A	Title: Shaft Assembly		Drwn. By: Chris Ewert
ME 429 - WINTER 2020	Part. #: 612	Nxt Asb: N/A	Date: 2/5/20	Scale: 1:1	Chkd. By:



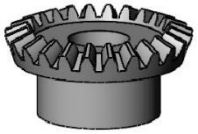
Cal Poly Mechanical Engineering	Lab Section: N/A	Assignment N/A	Title: Shaft		Drwn. By: Chris Ewert
ME 429 - WINTER 2020	Part #: 630	Nxt Asb: N/A	Date: 2/4/20	Scale: 3:2	Chkd. By:

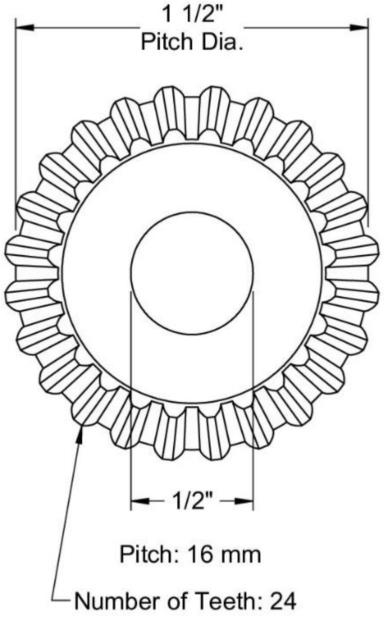
Pitch: 12

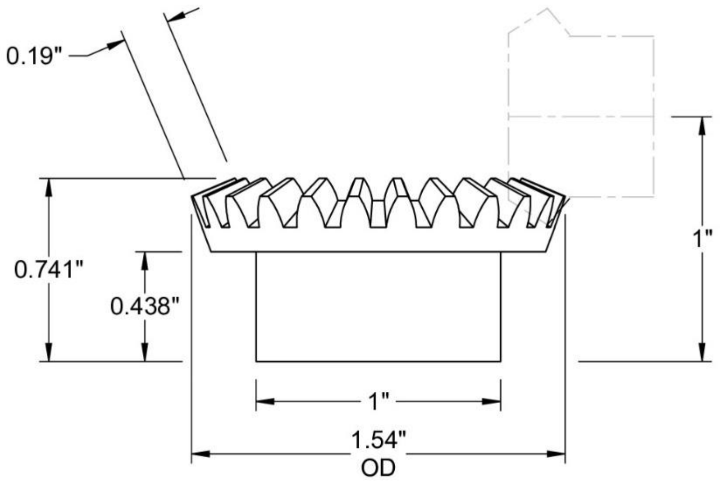




McMASTER-CARR CAD	PART NUMBER **631**
http://www.mcmaster.com Information in this drawing is provided for reference only.	Worm for Speed-Reducing Worm Gears for 90° Angle Motion Transfer - 14 1/2° Pressure Angle





