Cal Poly Microgrid – Solar Panel Mounts

by

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Date: _________________________

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Statement of Disclaimer

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Executive Summary

The purpose of this project was to demonstrate the difference in solar panel power output that can be achieved by tracking the sun versus using a stationary panel. Two systems have been designed: a stationary solar panel mount, and a two-dimensional tracking mount. This paper details the complete design process involved in creating these systems and includes all aspects of the design phase, from brainstorming to detailed specifications and analysis. The paper also includes manufacturing and assembly processes used to construct the mounts, as well as recommendations for improvements upon the processes relating to this project.

1.0 Introduction

The goal of this project was to develop two different systems of solar panel mounts to demonstrate the advantages of tracking solar panels vs. stationary panels. The first system will be stationary and the second will track the sun via dual-axis rotation. The dual-axis tracker will also be able to function as a single-axis tracker if necessary by constraining one axis. The systems will be mounted on Cal Poly's Building 20. It will be easy to disassemble and transport each solar panel mount should the location be changed. The systems will have the capability of being grid-tied and have a power monitoring system that will upload data to the web.

This project is being contracted to our group by Cal Poly, San Luis Obispo. Cal Poly is the main stakeholder in this project, with the idea being to provide a "Learn by Doing" experience for its faculty and students. Dr. Davol, a Cal Poly mechanical engineering professor, is acting as both our sponsor and advisor to the project. With the advising of Dr. Davol, our system will allow lab testing for various clean energy-based classes within the mechanical engineering and general engineering curriculum at Cal Poly. Our systems will also be tied into the future Cal Poly Micro Grid project.

2.0 Background

Initial research and preparation has shown that there are many facets of this project to consider, including solar mount types, tracking systems, solar panel efficiencies, and safety codes and standards. Each of these areas are very important in designing a solar tracking system, and will be our guide in ideation and choosing the best design.

2.1 Types of Solar Power Systems

Of the variety of solar power system implementations used throughout the world, we will be focusing on three common types: stationary panels, single-axis trackers, and dual-axis trackers. Single-axis trackers rotate along a single-axis, which can be oriented in a variety of directions. Common orientations of the axis of rotation include: horizontal, in which the panels rotate about a horizontal axis; vertical, in which the panels rotate about a vertical axis; and tilted, in which the axis of rotation lies between the horizontal and vertical planes. Dual-axis trackers rotate about two axes perpendicular to each other. Two common implementations of dual-axis trackers are tip-tilt trackers and azimuth-altitude trackers. Tip-tilt trackers have both axis of rotation located at the top of a pole, whereas azimuth-altitude trackers use rollers on a circular track to rotate about the vertical axis. While stationary panels face a single direction at all times (hence, stationary), single-axis trackers track the sun throughout the day, and dual-axis trackers also have the ability to adjust their angle throughout the year based on the angle of the sun.

2.2 Advantages and Disadvantages of Tracking

Compared to tracking systems, stationary solar panels have mechanical advantages. They are better able to withstand wind-loading than their tracking counterparts, and are also cheaper and easier to maintain. However, tracking systems have the advantage of higher power production. Compared to stationary solar systems, systems with single-axis tracking are able to produce significantly more power. Systems with dual-axis tracking are able to add to this increased power output. One study found that, after testing azimuth single-axis trackers a 217 different locations across the United States, the average power output was 29% higher than that of stationary panels. The same study found that dual-axis trackers output an average of 34% more than stationary panels [1].

However, trackers that rely on sensors to track the position of the sun have the potential to "mis-track." This occurs in conditions of lower light, when the trackers have the ability to shade themselves. Another study found that the energy losses experienced from this can be up to 30% for single-axis trackers and up to 52% for dual-axis trackers [2].

2.3 Tracking Methods

Tracking can be accomplished many different ways, but they can mostly be divided into two types: programmed and active. The programmed category includes methods that don't rely on getting feedback from the sun and accomplish tracking by using the panel's longitude, latitude, and current time to calculate the position of the sun. This has the advantage of being able to track regardless of weather or other interference that could disrupt sensor readings. Active tracking uses sensing methods to determine the position of the sun. Some examples of active tracking include video processing, light sensors, and temperature sensors. Light or temperature sensors can be used by having two or more sensors with a divider between them that casts a shadow when the panel is not pointed directly at the sun. The panel's orientation is then adjusted depending on which sensor is shaded. The benefit of active tracking is that it is more accurate than programmed when there is no interference. It is also less calculation-intensive and doesn't require accurate time keeping or location data.

2.4 Solar Panel Specifications

We will be using SunPower 425 Solar Panels for the Cal Poly Micro Grid Project. The specific panels we plan to use are Series E19, model number SPR-425E-WHT-D. These solar panels are each composed of 128 solar cells, and have a conversion efficiency of 19.7% and peak power output of 425 Watts. Each solar panel is 81.36 inches long, 15.68 inches wide, and 1.16 inches thick,and have a weight of 56.0 lbs [3].

2.5 Applicable Codes and Standards

Throughout the design and building process we will follow OSHA standards for green job hazards which describe hazards existing in manufacture, installation, and maintenance of solar energy. This includes standards for working with electricity and machinery [4].

2.6 Grid Tying

Solar panels require several electrical components in order to be safely tied to a grid [5]. First in line of connection from the solar panels to the grid is the combiner box, which combines all of the outputs of the solar panels [6]. Next is the DC disconnect, which allows for all power output from the solar panels to quickly be shut off when maintenance or repairs are performed [7]. Then is the charge controller, which prevents reverse current to the solar panels and prevents electrical overload. If a battery bank is also attached to the system, it also serves to prevent optional battery overcharge and overdischarge [8]. From the charge controller, the circuit may be split to the output and an optional battery bank. If a battery bank is included, one line from the charge controller is connected to a DC disconnect, which is in turn connected to the battery bank. Another line from the charge controller then connects to a DC breaker panel, allowing for multiple DC outputs. For a solar tracker system, one or more of the DC breaker panel outputs would be connected to the tracking electronics. Of the remaining outputs, one connects to an inverter, which would convert the DC power to AC power. The inverter is in turn connected to an AC disconnect, which allows for the AC power output to quickly be shut off. Connected to the AC disconnect is the AC breaker panel, the final component in the circuit required to connect the solar panels to the grid. The AC breaker panel allows for multiple AC outputs, one of which is connected to the grid.

3.0 Design Requirements and Specifications

After communicating with our sponsor, we have determined a list of important design specifications that our project must adhere to. Following these specifications will ensure that our project accomplishes the desired tasks that our sponsor has laid out for us.

We began with our sponsor's qualitative customer requirements: low cost, portable, and weather resistant. We then converted these qualitative requirements into quantitative specifications, i.e. less than $1500, transportable via pickup truck, and able to withstand frequent 30 mph winds. These quantitative measures give us concrete goals, which will allow us to more accurately determine our success in meeting our sponsor's initial requirements as we build and test our solar panel system.

Table 1. Engineering Specifications from Customer Requirements

Spec #	Parameter Description	Requirement or Target	Tolerance	Risk	Compliance
1	Weight	300 lbs	Max	M	A, S, I
2	Plot Area	225 sq. ft.	Max	L	A, T, I
3	Material Strength	Track accurately under 30 mph winds, survive 100 mph winds	Max	L	A, T
4	Material Cost	$1,500	Max	M	A, S
5	Maintenance Life	1 year	Min	M	T, I
6	Height	Panel height: 5 ft, Maintenance height: 3 ft	Max	L	A, T, S
7	Stability	Panels stay at specified angle	Plus/minus 5 deg	H	A, T, I
8	Driving Mechanism	270 degrees of rotation, toggle between 15-75 degrees of tilt	Min angle, min range of tilt	H	A, T, S, I
9	Power Requirements	20% of power produced by panels	Max	M	A, T, S
10	Power Output Data	Measure Locally and Remotely	N/A	H	A, T
11	Safety	OSHA standards	Min	L	S, I
12	Portability	Transportable via pickup truck and deconstructable by 2 people	N/A	M	A, T

Table 1 shows our various requirements with their tolerance, risk (L = Low, M = Medium, H = High), and compliance (A = Analysis, T = Test, S = Similarity, I = Inspection).

3.1 QFD House of Quality

These specifications were derived from the House of Quality seen in Appendix 1. This Quality Functional Deployment method was developed to help us determine parameter specifications based upon customer input and concerns. Our House of Quality helped us to determine the technical specifications from the customer demands. Customer demands such as “Durable” and “Weather-proof” turn into “Maintenance Cost” and “Corrosion”, respectively. We consequently determined the relationship between all of the customer requirements and the engineering specifications chosen by ourselves and classified into three categories: strong relationship, moderate relationship, and weak relationship. With all of the relationships defined, we could then look for correlations between our engineering specifications to determine how they are interrelated and which specifications are most important. Strong positive correlations include “Power” and “Weight”, as well as “Material Strength” and “Maintenance Life”. A strong negative correlation is “Height” and “Stability”. These were helpful for our team to focus our attention and design in an effective way. The most important requirements determined from the House of Quality are low cost, durability, and ease-of-use.

3.2 Weight

Our weight specification for the total weight of the systems is 300 lbs. This is scaled down from an original value of 750 lbs. The reduction in weight is largely due to the reduction of panels per mount. We have decided to mount one panel on each system instead of two to reduce the axial load on our rotating cap in the 2-D tracking system. We have also reduced the stationary system to a one panel mount to reduce the amount of space that our entire project will take up. With each panel weighing approximately 56 lbs, we have plenty of room left under this 300 lbs specification to use very sturdy materials.

3.3 Plot Area

The plot area refers to the plot of ground that the tracking systems will be stationed upon. Considering each panel is roughly 8 ft. long and 4 ft. wide and will need to rotate, we estimated that each mount will occupy approximately 75 square feet. Since there are two systems, and they will need to be placed apart from each other, our estimate of 200 square feet is conservative and should not be a problem to achieve. It is also important to note that the arrangement of the panel mounts can be altered depending on the location of the system.

3.4 Material Strength

The material strength is a very important parameter that will directly affect other areas of the project, such as material cost, weight, and stability. The material must be able to support the weight of the panels as well as various loads on the panels like wind pressure. For the San Luis Obispo Area, typical wind speeds hover between 10 and 25 mph, so, we would like our design to be able to track accurately under 30 mph winds and survive gusts of up to 3 times the normal wind speed high, or about 100 mph.

3.5 Material Cost

This parameter was given directly from our project sponsor. A $1,500 cap on the project is both reasonable and achievable. See Appendix 11 for our cost analysis breakdown.

3.6 Maintenance Life

Maintenance life is especially important in this project. The systems will be exposed to the outside environment nearly all the time, and the designers (ourselves) will not always be available to maintain the systems or fix issues if they arise. We believe that an annual maintenance schedule, at the least, will be sufficient to allow for the most efficient use of the panels and the tracking systems. However, it is important to note that more frequent maintenance may be necessary during the initial setup of the mounts to make sure all systems are functioning properly.

3.7 Height

The height at which the tracking systems will hold the panels is a less important parameter in this project, but important nonetheless. The systems should be accessible without a ladder or equipment to maintain them. A maintenance height of 3 ft. is low enough to achieve this goal, while we would like to keep the maximum panel height under 5 ft.

3.8 Stability

The motor responsible for the solar panel tracking tracking must be able to hold up against weather elements such as wind and rain. We decided that any variance caused by weather elements of more than 5 degrees was not acceptable because it would push the panels too far from the ideal perpendicular angle to the sun.

3.9 Driving Mechanism

In order to track the entire movement of the sun across the sky, our panels need to be able to rotate 270 degrees and tilt 15-75 degrees. It may not be necessary or beneficial to track to the full extent of this rotation and tilt, but we feel that it is important to have the ability to do so. The motor used to power the tracking must be able to complete the entire 270 degree rotation in less than 60 seconds and the actuator must be able to navigate the entirety of the 60 degrees of tilt in the same amount of time. This will allow us to more effectively test the panels' capabilities, as well as demonstrate the tracking system to other students and professors.

3.10 Power Requirements

Based on initial research, we estimate that our tracking panels will have 25-35% greater power production than our stationary panels [9]. We will power our tracking systems using the solar panels, so in order for the tracking panels to be a better option, the power consumption of the tracking panels must be significantly less than the power gained by tracking the sun. We want the tracking system to use up no more than one fifth of the extra power that the tracking panels produce, so we set a limit of 20% of the power generated to be used for our tracking system.

3.11 Power Output Data

One of the goals of this project is to show the difference in power production between various solar panel system types. We determined that it would be necessary to both remotely and locally measure and store power data from each panel. Measuring real-time data will allow us to observe real-time variability in power production, while recording data over time will likely provide a better insight into average power production and the efficiency of each solar panel set up. We would like to measure voltage, current, and power of the panels.

3.12 Safety

It would be irresponsible to design a system with any significant safety concerns, so we will ensure that there are no safety concerns, especially relating to electrical wiring and sharp edges. Considering students who are learning about or not familiar with solar panel technology will be working with this equipment, it is important to design the systems to be as simple and safe as possible, especially since there is school liability for students' well-being.

3.13 Portability

The ability to transport our rig easily is not very important because our project will mainly be used for educational purposes at Cal Poly. However, it would be ideal if the panels could be assembled and disassembled with minimal effort. To ensure that our design is reasonably portable, we would like the system to be designed so that two people can take the panels and mounts apart.

4.0 Design Selection

The design selection process for the stationary mount and dual-axis tracking mount was comprised of three parts: brainstorming, constructing concept models, and creating a Pugh matrix. Each of these three processes are described in the following sections.

4.1 Brainstorming and Design Development

The first step in our design process was to generate a large number of potential designs. We did this individually and sketched out our ideas. We then met briefly to discuss our initial designs. Any very similar or duplicate ideas were combined into a single design.

Team PolySolar has gone through the design process by narrowing our focus on specific project goals based upon customer input and requirements. Close contact with the project sponsor will continue to be maintained throughout the building and testing processes to ensure accuracy and a correct deliverable to the sponsor. Communication has occurred via email and weekly in-person meetings, and has worked well.

Researching current, relevant technologies in order to familiarize ourselves with possible solutions was the next step. We brainstormed designs using these ideas as well as our own in order to find the best solutions possible. This included the designs for the physical mount, tracking method, materials, and driving mechanism. The designs were compared using a house of quality and pugh matrices, seen in appendices 1 and 2 respectively. These design process tools have been useful in comparing which aspects of the product are most important and which are related to each other.

We found that the pugh matrices were very helpful in narrowing down exactly what each design offered relative to other designs, and it allowed us to compare and contrast designs to see which really offered us the desired characteristics. With the house of quality as a guide we were able to utilize the pugh matrices to their fullest extents in order to settle upon the best designs

Before moving on to the build phase we made prototypes for the best mount designs and driving mechanisms in order to get a better feel for their feasibility. We have also created Solidworks models, done analysis of the mounting designs, and researched materials based on the physical requirements. Hand drawings and calculations have preceded the computer models, however the computer models will ultimately be our reference in building. Once we settle on a design we will begin ordering parts and materials. Before starting the build, we will test the solar panels to choose sets that have as close to equal output as possible in order to ensure accurate data as well as create benchmarks for the expected power output. We will also practice welding before building to speed up the construction process. Throughout the design process we will revisit the engineering and customer specifications to keep us on track.

4.2 Concept Models

In order to better compare and contrast the ideas that we came up with during our initial brainstorm, we built small-scale concept models. We used cardboard, tape, and straws to made scale models of our potential designs. This gave us better insight into the functionality of each design. We built a total of seven different prototypes, all of which functioned in very different ways.

4.3 Pugh Matrix

The next step in our process was to add a quantitative measure to our design comparison. We used a Pugh matrix to compare designs to each other. This was the main tool that we used in order to determine our leading design for our stationary panels and dual-axis tracking panels. The small-scale concept models made comparing designs much easier. Seen Appendix 2 for our pugh matrix.

4.4 Stationary Mount

For the stationary panel, the main requirements are portability, stability, and cost. Our chosen concept for this satisfies portability by having legs that can be detached from the panels for storage.The panel mount is a simple setup that will allow the user to assemble and disassemble easily. With four connection points, the concept eliminates moment loads which improves stability. The concept satisfies the need for low cost by being simple to machine with the smallest and most complicated parts being the hinge connections between the legs and panels.

4.5 Single-Axis Tracking Mount

Though our design plans have since changed, our preliminary design included a third solar panel mount that would be capable of single-axis tracking. Initially, our leading design for this system utilized a control system to adjust the tilt of the panel in order to track the sun's movement on a daily basis. However, as we continued to work through the brainstorming process, it became clear that a better way to handle the daily tracking was through rotation about a central axis. Rotating the panel about a central vertical axis can easily track the sun during the day and the movement will be assisted by a strategically angled solar panel. However, after improving our single-axis tracking system design, we realized that it would actually be better to use a system that was capable of dual-axis rotation. We determined that a system with the capability to track the sun via single-axis rotation might as well be able to track about a second axis, as well. For this reason, we have decided to scrap the single-axis design and focus on a dual-axis tracking system. If it becomes necessary to compare multiple tracking systems, we believe building an additional dual-axis tracker would be more advantageous than a single-axis tracker. We believe that our dual-axis system is easily replicable if necessary.

4.6 Dual-Axis Tracking Mount

We were mainly considering two designs for our dual-axis tracking system. The first was a system with a single support in the middle that rotated about two horizontal axes in order to track the sun. The second was a system that rotated about a vertical axis, as well as a horizontal axis, effectively tracking daily solar movements by spinning around the vertical axis as well as as tilting about the horizontal axis in order to fully utilize the solar potential and track the sun as accurately as possible. These movements will be adjusted by a control system and will adjust in real time as the sun changes position.

5.0 Initial Leading Design Overview

From the Pugh matrix, the leading designs for the stationary mount and dual-axis tracking mount were selected. Each of these designs are described in the following sections, along with comments on their selection process. These were our leading designs after the brainstorming phase, but they did not turn out to be our final designs. Discussion about what led us away from these designs will be included after they are introduced.

5.1 Stationary Mount - Initial Leading Design

NOTE: This design below was created in an intermediate phase of the design process and is not a finalized design. It has since been altered and improved. The improved design will be shown in sections to follow.

The stationary mount is designed with four poles, one at each corner of the solar panel. Each of the four poles can be extended or retracted manually, allowing for the solar panel to be set at varying angles. Each pole is connected to the solar panel using a hinge, allowing for the poles to fold in during transportation. The mount includes two solar panels, also attached to each other using hinges. This allows for the solar panels to be folded together, further reducing its size during transportation for increased portability. See Figure 1 below for a visual representation of the stationary mount.

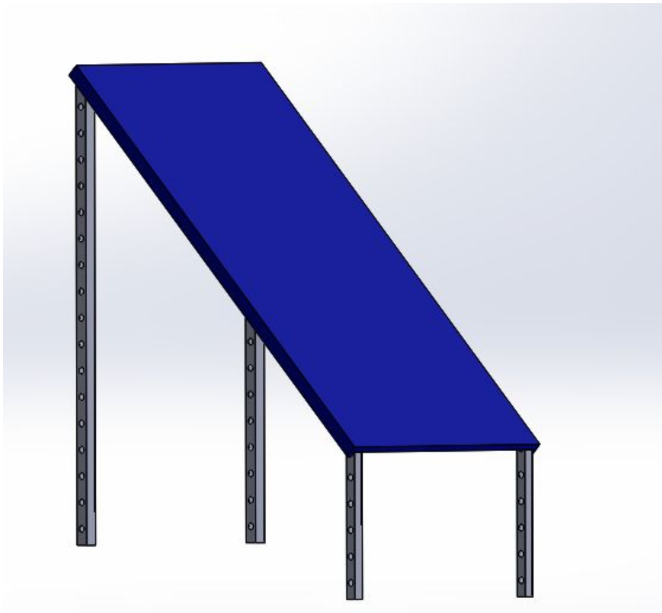


Figure 1: Three-dimensional CAD model of the stationary solar panel mount.

5.2 Single-Axis Tracking Mount - Initial Leading Design

NOTE: This design below was created in an intermediate phase of the design process and is not a finalized design. It has since been altered and improved. The improved design will be shown in sections to follow.

The single-axis tracking system is designed to track the sun by rotating daily about its base. A turntable run by a motor will allow for a full range of rotational motion. The solar panels themselves will be supported using two poles: one located at the center and one located off-center. The off-center pole has the ability to be extended or retracted manually. The top ends for both poles will be attached to the solar panels using hinges. Additionally, the bottom end of the off-center pole will be connected to the turntable with a hinge. These hinges will allow for the angle about the horizontal to be adjusted by extending or retracting the off-center pole. The tilt on this mount will be manually adjusted once every 3 months to the optimal angle for the given time of year. See Figure 2 below for a visual representation of the single-axis tracker mount.

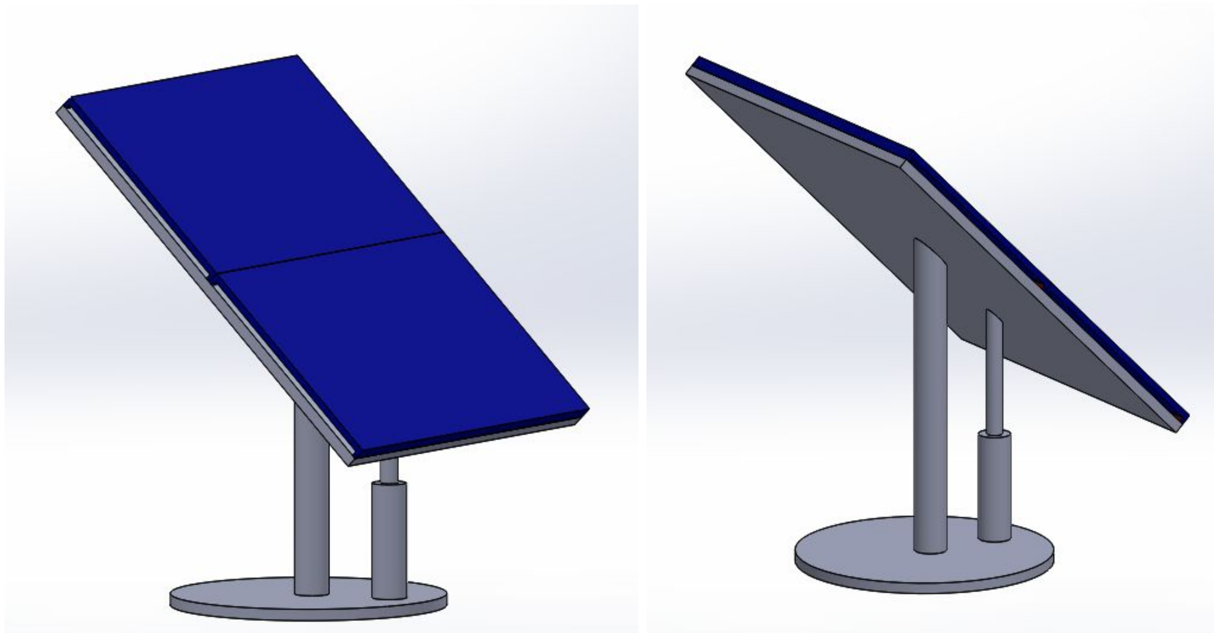


Figure 2. Preliminary three-dimensional CAD model of the single-axis and dual-axis tracker mount.

5.3 Dual-Axis Tracking Mount - Initial Leading Design

NOTE: This design below was created in an intermediate phase of the design process and is not a finalized design. It has since been altered and improved. The improved design will be shown in sections to follow.

The dual-axis tracking system will track the sun by rotating daily about a vertical axis. Rotation about the vertical axis will be accomplished using a turntable at its base. The turntable will be run by a motor, allowing for a full range of rotational motion. The tilt of the solar panel will be adjusted using an actuator attached to both the rotating base and the solar panel mount. This actuator will serve as a means to rotate the panels about a horizontal axis.The solar panels themselves will mainly be supported using both a pole located at the center of the turntable. Both the pole and the top end actuator will be attached to the solar panels using hinges. Additionally, the bottom end of the actuator will be connected to the turntable with a hinge. These hinges will allow for automatic rotation about the horizontal as the actuator extends or retracts. See Figure 2 above for a visual representation of the dual-axis tracker mount.

5.4 Deviations from Initial Leading Designs

After our initial design phase, we were extremely happy with our proposed designs. However, after attempting to get deeper into the detailed design phase, we noticed a few issues with our designs. Consulting with various professors in the mechanical engineering department at Cal Poly helped us understand that modifications had to be made to our designs. Initially, we had three distinct designs: one stationary panel mount, a one-dimensional tracking mount, and a two-dimensional tracking mount. While our stationary design remains relatively unchanged, our 1-D tracking design has been scrapped and our 2-D design has been improved in a variety of ways.

Due to time constraints and a main focus on the design process rather than the production process, we have decided to make one mount that can function as a 2-D solar tracking system, as well as 1-D tracking system if one axis of the tracker is held stationary. This reduces the materials needed to build our final design and allows us to focus more time on design than building, which will hopefully lead to a higher quality final product.

Another large change that we have made is reducing the number of solar panels per mount from two to one. The main reason for this is to reduce the weight of the top portion of our system. This will allow for easier rotation and require less expensive bearings because we will not need to account for as much axial force as we had previously anticipated. Using only one panel will also mean that our final design will be more portable and take up less space. The initial choice to make each array able to hold 2 panels was made by our sponsor because a total of 6 panels would give a similar output to the Cal Poly wind turbine. After consulting our sponsor, we decided that this was no longer important because the systems' performance can be compared without equal power outputs and the main goal of the project is to demonstrate the effectiveness of tracking the sun to increase solar panel power output.

A third modification that we have made to initial designs involves the rotation about a vertical axis. Our initial design included a base plate that, when rotated, was effectively spinning our entire system. We decided that the only necessary rotation was the panel, and that it would be more energy efficient, durable, and stable to have a stationary base plate and only rotate the top portion of our system. For these reasons, we have limited the rotation movement about a central vertical axis to the solar panel and actuator, which are mounted on top of a base shaft that will not move. We will add a system of bearings to allow rotation under the loads caused by the panel and actuator apparatus.

Stability was a consideration that we took too lightly at first. In order to compensate for the fault in our initial specifications of our base and main shaft of 2-D tracking system, we have redesigned the base to add stability by utilizing a square base plate attached to a guide polar that the support pole slides into.

5.5 Final Design - Stationary Mount

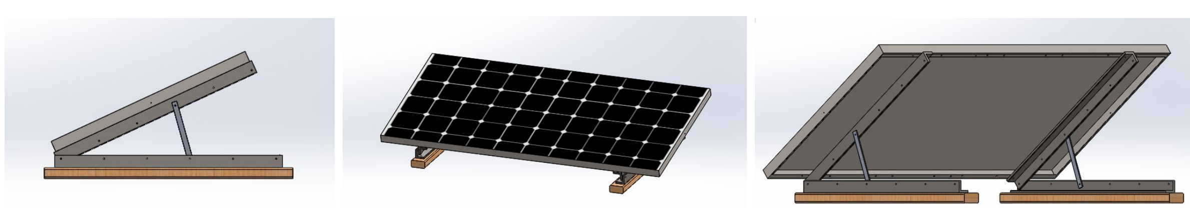


Figure 3. Various views of the Stationary Mount design.

The finalized stationary mount design is very simple, and will meet the targeted specs discussed previously. The solar panel itself will be positioned horizontally, due to the stability this orientation offers as well as making it easier to adjust manually. There will be two “L-channels” attached across the back of the solar panels where the panel manufacturer, SunPower, has already drilled mounting holes. These holes are 17/64” diameter, so ¼” bolts will be ideal for securing the L-channel to the panel. The bolts will also include a washer and a nut, so that the system can be disassembled in a straightforward manner. The flat side of the L-channel will be bolted in flush to the panel, while the other side of the L-channel will be attached to a 1 ft. long connecting rod. This connecting rod attaches the L-channel from either side of the panel to the other L-channel that is attached to the wood base legs. The connecting rod will be attached to the four L-channels (two on the panel and two on the wood base legs) with bolts, washers and nuts as well. All of the material aside from the wood base leg is 1018 steel, due to its wide range of capabilities, low cost, and manufacturing familiarity.

5.5.1 Panel Design

The solar panels are gifted to this project from Cal Poly via SunPower, and therefore already have manufacturer designated dimensions and mounting holes. There are eight mounting holes along both long sides of the solar panel, on the back. The L-channels that attach to the panel will bolt into the outermost mounting holes on both sides of the panel, but can be moved manually if desired. See Appendix 3 for detail drawings.

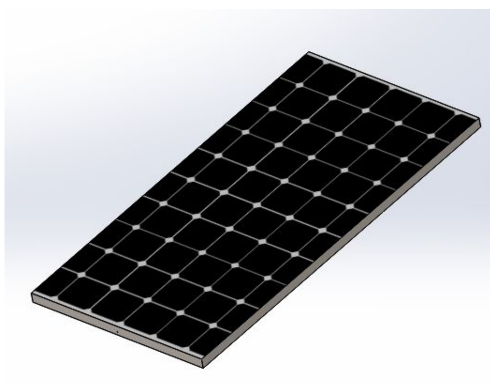


Figure 4. Panel Isometric.

5.5.2 L-Channel Design

To attach the panel to a ground support using the mounting holes already manufactured on the panel, we decided upon an L-channel. These “rods” allow for a flush attachment to the panel side, and for a parallel attachment to the connecting rod. This design lets the user simply move the panel mount with nuts and bolts, while also reducing the part number and cost. There will be four L-channels (two attached to the panel and two attached to the wood base legs), and each channel will have one side with 6 holes spaced evenly across them for manual adjustment with the nuts and bolts. See Appendix 6 for detail drawings.

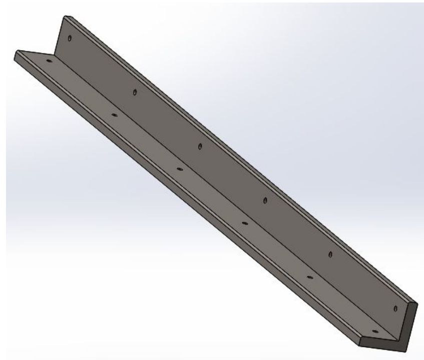


Figure 5. L-Channel Isometric.

5.5.3 Connecting Rod Design

The connecting rods are to attach the panel to the base support via the L-channels. These rods (rectangular beams) are very simple and require minimal effort to build, with only holes needing to be drilled in the ends of it. These rods allow for the user to manually adjust the angle of the solar panel by attaching the rods to various hole positions along the L-channels. See Appendix 6 for detail drawings.

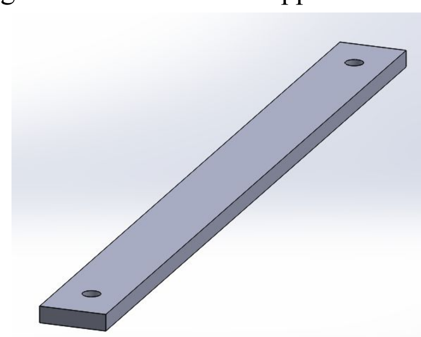


Figure 6. Connecting Rod Isometric.

5.5.4 Wood Base Leg Design

The wood base legs are simply for support of the system so that it does not rest directly on the ground and move around a lot. The bottom L-channels will be screwed into the wood panels, and the wood will be a treated lumber. See Appendix 6 for detail drawings.

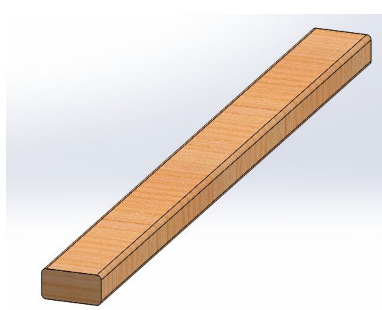


Figure 7. Wood Base Leg Isometric.

5.5.5 Safety Considerations

The stationary mount has fewer safety concerns than the two-dimensional tracking mount, since there are less parts that could possibly fail. The main concern as far as failure goes for this design is the connecting rods, which will be loaded in compression. The part would fail at the hole locations where the bolts go, so the concern is about “tear out” of the hole. There has been a lot of research on this phenomenon before us so we will utilize those resources to ensure we build a safe part. The other main safety concern is pinching of the user’s hands when moving the bolt, as well as the panel falling on the user if they are directly under it. We believe that most potential safety hazards can be avoided as long as there are two people adjusting the mount.

5.6 Final Design - Tracking Mount

The 2-D tracking mount that is our finalized design will meet the customer specifications defined previously as well as improve upon our old leading designs. The main features of the tracking design are the linear actuator, which will allow for rotation of the panel about the horizontal axis, as well as a slew drive and motor, which will allow for rotation about the vertical axis. The actuator will be mounted right underneath the panel, near the hinge, and will attach to the support pole and will push upwards on the panel. The motor will also be attached to the support pole, and will turn the slewing drive. The panel used for this system has the same specifications as the panel used in the stationary system. See Appendix 7 for drawings of all tracking mount parts.

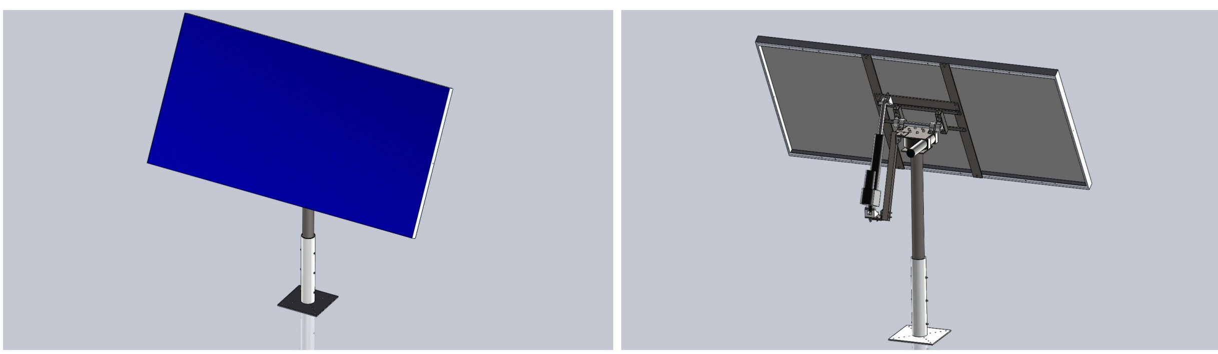


Figure 8. 2-D System Assembly Isometrics.

