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Sunplanter

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ENTITLED

SUNPLANTER

BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
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6/9/2015

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SUNPLANTER

By

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SENIOR DESIGN PROJECT REPORT

Submitted to
the Department of Mechanical Engineering

of

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Abstract

Although the cost of solar technology has been reduced by nearly seventy percent in the last ten years, the cost of implementing solar panels for residential and commercial use has remained stagnant. Due to the lack of affordable, easily installable solar panel systems on residential properties, the goal of our Senior Design Project is to design a stand-alone solar tracking structure. Since the system is stand-alone, it can be easily implemented on a wide range of properties in most areas of California. Our design for the support of the solar tracking system is a two-pole structure, with a wide base under each pole to eliminate the need for a deep foundation. An electric gearmotor system will drive the rotational motion of the solar tracking function, due to its high power output and relatively affordable cost. A hydraulic damping and blocking system was incorporated to precisely control rotational motion. After testing the system for both tracking and static operation, an 11.4% increase power production was observed. Sunplanter solar tracking systems have the potential to provide a financially viable investment opportunity for customers while having a positive impact on the environment.

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1 Introduction

1.1 Background and Motivation

Solar panels are an efficient, renewable means of collecting energy. They have been at the forefront of innovation for the last couple decades due to the necessity to find new sources of energy. While the cost of solar panels has been steadily decreasing over the last several years, as shown in the figure below, the cost of implementing solar systems on both residential and commercial buildings has stayed relatively constant. The stagnation of installation costs is largely due to what are often referred to as "soft costs", which include taxes, fees, labor costs and company overheads. We determined that a new method for the implementation of solar panels that reduces these soft costs was necessary in order for solar energy to become more economically advantageous. Sunplanter, a company founded by Alain Poivet, is in the process of innovating the design for an auxiliary solar tracking installation, designed to create functional shaded space beneath the panels for both residential and commercial applications.

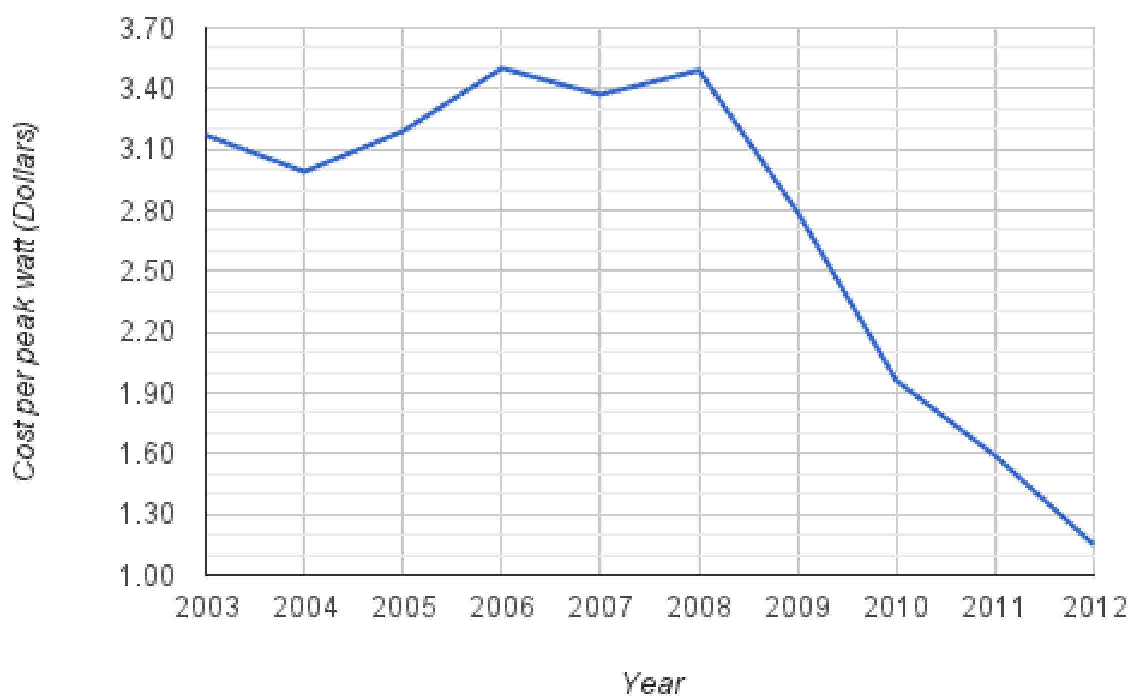


Figure 1.1: Average Price of Photovoltaic Modules (2003-2012)
Source: U.S. Environmental Information Administration [1]

Working alongside Mr. Poivet, our main objective was to design and build a functioning prototype of the Sunplanter solar-tracking photovoltaic system. The prototype consists of two fifteen square foot solar panels, mounted on top of a structure that tilts the panels over one rotational axis to the optimum angle for solar energy collection. In addition to the efficiency of solar energy collection, we worked to ensure the safety of our prototype given environmental conditions such as high-speed winds, earthquakes, and snow. In order to achieve the level of safety required by a system of this type, we used large structural supports and a hydraulic blocking system that will prevent unwanted tilting movement of the solar array. The final critical aspect of our project was redesigning the fabrication process so that the system can be produced, assembled and installed much faster than current industry standards. Decreases in production, assembly and installation times will help further reduce the final cost of the system to the consumer. Cost reduction should result in producing a broader market base and help solar energy become a more widespread and viable alternative energy source.

According to information from Sunrun [2] and Silicon Valley Power [3], the installed cost of residential photovoltaic systems is between \$5.00 and \$7.50 per Watt. This means that a 4 kilo-Watt system, a capacity equal to that of the proposed Sunplanter, would cost between \$20,000 and \$30,000. The full-scale Sunplanter system was designed with a consumer price point of \$18,000, putting it below the cost of existing static solar systems. The long-term objective of this project was to design a scalable auxiliary solar panel system which will stand entirely separate from the house. This system is designed to be easily installed in order to increase the potential for solar power as a major energy resource.

1.2 Review of Field and Literature

The closest products available on the market at this point only meet a few of the many needs of our project. The most similar products to ours that we were able to find are manufactured by Array Technologies Incorporated and All Earth Renewables. A comparison of the physical characteristics of these systems and the proposed Sunplanter system can be seen in Table 1.1 on page 3. Despite being the closest direct competitors, the systems found are more for open field installation and are not meant as an individual residential addition. They also do not provide the added utility of an outdoor canopy setting that our design does. Pricing for these similar solar systems currently on the market ranges from \$9,000 to \$12,000 while only producing approximately half of the energy generation in comparison to our system, and varies substantially based on geographical location. Including the price of a similarly sized backyard canopy, about \$3,000 to \$4,000, the economic utility of our solar tracking canopy system can be seen.

Table 1.1: Summary of major features of competing technologies

Features/Specifications	Array Tech. Inc. (DA Tracker) [4]	All Earth Renewables (All Sun Series 20) [5]	**SUNPLANTER (Proposed)**
Min. Height	3.25 ft.	2 ft.	7 ft.
Support Column Height	8 ft.	11 ft.	9.5 ft.
Tilt from Horizontal	5°to 60°	0°to 60°	±25°
Tracking Accuracy	±2°	Not Specified	±3°
Max Array (Panels)	16	20	16
Drive System	Gear Drive/ Linear Actuator	1/4 hp hydraulic power unit	Gear Drive
Tracking Axes	Dual Axis	Dual Axis	Single Axis
Maintenence Schedule	Once Yearly	Not Specified	Once Yearly

The main innovation of our senior project lies not in the solar panels and tracking system, but in the implementation of an easily installable and integrated residential solar system. In addition to reducing installation time, our system design provides an outdoor living space beneath the PV panels. By incorporating this functional feature in our design, an auxiliary solar system becomes more desirable to consumers. Unlike the other available solar tracking systems, customers will benefit from increased solar energy production, as well as the practicality of the additional covered outdoor area.

As the team began researching solutions, we noticed a few central issues. The problems could be broken down into the main categories of controls, structure, and economics. Using the Applied Science and Technology source from the Santa Clara Library, our team was able to find several articles that provided potential solutions to these limitations. The majority of the research focused on the problems involved in creating an appropriate controls system. The information has been condensed and tabulated in Table 1.2 on page 4.

Table 1.2: Key issues and useful information gathered regarding controls system

Key Issues	Sources	Information from Source
Tracking efficiency maximization	[6,7,8]	• Relationship between energy production and angle to the sun • Connections between drive system and controllers • Effectiveness of feedback loops
Using sensors for system feedback	[7]	• Effectiveness of Light Dependent Resistors (LDRs) as system feedback sensors • Pros and cons of using LDRs as primary aspect of tilt control
Algorithm programming	[6,7]	• Incorporation of feedback loops into an algorithm • Acceptable ranges of angle between sun and panel

The controls system is responsible for tracking the sun accurately and maximizing the net power output of the system. Before we began programming the system, we looked at several different solutions that had been previously attempted. Though the articles utilized different platforms and control techniques, they provided us with several insights into the process of solving this problem. The information gleaned from these sources provided us with a useful starting point. That being said, the research was by no means complete. As we developed our system, further research into the control of the individual subsystems, as well as how they will interact with each other, was required.

Our main concern in relation to the structure was how to design it in accordance with the building codes set by the state of California. In particular, we looked into the codes surrounding weather loads (e.g., wind putting torques on the vertical supports, snow piling onto the array and creating a bending or vertical force). With a system that has a large, flat, angled portion that moves, wind was the most difficult of these weather related issues to deal with. However, Shademan, Barron, Balachandar, and Hangan [9] provided us with safety information on the wind loads exerted on solar panels so that a safe solar tracking system could be created. Situations, such as roof and ground mounted panels creating different wind channels, were observed and simulated in this report. The simulation data also included different turbulences based on Reynolds and Navier-Stokes conditions. This information was useful with the design of the structure of our system and with design, building, and purchase of the drive and blocking systems. Once the structure had been fully designed, the team researched prices for the materials and companies to weld our parts together. OUtsourcing the welding activities was a necessary cost for the project since our team does does not have the capability to perform the types of strong welds necessary for our project. The cost and viability of several drive and blocking systems were also researched and compared.

The final problem that we worked to solve was an economic one. More specifically, how could we create this system so that it gives people an advantage economically over systems that are already on the market? Part of this problem was solved by virtue of the system being unique as a patio covering in addition to a solar tracker. Although customers will likely be willing to spend more for this added feature, we still aim to deliver a product that will be less expensive than installing solar panels on the existing home structure. Yilmaz, Saygin and Besnili [10] provided information on electricity production from solar panels as well as a cost analysis of photovoltaic modules. This information helped us develop more of an understanding of how to reduce certain costs within our system as well as develop a more realistic price point for our final system than the one we originally had.

1.3 Project Objectives and Goals

The main goals of our design project included, first and foremost, creating a drive and blocking system that was able to rotate the solar panels in a controlled manner in order to maximize the power output. Secondly, we strived to ensure the safe operation of the prototype that we created. We also aimed to design a system that can be prefabricated in order to streamline construction and installation as well as reduce total system cost.

Central to the success of the project was the ability to tilt the photovoltaic array, both positively and negatively twenty five degrees from its horizontal position, in order to maximize the energy collected from the sun. A solar tracking system was designed and created to track the optimal orientation of the solar panels through any given day. Our tracking system controls the drive and blocking subsystems, which moves the panels to the correct position and ensures they stay in place.

Initially, we also aimed to provide extra features in our prototype including wifi connectivity, a user friendly interface, and customizable user settings. Over the course of the project, however, these initial goals for the prototype were scrapped for several reasons. First was to save money for the project. A relatively small budget was decided on for the prototype, and adding these additional features held less value to the importance of the project than other features such as the hydraulic blocking system. Secondly, other more important systems of the design ended up requiring more attention than intially thought. Many weeks were spent testing and investigating different drive and blocking systems, many of which were either not strong enough, too expensive, orimpossible to implement. Since extra time was given to these all important aspects of the project, not enough time was left to add invital yet interesting, user-friendly features.

The safety goals of the design project were determined mainly by construction standards based on the location in which the system will be implemented. Such standards include increased loading due to wind, earthquakes, and precipitation. In addition to construction standards, when designing our system we took into account the minimum operating height, and maximum tilt speed.

In order for our design project to be considered successful, our team must create a system that can be easily constructed on site, and also within the desired time frame. The goal for construction and installation time for the full-size system is approximately eight to twelve hours. Thus the project can be completed in a single work day. The cost of the system is also essential to the success of the project because in order to be a desirable consumer product, it must make economic sense to implement the system.

We have worked collaboratively as a team to achieve these goals. In addition to creating a successful system, our team has furthered our abilities to work in coordination with others, and to share equally in both the work and success of our project.

2 System

2.1 Customer Needs

Instead of conducting interviews with potential customers, Alain Poivet [11], our industry project advisor, conveyed to us the exact needs and requests of two customers ready to buy the solar system we are in the process of designing. These customers wish to implement a solar installation on their property, however, it has been determined the roof mounted solar panels is not the optimum solution. Thus, they need to have the solar panels not attached to the house yet also not take up ground space on their property. In other words, they want the solar panels to act as an awning, under which they can safely have activities. They also need the system to be reasonably affordable (at least comparable to roofing systems). The system must be designed in such a way that it needs as little maintenance as possible, to make the product more marketable. The customers also want it to be user friendly and customizable. This would allow the user to override the normal solar tracking aspect of the system to create an individually tailored outdoor setting. Lastly the customer asked for the system to be designed so that it could accommodate for desired accessories such as a grill, picnic table, or lights and speakers . A breakdown of the importance of each need conveyed to us was tabulated and can be seen in Appendix B.

After researching other solar tracking PV systems that are currently on the market, we observed there are few options available. There are two main aspects of PV panel systems upon which we plan to improve for our design project. We plan to reduce the installation time and costs by making a system that is both easily fabricated and can be installed in a single day. Additionally we will design for a living area that will be, not only shaded by the solar panels, but weatherproof, allowing protection from precipitation as well. This will add value to the home of our customers not only because the system will collect and store solar energy, but it will also increase the functionality of the outdoor area.

During our weekly meetings with Mr. Poivet, we discussed specific customer desires such as the dimensions of the system, configurations of the photovoltaic array due to unique landscape requirements, and the desire for personal customization for user settings. One customer is mainly concerned with the logistics of implementing the system, such as the energy generated, the safety of the rotating panels, and the specifics of the motor incorporated within the driving system. This feedback indicated that the potential customers are informed and interested in knowing the technical aspects of the project.

The second customer was primarily interested in the living space aspects of the system, such as the lighting, speakers, and temperature control. They were also attracted to a system that would recognize the user and cater to their personal preferences for the system. To do this, the system would recognize the user and adjust to their settings for panel tilt, temperature, lighting, and possibly even music. Features such as these are unlikely to be included in our prototype, however it is informative to learn about the specific wants of certain customers, so that we are able to include space to incorporate recreational features such as these within our design. After the customer needs were thoroughly considered by our design team, they were organized by section with specific aspects being quantified by their importance to the project and the customers.

After conducting customer research, our goals were to prioritize those needs which we have deemed most important, as can be seen in Appendix B. Specifically, that means focusing on designing the system so that it can track the sun, be cost efficient, and be safe. These are the most important because if these needs are not met, then the project can be deemed a failure and not usable. They are the minimum benchmark which is needed to be passed by this project. Once the design is finalized and safety is no longer in question, then adding on features which make the system more customer friendly can be considered. These include making it aesthetically pleasing, reducing installation time, and rendering the system quiet. These enhance the experience and are important for making the system more marketable. Finally, if all or most of those needs have been met, our group may want to explore adding on features to the system which allow the user to customize certain aspects. For example, being the addition of accessories, or designing the system to remember certain settings that any user can implement easily. The addition of these custom features adds more value as a consumer product and further separates Sunplanter from existing systems.

2.2 System Sketch

Figure 2.1: Artistic representation of system implementation
Drawing done by Stephen Hight

The product was designed to be used by residents of housing in most parts of California. Some of the customer needs that we have decided to adress in our prototype solar tracker system are specific for those customers which have already been interviewed. However, most of their needs and desires were fairly universal, displaying viewpoints with different priorities of efficiency and functionality. The goal was to make the design such that as large a group of people as possible would want and be able to buy and use the product. This means meeting as many generic needs as possible. For example, the system must be quiet and look nice, be able to withstand high wind loads, be installed in a timely manner, and track the sun efficiently. We feel that with at least these minimum system requirements met, a large group of people would be willing to buy or try the Sunplanter backyard canopy system.

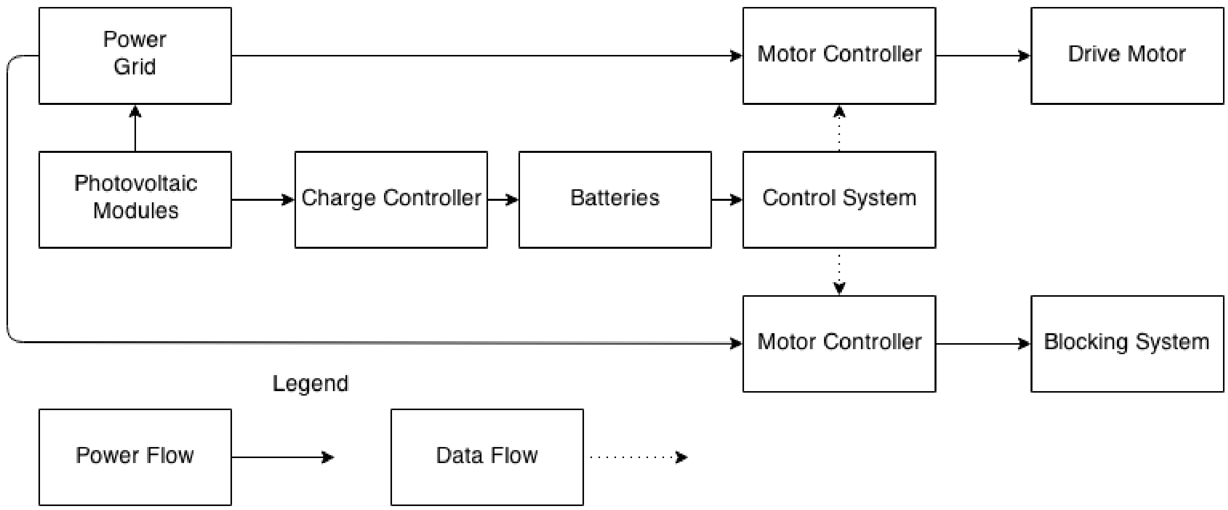


Figure 2.2: Simple block diagram indicating data and power paths through the system

As shown in the figure above, the system will create electricity to be pushed to the grid and will pull electricity from the grid as well. Since the motors and their associated controllers will require larger amounts of power, having them receive electricity from the grid, will reduce the need for a battery system to be incorporated. Though this aspect is not evident from the figure, the batteries will be a fail-safe measure to ensure that even if power from the grid is interrupted, the system will still be able to remain in a fully locked position.

As the solar tracker's main function is to track the sun and thereby produce as much electrical energy as possible, most of its use will be automated. The idea is that the user has to provide little to no input for the system to perform its main function. However, there will be functions which will allow the user to control certain aspects of the system. Any functions that the customers will need the system to perform will be available for programming into the system via some app-based user interface. It will make changing the angle of the system easy for any user, and possibly give the user the ability to control extra functions of the system, such as lights or music, that may be connected to the main system.

2.3 Functional Analysis

The main function of the product is to be a solar-tracking, photovoltaic structure that acts not only as an energy supplier but also as an energy efficient backyard accessory. The solar panels take in the sun's radiation, creating electricity that can be accessed by the structure and its accessories. These accessories are to be selected by the user and could possibly include lighting, heating elements, or speakers. It also functions as a patio roof, providing an area of shade while the panels absorb the sunlight. The structure will have an easy-to-use, customizable user interface. Depending on the amount of sun the solar panels receive, the ultimate goal is for the photovoltaic structure to be energy positive, creating more energy than it needs to power itself. This excess energy will be put to use for the house, reducing the amount of grid energy that the entire house uses.

Table 2.1: Itemization and description of system inputs

Inputs	**Description**
Sunlight	The energy source that powers the system
Data from Weather Stations/websites	In order to track the sun and provide adequate and reliable safety measures, information from weather sites or stations will be used to know where the sun will be throughout the day.
User Inputs	Any customizable option for the user, such as temperature setting, light setting, music, etc.

Table 2.2: Itemization and description of system outputs

Outputs	**Description**
Power	From the sunlight, the solar panels turn the sun's power into electrical power.
Data Display for Users	A display on the structure or via a mobile app with basic information, including the time, temperature, forecast, and other customizable options. Also current energy production, potential energy production, and total energy produced will be displayed.
Accessories	Any additional option available to the user, possibly lights, speakers, heating and cooling devices, TVs, electrical BBQ, etc.

As shown in the tables above, there is room for end user customization in both the inputs and outputs of the system. This gives the system as a whole more value to the end consumers, allowing them to make the system their own and to have it operate in whatever way they see fit.

2.4 Subsystems

2.4.1 Structure

The main structural component of the system will be the two vertically oriented poles which will provide support and a rotational axis for the solar tracking array at the midpoint of its shorter side. A two pole system was chosen over other potential structural configurations for both the aesthetic and functional benefit of the open space that it allows beneath the solar array. The columns must be a maximum of 9.5 feet tall in order to stay within the 12 foot maximum height limit for a patio cover, set by section AH102 of the California residential building codes [12]. 6061-T6 aluminum was chosen as the material for most of the structure because of its strength in withstanding all necessary loading conditions, low cost, natural weather resistance, and lightweight body.

2.4.2 Drive

The drive system chosen for our structure is a combination of an electric motor with a planetary gearbox. To come to this conclusion, the team created a concept scoring chart. This chart allows for the impartial weighing of every design concept available and, using a points system, ranks each idea in terms of how well it holds up to the criteria we specify. The team looked into several different options for the power behind the drive system such as linear actuators, hydraulic motors, stepper motors, and continuous electric motors. Several ideas were also weighed involving ways to reduce the torque and speed for some of the drive ideas. For example, a standard gear system, worm gears, or a planetary gearbox.

The criteria that we used to determine the usefulness of each idea included cost, weight, size, power, ease of implementation, and system maintenance. Each criterion was weighted differently, depending on its significance to the successful outcome of the project. Our objective is to have a relatively low-maintenance system. This will make it more desirable to the consumer and will assist in keeping the total lifetime cost low. As such, cost and maintenance ranked at the top of our list. Furthermore, one of the main selling points for our project is that it is easier to implement on residential properties than standard rooftop photovoltaic installations. Power is slightly less important than implementation, since any drive we use should at least have the power necessary to rotate the system. Lastly, weight and size were originally considered for potential effects on aesthetics and the overall ease of use of the system. Although these two specifications ended up being deemed least important, they were kept in the decision making process. By inputting these criteria into a concept scoring spreadsheet we systematically concluded that using an electric motor with a planetary gearbox was the best option. Detailed decision matrices can be seen in Appendix G.

2.4.3 Blocking

Blocking allows the system to operate safely by keeping the rotation contained to a specified range. In order to make sure the panels can rotate and operate safely in all conditions, we created a list of essential characteristics for the blocking system. The design of blocking and damping aspect of our structure took several iterations. Some of the ideas for types of blocking that were considered included a shifting pin design and ratchet and pawl systems. Unfortunately, of the required traits listed, both of these were unable to dampen rotation and were ultimately not cost effective. Another idea that was considered was a torsion bar. Although this was a much more cost effective solution, it did not provide a hard stop at full rotation and therefore would need to be supplemented.

The blocking that we finally incorporated into our system is a passive, dual piston hydraulic system. The system is passive in that it relies on the motor rotating the panels to push the fluid through the pistons. By using a passive system, we can ensure that it is stopped by blocking the fluid motion which is done with manually actuated solenoid valves. As a safety precaution, the valves will be in the off or closed position when the motor is not operating to guarantee that the system remains blocked. While the valves are open and the panels are in rotational motion, the hydraulic fluid acts as a damper, keeping motion slow and eliminating effects from outside factors such as wind.

2.4.4 Controls

The controls system that was to be created for our system was an open-loop design which rotates the solar panels based only on the time of day. We predicted that after designing the physical system there would only be enough time to code a simple system; however, due to some setbacks during the design and fabrication processes, we were forced to focus on the stability of the structure, drive, and blocking systems rather than writing the code for the contols. For the purpose of our tests, we simulated the controls by manually rotating the solar panels to follow the sun.

2.5 Team and Project Management

In order for our project to be successful, each person was given specific tasks in project management and individual tasks for project completion. The team is comprised of four members, Stephen Hight, team leader and controls system manager; Matt Diaz, organizer and blocking system manager; Joe Gaither, annotator and drive system manager; and Brandon Suehiro, team facilitator and structural manager. In order to design for this project, we divided into four main subsystems and designed each individually. The subsystem managers, as listed above, conducted research into their respective areas and gathered ideas, both on their own and from the entire group. From those ideas, the subsystem managers made decisions based on plausibility, cost, safety concerns and effectiveness of the solution in solving the given problem. The main consideration when making most decisions was looking at the overall cost of each individual subsystem due to the fact that it is being designed primarily as a cost-effective replacement to current consumer available options.

The budget for our prototype is just under $3,500, mostly comprised of hardware for the drive, blocking and structural components. It makes sense that these subsets would carry the bulk of the budget as they are the ones that are most closely related to the safety of our prototype. To begin with, we were able to acquire solar panels for use in our prototype from past Solar Decathlon competitions that Santa Clara University has participated in. We were also able to acquire Tigo Maximizer and Management units, which enabled the collection of data from the solar panels. The last donation to the project was the welding for the entire system, provided by Alan Owens and his team at Versaco Manufacturing Inc. Other than those services, all materials were purchased by the team using money granted by the Santa Clara University School of Engineering. A table of items, a detailed budget and funding sources can be seen in Appendix E.

The timeline for the Sunplanter project was based around the structured timeline for the general senior design process. In designing our timeline, we began with the endpoint of the senior design conference and worked our way backwards from that. We acquired much of our hardware and began assembly early in Winter 2015. The team expected to be done a month ahead of the design conference, giving us ample time to test, gather data and troubleshoot. Although that was not accomplished, we were able to learn from our setbacks and still build the system in time to gain valuable data and information. Our full initial schedule in the form of a Gantt chart is shown in Appendix F.

3 Structure

3.1 Introduction

The structure of the prototype system is a two vertical pole design which creates a shaded, functional space underneath. 6061-T6 aluminum was chosen as the main structural material because of its high strength to weight ratio, ability to resist corrosion, availability as a common stock material, and good machining and welding characteristics. We used aluminum for almost everything possible to minimize any problems that may arise from galvanic corrosion. The only items in the structure which were not made of aluminum were the pillow blocks, dollies, nuts and bolts. However, these parts do not create any risk of galvanic corrosion due to the contacting materials being plastic, wood or zinc-plated. The design of our system is divided into three major subsystems: the base support, vertical support, and the rotational axis assembly.

3.2 Options and Trade-offs

The most significant difference between the prototype and a full sized Sunplanter solar tracking system is the way in which it is mounted upon wooden dollies for mobility. A full sized Sunplanter system will have a foundation comprised of several feet of rebar reinforced concrete beneath ground level where the system is installed.

Several structures were considered at the beginning of the design process, including using a four pole support system instead of two. Although the four pole system would increase the stability of the system, and also allow for the use of linear actuators as a drive system, a two pole system was chosen to increase the functionality of the shaded space underneath as well as decrease material costs and overall system weight. The two pole design was also determined to be more aesthetically pleasing than the four pole design, which looked too square.

3.3 Design Description

The base support includes the aluminum sleeve and plate which hold the rest of the system up as well as the dollies which are used to make our prototype mobile. The sleeve and plate assembly allow for easy and efficient assembly and disassembly of our prototype; the vertical supports slip into and out of the aluminum sleeve smoothly. The vertical supports are two, 4 foot tubes with mounting plates on top. Although both supports are the same height, each one is slightly different; one support has a larger mounting plate than the other to account for the motor which is placed only on one side of the system. Both supports, however, are machined to hold a pillow block which holds and rotates the rotational axis assembly.

Figure 3.1: Photograph of completed structure on mobile foundation

The rotational axis assembly has four components: the rails, the racking flanges, a 6 foot horizontal tube, and two solid shafts. The horizontal tube is the main member; it acts as the axis of rotation and connects to the solid shafts and the racking supports. The three racking flanges are welded to the top of the tube and act as a flat surface to connect the rails to. The rails are rectangular tubes which are used for support and connect the rest of the system to the solar panels. The solid shafts are bolted into the tube, and are machined to fit into the pillow blocks and motor.