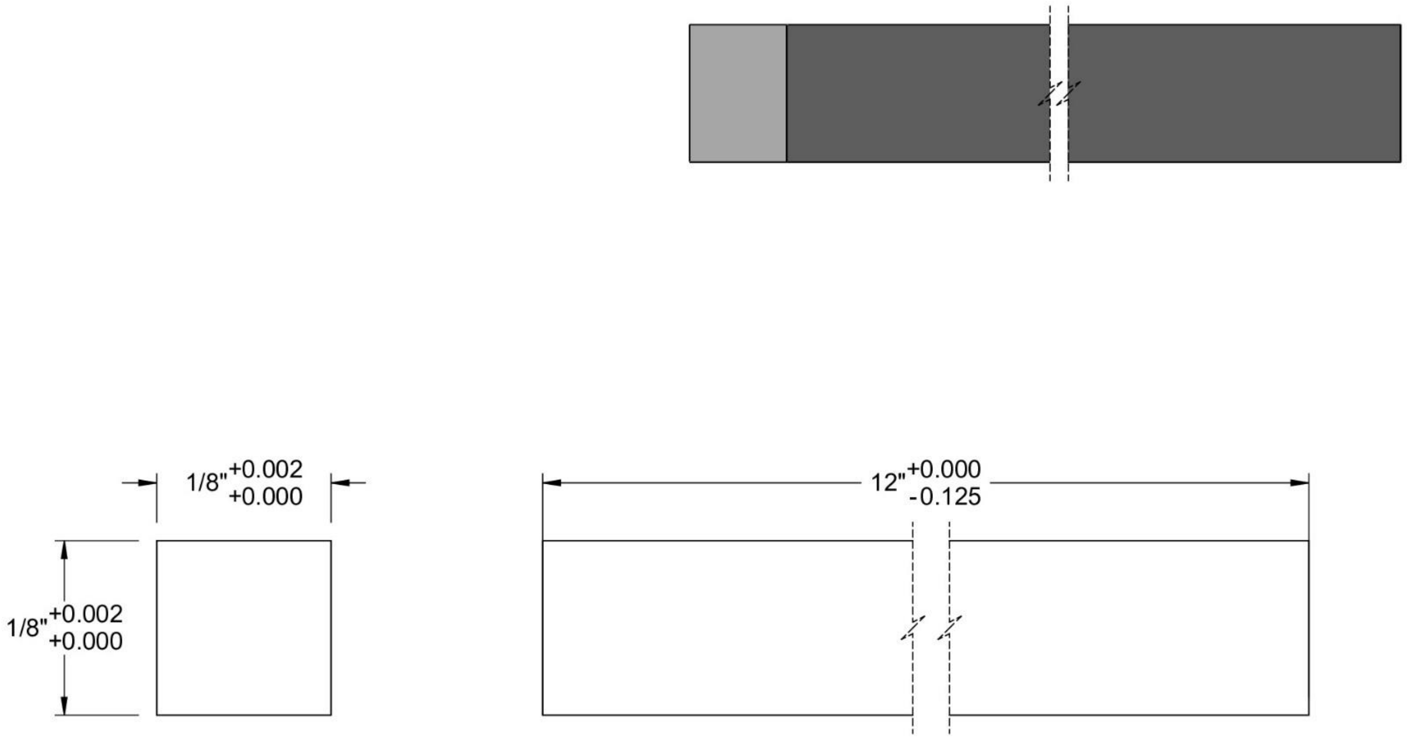


McMASTER-CARR CAD

PART NUMBER **632**

http://www.mcmaster.com

Metal
Bevel Gear

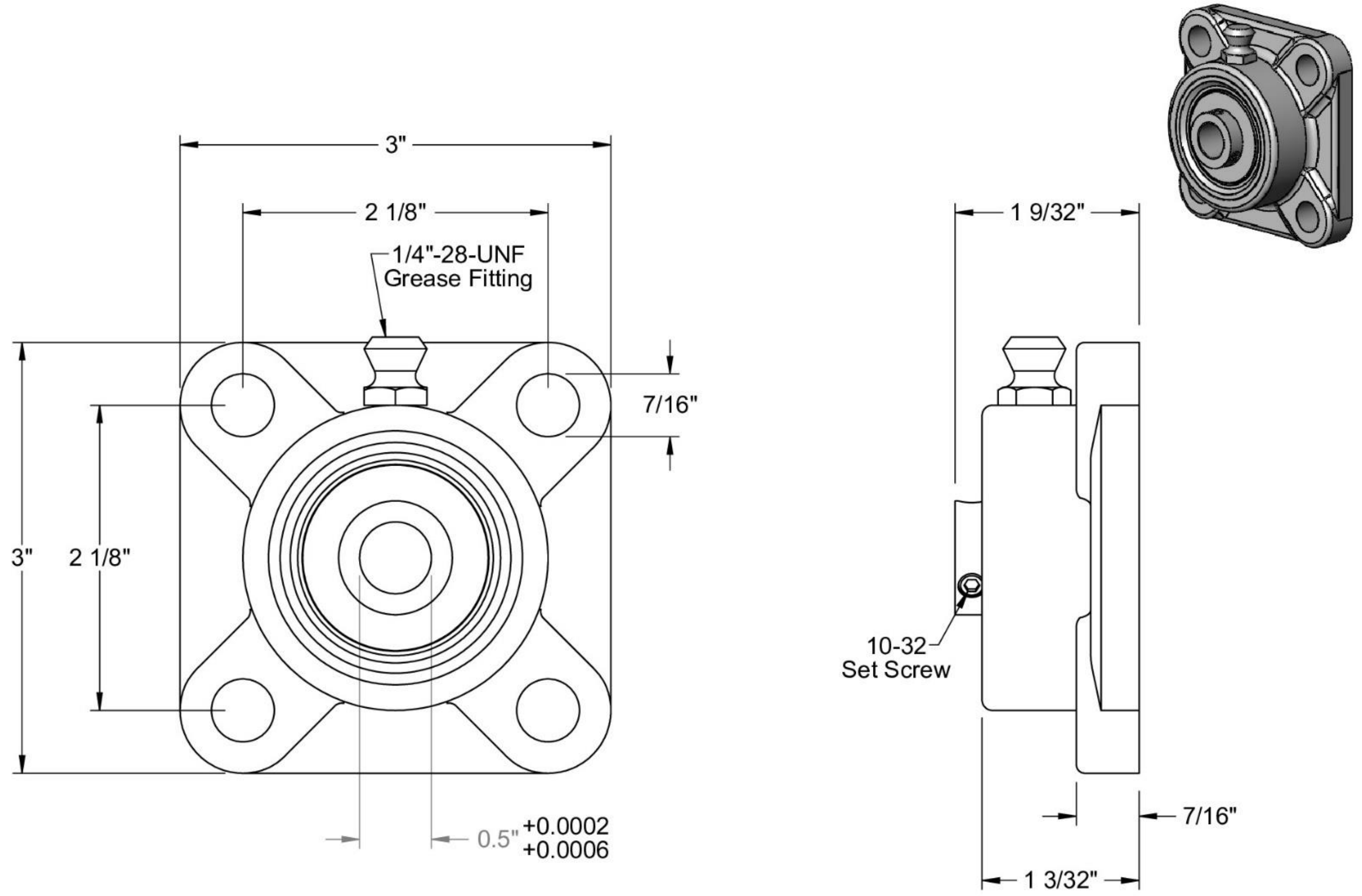


McMASTER-CARR CAD

PART NUMBER **633**

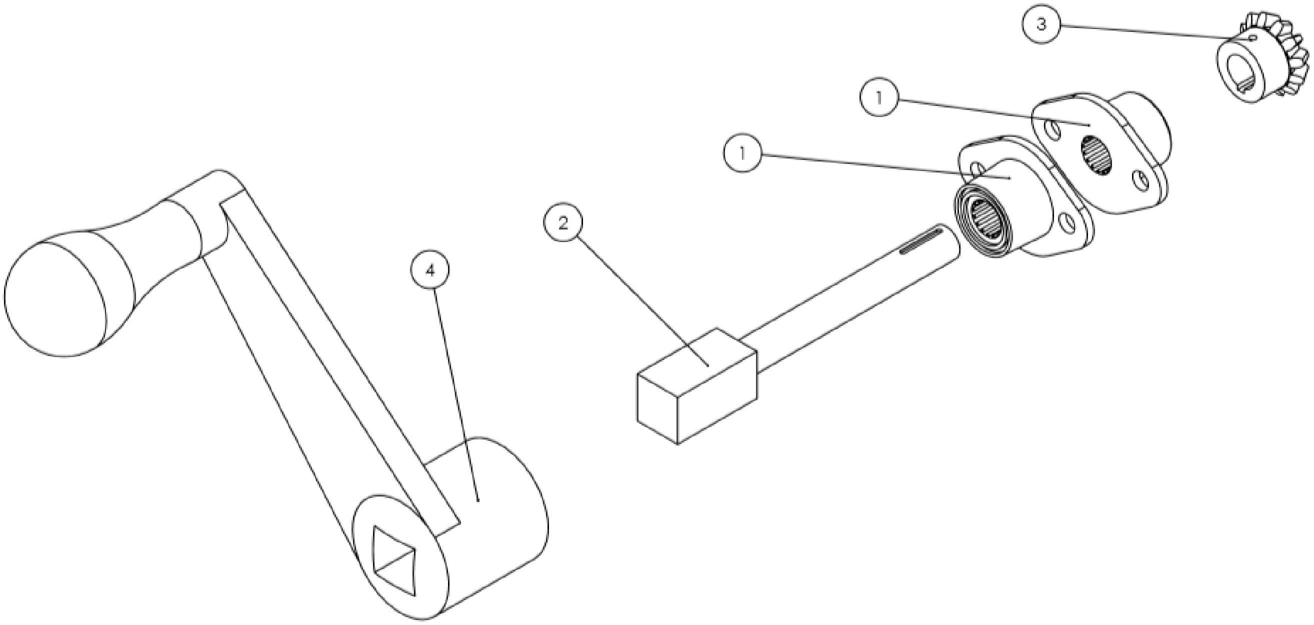
http://www.mcmaster.com
© 2019 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.

Machine
Key Stock

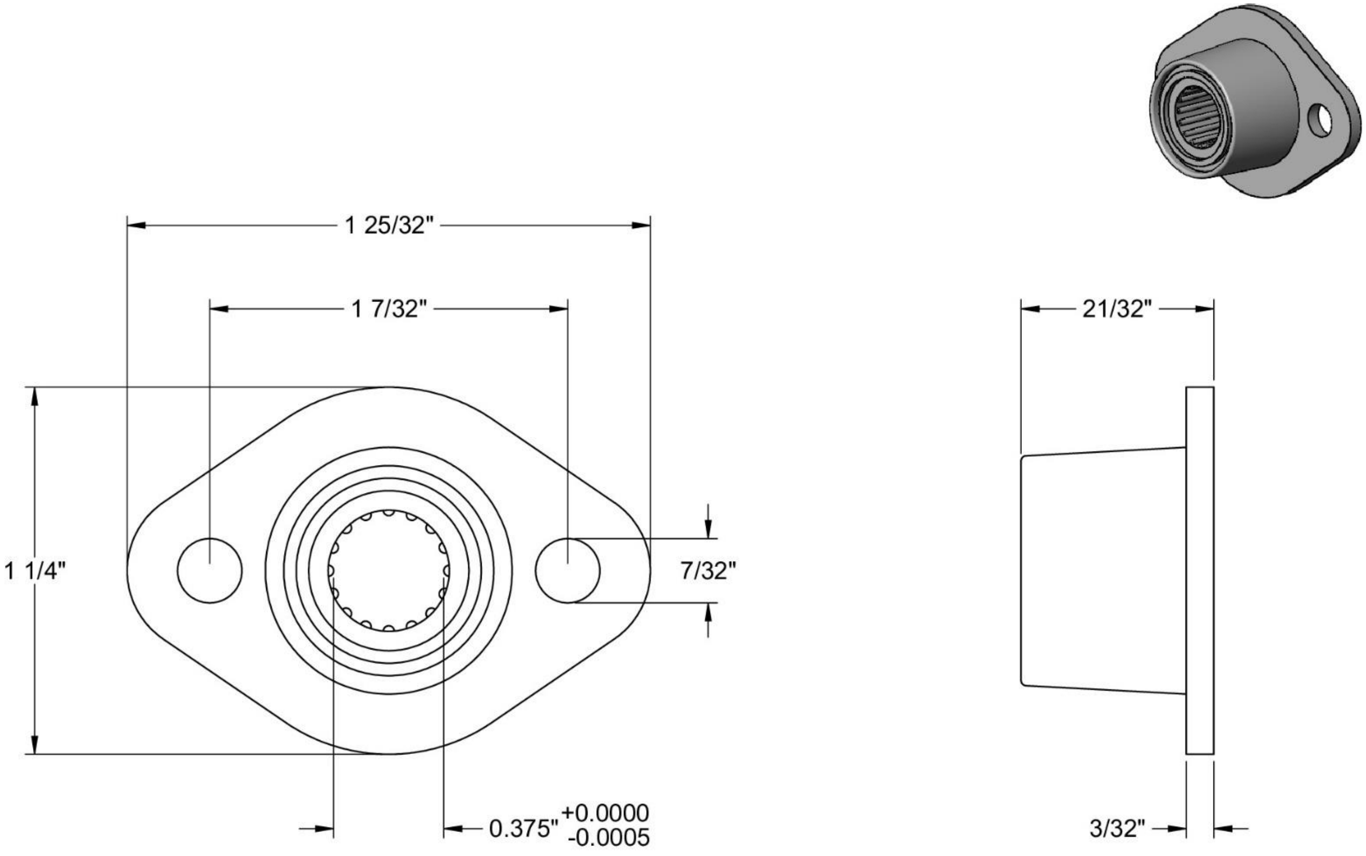


McMASTER-CARR CAD	PART NUMBER	634
http://www.mcmaster.com © 2017 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	Mounted Ball Bearing with Four-Bolt Flange	

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	640	ROLLER BEARING TWO FLANGE	2
2	641	SHAFT	1
3	642	BEVEL PINION	1
4	613	HAND CRANK TO BEVEL ASSEMBLY	1



Cal Poly Mechanical Engineering ME 429 - WINTER 2020	Lab Section: N/A	Assignment N/A	Title: Hand Crank to Bevel Assembly	Drwn. By: Chris Ewert
	Part #: 613	Nxt Asb: N/A	Date: 2/5/20	Scale: 1:1
				Chkd. By:

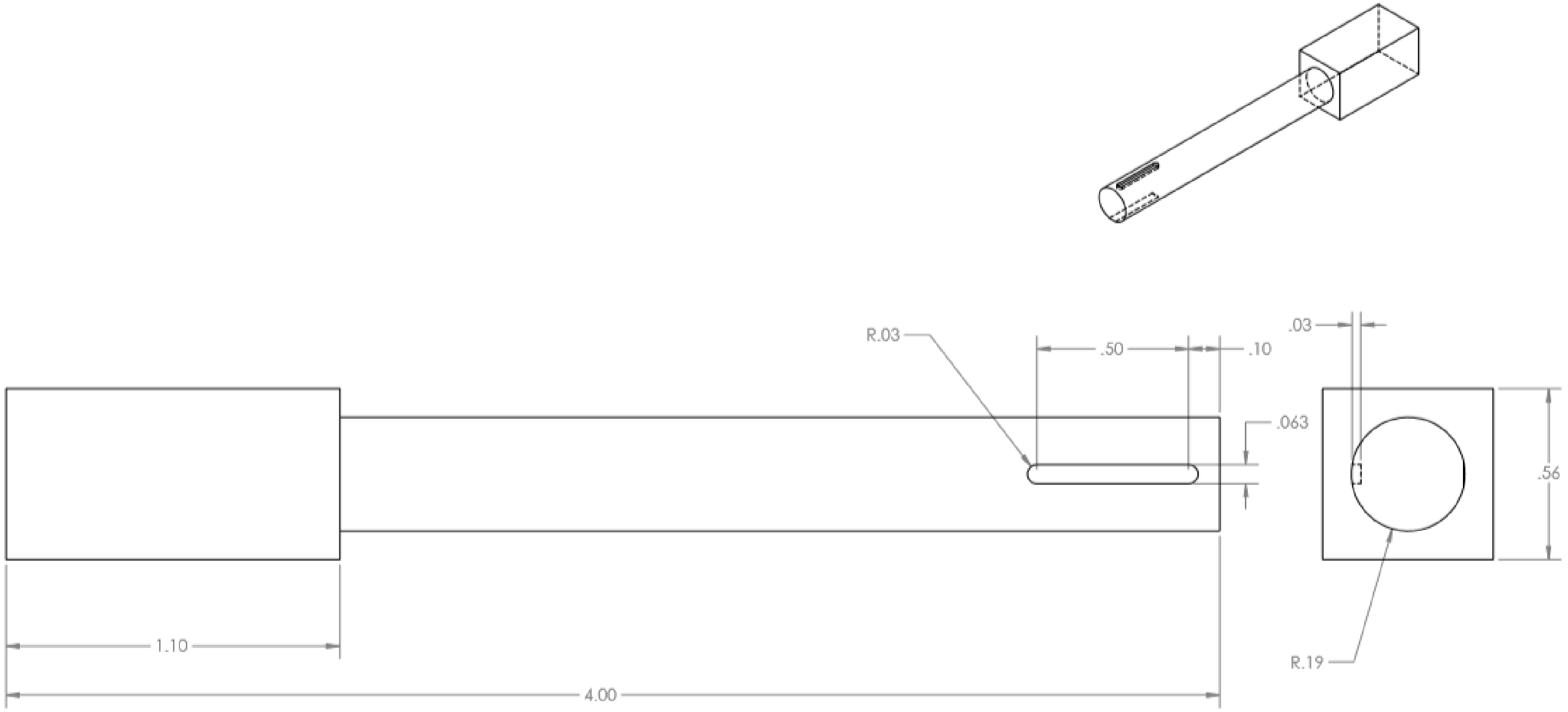


McMASTER-CARR

PART NUMBER 640

http://www.mcmaster.com

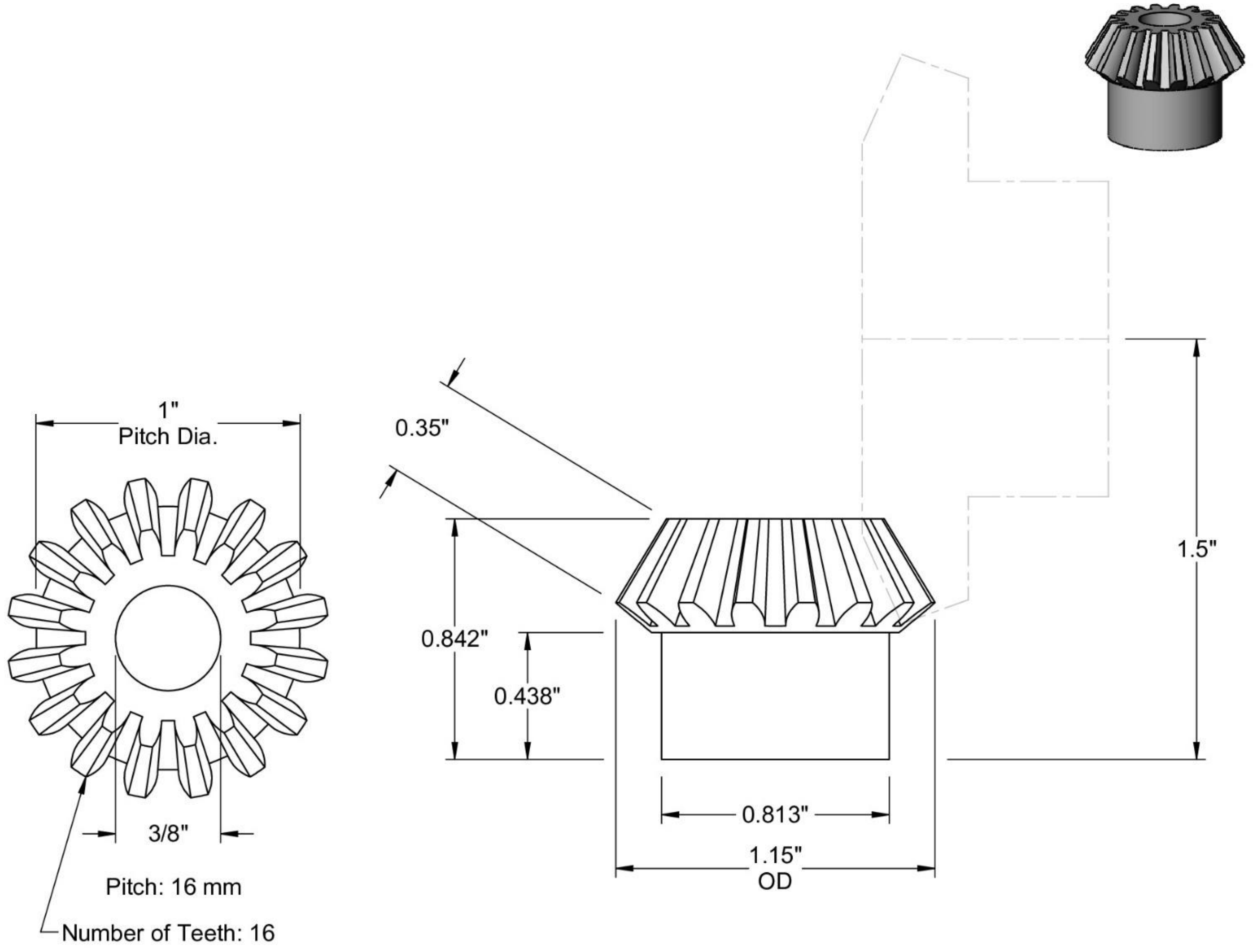
Mounted Roller Bearing
With Two-Bolt Flange



NOTES

UNLESS OTHERWISE SPECIFIED:
1. ALL DIMENSIONS IN INCHES
2. TOLERANCES:
   X.XX = ±0.01
   X.XXX = ±0.005
   ANGLES = ±1°
3. MATERIAL: 1018 CARBON STEEL
4. BREAK SHARP EDGES 0.005 MAX

Cal Poly Mechanical Engineering	Lab Section: N/A	Assignment N/A	Title: Shaft		Drwn. By: Chris Ewert
ME 429 - WINTER 2020	Dwg. #: 641	Nxt Asb: N/A	Date: 2/5/20	Scale: 3:1	Chkd. By:

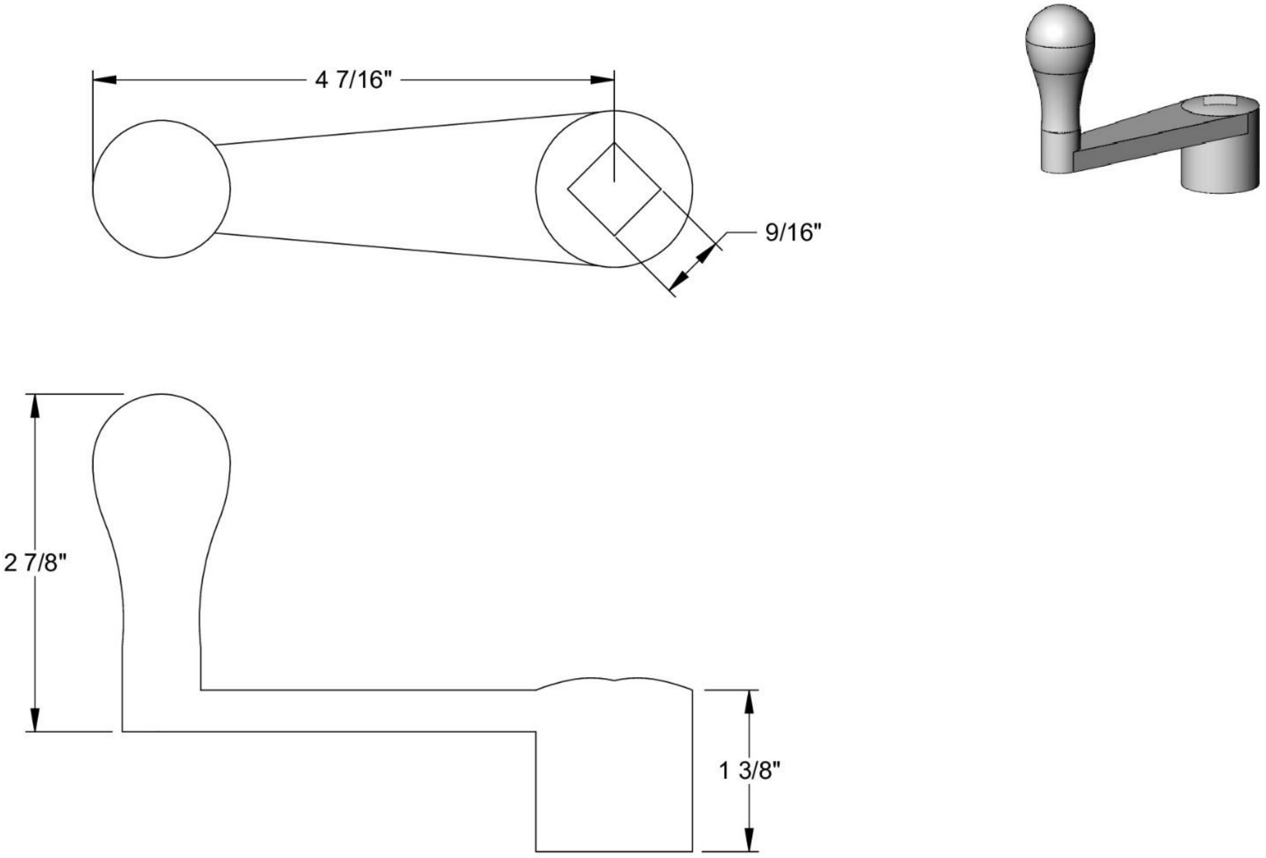


McMASTER-CARR CAD

PART NUMBER **642**

http://www.mcmaster.com

Metal Bevel
Pinion Gear



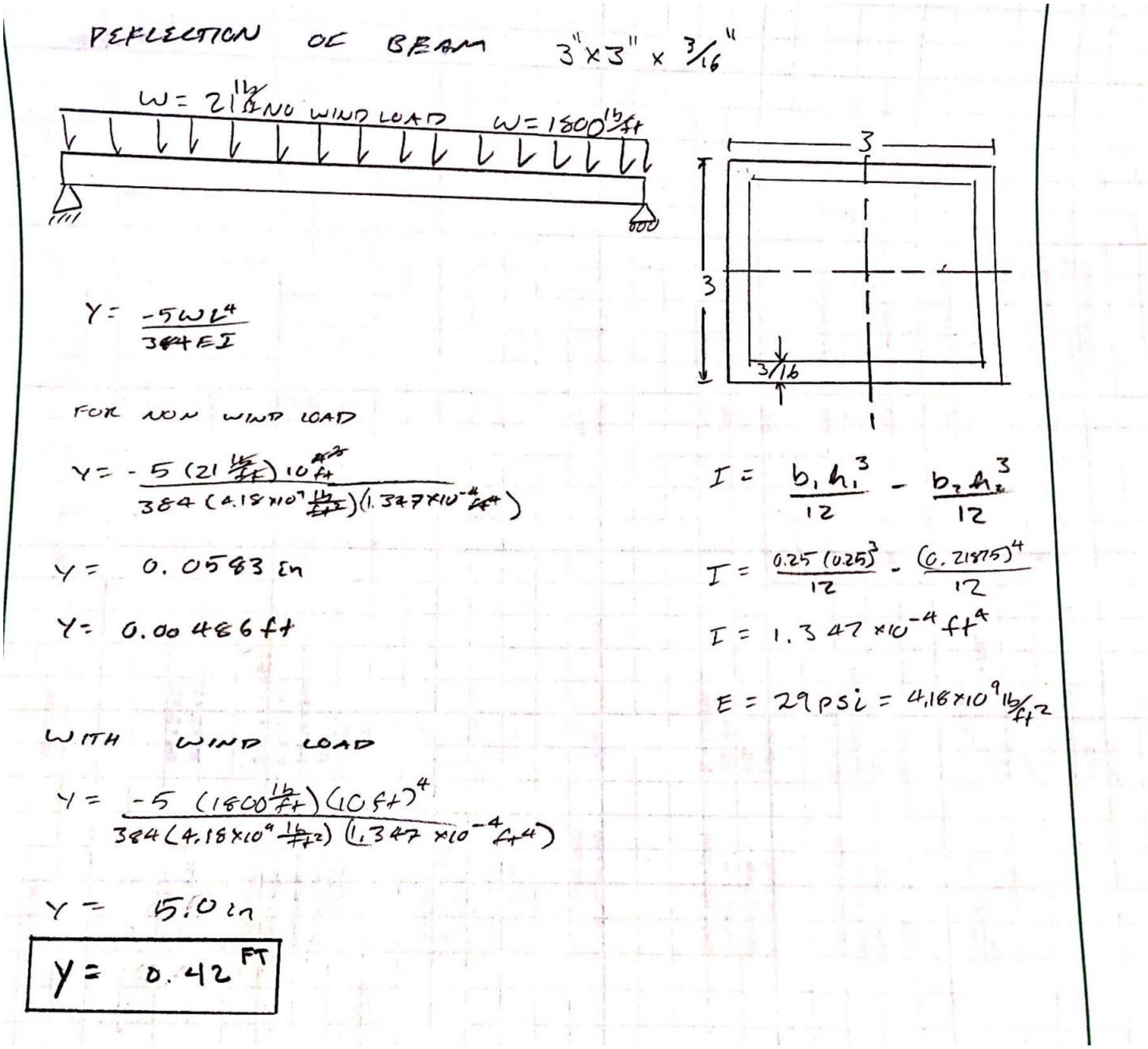
PART NUMBER **643**

http://www.mcmaster.com

Malleable Iron
Crank Handle

Unless otherwise specified, dimensions are in inches. Information in this drawing is provided for reference only.