5.6.1 Actuator

We chose the PA-17 Linear Actuator from Progressive Automations. This actuator comes in many variations with differing stroke lengths and maximum dynamic loads. The particular actuator we chose has a stroke length of 10 inches, and a maximum dynamic load of 2000 lbf. It also has a maximum specified static load of 8000 lbf, and a no load speed of 0.24 in/s. The actuator will be attached to rest of the tracking mount via a pair of hinges, one at each end of the actuator. A rectangular pipe is used to space the actuator effectively relative to the panel. The rectangular pipe will also be used to secure the actuator to the main support plate, which will be introduced in the following sections.

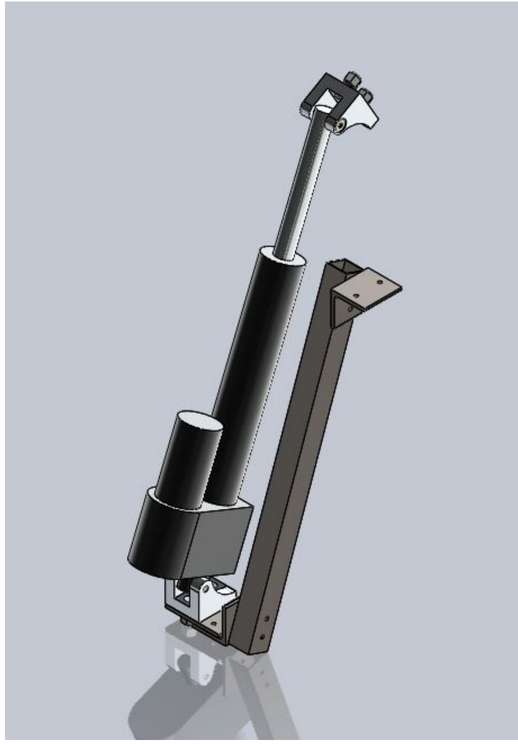


Figure 9. Actuator Isometric.

5.6.2 Base Plate Design

The base plate is simply a support for the pole that the panel will go on, and is a relatively simple part. It will be a 12 inch by 12 inch square and will have the pole welded onto it at the center. The center pole will have holes drilled through it so that the base pole of the tracking mount can be held stationary without rotating, limiting the rotation the upper portion of the tracking mount. Holes in the base plate will be used to attach the mount to its final location.

Figure 10. Base Plate Isometric.

5.6.3 Support Pole Design

The support pole is a 4 ft. long hollow cylinder that will support the panel and its components off the ground. It will be inserted into a slightly larger hollow pole, which is welded to the base plate. The poles will then be screwed together for stability. At the top of this pole, another smaller plate will be welded and used to attach all above components.

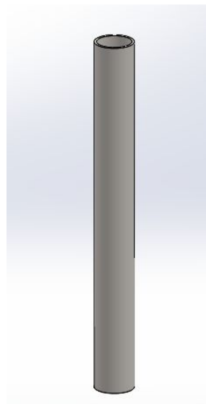


Figure 11. Support Pole Isometric.

5.6.4 Cross Brace Design

The cross brace is a series of rectangular bars that connect the panel to the hinge on top of the support pole. There will be two cross braces, one on each side of the panel crossing the back side of the panel horizontally (from long side to long side) and they will be bolted to the mounting holes of the panel, as well as bolted to the span that attaches the cross braces to the hinge. There are also three horizontal braces connecting the two cross braces that are attached to the panel.

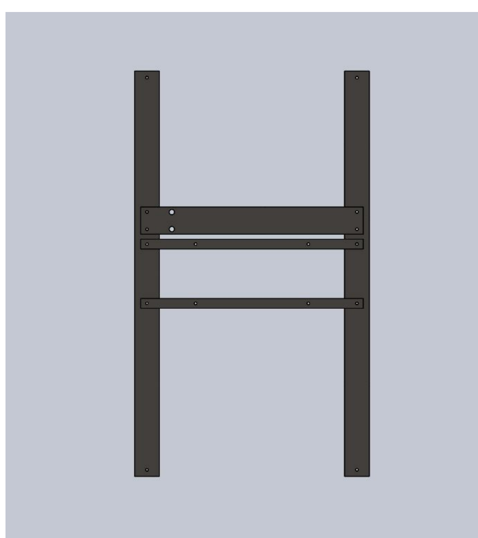


Figure 12. Cross Brace Isometric.

5.6.5 Slew Drive and Support Plates

The slew drive and motor are used for rotation about a vertical axis. A plate mounted atop the main support pole attaches the slew drive to the base. An additional plate is attached on top of the slew drive in order to attach additional components, such as the actuator and hinge, to the main support pole.

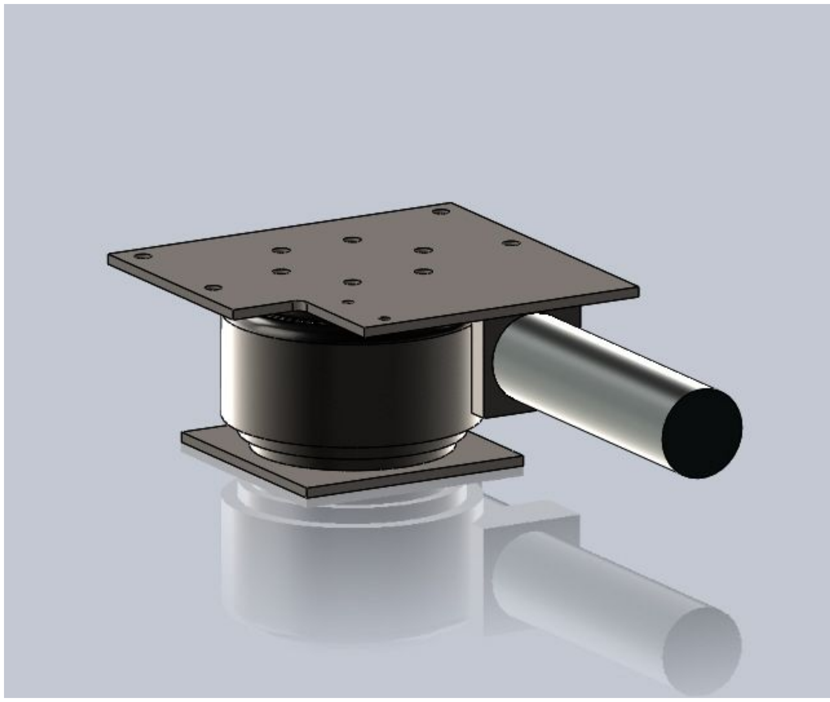


Figure 13. Top Cap Isometric.

5.6.6 Hinge Design

The hinge is made up of four bearings and a pin. The two outermost bearings will attach to the bracing on the back of the panel, while the center two bearings will attach to the central plate atop the support pole. The hinge will allow to panel to rotate about a horizontal axis, but this motion will be restricted by the actuator.

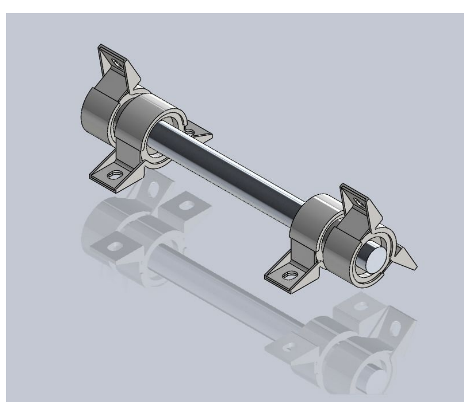


Figure 14. Hinge Isometric.

5.6.7 Safety Considerations

The 2-D system has many more safety considerations than the stationary system, and will therefore require much more in depth analysis. Since this system and the panel will be higher from the ground, there is more concern for individual part failure as well as sharp corners, longer electrical wires, etc. The main points of concern are the pin/hinge failing due to the amount of load it is being designed to support, as well as the actuator or motor pinching the user. We believe we reduced the pinch point hazard by using our design in section 5.12 as a hinge instead of using a traditional hinge made out of two plates. We also reduce the hazard of pinch points by using a relatively slow moving motor and actuator. There are no quick, sudden movements of the panel. One hazard that will have to be dealt with in the future is the stability of the tracking mount. It will need to be firmly attached to a roof or larger base plate to ensure that high winds to not tip the mount over. Though we do have potential electrical hazards, we believe that the risk of electrical issues is very low because all of our purchased electrical components are well build and can easily be operated without risk of electrocution.

5.7 Controls

Ideally, our tracking method would use programmed tracking to get close to the position of the sun, then use active tracking to dial in. This would allow us to avoid problems of active tracking due to interference, while still having sensor input to get an accurate position. However, the additional accuracy is not worth the added complication in the coding and design, so we will focus on programmed tracking and only add sensor input if time allows.

We considered having the calculations done on the server the power output data would be sent to in order to lower the computational requirements on the controller. But, since the grid tying and web data is not in the scope of this project and will be added later, we decided that the system should be able to track independently. Using a RTC (real time clock) chip and the longitude and latitude of the panels we can calculate the azimuth (horizontal) and altitude angles of the sun.

The programmed tracking will be accomplished using an IMU for orientation feedback. IMUs are sensors consisting of a 3 axis accelerometer, gyroscope, and magnetometer in one package. By calibrating the accelerometer based on the reading from gravity and the magnetometer for due north we can track the current orientation of the panel. Difference between the current orientation and the calculated sun position will be used by the controller to drive the actuators.

Controller choice was made by first tallying up the requirements of the system.

Table 2. Programming Requirements.

Part	Signal	Requirements
2 DC motors (one in the linear actuator)	PWM	2 Output Pins 2 TCR 2 Motor drivers
IMU	I2C	
RTC	I2C	
LCD display	Various	
photoresistors	2 ADC	2 ADC
Indicator LEDs		I/O Pins Number of LEDs

Since the controller is doing calculations for sun angle and not storing pre-programmed locations, memory requirements for the setup are low. Also, since calculations only need to occur once every 5-10 minutes, the controller doesn't have to have high processing power. We chose to use an ATmega328p as it has required power, memory, and pins. Additionally it has a low power consumption which follows the idea of generating as much power as possible with our system.

5.8 Motor and Actuator

There are many ways to accomplish the motion required for our panel's rotation about the horizontal axis including pneumatics, hydraulics, and electric motors. The range requirements of about 15 to 75 degrees made a linear actuator perfect for this system. Hydraulics would work well due to their strength and accuracy, however their speed is not required since the panels don't have to move quickly. Pneumatics don't give us the positional accuracy and control necessary. These considerations along with additional pumps,compressors, and tubing required for pneumatics or hydraulics made us decide to use an electronic linear actuator for the horizontal axis.

Even though this array is going to be used for educational purposes more than actually generating usable power, we decided it should be important to limit the system's power usage. Since the panels will only need to be moved once every 5-10 minutes, we should choose a system that requires little to no power while holding position against the wind between moves. This means looking for actuators with built in braking mechanisms. Stepper motors are eliminated from consideration since they use power holding position. These considerations led us to choose a power screw powered by a DC motor for our horizontal axis (altitude) linear actuator and a DC motor with a worm gear for the vertical axis (azimuth).

6.0 Engineering Analysis

When designing the solar panel mounts, considerations of the loads at critical points need to be taken into account. For each solar panel setup, the loads acting on the poles as well as the hinges at the top of the poles need to be calculated. The poles and hinges will be designed and manufactured to resist these loads. For both the single-axis tracker and the dual-axis tracker, the loads experienced by the actuator need to be calculated. These loads will vary based on the actuator's distance from the pole at its connection point to the solar panels. As such, our chose actuator must be able to withstand both the weight of the solar panels and wind loading for a given mounting distance from the pole, while still being able to provide the solar panels with a full range of movement. Preliminary wind load calculations can be seen in Figures 15 and 16 below.

6.1 Wind Load Calculations

Wind loads offer a potential strain on our system that could alter the angle of our panels. If is important to design our systems to both perform under normal wind loads and survive under severe wind load. The calculations involved in determining forces due to the wind also assist us in choosing our motor and actuator because these components must be able to function in windy conditions.

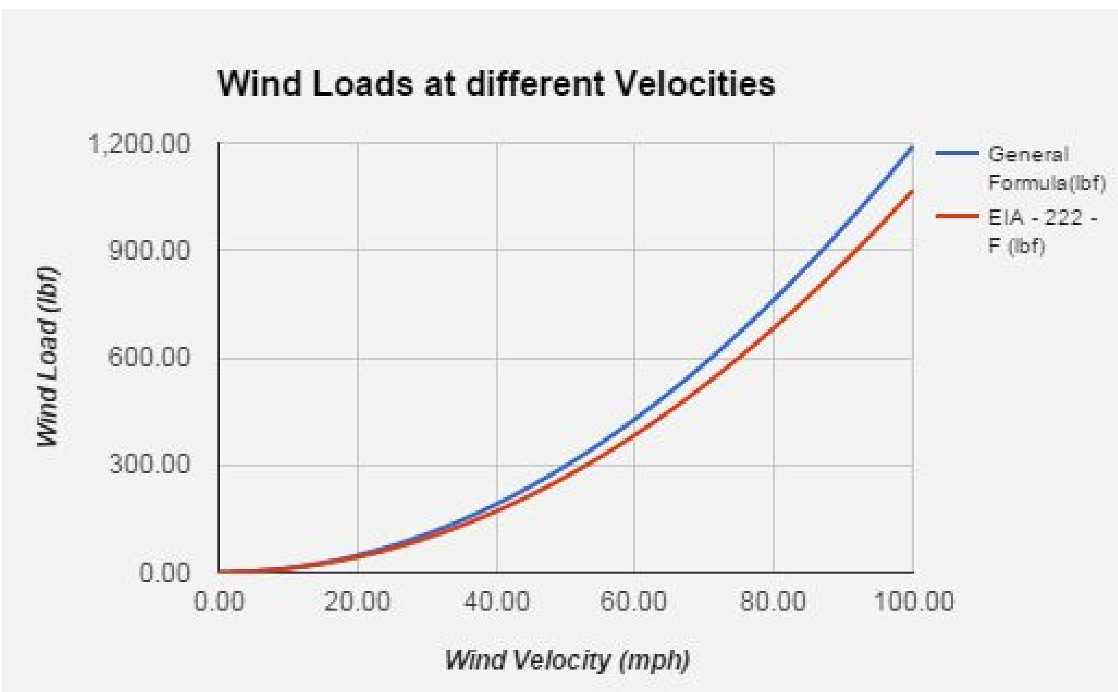


Figure 15. Wind loads based upon velocities.

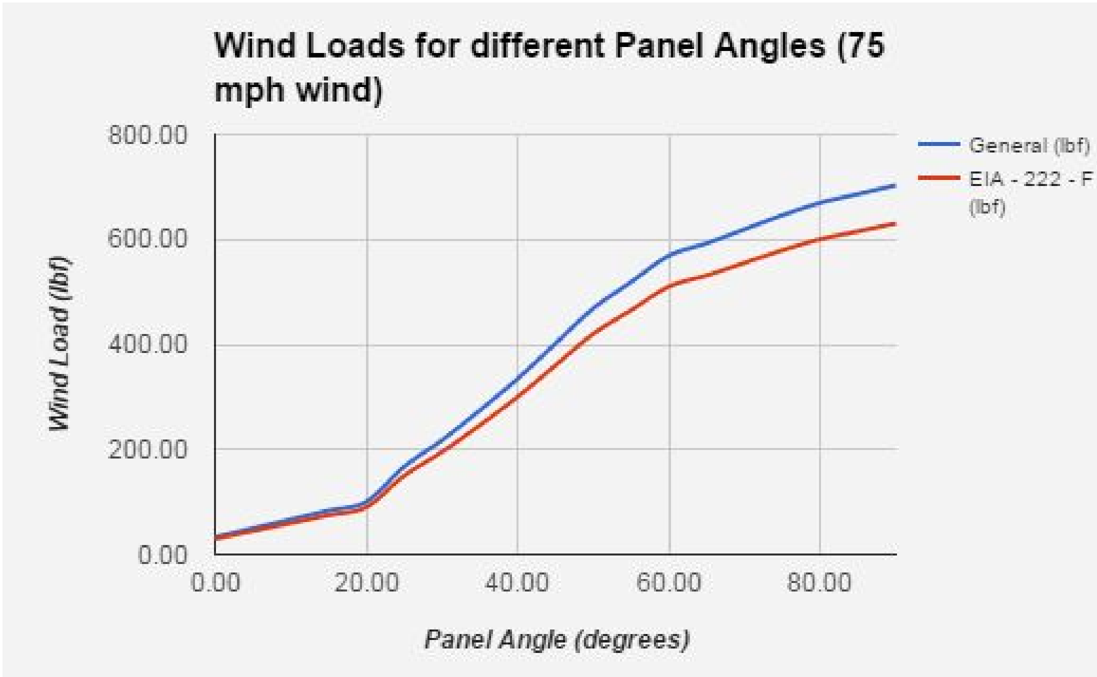


Figure 16. Wind loads based upon solar panel angle.

Calculations have been helpful up to this point to guide our process and to allow us to make better design decisions.

6.2 Actuator

When choosing the actuator, there were three specifications that needed to be addressed: the stroke length, maximum static load, and the maximum dynamic load. Using Matlab, we modeled the solar panel and actuator system which we used this model to calculate each of the three requirements. The Matlab code can be found in Appendix 8.

The first specification that was addressed was the required stroke length of the actuator. In order to do this, we needed to know how the actuator would attach to the solar panel. The extending cylinder end of the actuator is to be attached to the solar panel about six inches from the hinge. The motor end of the actuator is to be located about 12 inches horizontally from the hinge and 6 inches below the hinge. Using Matlab, the required minimum and maximum distances from the extending cylinder end to the motor end were found to be 9.77 inches and 15.76 inches, respectively. This correlates to a 6 inch required stroke length for the actuator.

For our force analysis of the actuator, we considered two cases. The first case was modeled as a stationary system that could withstand 100 MPH wind loading. The second case was a dynamic system with a constant actuator speed acting under 30 MPH wind loading. For both cases we made the highly conservative assumption that the wind load would be a point force acting on the edge of the solar panel, thus maximizing its exerted moment. Using Matlab, we analyzed both systems for each degree increment of the solar panel ranging from our minimum required angle to our maximum required angle. The dynamic system was also analyzed for several different actuator speeds, both in extension and retraction.

The resulting maximum required actuator force under static conditions was found to be just over 8300 lbf. This large value was the result of the highly conservative wind loading estimate, and most likely has a large factor of safety built into it. The maximum required actuator force under dynamic conditions was found to be just over 760 lbf. Although this loading is significantly smaller than that of the static condition, it most likely has a factor of safety built into it due to our conservative wind loading estimate.

The side loading on the actuator was an additional concern that needed to be addressed. Most linear actuators are not designed take side loading, and many suppliers don't even list the rated side loading of their actuators. In order to determine the maximum side load that could act on the actuator, we included it as an additional force to be calculated using our Matlab code. Even with our conservative wind loading estimate, the maximum side load acting on the actuator was found to be only 9.55 lbf. As a result, by choosing an industrial quality actuator, we can neglect this side load.

As was mentioned in section 5.6.1, our selected actuator has a stroke length of 10 inches, a maximum dynamic loading of 2000 lbf, and a maximum static loading of 8000 lbf. The stroke length and maximum dynamic load of this actuator exceed the requirements found by Matlab. However, the maximum static load falls below the requirement as found using Matlab. However, the difference between the specified maximum static load of the actuator and the calculated maximum static loading requirement is relatively small. Since we made a highly conservative wind loading estimate, the actual static loading that the actuator would experience in 100 MPH wind loading conditions would most likely fall below the 8000 lbf maximum static loading that the selected actuator can withstand.
Although not critical to the design, we also calculated the actuator speed under maximum dynamic loading conditions. Using Matlab, this speed was found to be 0.15 in/s for our chosen actuator. In comparison, the maximum speed of our chosen actuator is specified to be 0.24 in/s.

6.3 Support Pole Loads

For the tracking mount, an important aspect of safety and stability is the support pole, which lifts the mount up off the ground and holds the entire assembly. In order to design a correct support pole, we first needed to determine the material to use, which we decided to be steel, as well as the height of the pole, which was decided to be 3 feet. Next, various combinations of inside and outside diameters were chosen to drive the analysis, which ended up with buckling and bending stresses being compared to the strength of the various pole sizes. See Appendix 9 for hand calculations.

7.0 Testing

Testing was not executed for the Micro Grid project for several reasons. Principally, the scope of our project changed late in the design process due to time constraints, and we began to solely focus on the mechanical aspects of the mounts over the electrical and programming aspects. We also would not have been able to test the mounts in the locations that they would be on a more permanent basis, and the nature of our testing, with significant focus on sun and wind conditions, would mean that testing in a different location would not be very useful. In lieu of actual testing results, we have a few specific functions we would test if the project continued.

7.1 Panel Performance

The solar panels in use during this project are SunPower E19/425 panels, which were donated to Cal Poly from SunPower because they were not up to performance specifications. Consequently, in order to validate the results obtained from testing the stationary and tracking mounts, we must first test the solar panels to ensure the two we use perform equally. To test the panels, they would be set up on the same surface, at the same angle, and in the same amount of sunlight on a (preferably) sunny day. A simple multimeter would be used to measure output voltage and current at a specified time interval (i.e. every half hour), and results would be recorded and compared. Ideally, this test would be run on another sunny day, although at a different temperature, as well as on a cloudy day. Panels having voltage and current output levels of within five percent would be suitable to use in this project.

7.2 Mount Range of Motion

The next step in testing is to determine the range of motion, in degrees, that each mount can achieve. This would be done either by hand with a compass and ruler or utilizing a software application and mobile phone to digitally determine the angles. The tracking mount has a "true" range of motion because it is rotating about a pin, so it can achieve any angle between its minimum and maximum. These measurements would also be obtained using the above methods. The stationary mount has six specific angles it can achieve, and those are simply measured using the above methods and by shifting the support rod up and down the base at each hole position. For the stationary mount, the most efficient angle to use could be determined with more testing (discussed below), and this angle could be chosen based upon the mount's location on campus.

7.3 Programming and Electronics Calibration

With the mechanical mounts analyzed and data recorded, it would be time to turn to the electronics. It is important to note, however, that the stationary mount does not have any electronics, only the tracking mount does. The most important piece of the electronics is the microcontroller, which is telling the tracking mount what to do. For the optimum amount of electricity to be generated, the microcontroller must be adjusting the panel accurately to allow it to achieve the most efficient angle to the sun. The solar coordinates for the year will be programmed into the microcontroller, as well as the angle desirable for the panel to be at and what it takes from the motor and actuator to get the panel to that angle. The testing would then be to actually verify that the motor and actuator are doing what the microcontroller is telling them to do.

7.4 Mounts Performance Comparison

Finally, the last and most important part of testing is how the mounts perform relative to each other. This would be done by setting up both mounts in their optimum positions. For the stationary mount, this would be its optimum angle, and for the tracking mount this would be the microcontroller programmed with coordinates to follow. Then, similarly to how testing of the panels alone would be done, the mounts would be set in the same sunlight in the same area with multimeters connected to them and the voltage and current outputs would be recorded and compared. If everything is working properly, the tracking mount should produce significantly more electricity than the stationary mount, and the project will have performed its purpose.

7.5 Alternative Testing

Other types of testing could be done as well, depending upon the application desired by the user. For example, in an academic setting, a class could compare how much electricity is produced by the tracking mount when only utilizing the motor or when only utilizing the actuator. In this way, a more detailed image of why the panel is programmed to rotate the way it does can be formed, and more understanding of how the panels themselves work can be achieved.

7.6 Specification Verification

After completion of our mounts, we were able to evaluate our initial requirements.

7.6.1 Weight

Weight was a medium risk requirement for our mounts. Though we did not precisely measure the weight of each of our mounts, we estimate the both mounts combine to weigh approximately 290 lbs, about 10 lbs under our specified maximum weight. Regarding our stationary mount, we estimate that the panel weighs 50 lbs, the four L beams weigh 7 lbs each, the wood weighs 8 lbs and the fasteners and support rods weigh 4 lbs for a total of 90 lbs. Regarding our tracking mount, we estimate that the panel weighs 50 lbs, the support beams, plates, and fasteners weigh 25 lbs, the slew drive weighs 35 lbs, the actuator weighs 15 lbs, the steel base pole weighs 60 lbs, the aluminum support pole and plate weigh 15 lbs.

7.6.2 Plot Area

Plot area was a low risk requirement. We originally anticipated needing a large open area to ensure that our panels could be in complete sunlight without any obstructions. We also wanted to make sure that our tracking panel could rotate without obstruction. We met the initial 225 square foot requirement by constructing both a stationary mount and tracking mount that take up roughly 60 square feet and 90 square feet, respectively.

7.6.3 Material Strength

Material strength was a low risk requirement. We originally required our tracking mount to track accurately under 30 mph winds and survive gusts of up to 100 mph winds. While it is not likely to experience 100 mph winds in its final location, the objective of this requirement was to ensure that the mounts were overdesigned. While we are confident that some of the components of our tracking mount would be sufficient in surviving high winds, we were not able to test this requirement. We also have worries that weaker points on our mount might give out under such extreme wind loads and would not recommend putting our tracking mount into such extreme winds without first reinforcing the weak points of our mount.

7.6.4 Material Cost

Material cost was a medium risk requirement. While our goal was to meet a $1500 budget, we overshot that amount by about $300. However, this was signed off on by our sponsor as the total budget for this multi-year portion of the future Micro Grid project is actually $3000. We felt that it was necessary to go slightly over our original budget in order to purchase higher quality parts for our tracking mount.

7.6.5 Maintenance Life

Maintenance life was a medium risk requirement. Unfortunately, we are not able to determine whether this requirement was met because our mounts are not installed in their final location. However, we do believe that it may be necessary to do maintenance on our mounts more often than the original one year requirement. This is in part due to the potential use of our panel mounts by other projects and classes, who would be checking in on our project as they conducted their own project, lab work, or research.

7.6.6 Height

Height was a low risk requirement. The requirement was to limit the height of our tracking mount to 5 feet and allow the majority of maintenance to be performed at a height of approximately 3 feet. After constructing our tracking mount, the height of the panel at its steepest angle is just over 6 feet off of the ground, while the components of the mount that are most likely to need maintenance are about 4 feet off of the ground. Though this does not meet our initial requirement, we believe that these values are reasonable given the evolution of our project.

7.6.7 Stability

Stability was a high risk requirement that specified that the panel stay at a specified angle. This requirement can also be extended to the stability of the mounts themselves, which we will consider here. The stationary panel is very simple and low to the ground, so it is balanced and stable itself and the panel will not move around when it is locked in to a certain mount angle position. The tracking mount does not allow the panel to move much, since the motor and actuator are both self-locking, however the bracing to attach the panel to the motor and actuator is not very stiff and consequently allows the panel to move and “flutter” more than is probably safe in high winds. Also, the support pole for the tracking mount panel is only attached to a small base plate, and would not stand on its own without additional bracing from cable supports or being bolted down or planted in the ground. The base plate was attached for demonstration purposes.

7.6.8 Driving Mechanism

Driving mechanism was a high risk requirement specified to allow the tracking mount to rotate at least 270 degrees and to tilt at least 60 degrees. Both of these requirements were met successfully, with the tracking mount capable of rotating a full 360 degrees (being aware and careful of the power cables wrapping around the support pole), and the actuator capable of tilting the panel a full 90 degrees. This will allow for the maximum amount of panel positions relative to the sun to be able to test.

7.6.9 Power Requirements

Power was a medium risk requirement specified to allow the tracking mount to power itself with at least 20% of the electricity coming from the panel itself. Since the scope of the project changed throughout the final third of design, this requirement became shifted to a potential future group that would add the electronics to the mounts. However, we have set up the mounts to be electronics-friendly and to allow a future team to achieve this requirement.

7.6.10 Power Output Data

Power output data was a high risk requirement specified to be able to measure this data locally and remotely. Since the scope of the project changed throughout the final third of design, this requirement became shifted to a potential future group that would add the electronics to the mounts. However, we have set up the mounts to be electronics-friendly and to allow a future team to successfully add power output readouts.

7.6.11 Safety

Safety was a low risk requirement specified to meet OSHA standards, and we are confident that this requirement is met, however have not done testing to determine for sure. The stationary mount is very simple and has no moving parts, so it does not pose a significant safety risk. The tracking mount does have moving parts and is hoisted a few feet off the ground, however the components of this mount were highly over designed, with load factors that are extremely unlikely to be seen in real life.

7.6.12 Portability

Portability was a medium risk requirement specified to be transportable by two people and top also be taken apart by two people, and this requirement was met.. The stationary mount is relatively light and simple enough to be lifted and carried by one person, and easily placed into the bed of a truck by two people. The tracking mount is more unwieldy and heavy, however it can be taken apart at three places and more easily moved in that way. Two of our group members took it apart and moved it in around ten minutes, so we are confident others could do the same.

8.0 Changes from Final Design

Many improvements were made to the design over the manufacturing process. Some parts were changed as we experienced how they actually behaved once they were put together. Others changed as we fully fleshed out the design with exact dimensions.

8.1 Stationary Mount

Instead of treated lumber as planned, we used regular 2x4 planks. This was changed when we learned that the mount would only temporarily need wood legs since they wouldn't be required once they were attached to a roof. The design didn't include the extra spacers required to have the support bar be flush with both L beams it was connected to. It also didn't specify which direction the bolts and nuts were facing. We chose to put them on the inside so they will be easier to unfasten when changing the panel angle or disassembling the mount.

8.2 Tracking Mount

The original base design called for a steel plate welded on the bottom of the pole. We realized that the base design for when it is sitting on the solar balcony and attached to the roof would be different, so we changed it to something more temporary and cost effective. The base we made consists of a wider aluminum pole welded to an aluminum plate that the steel pole fits into. The steel tube is then locked in place with bolts that attach through the two poles. The aluminum plate has a pattern of holes in it that can be used to attach extra wood support legs. The new base design is cheaper than buying a large steel plate for the bottom. A large steel plate on the bottom would also have to be removed and wasted when the mount is moved to a roof.

The motor and worm gear mechanism that we originally planned for is the most common way of achieving vertical axis rotation in the solar industry. It was cheaper and less time consuming for us to purchase one that fit the specs of our system rather than try to manufacture one ourselves. One issue was that the motor sticks out of the side of the slew drive and could interfere with the panel or actuator. This was solved by flipping the slew drive so that the outer case and motor rotates with the top of the mount. This way, the motor is never moving relative to the actuator and panel.

The addition of the slew drive required a plate that allowed us to attach it to the top of the steel pole. One important thing we had to consider is interference between the bolt heads and the weld of the plate to the pole. We chose socket head bolts to account for this, but the thread depths in the slew drive were shorter than what was specified on its drawing. As a result, the spacers required to keep it tight were too wide to fit between the bolt head and the plate weld and had to be put in between the plate and the slew drive. The slew drive also required a plate on the top to interface between it and the hinge and actuator bracket arm.

The original design didn't fully define how we were going to attach the actuator to the pole or back of the panel. At first we planned on connecting the top plate to the actuator along its neck, but the side of the actuator wasn't designed to take the loads expected with our system. The other option was to use the actuator hinges it came with that attached on the top and bottom. To connect the bottom actuator hinge to the top plate we needed to extend an arm downward and off the side of the top plate so that it wouldn't interfere with the slew drive. This method also let us connect the actuator in the same geometry that was used to calculate the load requirements.

The main hinge from the design consisted of a shaft held with bearings attached to the top plate and a rectangular piece that fit on the shaft and connected to the panel braces. The final hinge consists of a shaft with two sets of bearings. One set is on the top plate and the other is connected directly to the panel braces. This provided a larger range of motion and allowed us to use the bearing manufacturer's load to size the hinge system. It also eliminated the pinch point between the two plates.

The cross braces that we had in the design in order to make the panel less flexible ended up being too flimsy when we first attached them. They were swapped out for thicker steel bars. More bars were added between the two braces in order to connect to the bearings and actuator hinge.

9.0 Manufacturing and Assembly

The stationary solar mount and solar tracker were both designed to minimize cost and number of parts. With the exception of the temporary baseplate and hinge pin for the tracker, all machined parts were made of steel because of its high yield strength.

9.1 Stationary Mount: Machining and Assembly

A total of six parts were machined for the stationary mount, three of which were unique. Drawings for each of the three unique parts can be found in Appendix 6; the official names for these parts are used throughout the remainder of the section. The stationary mount assembly consists of two Panel Beams, two Base Beams, and two Connecting Rods. All six parts were cut to length using a chop saw, and holes were drilled using a drill press.

The stationary mount was assembled using several fasteners. A drawing of the assembly, along with a Bill of Materials, can be found in Appendix 6. The Panel Beams were first attached to the solar panel. Next, the Base Beams were attached to the Panel Beams such that they acted as a large hinge. Finally, the Connecting Rods were attached to the Base Beams and Panel Beams, setting the angle of the stationary mount.

Figure 17. Front view of stationary mount.

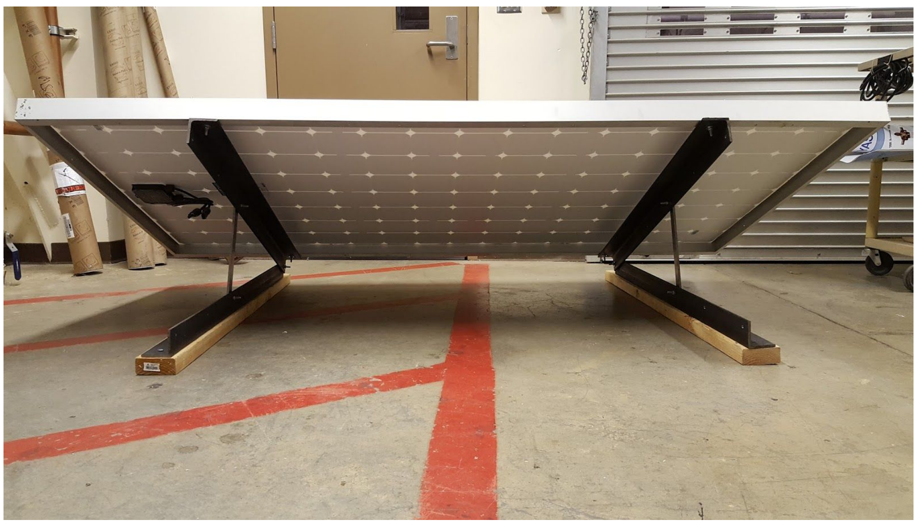


Figure 18. Rear View of stationary mount.