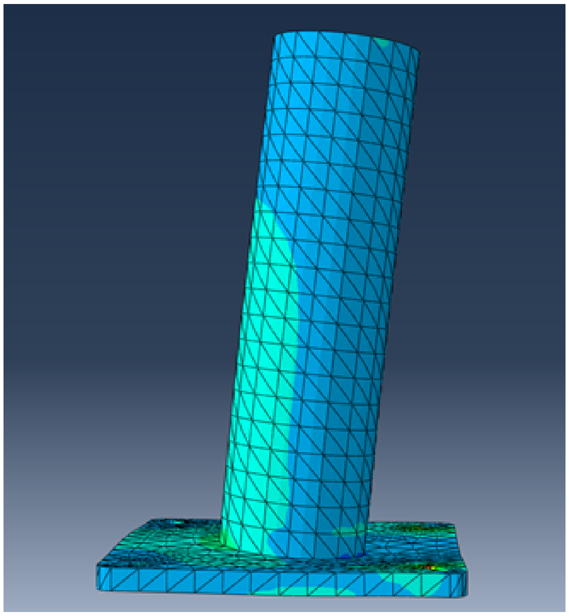
3.4 Approach and Results of Analysis

Following codes and regulations for California was one of the key elements to the success of this project; before we could begin to correctly size the elements of the structure, we first had to determine the types and magnitudes of the loads which would need to be accounted for. The codes that we followed are outlined in *ASCE: Minimum Design Loads for Buildings and Other Structures*

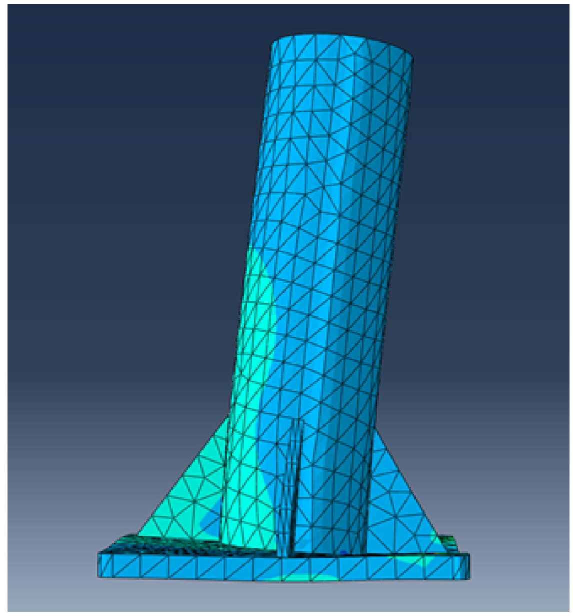
[13]. Within the codes, we focused on earthquake, wind and precipitation loads for open structures with a slanted roof. Because the panels are often slanted, under high wind loads, they act as a sail and create very large torques around the base and rotational axis of the system. Additionally, we needed to design the structure to withstand the fastest wind loads expected in California, 115 mph, which causes a load of 15 pounds per square foot on the solar panels. We were advised to prioritize designing the structure to handle these wind loads rather than the earthquake or precipitation loads since those loads are easier to design for.

It was determined that the greatest loads on the structure under expected loading conditions would occur at the base, specifically at the base support. This is because the system's center of gravity is very high, due to almost all of the weight being near the solar panels. This extra weight on top along with the wind load on the solar panels would create a torque around the base supports which would cause the most dangerous stresses in the structure. During the design of the base supports, we utilized finite element analysis (FEA) techniques to determine if our original specifications would perform structurally as we expected them to. When designing this subsystem we wanted to ensure that it could not only withstand the loads which were laid out in the ASCE codes, but also that under these loads it would bend as little as possible. If the top of the base were to bend even a little bit, the solar panels on top of the structure would create a bending moment about the base causing further loading which we are not accounting for in our design.

In our original design, seen on the left, we relied on a single weld connecting the sleeve to the foundation plate to provide enough strength to hold the vertical supports under all loading conditions. Through our analysis we found that this design was not strong enough for our standards. One of our goals for the structure was to achieve at least a factor of safety of 2 for the whole system, and the initial design barely withstood the load itself. The maximum stress found in the initial design was around 34,600 psi which translated to a factor of safety of only 1.3 since the ultimate tensile stress of 6061-T6 Aluminum is 45,000 psi. The largest stresses were found around the weld between the sleeve and the plate, meaning more support was needed in order to reduce these stresses.



(a) Original design



(b) Updated design

Figure 3.2: FEA showing foundation sleeve stress concentrations and deformations

In order to reduce the stresses and deformations, four gussets were added at even increments around the sleeve as seen in the picture on the right. This greatly reduced the stresses in the assembly, helping us achieve stresses of at most 20,260 psi and the factor of safety of greater than 2 which we had aimed for. In fact, although the model is a bit exaggerated, our new design should only move about .01 inches under the largest load conditions.

3.5 Test/Verification Data

In order to physically verify the strength of our structure, we were able to simulate certain loading conditions with the use of strategically placed weights. We wanted to test the effects of high torque conditions on the horizontal rotational axis, which in reality would be caused by high speed wind gust on the solar panels. In order to obtain similar results, weights of 170 lbs and 140 lbs were placed on opposite ends of the rails carrying the solar panels. Although the force caused by 115 mph winds could be simplified as a 225 lb point load, that load theoretically acts half the distance to the edge of the solar panels. By using a smaller force but extending the moment arm, a similar torque to the one caused by the wind was simulated. In fact, the torque caused by the weights in our test both exceed the theoretical torque caused by the wind load due to their distance from the rotational axis. These weights, both acting as downward forces, create torques around the rotational axis in opposing directions. This, in theory, puts large amounts of stress on the rails and, if not properly designed, will cause the rails to bend and potentially damage the solar panels to the point where they no longer produce power. The tests showed little to no bending anywhere in the system; therefore the solar panels received no bending stress and were safe from damage.

4 Drive

4.1 Introduction

A DC electric gearmotor was chosen to act as the drive for slow rotational motion of the solar panels. The motor was purchased as a stock part from Bison Gear and Engineering Corp. It was chosen because of its ability to have a sufficient amount of torque to rotate the system while the incorporated gear system allowed for a substantial speed reduction over non-geared motors. Choosing a DC electric gearmotor provided the most cost effective solution to the torque and RPM requirements for safe and successful rotation of the system. Unfortunately due to time and budget constraints the motor was not used in the process of data collection. In order to run the DC motor off of the battery used in the system a boost converter would have been required to increase the voltage from 12 volts coming from the battery to 90 volts required to operate the motor.

4.2 Options and Trade-offs

During the design process, one of the first options discussed for a drive system was a linear actuator. Although a linear actuator would have been a simple solution for accurate and smooth rotation of the system, minimum height requirements and support structure type did not allow for sufficient space for a linear actuator to be used. Another option discussed during the design process was the use of a gravity drive to rotate the system. The gravity drive would have worked by using a weight that would slide along a track to twist a torsion bar upon which the solar panels would be mounted to the optimum angle. This option was not realistic because of both the magnitude of rotation the torsion bar would be required to undergo, and the minimum 200kg mass required to twist the torsion bar.

4.3 Design Description

The motor purchased for use in the prototype system is a Bison 175 series PMDC 90V/130V DC parallel shaft gearmotor. its dimensions are 8.25 inches long, 3.75 inches wide, and 4.5 inches tall, weighing 9 pounds. The gear reduction is 1369.3:1, the torque is 160 in-lbs, and it runs at 1.3 RPM. The motor is mounted on top of the aluminum plate welded to the vertical support. A coupling is used to connect the motor to the machined aluminum connection shaft, which is in turn bolted inside of the horizontal rotational bar.

Figure 4.1: 175 Series Bison Parallel Shaft DC Gearmotor
Source: Bison Gear and Engineering [14]

4.4 Approach and Results of Analysis

When initially designing the drive system, a torsion bar was being heavily considered by our industrial adviser, Mr. Poivet. In order to see if a torsion bar would be a feasible system before going to prototyping, several MatLab codes were written. The torsion bar code is outlined in Section 4.5 and is included in its entirety in Section C.1 of Appendix C. Due to the results of the code showing that a torsion bar for the prototype system would require a shifting weight of at least 200kg, we were easily able to dismiss it for our uses. A main concern for the prototype of this system was mobility and ease of installation, by including this large weight, we would greatly decrease the system's ability to meet these requirements.

4.5 Code Description

For torsion bars to function properly, they must be able to withstand the shear stresses caused by torsional loading. A torsion bar's ability to endure these loads is dependent on the length, inner and outer diameters and the material chosen. The MatLab code written to solve the torsion bar issue made use of the fact that there are these 4 main variables. The user is prompted to choose a material from a set list. From the choice made, appropriate material properties are then used to analyze the performance of the torsion bar. The maximum stress in the torsion bar was calculated based on a predetermined loading condition. By comparing this maximum stress multiplied by a safety factor of 2 to the yield strength of the material chosen, we could determine if the bar would operate safely. If the bar fit this criteria, it was added to a matrix of potential solutions. For the prototype, the matrix was empty for most materials and required unwieldy masses to move the acceptable options.

5 Blocking

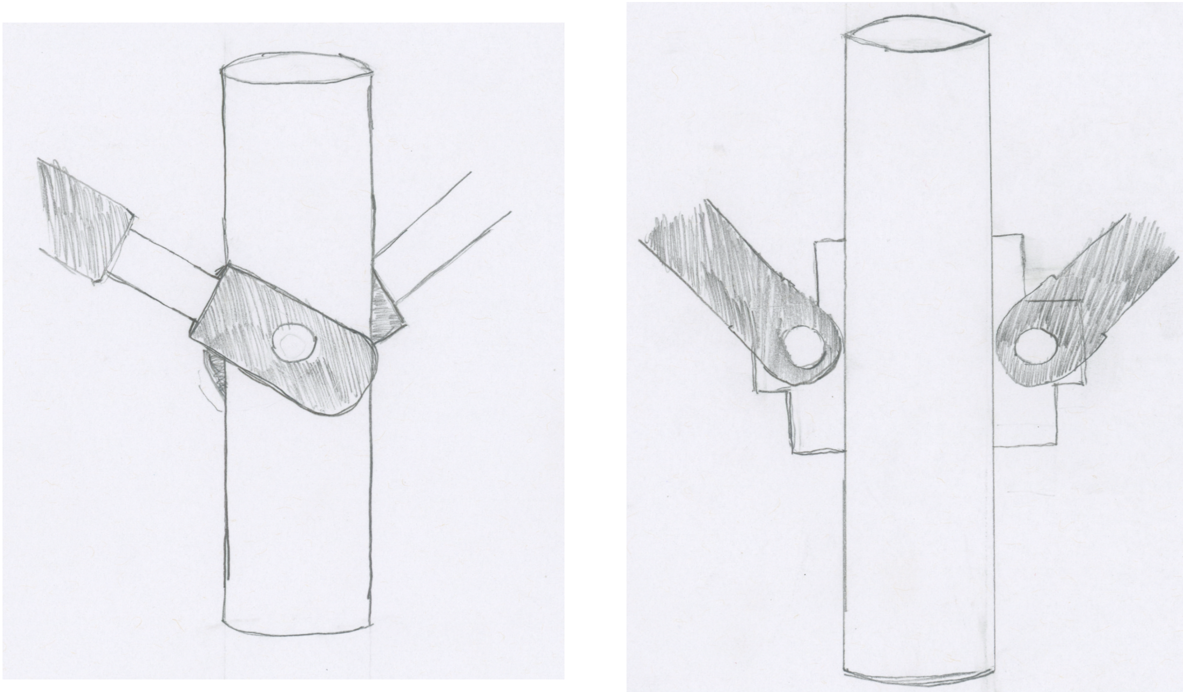
5.1 Introduction

A blocking system is required to ensure that the rotational motion of the solar panels is safe. If a strong gust of wind, or other environmental loads were to hit the panels, fail-safes must be in place to block the unwanted motion. In addition to improving the safety of the system, the blocking system also provides damping to make the rotation a more controlled motion. Two hydraulic pistons were chosen to act as the blocking system. They are attached using pinned connections with one end connected to the vertical support pole and the other to the flange that connects the racking rails and the horizontal bar.

5.2 Options and Trade-offs

Some options that were considered in the blocking system included a dual shifting pin system and a ratchet and pawl system. Both systems relied on physical stops that utilized the strength of materials to create hard stops of motion. In either case, there would be intermediate steps during rotation of the panels which would allow for sudden jerky motion from gusts of wind or other environmental factors. In addition, the shifting pin and ratchet systems would be extremely expensive, costing at least double any other system that was considered. Another option that was examined was the use of a rotational torsion bar. Although this created a more cost effective solution, it did not provide a hard stop at full rotation and therefore would need to be supplemented. For all of these reasons, we opted for the hydraulic blocking and motion damping system.

When choosing the appropriate hydraulics, we initially decided that both hydraulics would be mounted to the vertical support by way of a single pin. This pin would keep the clevis holes concentric and would allow for full rotation to ± 25 degrees from horizontal. After ordering and receiving the hydraulics, a design change was made to preserve structural integrity.



(a) Original design

(b) Updated design

Figure 5.1: Artistic representation of hydraulic pin connection designs
Drawing done by Brandon Suehiro

This change moved the hydraulics to be mounted with individual pinned connections. Due to the clevis pin locations changing between the initial design and sizing and the final implementation, we were only able to achieve an angle of ± 17 degrees from horizontal.

5.3 Design Description

The blocking that we incorporated into our system is a passive, dual piston hydraulic system. The system is passive in that it relies on the motor rotating the panels to push the fluid through the pistons. By using a passive system, we can ensure that it is stopped by blocking the fluid motion which, for the prototype version, was done with manually actuated valves. While the valves are open and the panels are in rotational motion, the hydraulic fluid acts as a damper, keeping motion slow and eliminating effects from outside factors such as wind. While the panels do not need to be rotated, the valves will remain in the closed position to stop fluid flow through the hydraulics and thus stop rotation.

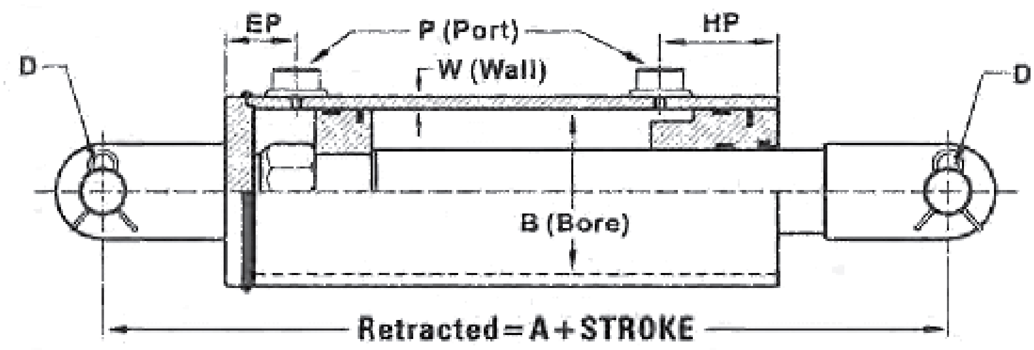


Figure 5.2: 2 Inch Bore, 6 Inch Stroke Welded Hydraulic Cylinder
Source: International Hydraulics US [15]

Due to the design change discussed earlier which altered the placement of the hydraulics, we needed to find the optimal placement for mounting holes in order for tilt to be maximized. In order to do this, we wrote a MatLab code which is outlined in Section 5.4 and is included in its entirety in Section C.2 of Appendix C.

5.4 Code Description

In order to locate where the clevis pin supports would be, we needed to find the combination of vertical and horizontal placements that would maximize the angle that the solar panels could achieve. In order to accomplish this, the vertical and horizontal distances from the clevis pins to the axis of rotation were varied. In addition, the angle of tilt was varied in order to find the maximum achievable value.

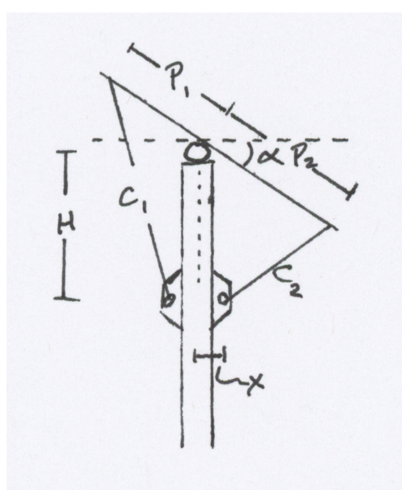


Figure 5.3: Simplified physical representation of MatLab code setup

For each configuration, we solved for the hydraulic cylinder length needed to attain the tilt angle. If the cylinder length needed was either larger than the maximum length or smaller than the minimum length of the cylinders that we had, the solution was discarded. Otherwise, the values of horizontal and vertical positions, angle, minimum cylinder length and maximum cylinder length were added to a matrix. From the viable solution matrix, we were able to find the vertical and horizontal positions for the clevis pin based on maximum angle.

6 Controls

6.1 Introduction

Our goal for the controls system for our prototype was an open-loop system. The program would be simple, rotating the solar panels based only on the time of day. This simple design would not be nearly as accurate as another type of controls program such as a closed-loop system;however, it was determined early in the design process that by using data and research from reputable sources, the system should have approximately been able to track the sun throughout the day. We decided that the most important breakthroughs for our project would be the structure, drive, and blocking system, and making sure that all those were up to our design standards took priority over the controls. Thus, due to time constraints, we were unable to code and test a usable controls system program. However, by manually rotating the panels every 15 minutes, we were able to simulate the same motion which we had planned on having our prototype perform.

6.2 Options and Trade-offs

Our initial design of the controls was to implement a closed-loop system in order to maintain a higher tracking accuracy. This implies some sort of feedback to the controller indicating the effectiveness of the system at that particular point in time. Possible ways to create this feedback would have been the use of LDRs, as mentioned in the literature review, or the utilization of micro-inverters to get information on individual panel production. An additional benefit in using micro-inverters would have been a reduction of the effect that shade, debris or even module failure could have on the entire system. Furthermore, data from the micro-inverters could have been used to alert consumers of maintenance that may have been needed on the system. Due to the scope of the project prototype, this type of closed-loop controls system was not manageable for our team; however, this could easily be implemented on the full-scale system by Sunplanter.

6.3 Design Description

The planned control system for our prototype was an Arduino based, open-loop system, which would have allowed us to easily program the system to perform what we needed it to. The control board would access two different subsystems: the driving motor and the hydraulic piston assembly.

Its function for the motor was fairly simple; it would turn on the motor for very brief periods of time to rotate the solar panels at 15 minute intervals only when necessary. As for the hydraulic piston assembly, it would simply open the solenoid valves just before turning on the motor to allow rotation of the panels, and close the valves just after the motor had ceased.

(a) 12:00 PM (b) 12:30 PM (c) 1:00 PM

Figure 6.1: Photographs of tracking progression throughout the day

The pictures above show the significant rotation of the solar panels around mid-day. These were taken during our testing phase, so the system was rotated manually in 15 minute increments when necessary. We determined the angle of the solar panels relative to the sun based on the shadows created by certain parts of the structure. Although slightly primitive, we believe this method still brought about a high level of accuracy for our data collection.

7 System Integration and Testing

7.1 Electrical Connections

Before we began testing, we first needed to gain an understanding of how the electrical circuit would connect for our prototype. We determined each component necessary to operate our system manually for testing and prepared the appropriate wires and equipment to properly connect them to each other. All the electrical components for our prototype were the MightyMax 12V rechargeable sealed lead-acid battery, the Tigo maximizer, gateway, and Maximizer Management Unit (MMU), Tristar charge controller, the 2 solar panels, and 6 50W light bulbs. The light bulbs were used to drain the battery, preventing it from becoming fully charged thus stopping the flow of power from the solar panels. An in depth look at the circuit and how the charge controller was connected can be seen below.

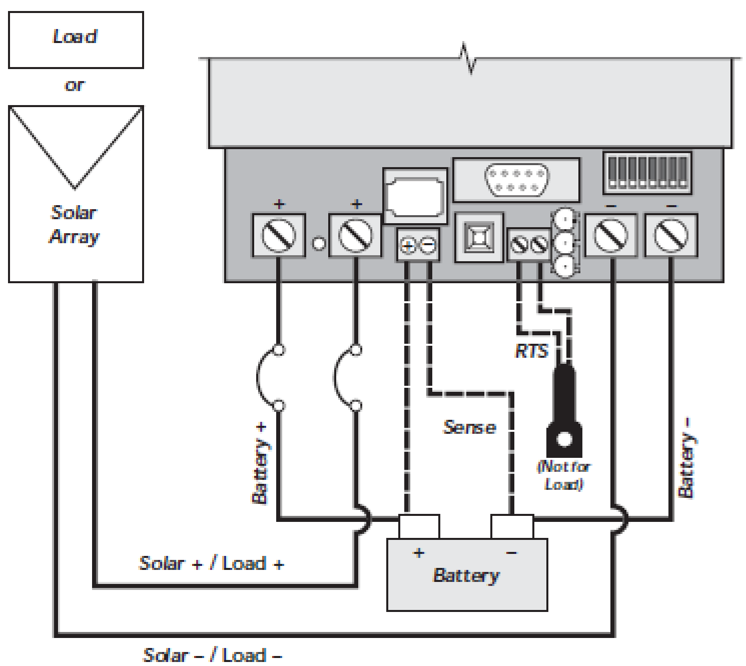


Figure 7.1: Wiring schematic for MorningStar TriStar TS-45 charge controller
Source: *TriStar Solar System Controller Installation and Operation Manual* [16]

Not pictured in the figure above is the Tigo Maximizer Unit, which replaces the solar panels in the figure. Both solar panels are connected to the Tigo Maximizer, which has positive and negative leads that connect to the the charge controller. The Tigo Maximizer Unit communicates wirelessly to the gateway unit which is connected to the MMU; the gateway and MMU provide us with the data from the solar panels which help us determine the usefulness of our system. The power from the PV units and the Tigo Maximizer then flows through the charge controller into the battery through both a positive and negative lead. The figure above is from the charge controller manual, and includes several connections which are optional or unnecessary; namely the sense wires from the battery to the charge controller and an Remote Temperature Sensor (RTS) connection. We chose not to include these extra features in our prototype, as they did not provide very significant benefits for our data collection.

The TriStar charge controller uses pulse width modulation (PWM) as a means of charging the battery. By incorporating PWM, the charge controller is able to provide an average voltage from the solar panels to the battery. PWM accomplishes this by quickly and repetitively alternating between allowing and not allowing power. PWM is a safe and effective way of charging because it avoids overheating and gassing of the battery by reducing the current of the charge when necessary. Even though the current may be reduced as charging occurs, it still puts out the maximum amount of energy in the shortest amount of time, making the process very efficient. It also extends battery life because it is able to charge the battery at a constant voltage without overcharging. For the same reasons, the battery being able to keep 90% to 95% of its total capacity.

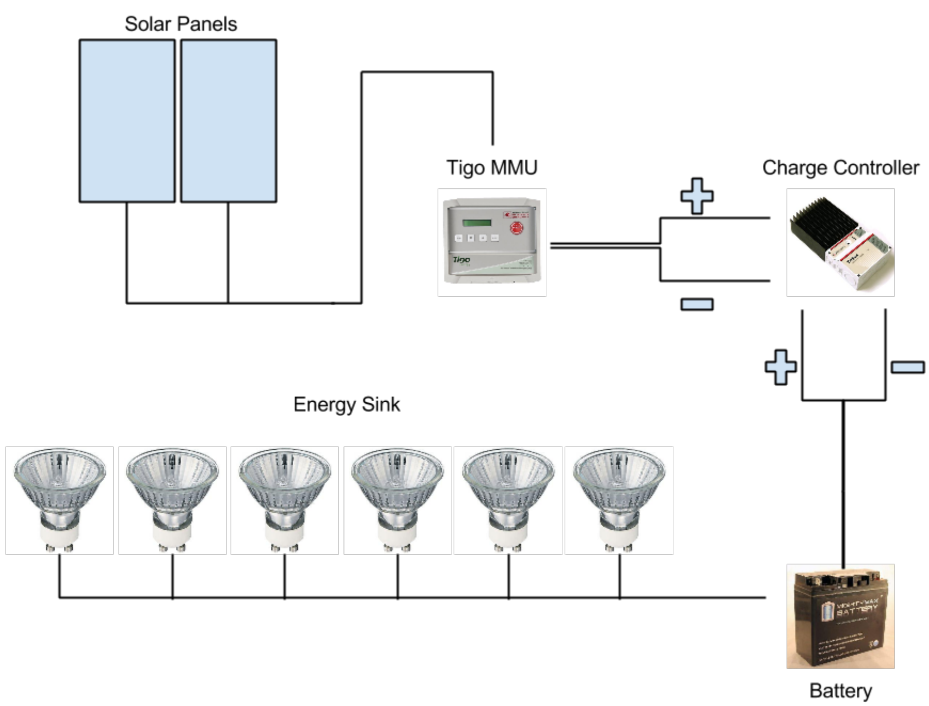


Figure 7.2: Basic wiring diagram of system circuit

The figure above shows a more general wiring diagram, showing each specific wired component. As seen in the figure, all six 50W light bulbs are connected in parallel, sharing a single node with the battery. This allowed for the optimal amount of power to be dissipated. Since they are all in parallel, they all share the same voltage, 12V, from the battery; additionally, they each draw slightly more than 4A of current from the battery, or 25A in total. This means that 300W of power is being drawn from the battery, which should drain it in about 45 minutes if not being charged by the solar panels.

7.2 Safety Precautions

In order to test the system in a safe and efficient way, there were several important safety precautions taken before, during, and after testing. Before testing, the battery, charge controller and Tigo equipment had to be secured to the system. The Tigo maximizer and gateway were mounted on the underside of the solar panels with the solar panel being electrically connected directly to the maximizer. The maximizer communicates with the gateway wirelessly, transmitting data regarding the solar panels' activity and production. The gateway connects to the Tigo MMU with a cord that runs along the horizontal axis assembly and down a vertical support pole. To simplify wiring, the Tigo MMU, charge controller were mounted on the dolly on the same side as the drive and blocking system. The battery was secured to the same dolly by using left over wood, creating a pocket for the battery to safely sit in. The battery had to be positioned somewhere where it could be well ventilated because it naturally produces hydrogen sulfide during charging. If a large amount of hydrogen sulfide is collected in one area, it could be extremely poisonous, corrosive, flammable, and explosive.

In any PV system, both the structure and the electrical connections need to be grounded. The aluminum structure can conduct some of the electricity that is travelling through the system. In order to ground the structure, bare, solid, AWG 4 copper wiring was attached to a mounting rail using a grounding lug. This grounding was done before any other electrical connections were made. The second grounding was that of grounding the charge controller; every electrical connection from the solar panels to the battery goes through the charge controller, thus grounding the charge controller means that the entire electrical system has a ground. Shielded, stranded, AWG 4 copper connected the charge controller to ground. In order to ensure that the connections remained fixed, all wires through the system were routed along the structure using zip ties and wire clips.

Initial Setup

The order that an electrical system is setup and wired is extremely important with regards to safety. By incorrectly wiring the system together, the chances of blowing out one of the components and of electrocution is much higher. To help mitigate these potential issues during installation, the Tigo system has a built in setting (PV-safe) that stops the current flowing from the solar panels to the charge controller. We implemented the PV-safe mode whenever data was not being collected from our system. Once the prototype was set up and ready for testing and data collection, meaning that the entire electrical system is wired and grounded, PV-safe mode was turned off and data collection began. In order to see if the PV-safe mode on the Tigo system worked properly, a multimeter was used to make sure the solar panels were not producing energy past the maximizer.

During initial setup, the first electrical connection made was the battery to the charge controller, followed by grounding the charge controller. At this point, the solar panels were not connected to the charge controller, therefore setting up the later half of the electrical system was safe. The output from the solar panels was then wired to the Tigo maximizer, which records the performance of each solar panel and allows for instantaneous data collection and visual results. The maximizer acts as the connection between the solar panels and the charge controller. The Tigo gateway connection to the MMU is completely independent of the electrical system and no safety precautions were needed during its setup.

Daily Testing

Throughout the night, when the apparatus was being stored, the PV-safe mode was activated and the solar panels were covered with a large blanket to eliminate the chance of the panels producing excess energy. After positioning the system in its desired location, grounding the entire system is the required first step so that electrocution does not occur. Once the system was grounded and ready for data collection, PV-safe mode was turned off and the blanket was taken off, starting energy and data collection. After a day of testing, the safety protocols for takedown and storage begin; PV-safe mode was first turned on to stop the flow from the panels. The panels were then covered for increased safety. The final safety step is ungrounding the entire system and returning the system to storage.

Furthermore, there were safety precautions for other aspects of the apparatus. The dual-piston hydraulic blocking system experienced some leakage after applying the hydraulic fluid and a fluid containment system was implemented. After setting up the solar tracking system each day, caution tape was used to tape off the testing area so that others could not interfere with the system and potentially injure themselves. Lastly, a multimeter was used throughout testing as a way to check voltages and currents throughout the system.

7.3 Testing Setup and Procedure

After understanding how to safely store, move, and test our system, a suitable location for testing was prepared. The major requirements were that the system be outside within reasonable range of a power outlet, Ethernet outlet, and a place for grounding. The power outlet was needed for the Tigo MMU since it required a three prong plug. The Tigo MMU also required an Ethernet outlet, since it does not have Wi-Fi capabilities; through the internet, we were able to receive all the power data for the system from the MMU. Lastly, the system was grounded using 4-AWG copper wire. With all of these requirements we found that the most suitable place to perform our testing was just outside the Refract Solar Decathlon house, at coordinates of 37°20’56"N 121°56’14"W. We designed our system to rotate from East to West, so we set up our prototype with the rotational axis pointing in the North-South direction using a compass.