Appendix G: Wind Load Analysis



DEFLECTION OF BEAM $3'' \times 3'' \times \frac{3}{16}''$

$W = 21 \frac{lb}{ft}$ NO WIND LOAD $W = 1800 \frac{lb}{ft}$

3

3

3/16

$$Y = \frac{-5WL^4}{384EI}$$

FOR NON WIND LOAD

$$Y = -\frac{5\left(21\frac{lb}{ft}\right)10\,ft^4}{384\left(4.18\times10^7\frac{lb}{ft^2}\right)\left(1.347\times10^{-4}ft^4\right)}$$

$Y = 0.0583$ in

$Y = 0.00486$ ft

$$I = \frac{b_1h_1^3}{12} - \frac{b_2h_2^3}{12}$$

$$I = \frac{0.25(0.25)^3}{12} - \frac{(0.21875)^4}{12}$$

$I = 1.347\times10^{-4}\,ft^4$

$E = 29\,psi = 4.18\times10^9\,lb/ft^2$

WITH WIND LOAD

$$Y = \frac{-5\left(1800\frac{lb}{ft}\right)(10\,ft)^4}{384\left(4.18\times10^9\frac{lb}{ft^2}\right)\left(1.347\times10^{-4}ft^4\right)}$$

$Y = 5.0$ in

$$\boxed{Y = 0.42\,FT}$$

Figure 35. Calculations for 3” x 3” Rotating Bar Deflection.

Appendix H: Failure Mode and Effect Analysis

													Action Results			
	System / Function	Potential Failure Mode	Potential Effects of the Failure Mode	Severity	Potential Causes of the Failure Mode	Current Preventative Activities	Occurence	Current Detection Activities	Detection	Priority	Recommended Action(s)	Responsibility & Target Completion Date	Actions Taken	Severity	Occurence	Criticality
Systems	GearBox	Exposed Gears may become loose	User injury, may have hand injured by rotating gears	4	Shield breaking, casing falling off	Gearbox housed by metal frame	1	Instruction to inspect gearbox before use	2	8						
	Gearbox	Teeth may shear	Cannot operate	7	Repeated use causing fatigue	Regular manitanence at expected gear life	3	monthly visual inspection	4	84	Use material that is hardened and treated to withstand wear and fatigue					
	Gearbox	Crank arm breaking	Cannot operate	1	Fatigued, improper use of system	Material strength, no improper loads added	1	Test ease of rotation for tilt adjustmeny	2	2						
	GearBox	Gears may lock up	Panels cannot be rotated	2	No lubrication and or rusting	Housing system for the gears	1	Turn Crank to se if it turns	1	2						
	GearBox	Crank system causes user hand fatigue	Injury to user	2	Repeated action performed by user	Ensuring gear ratio is conducive to user interface	1	user fatigue	1	2						
	Rotating Bar	Bearings may have shorter life spans due to deflections in beam	failure of operation	2	repetitive use, improper loading of panels	Load panels evenly, ensure bar is strong enough for deflection	1	Observe bearing condition before each use	1	2						
	Frame	Weight	Might be unable to move system	2	Poor choises of materials and ineffective frame design	FEA analysis on structure and finding light materials	1	Scale, and trial	3	6						
	Frame	Falling apart	User injury, failure of operation	9	Assembly of mount improper	Follow instructions for assembly	2	Visual inspection before use	4	72	Each bolt, nut, and pin are properly fitted and can have the proper torque applied to tighten each joint Create detailed assembly instructions for user assembly.					
	Frame	Frame may buckle	User Injury and System Failure	9	Unforeseen weight applied to rotating bar	Labels warning the users of unintentional loading on frame	1	List of specifications for loading and how to properly do so	2	18						
	Frame	Damage to level	No system	1	Dropping mount during transportation	Be careful during transportation	1	Carry assembly in components and not as one piece	1	1						
	Wheels	Wheels breaking off legs	Hitting lip, bump, or rock	1	Unaccounted for load and improper application of load on wheels	Proper mounting and fastening	1	Label indicating not to crash mount while moving	3	3						

													Action Results			
	System / Function	Potential Failure Mode	Potential Effects of the Failure Mode	Severity	Potential Causes of the Failure Mode	Current Preventative Activities	Occurence	Current Detection Activities	Detection	Priority	Recommended Action(s)	Responsibility & Target Completion Date	Actions Taken	Severity	Occurence	Criticality
Function	Azimuth Rotation	Wheel becoming unlocked	Wheels run overfeet	7	Lock mechanism not properly tightened after rotation	Put note ensuring wheels are locked after rotation	2	Test locking mechanism for first application	2	28						
	Azimuth Rotation	Tipping of mount	Damage mount, cause injury to user	8	Hitting large crack, moving mount to fast, run over object in way	Warning labels to not move mount too fast and awareness of objects moving over	1	Test moving application and warn users of objects being moved over	5	40	Ensure large enough wheels to ensure no tipping and require slow system transportation					
	Azimuth Rotation	inability to move	not capture proper sun angles	1	Mount is too heavy to move	Decrease the overall weight to improve function	5	Test and Analysis	1	5						
	Azimuth Rotation	Low resolution to angle towards sun	Customer may be dissatisfied when locating panel	1	Too large of tolerance in relocation, possible uneven surface	Implement an axis for the system to rotate with	5	Slowly adjust panel to needed angle and analyze each position	2	10						
	Tilt Rotation	Pinch points	User injury or bodily harm	7	User sticking body parts or clothing in these locations	Label pinch points and no loose articles on user exposed	5	Test locations and probability of possible action occurring	2	70	Remove dangling articles on user and keep body parts clear during operation					
	Panel Mounting	Disconnecting	Damage brackets, injure user, and damage panel connections	3	Too heavy for single user and not properly informed of how to dismount	Multiple users to remove single panel	3	Strength and size of user	1	9						
	Panel Mounting	Bolts shearing	Damage panels, injure user, and cannot operate	8	Wrong bolts used on system or bolts are loose during operation	Ensure nuts are fastened tight to bolts and	2	Wiggle/shake system before panel is mounted to ensure system does not move	2	32	Verify all bolts are tight at each joint with very little tolerance before operation					

Appendix I: Manufacturing Plan

Manufacturing Plan

Support Frame

A-Frame (200)

Circular Saw

1. Cut four pieces of 2” x 2” steel at a length of 4’ with a 30-degree cut on the top and bottom that are parallel to each other
2. Cut two pieces at a length of 1.5 feet from tip to tip with a 30-degree angle cut angling in toward each other to mate with the interior faces of the four-foot-long pieces.
3. Cut out two 2” x 2” x 6” square tubing to act as the base for the pillow bearing.

Water Jet

4. Cut four pieces of plate steel to 5” x 4” x 1/8” for the caster wheel support base.

Drill Press

5. Drill eight small holes that are ¼"-20 into each interior face of the horizontal 2.5-foot piece to connect each 2” heavy duty galvanized square tube fitting with a ¼"-20 bolt
6. Drill out the holes in each of the T-joints to widen the hole and allow for the ¼"-20 bolt to fit in, the existing holes that are predrilled are not large enough to allow for the necessary bolt to hold the load.
7. Drill four ¼”-20 thru holes on each 4” x 4” x 1/8” base plate in the corners that are concentric to the holes in the caster wheels.
8. Drill a 3/8” thru hole in the perpendicular leg of the T-joint for each of the two joints on the side faces.
9. Drill two 3/8” diameter holes that penetrate the top face of the steel tubing but do not go all the way through. These holes will be used for mounting points of the pillow bearing and the base.

Grinding Wheel

10. Grind down the sharp edges of the 4” x 4” x 1/8” steel plates that are being fastened to the caster wheels.

Mill

11. Mill out the top face of each T-joint to allow for the cross bar to be able to slide in and be pinned on the side.

Weld

12. Weld a 4” x 4” plate, centered at the bottom of each leg to act as a base for the frame.
13. Weld each of the 1.5-foot horizontal beams with the 30-degree angle facing up to weld to the inside of the four-foot pieces.
14. Weld each 2” x 2” x 6” square tube to the top of each portion of the A-frame to act as a tabletop.

Assembly

15. Bolt the pillow bearing down to the top of the 2” x 2” x 6” square tube on each frame.

Support Bar (500)

Circular Saw

1. Cut two 10’ piece of 1.5” x 1.5” steel to span the lower cross section for stability.

Drill Press

2. Drill a 3/8” diameter hole in each end of the bottom ten-foot bars that is the same distance away from the T-joint to make the connection with a bolt.