9.2 Dual-Axis Tracker: Machining

A total of sixteen parts were machined for the solar tracker, fourteen of which were unique. Drawings for each of the fourteen unique parts can be found in Appendix 7; the official names for these parts are used throughout the remainder of the section. Ignoring the solar panel, actuator, slew drive, and all fasteners, the parts (both machined and purchased) can be separated into six different categories: panel crossbars, hinge, slew drive mount, actuator mount, pole, and baseplate.

The panel crossbars create attachment points on the solar panel for the hinge and actuator. They consist of five bars: two Vertical Crossbars, two Horizontal Crossbars, and an Actuator Crossbar. These parts were cut to length using a chop saw, then the holes were drilled using a drill press. The inaccurate nature of using a drill press resulted in some holes needing to be redrilled.

The hinge allows for panel rotation about the horizontal. It consists of seven parts: four pillow block bearings, one Hinge Shaft, and two Hinge Panel Mount Spacers. The Hinge Shaft was cut to size using a chop saw, and its diameter fine-tuned by sanding. The Hinge Panel Mount Spacers were cut using a chop saw, and holes located and drilled using a mill. The four pillow block bearings were purchased.

The slew drive mount provides attachment points on the pole and hinge for the slew drive. It consists of two plates: one Slew Drive Bottom Plate and one Slew Drive Top Plate. Both parts were cut to size using a bandsaw, and all remaining features located and cut using a mill.

The actuator mount provides attachment points on the panel and slew drive for the actuator. It consists of six parts: one Actuator Base Bracket, one Actuator Angle A, one Actuator Angle B, one Actuator Base Mount Extension, and two actuator mounting brackets. The Actuator Angle A, Actuator Angle B, and Actuator Base Mount Extension were cut to length using a chop saw; alternatively, the Actuator Base Bracket was cut to size using a bandsaw. Holes were drilled in the Actuator Angle A and Actuator Angle B using a drill press. The inaccurate nature of using a drill press resulted in some holes needing to be redrilled. Alternatively, holes were located and drilled in the Actuator Base Bracket and Actuator Base Mount Extension using a mill. The two actuator mounting hinges came with the purchased actuator.

The pole provides support to the dual-axis tracker. It consists of only one part: the Support Pole. The pole was cut to length using a portable bandsaw, and the cut edge flattened and chamfered using a grinder. Holes were drilled in the Support Pole using drill press. The holes were located relative to those of the Support Pole Sleeve (see next paragraph); however, the inaccurate nature of using a drill press resulted in each of the six holes being widened.

Finally, the baseplate provides an attachment point between the dual-axis tracker and the ground. Due to its planned temporary use, it is also referred to as the temporary baseplate. It consists of two parts: one Support Pole Sleeve and one Baseplate. The Support Pole Sleeve was cut to length using a portable band saw. Holes were drilled in both parts using a drill press. The accuracy of the hole locations for these parts were of less importance; the holes in the Support Pole Sleeve were used to located the holes in the Support Pole, and the base plate will be bolted directly to the ground.

9.3 Dual-Axis Tracker: Assembly

The solar tracker was assembled using many bolts and two welds. A drawing of the assembly, along with a Bill of Materials, can be found in Appendix 7. The two welds were the first step of assembly. The Support Pole was welded to the Slew Drive Bottom Plate, and the Support Pole Sleeve was welded to the Baseplate. Fasteners were then used to complete the remainder of the assembly. First, the panel crossbars were first attached to the solar panel. The two Hinge Panel Mount Spacers and one actuator mounting bracket were attached to the panel crossbars. Second, the Support Pole was slid into the Support Pole Sleeve and bolted. Third, the slew drive was attached to the top of the Support Pole such that the slew drive rotated with the panel. On top of the slew drive, the Slew Drive Top Plate as attached. Fourth, two pillow block bearings and the Hinge Shaft were attached to the Slew Drive Top Plate. Fifth, the actuator mount, excluding the one already mounted actuator mounting bracket, was assembled. It was then attached to the Slew Drive Top Plate. Sixth, the panel was attached to the pole, while the remaining two pillow bearing blocks for the hinge were simultaneously assembled. Finally, the actuator was attached to both actuator mounting brackets.

Figure 19. Rear view of assembled tracking mount.

Figure 20. Rear view of tracking mount.

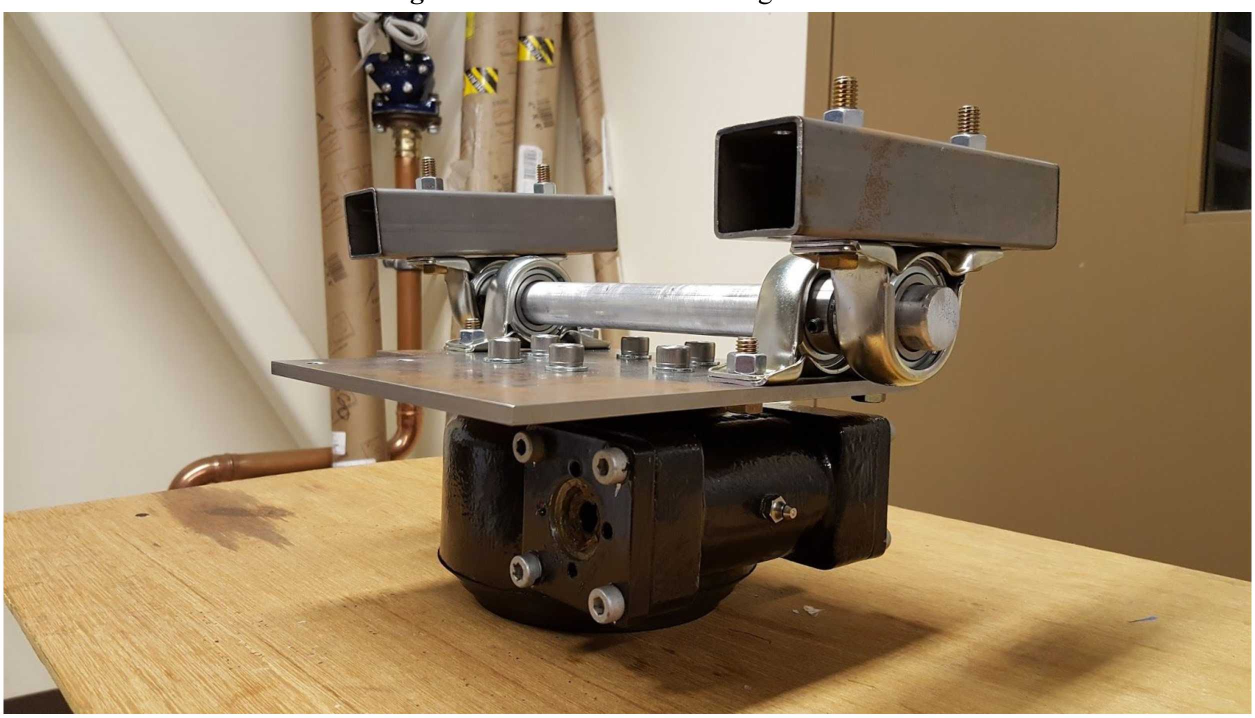


Figure 21. Slew Drive and bearing system for tracking mount.

Figure 22. View of base and support pole.

10.0 Cost Analysis

Cost breakdown for all of our parts can be seen in Appendix 11. The total cost for our stationary mount was approximately $210 and the total cost of the tracking mount was approximately $1,569, for a total of $1,779. While this is slightly over our initial budget of $1,500, we tapped into an additional amount of money set aside for other aspects of the Micro Grid. This was approved by our sponsor.

11.0 Safety and Functionality

This Micro Grid project will involve building three rather large solar panel mounts with moving parts and heavy materials. With all designs, safety is an extremely important factor, and for this project it is paramount. The desired outcome of this project is to have faculty and students work hands-on with these mounts, and for them to be able to learn and explore solar technology in a safe and controlled environment. The hazards presented with our designs are mostly associated with the wind loads on the panel. Risks would include the panel blowing off of the mount, or the panel and the mount failing in bending together and falling. Other hazards could include exposed electrical components, light reflecting off of the panels towards higher-up buildings or classrooms, and for our stationary, manually adjusted mount, there is a hazard of the panel falling onto the user if operated incorrectly. The designs will include safety features to account for these hazards, and the hazards themselves will be minimized when at all possible. Full design functionality will be maintained while accounting for all of the safety hazards that arise.

One of our most important duties as engineers is to ensure the safety of users that could potentially handle products that we design. The easiest way to do so is simply to design a product with minimal hazards to begin with. However, sometimes systems will have inherent safety hazards related to subsystems that cannot be altered easily in order to make them safer. At this point, adding on protective features, as well as cautionary labels can be helpful in improving the safety of a design. In order to make our design as safe as possible, we have taken into account potential hazards during the design phase. We attempted to minimize hazards during our initial design, but realized that we would also need to utilize additional protective features in order to increase the safety of our solar panel mounts.

11.1 Safety Features - Initial Design

Some potential safety concerns were dealt with immediately in our design process. One way we did this was to constrain our designs to only be able to achieve the specifications that were considered necessary by our sponsor. For example, because the sun travels very slowly across the sky, our tracking system does not need to be able to turn at very high speeds. Though it is possible that a tracking system with the capability of spinning extremely quickly, it is not necessary. Furthermore, a system that can spin very quickly has the potential hazard of injuring somebody who is unaware of how quickly the equipment is moving. This is just one of a few examples that show how over-designing can actually be hazardous. We also thought that making the change from rotating our entire system to rotating on the top portion with the solar panel makes the system safer because fewer parts are moving. Even though safety wasn't the main consideration that lead to the change, increased safety was a byproduct of the alteration.

Another way to eliminate potential safety hazards from the beginning of the design phase is to consider very basic level design features such as sharp corners and other protruding components. We were careful to minimize these types of features as they offer unnecessary safety concerns.

11.2 Additional Protective Features

Though we attempted to minimize safety hazards as much as possible in our initial design, some hazards were unavoidable. For these cases, we had to add features to our design in order to improve safety. One area of concern was the gear mesh between the motor and rotating shaft. This intersection of gears creates a 'pinch point' hazard, which can be dangerous for operators, specifically dangerous in terms of crushing fingers. In order to combat this hazard, it would be beneficial to add on a casing for our motor and gear mesh. This would cover the moving parts and potential pinch points. An additional benefit of this casing is that it would protect the moving parts from the wear and tear from weather elements.

11.3 Labeling and Instructions

Even when a system is designed with safety in mind, there is always a way for somebody to bypass these safety features. To handle this situation, our last effort would be to add warning labels and cautionary signs on to our systems. One advantage that we have is that our solar panel mounts will reside on either the roof of a building or the balcony of building 13 on the Cal Poly campus. These areas are inherently very low traffic so hopefully we won't have many people who weren't involved in the project hanging out in the vicinity of our completed system. That being said, it still would be a good idea to be overly safe than not safe enough. For this reason, we could add signs to warn future users of electrical hazards in our circuitry, as well as physical hazards such as moving parts. Even though most of our moving parts will be covered, the actuator will likely be open to the environment and could be an area of injury risk if a user is not careful. Another potential safety hazard is the mechanism used to change the tilt of our stationary panel. Fingers could be pinched between the metal supports.

11.4 Disassembly

We recommend taking both mounts apart with at least two people. For the stationary mount, have one person hold the panel while the other unfastens the support bars For the tracking mount, start by disconnecting both ends of the actuator and letting the panel rest against a table or the base pole. Have two people hold either side of the panel while the third person unfastens the bolts that connect the panel braces to the bearings. If there are only two people, rest the bottom of the panel on a table and have both people steady it while one carefully unfastens the bolts. Lastly, remove the slew drive from the top of the pole by removing the bolts connecting it to the plate on the pole. The slew drive, top plate, and bearing assembly can be moved as one piece.

11.5 Motor and Actuator Use

The Actuator runs on 12VDC and has a current limit of 20A. It is powered using the two wires coming off the bottom. Switch the polarity to change actuation direction. The data sheet is available in Appendix 9.

The motor for the slew drive runs on 24VDC and has a rated current of 4.7A. The motor includes a hall effect sensor. The data sheet is in Appendix 9. Take care when powering the motor as accidently wiring the hall effect sensor in the wrong direction can break it.

12.0 Management Plan

This section outlines responsibilities for the team and each team member. Each team member is in charge of a few elements of designing, building, and testing the solar panel system. They are to oversee these project elements rather than take them on single-handedly.

12.1 Team

As a team, we made large decisions and combine our skillsets to effectively resolve the problems that we encounter. Research, for example, was conducted by all members of the team because it is necessary to have adequate background knowledge of the topics that we will encounter during our design, build, and testing phases.

Brainstorming is often very effective when team members individually generate ideas, then bounce ideas off of each other. Although brainstorming designs will start as an individual process, our final design decisions was made by the entire team. This includes decisions made on necessary parts and materials, as well as methods of construction.

A very large portion of our project is centered around constructing our solar panel mounts, so we would like to split up this work as evenly as possible amongst the team so that no team member is left out of the process and so that no team member is overloaded with work during the most important parts of the design process.

12.2 Dylan Mayer

Smaller portions of the project can be worked on by multiple members of the team, but it is beneficial to have one member take the lead and manage certain aspects of the design process. Dylan managed the initial design prototyping and design selection phase of the project. Additionally, he aided in the selection, machining and assembly of various support poles, plates, and beams. Dylan also laid out an outline for the technical writing aspect of the project and monitored progress with written materials.

12.3 Connor McKay

Connor focused on developing a tracking method for the rotating solar panel system. Another of Connor's responsibilities was to manage ordering parts and materials relating to the motor and control system of the tracking mount. Though a web-based monitoring system turned out to be out of the scope of our project, Connor obtained all of the supplies necessary for a future group to continue with our work in this area. Connor also assisted in the machining and assembly of various parts of both mounts.

12.4 Christian Odegard

Christian assisted in managing prototyping initial design ideas. Additionally, he took charge of the analysis behind determining material strengths and sizes in order to meet our specifications. Christian also handled a substantial portion of the CAD drawings. He took part in ordering parts and contacting multiple companies in order to select the correct slew drive for our project, as well.

12.5 Greg Pellegrino

Greg was in charge of all analysis related to the actuation system in our tracking mount. He also assisted Christian in managing calculations that were used to transfer our focus from small scale designs into building a full-scale system. This includes making key decisions on the final dual-axis solar-tracking method. Greg did an extremely thorough and professional job of creating our final design in SolidWorks and created drawings of all of our final parts, in addition to a bill of materials.

13.0 Recommendations

Throughout this project, we have determined several steps that we have taken that we would likely do differently if we were to do this project over again. We have outlined the following recommendations for any other groups potentially undergoing a similar project to ours.

13.1 General Project Suggestions

Don't try to reinvent the wheel. During our initial research, we examined a variety of pre-existing designs and used them to influence our prototypes. However, while trying to come up with an original design, there were a few main concepts of established solar tracking designs that we drifted away from. For example, we were going to order a group of parts in order to create our own bearing system, rather than just buying a mass-produced central bearing system that is commonly used in commercial designs. When we realized that it would be much more effective and sturdy to purchase a bearing system instead of making our own, we realized we had wasted a significant amount of time making design decisions when we could have been assembling and testing our panel mounts instead.

Don't delay ordering parts. Try to order and assemble parts as soon as possible because there will be problems with machining and putting parts together. One problem that we ran into during this phase of the project was a mistake in the measurement of the distance between two holes that resulted in drilling holes that did not line up well enough for fasteners to attach the beams that the holes were drilled into on the back of the solar panel. Luckily, we had extra stock metal that we were able to use to resolve this issue, but it required additional time in the machine shop that could have been spent working on other aspects of the project. Another mistake we made was ordering support beams that were not rigid enough to support the weight of our tracking mount. We had to order additional beams that were about double the width of the original beams in order to get enough rigidity. Not only was this a waste of material and money, but the timing of the realization that we would need to order new beams came during the peak of our machining and added unnecessary stress to our project that could have been avoided if we had ordered the beams farther ahead of time and more thoroughly investigated their supportive capabilities.

Be very careful with precision when assembling parts in SolidWorks. This saved us towards the end of our project because we very carefully selected fasteners to fit precisely with our slew drive and supporting beams. We were close to running out of time and not having an assembled project for the Senior Project Expo, but successfully assembled our tracking mount in time because the last minute parts that we ordered fit exactly as expected. While it is obviously not a good idea to wait until the last minute to order parts, it is very beneficial to make sure that each part of a final design only needs to be ordered once.

Go through sanity checks throughout the project. Several of the components that we selected early on were extremely over designed. Later on in our project, we realized that while over-designing these parts gave us a favorable factor of safety, we had gone through enough of our budget that the rest of our parts could not be over-designed to the same extent. This left us with some parts of our tracking mount being extremely powerful and sturdy, while others weren't as secure and allowed unfavorable wobbling of our solar panel.

13.2 Specific Solar Mount Project Suggestions

Understand the scale of your project. Larger panels will require more powerful actuators and motors, while smaller panels don't need as much support. Also understand how your budget will influence your part selection. While is is advantageous to have extremely over-designed parts in order to ensure that your design will not fail, consider the economics of the project and ensure that you save some of your budget for additional parts that may be necessary.

Another suggestion would be to minimize unnecessary movement. We originally planned on spinning the entire tracking mount on a rotating base plate, but settled on only the top half of our mount rotating. This is beneficial because it did not require nearly as powerful of a motor. It also makes the mount easier to maintain, while simultaneously making it safer by minimizing moving parts.

A third suggestion is to use geometry to minimize the distance that your actuator needs to travel in order to achieve full range of motion. Assuming you are using an actuator, this should both reduce cost and increase stability.

13.3 Manufacturing Suggestions

One area of improvement in our manufacturing is precision. We used a drill press to drill a total of 30+ holes in various beams. This may have been simpler than setting up a CNC mill to drill the holes, but it proved to be less accurate. In multiple locations, we had to use additional tools in order to extend some of our holes into slots in order to allow fasteners to fit correctly. This slightly compromised the rigidity of our mounts. Though this could have been prevented with more careful measuring and drilling, we could have had perfectly aligned holes if we had used more advanced machinery to drill them.

13.4 Time Management Suggestions

We originally set up a Gantt chart in order to track our progress throughout the project. Unfortunately, we did not stick to the calendar laid out by the Gantt chart very effectively. During the second quarter of our project, we realized that this tool was not particularly effective for our group and that we were getting off track with our project. The main reasons for getting off track included delays in our design process and inefficient time management. We believe that an organizational tool of this nature is much more effective in a workplace environment than in a university setting. The main reason for this is that employees are entirely focused on their project, whereas student have a variety of classes going on alongside their projects. We experienced quite a few delays due to difficulties in meeting as a team because of conflicts from other classes.

Although the Gantt chart was not effectively used during our project, we still see its benefits and would recommend the tool to future groups. However, it is important to note potential setbacks during the creation of the chart in order to make it as realistic as possible.

14.0 Conclusion

Though this project evolved significantly from our initial requirements and our final products differed from what our sponsor originally asked for, our team was successful in learning about the design, build, and test processes. Over three quarters, we discovered how both well-conducted and inefficient strategies can influence progress in a group project of this nature. We had some weeks of immense progress and other weeks of extreme setbacks, but actually learned a great deal more during our setbacks than our accomplishments. Not only did this project prepare us for potential jobs in the industry, but it also gave us a larger sense of appreciation for products around us that have likely undergone similar processes to what we did during this project.

We look forward to hearing about the future of the Micro Grid project and how other groups were able to use the systems that we designed and built in order to advance the project as whole. We believe that with our solar mounts, a series of wind turbines, and additional expertise regarding control systems and electrical system regulation, the Micro Grid project will grow to be a very impressive part of the Senior Project curriculum at Cal Poly.

15.0 Appendices

1. Quality Functional Deployment - House of Quality
2. Pugh Matrices
3. Panel Statistics Sheet
4. Gantt Chart
5. References
6. Stationary System Drawings
7. 2-D System Drawings
8. Matlab Actuator Calculations
9. Support Pole Hand Calculations
10. Slew Drive, Motor and Actuator Data Sheets
11. Parts List and Cost Breakdown

Appendix 1

Quality Functional Deployment - House of Quality

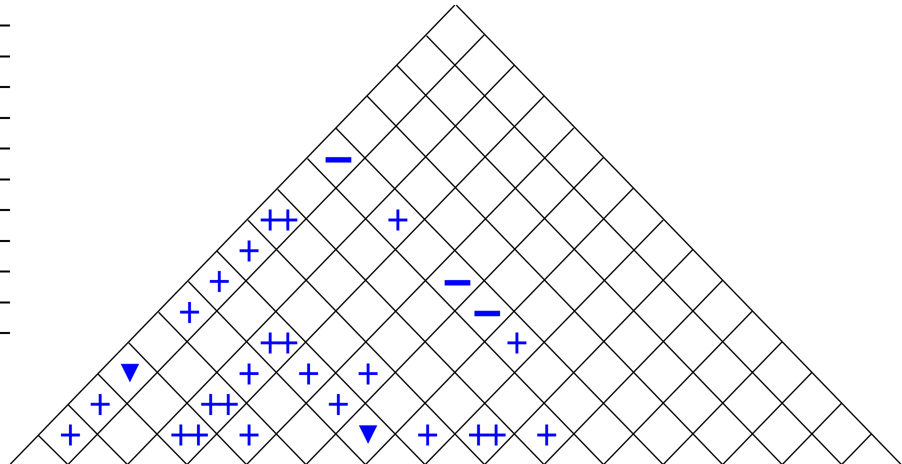
Title: Micro Grid House of Quality

Author: Team PolySolar

Date: 1/19/2016

Notes:

Legend		
Θ	Strong Relationship	9
O	Moderate Relationship	3
▲	Weak Relationship	1
++	Strong Positive Correlation	
+	Positive Correlation	
−	Negative Correlation	
▼	Strong Negative Correlation	
▼	Objective Is To Minimize	
▲	Objective Is To Maximize	
x	Objective Is To Hit Target	



Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Demanded Quality (a.k.a. "Customer Requirements" or "Whats") / Quality Characteristics (a.k.a. "Functional Requirements" or "Hows")	1 Weight	2 Plot Area	3 Material Strength	4 Material Cost	5 Maintenance Life	6 Height	7 Stability	8 Driving Mechanism	9 Power Requirements	10 Web Data	11 Safety (Third party criteria)	12	13	14	15	Our Company	Competitor 1	Competitor 2	Competitor 3	Competitor 4	Competitor 5
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▼	▼	x	▼	x	▼	▲	x	▼	x	▲										
1	9	20.0	25.0	Low Cost	Θ	O	Θ	Θ	Θ		▲	Θ	Θ	O	Θ										
2	9	16.0	20.0	Durable	▲		Θ	Θ	Θ	O	Θ	O			Θ										
3	9	8.0	10.0	Simple		▲	▲		Θ		▲	Θ	▲	Θ											
4	3	8.0	10.0	Looks Cool						▲		O		O											
5	9	16.0	20.0	Weather-Resistant			Θ	Θ	Θ	▲	O	Θ			O										
6	9	4.0	5.0	Lightweight	Θ	Θ	Θ	Θ		O	O	O		▲	O										
7	9	12.0	15.0	Easy to use and record data	▲	O			▲	▲		▲	O	Θ											
8	9	12.0	15.0	Easy to Maintain	Θ	Θ	O	O	Θ	Θ	▲	Θ	O	Θ	O										
9	9	4.0	5.0	Portable	Θ	Θ		O		Θ		O		▲	Θ										
10																									
				Target or Limit Value	750 lbs	300 sq ft.	Withstand wind pressure force of 30 mph	Less than $1500 total cost	4 years	Max panel height (10ft); maint. Height (5 ft.	Doesn't move from desired positio more than +- 10 deg	180 deg rotation and resist 30 mph wind	5% of power produced by panel	measure locally and remotely	OSHA standards										
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	3	3	8	9	8	3	7	5	2	2	6										
				Max Relationship Value in Column	9	9	9	9	9	9	9	9	9	9	9										
				Weight / Importance	388.0	284.0	548.0	552.0	660.0	240.0	244.0	612.0	260.0	380.0	456.0										
				Relative Weight	8.4	6.1	11.9	11.9	14.3	5.2	5.3	13.2	5.6	8.2	9.9										

Competitive Analysis (0=Worst, 5=Best)

Our Company — Competitor 1 — Competitor 2 — Competitor 3 — Competitor 4 — Competitor 5

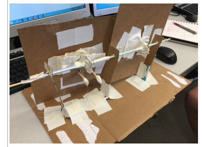
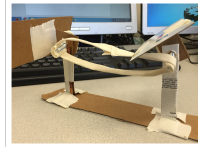
0 1 2 3 4 5

Powered by QFD Online (http://www.QFDOnline.com)

Appendix 2

Pugh Matrices

Pugh Matrix

Concept							
	1	2	3	4	5	6	7
Tracking Type	Stationary	2-D	2-D	1-D	1-D & 2-D	1-D	1-D
Criteria							
Low Cost	Up	**	Down	Down	Down	Down	Same
Durable	Up	**	Up	Down	Down	Down	Up
Simple	Up	**	Down	Down	Down	Down	Down
Looks Good	Down	**	Same	Up	Up	Up	Up
Weather-Resistant	Same	**	Same	Same	Same	Down	Same
Lightweight	Down	**	Down	Same	Down	Same	Same
Easy to Use	Same	**	Up	Down	Down	Down	Up
Easy to Maintain	Up	**	Up	Same	Same	Down	Up
Portable	Same	**	Down	Down	Down	Same	Same
Innovation	Down	**	Same	Up	Up	Up	Same
∑ Up	4	**	3	2	2	2	4
∑ Down	3	**	4	5	6	6	1
∑ Same	3	**	3	3	2	2	4
Score	5	Datum	1	-3	-6	-6	**10**
Concept	1	2	3	4	5	6	7
Criteria							
Low Cost	Up	Same	Down	Down	Down	Down	**

Pugh Matrix

Durable	Up	Same	Same	Down	Down	Down	**
Simple	Up	Same	Same	Down	Down	Down	**
Looks Good	Down	Same	Same	Up	Up	Up	**
Weather-Resistant	Up	Same	Same	Down	Down	Down	**
Lightweight	Up	Up	Same	Up	Down	Down	**
Easy to Use	Up	Down	Same	Same	Down	Down	**
Easy to Maintain	Up	Same	Same	Same	Down	Down	**
Portable	Up	Same	Same	Same	Down	Up	**
Innovation	Same	Same	Same	Up	Up	Up	**
∑ Up	8	1	0	3	2	3	**
∑ Down	1	1	1	4	8	7	**
∑ Same	1	8	9	3	0	0	**
Score	**15**	8	7	1	-12	-8	Datum
Concept	1	2	3	4	5	6	7
Criteria							
Low Cost	**	Down	Down	Down	Down	Down	Same
Durable	**	Same	Same	Same	Down	Down	Same
Simple	**	Down	Down	Down	Down	Down	Down
Looks Good	**	Up	Up	Up	Up	Up	Up
Weather-Resistant	**	Same	Down	Same	Same	Down	Same
Lightweight	**	Same	Down	Same	Down	Same	Down
Easy to Use	**	Down	Down	Same	Down	Down	Same
Easy to Maintain	**	Same	Down	Down	Down	Down	Same
Portable	**	Up	Same	Same	Down	Down	Same
Innovation	**	Same	Up	Up	Up	Up	Up

Pugh Matrix

∑ Up	**	2	2	2	2	2	2
∑ Down	**	3	6	3	7	7	2
∑ Same	**	5	2	5	1	1	6
Score	**Datum**	3	-6	3	-9	-9	**6**

Appendix 3

Panel Statistics Sheet

E19 / 425 SOLAR PANEL

MAXIMUM EFFICIENCY AND PERFORMANCE

SUNPOWER®

SERIES

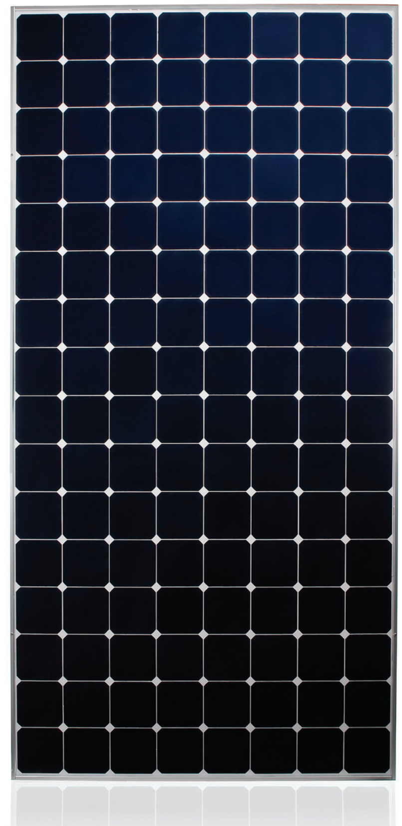
BENEFITS

Highest Efficiency
SunPower™ Solar Panels are the most efficient photovoltaic panels on the market today.

More Power
Our panels produce more power in the same amount of space—up to 50% more than conventional designs and 100% more than thin film solar panels.

Reduced Installation Cost
More power per panel means fewer panels per install. This saves both time and money.

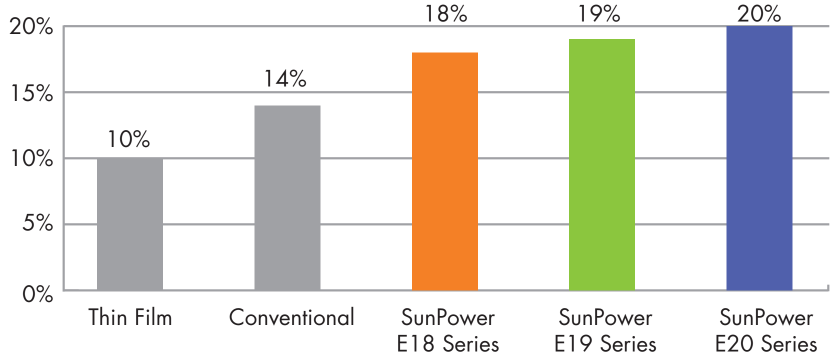
Reliable and Robust Design
Proven materials, tempered front glass, and a sturdy anodized frame allow panel to operate reliably in multiple mounting configurations.



A new standard for power plants.

The SunPower® 425 Solar Panel provides today's highest efficiency and performance. Utilizing 128 back-contact solar cells, the SunPower 425 delivers a total panel conversion efficiency of 19.7%. The panel's reduced voltage-temperature coefficient, anti-reflective glass and exceptional low-light performance attributes provide outstanding energy delivery per peak power watt.

SunPower's High Efficiency Advantage



SPR-425E-WHT-D

c UL us

SUNPOWER

E19 / 425 SOLAR PANEL

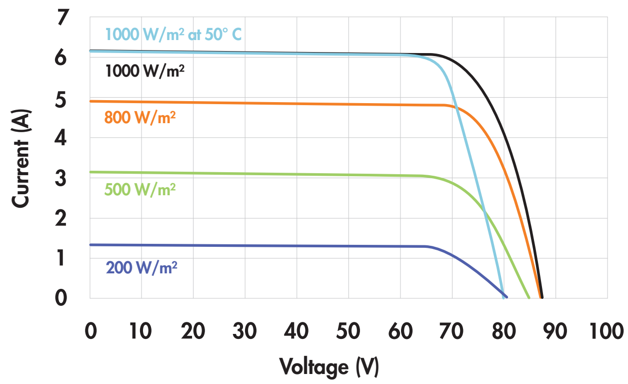
MAXIMUM EFFICIENCY AND PERFORMANCE

Electrical Data

Measured at Standard Test Conditions (STC): irradiance of 1000W/m², AM 1.5, and cell temperature 25° C

Peak Power (+/-5%)	P_{max}	425 W
Efficiency	η	19.7 %
Rated Voltage	V_{mpp}	72.9 V
Rated Current	I_{mpp}	5.83 A
Open Circuit Voltage	V_{oc}	85.6 V
Short Circuit Current	I_{sc}	6.21 A
Maximum System Voltage	UL	600 V
Temperature Coefficients	Power (P)	-0.38% / K
	Voltage (V_{oc})	-235.5mV / K
	Current (I_{sc})	3.5mA / K
NOCT		45° C +/-2° C
Series Fuse Rating		20 A

I-V Curve



Current/voltage characteristics with dependence on irradiance and module temperature.