Testing began early in the day so that a complete set of data could be gained, giving a better idea of how much and at what times the rotation of the solar panels increases their power output. Once, the system was grounded and all electrical connections were made, at 9 AM, we rotated the solar panels full tilt, 17°, toward the sun rising in the east, to begin testing. Due to time constraints and the desire to obtain data on both a rotating system and a flat static system, the panels were alternately rotated between optimum angle for solar collection and a static position parallel to the ground. At 9:15, we rotated the solar panels to be horizontal with the ground, ensuring its accuracy by using a leveling device. Fifteen minutes later at 9:30 the panels were rotated towards the sun again, continuing the pattern of alternating the panels every 15 minutes. This was done at a frequent pace so that both the static and solar tracking data would receive similar amounts of sunlight. Testing was completed at 6 PM, shortly after the sun had set lower than the system could be oriented.

While collecting data in this way, the battery needed to be periodically drained so that the flow of energy from the panels to the battery would continue. However, draining the battery excessively would lead to inconsistent data. Six 50W light bulbs were connected to the battery for 15 minutes of every hour. This pattern allowed the battery charge level to remain in the desired range, improving the consistency of data collected.

7.4 Data and Analysis

The data that we received from the Tigo MMU showed the power that each solar panel output every minute. From this data, we filtered out the points that were zero due to the pulse width modulation, as well as the points which resulted from the spikes of the same phenomenon. These outlying points were only due to the charge controller's pulse width modulation and did not accurately portray the power generated by each solar panel. After filtering out the bad data, we graphed the data from the rotated panels and the horizontal panels separately.

By observing the full system power output, a clear parabola can be observed throughout the day with the highest power at midday when the sun is at or close to its zenith. After separating the data by type of system, either tracking or static operation, there was a significant difference in the amount of solar energy generated. Because of inconsistencies and outliers in the collected data, largely due to spikes caused by PWM, wattage readings over 150 and below 75 were filtered out to improve data stability.

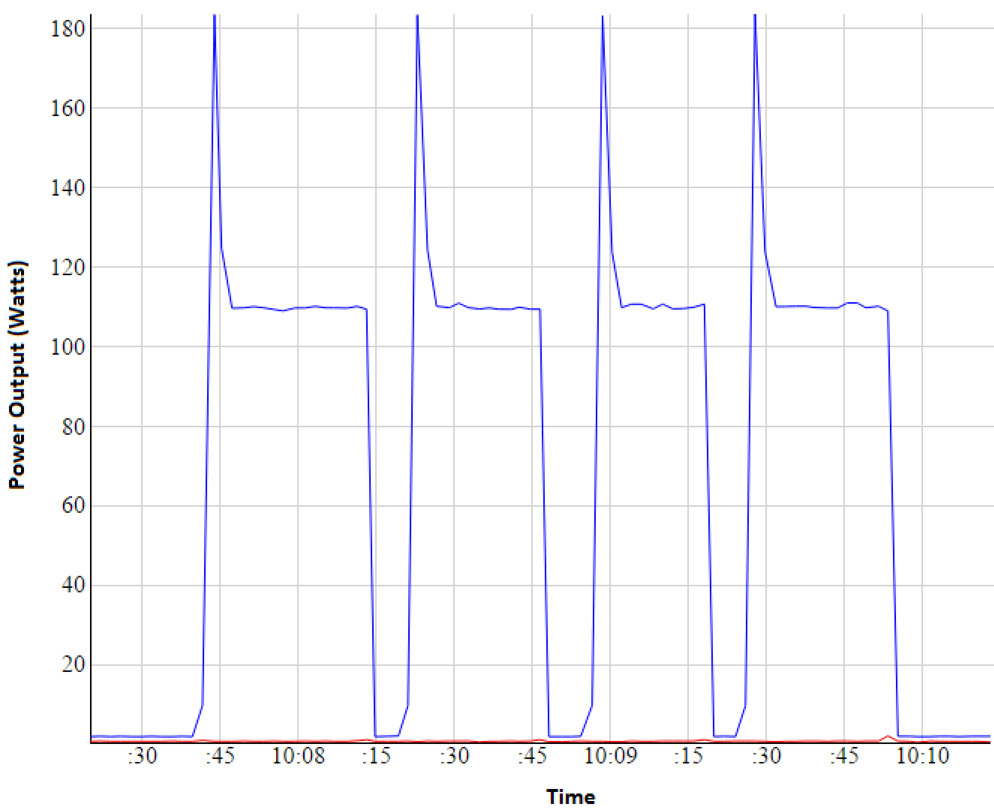


Figure 7.3: Screenshot of Tigo data output showing PWM

Trendlines were generated for each of the sets of data following the rate of energy generation throughout the day as seen in Figure 7.5 on page 38 and Figure 7.6 on page 39. By integrating this trendline over the entire data set, an adjusted value for total energy generation over the period of a day was calculated. Under static operation it was calculated that 935.8Wh would be produced, while tracking produced 1042Wh. In the observed results, tracking allowed for 11.4% more energy to be generated in comparison to static operation. This is a lower improvement than our originally expected 15%; the greatest contributing factor in reduced enhancement is likely the decreased freedom to rotate from 25 to 17 degrees in either direction. In addition, the largest disparities between the trendlines were found in the early morning and late afternoon. If we had started data collection earlier and concluded later, we would have likely seen results closer to the originally predicted 15%. Although the initial expectation was for a 15 to 20 percent improvement, the observed results are still well within a practical range of the prediction.

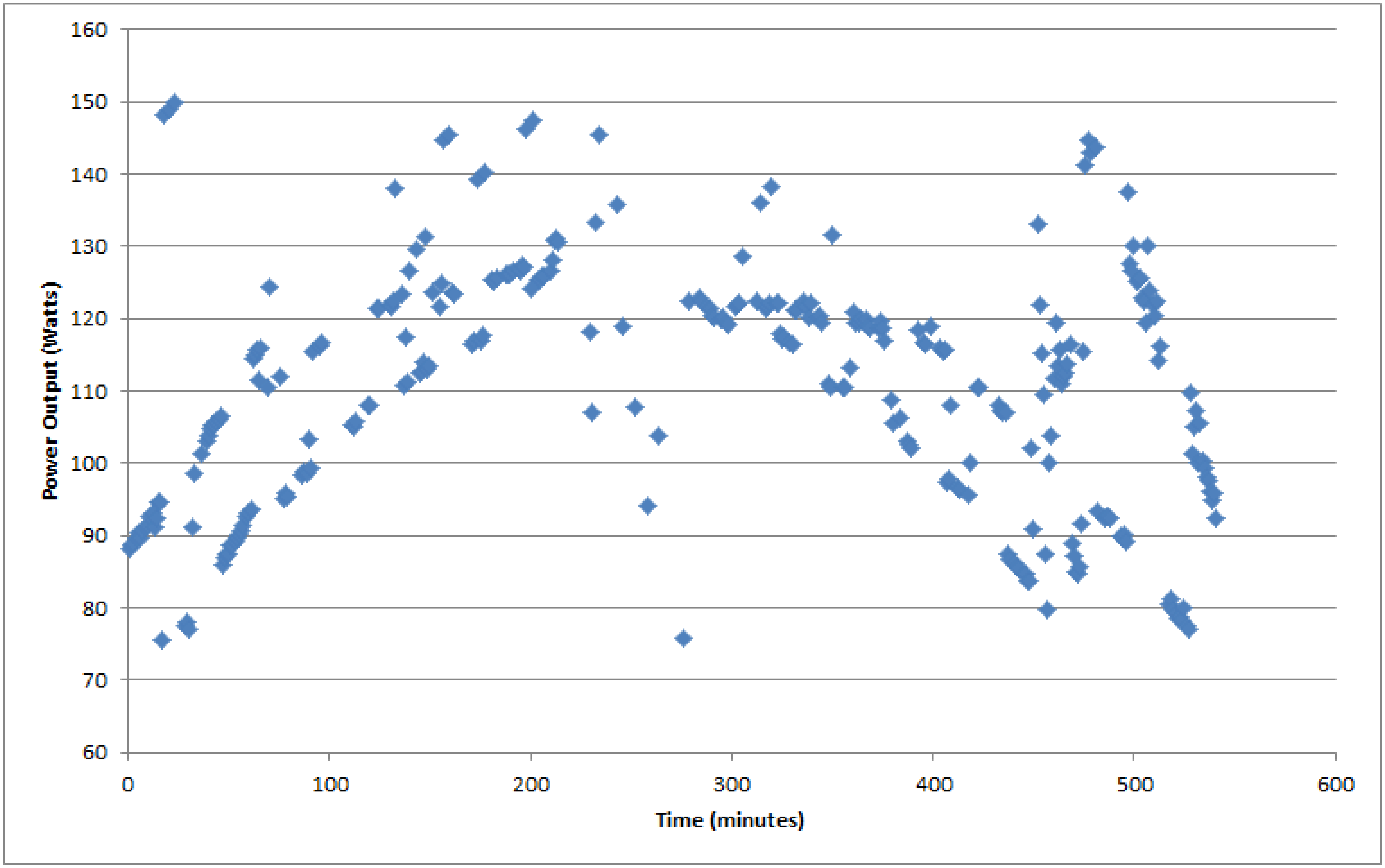


Figure 7.4: Total system power output

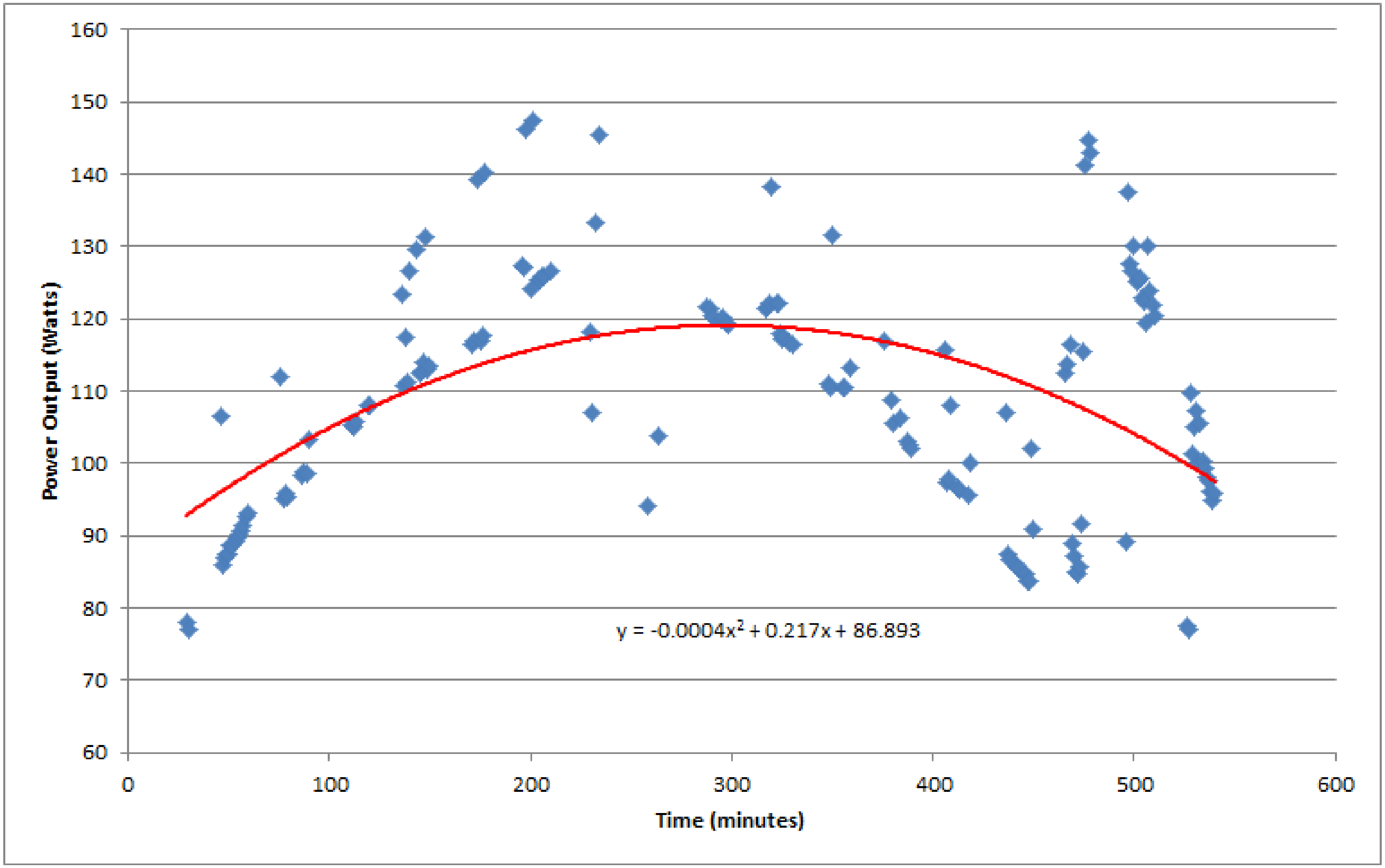


Figure 7.5: Power output from static system including trendline

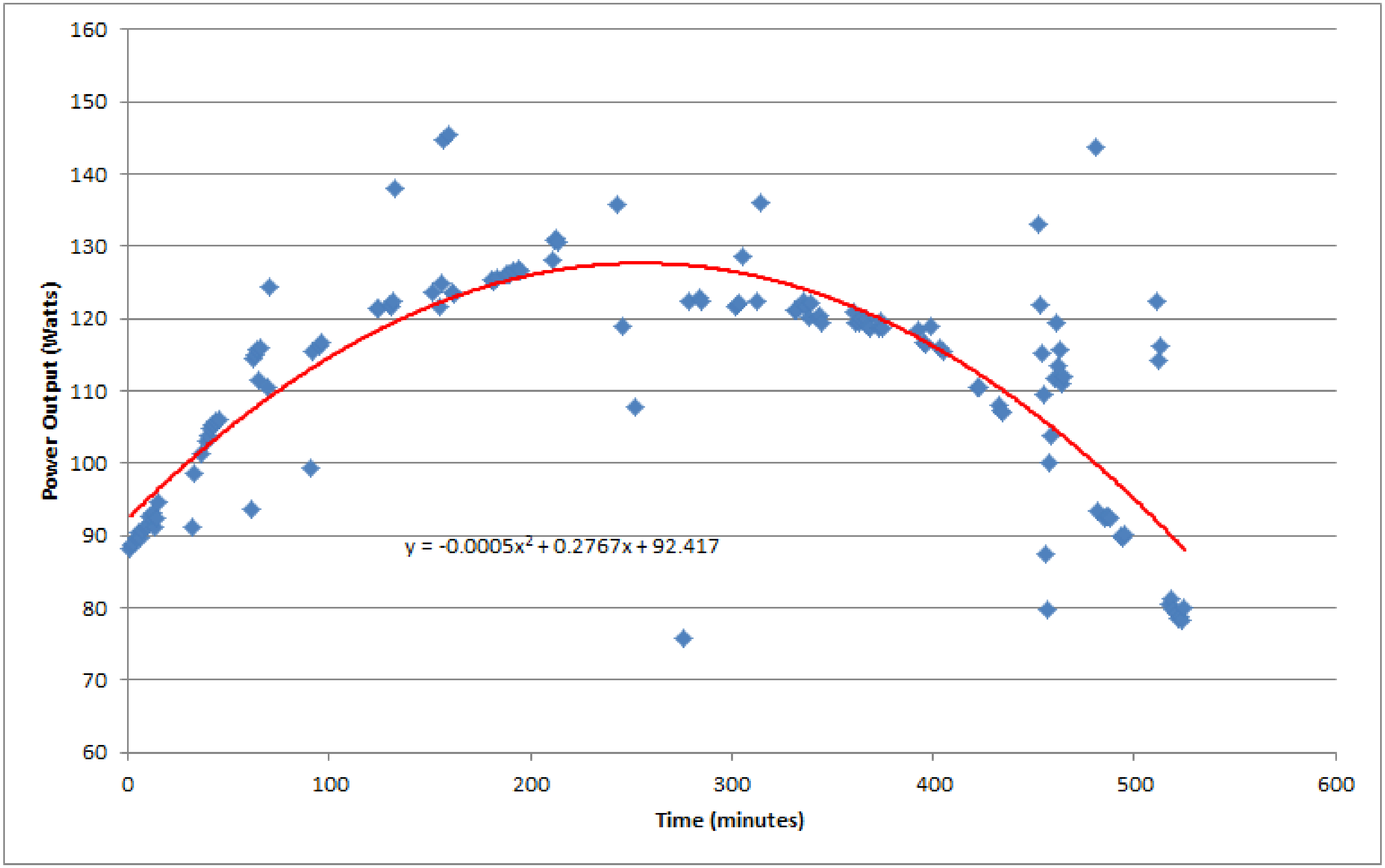


Figure 7.6: Power output from tracking system including trendline

8 Business Plan

8.1 Introduction

During the course of senior design, we have designed and fabricated a scaled down prototype of an auxiliary backyard solar tracking system. The actual product that would theoretically be sold during commercialization would be a larger sixteen panel system designed for residential application. This system would serve the dual function of cutting down on the monthly energy bill and acting as a livable, weatherproof, outdoor space. Both of these functions, along with a potential to accessorize the system with heaters, speakers or other add-ons, have economic benefits to the consumer in that they add a level of functionality and value to the home that was not there before.

Currently, there are no products that can be found on the market that perform the same functions as Sunplanter. Though there are several residential solar tracking options, none of them are designed to provide livable space. This means that they are single pole designs that do not have weatherproofing or the possibility for accessorization. Our system will also be manufactured in a modular fashion which will allow for faster and easier installation over roof-mounted systems and over non-modular tracking systems.

Once the design is complete, new personnel must be added to the company in order to efficiently advertise, sell, manufacture, ship, assemble, and maintain the Sunplanter solar tracking systems. A sales force would likely be necessary to inform the public about the product through advertisements, and to sell the system to consumers wishing to make the purchase. Warehouses will need to be established to handle the manufacturing and act as shipping hubs for sales orders. A workforce must be trained in order to take care of the assembly and maintenance of the systems once shipped to the residential locations.

8.2 Goals and Objectives

The main objective of the Sunplanter company is to provide an affordable and easily installable solar tracking system in order to increase the amount of green energy produced in California. By selling the solar tracking systems, the Sunplanter company will be able to generate an income that will be used to continue improving the system design while creating sales and work forces to market and install the systems.

8.3 Potential Markets

Our initial customer base will include middle and upper class households in the bay area. This is because those are likely the groups of people with enough room in their yards, as well as sufficient disposable funds to invest in the system. In addition to residential applications, schools, corporate offices, and government facilities may also wish to purchase the Sunplanter system for outdoor or even rooftop installations. The Sunplanter solar tracking system can be implemented wherever there is sufficient outdoor space for the system to be installed and operated safely.

As the company grows, installations of the system will expand throughout California focusing on the geographic areas that receive the most sunlight. Households, schools, corporate offices, and even government buildings may wish to purchase the system to integrate a energy generating outdoor living space.

8.3.1 Competition

The main way that solar panels are installed in residential applications is by rooftop mounting systems. This would currently be our main competition in the field of residential solar installations. Pre-existing solar tracking installations such as those pictured in Appendix A are normally not practical for the standard backyard since they take up a significant amount of space. Solar tracking technology is more commonly utilized in larger applications such as solar fields. There are a few examples of solar trackers that have been designed with residential installation in mind such as the DuraTrack DA tracker from Array technologies. However, these systems do not provide functional, livable space underneath the panels, instead taking up lots of area around the home due to their single pole structure design.

As a patio or deck covering, Sunplanter systems would have competition from pre-existing prefabricated patio and deck coverings or awnings. These types of space coverings can be purchased from any local store of the Home Depot ilk. Although almost quadruple the cost of a similarly sized patio cover, the Sunplanter system provides the added benefit of solar energy production, therefore bringing together the best aspects of the two main competitive markets.

8.4 Sales and Marketing Strategies

A marketing strategy that informs potential customers about the stand-alone auxiliary solar tracking apparatus is crucial in order for the company to be successful in selling the product. The approach for the marketing of the product must first convince the customers that solar energy is a good thing for them as well as the environment. However, this may not need to be a focus of a direct marketing strategy, as California already widely accepts solar as a viable alternative to conventionally purchased electricity.

Secondly, our marketing must also show convincingly that our product is better than a standard solar installation. This can be done through a variety of ways including showing the upfront cost benefits of the system over conventional rooftop installation methods. Furthermore, in area-specific sales, a direct comparison can be made between our product and typical rooftop installations to deepen the impact and effectiveness of this strategy. Considering a widespread marketing and social networking campaign utilizing several mediums in order to spread awareness of the product, the initial budget for marketing alone would be between $2,500 and $10,000 per quarter depending on the season and amount of sales.

8.5 Manufacturing Plans

In order to manufacture the initial Sunplanter systems we will need to subcontract a manufacturing company to machine and weld the subsystems before they are shipped to their installation sites. The manufacturing of each system will likely take less than one day to complete once processes are set up to efficiently manufacture each system. Since the systems are large and costly to produce they will be manufactured only to order until a consistent flow of orders begins. Additionally when a larger amount of orders begins to flow through, Sunplanter may be able to invest in their own manufacturing facilities to save on the manufacturing costs.

8.6 Product Cost and Price

One of the initial goals for our project was to achieve a price of around $12,000 to manufacture, deliver, and successfully install one Sunplanter system. We determined through analysis that economically this price would not be sufficient to sustain growth of the company selling this product. From our analysis we decided that a reasonable price for the proposed Sunplanter system would be $18,000. This price point was chosen due to the desire to lower the cost of installing a solar system in a residential establishment. At the moment, according to California Solar Statistics [17], residential installations of this size average approximately $7.50 per watt in California; so, for a 4kW system like the proposed Sunplanter model, the cost is around $30,000.

The table below shows a breakdown of system costs for both the prototype and the full size residential unit. Estimates for the full size system were based on scaling the prototype from two panels to sixteen panels. Added in to this estimate were assumptions that purchasing materials, machining parts and fabricating subsystem assemblies would be less expensive when done in bulk. A contingency was also included to the full size estimate to account for unforeseen costs of large-scale manufacturing.

Table 8.1: Cost breakdown of prototype and residential Sunplanter systems

Expense	**Prototype Cost**	**Full Size System Estimate**
Structural Materials	$669.56	$1,500
Drive and Blocking	$1,180.10	$1,400
Solar Panels*	$720	$3,200
Maximizer Hardware*	$500	$1,200
Foundation Materials	$161.61	$500
Electronics	$208.05	$1,500
Machining and Welding*	$300	$750
Transport	—	$500
Installation	—	$1,200
Contingency (5%)	$186.97	$587.50
Total	**$3926.29**	**$12,337.50**

* - Goods/Services donated for prototype; Cost listed is an estimate based on MSRP

Even with a contingency included, a $12,000 initial price point for the end product was not far off. That being said, as is the case with any company looking to make money and continue to produce products, Sunplanter systems will have to be sold at a significant mark-up. An end cost to the consumer of $18,000 will allow for a 46% profit margin on each system, assuming that the estimate detailed above are completely accurate. In addition, the $18,000 price tag will allow the company to sell equally sized systems at 60% the cost of the average competitor.

8.6.1 Service and Warranties

Yearly maintenance will be required to ensure that the high pressure line, hydraulics, motor, and electrical connections are all functioning properly and safely. The workforce trained to install the system will also be trained to maintain the systems for the yearly scheduled maintenance. We hope to offer a lifetime warranty for the structure of the system. All other aspects of the system such as the motor, hydraulics and rotational bearings, will be covered under independent warranties, issued by their respective manufacturers.

Table 8.2: Part warranties and their respective providers

Item	Warranty/Expected Lifetime	Warranty Provider
Bison DC Gearmotor	1 Year	Bison Gear and Engineering [18]
Inverter	12 Years (extendable to 20 years)	SolarEdge [19]
Maximizers	5 Years	Tigo Energy [20]
Gateways and MMU	10 Years	Tigo Energy [20]
Hydraulic System	3 Years	International Hydraulics US [21]
Solar Panels	25 Years	SunPower Corp. [22]
Structure	25 Years	Sunplanter Inc.

8.7 Financial Plan and Return on Investment

8.7.1 Business Investors

To kickstart the sales of the Sunplanter system, an initial amount of money will be necessary for cost of development, marketing, and manufacturing. The initial funding required to start the company we are estimating to be about $200,000. This amount includes an initial store of money that will be needed in order to produce the first few systems to be manufactured and sold. Although this amount of money is more than we estimated spending in the first few quarters, we anticipate that there may be unexpected costs which have not yet been accounted for.

Using an estimation for systems sold and the net profit gained from each sale, we were able to approximate income over the first five years of business. Sales per quarter begin at twelve and then increase each year accommodating for the expansion of business, while also fluctuating based on the season. Marketing, inventory, and manufacturing costs were estimated so that a break even point and profit margins could be calculated. By the sixth quarter we hope to be roughly $65,000 positive, and using our cost analysis model by the twentieth quarter, or fifth year of business, we aim to have made $2,270,000 incorporating for inflation [23]. This is a 1135% increase from the initial $200,000 in expected funding in just 5 years.

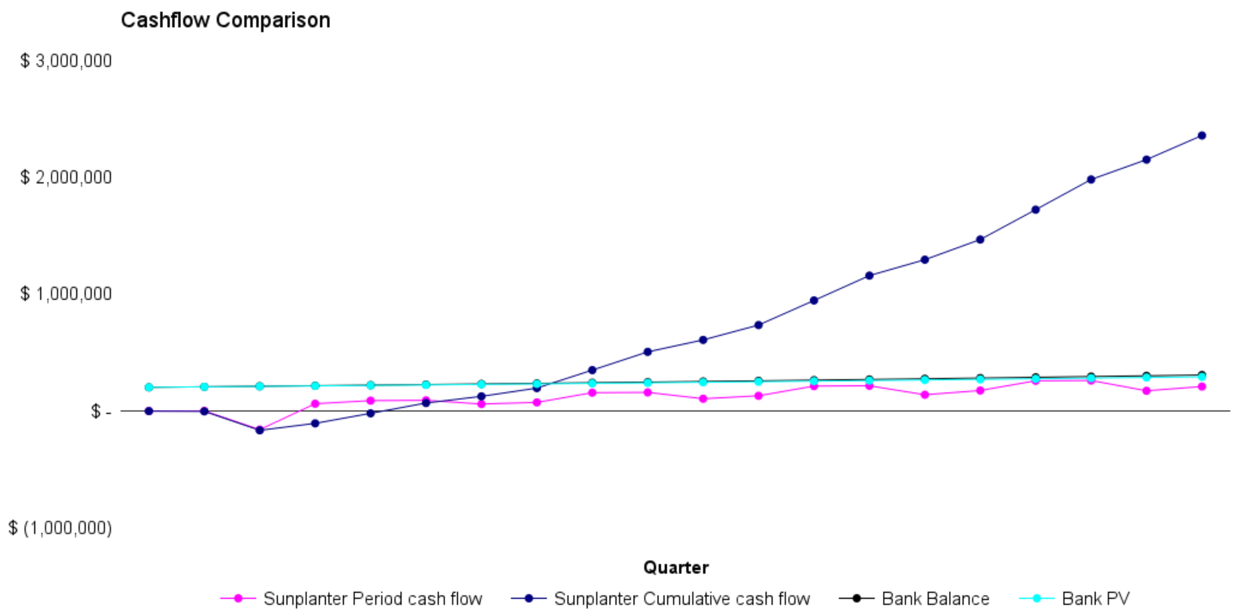


Figure 8.1: Investment in Sunplanter Inc. compared to High-Yield fixed rate CD

As the comparison above shows, investing money into the Sunplanter company would be a quick return beyond what could be gained by simply saving the money. Since we estimated a startup cost of roughly $200,000, we used that value of investment to compare. By simply saving the money and investing in a guaranteed return option such as a high-yield certificate of deposit (CD) at a rate of 2.25% [24] an investor could expect a return of $89,600. Although this seems to be a good amount of money, the same investment in Sunplanter could yield almost 8 times that amount as the dark blue line denotes.

8.7.2 Consumer Investment

Not only will our customers experience savings from the collection of solar energy cutting down their electric bills [25], there are also several other monetary benefits that come with owning a solar system. Using data from SEIA [26] and DSIRE [27], we found that for the state of California, residential solar installations are subsidised through a tax credit that amounts to 30% of the system cost. Furthermore, many utility providers grant a production based incentive (PBI) giving system owners money back based on the amount of energy produced. From this data, we were able to set up cost analysis that compared the overall monetary savings of a Sunplanter system to those garnered from a traditional rooftop installation.