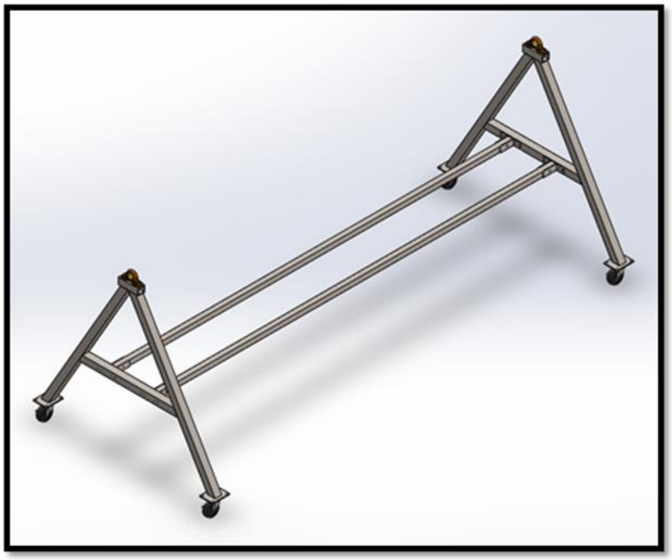


Figure 36. Support Frame

Rotating Bar (300)

Rotating Horizontal Long Cross Beam

Circular Saw

1. Cut a piece of 3” x 3” steel to a length of 10’ that will span from one bearing on top to the other bearing.

Drill Press

2. Drill nine thru holes at 3/8" diameter in increments of three holes at 13-¾” apart to fasten each of the panels to.

Joint Piece at Bearing

Circular Saw

1. Cut down two solid pieces of steel that are 2-¾” thick, with length of 9-½”.

Lathe

2. Turn down the non-gear insert piece to a diameter of 1” and a depth of 4” on one side of the metal square rod.
3. Turn down the gear side insert of the solid square steel piece to a diameter of 1” and length of 2” and then to a diameter of 5/8” at a length of 3-3/8”.

Milling

4. Mill a keyseat on the 5/8” section a half inch from the 1” section toward the outside edge of the shaft.
5. Remove a 1/16” on each edge of the solid end of the square bar to reach a steel thickness of 2-5/8” all the around the bar.

Weld

6. Weld the square end that is inserted to the depth of the turned down steel into the long horizontal bar to connect the pieces together.

Figure 37. Rotating Bar

H-frame – Mounting bracket (400)

Panel Brackets

Circular Saw

1. Cut six 1” x 1” square hollow tubing to the length of the residential size solar panels.
2. Cut six 39” x 1-½" x 2” with a thickness of 1/8” L-shape steel

Drill Press

3. Drill four holes to a diameter of ¼" for the mounting points of the solar panels for each one of the six longitudinal members, with the first hole being 4-1/8” to the center point from the bottom, the second hole being 11-¼" from the bottom, the third hole located 43-½" from the bottom, and the fourth hole 61-¾" from the bottom. The holes will be in the exact location they are located on the panel holes.
4. Drill three 3/8” thru holes in each L-shape steel piece cross member at equal spacing on each cross to mate the bolts and fasten them to it. The hole offset will be 6” from each end of the L-shape steel with the center hole residing 13-¾" from each outer hole.

Weld

5. Weld the 2” face of the L-steel to the vertical 1” x 1” bars to act as an H-design for a mounting system to the rotating bar.
6. Process will be repeated for the commercial size panels once those dimensions are known for future use.

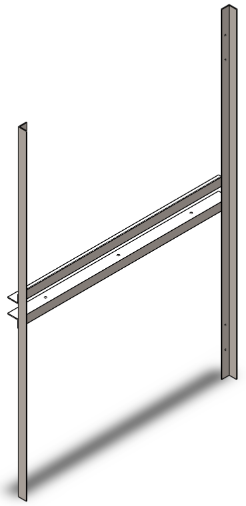


Figure 38. H-Frame

Gear Box and Crank (600)

Gear Box

Water Jet

1. Cut a hard plastic/acrylic plate to the dimensions 8” x 8” x 1/8”. Then use the jet to design a desired in the face of the plate.
2. Cut two pieces of plate steel at 7-¾" x 3-¾" x 1/8” to act as side faces.
3. Cut two pieces of plate steel at 8" x 3-¾" x 1/8” to act as the top and bottom faces of the box.
4. Cut a backing plate for the box 8” x 8” x 1/8” and drill a hole with a diameter of 5/8”.

Drill Press

5. Drill four holes in both the top and bottom faces of the plate steel to hold each face mount bearings with a diameter of 7/16”.
6. Machine the one of the side plates to hold crank 3” x 3-½” x 1/8” with a 1-½” fillet, hole diameter 3/8”.

Circular Saw

7. Cut down an 8” in length bar with a diameter of 1-½” to 7-¾" length.

Lathe

8. Turn down the diameter to 5/8” for 1-¼” in the middle of the rod.
9. Turn down the top to ½" diameter with a length of 3-¾" from the top of the bar.
10. Turn down the bottom of the bar down to ½" and length of 2-¾" from the bottom.

Milling

11. Mill a key seat into the top portion of the 8” rod that is 1/8” wide, 1/16” deep, and 1-1/8” long in the top half of the rod that is flushed up to the maximum diameter of the turned down rod for the worm gear.

Arbor Press

12. Broach a keyway into the bevel gear that is 1/8” wide and spans the entire length of the bevel gear.
13. Broach a keyway into the spur gear that is ¼" wide and spans the entire length of the gear to allow for the gear to rotate the entire bar and not slip when rotating the system.
14. Broach a keyway into the pinion bevel gear that is 1/8” wide and spans the entire length of the pinion bevel gear.

Hacksaw

15. Each key will be cut to the desired length with the use of a hacksaw.

Weld

16. Metal inert weld (MIG) the four faces of the steel plates together at their edges
17. Weld the back-plate flush to four edges and enclose the back side of the entire gear box.

Assembly

18. Slide the worm gear that is 1-1/8” long and pitch diameter of 1” over the vertical bar on the top end that flushes to the turn down edge of the 5/8” diameter.
19. Slide the 2” bevel gear from the bottom of the casing to the bottom edge of the 5/8” diameter that has the worm gear mounted to the same shaft.
20. Slide the mounted ball bearings with four-bolt flanges on each side end of the 8” bar.
21. Fasten the top and bottom flanges with 7/16”-14 bolts and nuts.

Circular Saw

22. Cut a square peg steel beam to a length of 3-5/8” that is 9/16” x 9/16” x 1-1/8" for the handle of the crank.

Lathe

23. Turn the remaining length of the square bar down to 3/8” for the pinion bevel gear insert.

Assembly

24. Fasten down each face mount bearing to the top and bottom faces of the steel plates using 7/16” bolts.
25. The bevel gear has a 2:1 ratio and is driven by a pinion bevel gear that is mounted to a 3/8” shaft that has a hand crank connected to the shaft and insert it into the hole cut out of the side plate in the bottom right end of the case. Before inserting the entire handle assembly, place one of the roller bearings on the exterior of the side plate, after it has been inserted, slide the other roller bearing on the back side of the side plate.
26. Press fit the pinion bevel gear to the inside shaft with the teeth end facing in toward the entire assembly.
27. Flush the bevel gear and mate them together to allow function.
28. Fasten the roller bearings using two ¼"-20 bolts and nuts.
29. Fasten the specific spur gear that has 60 teeth and a pitch diameter of 5” to the shaft that is ½" diameter and length of 8” and tighten it with a set screw.

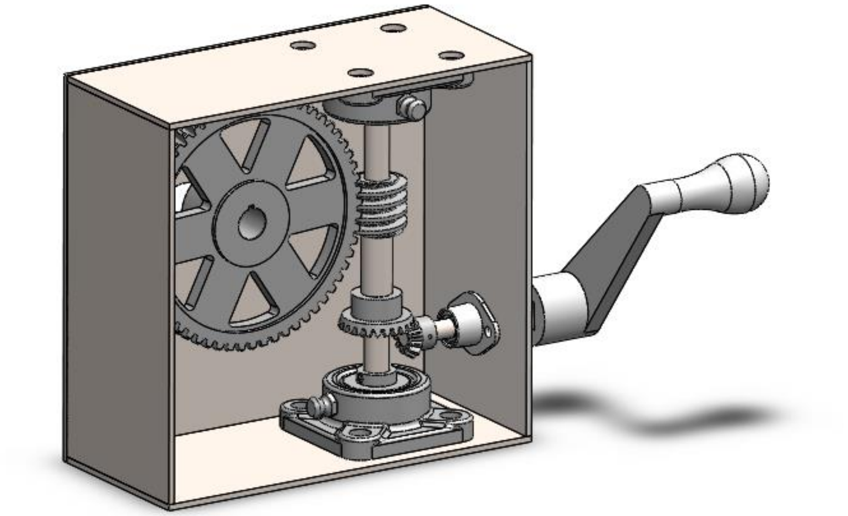
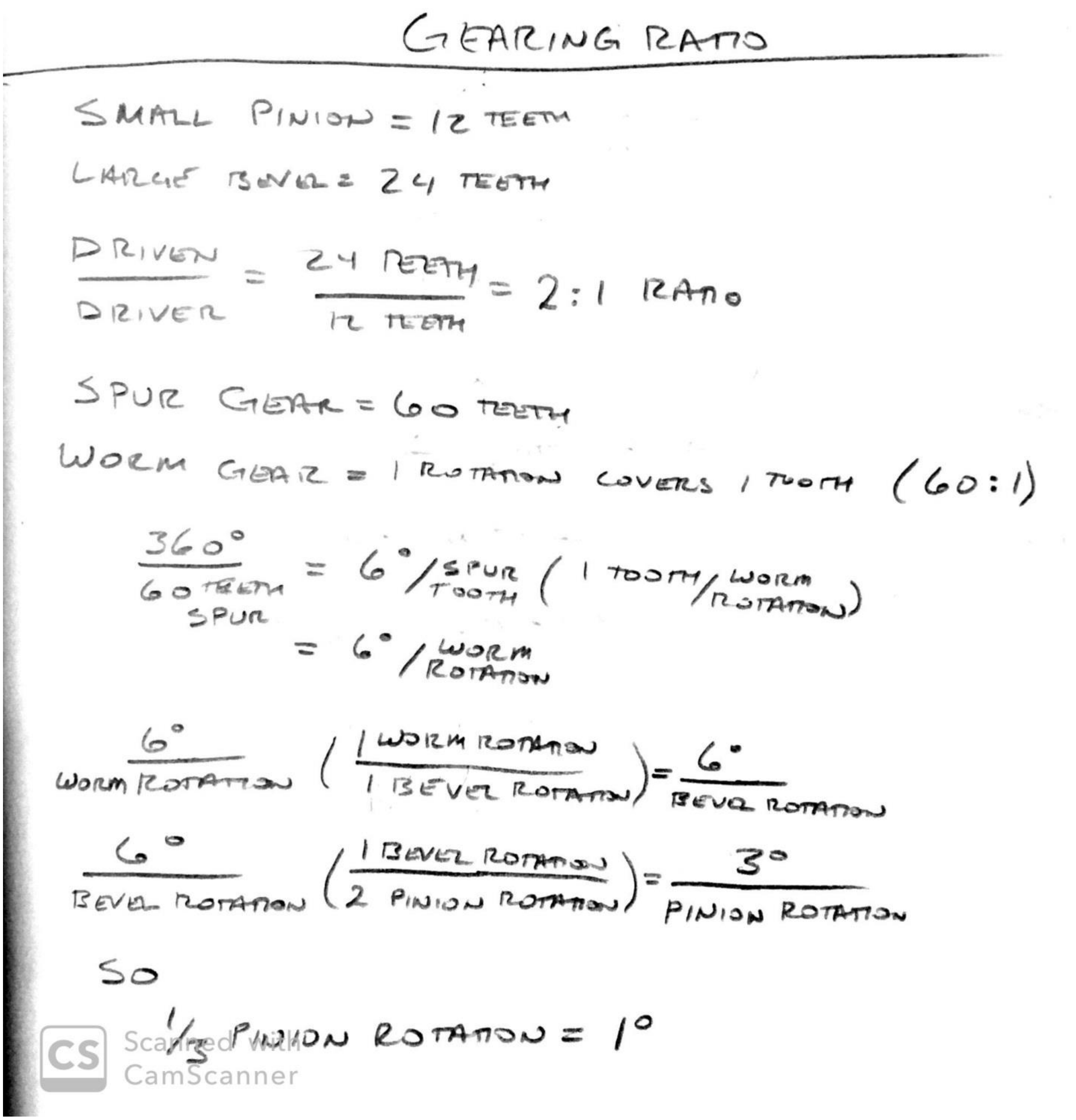