Mechanical Data

Solar Cells	128 SunPower all-back contact monocrystalline
Front Glass	High transmission tempered glass with anti-reflective (AR) coating
Junction Box	IP-65 rated with 3 bypass diodes Dimensions: 32 x 155 x 128 (mm)
Output Cables	700 mm cables/ Multi-Contact (MC4) compatible connectors
Frame	Anodized aluminum alloy type 6063 (silver); stacking pins
Weight	56.0 lbs. (25.4 kg)

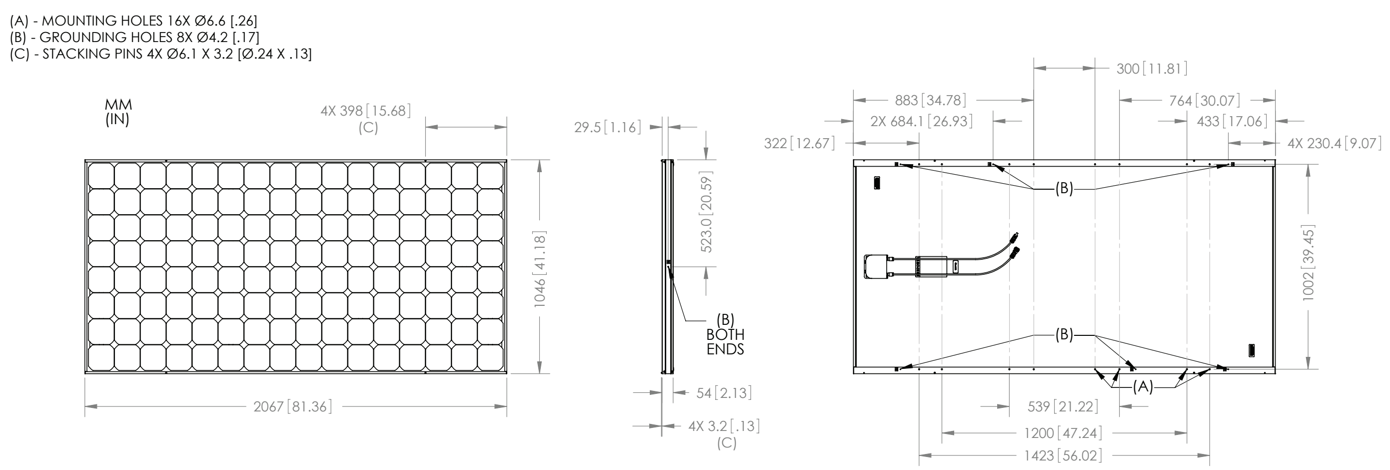
Tested Operating Conditions

Temperature	-40° F to +185° F (-40° C to + 85° C)
Max load	50 psf (245 kg/m²) (2400 Pa) front and back – e.g. wind
Impact Resistance	Hail 1 in (25 mm) at 52mph (23 m/s)

Warranties and Certifications

Warranties	25 year limited power warranty
	10 year limited product warranty
Certifications	Tested to UL 1703. Class C Fire Rating

Dimensions



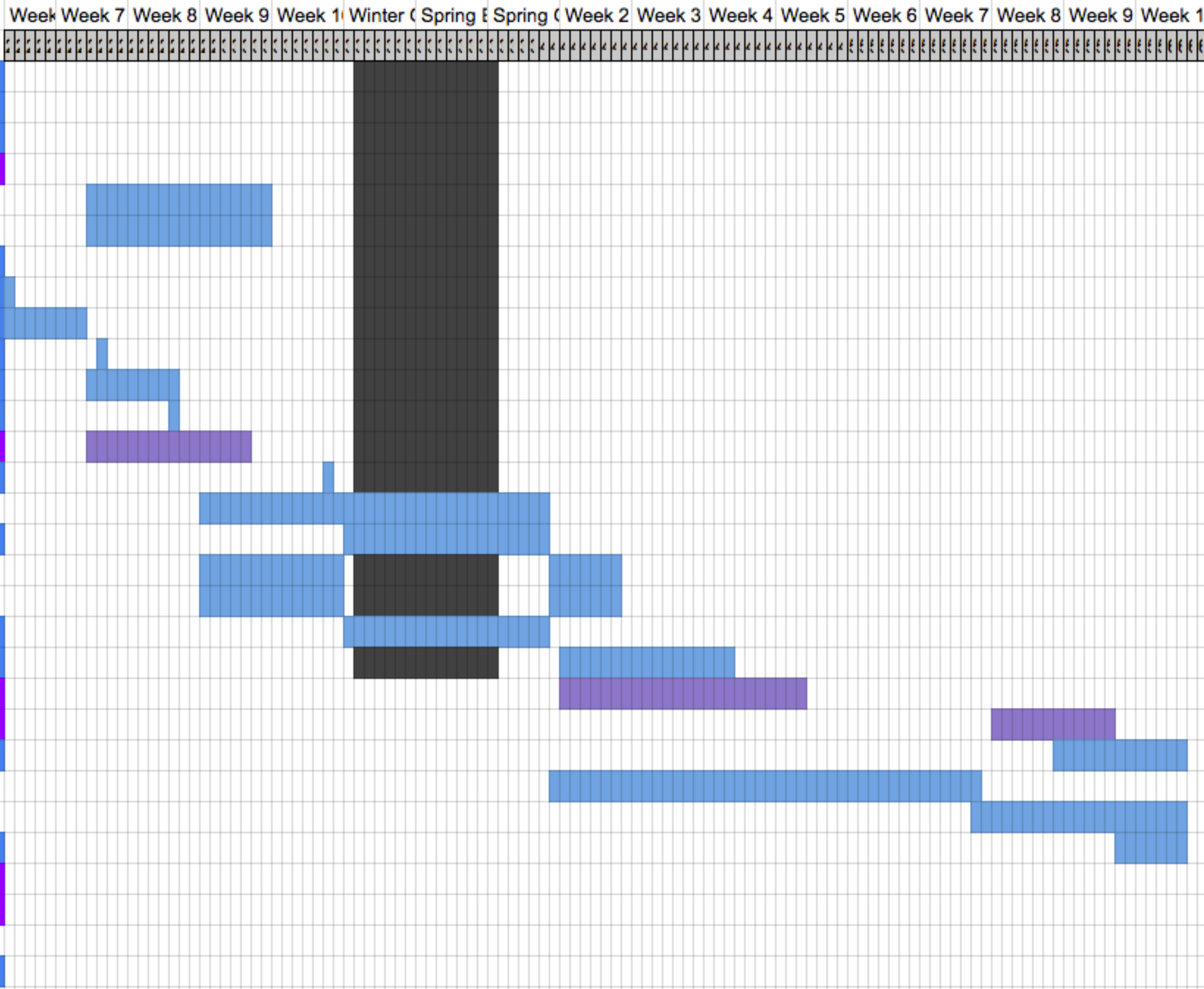
CAUTION: READ SAFETY AND INSTALLATION INSTRUCTIONS BEFORE USING THE PRODUCT.

Visit sunpowercorp.com for details

Appendix 4

Gantt Chart

KEY		TASK
Incomplete	C	Team Contract
Completed	C	Problem Statement
Behind Schedule	C	QFD House of Quality
possibly do color coding by type of task instead	C	Project Proposal
	C	Research/Technologies
Items with Due Dates	C	Initial work/calculations
Important Items	C	1st Team Evaluation
	C	1st Reflection
	C	Concept Models/Pugh Matrices
	C	PDR with Sponsor
	C	Final Decision Matrix
	I	Machine Shop Yellow Tag
	C	Preliminary Design Report
	C	PDR with Sponsor
	I	Calculations and Models
	I	Order Long Lead-Time parts
	I	Final Calcs/Models Review
		Final Sponsor Check
		Order all parts
		CDR with sponsor
		Final Design Report
		Expo?
		Status Report
		Build Completion
		Testing
		Project Status Memo to Sponsor
		Project Hardware/ Safety /Demo
		Final Project Report
		Complete Testing
		Final Checklist Complete



Appendix 5

References

Appendix 5: References

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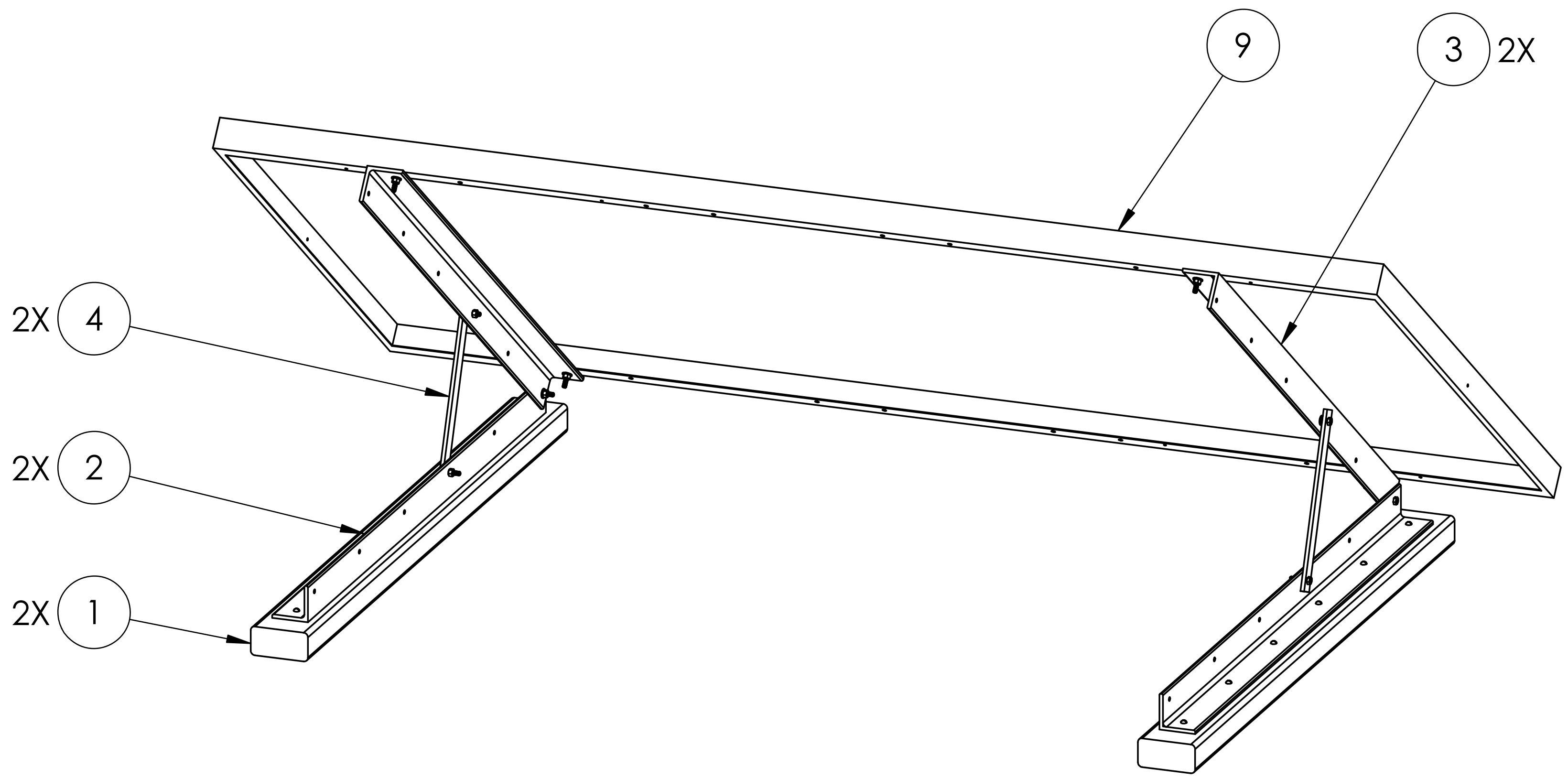
Appendix 6

Stationary System Drawings



ITEM NO.	PART NO.	DESCRIPTION	QTY.
1	STATIONARY 01	WOOD BASE BEAM	2
2	STATIONARY 02	STEEL BASE BEAM	2
3	STATIONARY 03	PANEL BEAM	2
4	STATIONARY 04	ADJUSTMENT ROD	2
5	92407A296	WOOD SCREW, #12-11, 1 LG	12
6	90201A115	HEX HD SCREW, 1/4-20, 1-1/4 LG	10
7	95036A012	HEX NUT, 1/4-20	10
8	92141A029	WASHER, 1/4 DIA.	14
9	SPR-425E-WHT-D	E19/425 SOLAR PANEL	1

NOTES: UNLESS OTHERWISE SPECIFIED

1. FASTNERS ARE NOT CALLED OUT BY BALLONS.
2. VENDORS FOR PURCHASED PARTS ARE AS FOLLOWS:
   ITEMS 6 THROUGH 8: MCMASTER-CARR
   ITEM 9: SUNPOWER

CAL POLY MICROGRID

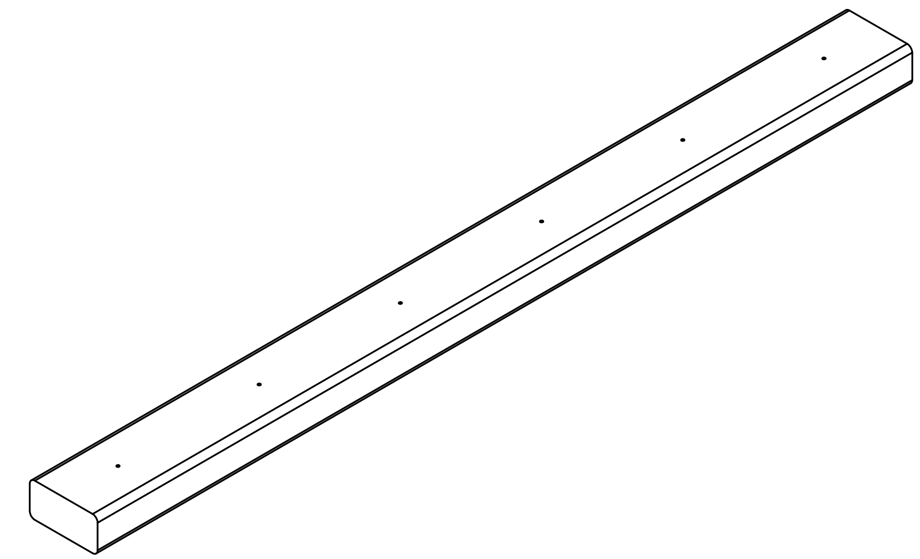
TITLE: STATIONARY PANEL MOUNT ASSY

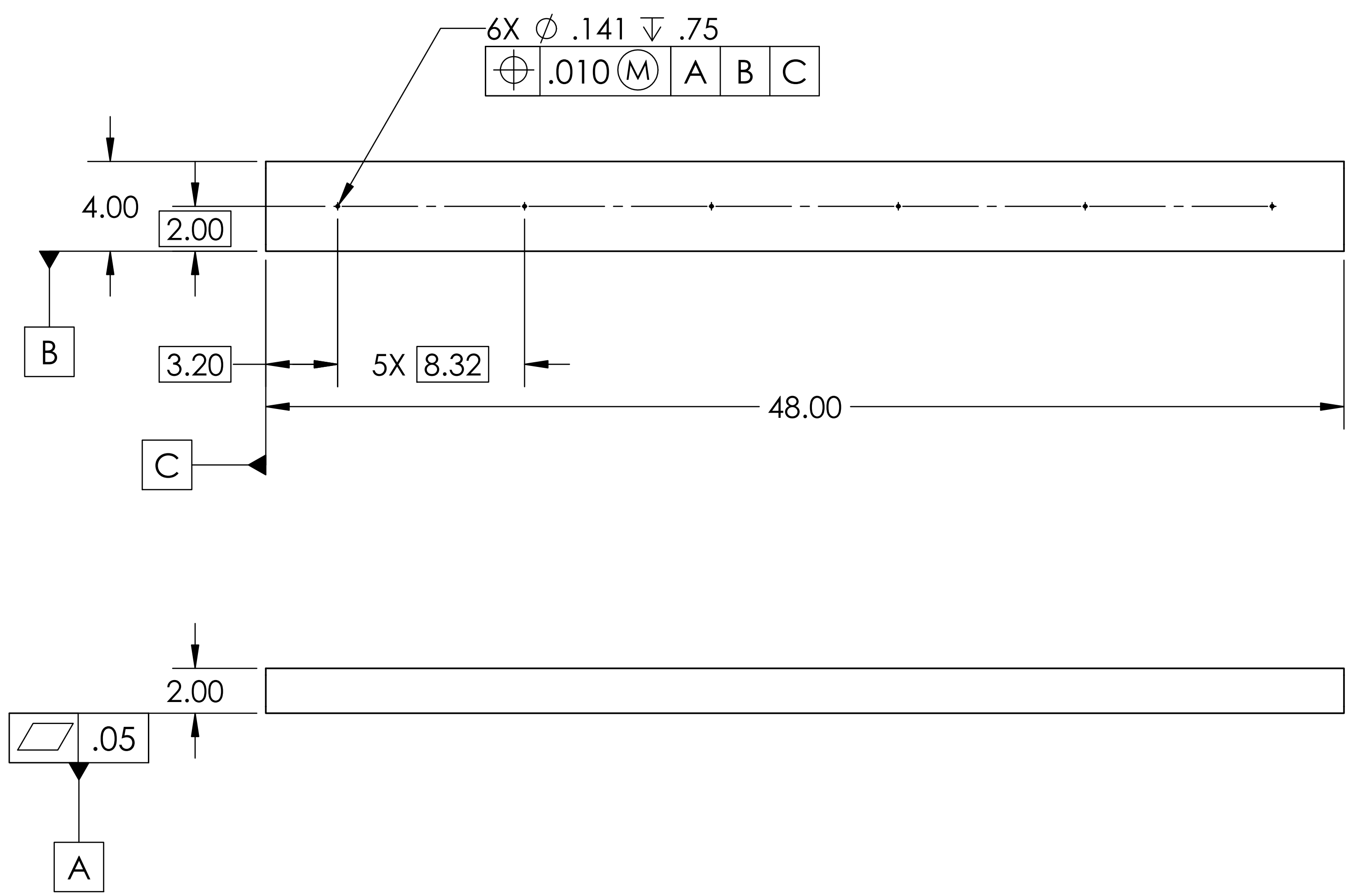
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: ± 2°
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005

	NAME	DATE
DRAWN	G.P.	12/11/16
CHECKED	C.M.	12/11/16
ENG APPR.	C.O.	12/11/16
MFG APPR.	D.M.	12/11/16

SIZE **B** DWG. NO. STATIONARY ASSY

SCALE: 1:12 SHEET 1 OF 5





NOTES: UNLESS OTHERWISE SPECIFIED

1. MATERIAL: WOOD

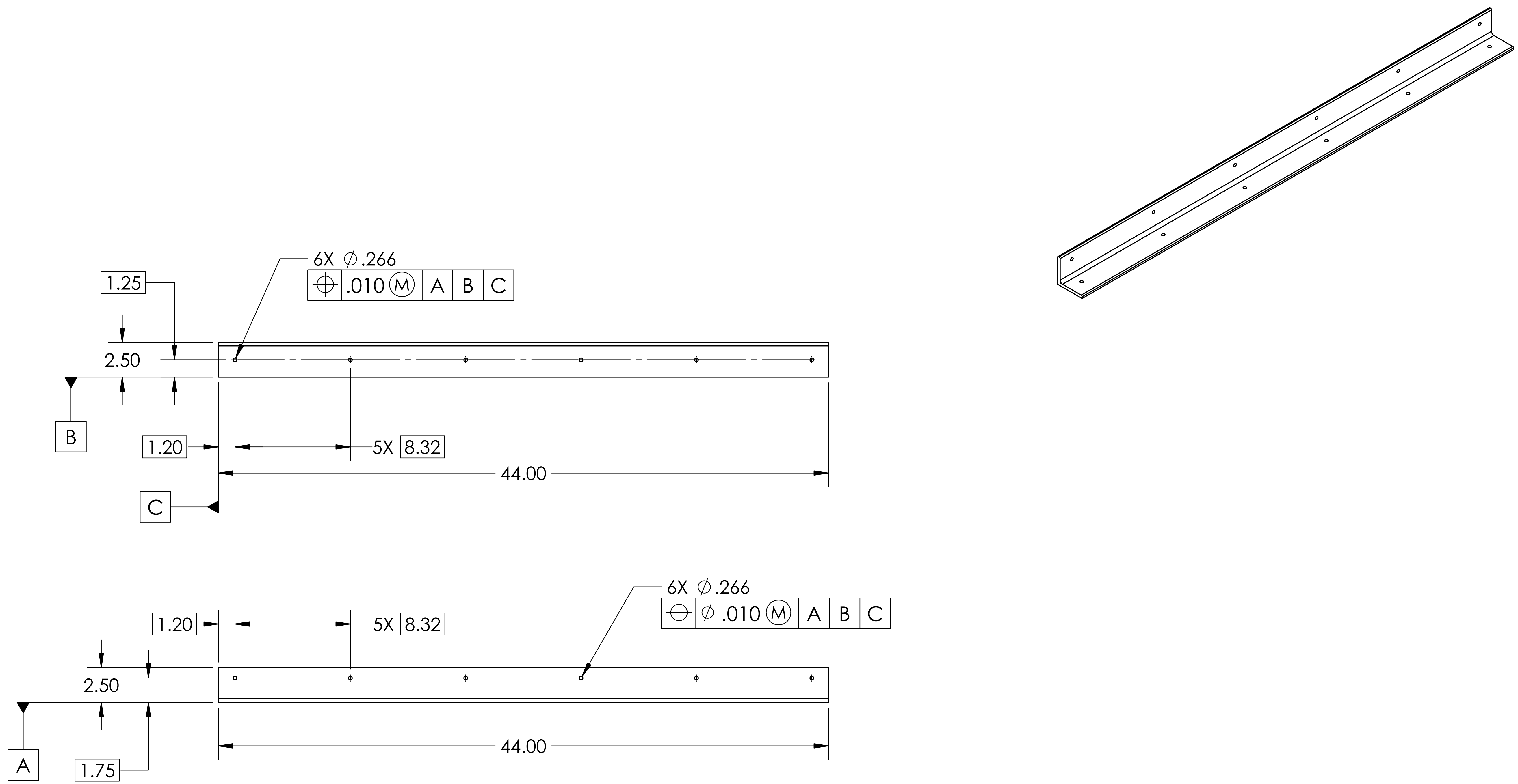
CAL POLY MICROGRID

TITLE: WOOD BASE BEAM

UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: ± 2° TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005	DRAWN	G.P.	12/11/16
	CHECKED	C.M.	12/11/16
	ENG APPR.	C.O.	12/11/16
	MFG APPR.	D.M.	12/11/16

SIZE: B | DWG. NO. STATIONARY 01

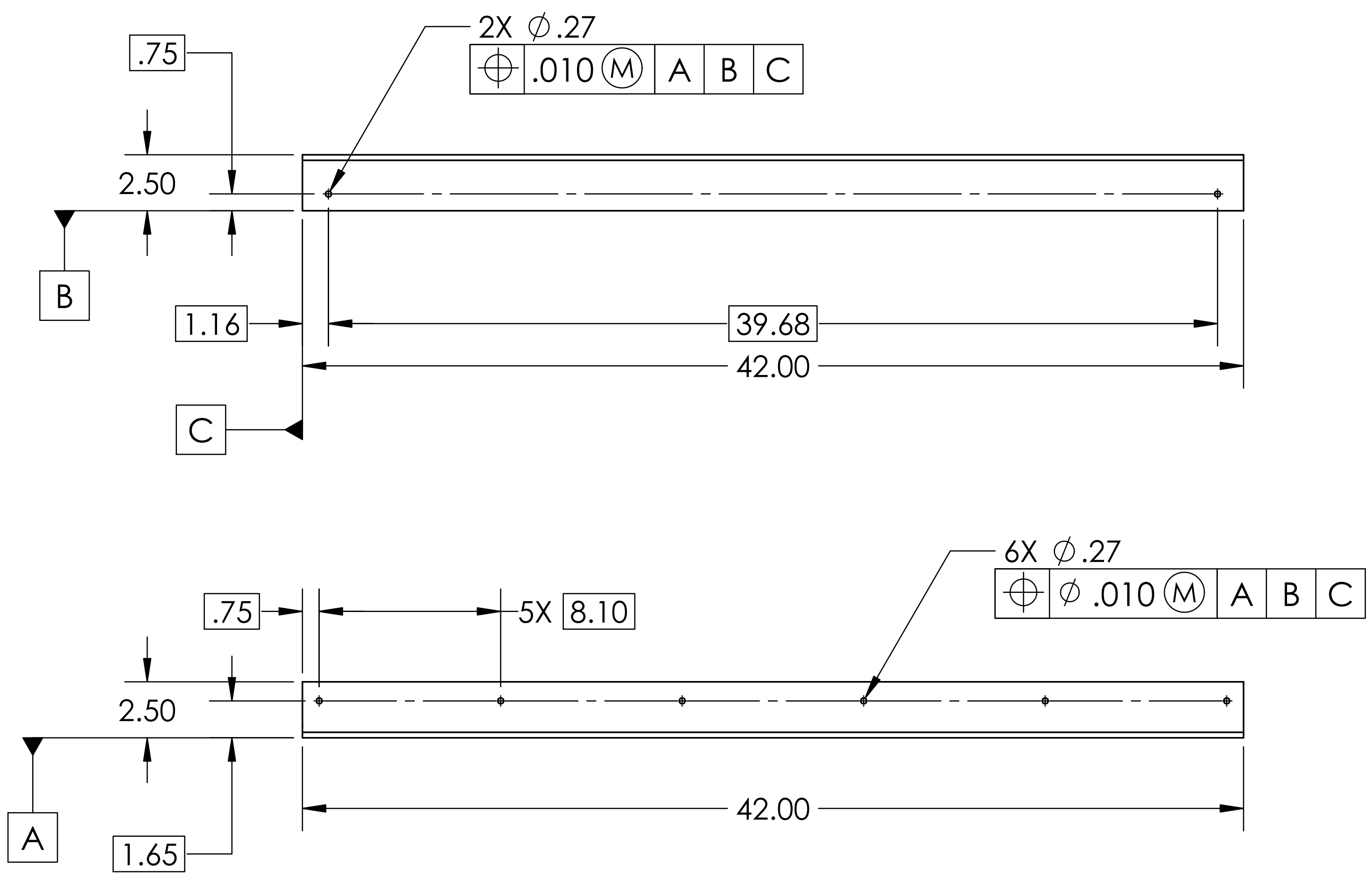
SCALE: 1:8 | SHEET 2 OF 5

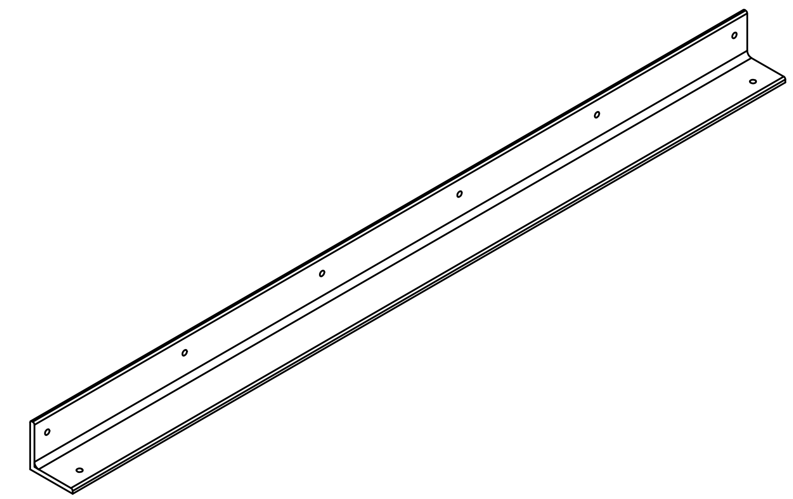


CAL POLY MICROGRID				TITLE: STEEL BASE BEAM
UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: ± 2° TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005	DRAWN	G.P.	12/11/16	SIZE B
	CHECKED	C.M.	12/11/16	DWG. NO. STATIONARY 02
	ENG APPR.	C.O.	12/11/16	
	MFG APPR.	D.M.	12/11/16	SCALE: 1:8 / SHEET 3 OF 5

NOTES: UNLESS OTHERWISE SPECIFIED

1. MAKE FROM MCMASTER CARR PART NO. 9017K714





NOTES: UNLESS OTHERWISE SPECIFIED

1. MAKE FROM MCMASTER CARR PART NO. 9017K714

CAL POLY MICROGRID

UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: ± 2° TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005	DRAWN	G.P.	12/11/16
	CHECKED	C.M.	12/11/16
	ENG APPR.	C.O.	12/11/16
	MFG APPR.	D.M.	12/11/16

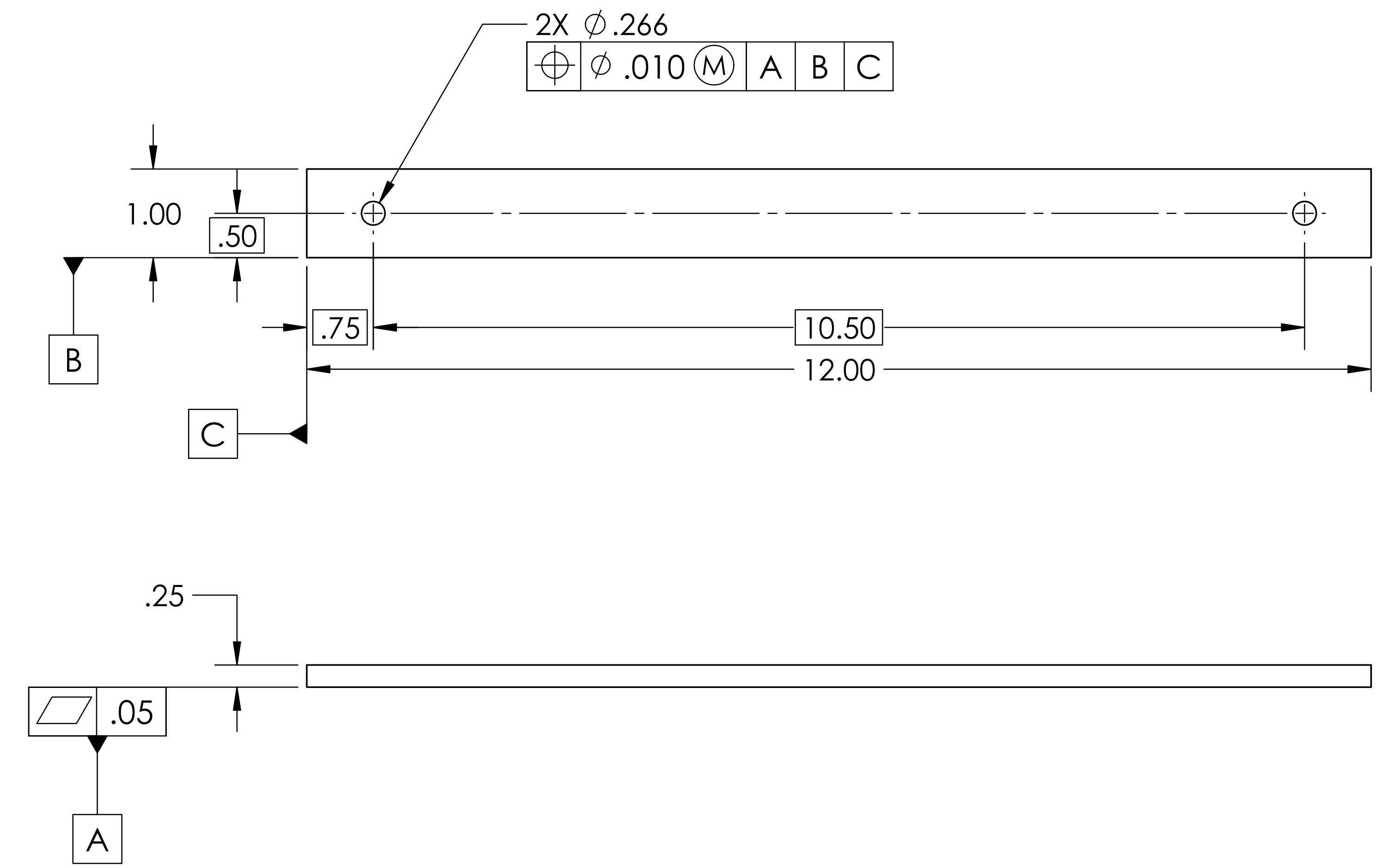
TITLE: PANEL BEAM

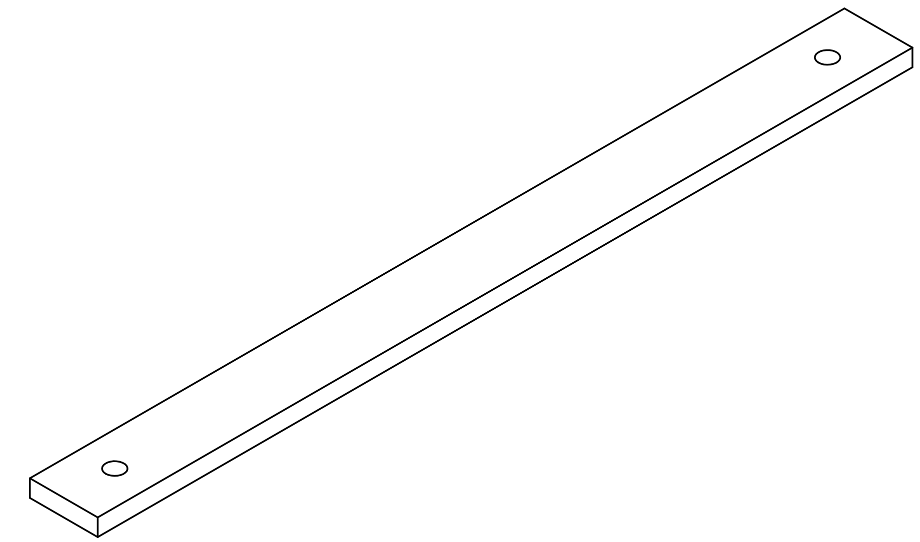
SIZE: B

DWG. NO. STATIONARY 03

SCALE: 1:8

SHEET 4 OF 5





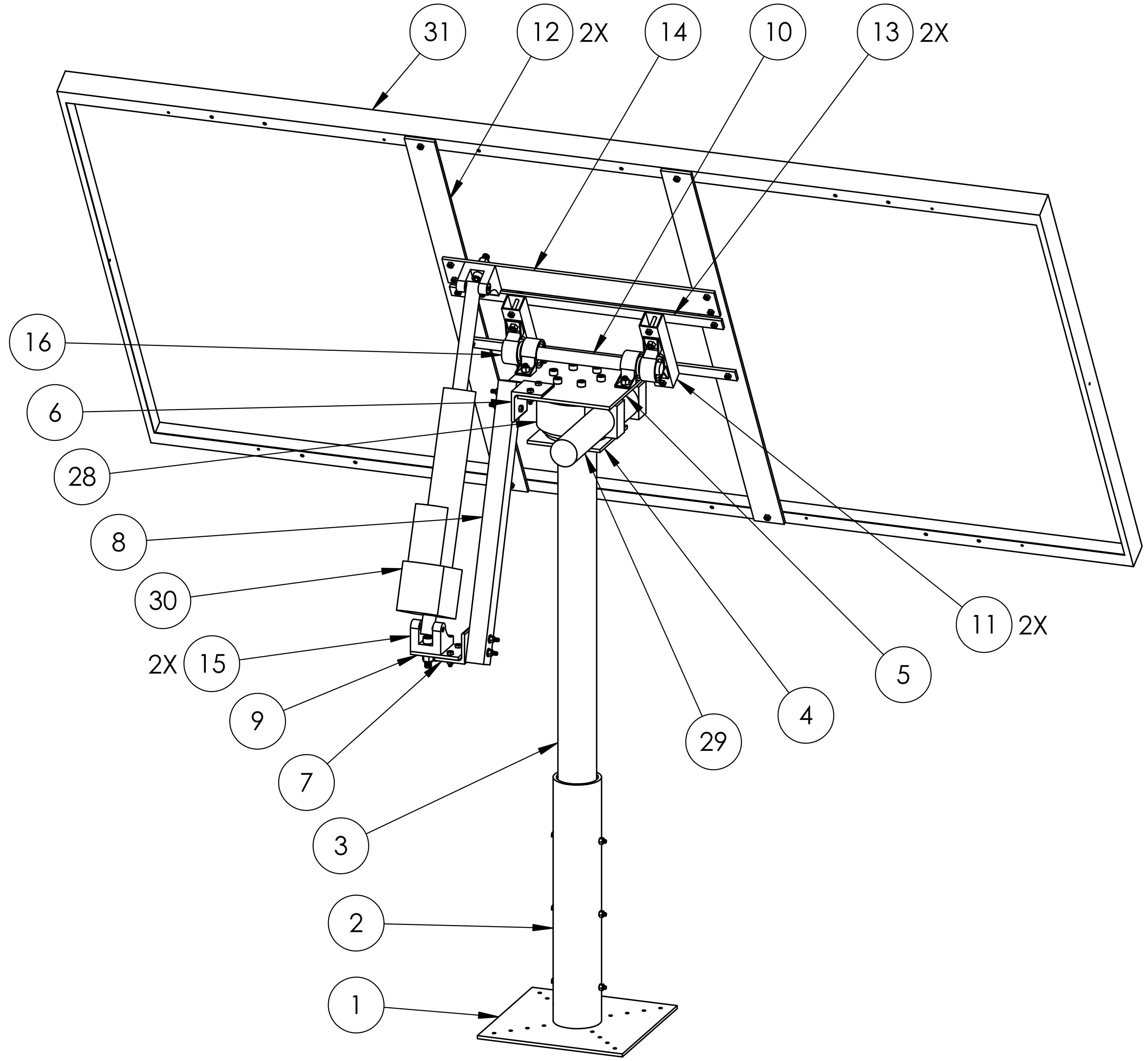
NOTES: UNLESS OTHERWISE SPECIFIED

1. MATERIAL: STEEL

CAL POLY MICROGRID			TITLE: ADJUSTMENT ROD
UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: ± 2° TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005	DRAWN	G.P.	12/11/16
	CHECKED	C.M.	12/11/16
	ENG APPR.	C.O.	12/11/16
	MFG APPR.	D.M.	12/11/16
SIZE B	DWG. NO. STATIONARY 04	SCALE: 1:2	SHEET 5 OF 5

Appendix 7

2-D System Drawings



NOTES: UNLESS OTHERWISE SPECIFIED

1. DUAL DIMENSIONS IN BRACKETS ARE IN MILLIMETERS.
2. FASTNERS ARE NOT CALLED OUT BY BALLONS.
3. VENDORS FOR PURCHASED PARTS ARE AS FOLLOWS:
   ITEMS 16 THROUGH 27: MCMASTER-CARR
   ITEMS 28 AND 29: KINEMATICS MANUFACTRING
   ITEMSS 15 AND 30: PROGRESSIVE AUTOMATIONS
   ITEM 31: SUNPOWER
4. WELDS NEEDED ARE AS FOLLOWS:
   ITEM 2 IS WELDED ONTO THE CENTER OF ITEM 1.
   ITEM 3 IS WELDED ONTO THE CENTER OF ITEM 4.