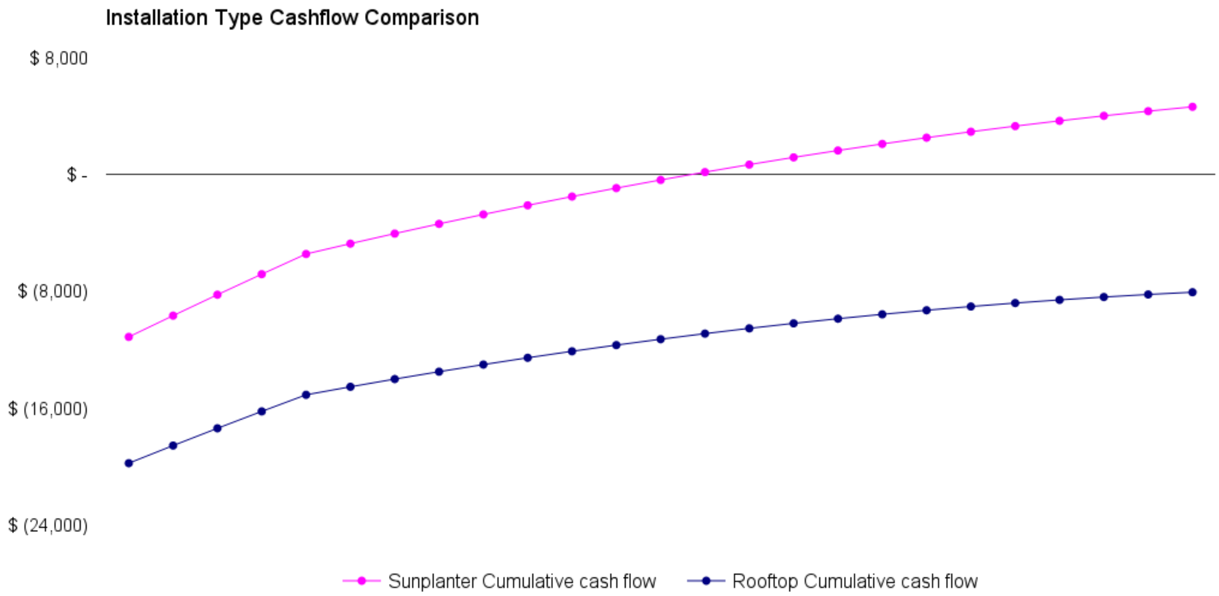


Figure 8.2: Return on investment comparison between Sunplanter and rooftop solar

The figure above shows the total monetary investment over the lifetime of a solar system from the perspective of a homeowner. The upper line indicates the financial benefit of the Sunplanter system. After only 13 years, the Sunplanter system pays itself off and begins to be a positive investment for the customer. Conversely, a traditional rooftop mounted system would have only repaid two thirds of the upfront cost after the entirety of its expected 25 year lifetime. The complete raw data for Figure 8.1 on page 45 and Figure 8.2 on page 46 can be seen in Appendix H.

9 Engineering Standards and Realistic Constraints

9.1 Design Consideration Areas

9.1.1 Economic

Consumer Perspective

Due to the nature of this project and the close association with a business professional, many of the design decisions were economically based. There was a need from this perspective to make the system cost effective, easy to maintain and easy to install. As has been mentioned previously, the Sunplanter residential system has an upfront cost of only $18,000 compared to current standard installations costing upwards of $30,000 for a similarly sized system. As with most solar installations, the upfront cost for materials and installation is the largest investment. Fortunately, solar systems begin to accrue monetary gains for the consumer almost immediately.

In the state of California, there is a solar tax incentive which refunds 30% of the total cost of the installation of the system. This type of refund is in place to incentivise consumers to purchase larger systems where they will be able to generate more energy for a lower price. In our scenario, although the rebate would not be as large on the Sunplanter system as on a traditional system, the net expenditure after factoring in the tax rebate is equivalent to the manufacturing cost of the system. This means that a Sunplanter customer would need to produce only $12,000 worth of electricity over the life of the system to break even.

Another solar rebate program is a Performance Based Incentive (PBI) that is based on the production of the solar array. In California, the PBI amounts to $.09/kWh for the first 5 years after installation. This is on top of the savings that a consumer would receive from using solar power produced on-site as opposed to purchasing electricity from the grid. At the current average electricity sale rate, an average customer would receive $.25/kWh over the first 5 years of the system. Since the PBI is within the first few years of system installation, there is the added benefit of using new equipment that has not undergone any kind of efficiency degradation that electrical systems often experience.

Some downsides of the tracking system that would not be present in the standard installation would be maintenance and part replacement costs. Every part that is incorporated into a solar system, whether tracking or static, is protected under some kind of warranty. If the part breaks during the warranty period, there is no monetary drawback felt by the customer. However, solar tracking systems have more moving parts and are thus more susceptible to breaking down. In this case, replacement costs would need to be covered by the initial purchaser. During periods where a tracking system is unable to track, the panels will still produce electricity at a lower level of efficiency than before.

Sunplanter Inc. Perspective

In relation to the Sunplanter company, the solar canopy system is a positive financial investment even though there are some major costs. One of the fixed costs for the company will be the money needed for storage space. This space will be used to house raw materials, completed systems ready for shipping and installation, and other items of importance. We estimated that a reasonable amount of required space for this company would be around 2,000 sq.ft.; with this assumption we found that a reasonable price for a storage space of this size was about $2,000 per month. Following our business plan, there would be no need to increase the storage space, even as production volume increases; so these storage costs would be relatively constant for the company.

Another more obvious fixed cost for the company will be the cost of manufacturing each system. As stated, this cost will be about $12,337 for each system built; however, this cost is covered by the $18,000 retail price of the system. Because neither of the cost or price are predicted to change over time, the profit margin of roughly $6,000 will be constant for the company. For this reason a reasonable plan for the company was to have a small number of systems already made on standby to be installed (around 6) and for the company to simply make a system every time one is ordered. This way the number of manufactured systems will never be greater than the number of systems sold except for in the first few months.

The company will also have to deal with some variable costs as well, including replacement and marketing costs. Due to the nature of solar power, solar installations are generally more popular to have during the spring and summer seasons when the sun is at its strongest. For this reason it makes more sense to change the marketing strategy for the product season by season. More funding will go towards marketing during the late winter months in anticipation for the spring and summer. Naturally, a lot of money will still be going into marketing for spring and summer, however less in the summer than in the spring due to the short amount of time left for long sunny days. Lastly, the fall will have very little financial support for marketing, due to the low demand for solar systems during those months.

As stated earlier, different parts of the system are under different warranties. When a part breaks and needs to be replaced, the resulting monetary transaction can be either net positive or negative for the company depending on the warranty. If the warranty is still in place, the company will have to pay for the part instead of the customer, resulting in a loss for the company. On the other hand, if the item is past its warranty, the customer will have to pay the company to replace it, covering the cost of the item plus a little extra, so the net result for the company is positive. Overall, the gains and losses for the replacement of parts should even out for the company over the years.

9.1.2 Environmental

The main impact of the Sunplanter systems with regards to the environment is the production of solar energy through the panels, reducing the amount of energy consumed from the grid. This impact will be seen in reducing the need for non renewable energy sources such as natural gas, which California is currently largely dependent upon for its energy requirements. In addition to reducing pollution causing methods of energy production in California, Sunplanter will work to increase popular knowledge of the many financial and environmental benefits achieved with the incorporation of solar technology, acting as a new and innovative way of incorporating PV panels in both residential and commercial applications. By focusing sales in California, transportation related emissions will also be minimized.

During the design of the prototype system, aluminum was chosen as the primary structural material not only for its good material strength and favorable corrosive qualities, but also because it is an easily recyclable material. The 6061-T6 Aluminum that was chosen is a readily available standard material, cutting down on transportation costs prior to manufacturing. With an efficient two pole design that meets reasonable safety factor requirements, the amount of material used to construct each system will be reduced. By designing our system out of a material that can be easily recyclable and is readily available, we are able to reduce the environmental degradation caused by the system to an acceptable minimum, especially in comparison to the solar energy capacity created by each system.

Using data analysis and algorithm implementation, the net power output of the system will be increased. The use of these methods, in conjunction with solar tracking, will allow our system to create the maximum possible amount of solar energy, so that the greatest positive impact on the environment can be realized. Planning so that the systems create the least possible environmental degradation, while designing so that the maximum possible energy generation can be achieved, will allow Sunplanter to have a positive financial effect for those choosing to invest in the system, as well as a positive impact on the environment.

9.1.3 Sustainability

Solar technology has been a growing market in recent years due to the overdependence that developed countries have on non-renewable energy sources such as coal, natural gas and petroleum. Sustainability is a major focus of all solar systems, and is ultimately the reason why solar power exists. Our system was designed to be more sustainable because it uses a solar/renewable energy source in the most efficient way. The decision to have the system be solar tracking increases the output of each solar panel. A solar tracking system does more than increase the output of the system, it also reduces the need for larger solar systems, eliminating unnecessary and excess material, and reduces the need for nonrenewable energy from the grid. Because the system is solar tracking, it does have to use more energy than a static system; however, the solar tracking increases the energy production enough to compensate for the energy used by the system. The Sunplanter solar system is completely self-sustainable with positive net energy production.

Another way that the Sunplanter design is sustainable is that it was designed to have a long lifespan of 25 years with little maintenance. Also, it was designed to be recyclable after its lifespan. The structure is made completely of recyclable 6061-T6 aluminum. 6061-T6 aluminum is very cost effective because of its low cost, good strength, and recyclability. Because of the relatively new market of solar systems, solar recycling is still in the developmental stages but they are starting up to anticipate a large portion of older modules reaching the end of their lives.

Furthermore, the system inherently promotes sustainable communities. This auxiliary, stand-alone system is easily installable and can be implemented in a variety of locations. It also provides a functional space beneath the solar panels which can add to a backyard or garage. By the system being prefabricated and easily installable, as well as it having a low cost, the Sunplanter system promotes the use of solar power.

9.1.4 Manufacturability

Design for Manufacturability was one of the main goals set out for our project when we first discussed the idea with our professional advisor. As a business professional, he stressed that no matter how amazing a product is, if it is meant to be mass produced but cannot be easily or autonomously constructed, the cost of the product rises. Not only does it take more time to produce, but also more effort and manpower must generally be invested to build things that are not designed for manufacturability.

Simplify Design and Reduce Parts

From the very beginning and throughout the design process, we attempted to design our project to be as simple as possible. For us, this meant choosing a design with as few parts as possible while still achieving all the functions which we required of it. For example, some of our initial designs featured 4 poles holding up the solar canopy system rather than 2. We decided, however, that although the structure would be more stable, a 2 pole structure would be able to withstand the design loads safely, and the extra poles would be an unnecessary cost. On the other hand, we found several solar systems from other companies with only 1 pole holding the PV panels. Although this would have reduced the cost of the system and provided strong support in the middle of the solar array, 1 pole did not give us the functionality which we desired the system to achieve (i.e. a usable living space underneath the panels).

Standardize Parts and Materials

Another problem which we tackled during the design process was attempting to use only standard parts which are easily accessible and manufacturable. We achieved this through several means. For the entire structure, we used only stock 6061-T6 Aluminum tubes, extrudes, and plates. We used sizes which many metal companies produce daily, ensuring the ability of the Sunplanter company to easily obtain all the metal components of the system for affordable prices. We also used stock parts in other parts of the system, such as the pillow blocks from McMaster-Carr, the motor from Bison Engineering, and the hydraulic cylinders from International Hydraulics. We also designed our prototype to use the same size fasteners for most of the system, 7/16" bolts, nuts and washers. By designing the product in such a way, manufacturing can be done cheaply and efficiently with less opportunity for error.

Ease of Fabrication

One of the most important ideas when designing for manufacturability is the ease of fabrication; in other words, how simple are the fabrication processes. For the most part, we began determining how to machine our project after most of the crucial design choices had been made, although some design changes were made based on fabrication. We were mostly only able to do simple machining processes, so designing our prototype to be machined simply was not only helpful but also required. The only machining processes needed for our project were holes and a keyway from the mill, cuts from a tablesaw, fitting by a lathe. Furthermore, all the machining operations use standard cutters and equipment that most machine shops have. When doing the machining ourselves, we came up with ways which could make the machining process much faster and more efficient, including using jigs and fixtures to reliably produce the same results many times. We also avoided drilling holes which were too small or too large to avoid the wearing down or potential breaking of drill bits as well as problems of straightness deviation.

Product Design and Assembly

A critical aspect of the fabrication of any product is reducing the number of opportunities for mistakes to be made. This can be difficult, especially since we know exactly what we want the end product to be. However, once other people are trained to manufacture and fabricate our product, simple mistakes can be made. One way to avoid this is, as discussed earlier, reducing the number of parts in the assembly. Another way is to make the product "mistake-proof." We did this in a couple of ways. Our design is fairly symmetric, however there are easily observable differences between parts on opposing sides of the structure. We also divided the structure into three different assemblies; each assembly has different parts from the rest, and once each is fabricated they can only be put together in one way. This means no simple mistakes during fabrication or installation.

9.1.5 Health and Safety

As with any structure, health and safety of those constructing it as well as of the end users is paramount. In order to ensure the safety of the end users, the structural elements were all designed under ASCE codes in the *ASCE: Minimum Design Loads for Buildings and Other Structures* [13]. As our project is currently constrained to California, the structure was designed as an open structure with a slanted roof for loading conditions for the geographic region. The final product will also come with a guide for its proper use, maintenance, and several safety guidelines for handling and emergencies. Some of the safety guidelines should include avoiding the addition of excessive weight to the rotating part of the system, especially the solar panels. Attempting to rotate the panels manually should also be avoided; if there is ever a problem with the automatic rotation a maintenance or repair professional should be contacted to take care of any issues safely and efficiently. If an earthquake or heavy storm were to occur while the user is underneath the system, he or she should still take precautions to remove themselves from the vicinity of the system. Even though it has been designed to withstand heavy wind, precipitation, and earthquake loads, unexpected occurences could happen which endanger the integrity of the system.

The safety of the people fabricating and installing the system is also important to take into account. When fabricating and building the system, all the safety precautions we adhered to in building our prototype will have to be followed, as well as any extra safety precautions which come with building not only a larger system but many of them. This may include wearing a hard hat or other protective gear due to the sheer size of the system. An effective method of containing and cleaning up hydraulic fluid spills will also have to be prepared whenever the hydraulic blocking system is being filled, installed, or simply in place on the system. To ensure that the system is built properly and up to the standard of quality which is expected, only ISO 9001 certified companies will be employed for any aspect of the process where applicable.

9.1.6 Art and Aesthetics

As part of satisfying the SCU Core Arts & Humanities requirements, members of this team have all contributed original drawings, sketches, and/or CAD models and drawings to this project. Below are listed a sampling of at least one such artifact, and a reference to it, for each of the team members.

Team Member	**Description**	**Location**
Matt Diaz	General schematic of electrical circuit	Figure 7.2 on page 31
Joe Gaither	Panel Support Weldment Drawing	S-04-0W in Appendix I
Stephen Hight	Drawing of full-size residential Sunplanter system implementation	Figure 2.1 on page 10
Brandon Suehiro	Drawing of hydraulic pin connection designs	Figure 5.1 on page 25

10 Conclusion

Our senior design project is a scaled-down prototype of a residential solar tracking PV canopy system. The goal of building the prototype was to determine two things: that, given the right design, the system could be both cost-effective and safe under the harshest loading conditions, and that a solar-tracking system is worthwhile compared to a static operation. Our design for the prototype was a two pole, 6061-T6 Aluminum structure, a Bison DC gearmotor, a passive hyrdraulic piston blocking system, and an Arduino, time-based control system. Although we were unable to complete the control system within the timeline of the project, we were still able to test our system against our initial goals to determine the practicality of the design.

We determined through the ASCE codes and regulations for the safety of structures that the most dangerous loading conditions our structure would have to endure were 115 mph winds. We designed our structure to handle the massive torques which would be caused by such wind speeds. To test our structure, we simulated the torque that the wind would place on the horizontal rotational axis using strategically placed weights on the rails of the system. Even under higher loading conditions than the 115 mph winds, our structure showed little to no signs of bending, ensuring the safety of the user and the delicate PV panels.

In order to test the effectiveness of the rotation of the system, we performed a full day's worth of testing from 9AM until 6PM. We recorded data from the solar panels, alternating the system every 15 minutes from tracking the sun to a static horizontal orientation. The data we received from these tests showed that during almost all times of the day, the solar tracking system performed better than the horizontal static system.

With more time to spend on the project, there are several improvements that could be made to the system. The most important of these improvements to be made is the incorporation of the DC gearmotor. This was not completed during the course of the project for two reasons, due to budget and time restraints a boost converter could not be acquired. The boost converter would have been used to convert the 12V output from the battery to the necessary 90V required to power the DC gearmotor. Additionally there was not sufficient time post senior design conference for controls to be written for the arduino control board to regulate the motor and solenoid valves.

Original plans for the blocking system included solenoid valves actuated by the control board. Because controls were not completed by the testing dates, the solenoid valves were replaced with manually actuated valves on the hydraulic blocking system. Also, we were unable to obtain our initial goal of 25 degrees of rotation in each direction; instead we only had 17 degrees due to a miscalculation during the design process. The solution for this mistake could be fairly simple. Longer hydraulics could be used on the system; however, this would add cost to the project. If the project were to be continued, the system should be automated completely with the integration of the drive and blocking into the controls, and a means of obtaining the desired 25 degrees on the prototype system should be found. Lastly, with more time to spend on the project, improvements to the aesthetic appearance of the system could have been made to improve commercial marketability.

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Appendix A: Competing Technologies

Figure A.1: DuraTrack DA Solar Tracker
Source: Array Technologies Inc. [4]

Figure A.2: AllSun Tracker Series 20
Source: All Earth Renewables Inc. [5]

Appendix B: Customer Needs

Table B.1: Customer Needs and Importance

Source: Information Gathered by Alain Poivet [11]

	Customer Need	**Importance (1-Low 10-High)**
PERFORMANCE	Quiet Performance	7
	Aesthetically Pleasing	8
	Maximization of power output	9
	Easy user interface (UI)	5
	Waterproof roof	9
	Customizable static settings	4
	Multiple UI users	3
	App based UI	2
	Able to have added accessories	6
SAFETY	Withstand wind load	10
	Withstand earthquake load	10
	Withstand precipitation loads	10
	Minimum allowable height	10
	Electrical	10
	"Lock" position	10
TIME SCALE	Preparation period (surveying/landscaping)	7
	Installation	8
	System longevity	8
	Maintenance frequency	7
COST	Initial system	10
	Installation	9
	Maintenance	8

Appendix C: MatLab Code and Results

C.1 Torsion Bar Minimum Requirements

```
format long
clear
%Constants
g = 9.81;   %gravity constant (m/s^2)

%System Requirements
    %Safety Factor to be included in Tau < Taumax checks
SF = 2;
    %What is the desired angle (Degrees)?
Theta = 25;
    %What foot increment would you like to use?
    %Used in varying the length of torsion bars
Finc = .5;
    %What inch increment do you want to use?
    %Used in varying diameters of torsion bars
inc = .25;
    %how many panels will your array have?
panels = 2;

%Sets the maximum diameter for the torsion bar depending on the number of
%panels that are in the system. It will display an error message if the
%number of panels is outside of the acceptable range [0<x=<500]
errorstring = ['The number of panels you have entered is invalid!'...
        'Please enter a new number and try again.'];
if(panels<=500&&panels>100)
    Dmax = 18;
elseif(panels<=100&&panels>20)
    Dmax = 12;
elseif(panels<=20&&panels>0)
    Dmax = 6;
else
    error('myApp:Pipe',errorstring)
end
%
```

```
%User Input for material properties
%Provides Modulus of Rigidity and yield strength in shear for material
%depending on user input. Default material is 6061-T6 Al
materialstring = ['What material would you like to use? \n(1)ASTM-A36'...
    'Steel \n(2)AISI 302 Steel \n(3)2024-T6 Aluminum \n(4)6061-T6'...
    'Aluminum\n'];
a = input(materialstring);
switch a
    case 1
        X = 'ASTM-A36 Steel';
        disp('The program is running with values for ');
        G = 77.2E9;
        Taumax = 145E6;
    case 2
        disp('The program is running with values for AISI 302 Steel');
        G = 75E9;
        Taumax = 150E6;
    case 3
        disp('The program is running with values for 2024-T6 Aluminum');
        G = 27E9;
        Taumax = 230E6;
    otherwise
        disp('The program is running with values for 6061-T6 Aluminum');
        G = 26E9;
        Taumax = 140E6;
end

%Calculated Values & Unit Conversions
    %torque from wind (N*m/ft)
Wind = 5420*1.35581795;
    %creates an array with length and width orientation possibilities for
    %the number of panels assuming 3:1 ratio or lower
LandW = PanelOrient(panels);
    %Creates a length vector with all possibilities for the
    %total overhang length
Length = LandW(:,1);
    %Creates a width vector with all possibilities for
    %total system width (axial length)
Width = LandW(:,2);
Over = zeros(length(Length));
%converts length of overhangs to meters
for i=1:length(Length)
    Over(i) = FeetToMeters(Length(i)/2);
```

```
end

Ltormin = 0; %minimum Torsion Bar Length
Theta = DegToRad(Theta);
D = inc:inc:Dmax;
d = 0:inc:Dmax-inc;
Dmeter = length(D);
dmeter = length(d);
for i= 1:length(d)
    Dmeter(i) = InchToMeter(D(i));
    dmeter(i) = InchToMeter(d(i));
end

A = [0,0,0,0,0,0];
Viable = 0;
for i = 1:length(Length) %varying length of torsion bar
    Ltor = FeetToMeters(Finc:Finc:(Width(i)/2));
    Twind = Wind*Over(i);
    for j = 1:length(Dmeter) %Varying outer diameter of Torsion Bar
        for k = 1:length(dmeter) %varying inner diameter of Torsion Bar
            if(k<=j) %Making sure inner diameter is less than Outer
                for x = 1:length(Ltor)
                        %calculate torque needed to produce rotation angle
                        %based on material properties
                    Torque = (Theta*G*pi*((Dmeter(j)^4)-(dmeter(k)^4)))...
                        /(32*Ltor(x));
                        %Claculate shear stress based on previously
                        %calculated torque
                    Tau = (16*Torque*Dmeter(j))/(pi*((Dmeter(j)^4)-...
                        (dmeter(k)^4)));
                    Mass = Torque/(Over(i)*g);
                    if (SF*Tau < Taumax)
                        Viable = Viable+1;
                        if(Viable == 1)
                            Ltormin = Ltor(x);
                        end
                        B = [D(j),d(k),Ltor(x),Mass,Length(i),Width(i)];
                        A = [A;B];
                    end
                end
            end
        end
    end
```

```
end
A = A(2:end,:);
Viable
```

C.1.1 Feet to Meters Conversion

```
function meters = FeetToMeters(feet)
%simple conversion from feet to meters
meters = feet*.3048;
return;
end
```

C.1.2 Degree to Radian Conversion

```
function rads = DegToRad(degrees)
%Degree to Radian conversion
rads = degrees*pi()/180;
return;
end
```

C.1.3 Inch to Meter Conversion

```
function meters = InchToMeter(inches)
%Conversion from inches to meters
meters = inches*.3048/12;
return;
end
```

C.1.4 Panel Orientation Possibilities

```
function Orientations = PanelOrient(a)
%find factor pairs of the number of panels
%to create different configurations
```

```
b = factorpairs(a);

%eliminate any orientations that are outside a 3:1 ratio
for i = 1:size(b)
    if(b(i,1)/b(i,2) > 3 || b(i,1)\b(i,2) > 3)
        b(i,:)=0;
    end
end
b(all(b==0,2),:)=[];
emptyerror = ['There are no valid orientations for this number of'...
    'panels! Please enter a new number and try again.'];
if(isempty(b)==1)
     error('myApp:Ratio', emptyerror)
end

%creates possible orientations for systems with perfect square number of
%panels
if(b(end,1) == b(end,2))
    orients = 4*size(b,1)-2;
    l = zeros(orients/2,1);
    w = zeros(orients/2,1);
    if(size(b,1)==1)
    l(1) = 3*b(1,1);
    w(1) = 5*b(1,2);
    else
      for i = 1:(size(b,1)-1)
        for j = 1:size(b,2)
            l((2*i)-1) = 3*b(i,1);
            l((2*i)) = 5*b(i,1);
            w((2*i)-1) = 5*b(i,2);
            w((2*i)) = 3*b(i,2);
        end
      end
    l(2*size(b,1)-1) = 3*b(size(b,1),1);
    w(2*size(b,1)-1) = 5*b(size(b,1),2);
    end

%creates possible orientations for systems with non perfect square panel
%numbers
else
    orients = 4*size(b,1);
    l = zeros(orients/2,1);
    w = zeros(orients/2,1);
```

```
    for i = 1:size(b,1)
        for j = 1:size(b,2)
            l((2*i)-1) = 3*b(i,1);
            l((2*i)) = 5*b(i,1);
            w((2*i)-1) = 5*b(i,2);
            w((2*i)) = 3*b(i,2);
        end
    end
end
%returns side lengths and widths based on 3'*5' panel dimensions
Orientations = [[l;w],[w;l]];
return;
end
```

Factor Pairs

```
function pq = factorpairs(N)
% initialization checks and error tests
if nargin ~= 1
  error('FACTORPAIRS:invalidarguments',...
      'Exactly one argument must be provided.')
end
if isempty(N)
  % empty begets empty
  pq = [];
  return
end
% verify that N is scalar, positive integer
if (numel(N) > 1) || (N <= 0) || (N~= round(N))
  error('FACTORPAIRS:invalidarguments',...
      'N must be scalar, positive, integer.')
end

% a few simple special cases
if N == 1
  pq = [1 1];
  return;
elseif isprime(N)
  pq = [1 N];
  return;
end
```

```

% N must now be composite. Extract the factors of N
% This is why N must be no more than 2^32, as factor
% will not accept any larger number.
F = factor(N).';

% Determine multiplicities of those factors
[unikF,I,J] = unique(F);
countF = accumarray(J,1);
nF = numel(unikF);

% for each unique factor, get the factor pairs
pqF = cell(1,nF);
for i = 1:nF
  % ni must always be at least 1
  ni = countF(i);
  Fi = unikF(i);
  if ni == 1
    % special case, a single prime factor
    fpows = [0 1];
  elseif mod(ni,2) == 0
    % general case: ni is even
    n2 = ni/2;
    fpows = [0:n2;ni:-1:n2].';
  else
    % general case: ni is odd
    n2 = (ni - 1)/2;
    fpows = [0:n2;ni:-1:(n2+1)].';
  end
  pqF{i} = Fi.^fpows;
end

% combine the factor pairs in pqF into one
% set of factor pairs
pq = pqF{1};
for i = 2:nF
  pqi = pqF{i};
  pq = [[kron(pq(:,1),pqi(:,1)),kron(pq(:,2),pqi(:,2))]; ...
    [kron(pq(:,1),pqi(:,2)),kron(pq(:,2),pqi(:,1))]];
  pq = unique(sort(pq,2),'rows');
end
```

C.2 Hydraulic Clevis Pin Location

```
format long
format compact
clear all
close all

%Givens
x = 2.75;
Cmin = 16.25;
Cmax = 22.25;
alpha = 20:-.1:0;
Pmax = 17;
Pmin = 4.5;

%Creation of variables
H = Pmin:.1:Pmax;
P = Pmin:.1:Pmax;
A = zeros(1,length(H));
Beta = zeros(1,length(H));
GammaMin = zeros(1,length(alpha));
GammaMax = zeros(1,length(alpha));
Solutions = zeros((length(H)*length(P)),5);
%Solving for  H, P, C, etc
iterations = 0;
alphamax = 0;
for i = 1:length(H)
    A(i) = sqrt(x^2+H(i)^2);
    Beta(i) = atand(x/H(i));
    for j=1:length(alpha)
        GammaMin(j) = (90-Beta(i)-alpha(j));
        GammaMax(j) = (90-Beta(i)+alpha(j));
        for k=1:length(P)
            MaxSide = SAS(P(k),GammaMax(j),A(i));
            MinSide = SAS(P(k),GammaMin(j),A(i));
            if(MaxSide(1)<=Cmax && MinSide(1)>=Cmin && alpha(j)>=alphamax)
                iterations= iterations+1;
                Solutions(iterations,:) = [H(i),P(k),alpha(j),...
                    MaxSide(1),MinSide(1)];
                alphamax=alpha(j);
            end
```

```
        end
    end
end
Solutions(~any(Solutions,2),:)=[];
```

C.2.1 Side-Angle-Side Theorem

```
function abc = SAS(SideOne, Angle, SideTwo)
abc = [0,0,0];
abc(1) = sqrt(SideOne^2+SideTwo^2-2*SideOne*SideTwo*cosd(Angle));
abc(2) = asind((sind(Angle)*SideOne)/abc(1));
abc(3) = (180-(Angle+abc(2)));
return;
end
```

Appendix D: Hand Calculations

Wind Load Calculations

This method was taken from the ASCE Minimum Design Loads for open structures

Conditions

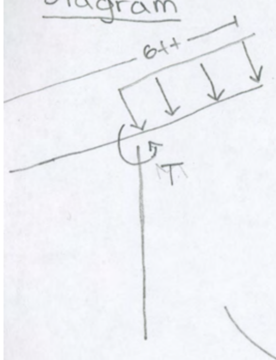
- 115 mph (169 fps)
- Height: 0-15 ft
- Exposure B
- $k_d = 0.85$
- $K_{zt} = 1$
- $K_n = 0.57$
- $K_z = 2.01 (15/z_g)^{2/\alpha}$; $z_g = 1200$, $\alpha = 7$
  $= .57$
- $GC_{pi} = 0$

$$q_z = 0.00256 K_z K_{zt} K_d V^2$$

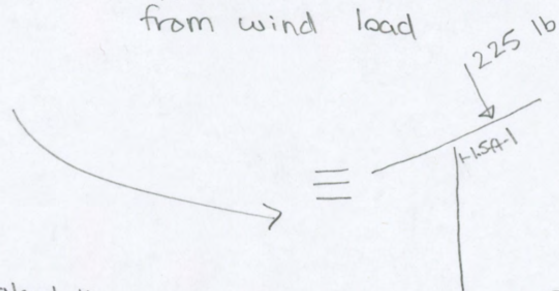
$$\boxed{q_z = 15 \text{ lb/ft}^2}$$

Max Torque Around Horizontal Support

Diagram



T = torque required to oppose moment created from wind load



T = 337.5 lbft

* This calculation was performed under the assumption that the max load conditions would occur under a 115 mph wind load applied directly perpindicularly to the surface of the panels

Stress Created

$\tau = \frac{Tr}{J}$

D = 2 in, d = 1.5 in

$J = \frac{\pi}{32}(D^4 - d^4)$

d = 1.5 in

T = 337.5 lb·ft
= 4050 lb·in

$$\tau = \frac{4050\,(1)}{\frac{\pi}{32}(2^4 - 1.5^4)}$$

τ = 3772 psi

yield strength of Aluminum = 35,000 psi

$$\frac{35,000}{3772} = 9.28$$

Factor of Safety ≥ 9

Appendix E: Budget

Table E.1: Original Budget Spending and Source Itemization Estimate

Item	Number Needed	Cost per unit	Total Cost	Cost to Team	NOTES
Arduino Board	1	80	80	80	4
Arduino WiFi Connection	1	50	50	50	4
Bosch Solar Panels	2	360	720	0	1
Foundation	1	500	500	500	3
Structure	1	300	300	300	2
Sensors	4	50	200	200	3
Drive System	1	450	450	450	4
Motor Controller	2	150	300	300	3
Blocking System	1	400	400	400	4
Waterproofing	2	50	100	100	2
Insulation	2	25	50	50	2
Batteries	2	100	200	200	3
Inverter	1	250	250	250	3
Charge Controller	1	100	100	100	3
		Total Cost	3700	2980	

[1] - Available for use from previous Solar Decathlon projects

[2] - To be donated by Sunplanter

[3] - To be funded with money received from Santa Clara University School of Engineering

[4] - To be funded by Sunplanter

Table E.2: Final Budget Spending and Source Itemization

Item	**Number Needed**	**Cost per unit**	**Total Cost**	**Cost to Team**	**NOTES**
Bosch Solar Panels	2	360	720	0	1
Tigo Hardware Package	1	500	500	0	1
Foundation Materials	-	161.61	161.61	161.61	2
Structural Materials	-	669.56	669.56	669.56	2
Racking Materials	-	261.44	261.44	261.44	2
Bison DC Gearmotor	1	536.11	536.11	536.11	2
Motor Coupling	1	85.10	85.10	85.10	2
Pillow Blocks	2	86.37	172.74	172.74	2
Hydraulic Pistons	2	124.65	249.30	249.30	2
Hydraulic Hoses	4	34.22	136.86	136.86	2
Batteries	1	42.76	42.76	42.76	2
Charge Controller	1	165.29	165.29	165.29	2
		Total Cost	3700.76	2480.76	

[1] - Available for use from previous Solar Decathlon projects

[2] - Funded with money received from Santa Clara University School of Engineering Department of Mechanical Engineering

Appendix F: Gantt Chart

A Gantt Chart showing initial goals for tasks and team progress appears on the following page, F-2. An updated Gantt chart with progress as of June 11, 2015 is shown in Figure F.2 on page F-3.