Figure 39. Gear Box

Appendix J: Hand Calculations for Gear Ratio and Panel Angle Limit



GEARING RATIO

SMALL PINION = 12 TEETH

LARGE BEVEL = 24 TEETH

$$\frac{\text{DRIVEN}}{\text{DRIVER}} = \frac{24 \text{ TEETH}}{12 \text{ TEETH}} = 2:1 \text{ RATIO}$$

SPUR GEAR = 60 TEETH

WORM GEAR = 1 ROTATION COVERS 1 TOOTH (60:1)

$$\frac{360°}{60 \text{ TEETH SPUR}} = 6°/\text{SPUR TOOTH} \left(1 \text{ TOOTH}/\text{WORM ROTATION}\right)$$

$$= 6°/\text{WORM ROTATION}$$

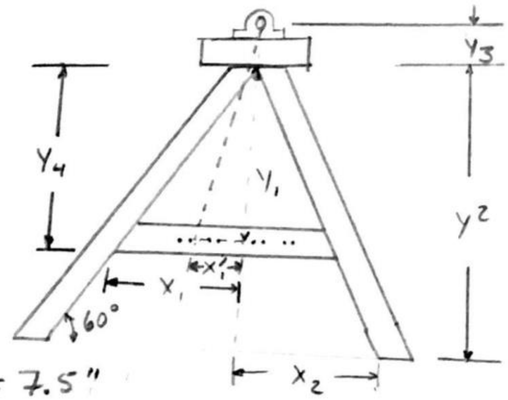
$$\frac{6°}{\text{WORM ROTATION}} \left(\frac{1 \text{ WORM ROTATION}}{1 \text{ BEVEL ROTATION}} \right) = \frac{6°}{\text{BEVEL ROTATION}}$$

$$\frac{6°}{\text{BEVEL ROTATION}} \left(\frac{1 \text{ BEVEL ROTATION}}{2 \text{ PINION ROTATION}} \right) = \frac{3°}{\text{PINION ROTATION}}$$

SO

$\frac{1}{3}$ PINION ROTATION = 1°

Figure 40. Gear Ratio Calculations



$X_1' = 7.5''$

$Y_1 = Y_4 + Y_3 - 1''$

$Y_1 = 25.98'' + 3.4375'' - 1''$

$\boxed{Y_1 = 28.412''}$

$\tan\theta = \frac{x_1'}{y_1}$

$\theta = \tan^{-1}\left(\frac{x_1'}{y_1}\right)$

$\theta = \tan^{-1}\left(\frac{7.5}{28.412}\right)$

$\boxed{\theta = 14.78°}$

$\boxed{\theta < 15° \text{ (MIN. PANEL ANGLE)}}$

$Y_2 = 48'' \sin 60 = 41.57''$

$Y_T = Y_2 + Y_3 = 45.0''$

SIMILAR TRIANGLES

$$\frac{X_2}{Y_2} = \frac{X_1}{Y_4}$$

$$Y_4 = \frac{X_1}{X_2} y_2 = \frac{15}{48''\cos 60}(41.57)$$

$Y_4 = 25.98''$

$Y_3 = 2'' + 1.4375'' = 3.4375''$

$$X_1' = X_1 - \overset{\text{CORNER TO FIRST HOLE}}{6.0''} \underbrace{- 1.0'' - (2.125'' - 1'' - .5'' - 0.125'')}_{\text{T-JOINT ASSEMBLY}}$$

$X_1' = 15'' - 7'' - 0.5''$

$\boxed{X_1' = 7.5''}$

Figure 41. Panel Angle Minimum Limit

Appendix K: Design Verification Plan

Specification Table

Spec. #	Specification Description	Requirement or Target	Tolerance	Risk	Compliance
1	Weight	350 lbs. (Excludes Panels)	Max	L	A, I
2	Production Cost	$1500	Max	L	A
3	Time to Clean	20 min	Max	L	T
4	Maintenance Time	60 min	Max	L	T
5	Forces/Loads	90 mph winds	Max	H	A
6	Demo Survey	Operable by untrained student		L	I
7	Time to adjust	2 min	Max	H	T, A
8	Range of tilt	15°- 90°	Range	L	A

Specification 1: Weight

Test Setup: Upon completion of the final assembly, the mount will be placed on the digital scale and weighed. If full assembly is too large for scale, each component can be disassembled and stacked.

Equipment Needed: Cal Poly Engines Lab digital scale

Estimated Time to Test: 3 hours

Specification 2: Production Cost

Test Setup: Production cost will be verified through careful creation of the iBOM. All parts are accounted for and given a corresponding price.

Equipment Needed: None

Estimated Time to Test: None

Specification 3: Time to Clean

Test Setup: Upon completion of the final assembly, the user will be asked to perform a routine cleaning of the mount. This cleaning will not require the user to disassemble the mount. The user will be given chemical resistant cleaning solution and cotton rags. Our team will use a stopwatch to time the process and verify the absence of fingerprints, smudges and other residues on all steel parts.

Equipment Needed: Multipurpose steel cleaning solution, cotton rags, stopwatch

Estimated Time to Test: 1 hour

Specification 4: Maintenance Time

Test Setup: Upon completion of the final assembly we will verify the time to swap a panel is under the required 60 minutes. The user will be asked to dismount a singular panel and remove it from the mount fixture and rotating bar. Once completed, the user will remount the panel to the fixture and then mount the fixture back on the rotating bar. Once remounted it will signify the end of the test and the timer will be stopped.

Equipment Needed: Stopwatch

Estimated Time to Test: 2 hours

Specification 5: Forces/Loads

Test Setup: Initial verification of specification success was done with engineering evaluation. Hand calculations and FEA was performed to confirm deflections during 90 mph winds are acceptable. Acceptable deflections are classified as any deformation that does not cause permanent damage to the assembly. To test the fully assembled prototype we will apply forces at various locations on the mount and visually inspect deflections.

Equipment Needed: None

Estimated Time to Test: 6 hours

Specification 6: Demo Survey

Test Setup: The concept prototype of the gearbox will be used to verify the user interface is operable by untrained users. The prototype will be given to students in Dr. Davol's freshman class and our team will ask them to spin a dummy rotating bar using the crank. We will also request the student to determine the rotation relationship between the crank and rotating bar.

Specification completion will require the student to both turn the crank and determine the rotation relationship.

Equipment Needed: Concept prototype of Gear Box, Untrained user

Estimated Time to Test: 6 hours

Specification 7: Time to Adjust

Test Setup: The concept prototype of the gearbox will be used to verify the panel tilt can be modified in under 2 minutes. Using the prototype gearbox, we will determine how long it takes to rotate the dummy bar from the minimum value of 15° to the maximum value of 90°.