ITEM NO.	PART NO.	DESCRIPTION	QTY.
1	TRACKER 01	BASEPLATE	1
2	TRACKER 02	SUPPORT POLE MOUNT	1
3	TRACKER 03	SUPPORT POLE	1
4	TRACKER 04	SLEWING DRIVE BOTTOM PLATE	1
5	TRACKER 05	SLEWING DRIVE TOP PLATE	1
6	TRACKER 06	ACTUATOR BASE TOP ANGLE	1
7	TRACKER 07	ACTUATOR BASE BOTTOM ANGLE	1
8	TRACKER 08	ACTUATOR BASE EXTENSION BAR	1
9	TRACKER 09	ACTUATOR BASE BRACKET	1
10	TRACKER 10	HINGE SHAFT	1
11	TRACKER 11	HINGE SPACER	2
12	TRACKER 12	VERTICAL CROSSBAR	2
13	TRACKER 13	HORIZONTAL CROSSBAR	2
14	TRACKER 14	ACTUATOR END CROSSBAR	1
15	BRK-17	HEAVY-DUTY MOUNTING BRACKET	2
16	5913K64	MOUNTED BALL BEARING	4
17	90201A113	HEX HD SCREW, 1/4-20, 1 LG	16
18	90201A121	HEX HD SCREW, 1/4-20, 2-1/2 LG	8
19	91257A103	HEX HD SCREW, 1/4-20, 4-1/4 LG	3
20	90201A314	HEX HD SCREW, 3/8-16, 1 LG	4
21	90201A324	HEX HD SCREW, 3/8-16, 2-1/4 LG	4
22	91022A183	SKT HD SCREW, 1/2-13, 2 LG	4
23	91290A516	SKT HD SCREW, M10X1.5, 20 LG	6
24	91290A534	SKT HD SCREW, M10X1.5, 55 LG	6
25	95036A012	HEX NUT, 1/4-20	27
26	95036A020	HEX NUT, 3/8-16	8
27	92141A029	WASHER, 1/4 DIA.	8
28	SE3B-62MHQ-12MRC	SLEWING DRIVE	1
29	24H-2500-35-8-V-12S-40	DC BRUSHED GEAR MOTOR	1
30	PA-17-10-2000	LINEAR ACTUATOR, 10 IN. STROKE	1
31	SPR-425E-WHT-D	E19/425 SOLAR PANEL	1

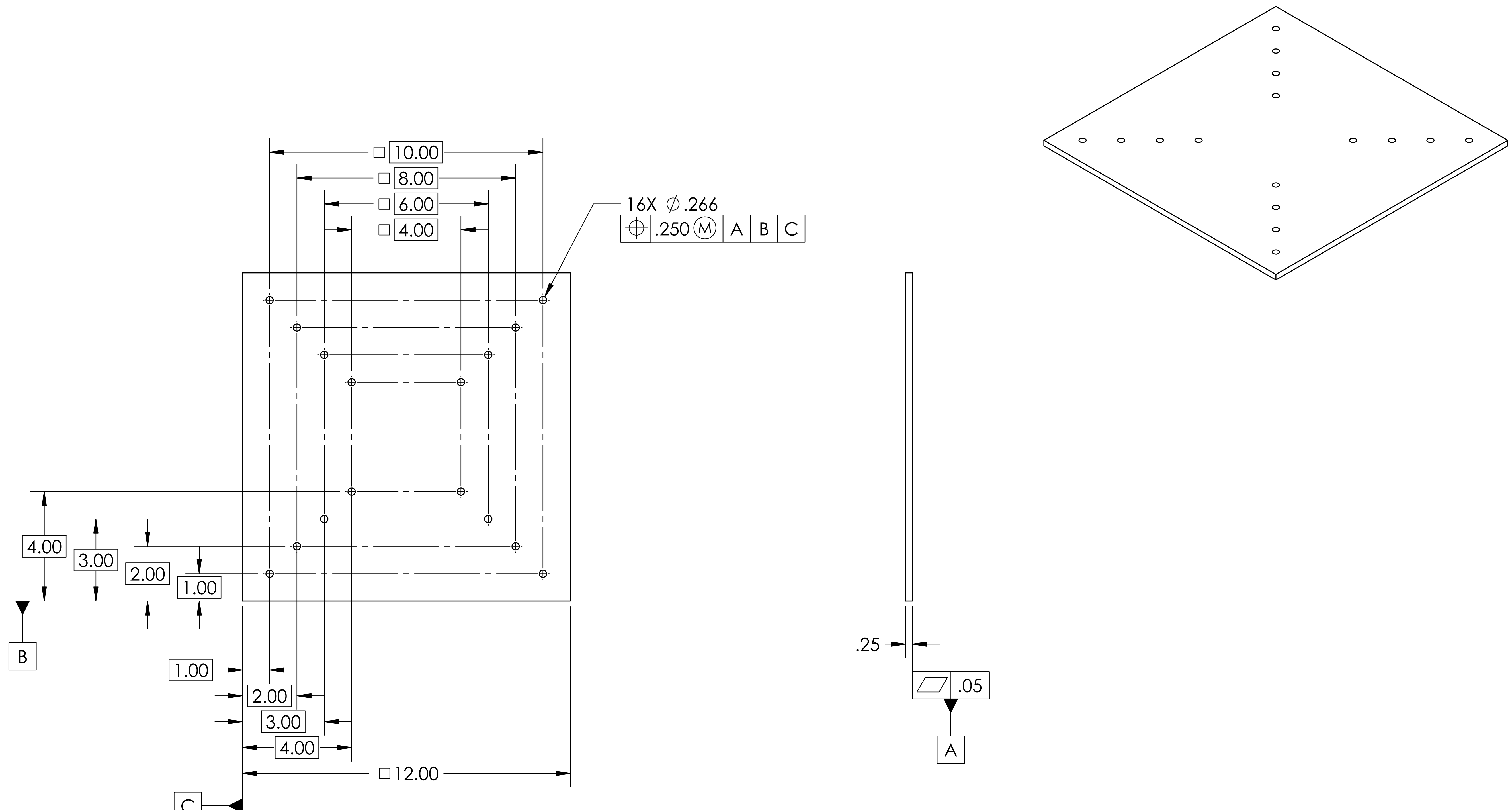
CAL POLY MICROGRID

TITLE: DUAL AXIS SOLAR TRACKER

UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: ± 2° TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005	DRAWN	G.P.	12/11/16
	CHECKED	C.M.	12/11/16
	ENG APPR.	C.O.	12/11/16
	MFG APPR.	G.P.	12/11/16

SIZE: B | DWG. NO.: TRACKER ASSY

SCALE: 1:12 | SHEET 1 OF 15



NOTES: UNLESS OTHERWISE SPECIFIED

1. MATERIAL: ALUMINUM

CAL POLY MICROGRID

UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: ± 2° TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005	DRAWN	G.P.	12/10/16
	CHECKED	C.M.	12/10/16
	ENG APPR.	C.O.	12/10/16
	MFG APPR.	G.P.	12/10/16

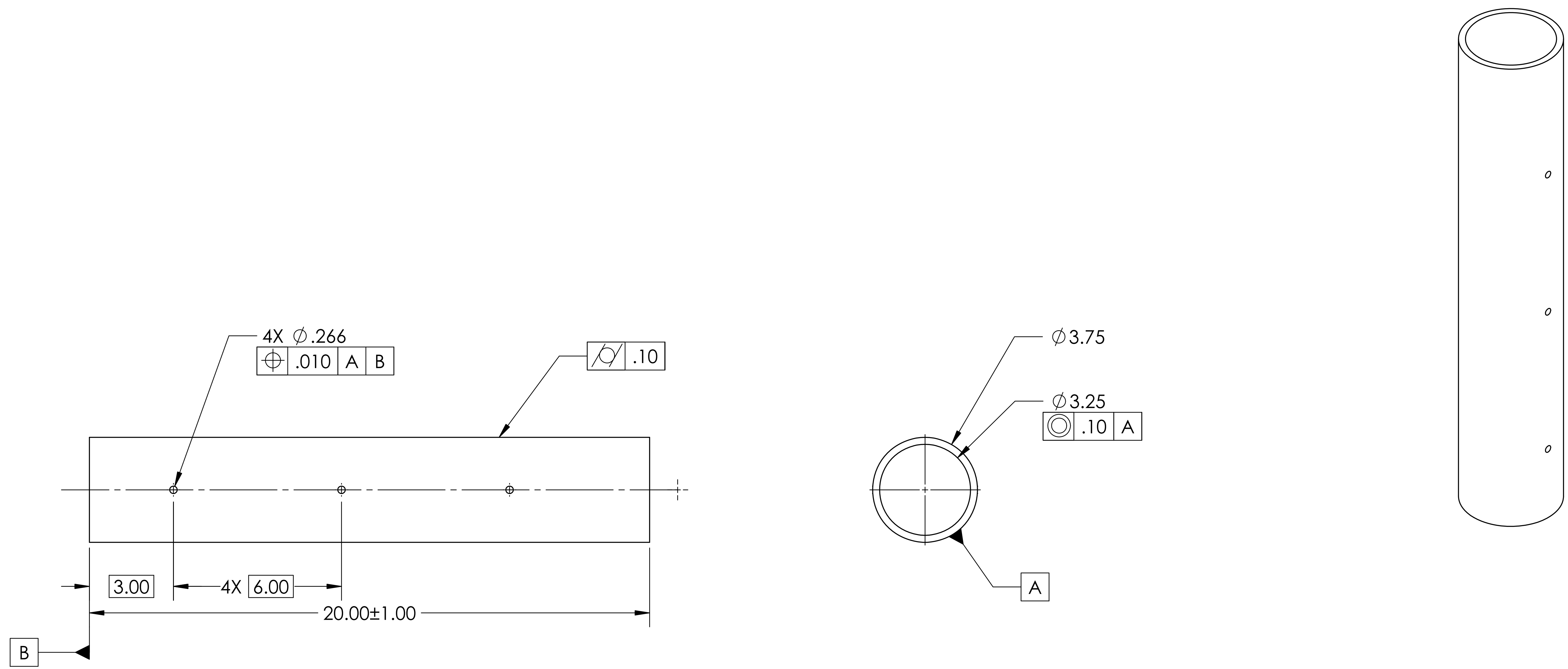
TITLE: BASEPLATE

SIZE: B

DWG. NO. TRACKER 01

SCALE: 1:4

SHEET 2 OF 15



NOTES: UNLESS OTHERWISE SPECIFIED

1. MATERIAL: ALUMINUM

CAL POLY MICROGRID

UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: ± 2° TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005	DRAWN	G.P.	12/10/16
	CHECKED	C.M.	12/10/16
	ENG APPR.	C.O.	12/10/16
	MFG APPR.	G.P.	12/10/16

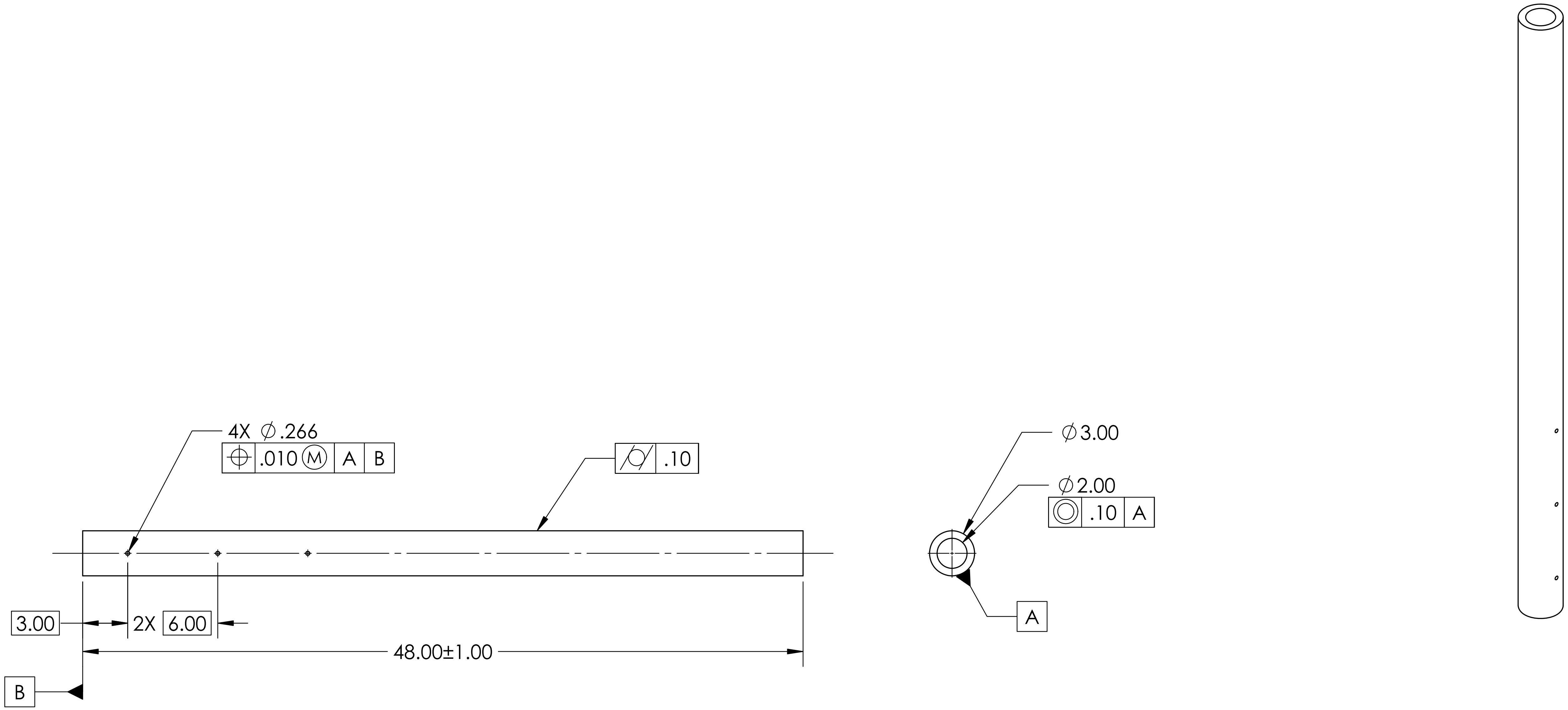
TITLE: SUPORT POLE MOUNT

SIZE: B

DWG. NO. TRACKER 02

SCALE: 1:4

SHEET 3 OF 15



NOTES: UNLESS OTHERWISE SPECIFIED

1. MATERIAL: STEEL

CAL POLY MICROGRID

UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: ± 2° TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005	DRAWN	G.P.	12/10/16
	CHECKED	C.M.	12/10/16
	ENG APPR.	C.O.	12/10/16
	MFG APPR.	G.P.	12/10/16

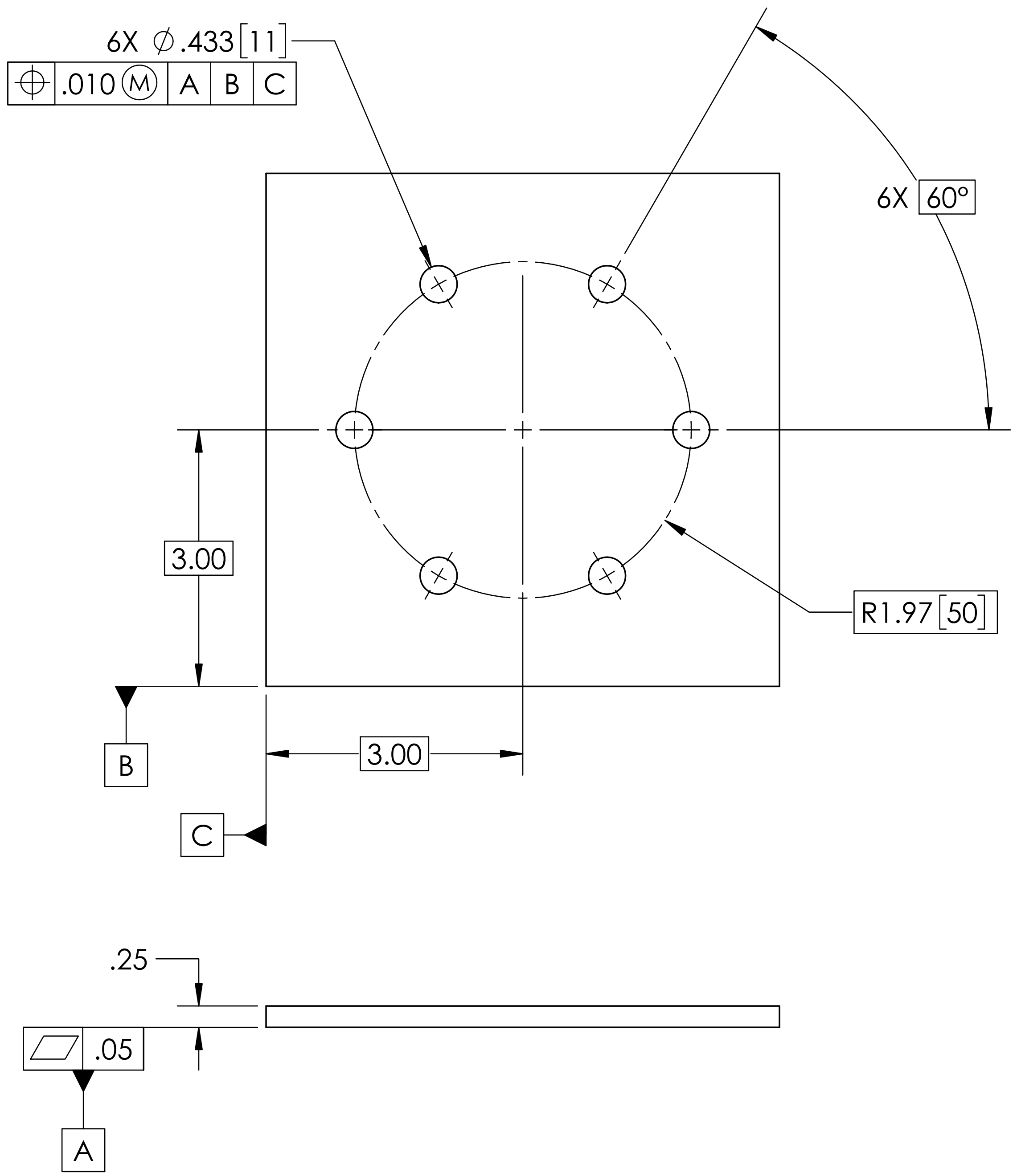
TITLE: SUPPORT POLE

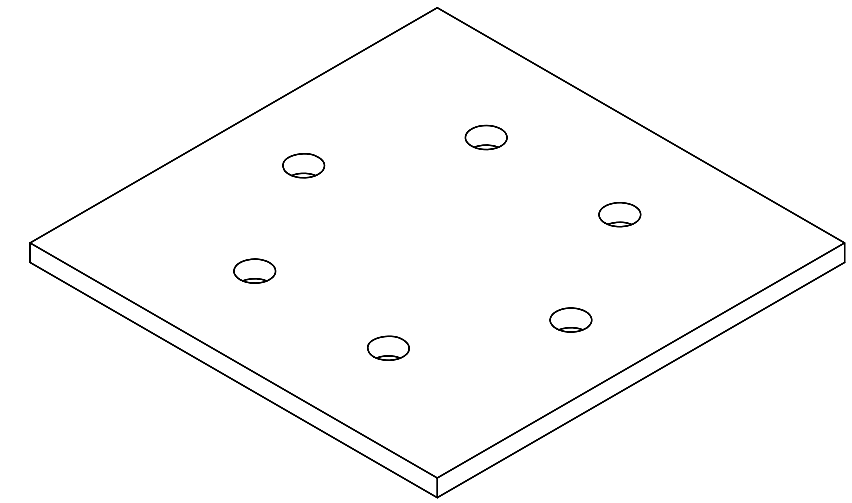
SIZE: B

DWG. NO. TRACKER 03

SCALE: 1:8

SHEET 4 OF 15

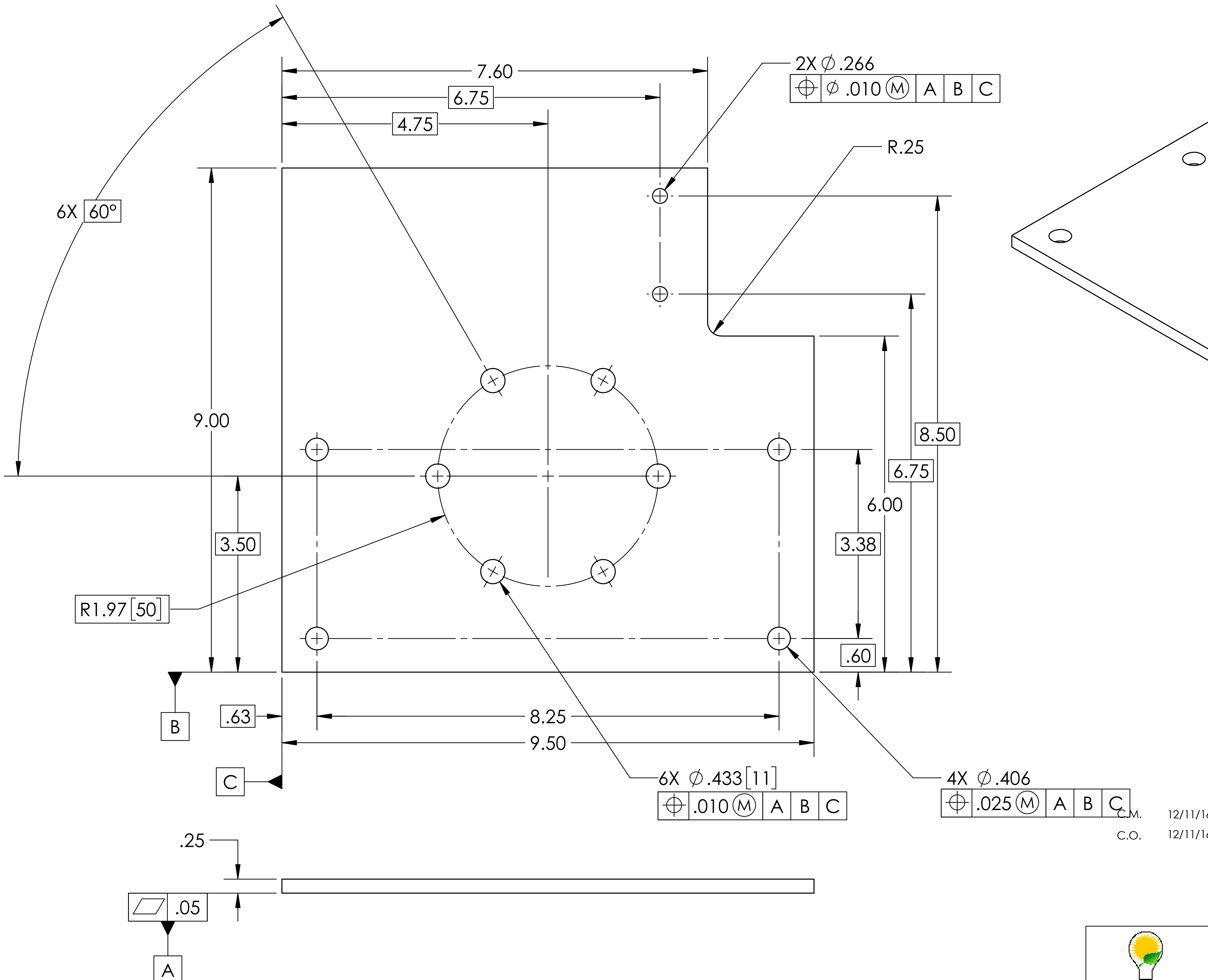


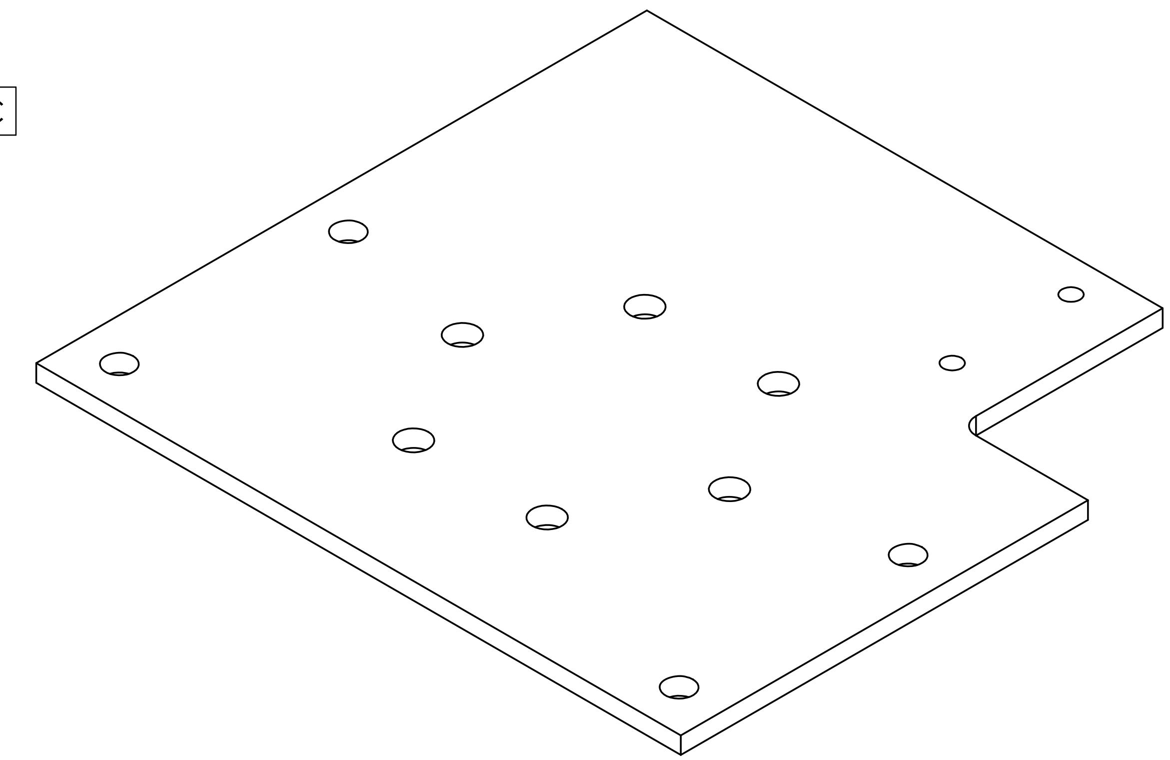


CAL POLY MICROGRID			TITLE: SLEWING DRIVE BOTTOM PLATE
UNLESS OTHERWISE SPECIFIED:	NAME	DATE	
DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: ± 2° TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005	DRAWN G.P.	12/10/16	SIZE B
	CHECKED C.M.	12/10/16	DWG. NO. TRACKER 04
	ENG APPR. C.O.	12/10/16	
	MFG APPR. G.P.	12/10/16	SCALE: 1:2 — SHEET 5 OF 15