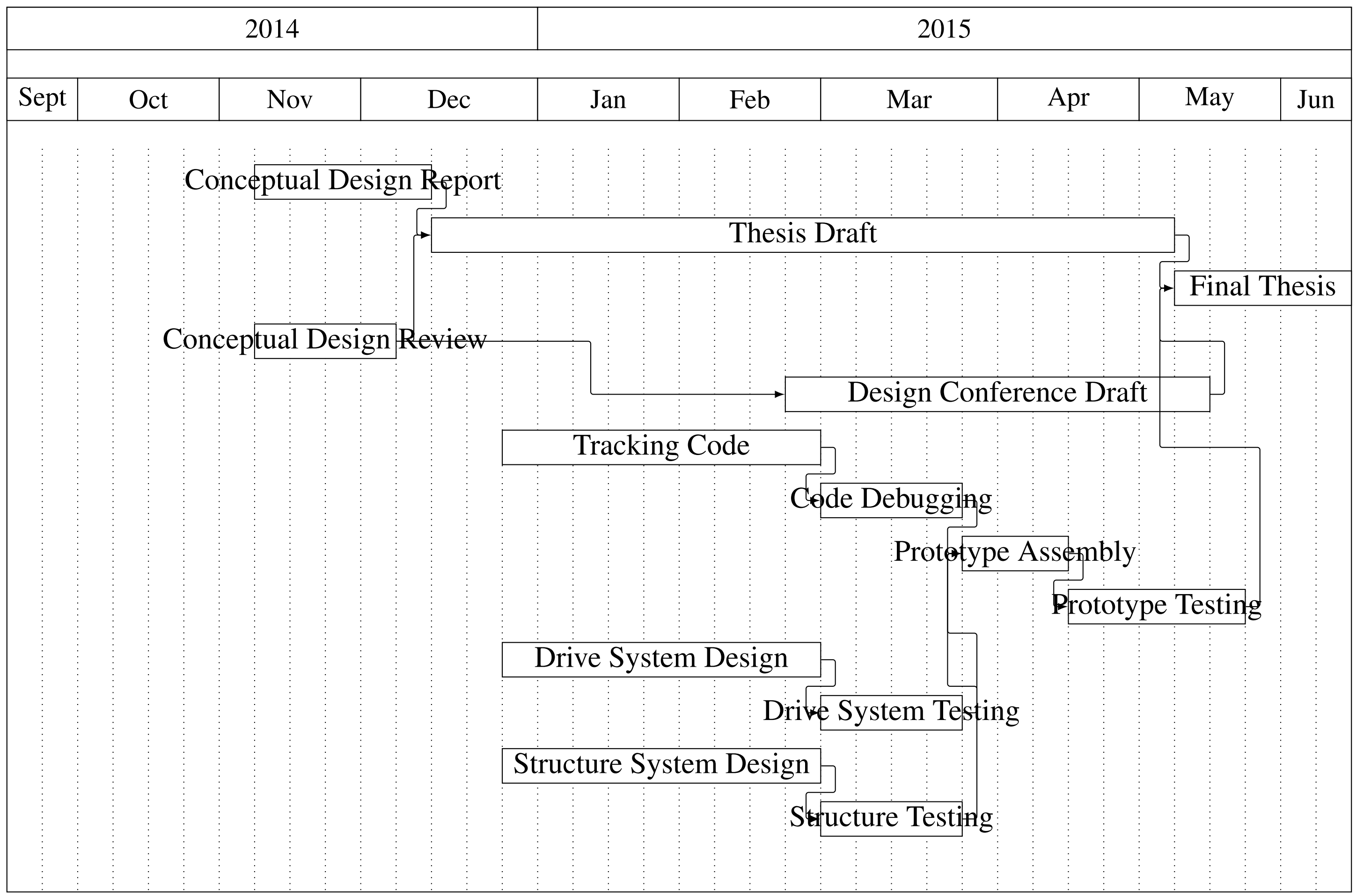


Figure F.1: Initial Gantt Chart

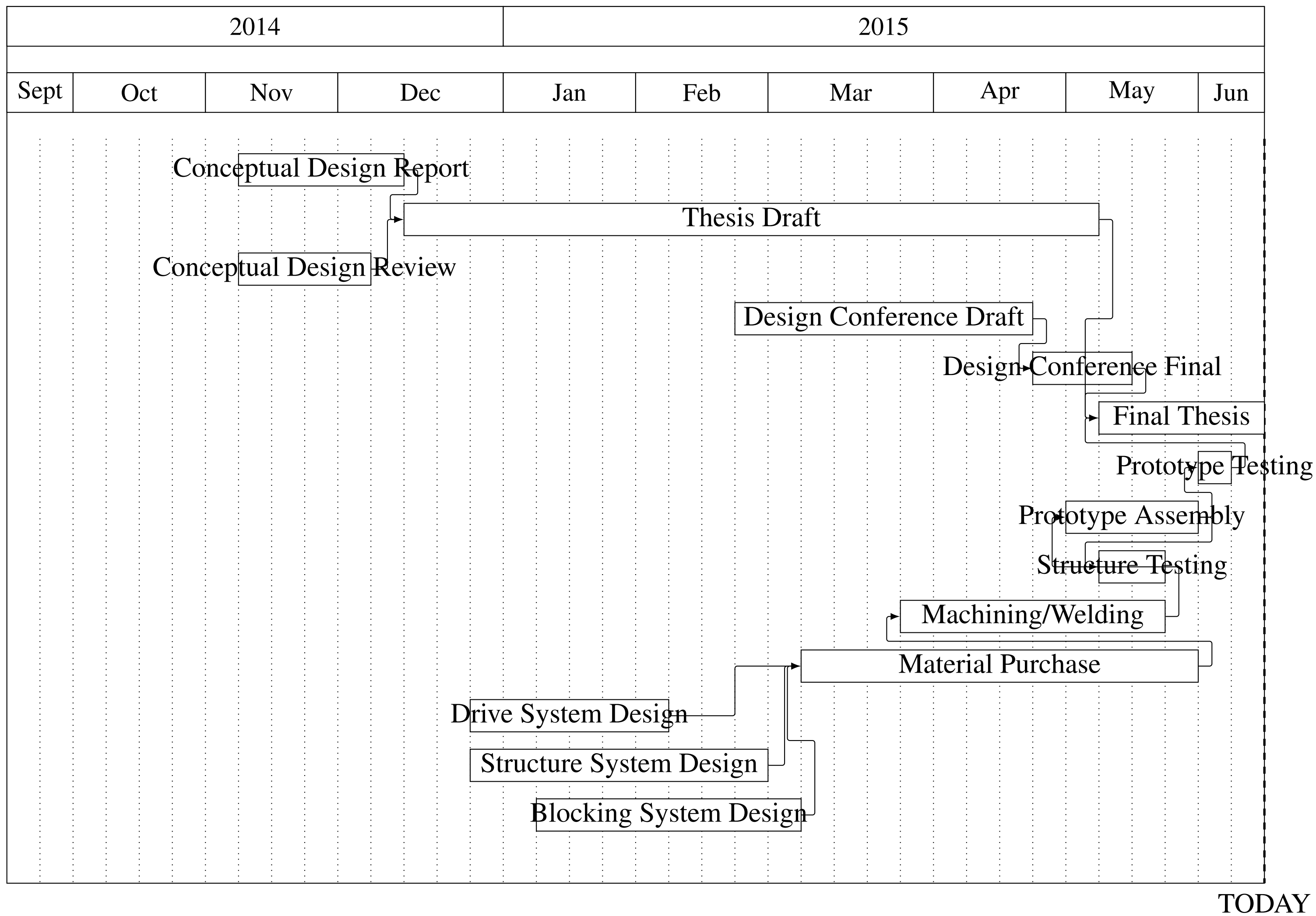


Figure F.2: Updated Gantt Chart and progress

Appendix G: Decision Matrices

Table G.1: Drive system criterion weighting matrix

	Criterion	**One**	**Two**	**Three**	**Four**	**Five**	**Six**	**Sum**	**Factor**
One	Cost		1	1	1	1	0	4	5
Two	Weight	-1		0	-1	-1	-1	-4	1
Three	Size	-1	0		-1	-1	-1	-4	1
Four	Power	-1	1	1		-1	0	0	3
Five	Implementation	-1	1	1	1		-1	1	4
Six	Maintenence	0	1	1	0	1		3	5

Weighting factors are based on the sums across each row. Individual cell entries were entered by moving across the row and determining if the listed criterion was more than [1], less than [-1] or equally as [0] important as the criterion shown in each column's corresponding row.

Table G.2: Drive system concept scoring spreadsheet

		DESIGN IDEAS									
Criteria	**Factor**	**Baseline***		**Linear Actuator**		**Hydraulic Motor**		**Stepper Motor**		**Planetary Gear**	
Time – Design	30	30		45		50		50		40	
Time – Build	35	35		30		30		30		30	
Time – Test	65	65		65		65		65		65	
Time Score	20		20		22.38		23.49		23.49		21.27
Cost	5	3	15	1	5	2	10	1	5	3	15
Weight	1	3	3	3	3	2	2	3	3	3	3
Size	1	3	3	2	2	4	4	4	4	4	4
Power	3	3	9	3	9	5	15	2	6	5	15
Implementation	4	3	12	3	12	5	20	5	20	5	20
Maintenence	5	3	15	2	10	4	20	1	5	3	15
	TOTAL		57.0		38.6		52.5		54.5		70.7
	RANK		2		5		4		3		1
	% MAX		80.6%		54.6%		74.2%		77.1%		100.0%
	MAX		70.7								

*Baseline is a tension cable and pulley system

Appendix H: Cashflow Analysis Charts

	Sunplanter	(FY15 Q4)	(FY16 Q1)	(FY16 Q2)	(FY16 Q3)	(FY16 Q4)	(FY17 Q1)	(FY17 Q2)	(FY17 Q3)	(FY17 Q4)	(FY18 Q1)
	Quarter	1	2	3	4	5	6	7	8	9	10
	Fixed costs										
	Development	$ 1,000	$ 2,000	$ 3,000							
	Jigs & fixtures	$ 300	$ 200	$ 250							
	Prototypes	$ 2,492	$ -	$ -							
	Marketing			$ 5,000	$ 2,500	$ 10,000	$ 7,500	$ 5,000	$ 2,500	$ 10,000	$ 7,500
	Inventory			$ 6,000	$ 6,000	$ 6,000	$ 6,000	$ 6,000	$ 6,000	$ 6,000	$ 6,000
	Unit Costs										
	Unit Production cost			$ 12,337.50	$ 12,337.50	$ 12,337.50	$ 12,337.50	$ 12,337.50	$ 12,337.50	$ 12,337.50	$ 12,337.50
	Production volume			12	12	18	18	12	14	30	30
	Total product cost			$ 148,050	$ 148,050	$ 222,075	$ 222,075	$ 148,050	$ 172,725	$ 370,125	$ 370,125
	Unit Sales										
$ 18,000	Unit sales price				$ 18,000	$ 18,000	$ 18,000	$ 18,000	$ 18,000	$ 18,000	$ 18,000
	Sales volume				12	18	18	12	14	30	30
	Sales income				$ 216,000	$ 324,000	$ 324,000	$ 216,000	$ 252,000	$ 540,000	$ 540,000
	Sunplanter Period cash flow	$ (3,792)	$ (2,200)	$ (162,300)	$ 59,450	$ 85,925	$ 88,425	$ 56,950	$ 70,775	$ 153,875	$ 156,375
	Sunplanter Cumulative cash flo	$ (3,792)	$ (5,992)	$ (168,292)	$ (108,842)	$ (22,917)	$ 65,508	$ 122,458	$ 193,233	$ 347,108	$ 503,483
	PV, month 1	$ (3,792)	$ (2,194)	$ (161,403)	$ 58,958	$ 84,978	$ 87,208	$ 56,011	$ 69,415	$ 150,501	$ 152,523
	Project PV	$ 2,270,137									
$ 5,663	profit per system										
3.33%	Yearly Inflation										

	Sunplanter	(FY18 Q2)	(FY18 Q3)	(FY18 Q4)	(FY19 Q1)	(FY19 Q2)	(FY19 Q3)	(FY19 Q4)	(FY20 Q1)	(FY20 Q2)	(FY20 Q3)	TOTALS
	Quarter	11	12	13	14	15	16	17	18	19	20	
	Fixed costs											
	Development											$ 6,000
	Jigs & fixtures											$ 750
	Prototypes											$ 2,492
	Marketing	$ 5,000	$ 2,500	$ 10,000	$ 7,500	$ 5,000	$ 2,500	$ 10,000	$ 7,500	$ 5,000	$ 2,500	$ 107,500
	Inventory	$ 6,000	$ 6,000	$ 6,000	$ 6,000	$ 6,000	$ 6,000	$ 6,000	$ 6,000	$ 6,000	$ 6,000	$ 108,000
	Unit Costs											
	Unit Production cost	$ 12,337.50	$ 12,337.50	$ 12,337.50	$ 12,337.50	$ 12,337.50	$ 12,337.50	$ 12,337.50	$ 12,337.50	$ 12,337.50	$ 12,337.50	
	Production volume	20	24	40	40	26	32	48	48	32	38	494
	Total product cost	$ 246,750	$ 296,100	$ 493,500	$ 493,500	$ 320,775	$ 394,800	$ 592,200	$ 592,200	$ 394,800	$ 468,825	$ 6,094,725
	Unit Sales											
$ 18,000	Unit sales price	$ 18,000	$ 18,000	$ 18,000	$ 18,000	$ 18,000	$ 18,000	$ 18,000	$ 18,000	$ 18,000	$ 18,000	
	Sales volume	20	24	40	40	26	32	48	48	32	38	482
	Sales income	$ 360,000	$ 432,000	$ 720,000	$ 720,000	$ 468,000	$ 576,000	$ 864,000	$ 864,000	$ 576,000	$ 684,000	$ 8,676,000
	Sunplanter Period cash flow	$ 102,250	$ 127,400	$ 210,500	$ 213,000	$ 136,225	$ 172,700	$ 255,800	$ 258,300	$ 170,200	$ 206,675	$ 2,356,533
	Sunplanter Cumulative cash flo	$ 605,733	$ 733,133	$ 943,633	$ 1,156,633	$ 1,292,858	$ 1,465,558	$ 1,721,358	$ 1,979,658	$ 2,149,858	$ 2,356,533	
	PV, month 1	$ 99,455	$ 123,575	$ 203,615	$ 205,463	$ 131,041	$ 165,668	$ 244,706	$ 246,414	$ 161,919	$ 196,075	$ 2,270,137

	(FY15 Q4)	(FY16 Q1)	(FY16 Q2)	(FY16 Q3)	(FY16 Q4)	(FY17 Q1)	(FY17 Q2)	(FY17 Q3)	(FY17 Q4)	(FY18 Q1)
Quarter	1	2	3	4	5	6	7	8	9	10
Deposit										
Deposit	$ 200,000									
Bank Balance	$ 200,000	$ 204,500	$ 209,101	$ 213,806	$ 218,617	$ 223,536	$ 228,565	$ 233,708	$ 238,966	$ 244,343
Savings Period cash flow		$ 4,500	$ 4,601	$ 4,705	$ 4,811	$ 4,919	$ 5,030	$ 5,143	$ 5,258	$ 5,377
Bank PV	$ 200,000	$ 203,934	$ 207,946	$ 212,036	$ 216,207	$ 220,460	$ 224,796	$ 229,218	$ 233,727	$ 238,324
Bank PV at end	$ 289,579		Bank Interest rate		inflation rate					
Final bank balance	$ 305,234		2.25%		3.33%					

	(FY18 Q2)	(FY18 Q3)	(FY18 Q4)	(FY19 Q1)	(FY19 Q2)	(FY19 Q3)	(FY19 Q4)	(FY20 Q1)	(FY20 Q2)	(FY20 Q3)	
Quarter	11	12	13	14	15	16	17	18	19	20	
Deposit											
Deposit											
Bank Balance	$ 249,841	$ 255,462	$ 261,210	$ 267,087	$ 273,097	$ 279,241	$ 285,524	$ 291,949	$ 298,517	$ 305,234	
Savings Period cash flow	$ 5,498	$ 5,621	$ 5,748	$ 5,877	$ 6,009	$ 6,145	$ 6,283	$ 6,424	$ 6,569	$ 6,717	$ 105,234
Bank PV	$ 243,012	$ 247,792	$ 252,667	$ 257,637	$ 262,704	$ 267,872	$ 273,141	$ 278,514	$ 283,992	$ 289,579	
Bank PV at end											
Final bank balance											

	Sunplanter																										TOTALS
	Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	
	Fixed costs																										
	Up Front Installation	$ 18,000																									$ 18,000
	Maintenence	$ 450	$ 465	$ 480	$ 495	$ 510	$ 525	$ 540	$ 555	$ 570	$ 585	$ 600	$ 615	$ 630	$ 645	$ 660	$ 675	$ 690	$ 705	$ 720	$ 735	$ 750	$ 765	$ 780	$ 795	$ 810	$ 15,746
	Solar Production																										
	System Rating (kW)	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	
	Average Peak Sun Hours	5.35	5.35	5.35	5.35	5.35	5.35	5.35	5.35	5.35	5.35	5.35	5.35	5.35	5.35	5.35	5.35	5.35	5.35	5.35	5.35	5.35	5.35	5.35	5.35	5.35	
Panel Annual Degradation	Tracking Effeciency	115.00%	115.00%	115.00%	115.00%	115.00%	115.00%	115.00%	115.00%	115.00%	115.00%	115.00%	115.00%	115.00%	115.00%	115.00%	115.00%	115.00%	115.00%	115.00%	115.00%	115.00%	115.00%	115.00%	115.00%	115.00%	
0.50%	Panel Efficiency	95.00%	94.50%	94.00%	93.50%	93.00%	92.50%	92.00%	91.50%	91.00%	90.50%	90.00%	89.50%	89.00%	88.50%	88.00%	87.50%	87.00%	86.50%	86.00%	85.50%	85.00%	84.50%	84.00%	83.50%	83.00%	
	Inverter Effeciency	95.00%	95.00%	95.00%	95.00%	95.00%	95.00%	95.00%	95.00%	95.00%	95.00%	95.00%	95.00%	95.00%	95.00%	95.00%	95.00%	95.00%	95.00%	95.00%	95.00%	95.00%	95.00%	95.00%	95.00%	95.00%	
	Wiring Effeciency	91.00%	91.00%	91.00%	91.00%	91.00%	91.00%	91.00%	91.00%	91.00%	91.00%	91.00%	91.00%	91.00%	91.00%	91.00%	91.00%	91.00%	91.00%	91.00%	91.00%	91.00%	91.00%	91.00%	91.00%	91.00%	
	Total Effeciency	82.13%	81.70%	81.26%	80.83%	80.40%	79.97%	79.53%	79.10%	78.67%	78.24%	77.81%	77.37%	76.94%	76.51%	76.08%	75.64%	75.21%	74.78%	74.35%	73.91%	73.48%	73.05%	72.62%	72.19%	71.75%	
	Daily Energy Production (kWh)	20.21	20.11	20.00	19.89	19.79	19.68	19.57	19.47	19.36	19.25	19.15	19.04	18.94	18.83	18.72	18.62	18.51	18.40	18.30	18.19	18.08	17.98	17.87	17.76	17.66	
	Savings																										
PBI Incentive Rate ($/kWh)	Tax Rebate	$ 5,400																									$ 5,400
0.09	PBI	$664.41	$660.91	$657.41	$653.91	$650.42																					$ 3,287
Electricity rate ($/kWh)	Electricity Bill Savings	$1,268.28	$ 1,262	$ 1,255	$ 1,248	$ 1,242	$ 1,235	$ 1,228	$ 1,222	$ 1,215	$ 1,208	$ 1,202	$ 1,195	$ 1,188	$ 1,181	$ 1,175	$ 1,168	$ 1,161	$ 1,155	$ 1,148	$ 1,141	$ 1,135	$ 1,128	$ 1,121	$ 1,115	$ 1,108	$ 24,097
0.1718																											
Days/yr	Sunplanter Period cash flow	$ (11,117)	$ 1,458	$ 1,432	$ 1,407	$ 1,382	$ 710	$ 688	$ 667	$ 645	$ 623	$ 602	$ 580	$ 558	$ 537	$ 515	$ 493	$ 472	$ 450	$ 428	$ 407	$ 385	$ 363	$ 342	$ 320	$ 298	$ 2,937
365.25	Sunplanter Cumulative cash flo	$ (11,117)	$ (9,660)	$ (8,227)	$ (6,820)	$ (5,438)	$ (4,728)	$ (4,040)	$ (3,373)	$ (2,728)	$ (2,105)	$ (1,503)	$ (923)	$ (365)	$ 172	$ 687	$ 1,180	$ 1,652	$ 2,102	$ 2,530	$ 2,937	$ 3,322	$ 3,686	$ 4,027	$ 4,347	$ 4,646	
	PV, Year 1	$ (11,117)	$ 1,453	$ 1,424	$ 1,396	$ 1,367	$ 700	$ 677	$ 654	$ 631	$ 608	$ 585	$ 563	$ 540	$ 518	$ 495	$ 473	$ 451	$ 429	$ 408	$ 386	$ 364	$ 343	$ 322	$ 300	$ 279	$ 2,641
	Project PV	$ 2,641																									
3.33%	Yearly Inflation																										

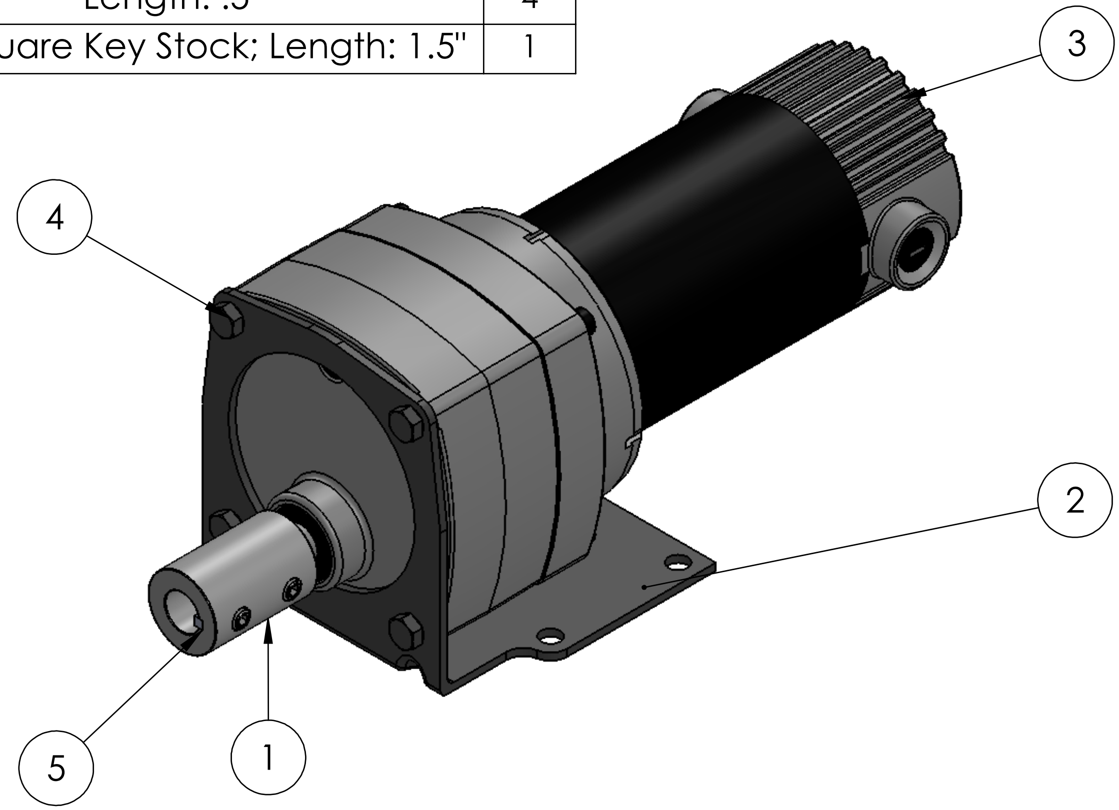
	Rooftop												
	Year	1	2	3	4	5	6	7	8	9	10	11	12
	Fixed costs												
	Up Front Installation	$ 30,000											
	Maintenance	$ 450	$ 465	$ 480	$ 495	$ 510	$ 525	$ 540	$ 555	$ 570	$ 585	$ 600	$ 615
	Solar Production												
	System Rating (kW)	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
	Average Peak Sun Hours	5.35	5.35	5.35	5.35	5.35	5.35	5.35	5.35	5.35	5.35	5.35	5.35
Panel Annual Degradation	Tracking Effeciency	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
0.50%	Panel Efficiency	95.00%	94.50%	94.00%	93.50%	93.00%	92.50%	92.00%	91.50%	91.00%	90.50%	90.00%	89.50%
	Inverter Effeciency	95.00%	95.00%	95.00%	95.00%	95.00%	95.00%	95.00%	95.00%	95.00%	95.00%	95.00%	95.00%
	Wiring Effeciency	91.00%	91.00%	91.00%	91.00%	91.00%	91.00%	91.00%	91.00%	91.00%	91.00%	91.00%	91.00%
	Total Effeciency	82.13%	81.70%	81.26%	80.83%	80.40%	79.97%	79.53%	79.10%	78.67%	78.24%	77.81%	77.37%
	Daily Energy Production (kWh	17.58	17.48	17.39	17.30	17.21	17.11	17.02	16.93	16.84	16.74	16.65	16.56
	Savings												
PBI Incentive Rate ($/kWh)	Tax Rebate	$ 9,000											
0.09	PBI	$577.74	$574.70	$571.66	$568.62	$565.58							
Electricity rate ($/kWh)	Electricity Bill Savings	$1,102.85	$ 1,097	$ 1,091	$ 1,085	$ 1,080	$ 1,074	$ 1,068	$ 1,062	$ 1,056	$ 1,051	$ 1,045	$ 1,039
0.1718													
Days/yr	TF Period cash flow	$ (19,769)	$ 1,207	$ 1,183	$ 1,159	$ 1,135	$ 549	$ 528	$ 507	$ 487	$ 466	$ 445	$ 424
365.25	Rooftop Cumulative cash flow	$ (19,769)	$ (18,563)	$ (17,380)	$ (16,221)	$ (15,085)	$ (14,536)	$ (14,008)	$ (13,501)	$ (13,014)	$ (12,549)	$ (12,104)	$ (11,680)
	PV, Year 1	$ (19,769)	$ 1,203	$ 1,176	$ 1,150	$ 1,123	$ 541	$ 519	$ 498	$ 476	$ 454	$ 433	$ 411
	Project PV	$ (9,249)											
3.33%	Yearly Inflation												