Equipment Needed: Concept prototype of Gear Box, Stopwatch

Estimated Time to Test: 1 hour

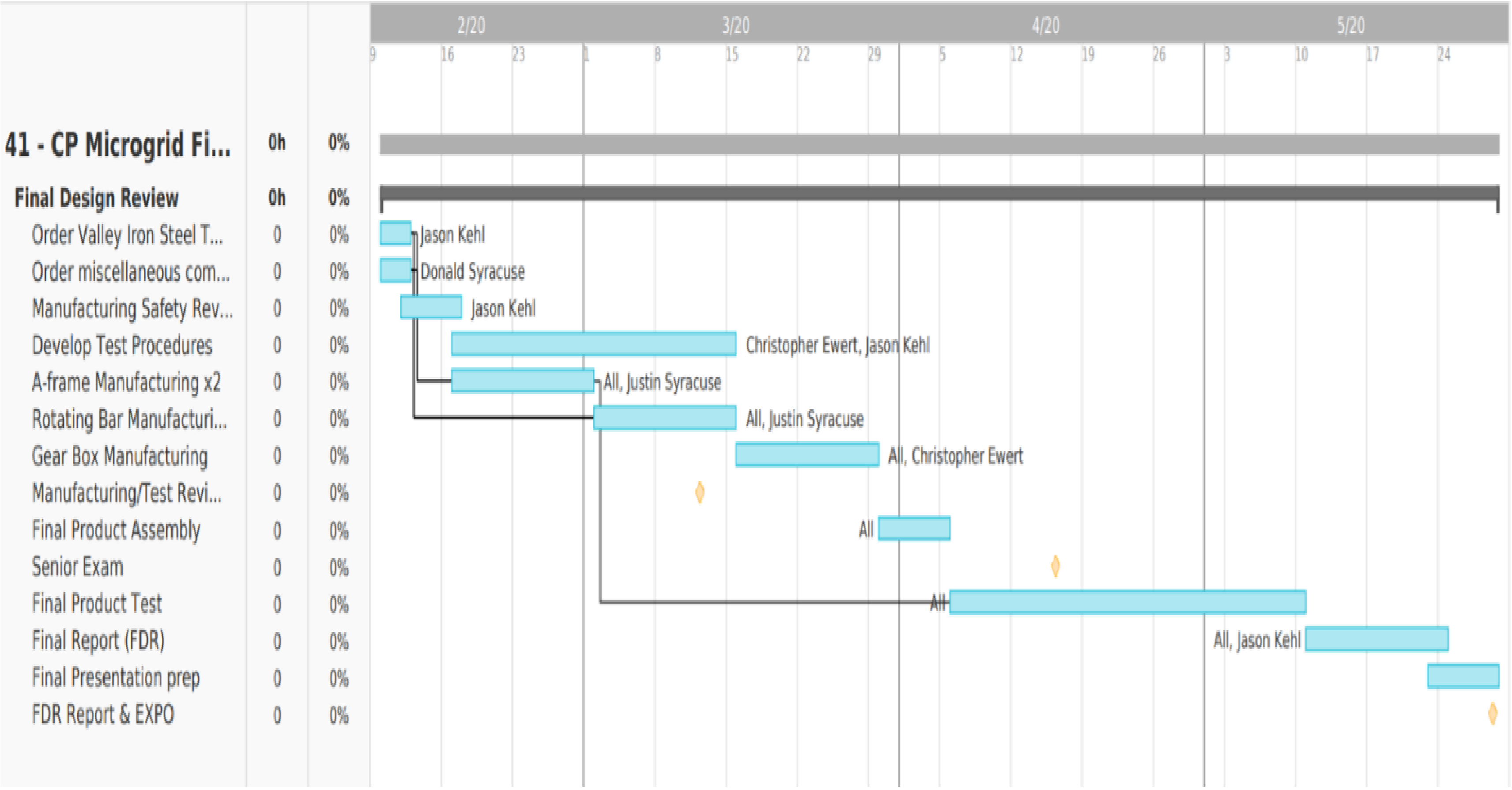
Specification 8: Range of Tilt

Test Setup: Hand Calculations were performed to verify the panels can rotate from 15° from vertical to 90° or horizontal and ensure specification completion. The concept prototype of the gearbox will also be used to verify the range of panel tilt; however, a full 360° revolution ability is expected.

Equipment Needed: Concept Prototype of Gear Box

Estimated Time to Test: 1 hour

Appendix L: Project Gantt Chart – CDR to FDR



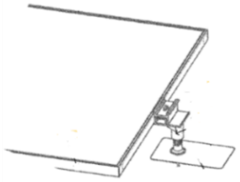
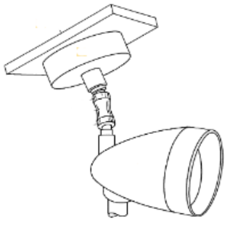
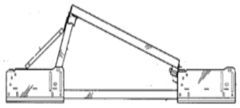
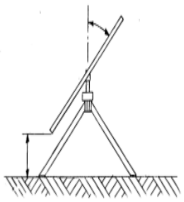
Appendix L references our Gantt chart for the upcoming phase of senior project up to Final Design Review

Appendix M: Table of Patent Search Results

Table 16 lists patents applicable to the project. The patents selected to observe for this project are based on three driving factors: rotatable, system fastening and adjustability. Patents one, two, and four were selected because they have the characteristics of rotation and dual axis movement. The third patent provides the group with system fastening (if necessary) and adjustability for different angle orientation to the sun.

<u>**Note**</u>: We have decided to relocate the patents table from our report into the appendix. We have found our scope no longer applies to the patents referenced here.

Table 17: Relevant Patent Research

Patent Title	Patent Application Publication	Keywords	Visual References
1. Mounting Assembly for Solar Panel Systems and Methods for using the same [4]	US20170093327A1	Mounting Assemblies Solar Panels	
2. Double-Jointed Mounting for Solar Panel [5]	US20070084500A1	Dual Axis Mounts Double Jointed	
3. Solar Array Mounting System [6]	US20100089390A1	Solar Array Adaptable Systems	
4. Balanced Support and Solar Tracking System for Panels of Photovoltaic Cells [7]	US20100139645A1	PV Array Systems Solar Tracking Photovoltaic Cell	

Appendix N: Assembly Instructions

1.0 Assembly Instructions

The assembly of the dual axis mount requires two team members and access to a standard adjustable wrench. While the mount will remain assembled for the foreseeable future, initial assembly and transportation requirements may require the mount to be disassembled and reassembled at a later time. Assembly has been broken down into 4 main components: Assembling the mount frame, assembling the gearbox, fastening the panels to the H-frames, and fastening the H-frames to the mount.

1.1 Mount Assembly

The mount consists of the A-frames (2), the support beams (2), and the rotating bar. This assembly constitutes the body of the panel mount and is essential to both stability and safety. The assembly procedure can be summarized as follows

1. Begin by fastening the pillow bearing (PN 231) to the A-frame assembly (PN 200). This is done by securing the pillow bearing using two hex head bolts (PN 901-A), two washers (PN 901-B), and two nuts (PN 901-C). Use the wrench and ensure the pillow bearings are tightly secured to the 6-inch tube at the top of the A-frame. Repeat this step to produce two assembled A-frames.

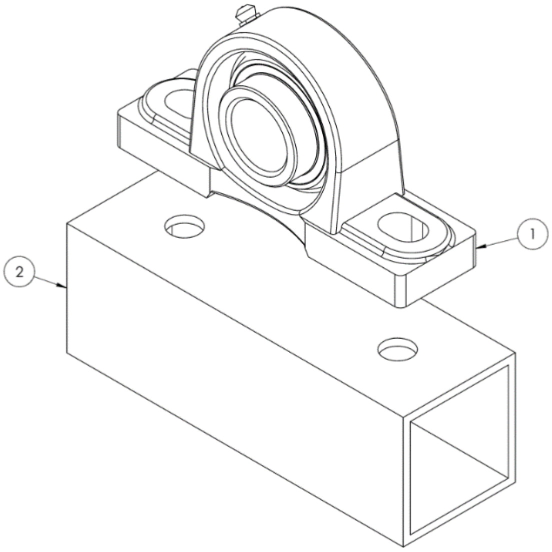


Figure 42: Pillow Bearing to A-frame Assembly

2. Next fasten two casters (PN 242) to the bottom of each frame. This is done with four bolts (PN 901-B), four washers (PN 902-A), and four nuts (PN 903-A) per caster wheel. The bolts are located on the preexisting holes on each caster wheel and secure to the flat on the bottom of each A-frame leg (PN 241).

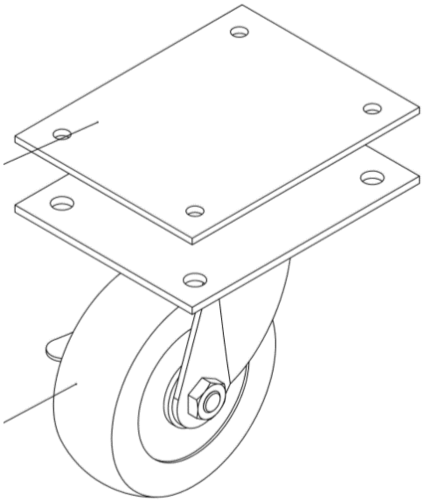


Figure 43: Caster Wheel to A-frame Flat (PN 241)

3. The next step requires the support bar (PN 520) and the tube fitting (PN 510). Secure the tube fitting to the outside of the support bar using a bolt (PN 901-F), washer (PN 902-F) and nut (PN 903-F). Repeat on the other end of the support bar. Repeat for the second support bar so both ends on both support bars are fitted as shown in figure 3.

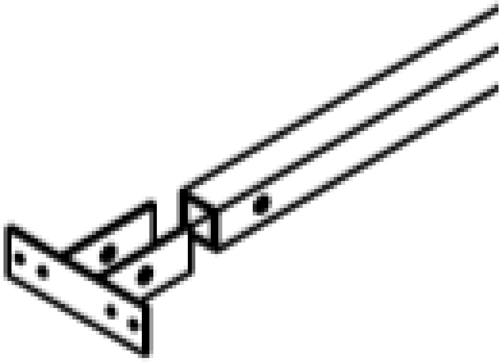


Figure 44: Tube Fitting to Support Bar

4. The next step requires the rotating bar (PN 300) and the fully assembled A-frames from steps 1 and 2. Begin at the side away from the gear box (i.e. Insert without key). Have one team member support the A-frame while the other secures the rotating bar insert through the bearing. When fully inserted, tighten the set screw located on the bearing to ensure the rotating bar does not slip within the bearing. Repeat this step for the gear side. When fully inserted tighten the set screw and place the spur gear back on the insert.

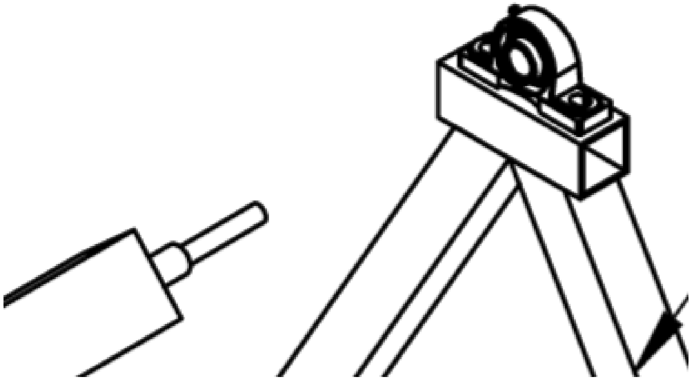


Figure 45: Rotating Bar Insert to Pillow Bearing

NOTE: The frame from step 4 is unstable! Take caution when moving around the frame and securing the spur gear on the rotating bar insert.

5. The last step for the mount assembly requires the fully assembled support bars from step 3. While one team member holds the assembled frame from step 4, the other fastens the tube fittings to the cross members of each A-frame. This is done using four bolts (PN 901-E), four washers (PN 902-D), and four nuts (PN 903-D) at each of the tube fitting faces. Secure both support beams to the preexisting holes on the A-frame cross member.

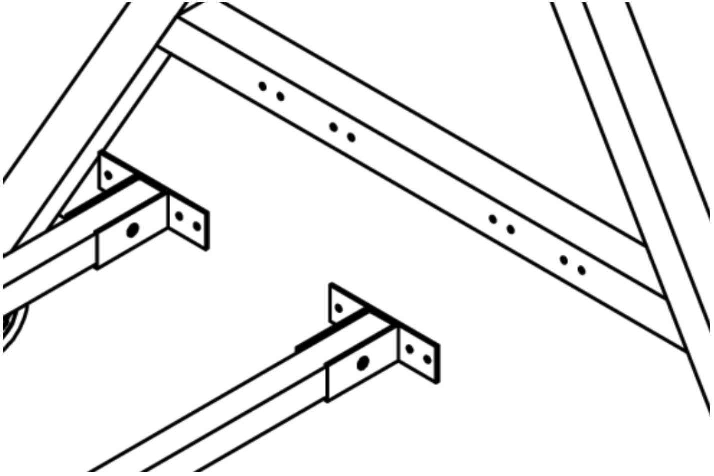


Figure 46: Support Bars to A-frame

At this point the frame is completely assembled and consists of the two support bars, two A-frames, and the rotating bar.