NOTES: UNLESS OTHERWISE SPECIFIED

1. MATERIAL: STEEL

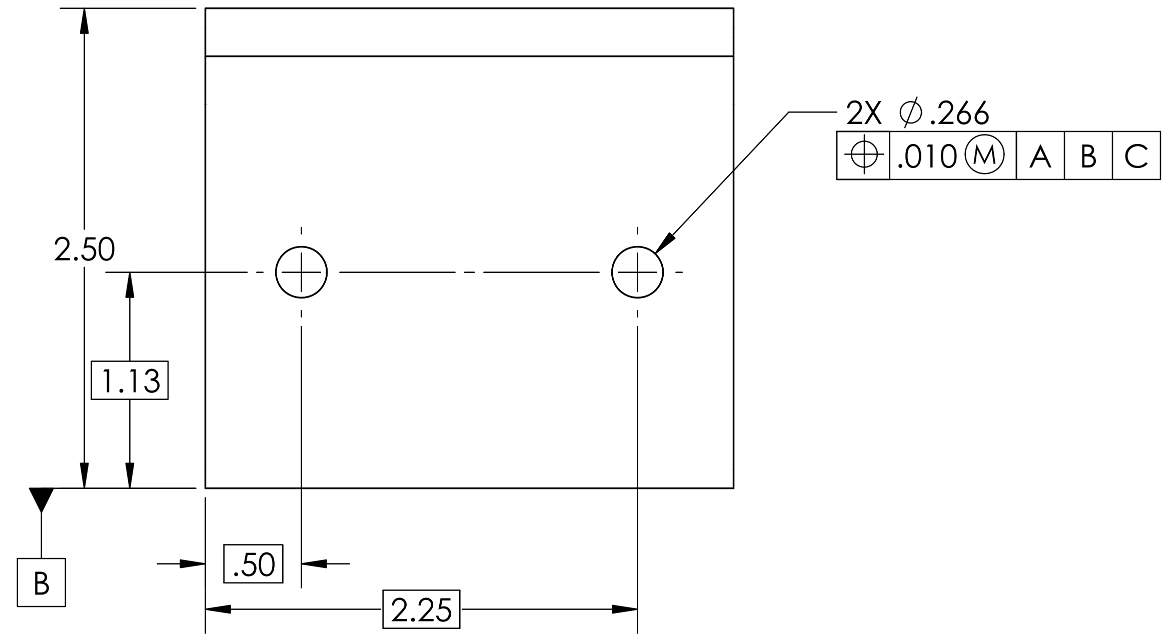


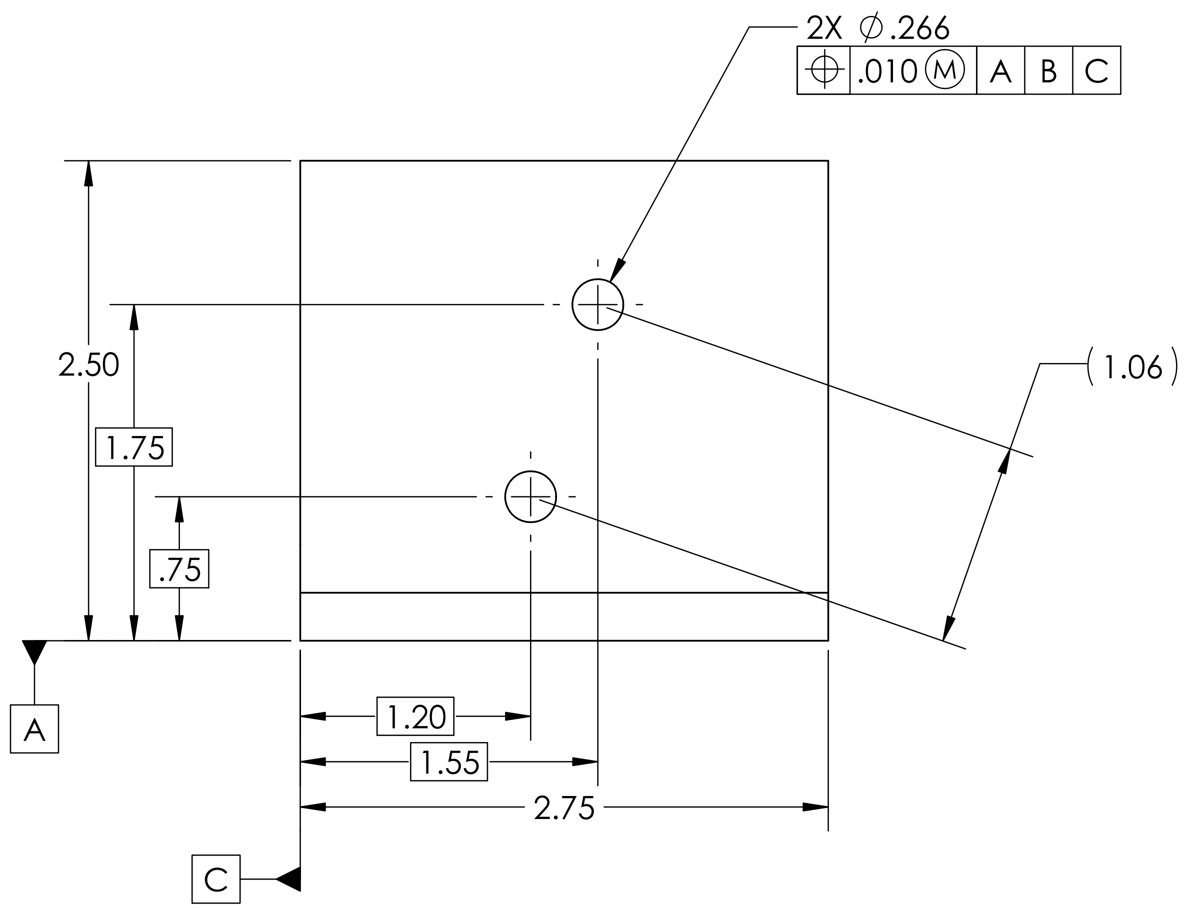


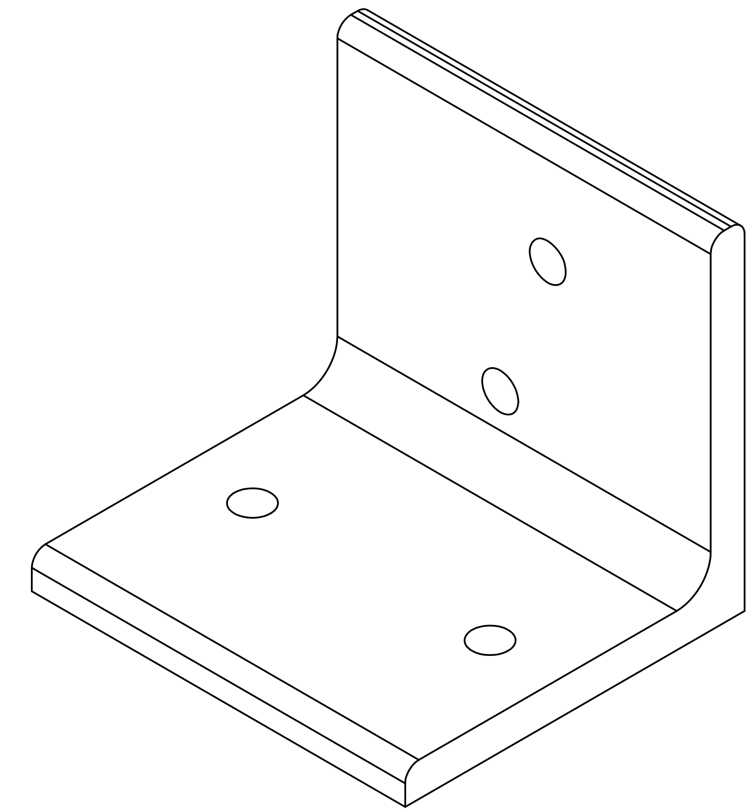
NOTES: UNLESS OTHERWISE SPECIFIED

1. MATERIAL: STEEL

CAL POLY MICROGRID			TITLE: SLEWING DRIVE TOP PLATE	
UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: ± 2° TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005	DRAWN	G.P.	12/10/16	SIZE B — DWG. NO. TRACKER 05
	CHECKED	C.M.	12/10/16	
	ENG APPR.	C.O.	12/10/16	
	MFG APPR.	G.P.	12/10/16	SCALE: 1:2 — SHEET 6 OF 15







NOTES: UNLESS OTHERWISE SPECIFIED

1. MAKE FROM MCMASTER CARR PART NO. 9017K714

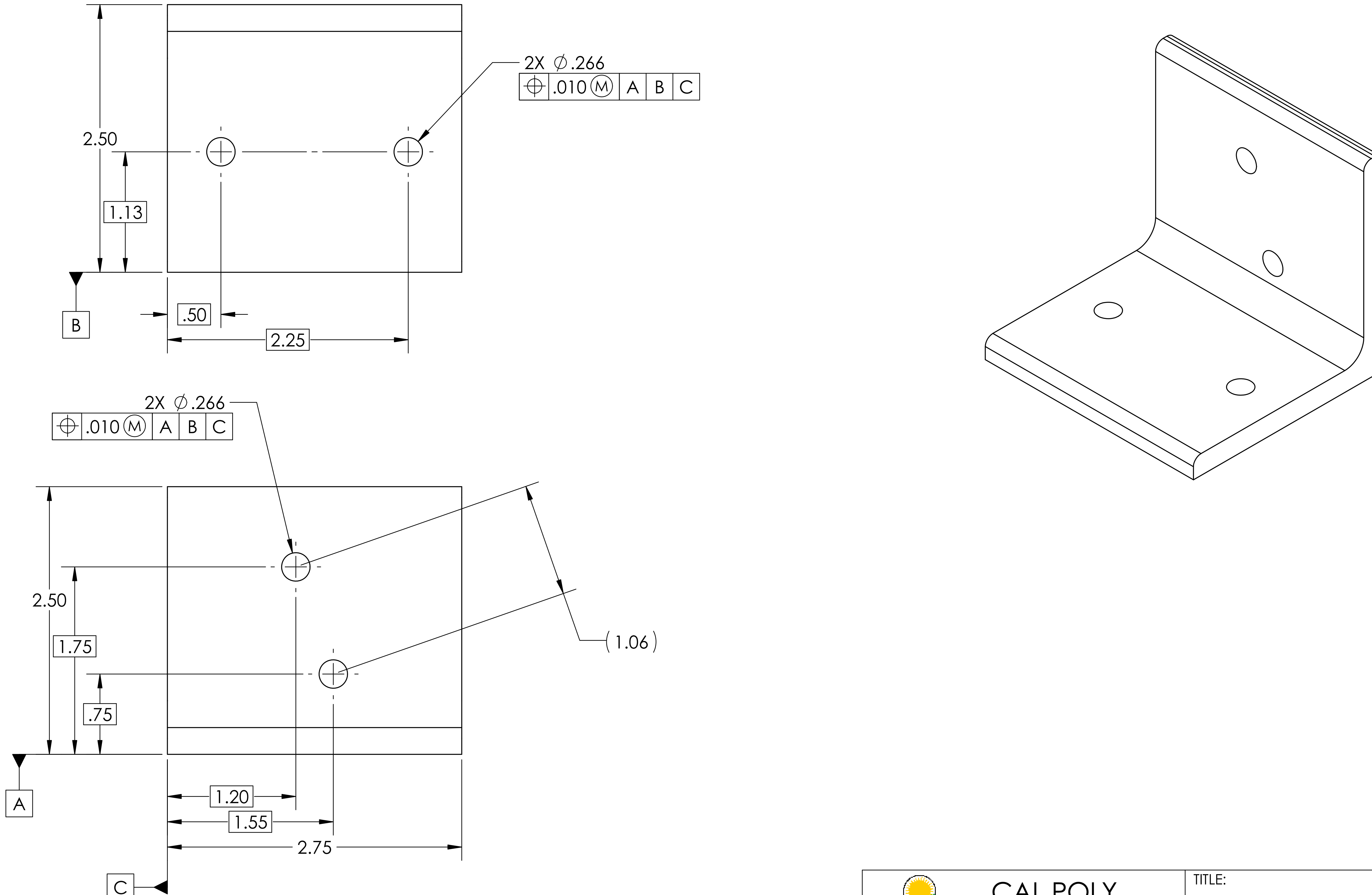
CAL POLY MICROGRID

TITLE: ACTUATOR BASE TOP ANGLE

UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: ± 2° TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005	DRAWN	G.P.	12/10/16
	CHECKED	C.M.	12/10/16
	ENG APPR.	C.O.	12/10/16
	MFG APPR.	C.O.	12/10/16

SIZE B — DWG. NO. TRACKER 06

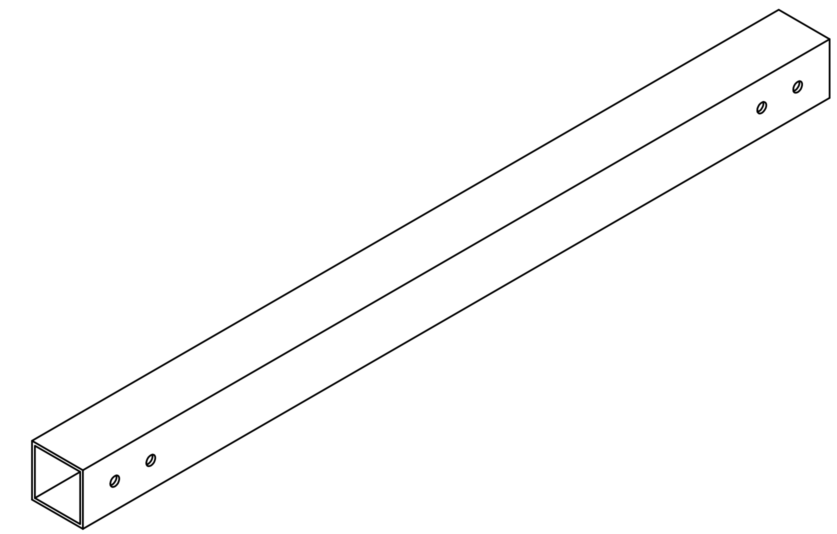
SCALE: 1:1 — SHEET 7 OF 15

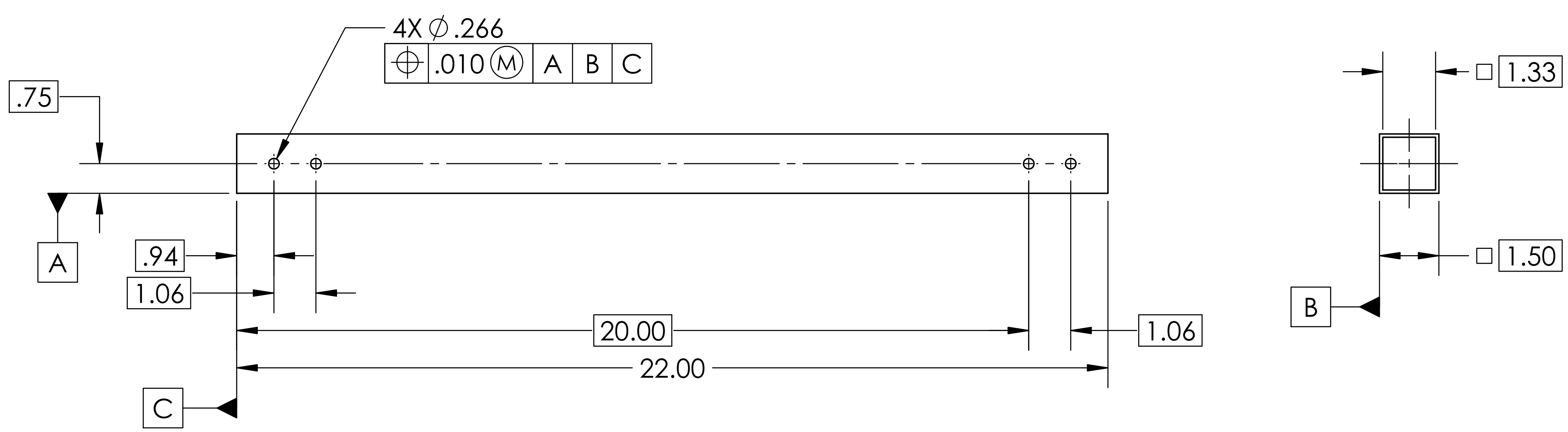


NOTES: UNLESS OTHERWISE SPECIFIED

1. MAKE FROM MCMASTER CARR PART NO. 9017K714

CAL POLY MICROGRID			TITLE: ACTUATOR BASE BOTTOM ANGLE
UNLESS OTHERWISE SPECIFIED:	NAME	DATE	
DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: ± 2° TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005			
DRAWN	G.P.	12/10/16	SIZE B
CHECKED	C.M.	12/10/16	DWG. NO. TRACKER 07
ENG APPR.	C.O.	12/10/16	
MFG APPR.	C.O.	12/10/16	SCALE: 1:1 — SHEET 8 OF 15

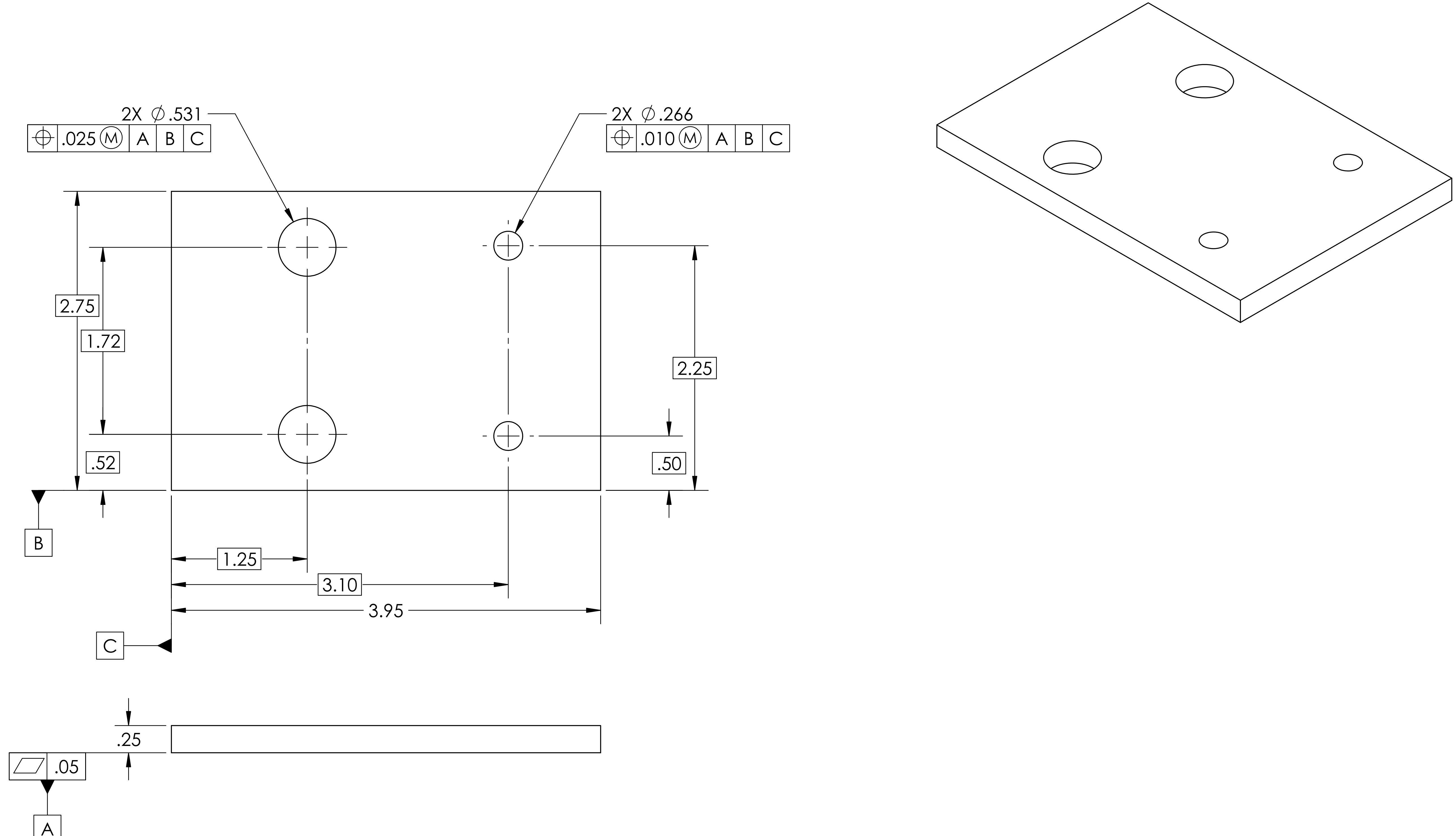




NOTES: UNLESS OTHERWISE SPECIFIED

1. MAKE FROM MCMASTER CARR PART NO. 6527K274

CAL POLY MICROGRID			TITLE: ACTUATOR BASE EXTENSION BAR
UNLESS OTHERWISE SPECIFIED:	NAME	DATE	
DIMENSIONS ARE IN INCHES / DRAWN	G.P.	12/10/16	SIZE B
TOLERANCES: ANGULAR: ± 2° / CHECKED	C.M.	12/10/16	DWG. NO. TRACKER 08
TWO PLACE DECIMAL ± .01 / ENG APPR.	C.O.	12/10/16	
THREE PLACE DECIMAL ± .005 / MFG APPR.	G.P.	12/10/16	SCALE: 1:4 — SHEET 9 OF 15



NOTES: UNLESS OTHERWISE SPECIFIED

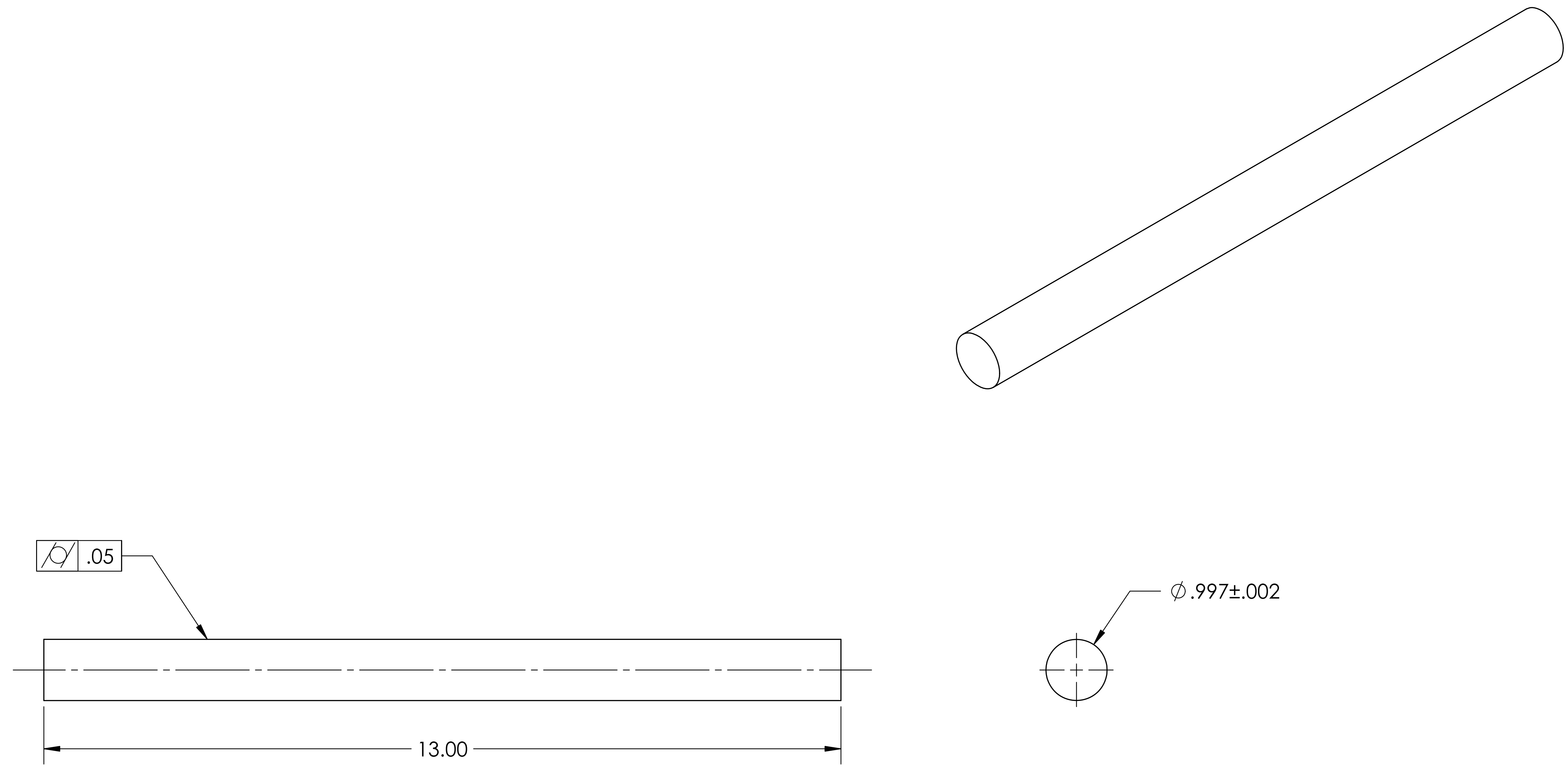
1. MATERIAL: STEEL

CAL POLY MICROGRID

TITLE: ACTUATOR BASE BRACKET

UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: ± 2° TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005	DRAWN	G.P.	12/10/16
	CHECKED	C.M.	12/10/16
	ENG APPR.	C.O.	12/10/16
	MFG APPR.	G.P.	12/10/16

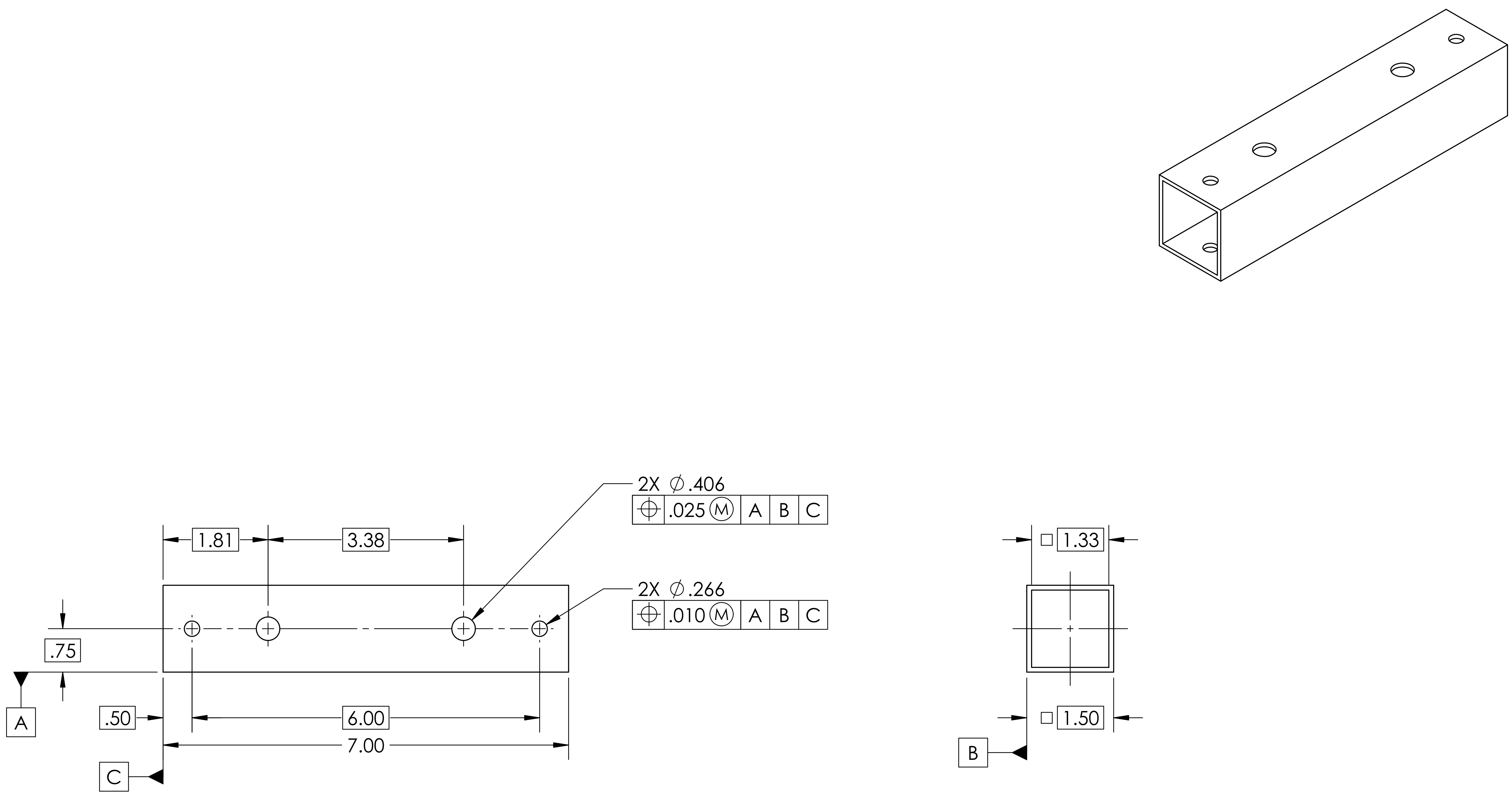
SIZE	DWG. NO.
B	TRACKER 09
SCALE: 1:1	SHEET 10 OF 15



NOTES: UNLESS OTHERWISE SPECIFIED

1. MATERIAL: ALUMINUM

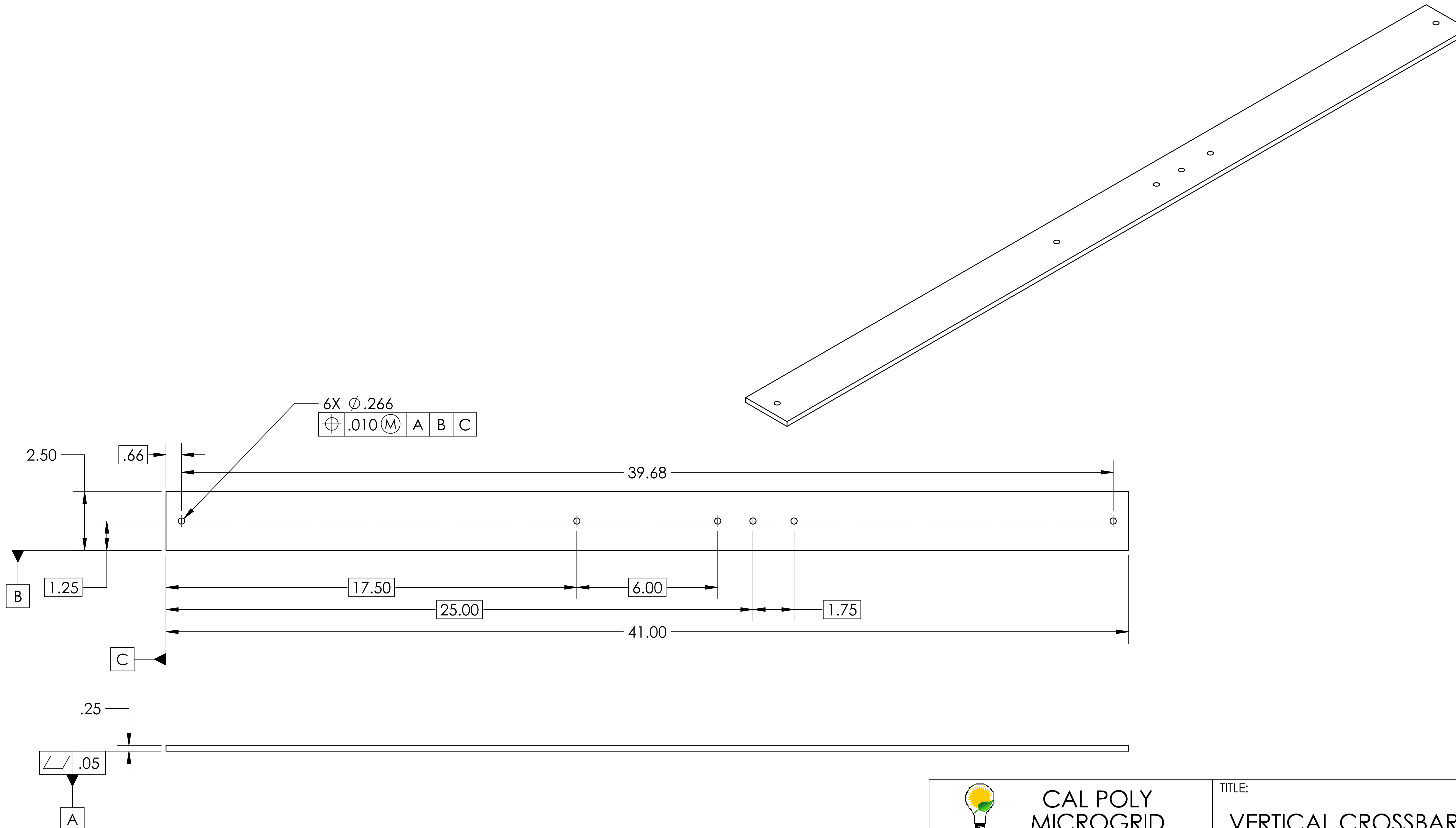
CAL POLY MICROGRID			TITLE: HINGE SHAFT
UNLESS OTHERWISE SPECIFIED:	NAME	DATE	
DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: ± 2° TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005			
DRAWN	G.P.	12/10/16	SIZE B
CHECKED	C.M.	12/10/16	DWG. NO. TRACKER 10
ENG APPR.	C.O.	12/10/16	SCALE: 1:2
MFG APPR.	C.M.	12/10/16	SHEET 11 OF 15



NOTES: UNLESS OTHERWISE SPECIFIED

1. MAKE FROM MCMASTER CARR PART NO. 6527K274

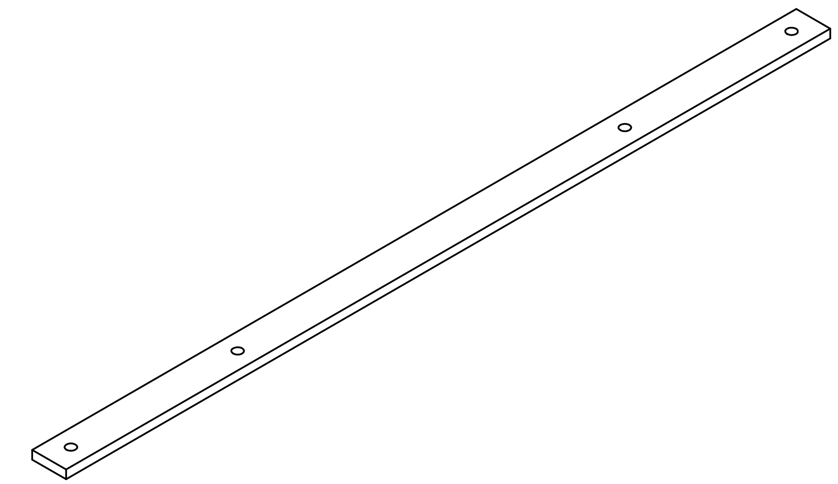
CAL POLY MICROGRID				TITLE: HINGE SPACER	
UNLESS OTHERWISE SPECIFIED:		NAME	DATE		
DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: ± 2° TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005	DRAWN	G.P.	12/10/16	SIZE B	DWG. NO. TRACKER 11
	CHECKED	C.M.	12/10/16		
	ENG APPR.	C.O.	12/10/16		
	MFG APPR.	G.P.	12/10/16	SCALE: 1:2	SHEET 12 OF 15