Rooftop														TOTALS
Year	13	14	15	16	17	18	19	20	21	22	23	24	25	
Fixed costs														
Up Front Installation														$ 30,000
Maintenance	$ 630	$ 645	$ 660	$ 675	$ 690	$ 705	$ 720	$ 735	$ 750	$ 765	$ 780	$ 795	$ 810	$ 15,746
Solar Production														
System Rating (kW)	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	
Average Peak Sun Hours	5.35	5.35	5.35	5.35	5.35	5.35	5.35	5.35	5.35	5.35	5.35	5.35	5.35	
Tracking Effeciency	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	
Panel Efficiency	89.00%	88.50%	88.00%	87.50%	87.00%	86.50%	86.00%	85.50%	85.00%	84.50%	84.00%	83.50%	83.00%	
Inverter Effeciency	95.00%	95.00%	95.00%	95.00%	95.00%	95.00%	95.00%	95.00%	95.00%	95.00%	95.00%	95.00%	95.00%	
Wiring Effeciency	91.00%	91.00%	91.00%	91.00%	91.00%	91.00%	91.00%	91.00%	91.00%	91.00%	91.00%	91.00%	91.00%	
Total Effeciency	76.94%	76.51%	76.08%	75.64%	75.21%	74.78%	74.35%	73.91%	73.48%	73.05%	72.62%	72.19%	71.75%	
Daily Energy Production (kWh	16.47	16.37	16.28	16.19	16.10	16.00	15.91	15.82	15.73	15.63	15.54	15.45	15.36	
Savings														
Tax Rebate														$ 9,000
PBI														$ 2,858
Electricity Bill Savings	$ 1,033	$ 1,027	$ 1,022	$ 1,016	$ 1,010	$ 1,004	$ 998	$ 993	$ 987	$ 981	$ 975	$ 969	$ 964	$ 20,954
TF Period cash flow	$ 403	$ 383	$ 362	$ 341	$ 320	$ 299	$ 279	$ 258	$ 237	$ 216	$ 195	$ 175	$ 154	$ (9,035)
Rooftop Cumulative cash flow	$ (11,276)	$ (10,894)	$ (10,532)	$ (10,191)	$ (9,871)	$ (9,571)	$ (9,293)	$ (9,035)	$ (8,798)	$ (8,581)	$ (8,386)	$ (8,211)	$ (8,057)	
PV, Year 1	$ 390	$ 369	$ 348	$ 327	$ 306	$ 286	$ 265	$ 245	$ 224	$ 204	$ 184	$ 164	$ 144	$ (9,249)

Appendix I: Technical Drawings

Table I.1: Technical Drawing Table of Contents

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	6412K41	Shaft Coupling	1
2	125-100-9998	Motor Mounting Bracket	1
3	175DC-011-175-1369	DC Gearmotor	1
4	Hex Finished Bolt 10-32	Length: .5"	4
5	98535A130	1/8" Square Key Stock; Length: 1.5"	1



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NEXT ASSY | USED ON

APPLICATION

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±.05
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Mixed

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	S. Hight	5/7/15
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

Sunplanter

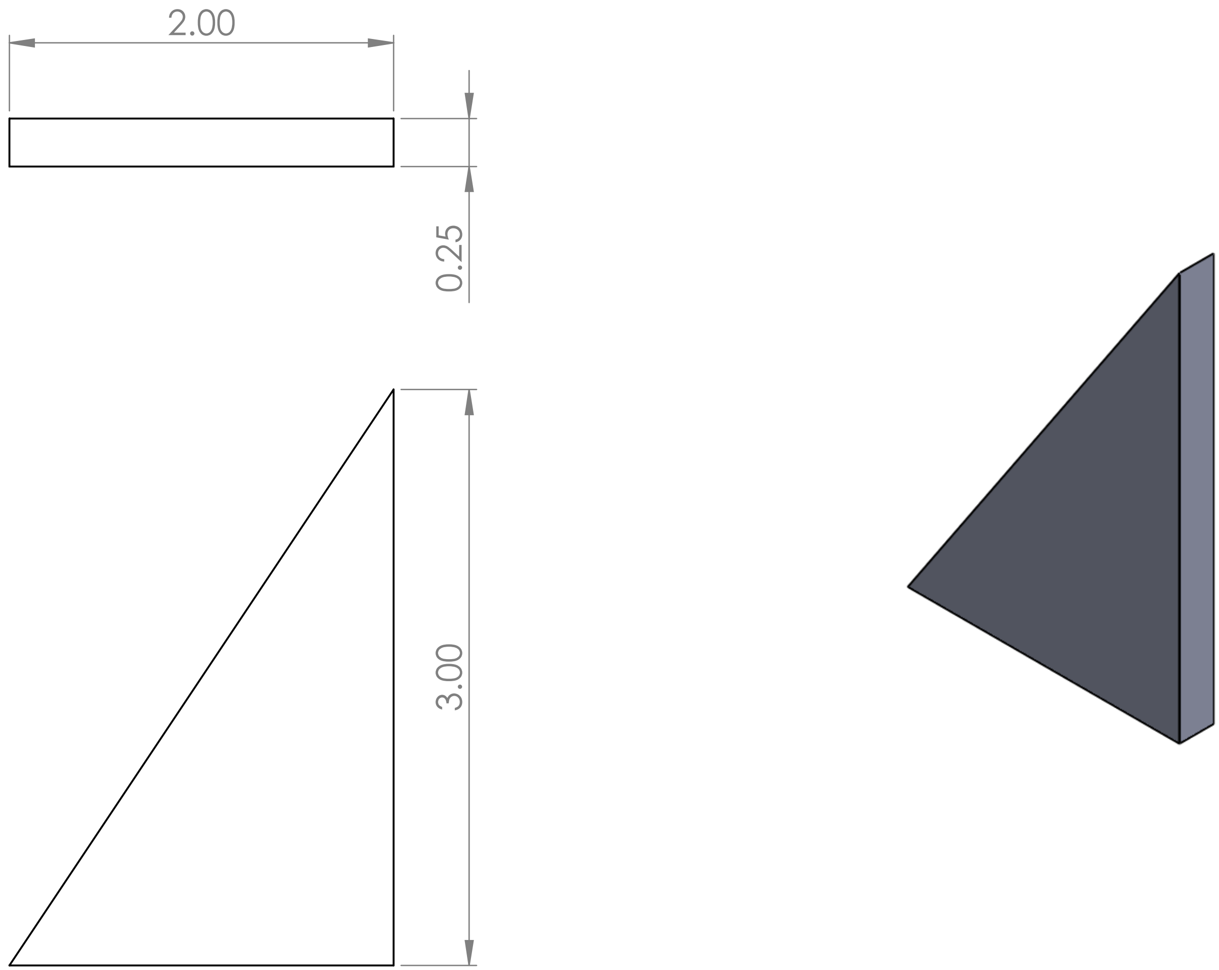
TITLE:

Drive Assembly

SIZE	DWG. NO.	REV
A	D-01-0A	A

SCALE: 1:2 | WEIGHT: | SHEET 1 OF 1

5 4 3 2 1



		UNLESS OTHERWISE SPECIFIED:
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ±.05 ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.005
		INTERPRET GEOMETRIC TOLERANCING PER:
		MATERIAL 6061-T6 Al
NEXT ASSY	USED ON	FINISH
APPLICATION		DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	J. Gaither	5/7/2015
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

PROPRIETARY AND CONFIDENTIAL

Sunplanter

TITLE:

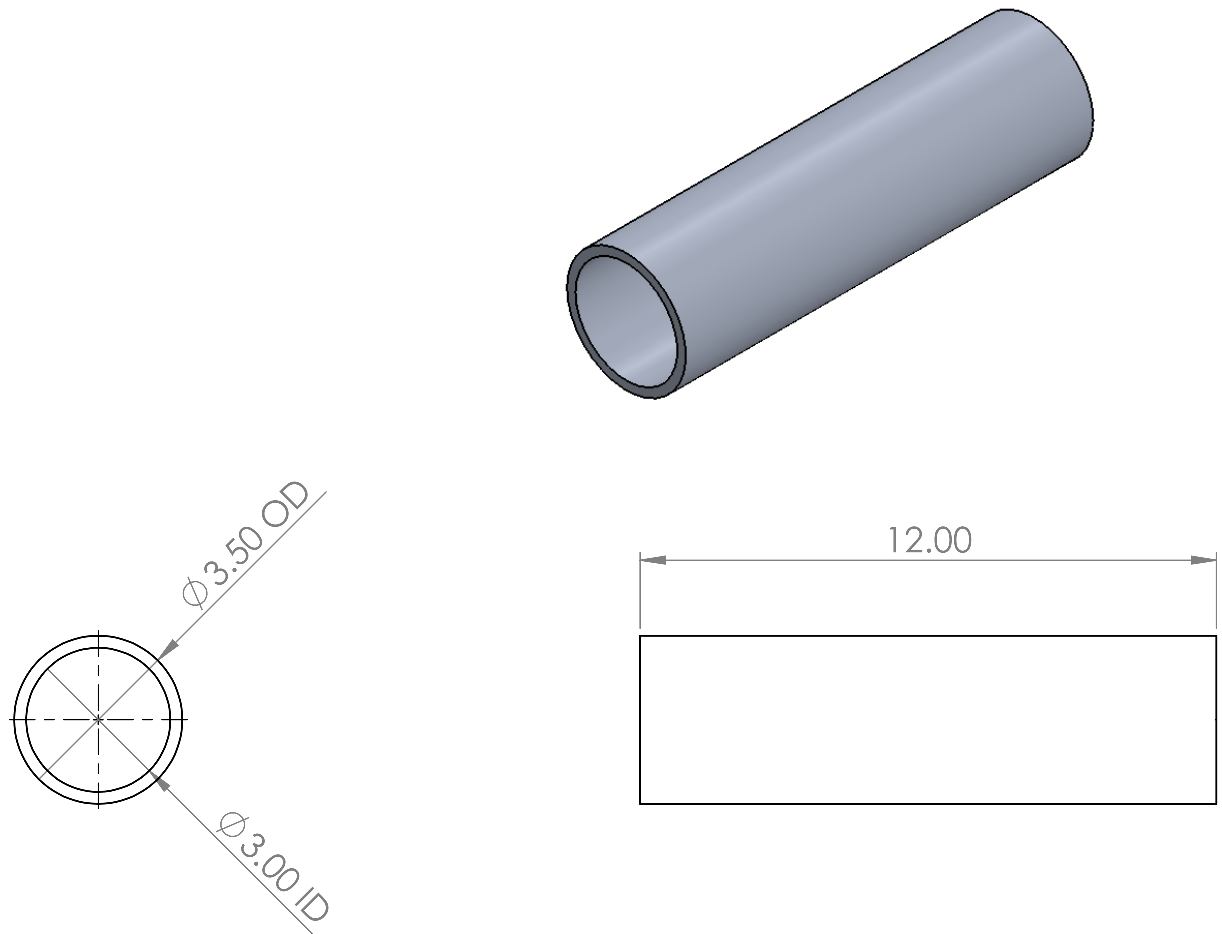
Reinforcing Fin

SIZE	DWG. NO.	REV
A	F-01-0	A

SCALE: 1:1 WEIGHT: SHEET 1 OF 1

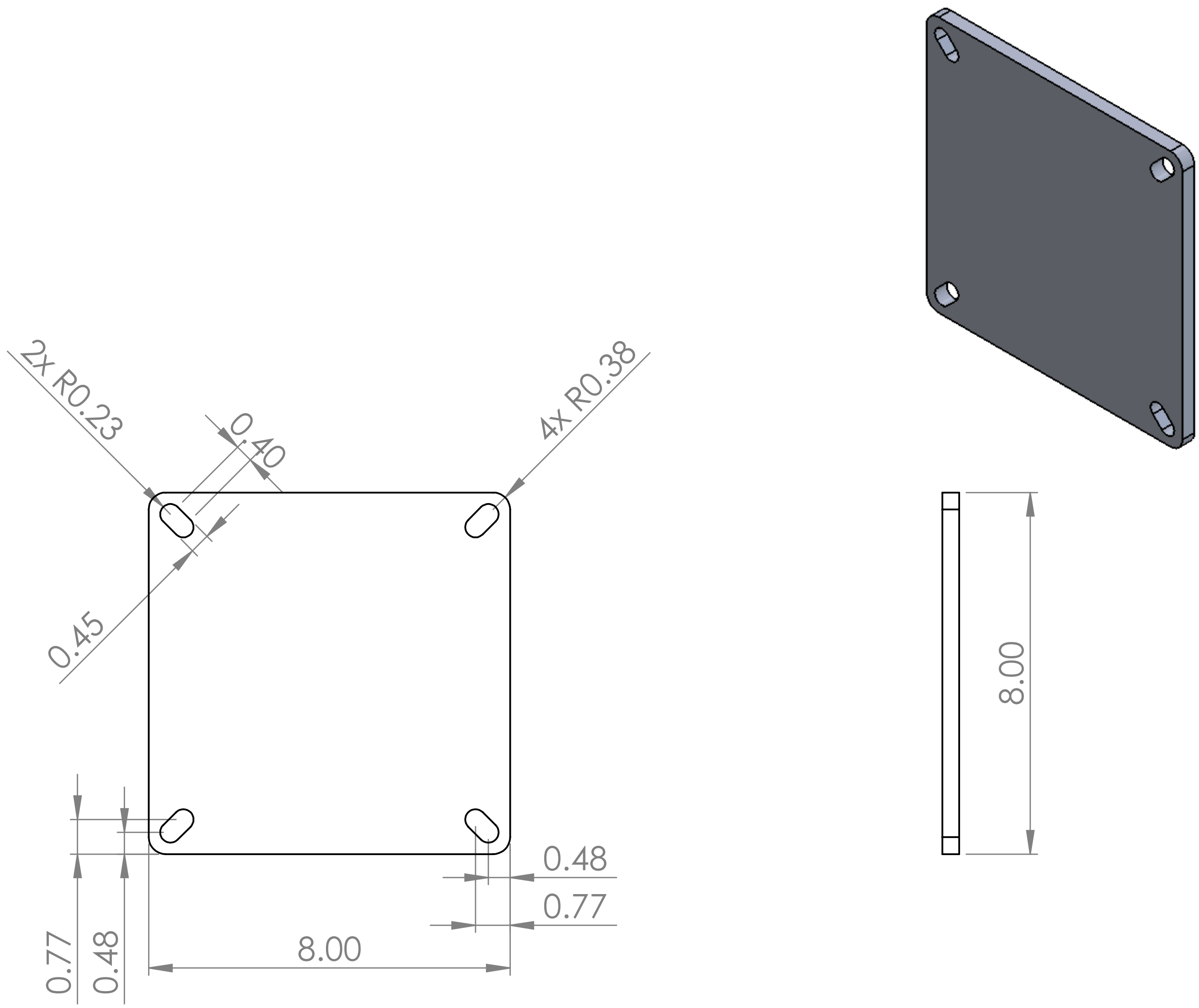
5 4 3 2 1

I-5



		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	**Sunplanter**
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ±.05 ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.005	DRAWN	S. Hight	5/20/15	TITLE: Foundation Sleeve
			CHECKED			
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL 6061-T6 Al	COMMENTS:			SIZE A · DWG. NO. F-02-0 · REV A
NEXT ASSY	USED ON	FINISH				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:4 · WEIGHT: · SHEET 1 OF 1

5 4 3 2 1



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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±.05
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
6061-T6 Al

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	S. Hight	5/20/15
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

Sunplanter

TITLE:

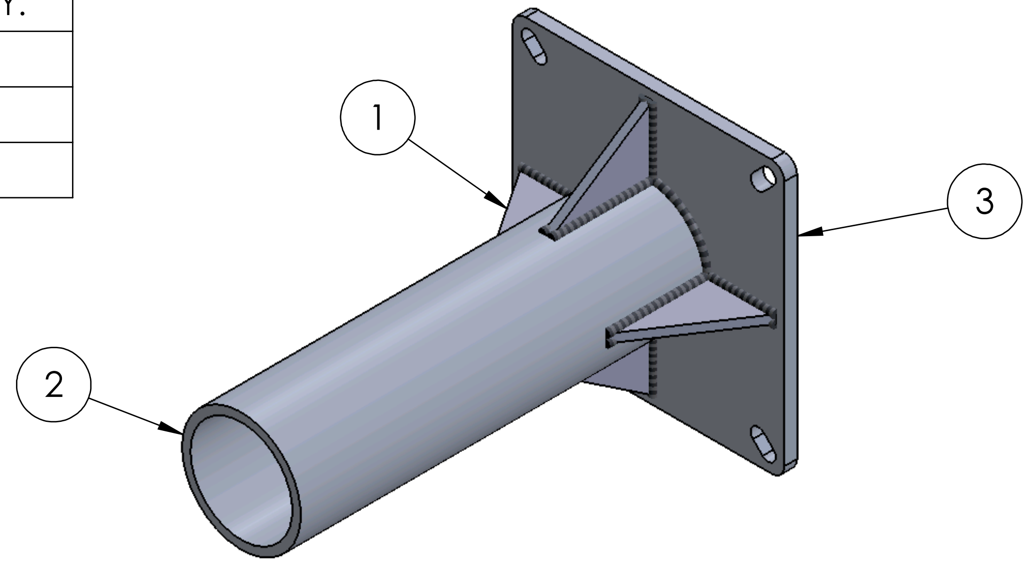
Foundation Plate

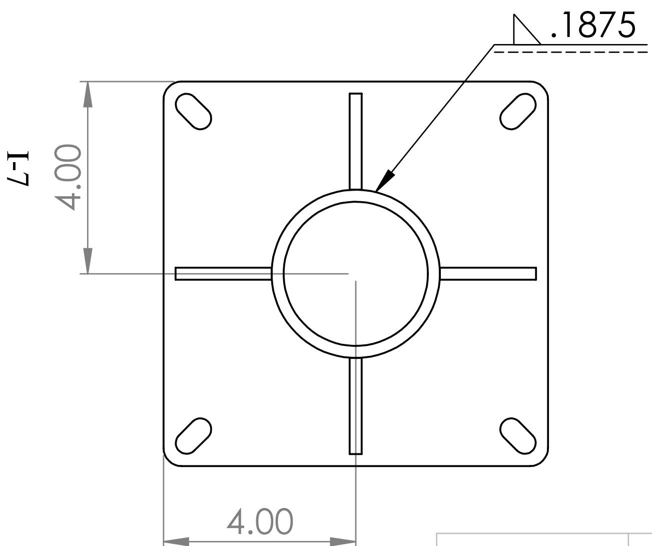
SIZE	DWG. NO.	REV
A	F-03-0	A

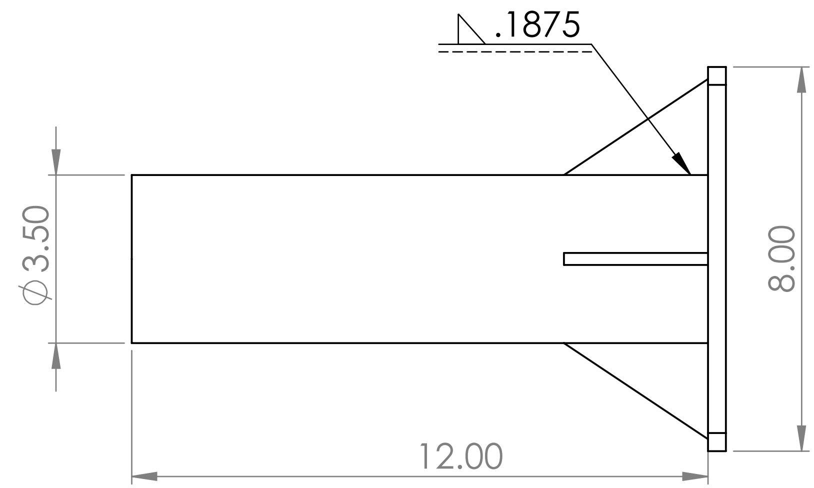
SCALE: 1:4 WEIGHT: SHEET 1 OF 1

5 4 3 2 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	F-01-0	Reinforcing Fin	4
2	F-02-0	Foundation Sleeve	1
3	F-03-0	Foundation Base	1







UNLESS OTHERWISE SPECIFIED:		
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ±.05 ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.005		
INTERPRET GEOMETRIC TOLERANCING PER:		
MATERIAL 6061-T6 Al		
FINISH	NEXT ASSY	USED ON
DO NOT SCALE DRAWING	APPLICATION	

	NAME	DATE
DRAWN	S. Hight	5/20/15
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:
TIG Welds all 3/16 inch fillet

Sunplanter

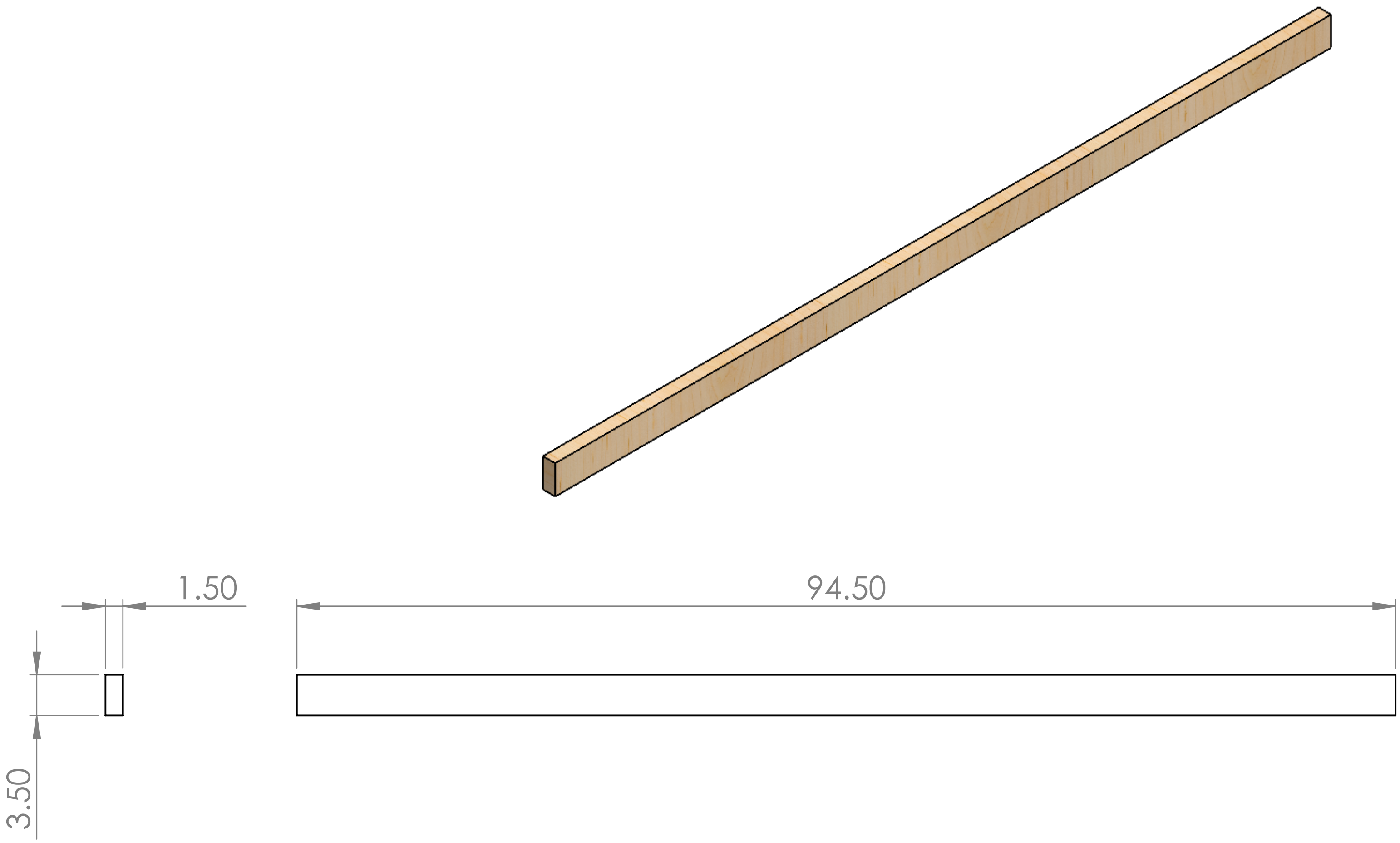
TITLE:

Foundation Weldment

SIZE	DWG. NO.	REV
A	F-04-0W	A

SCALE: 1:4 WEIGHT: SHEET 1 OF 1

5 4 3 2 1



NEXT ASSY	USED ON
APPLICATION	

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UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±.05
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Maple

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	S. Hight	6/4/15
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

Sunplanter

TITLE:

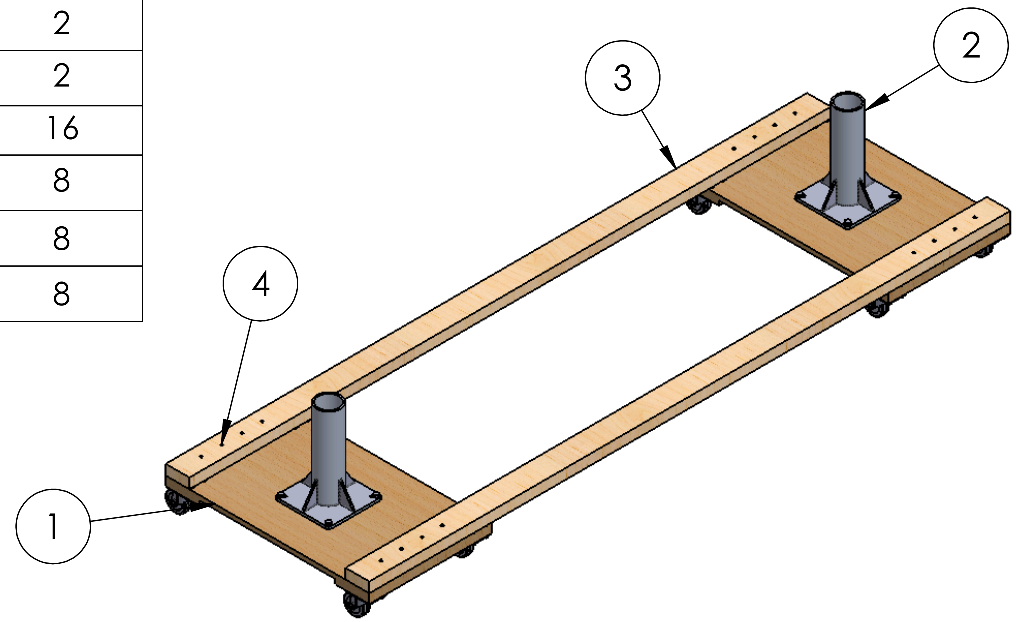
Platform Coupler

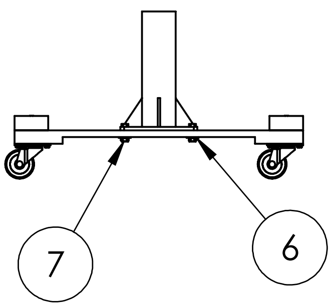
SIZE	DWG. NO.	REV
A	F-05-0	A

SCALE: 1:20 WEIGHT: SHEET 1 OF 1

5 4 3 2 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	41696	Solid Deck Dolly	2
2	F-04-0W	Foundation Weldment	2
3	F-05-0	Platform Coupler	2
4	#8 Wood Screw	Length: 2.5"	16
5	7 16-14 Bolt	Length: 1.5"	8
6	7/16 Flat Washer		8
7	7/16-14 Nut		8





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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±.05
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Mixed

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	B. Suehiro	6/4/15
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