Figure 47: Fully Assembled Frame Mount

1.2 Gear Box Assembly

The gear box assembly consists of three main components. The shaft assembly in figure 7, the welded box assembly in figure 8 and the hand crank assembly in figure 9. First mount the two flanged bearings on the inside and outside of the box with two bolts (PN 901-H), washers (PN 902-H) and nuts (PN 903-H). Once mounted slide the handle shaft through, insert the key into the key slot, then tap on the bevel pinion. Finally, secure the handle on the end of the hand crank shaft outside of the box. Next, insert the shaft assembly so that the four bolt holes of the face bearings line up with the four bolt holes in the box. Secure the face bearings with eight bolts (PN 901-G), nuts (PN 902-A) and washer (PN 903-A). You may need to rotate the bevel gear while inserting the shaft to line up with the bevel pinion. Once bolted together, check that the worm gear rotates when the hand crank is turned. Finally slide the entire box over the insert that extends past the pillow bearing until the back of the box is flush with the A-Frame. Place the key in the slot on the insert, and then press on the spur gear so that it lines up with the worm gear. The slot in the box can be used to engage or disengage the spur gear from the worm gear. When finished the results should look like figure 9.

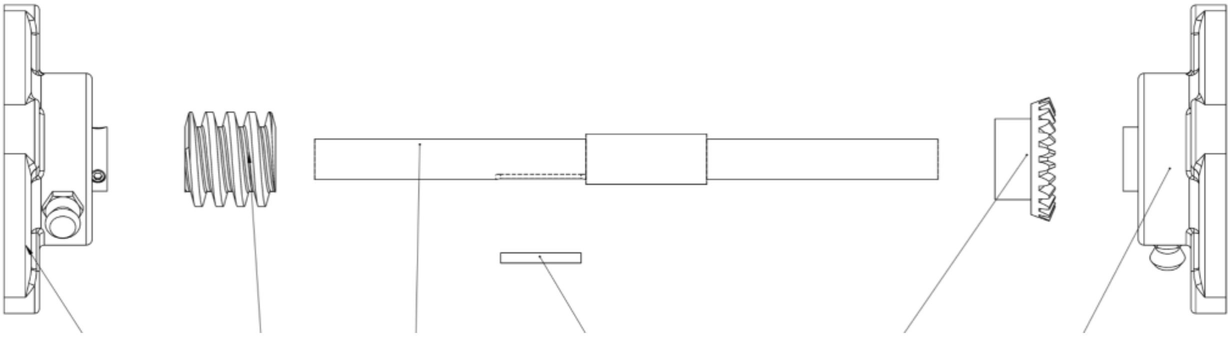


Figure 48: Gear Box Shaft Assembly

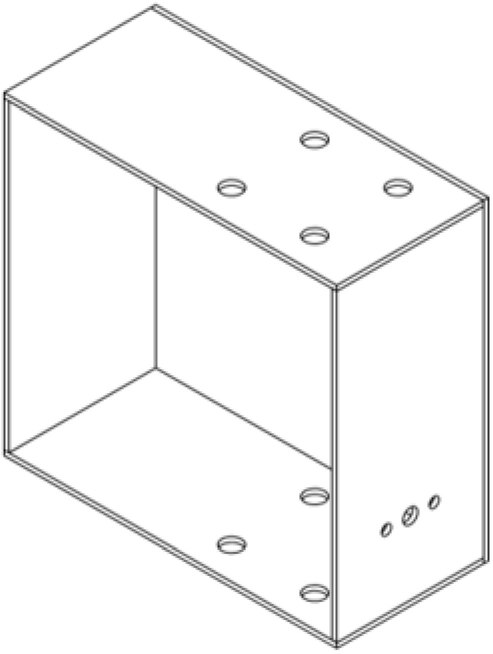


Figure 49: Empty Gear Box

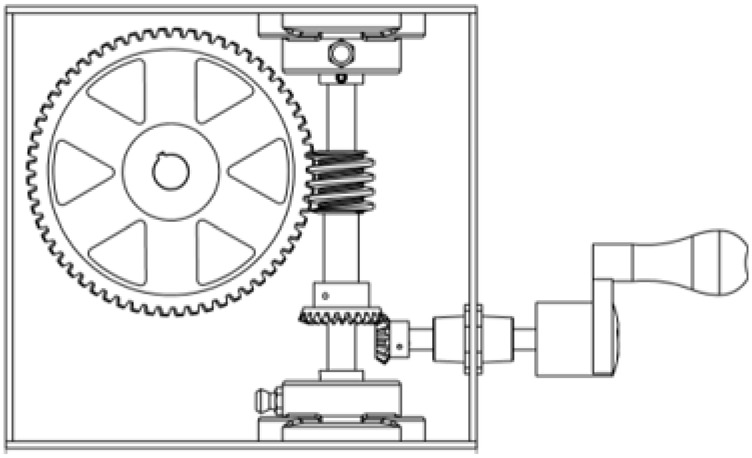


Figure 50: Fully Assembled Gear Box

Finally, the gearbox is ready to be operated. Be aware of the orientation of the panels so that a collision does not occur between the frame and the panels. Keep arms and legs away from the rotating parts. To safely operate, stand facing the gear box and rotate with one hand on the hand crank. One rotation of the hand crank will correspond to a three-degree change of angle of the panels. Be sure to know which direction the shaft will rotate when turning the hand crank before installing the panels.

1.3 Panel to H-frame Assembly

The H-frame to panel assembly consists of the welded H frame and eight bolt, washer, and nut combos. The H-frame fastens to the back of the panel at eight locations, four on each of the vertical members to the side of the panels. Use the bolts (PN 901-D), washers (PN 902-D), and nuts (PN 903-D) to fasten the back of the panel to the vertical members of the H-frame at the locations shown in Figure 6. Repeat this step for the other two panels.

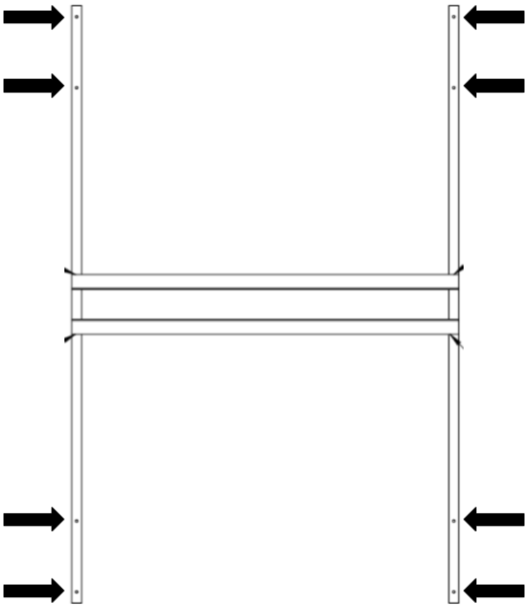


Figure 51: H-frame Bolt Hole Guide

1.4 H-frame to Rotating Bar Assembly

The final step to assemble the solar panel mount is to fasten the H-frame/Panel assembly to the rotating bar. Slide the angle iron guides over the top and bottom of the rotating bar and align the predrilled holes on the angle iron to the predrilled holes on the rotating bar. Fasten the H-frame in place using three bolts (PN 901-C), three washers (PN 902-A), and three nuts (PN 903-A).

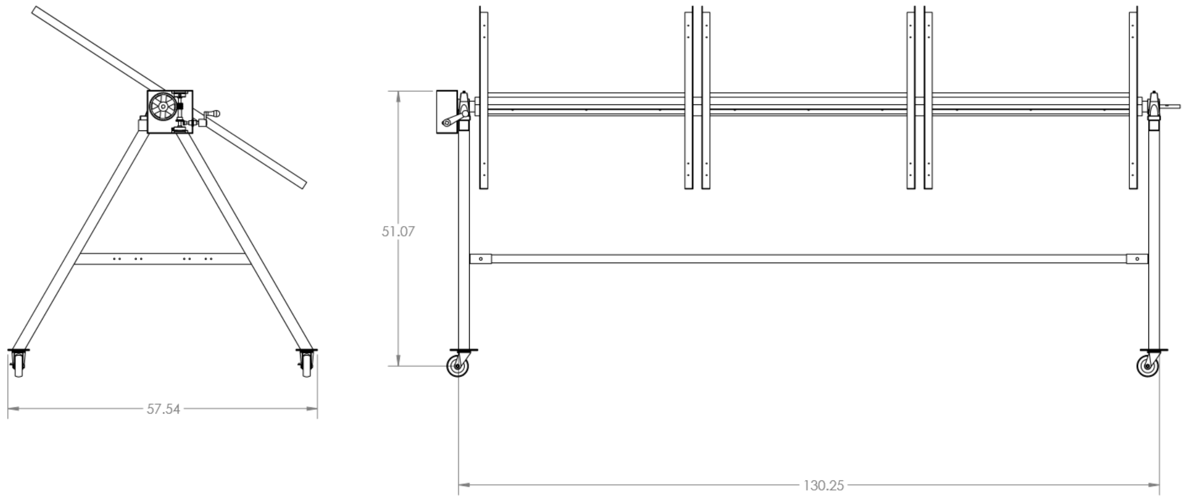


Figure 52: Fully Assembled Solar Panel Mount

2.0 Safety Instructions for Standard Use

This list highlights key safety features to remember when operating the mount.

1. Under no circumstances should anyone be located underneath the panels or between the legs of the A-frame.
2. While panels are in motion all team members shall be no less than three feet away.
3. All four casters wheels must be locked before operation of the pitch control.
4. Do not operate the gear box until ensuring the gearing mechanism is encased within the box. Hair should be tied up and anyone not operating the crank shall be no less than three feet away.
5. When not in use the panels should be removed from the mount or be oriented in the vertical position.
6. Do not attempt to remove panels from the H-frames without first removing the H-frames from the rotating bar.

3.0 Instructions for Maintenance

The mount should be routinely inspected for signs of rust or other corrosion. We recommend a bi-yearly inspection if stored continuously outside. Anti-corrosion lubricant sprays are commercially available and should be applied yearly or upon discovery of rust. Further we recommend a bi-yearly inspection of all 83 bolts throughout the assembly to ensure the structural integrity of the mount. This inspection should include signs of shearing, backing out, and corrosion.