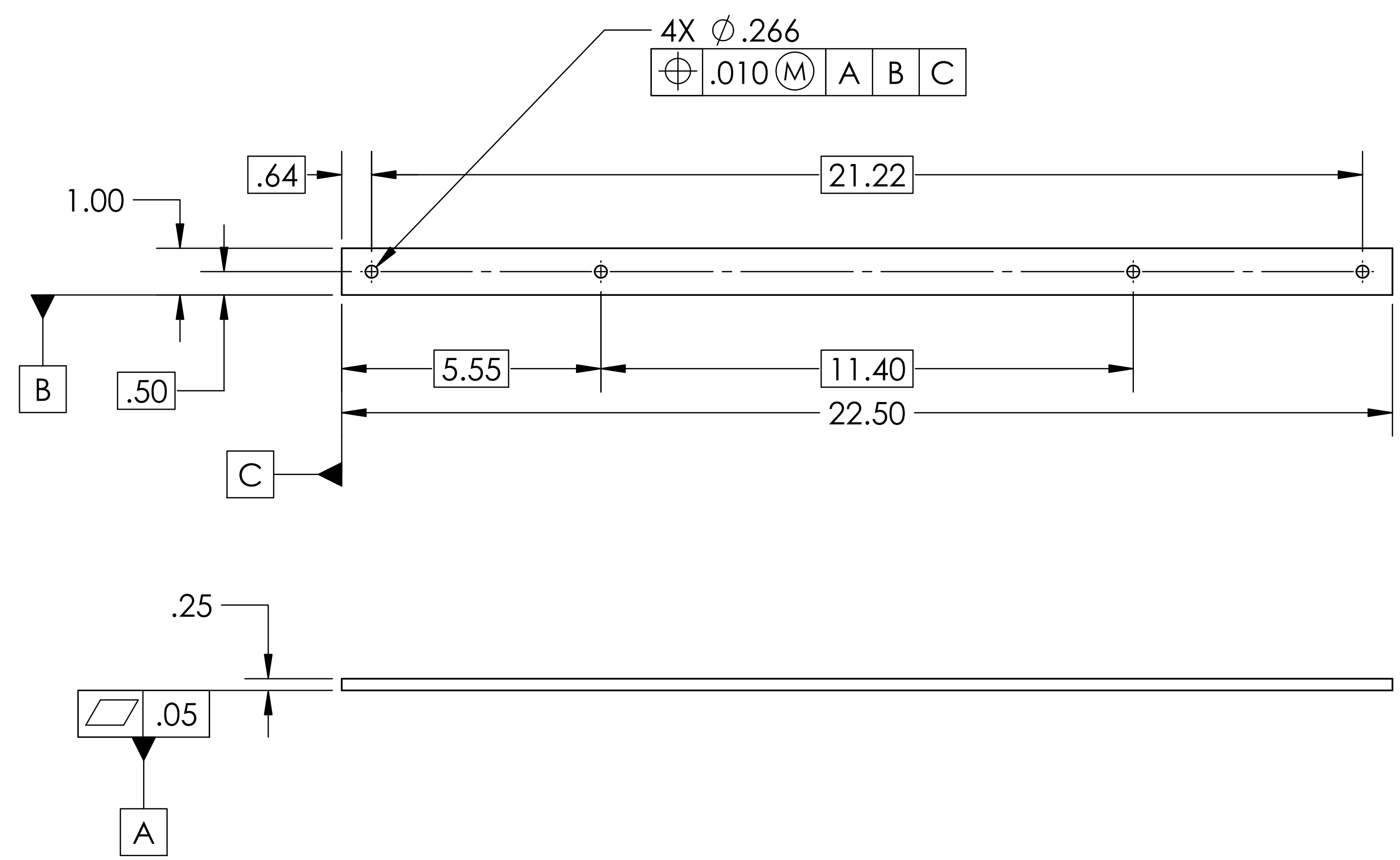


NOTES: UNLESS OTHERWISE SPECIFIED

1. MATERIAL: STEEL

CAL POLY MICROGRID			TITLE: VERTICAL CROSSBAR
UNLESS OTHERWISE SPECIFIED:	NAME	DATE	
DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: ± 2° TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005	DRAWN G.P.	12/10/16	SIZE B
	CHECKED C.M.	12/10/16	DWG. NO. TRACKER 12
	ENG APPR. C.O.	12/10/16	
	MFG APPR. D.M.	12/10/16	SCALE: 1:4 — SHEET 13 OF 15

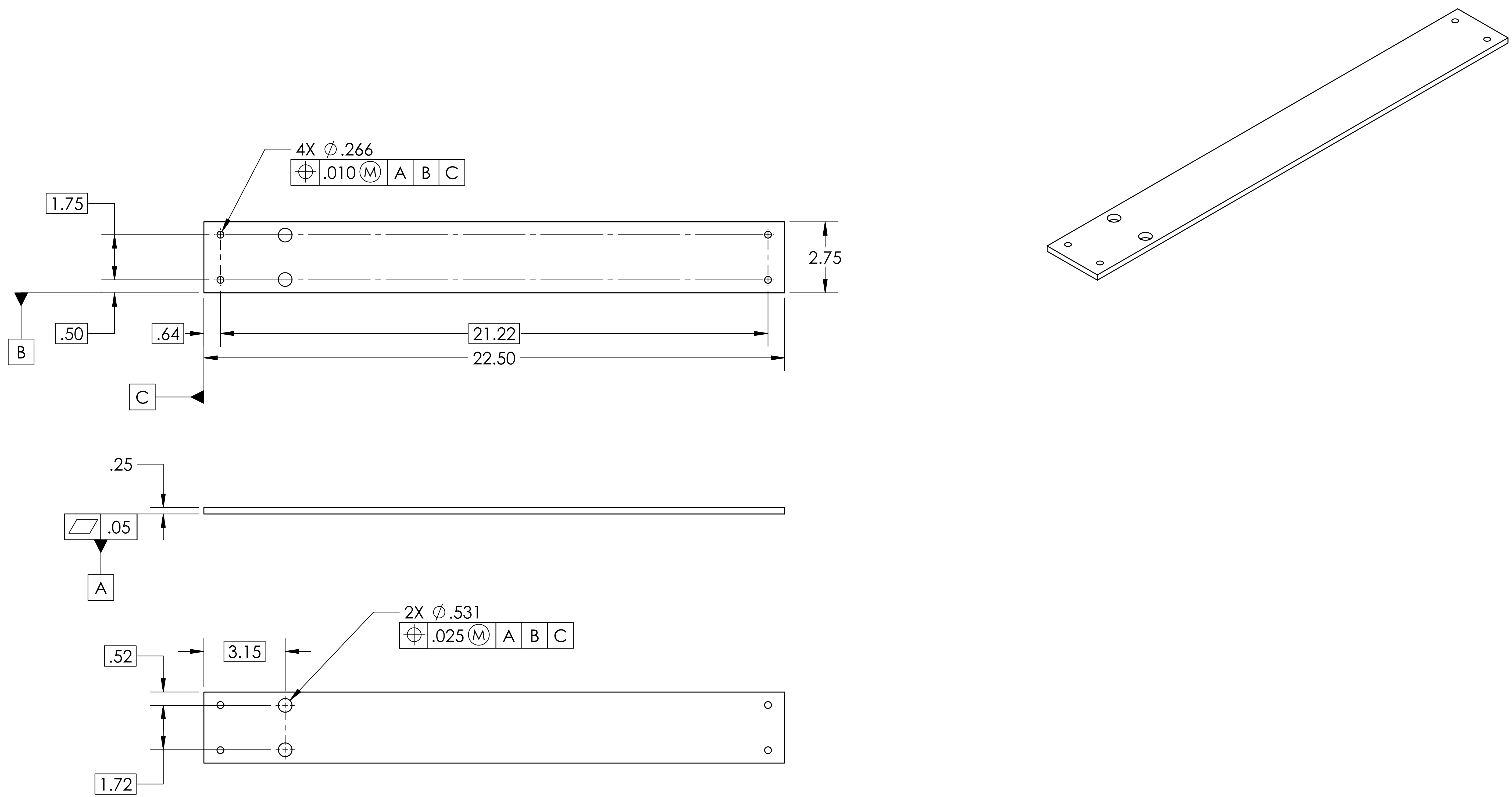




NOTES: UNLESS OTHERWISE SPECIFIED

1. MATERIAL: STEEL

CAL POLY MICROGRID			TITLE: HORIZONTAL CROSSBAR
UNLESS OTHERWISE SPECIFIED:	NAME	DATE	
DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: ± 2° TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005	DRAWN G.P.	12/10/16	SIZE B
	CHECKED C.M.	12/10/16	DWG. NO. TRACKER 13
	ENG APPR. C.O.	12/10/16	
	MFG APPR. D.M.	12/10/16	SCALE: 1:4 / SHEET 14 OF 15



NOTES: UNLESS OTHERWISE SPECIFIED

1. MATERIAL: STEEL

CAL POLY MICROGRID			TITLE: ACTUATOR END CROSSBAR
UNLESS OTHERWISE SPECIFIED:	NAME	DATE	
DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: ± 2° TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005			
DRAWN	G.P.	12/10/16	SIZE B — DWG. NO. TRACKER 14
CHECKED	C.M.	12/10/16	
ENG APPR.	C.O.	12/10/16	
MFG APPR.	G.P.	12/10/16	SCALE: 1:4 — SHEET 15 OF 15

Appendix 8

Matlab Actuator Calculations

Contents

Actuator Length and Load Calculations

```
% This script calculates the length and load requirements for the actuator
% given the minimum and maximum angle requirements for the solar panel.  It
% also calculates the horizontal and vertical loads acting on the pivot and
% the base of the actuator.


% Notes:
%   - Solar panel center of gravity is assumed to be at its geometric
%     center.
%   - The solar panel pivot is assumed to be located at the center of its
%     bottom face.
%   - All variables are used in accordance to their specified unit.  Any
%     inputs with units other than those specified below must be converted
%     for this sciprt to work properly.
```

Setup

```
clear;
clc;
```

Inputs

```
% Variable          Unit         Description
% -----------------------------------------------------------------------
% L ............... in ......... Solar panel length.
% w ............... in ......... Solar panel width.
% t ............... in ......... Solar panel thickness.
% de .............. in ......... Distance from solar panel pivot to
%                                actuator end.
% db .............. in ......... Horizontal distance from actuator base to
%                                solar panel pivot.
```

```
% h ............... in ......... Vertical distance from actator base to
%                                 solar panel pivot.
% theta_min ....... deg ........ Mimimum angle of solar panel with respect
%                                 to the horizontal.
% theta_max ....... deg ........ Maximum angle of solar panel with respect
%                                 to the horizontal.
% g ............... ft/s^2 ..... Gravity.
% W1 .............. lbf ........ Weight of solar panel.
% W2 .............. lbf ........ Weight of actuator.
% Fa_stat ......... lbf ........ Maximum static force that the actuator can
%                                 withstand.
% Fa_max .......... lbf ........ Maximum moving actuator force.
% Fa_crit ......... lbf ........ Critical actuator force at which the
%                                 force-speed curve changes.
% va_crit ......... in/s ....... Critical actuator speed at which the
%                                 force-speed curve changes.
% va_nl ........... in/s ....... Maximum actuator speed.
% v_w_ls .......... MPH ........ Maximum wind speed at which all components
%                                 of the tracking mount can still operate.
% v_w_hs .......... MPH ........ Maximum wind speed at which all components
%                                 of the tracking mount will not fail.
% K ............... N/A ........ Wind loading constant.
```

Outputs

```
% Variable          Unit         Description
% ----------------------------------------------------------------------
% La,min .......... in ......... Mimimum actuator length.
% La,max .......... in ......... Maximum actuator length.
% va,max .......... in/s ....... Actuator speed at maximum dynamic
%                                 conditions.
% Fp,x ............ lbf ........ Horizontal force acting on pivot.
% Fp,y ............ lbf ........ Vertical force acting on pivot
% Fa,stat ......... lbf ........ Force exerted by actuator under maximum
%                                 static conditions.
% Fa,dyn .......... lbf ........ Force exerted by actuator under maximum
%                                 dynamic conditions.
% Fs .............. lbf ........ Transverse force exerted on actuator.
% Fb,x ............ lbf ........ Horizontal force exerted by the actuator
%                                 base onto its mount.
% Fb,y ............ lbf ........ Vertical force exerted by the actuator
%                                 base onto its mount.
```

System Variables

```
% Solar Panel Geometry
  L = 81.36;          % [in]
  w = 41.18;          % [in]
  t = 2.13;           % [in]
```

```
% Actuator Placement
  de = 6;              % [in]
  db = 12;             % [in]
  h = 6;               % [in]

% Angles
  theta_min = 15;      % [deg]
  theta_max = 75;      % [deg]

% Gravity
  g = 32.2;            % [ft/s^2]

% Solar Panel and Actuator Weights
  W1 = 56.0;           % [lbf]
  W2 = 14.4;           % [lbf]

% Actuator Specs
  Fa_stat = 8500;      % [lbf]
  Fa_max = 2000;       % [lbf]
  Fa_crit = 0;         % [lbf]
  va_crit = 0.24;      % [in/s]
  va_nl = 0.24;        % [in/s]

% Wind Loading
  v_w_ls = 30;         % [MPH]
  v_w_hs = 100;        % [MPH]
  K = 2*0.55*1.64;
```

Actuator Length Calculations

```
phi_min = (180-theta_max)*(pi/180);
phi_max = (180-theta_min)*(pi/180);
phi_step = 1*(pi/180);
delta_theta = theta_max-theta_min;

La = zeros(delta_theta+1,1);
n = 1;

for phi=phi_min:phi_step:phi_max
    la_x = (de*sin(phi))-db;
    la_y = h-(de*cos(phi));
    la = sqrt((la_x^2)+(la_y^2));
    La(n,1) = la;
    n = n+1;
end

La_min = min(La);
La_max = max(La);
```

Static Force Calculations

```
P_ls = 0.00256*(v_w_ls^2);
P_hs = 0.00256*(v_w_hs^2);


Static_Vars = zeros(6, delta_theta+1,18);
Max_Vars = zeros(6,4);
Max_Act_Push = zeros(1,4);
Max_Act_Pull = zeros(1,4);

for Fw_Case=1:6
    n = 1;

    for phi=phi_min:phi_step:phi_max

        for act_CG_Case=1:3
            Vec_Out = Actuator_Stationary(L, w, t, de, db, h, phi, W1,  ...
                                          W2, P_hs, K, Fw_Case,         ...
                                          act_CG_Case);
            k = Fw_Case+(6*(act_CG_Case-1));
            Static_Vars(:,n,k) = Vec_Out;

            Fa = Vec_Out(3,1);

            if Fa > Max_Act_Push(1,1)
                Max_Act_Push(1,1) = Fa;
                Max_Act_Push(1,2) = phi;
                Max_Act_Push(1,3) = act_CG_Case;
                Max_Act_Push(1,4) = Fw_Case;
            end

            if Fa < Max_Act_Pull(1,1)
                Max_Act_Pull(1,1) = Fa;
                Max_Act_Pull(1,2) = phi;
                Max_Act_Pull(1,3) = act_CG_Case;
                Max_Act_Pull(1,4) = Fw_Case;
            end

            for i=1:6
                new = abs(Vec_Out(i,1));
                old = abs(Max_Vars(i,1));

                if new > old
                    Max_Vars(i,1) = Vec_Out(i,1);
                    Max_Vars(i,2) = phi;
                    Max_Vars(i,3) = act_CG_Case;
                    Max_Vars(i,4) = Fw_Case;
                end

            end
```

```
        end

        n = n+1;
    end

end


err1 = 0;

if Fa_stat < abs(Max_Vars(3,1));
    err1 = 1;
end
```

Dynamic Force Calculations

```
va_step = va_nl/50;

Const_Vars = zeros(6,delta_theta+1,101,18);
Max_Moving_Vars = zeros(6,5);
Max_Moving_Push = zeros(1,5);
Max_Moving_Pull = zeros(1,5);

for Fw_Case=1:6
    n = 1;

    for phi=phi_min:phi_step:phi_max

        for va=-va_nl:va_step:va_nl
            m = 1;

            for act_CG_Case=1:3
               Vec_Move = Actuator_Constant_Speed(L, w, t, de, db, h,   ...
                                                   phi, g, W1, W2,       ...
                                                   Fa_max, Fa_crit, va,  ...
                                                   va_crit, va_nl, P_ls, ...
                                                   K, Fw_Case, act_CG_Case);

                k = Fw_Case+(6*(act_CG_Case-1));

                Const_Vars(:,n, m, k) = Vec_Move;


                Fa = Vec_Move(3,1);

                if Fa > Max_Moving_Push(1,1)
                    Max_Moving_Push(1,1) = Fa;
                    Max_Moving_Push(1,2) = phi;
                    Max_Moving_Push(1,3) = va;
                    Max_Moving_Push(1,4) = act_CG_Case;
                    Max_Moving_Push(1,5) = Fw_Case;
                end
```

```
                if Fa < Max_Moving_Pull(1,1)
                    Max_Moving_Pull(1,1) = Fa;
                    Max_Moving_Pull(1,2) = phi;
                    Max_Moving_Pull(1,3) = va;
                    Max_Moving_Pull(1,4) = act_CG_Case;
                    Max_Moving_Pull(1,5) = Fw_Case;
                end

                for i=1:6
                    new = abs(Vec_Move(i,1));
                    old = abs(Max_Moving_Vars(i,1));

                    if new > old
                        Max_Moving_Vars(i,1) = Vec_Move(i,1);
                        Max_Moving_Vars(i,2) = phi;
                        Max_Moving_Vars(i,3) = va;
                        Max_Moving_Vars(i,4) = act_CG_Case;
                        Max_Moving_Vars(i,5) = Fw_Case;
                    end

                end

            end

        end

        n = n+1;
    end

end


Max_F = zeros(7,1);

for i=1:2

    if abs(Max_Vars(i,1)) > abs(Max_Moving_Vars(i,1))
        Max_F(i,1) = abs(Max_Vars(i,1));
    else
        Max_F(i,1) = abs(Max_Moving_Vars(i,1));
    end

end

Max_F(3,1) = abs(Max_Vars(3,1));
Max_F(4,1) = abs(Max_Moving_Vars(3,1));

for i=5:7

    if abs(Max_Vars(i-1,1)) > abs(Max_Moving_Vars(i-1,1))
        Max_F(i,1) = abs(Max_Vars(i-1,1));
    else
```

```
        Max_F(i,1) = abs(Max_Moving_Vars(i-1,1));
    end

end


err2 = 0;

if Max_F(4,1) == 0;
    err2 = 1;
elseif Max_F(4,1) >= Fa_crit

    if Fa_max == Fa_crit
        va_max = va_crit;
    else
        va_max = ((Fa_max-Max_F(4,1))/(Fa_max-Fa_crit))*va_crit;
    end

else
    va_max = va_nl-(Max_F(4,1)*((va_nl-va_crit)/Fa_crit));
end
```

Display Results

```
if err1 == 1

    fprintf('The required static actuator force\n');
    fprintf('exceeds that of the selected actuator.\n');
    fprintf('\n');
    fprintf('\n');

elseif err2 == 1

    fprintf('The required dynamic actuator force\n');
    fprintf('exceeds that of the selected actuator.\n');
    fprintf('\n');
    fprintf('\n');

else

    fprintf('Actuator Length      [in]\n');
    fprintf('------------------------\n');
    fprintf('La,min          %8.2f\n', La_min);
    fprintf('La,max          %8.2f\n', La_max);
    fprintf('\n');
    fprintf('\n');

    fprintf('Dynamic Case\n');
    fprintf('Actuator Speed    [in/s]\n');
    fprintf('------------------------\n');
    fprintf('va,max          %8.2f\n', va_max);
    fprintf('\n');
```

```
    fprintf('\n');

    fprintf('Maximum Forces      [lbf]\n');
    fprintf('------------------------\n');
    fprintf('Fp,x             %8.2f\n', Max_F(1,1));
    fprintf('Fp,y             %8.2f\n', Max_F(2,1));
    fprintf('Fa,stat          %8.2f\n', Max_F(3,1));
    fprintf('Fa,dyn           %8.2f\n', Max_F(4,1));
    fprintf('Fs               %8.2f\n', Max_F(5,1));
    fprintf('Fb,x             %8.2f\n', Max_F(6,1));
    fprintf('Fb,y             %8.2f\n', Max_F(7,1));
    fprintf('\n');
    fprintf('\n');

end
```

```
Actuator Length      [in]
------------------------
La,min              9.77
La,max             15.76


Dynamic Case
Actuator Speed     [in/s]
------------------------
va,max              0.15


Maximum Forces      [lbf]
------------------------
Fp,x             6493.22
Fp,y             6304.48
Fa,stat          8338.42
Fa,dyn            766.68
Fs                  9.55
Fb,x             5524.36
Fb,y             6234.60
```

Published with MATLAB® R2015a

Contents


```
function Vec_Out = Actuator_Stationary(L, w, t, de, db, h, theta, W1,   ...
                                       W2, P_hs, K, Fw_Case, act_CG_Case)
```

```
% This function calculates the load requirements for the actuator at a
% given constant actuator speed.  It  also calculates the horizontal and
% vertical loads acting on the pivot and the base of the actuator.


% Notes:
%   - Solar panel center of gravity is assumed to be at its geometric
%     center.
%   - The solar panel pivot is assumed to be located at the center of its
%     bottom face.
%   - All variables are used in accordance to their specified unit.  Any
%     inputs with units other than those specified below must be converted
%     for this scirpt to work properly.
```

Inputs

```
% Variable          Unit         Description
% ------------------------------------------------------------------------
% L ............... in ......... Solar panel length.
% w ............... in ......... Solar panel width.
% t ............... in ......... Solar panel thickness.
% de .............. in ......... Distance from solar panel pivot to
%                                actuator end.
% db .............. in ......... Horizontal distance from actuator base to
%                                solar panel pivot.
% h ............... in ......... Vertical distance from actator base to
%                                solar panel pivot.
% theta ........... rad ........ Angle of solar panel with respect to the
%                                vertical centerline of the pivot, measured
%                                on the side of the actuator.
% W1 .............. lbf ........ Weight of solar panel.
% W2 .............. lbf ........ Weight of actuator.
% P_hs ............ lbf/ft^2 ... Maximum wind pressure at which all
%                                components of the tracking mount will not
%                                fail.
% K ............... N/A ........ Wind loading constant.
% Fw_Case ......... N/A ........ Flag for determining the position of the
%                                wind load.
```

```
% act_CG_Case ..... N/A ........ Flag for determining the position of the
%                                 center of gravity of the actuator.
```

Outputs

```
% Variable           Unit         Description
% ------------------------------------------------------------------------
% Fp,x ............ lbf ........ Horizontal force acting on pivot.
% Fp,y ............ lbf ........ Vertical force acting on pivot
% Fa .............. lbf ........ Force exerted by actuator.
% Fs .............. lbf ........ Transverse force exerted on actuator.
% Fb,x ............ lbf ........ Horizontal force exerted by the actuator
%                                base onto its mount.
% Fb,y ............ lbf ........ Vertical force exerted by the actuator
%                                base onto its mount.
```

Calculations

```
la_x = (de*sin(theta))-db;
la_y = h-(de*cos(theta));
la = sqrt((la_x^2)+(la_y^2));


switch Fw_Case
    case 1
        n = 1;
        rw = (t*sin(theta))-((1/2)*L*cos(theta));
    case 2
        n = 1;
        rw = (t*sin(theta))+((1/2)*L*cos(theta));
    case 3
        n = -1;
        rw = (1/2)*L*cos(theta);
    case 4
        n = -1;
        rw = -(1/2)*L*cos(theta);
    case 5
        n = 1;
        rw = (1/2)*L*cos(theta);
    case 6
        n = -1;
        rw = (t*sin(theta))-((1/2)*L*cos(theta));
end

Fw = n*K*P_hs*w*((t*sin(theta))-(L*cos(theta)))*((1/12)^2);


rs = ((la_y*cos(theta))-(la_x*sin(theta)))*(de/la);
ra = ((la_x*cos(theta))+(la_y*sin(theta)))*(de/la);
```

```
r2 = ((act_CG_Case-1)/2)*la;


A = [[  1   0    la_x/la    la_y/la   0       0     ];...
     [  0   1    la_y/la   -la_x/la   0       0     ];...
     [  0   0    ra         rs        0       0     ];...
     [  0   0   -la_x/la   -la_y/la   1       0     ];...
     [  0   0   -la_y/la    la_x/la   0       1     ];...
     [  0   0    0          0         la_y   -la_x  ]];

B = [[  -Fw                             ];...
     [   W1                             ];...
     [  (Fw*rw)+((1/2)*W1*t*cos(theta)) ];...
     [   0                              ];...
     [   W2                             ];...
     [  -W2*(la-r2)*(la_x/la)           ]];

y = linsolve(A,B);


Vec_Out = zeros(6,1);

Vec_Out(1,1) = y(1);
Vec_Out(2,1) = y(2);
Vec_Out(3,1) = y(3);
Vec_Out(4,1) = y(4);
Vec_Out(5,1) = y(5);
Vec_Out(6,1) = y(6);
```

```
end
```

Published with MATLAB® R2015a

Contents


```
function Vec_Out = Actuator_Constant_Speed(L, w, t, de, db, h, theta, g,...
                                           W1, W2, Fa_max, Fa_crit, va, ...
                                           va_crit, va_nl, P_ls, K,     ...
                                           Fw_Case, act_CG_Case)
```

```
% This function calculates the load requirements for the actuator at a
% given constant actuator speed.  It  also calculates the horizontal and
% vertical loads acting on the pivot and the base of the actuator.


% Notes:
%   - Solar panel center of gravity is assumed to be at its geometric
%     center.
%   - The solar panel pivot is assumed to be located at the center of its
%     bottom face.
%   - All variables are used in accordance to their specified unit.  Any
%     inputs with units other than those specified below must be converted
%     for this sciript to work properly.
```

Inputs

```
% Variable          Unit         Description
% -----------------------------------------------------------------------
% L ............... in ......... Solar panel length.
% w ............... in ......... Solar panel width.
% t ............... in ......... Solar panel thickness.
% de .............. in ......... Distance from solar panel pivot to
%                                actuator end.
% db .............. in ......... Horizontal distance from actuator base to
%                                solar panel pivot.
% h ............... in ......... Vertical distance from actator base to
%                                solar panel pivot.
% theta ........... rad ........ Angle of solar panel with respect to the
%                                vertical centerline of the pivot, measured
%                                on the side of the actuator.
% g ............... ft/s^2 ..... Gravity.
% W1 .............. lbf ........ Weight of solar panel.
% W2 .............. lbf ........ Weight of actuator.
% Fa_max .......... lbf ........ Maximum actuator force.
% Fa_crit ......... lbf ........ Critical actuator force at which the
%                                force-speed curve changes.
% va .............. in/s ....... Actuator speed.
```

```
% va_crit ......... in/s ....... Critical actuator speed at which the
%                                force-speed curve changes.
% va_nl .......... in/s ....... Maximum actuator speed.
%                                of the tracking mount will not fail.
% P_ls ........... lbf/ft^2 ... Maximum wind pressure at which all
%                                components of the tracking mount can still
%                                operate.
% K ............... N/A ........ Wind loading constant.
% Fw_Case ......... N/A ........ Flag for determining the position of the
%                                wind load.
% act_CG_Case ..... N/A ........ Flag for determining the position of the
%                                center of gravity of the actuator.
```

Outputs

```
% Variable          Unit         Description
% ------------------------------------------------------------------------
% Fp,x ........... lbf ........ Horizontal force acting on pivot.
% Fp,y ........... lbf ........ Vertical force acting on pivot
% Fa ............. lbf ........ Force exerted by actuator.
% Fs ............. lbf ........ Transverse force exerted on actuator.
% Fb,x ........... lbf ........ Horizontal force exerted by the actuator
%                                base onto its mount.
% Fb,y ........... lbf ........ Vertical force exerted by the actuator
%                                base onto its mount.
```

Calculations

```
la_x = (de*sin(theta))-db;
la_y = h-(de*cos(theta));
la = sqrt((la_x^2)+(la_y^2));


dtheta = va/((de/la)*((la_x*cos(theta))+(la_y*sin(theta))));
dpsi = (de/(la^2))*((la_x*sin(theta))-(la_y*cos(theta)))*dtheta;


switch Fw_Case
    case 1
        n = 1;
        rw = (t*sin(theta))-((1/2)*L*cos(theta));
    case 2
        n = 1;
        rw = (t*sin(theta))+((1/2)*L*cos(theta));
    case 3
        n = -1;
        rw = (1/2)*L*cos(theta);
    case 4
        n = -1;
        rw = -(1/2)*L*cos(theta);
```

```
    case 5
        n = 1;
        rw = (1/2)*L*cos(theta);
    case 6
        n = -1;
        rw = (t*sin(theta))-((1/2)*L*cos(theta));
end

Fw = n*K*P_ls*w*((t*sin(theta))-(L*cos(theta)))*((1/12)^2);


rs = ((la_y*cos(theta))-(la_x*sin(theta)))*(de/la);
ra = ((la_x*cos(theta))+(la_y*sin(theta)))*(de/la);


r2 = ((act_CG_Case-1)/2)*la;


A = [[  1   0    la_x/la    la_y/la   0       0      ];...
     [  0   1    la_y/la   -la_x/la   0       0      ];...
     [  0   0    ra         rs        0       0      ];...
     [  0   0   -la_x/la   -la_y/la   1       0      ];...
     [  0   0   -la_y/la    la_x/la   0       1      ];...
     [  0   0    0          0         la_y   -la_x  ]];

B = [[  -Fw-((1/2)*(W1/g)*t*(dtheta^2)*cos(theta)*(1/12))  ];...
     [  W1-((1/2)*(W1/g)*t*(dtheta^2)*sin(theta)*(1/12))   ];...
     [  (Fw*rw)+((1/2)*W1*t*cos(theta))                    ];...
     [  -((W2/g)*(la_x/la)*r2*(dpsi^2)*(1/12))             ];...
     [  W2-((W2/g)*(la_y/la)*r2*(dpsi^2)*(1/12))           ];...
     [  -W2*(la-r2)*(la_x/la)                              ]];...

y = linsolve(A,B);


Vec_Out = zeros(6,1);


if abs(va) <= va_crit
    Fa = Fa_max-(((Fa_max-Fa_crit)/va_crit)*abs(va));
else
    if va_crit == va_nl
        Fa = 0;
    else
        Fa = (Fa_crit/(va_nl-va_crit))*(va_nl-abs(va));
    end
end


if abs(y(3,1)) < Fa
    Vec_Out(1,1) = y(1);
    Vec_Out(2,1) = y(2);
    Vec_Out(3,1) = y(3);
```

```
    Vec_Out(4,1) = y(4);
    Vec_Out(5,1) = y(5);
    Vec_Out(6,1) = y(6);
end
```

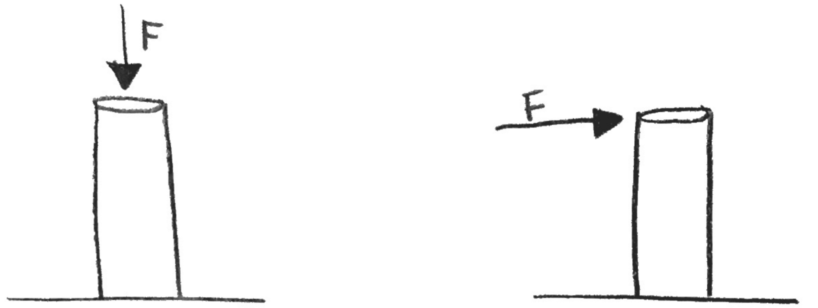
```
end
```

Published with MATLAB® R2015a

Appendix 9

Support Pole Hand Calculations

TEAM POLY SOLAR | SUPPORT POLE CALCS | TRACKING MOUNT | 7/17/



BUCKLING BENDING

CONSTANTS

Height (h) = 36 in.
Constraint (n) = FIX-FREE = 0.25
Modulus of Elasticity (E) = 30,000,000 (lb/in²)

VARIABLES

Inner Diameter : 2 in.
Outer Diameter : 3 in.
→ chosen values for hand calc

CALCULATIONS

$$\text{Volume} = \pi h (OD^2 - ID^2)$$
$$= \pi (36\,in.)(3^2 in^2 - 2^2 in^2) = \underline{\underline{565\ in^3}}$$

☆ STEEL ☆

$$\text{mass} = \rho V$$
$$= (0.2836\ \tfrac{lb}{in^3})(254\ in^3) = \underline{\underline{160\ lbm}}$$

$$\text{Moment of Inertia} = \frac{\pi (OD^4 - ID^4)}{64}$$
$$= \frac{\pi (3^4 in^4 - 2^4 in^4)}{64} = \underline{\underline{3.19\ lb\text{-}in^2}}$$

$$\text{AREA} = \frac{\pi}{4}(OD^4 - ID^4)$$
$$= \frac{\pi}{4}(3^4 in^4 - 2^4 in^4) = \underline{\underline{3.93\ in^2}}$$

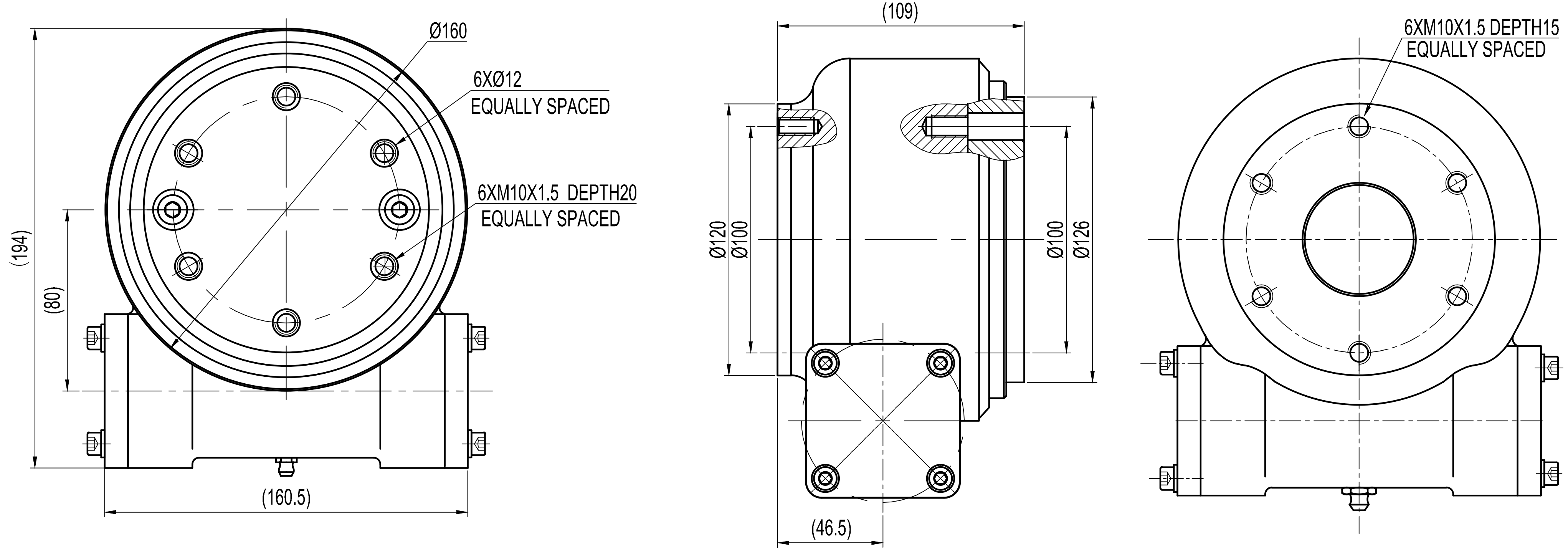
BUCKLING FORCE:
$$F_{bu} = \frac{\pi^2 n E I}{h}$$
$$F_{bu} = \frac{\pi^2 (0.25)(3\times10^6\ \frac{lb}{in^2})(3.19\ lb\cdot in^2)}{36\ in.} = \boxed{6.5\times10^6\ lb\text{-}f}$$