Sunplanter

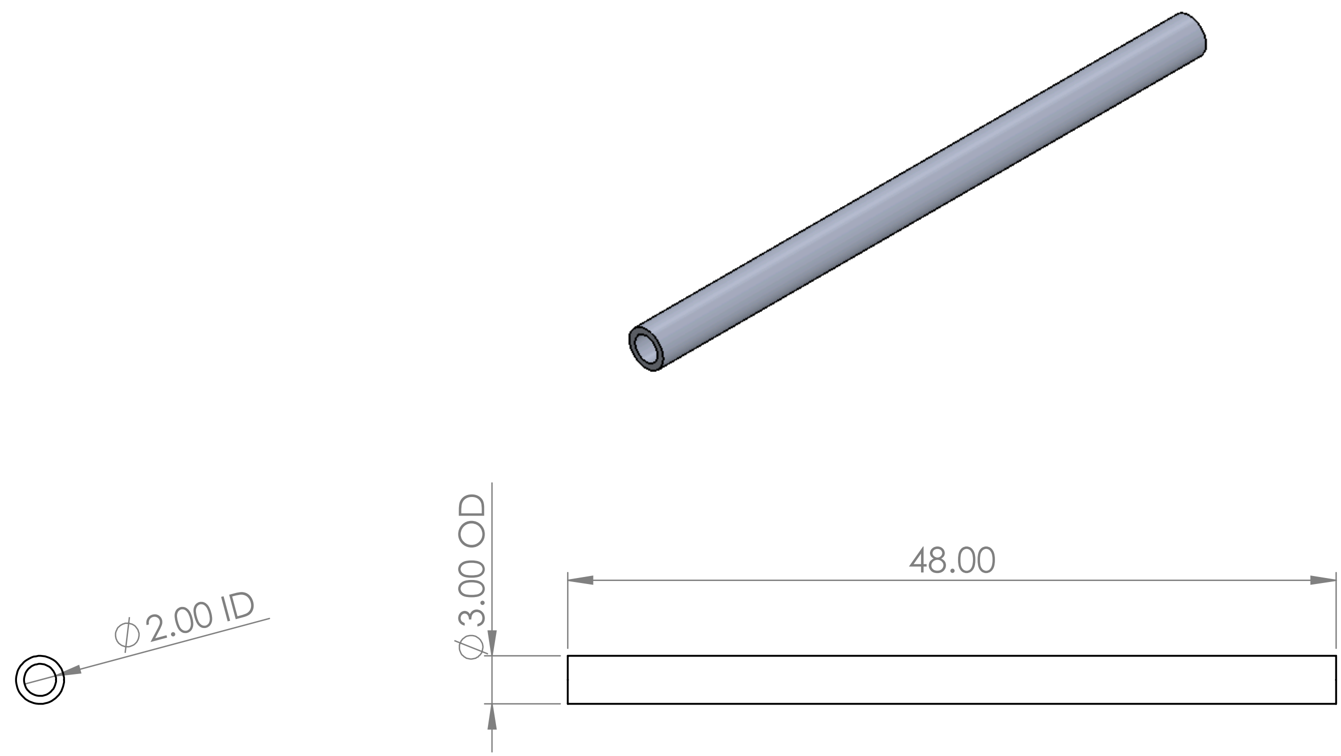
TITLE:

Mobile Foundation Assembly

SIZE	DWG. NO.	REV
A	F-06-0A	A

SCALE: 1:20 WEIGHT: SHEET 1 OF 1

5 4 3 2 1



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	APPLICATION	

UNLESS OTHERWISE SPECIFIED:		
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± .05 ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005		
INTERPRET GEOMETRIC TOLERANCING PER:		
MATERIAL 6061-T6 Al		
FINISH		
DO NOT SCALE DRAWING		

	NAME	DATE
DRAWN	J. Gaither	5/7/2015
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

Sunplanter

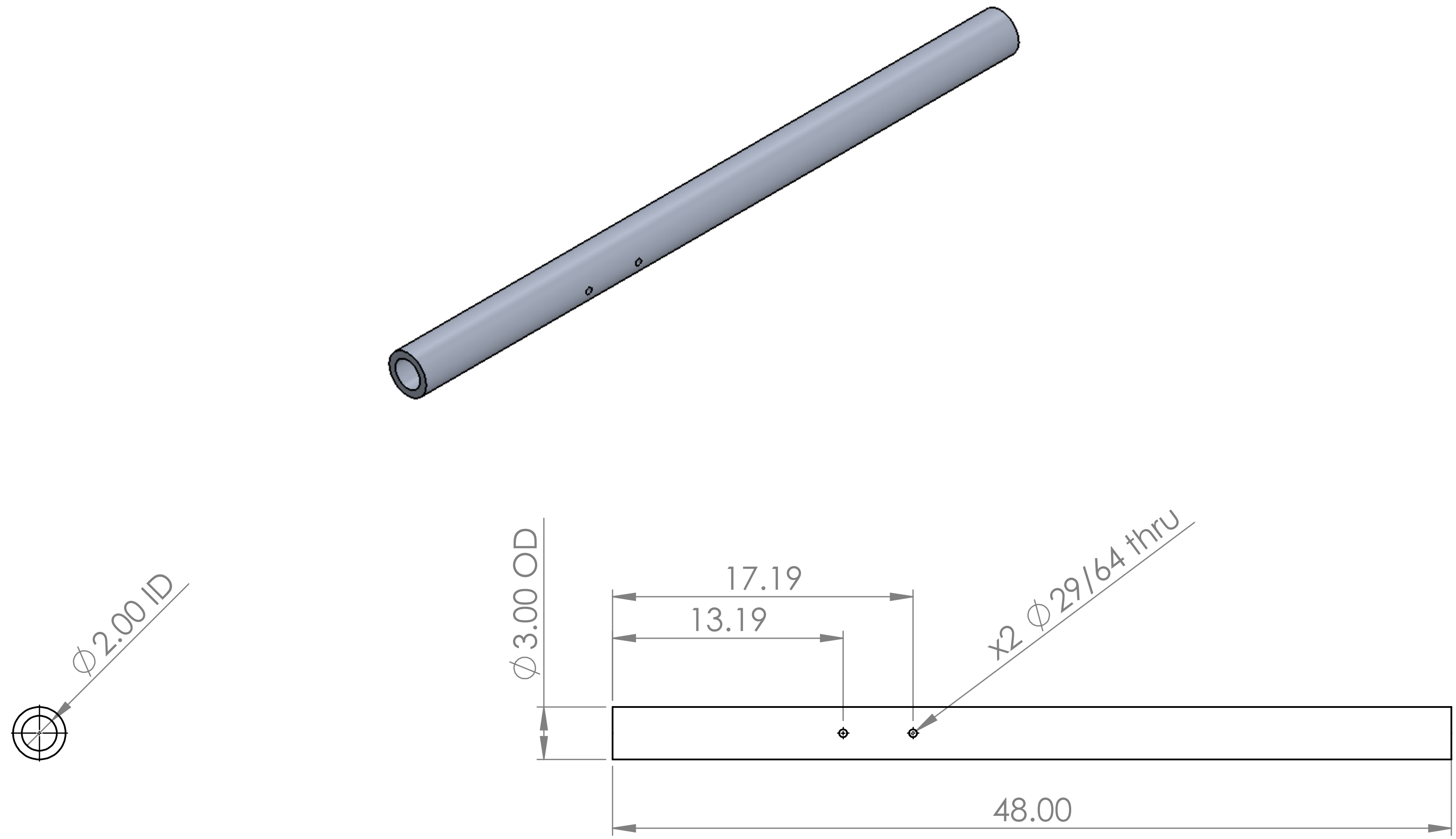
TITLE:

Vertical Support

SIZE	DWG. NO.	REV
A	S-01-0	A
SCALE: 1:12	WEIGHT:	SHEET 1 OF 1

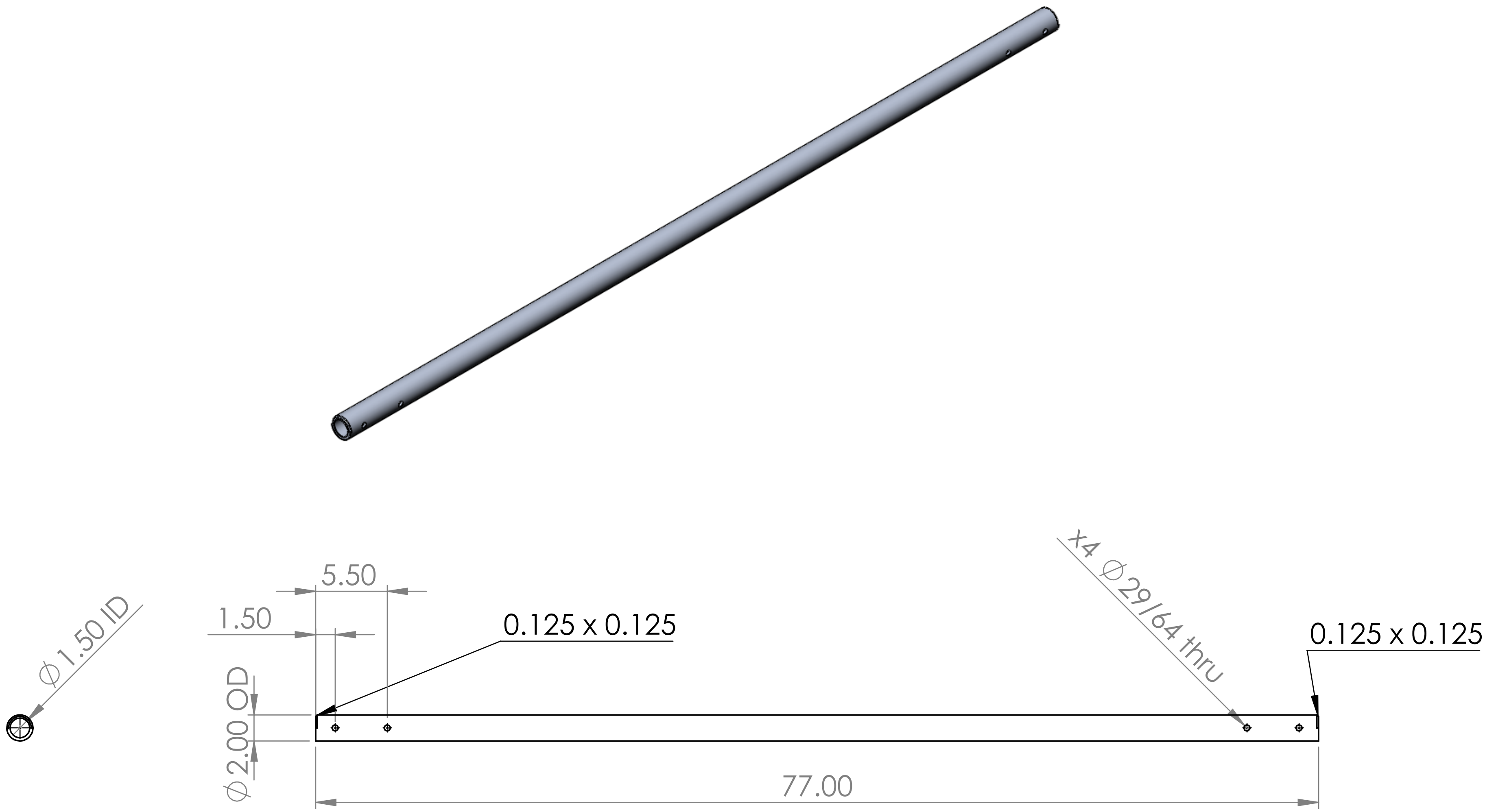
5 4 3 2 1

I-11



		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	Sunplanter
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ±.05 ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.005	DRAWN	J. Gaither	5/7/2015	TITLE: Vertical Support w/ Holes
			CHECKED			
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL 6061-T6 Al	COMMENTS:			SIZE A
NEXT ASSY	USED ON	FINISH				DWG. NO. S-01-1
APPLICATION		DO NOT SCALE DRAWING				REV B
						SCALE: 1:12
						WEIGHT:
						SHEET 1 OF 1

5 4 3 2 1



		UNLESS OTHERWISE SPECIFIED:
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ±.05 ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.005
		INTERPRET GEOMETRIC TOLERANCING PER:
		MATERIAL 6061-T6 Al
NEXT ASSY	USED ON	FINISH
APPLICATION		DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	J. Gaither	5/7/2015
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

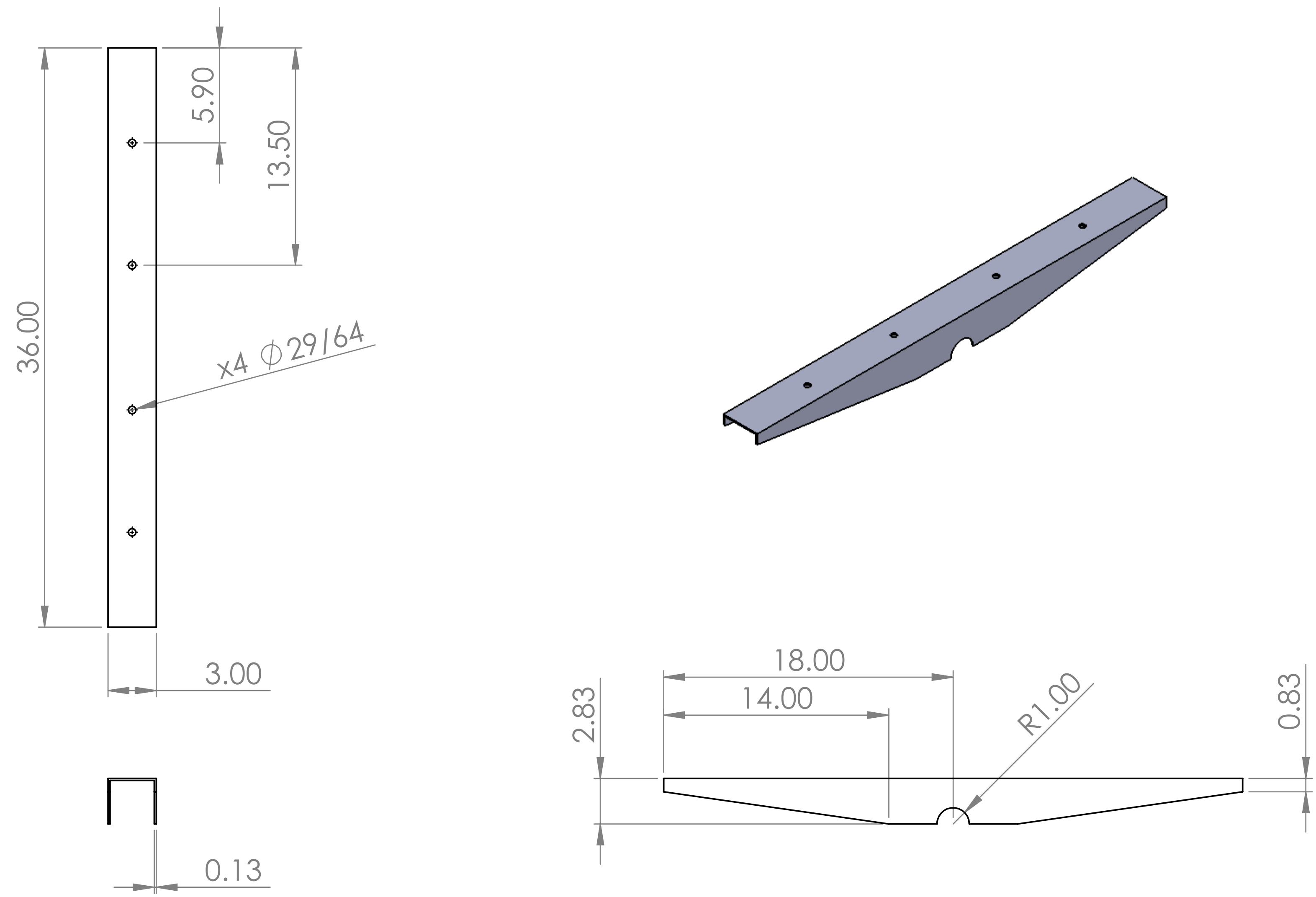
Sunplanter

TITLE:

Horizontal Support

SIZE	DWG. NO.	REV
A	S-02-0	B
SCALE: 1:12	WEIGHT:	SHEET 1 OF 1

5 4 3 2 1



		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ±.05 ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.005	DRAWN	J. Gaither	5/7/2015
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL 6061-T6 Al	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

PROPRIETARY AND CONFIDENTIAL

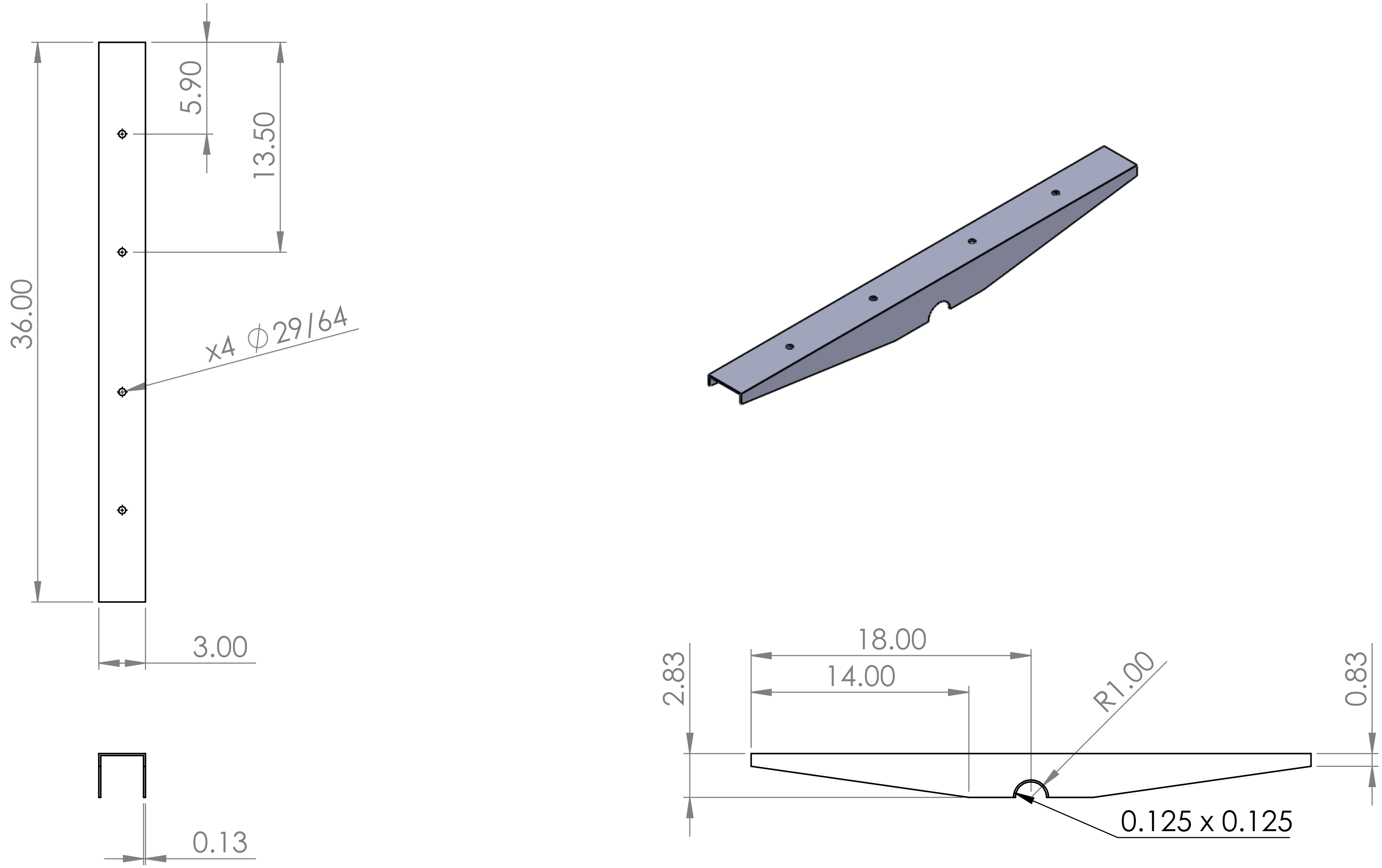
Sunplanter

TITLE: Rail Support Flange

SIZE	DWG. NO.	REV
A	S-03-0	C

SCALE: 1:12 WEIGHT: SHEET 1 OF 1

5 4 3 2 1



		UNLESS OTHERWISE SPECIFIED:
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ±.05 ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.005
		INTERPRET GEOMETRIC TOLERANCING PER:
		MATERIAL 6061-T6 Al
NEXT ASSY	USED ON	FINISH
APPLICATION		DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	J. Gaither	5/7/2015
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

Sunplanter

TITLE:

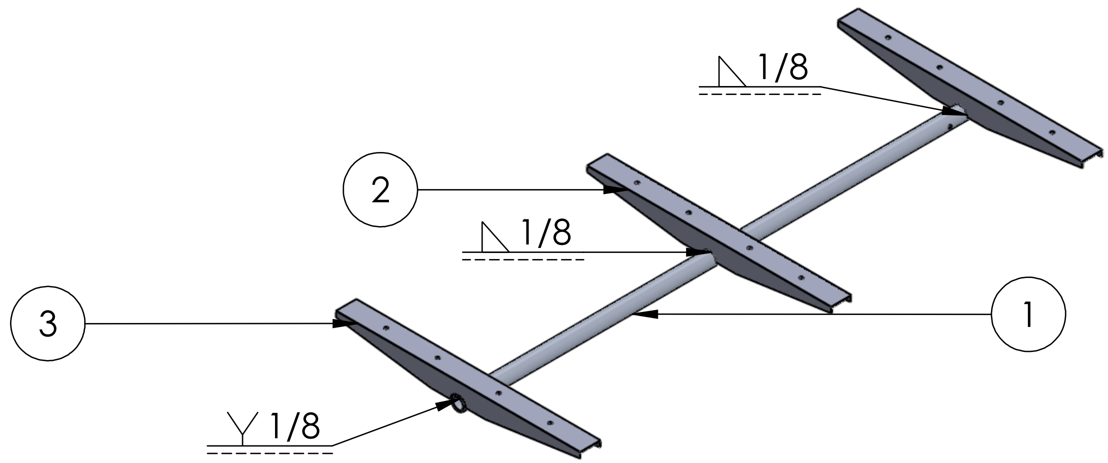
Rail Support Flange w/ Chamfer

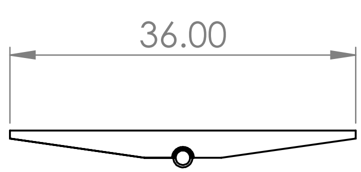
SIZE	DWG. NO.	REV
A	S-03-1	C

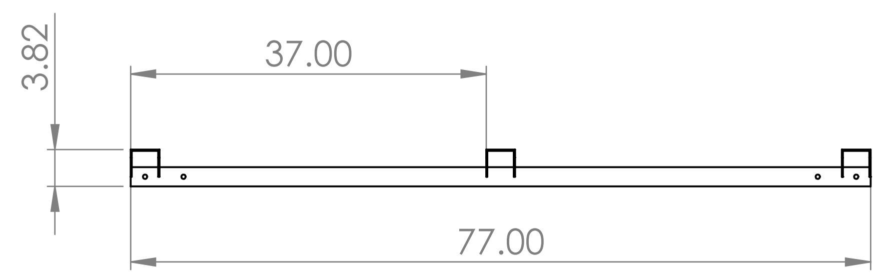
SCALE: 1-12 WEIGHT: SHEET 1 OF 1

5 4 3 2 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	S-02-0	Horizontal Support	1
2	S-03-0	Rail Support Flange	1
3	S-03-1	Rail Support Flange w/ Chamfer	2







NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±.05
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
6061-T6 Al

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	J. Gaither	5/7/2015
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

Sunplanter

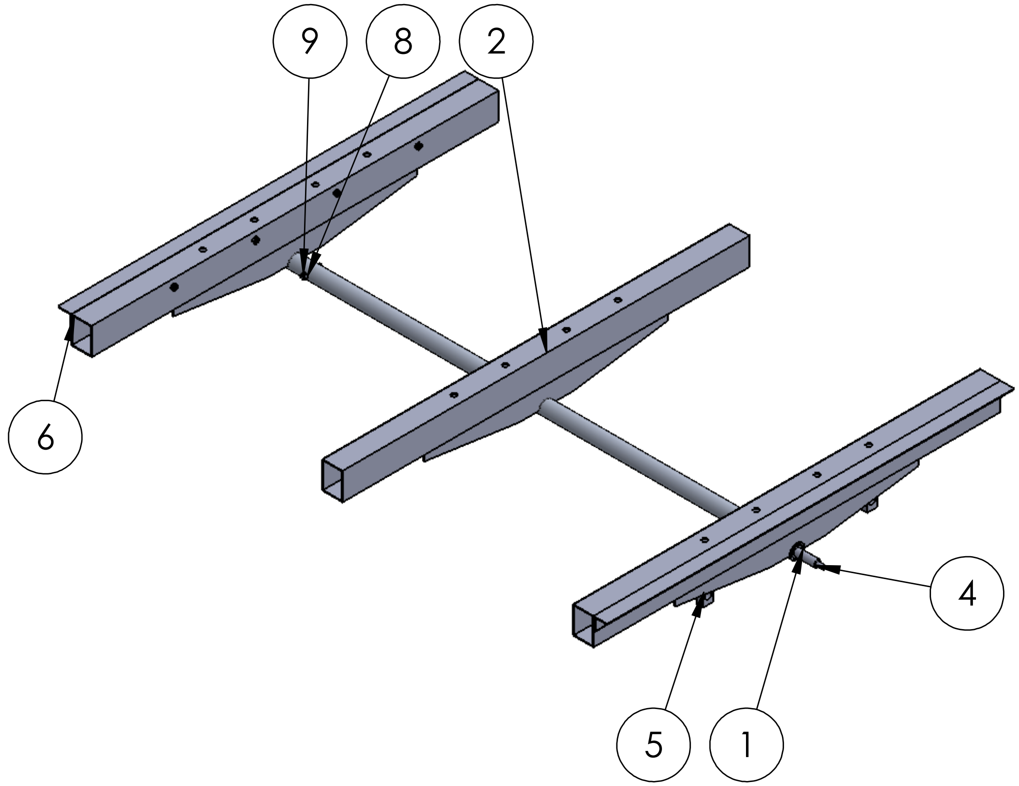
TITLE:
Panel Support Weldment

SIZE	DWG. NO.	REV
A	S-04-0W	A

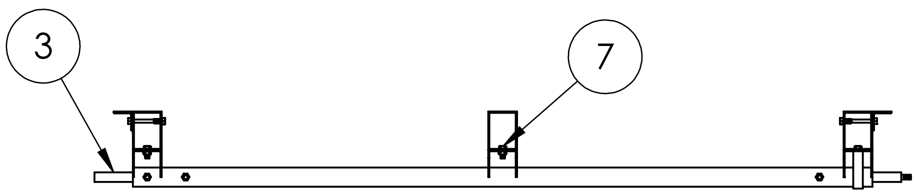
SCALE: 1:20 WEIGHT: SHEET 1 OF 1

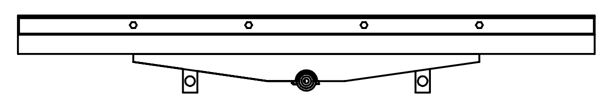
5 4 3 2 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	S-04-0W	Panel Support Weldment	1
2	S-08-0	Center Mounting Rail	1
3	S-10-0	Support Shaft	1
4	S-10-1	Rotational Shaft	1
5	S-11-0	Clevis Bar	2
6	S-16-0A	Edge Rail Assembly	2
7	7/16-14 Bolt	Length: 1"	12
8	7/16-14 Bolt	Length 2.5"	4
9	7/16-14 Nut		14



I-16





NEXT ASSY	USED ON
APPLICATION	

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ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Mixed

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	B Suehiro	6/4/15
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

Sunplanter

TITLE:

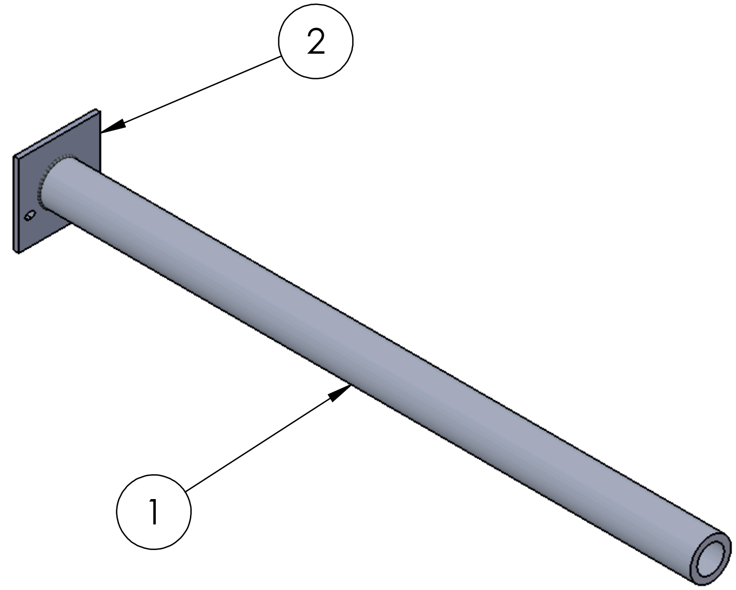
Panel Support Assembly

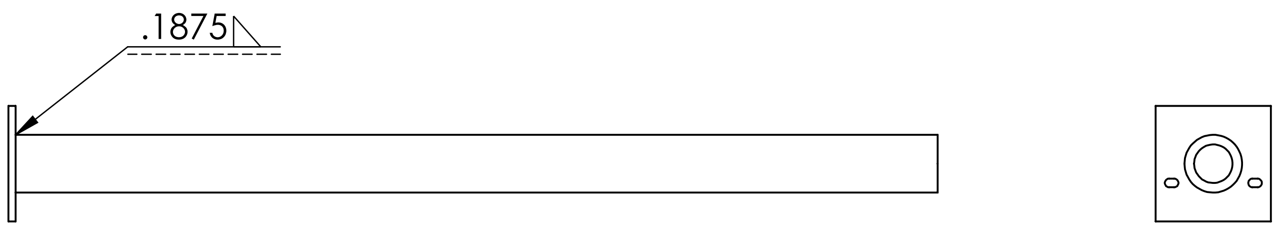
SIZE	DWG. NO.	REV
A	S-05-0A	A

SCALE: 1:20 WEIGHT: SHEET 1 OF 1

5 4 3 2 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	S-01-0	Vertical Support	1
2	S-12-0	Pillow Block Shelf	1