BENDING FORCE:
$$F_{be} = \frac{1000h(\frac{OD}{2})}{I}$$
$$= \frac{1000(36\,in)(\frac{3\,in}{2})}{3.19\ lb\cdot in^2} = \boxed{16,933\ \frac{lb}{in^2}}$$

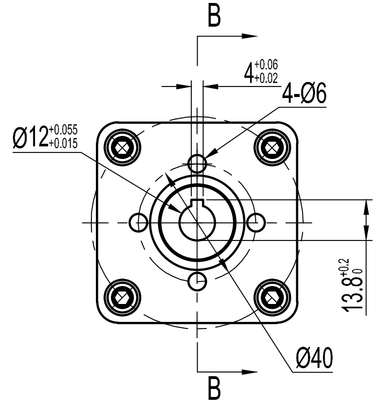
Appendix 10

Slew Drive, Motor and Actuator Data Sheets

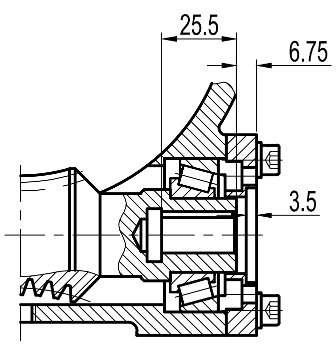
HOURGLASS WORM SLEW DRIVE



VIEW A



Section B-B



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CHECKED BY	ZMF 2013/08/06			
APPROVED BY	WCH 2013/08/06			
ALL PROPRIETARY RIGHTS IN THE SUBJECT MATTER HEREOF ARE RESERVED, AND NO PERMISSION IS GRANTED TO REPRODUCE THIS PRINT IN WHOLE OR IN PART, OR TO DISCLOSE ANY OF THE INFORMATION TO OTHERS.	WEIGHT	SCALE: NTS	SLEWING DRIVE	
SYMBOLE ISO	SIZE: A3	SHEET: 1/1	SE3B-62MHQ-12MRC	REV A
	THE TOLERANCE NOT MENTIONED IS REFERRED TO ISO 2768-vL,CASTING TOLERANCE ISO 8062-CT10			

REV.	DATE	PAGE	REVISER	CHECKED BY	DESCRIPTION
A	2013/08/06	MODEL	WJY	ZMF	ORIGINAL DRAW

REV.	DATE	PAGE	REVISER	CHECKED BY	DESCRIPTION

DESIGNED BY	WJY	2013/08/06
CHECKED BY	ZMF	2013/08/06
APPROVED BY	WCH	2013/08/06

KMI GROUP

www.kinematicsmfg.com

WEIGHT	SCALE
	NTS

SLEWING DRIVE

SYMBOLE	SIZE	A3	SHEET	1/1
ISO				

SE3B-62MHQ-12MRC

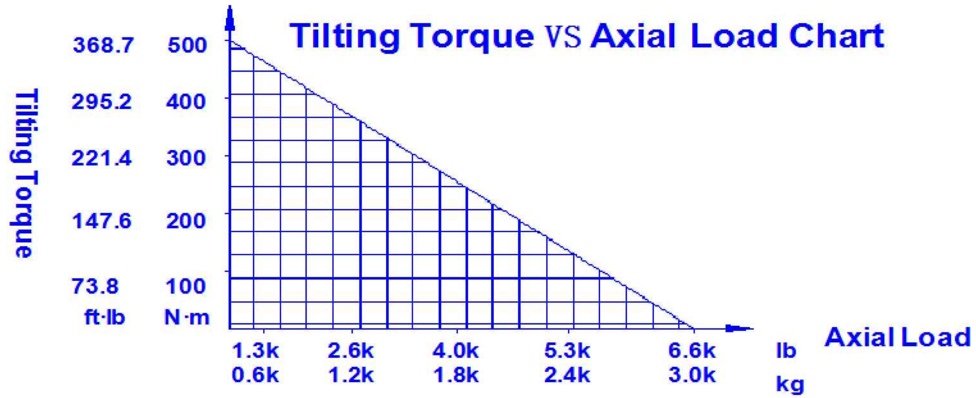
REV
A

SLEWING DRIVES PERFORMANCE DATA

Model Code： SE3B-62MHQ-12MRC

Slewing Drive Ratio	62:1	_		
Rotating Output Rated Speed	_	Type Code	_	
Efficiency	30%	Rated Voltage	_	VDC
International Protection (IP)	55	Output Speed	_	rpm
Motor Temperature	—	Rated Current	_	A
Worm Drive Temperature	－20℃ to＋120℃	Rated Output Power	_	w
Traceability	CEDS	Motor Rated Speed	_	rpm
Torsion Stiffness	137 Nm/mRad	Output Torque	_	N·m
Bending Stiffness	190Nm/mRad	Stall Torque	_	N·m

Slewing Drive Loading Data	HQ Type			
Normal Output Torque	599	N·m	442	ft·lb
Max. Output Torque(3 sec.)	899	N·m	663	ft·lb
Backwards Holding Torque	3,000	N·m	2,213	ft·lb
Tilting Torque	500	N·m	369	ft·lb
Static Radial Rating	16.60	kN	3,732	lb
Static Axial Rating	29.40	kN	6,609	lb
Dynamic Radial Rating	8.40	kN	1,888	lb
Dynamic Axial Rating	9.60	kN	2,158	lb



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APPROVED BY	WCH 2013/08/06			
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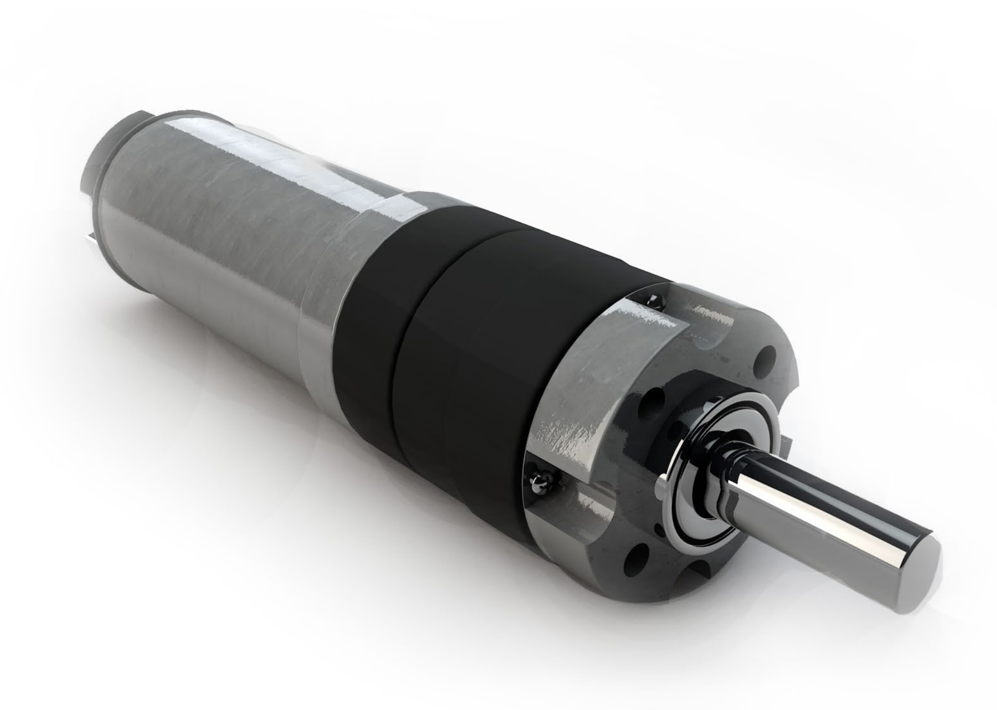
SYMBOLE ISO	SIZE A4	SHEET 1/1	SE3B-62MHQ-12MRC	REV A

Kinematics Manufacturing, Inc.

Process Solutions through Excellence in Innovation



DC Gear Motors

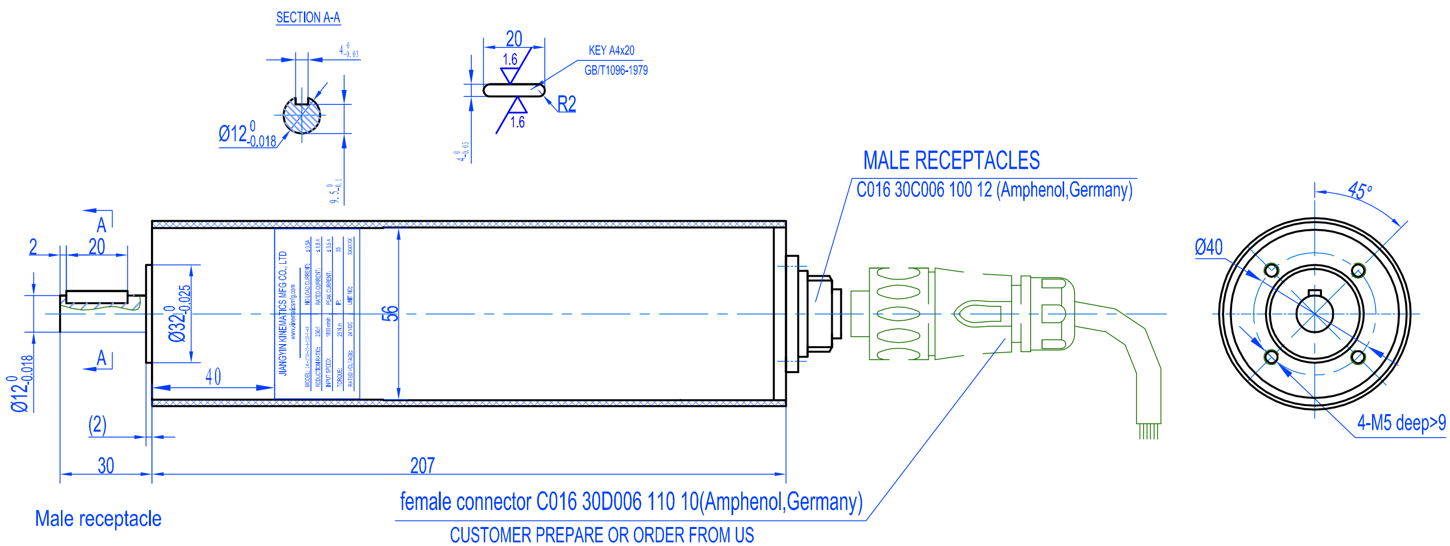
KMI Standard DC Brushed Gear Motors

KMI Code	VDC	Motor Rated Speed (rpm)	Reduction Ratio	Output Speed (rpm)	Rated Torque (N-m)	Rated Current (A)	Stall Torque (N-m)	IP Rating	Hall Effect Sensor
12H-1700-575-30-V-12S-46	12	1700	575	3.0	30	2.4	60	55	Y
12H-1900-236-25-V-12S-40	12	1900	236	8.1	25	3.6	60	55	Y
24-1000-422-150-AS-25S-130	24	1000	422	2.4	150	4	300	55	N
24-1200-283.5-180-25S-130	24	1200	283.5	4.2	180	8.2	360	55	N
24-1700-575-33-12S-46	24	1700	575	3.0	33	1.2	60	55	N
24-2500-35-8-12S-40	24	2500	35	71.4	8	4.7	16	55	N
24-2500-35-8-12S-46	24	2500	35	71.4	8	4.7	16	55	N
24-2500-35-11-12S-40	24	2500	35	69.0	11	7	22	65	N
24-3000-35-25-16S-62	24	3000	35	85.7	25	3	50	55	N
24H-1500-216-60-V-20S-70	24	1500	216	6.9	60	4.7	120	55	Y
24H-1700-575-33-V-12S-46	24	1700	575	3.0	33	1.2	60	55	Y
24H-1800-2277-40-V-12S-40	24	1800	2277	0.8	40	0.6	60	55	Y
24H-1900-236-25-V-12S-40	24	1900	236	8.1	25	1.8	60	55	Y
24H-1900-236-25-V-12S-46	24	1900	236	8.1	25	1.8	60	55	Y
24H-2100-236-100-V-20S-70	24	2100	236	8.9	100	11	200	55	Y
24H-2500-35-8-V-12S-40	24	2500	35	71.4	8	4.7	16	55	Y

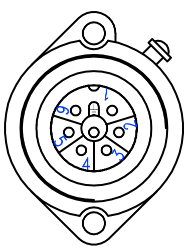
KMI Standard DC Brushless Gear Motors

KMI Code	VDC	Motor Rated Speed (rpm)	Reduction Ratio	Output Speed (rpm)	Rated Torque (N-m)	Rated Current (A)	Stall Torque (N-m)	IP Rating	Hall Effect Sensor
24LH-1350-192-60-20S-70	24	1350	192	7.0	60	5.5	120	55	Y
24LH-1700-575-50-20S-70	24	1700	575	3.0	50	3	100	55	Y
24LH-1800-236-29-12S-40	24	1800	236	7.6	29	2.2	60	55	Y
24LH-1900-0.7-14S-100	24	1900	Per Application	Per Application	0.7	12.8	1.4	55	Y
24LH-1900-1.5-14S-145	24	1900	Per Application	Per Application	1.5	24	3	55	Y

DC Brushed Gear 24H-2500-35-8-V-12S-40



Male receptacle



face view of male receptacle

Motor Parameters	
Rated voltage U_N (VDC)	24
Speed V_{RM} (RPM)	2500±8%
Rated torque T_{RM} (N.m)	0.28
Current I_{RM} (A)	<4.7
Planetary Reducer Parameters	
Ratio	35:1
Stage	3
Rated output torque T_{RR} (N.m)	8
Maximum output torque T_{SR} (N.m)	16
Other Parameters	
Average life-span (h)	2000h
Noise (dB)	≤65
Rated efficiency η (%)	50
Environmental temperature T_A (℃)	-40 to +80
IP	55

MAGNETIC PULSE GENERATOR DATA		
Output type	-	voltage output
Pull-up resistor	-	yes
Output signal	-	2 square wave signals
phase quadrature	-	90°
Impulses per revolution	ppr	2,channels A and B
Operating voltage	VDC	UN=12 (5 ... 24)
Operating current	mA	max. 12 (U=12V)
Deviation of pulse width	-	max. 15°
Deviation of phase shift	-	max. 15°
Output voltage(low level)	VDC	max. 0.4 (20mA)
SIGNAL RISE TIME	ns	85
SIGNAL DECAY TIME	ns	60
Operating temperature	℃	-40 to +85

Electric Connection:

Pin 1: Motor, 0V (MOTOR INPUT), (Black thick wire inside)
Pin 2: Motor, +24V (MOTOR INPUT), (Red thick wire inside)
Pin 3: Hall, 0V (HALL INPUT), (Black thin wire inside)
Pin 4: Hall, +12V(5-24) (HALL INPUT), (Red thin wire inside)
Pin 5: Hall, Signal A (HAll OUTPUT,square wave signal)(Green thin wire inside)
Pin 6: Hall, Signal B (HAll OUTPUT,square wave signal)(Yellow thin wire inside)
Pin 7: GROUND (G)

⚠ ATTENTION

Do not exchange the connection for Pin3 and Pin4!
If you do so, Hall will be destroyed!

Rotate Direction:

Pin 1 connect to Power (-), Pin 2 connect to Power (+), view from motor output shaft, Motor rotate on CCW direction.

DESIGNED BY	WJY	2012/04/12
CHECKED BY	ZMF	2012/04/12
APPROVED BY	WCH	2012/04/12

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WEIGHT	SCALE	
	NTS	MOTOR

SYMBOLE ISO	SIZE	A3	SHEET	1/1	24H-2500-35-8-V-12S-40	REV A

THE TOLERANCE NOT MENTIONED IS REFERRED TO ISO 2768-vL,CASTING TOLERANCE ISO 8062-CT10

PROGRESSIVE AUTOMATIONS
FORWARD THINKING

PA-17 LINEAR ACTUATOR

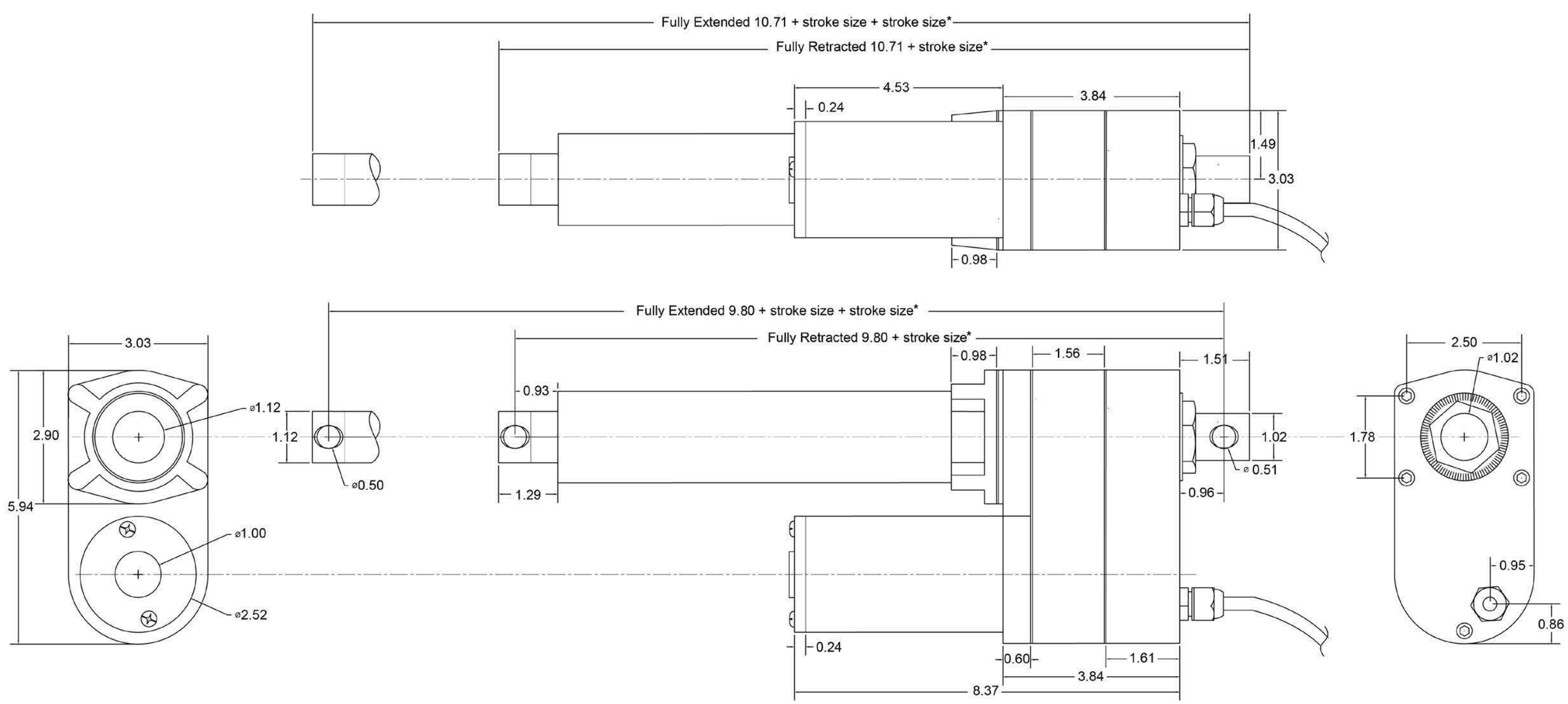
HOW TO ORDER
1.800.676.6123
sales@**progressive**automations.com
www.**progressive**automations.com

SPECIFICATIONS

- Input Voltage: 12 VDC
- Current: 20A at full load
- Load Capacity: 850 lbs, 2000 lbs
- Static Load: 2 x max load capacity
- Stroke length: 1” to 40”
- Mounting holes: 0.50” diameter
- Screw: ACME Screw
- Duty Cycle 25%
- Operational Temperature: -40°C~65°C (-40°F~150°F)
- Limit Switch: built-in, adjustable
- IP Grade: IP65
- Certification: CE and RoHS
- Housing: Stainless Steel
- Gear: Powder Metallurgy
- Works great for projects that require lots of force
- Gear Ratio: 850 lbs – 20:1, 2000 – 40:1
- Wire Length: 40”

For Custom Options See Page 5

DIMENSIONS IN INCHES



*For Stroke Length above 24”
Fully Extended 12.71” + stroke size + stroke size
Fully Retracted 12.71” + stroke size

*For Stroke Length above 24”
Fully Extended 11.8” + stroke size + stroke size
Fully Retracted 11.8” + stroke size

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PA-17 LINEAR ACTUATOR

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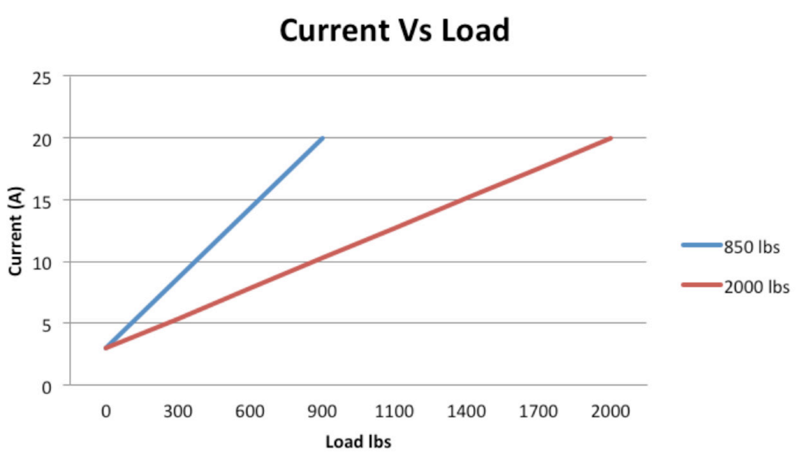
12 VDC CURRENT VS LOAD



HOLE TO HOLE DIMENSIONS

Stroke Sizes (in inches)	Fully Retracted (in inches)	Fully Extended (in inches)
0	9.8	9.8
1	10.8	11.8
2	11.8	13.8
4	13.8	17.8
6	15.8	21.8
8	17.8	25.8
9	18.8	27.8
10	19.8	29.8
12	21.8	33.8
14	23.8	37.8
16	25.8	41.8
18	27.8	45.8
20	29.8	49.8
22	31.8	53.8
24	33.8	57.8
30	41.8	71.8
40	51.8	91.8

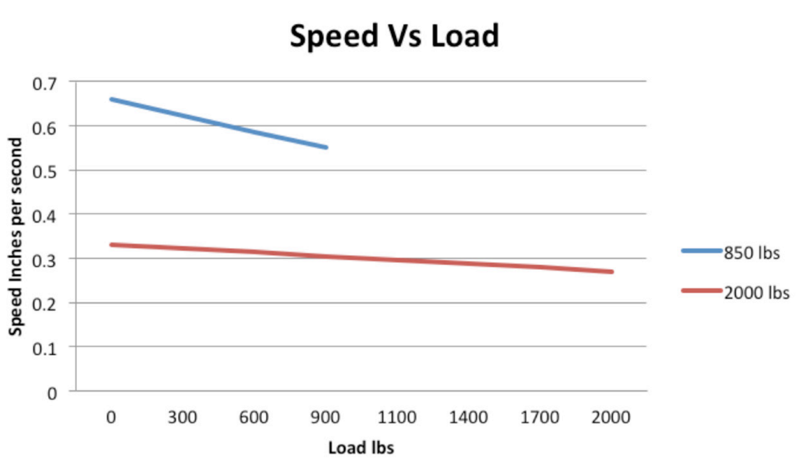
SPEED IN INCHES PER SECOND

Force (lbs)	No Load Speed	Full Load Speed	Max Current (A) 12V	Rpm
850	0.66	0.55	20	4000
2000	0.33	0.27	20	4000

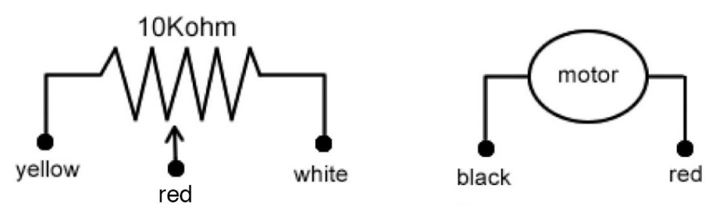
PRODUCT ACCESSORIES

- Will work with any PA's AC controls boxes (see control box selection for details)
- Mounting Brackets: BRK-17 (for each end)
- Rocker Switches: any PA's Rocker Switches
- Foot Controls: PDL-01, PDL-03

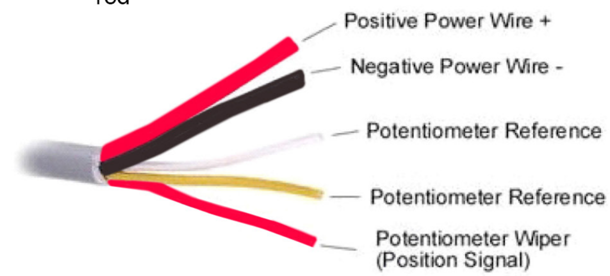
12 VDC SPEED VS LOAD



POTENTIONMETER (OPTIONAL)



Red + 12 vdc
Black gnd



(Actuator extends, reverse polarity to retract)

PA-17 LINEAR ACTUATOR

HOW TO ORDER
1.800.676.6123
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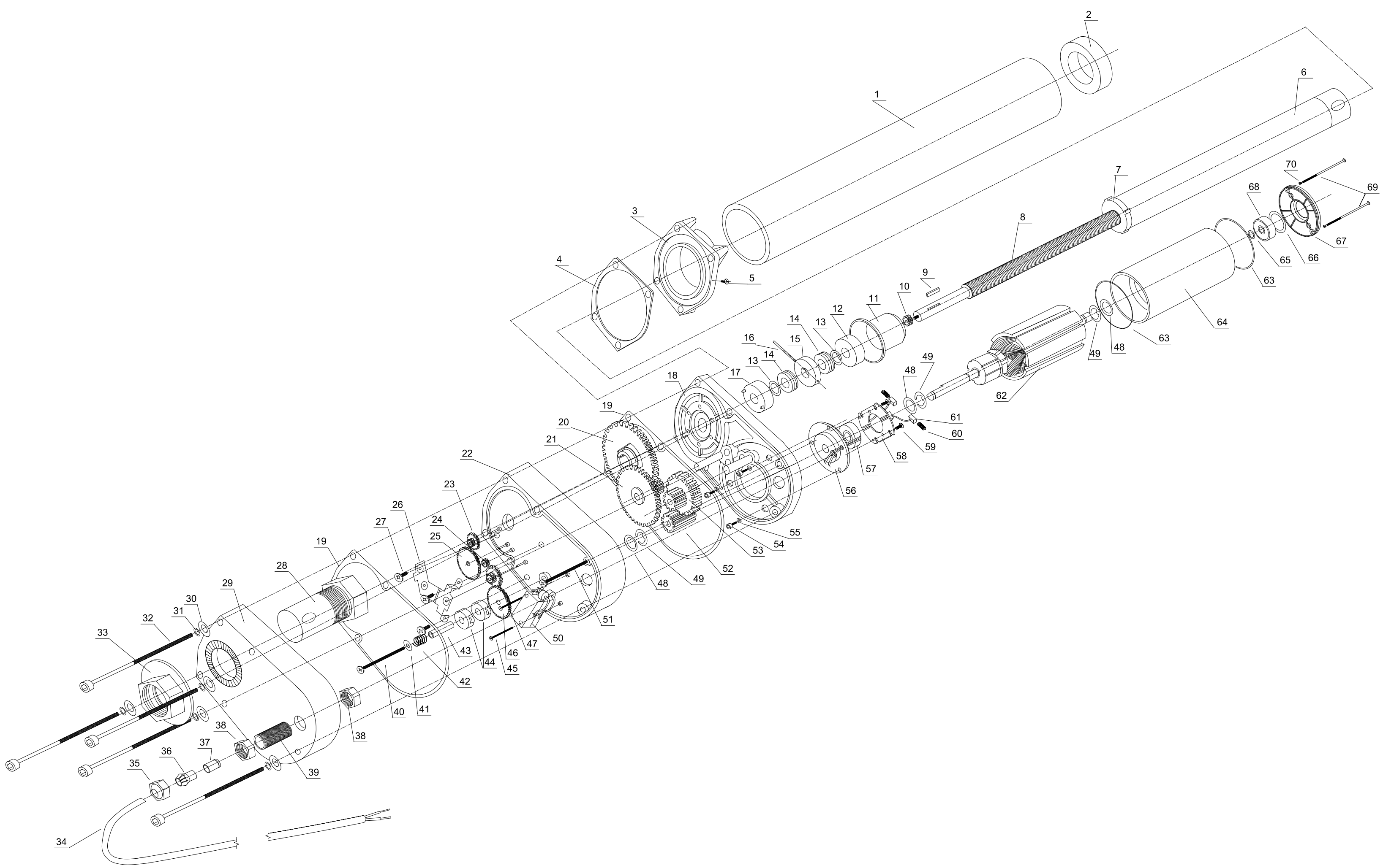
www.**progressive**automations.com

ACTUATOR INTERNALS



PA-17
LINEAR ACTUATOR

HOW TO ORDER
1.800.676.6123
sales@**progressive**automations.com
www.**progressive**automations.com

ACTUATOR ASSEMBLY EXPANDED VIEW PARTS DESCRIPTION

Item	Description	Qty
1	Actuator Case	1
2	Case Top Cap	1
3	Case Base Support	1
4	Case Base Gasket	1
5	Case Base Screw	1
6	Shaft With Mounting Hole	1
7	Shaft Guide	1
8	Treaded Shaft Drive	1
9	Shaft Gear Lock	1
10	Limit Switch Gear	1
11	Shaft Bearing Enclosure	1
12	Shaft Top Bearing Holder	1
13	Washer	2
14	Shaft Ball Bearing	2
15	Shaft Holder	1
16	Shaft Holder Lock	1
17	Shaft Bearing Bottom Support	1
18	Actuator Base	1
19	Actuator Base Gasket	2
20	Shaft Gear Wheel	1
21	Intermmediate Gear	1
22	Limit Switch Base	1
23	Limit Switch Gear 1	1
24	Limit Switch Gear 2	1
25	Limit Switch Gear 3	1
26	Limit Switch Gear Support	1
27	Limit Switch Gear Support Screw	3
28	Actuator Bottom Mount	1
29	Actuator Bottom Case	1
30	Actuator Base Screw Gasket	5
31	Actuator Base Screw O-Ring	5
32	Actuator Base Screw	5
33	Actuator Bottom Mount Nut	1
34	Power Cable	1
35	Power Cable Lock Screw	1

Item	Description	Qty
36	Power Cable Lock	1
37	Power Cable Sleeve	1
38	Power Cable Nut	2
39	Base Cable Sleeve	1
40	Limit Switch Trigger Screw	1
41	Limit Switch Trigger Washer	1
42	Limit Switch Trigger Spring	1
43	Limit Switch Trigger Support	1
44	Limit Switch Trigger	2
45	Limit Switch Screw	2
46	Llimit Switch Gear 5	1
47	Llimit Switch Gear 4	1
48	Motor Washer	3
49	Motor Locking Washer	3
50	Limit Switch	2
51	Base Holding Screw	1
52	Motor Gear	1
53	Motor Intermediate Gear	1
54	Motor Base Screw	3
55	Motor Base Screw Washer	3
56	Motor Bottom Cap	1
57	Motor Bottom Bearing	1
58	Brush Holder PCB	1
59	Brush Holder PCB Screw	2
60	Motor Brush Spring	2
61	Motor Brush	2
62	Electric Motor Rotor	1
63	Motor Case O-Ring	2
64	Motor Case and Stator	1
65	Motor O-Ring	1
66	Motor Top Spring Washer	1
67	Motor top Cap	1
68	Motor Top Bearing	1
69	Motor Case Screw	2
70	Motor Case Screw Washer	2

HOW TO ORDER
1.800.676.6123
sales@progressiveautomations.com
www.progressiveautomations.com

CUSTOM OPTIONS

- Voltage: 24/36/48
- Feedback: Potentiometer or Hall Effect Sensor (Potentiometer only available for Stroke Length up to 24")
- Wire length: Customizable
- Stroke Size: 1" – 40" in increments of 0.25"
- Mounting Holes: Customizable size and Dimensions
- Connectors: Add your specific connector
- Custom Dimensions: Change size and stroke of unit based on your requirement
- Customizable forces available: 450 lbs (speed 1.5"/sec), 1600 lbs (0.39"/sec)
- Mounting holes: Please ask for other mounting options

ADDITIONAL OPTIONS ARE ALWAYS BEING ADDED, PLEASE GIVE US A CALL IF YOU NEED A CUSTOM OPTION YOU DO NOT SEE HERE 1-800-676-6123.

3D MODEL (CLICK TO ACTIVATE)

Appendix 11

Parts List and Cost Breakdown

Appendix 11 Parts list and cost breakdown

Table 1. Stationary Mount Equipment & Cost Breakdown.

Part	Quantity	Material Cost
Wood Base Supports	2	$15
L-channels	2	$88
Connect Rod	2	$20
Bolts	10	$20
Nuts	10	$10
Washers	40	$10
Wood Screws	12	$5
Tax and Shipping		$42
Total		$210

Table 2. Tracking Mount Equipment and Cost Breakdown.

Part	Quantity	Material Cost
Base Plate	1	$30
Guide Pole	1	$0
Support Pole	1	$0
Connect Plate	1	$15
Slew Drive	1	$342
Slew Drive Motor	1	$150
Top Plate	1	$42
Bearings	4	$52
Bearing Shaft	1	$6
Actuator	1	$305
Actuator Brackets	2	$48
Actuator Connect Rod	1	$20
Actuator L-attachments	2	$15
Bearing Square Channels	2	$34
Cross Rods	2	$20
Panel Rods	2	$30
Bolts	52	$70
Nuts	36	$15
Washers	52	$15
Shop Tech Labor		$120
Tax and Shipping		$240
Total		$1569

Vendors

1. **McMaster Carr** (raw materials, nuts, bolts, washers)
2. **ACE Hardware** (nuts, bolts, washers)
3. **Home Depot** (wood, nuts, bolts, washers)
4. **Kinematics Manufacturing** (slew drive, slew drive motor)
5. **Progressive Automations** (actuator, actuator mounting bracket)