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NEXT ASSY	USED ON
APPLICATION	

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TOLERANCES:
FRACTIONAL ±.05
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
6061-T6 Al

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	S. Hight	6/4/15
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

Sunplanter

TITLE:

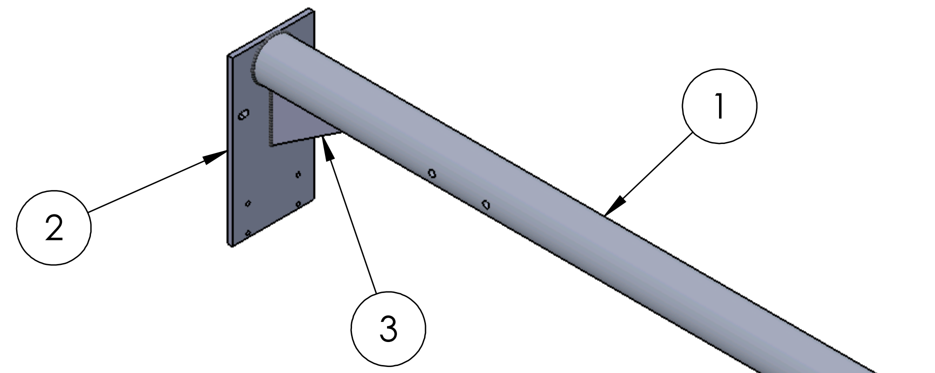
Vertical Support Weldment

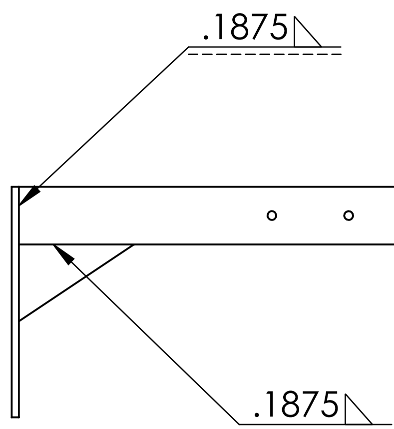
SIZE	DWG. NO.	REV
A	S-06-0W	A

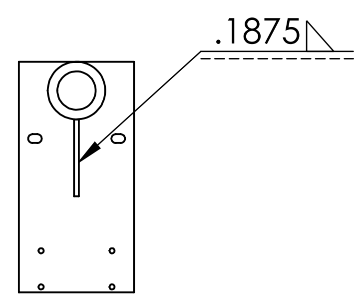
SCALE:1:10 WEIGHT: SHEET 1 OF 1

5 4 3 2 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	S-01-1	Vertical Support w/ Holes	1
2	S-12-1	Pillow Block Shelf	1
3	S-13-0	Shelf Support	1







NEXT ASSY	USED ON	
APPLICATION		

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±.05
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
6061-T6 Al

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	S. Hight	6/4/15
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

Sunplanter

TITLE:

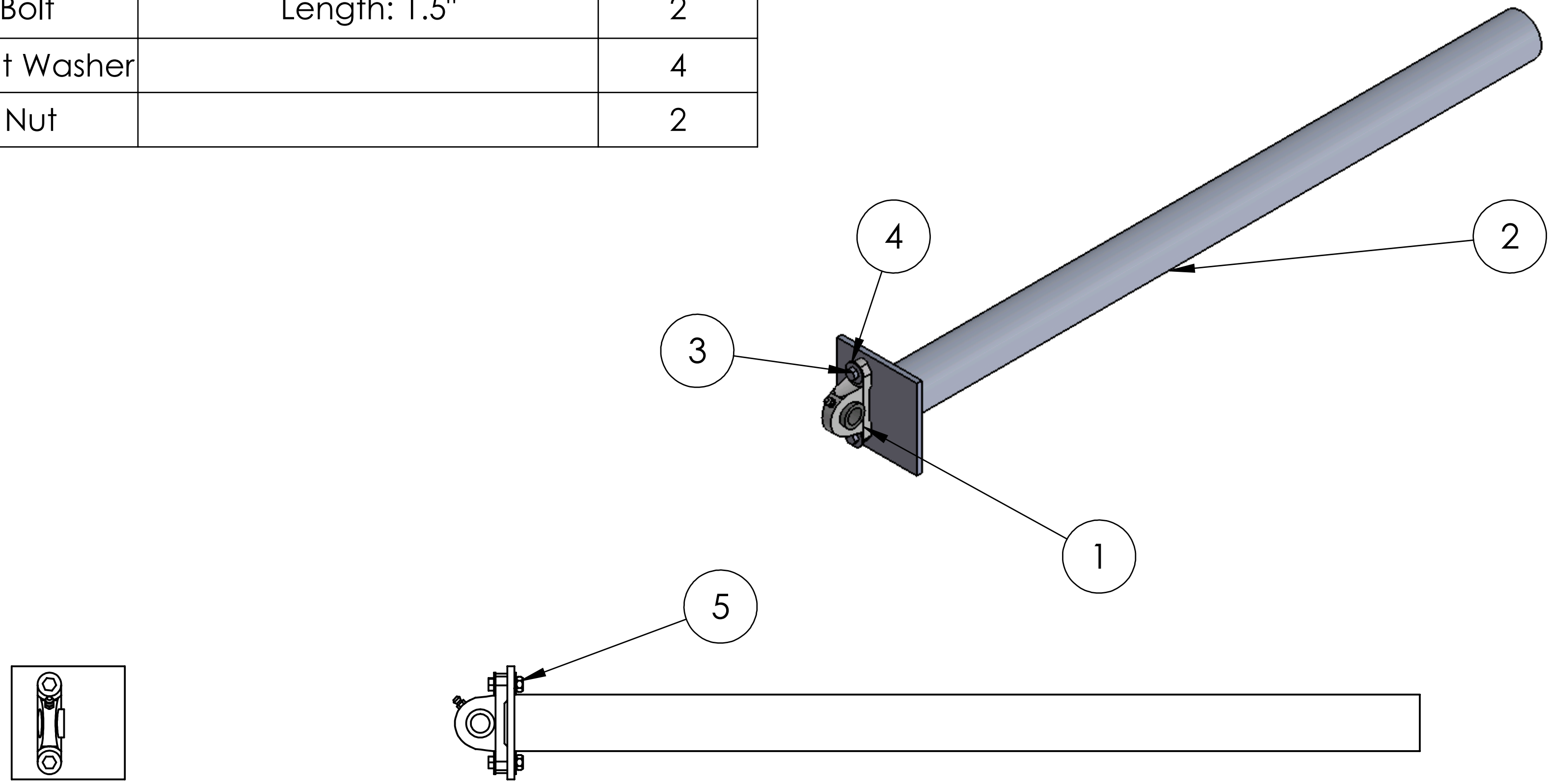
Vertical Support Weldment w/ Holes

SIZE A | DWG. NO. S-06-1W | REV A

SCALE: 1:10 | WEIGHT: | SHEET 1 OF 1

5 4 3 2 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	6668K42	Pillow Block	1
2	S-06-0W	Vertical Support Weldment	1
3	7 16-14 Bolt	Length: 1.5"	2
4	7/16 Flat Washer		4
5	7/16-14 Nut		2

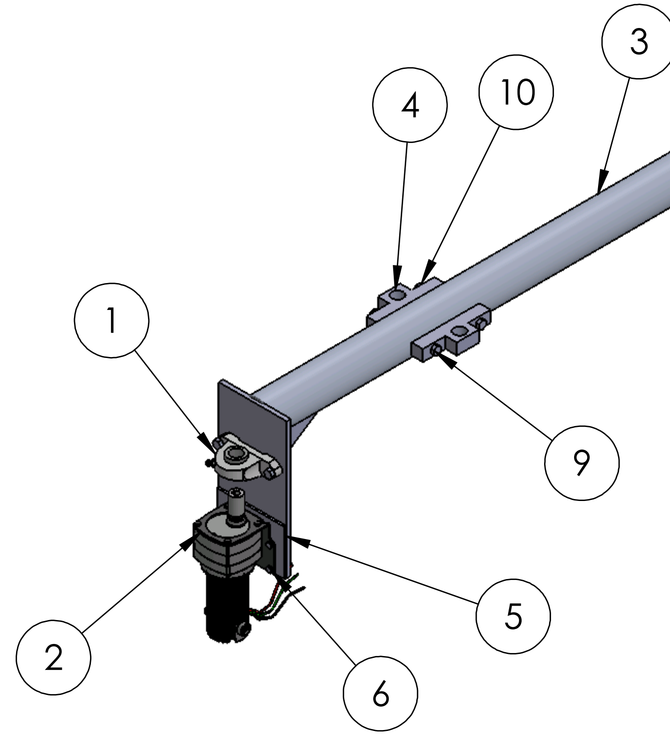


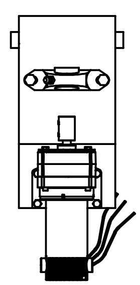
UNLESS OTHERWISE SPECIFIED:		NAME	DATE	**Sunplanter**	
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ±.05 ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.005	DRAWN	S. Hight	6/4/14	TITLE:	
	CHECKED			Rotational Support Assembly	
	ENG APPR.				
	MFG APPR.				
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.				
MATERIAL Mixed	COMMENTS:			SIZE A	DWG. NO. S-07-0A	REV A
FINISH					
DO NOT SCALE DRAWING				SCALE: 1:10 WEIGHT:	SHEET 1 OF 1

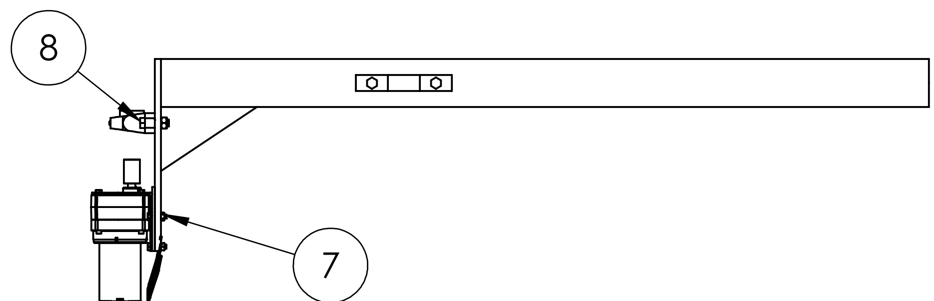
NEXT ASSY	USED ON
APPLICATION	

5 4 3 2 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	6668K42	Pillow Block	1
2	D-01-0	Drive Assembly	1
3	S-06-1W	Vertical Support Weldment w/ Holes	1
4	S-09-0	Hydraulic Support	2
5	S-14-0	Motor Shim Plate	1
6	1/4-20	Length: 1"	4
7	1/4 Nut		4
8	7/16-14 Bolt	Length: 1.5"	2
9	7/16-14 Bolt	Length: 5.5"	2
10	7/16-14 Nut		4



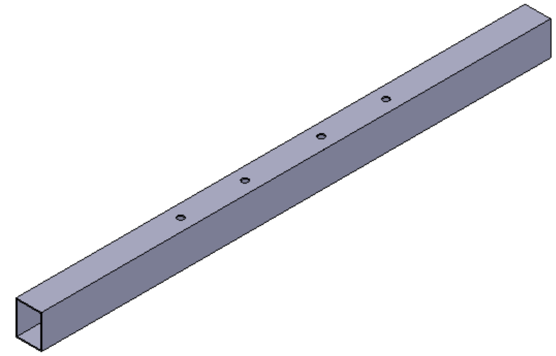


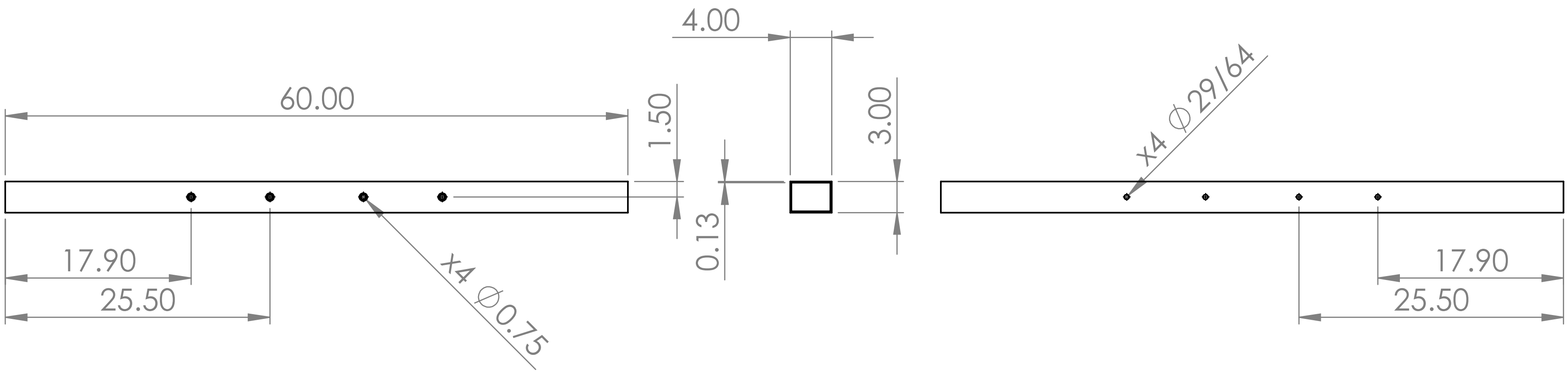


UNLESS OTHERWISE SPECIFIED:		NAME	DATE	**Sunplanter**
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ±.05 ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.005	DRAWN	S. Hight	6/4/15	TITLE:
	CHECKED			Drive and Blocking Support Assembly
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL Mixed	COMMENTS:			SIZE A · DWG. NO. S-07-1A · REV A
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:10 · WEIGHT: · SHEET 1 OF 1

NEXT ASSY	USED ON
APPLICATION	

5 4 3 2 1





		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ±.05 ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.005	DRAWN	J. Gaither	5/7/2015
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL 6061-T6 Al	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

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Sunplanter

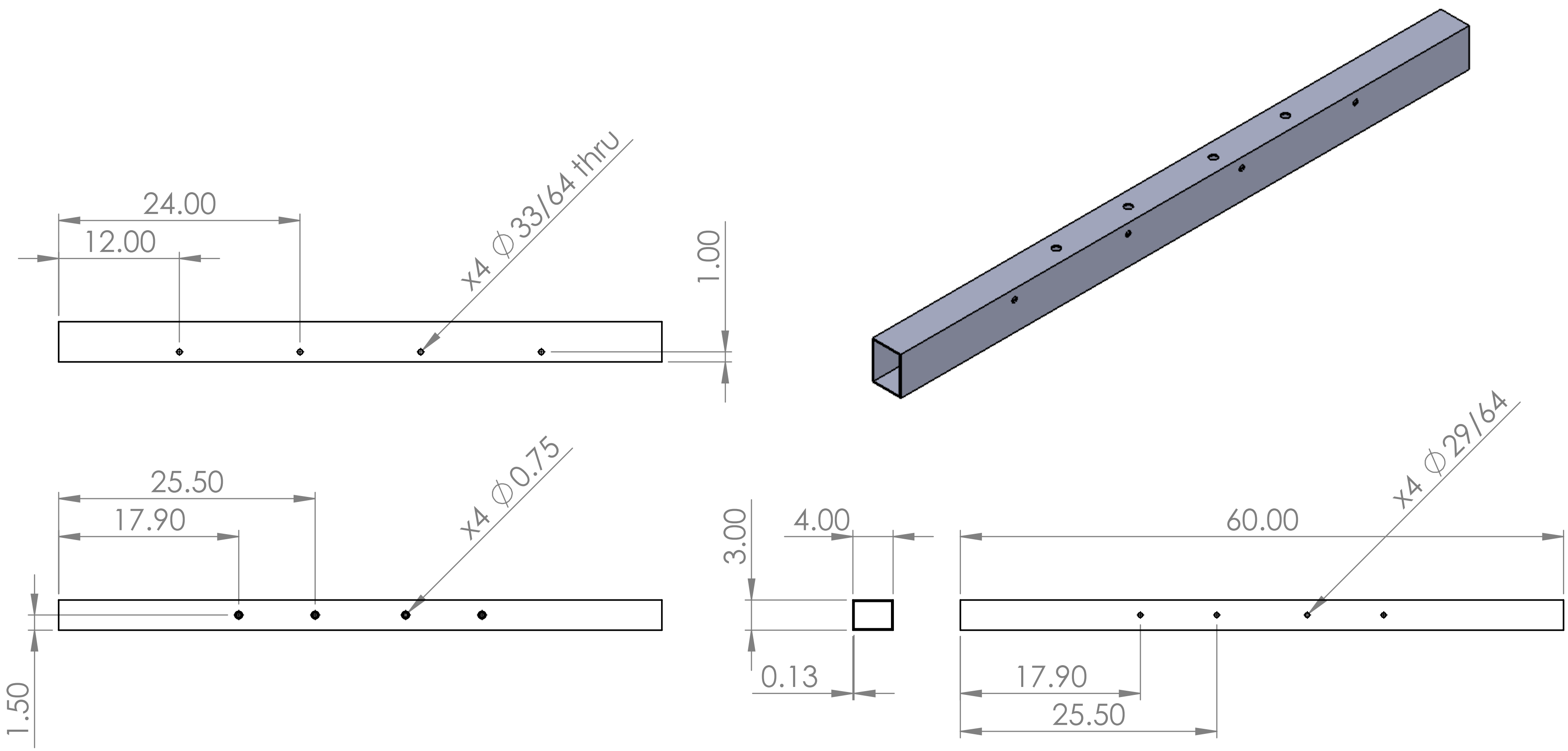
TITLE:

Center Mounting Rail

SIZE	DWG. NO.	REV
A	S-08-0	B

SCALE: 1:16 WEIGHT: SHEET 1 OF 1

5 4 3 2 1



		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ±.05 ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.005	DRAWN	J. Gaither	5/7/2015
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL 6061-T6 Al	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

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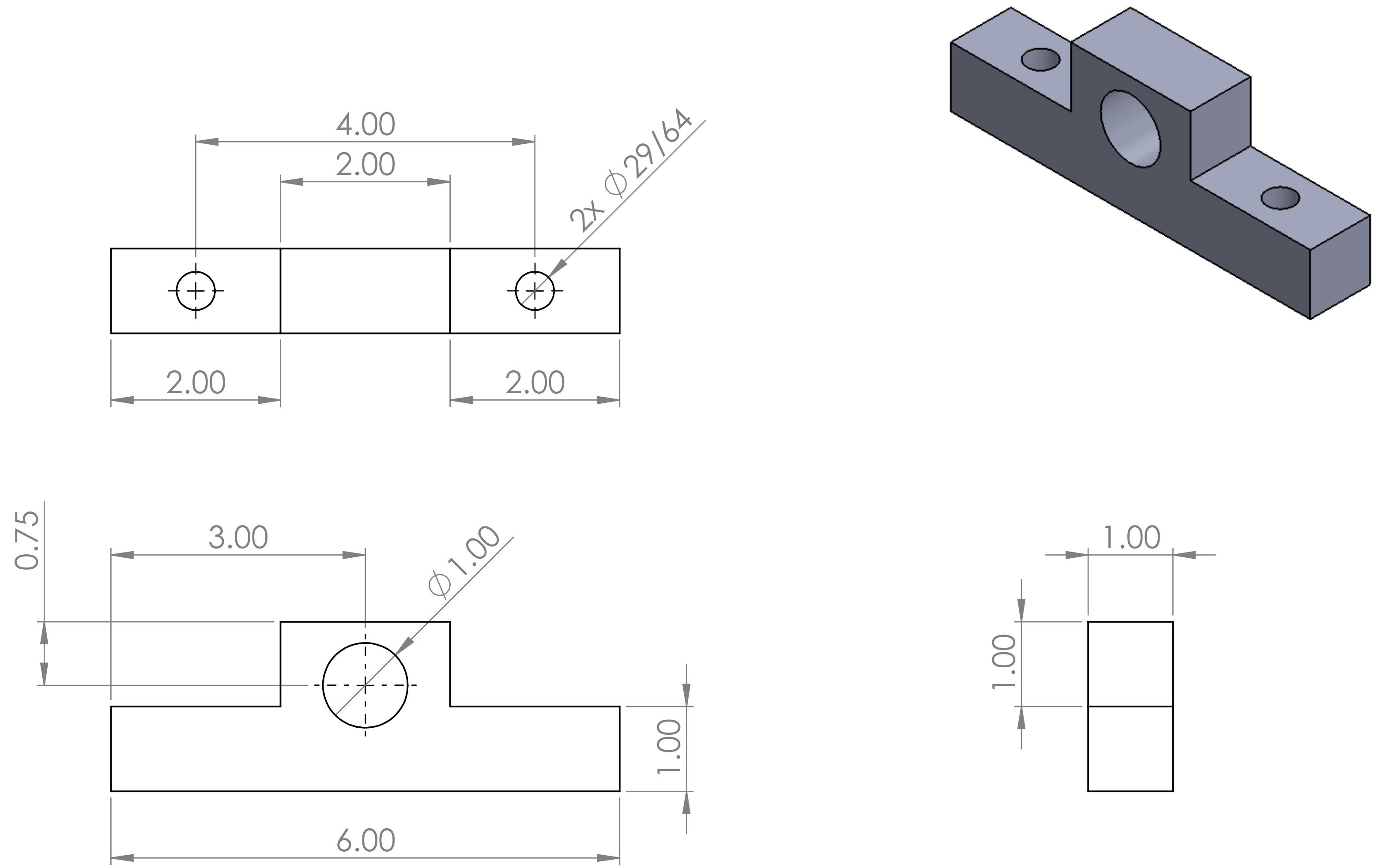
Sunplanter

TITLE:

Edge Support Rail

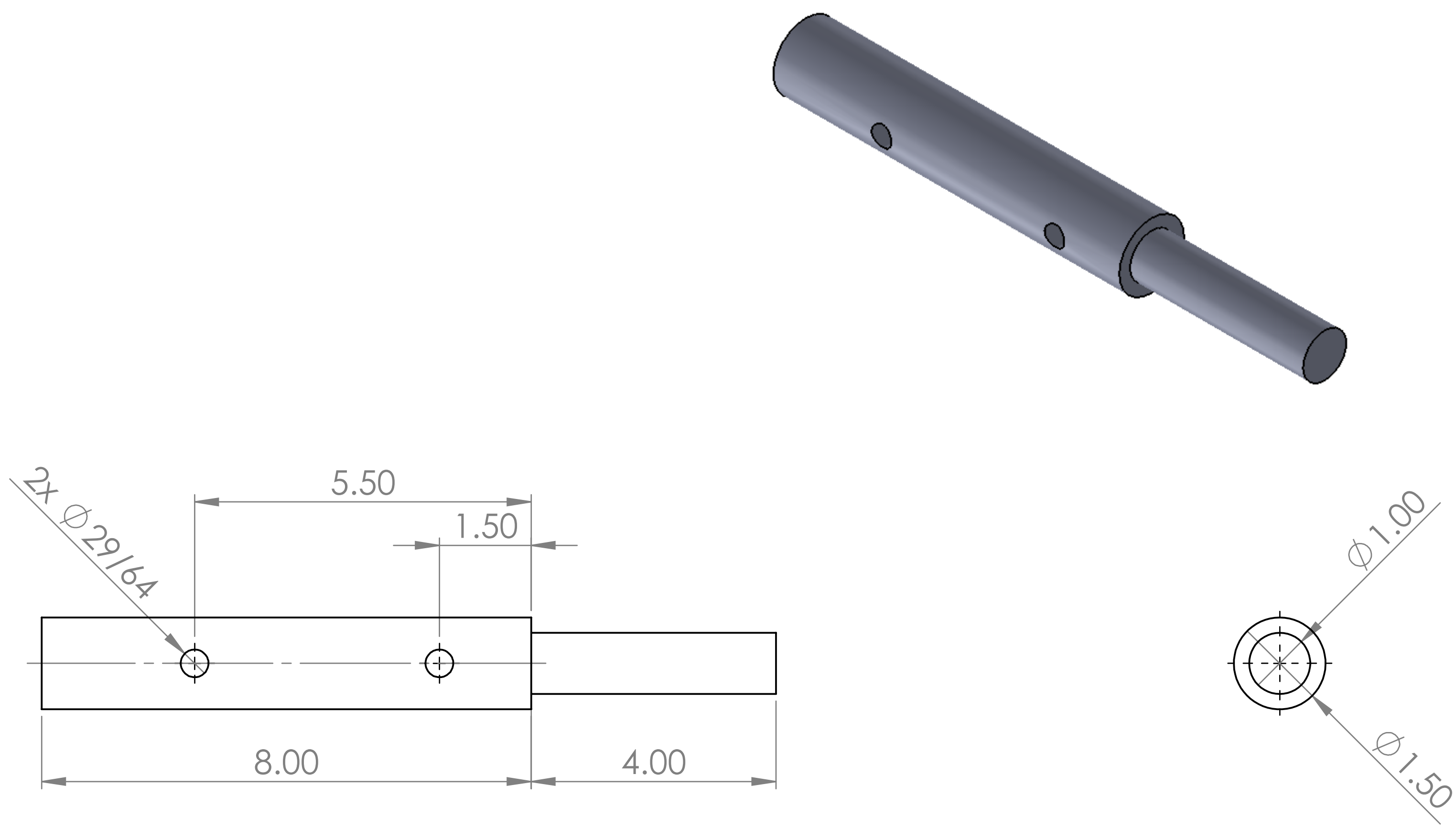
SIZE	DWG. NO.	REV
A	S-08-1	C
SCALE: 1:16	WEIGHT:	SHEET 1 OF 1

5 4 3 2 1



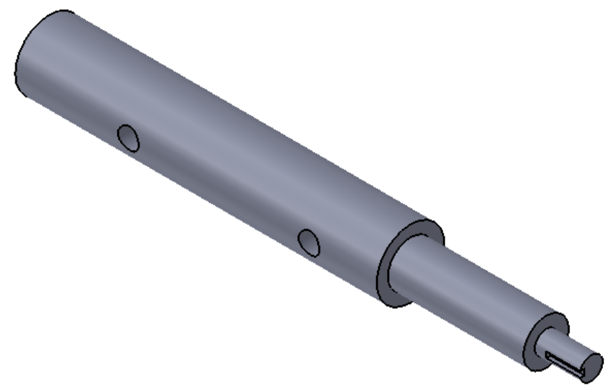
		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	**Sunplanter**
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ±.05 ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.005	DRAWN	S. Hight	5/20/15	TITLE:
			CHECKED			Hydraulic Support
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL 6061-T6 Al	COMMENTS:			SIZE A · DWG. NO. S-09-0 · REV A
NEXT ASSY	USED ON	FINISH				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:2 · WEIGHT: · SHEET 1 OF 1

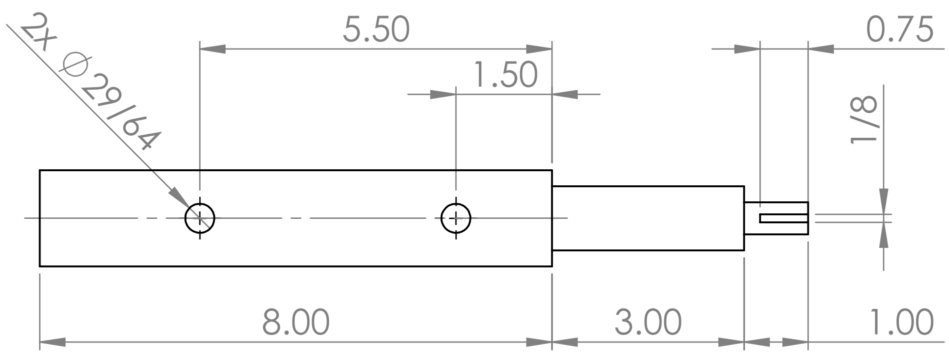
5 4 3 2 1

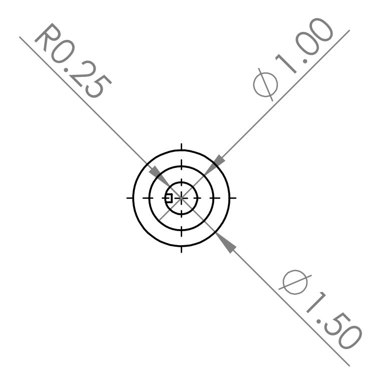


		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	Sunplanter
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ±.05 ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.005	DRAWN	S. Hight	5/20/15	TITLE:
			CHECKED			Support Shaft
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL 6061-T6 Al	COMMENTS:			SIZE A · DWG. NO. S-10-0 · REV A
NEXT ASSY	USED ON	FINISH				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:3 · WEIGHT: · SHEET 1 OF 1

5 4 3 2 1







NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±.05
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL 6061-T6 Al

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	S. Hight	5/20/15
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

Sunplanter

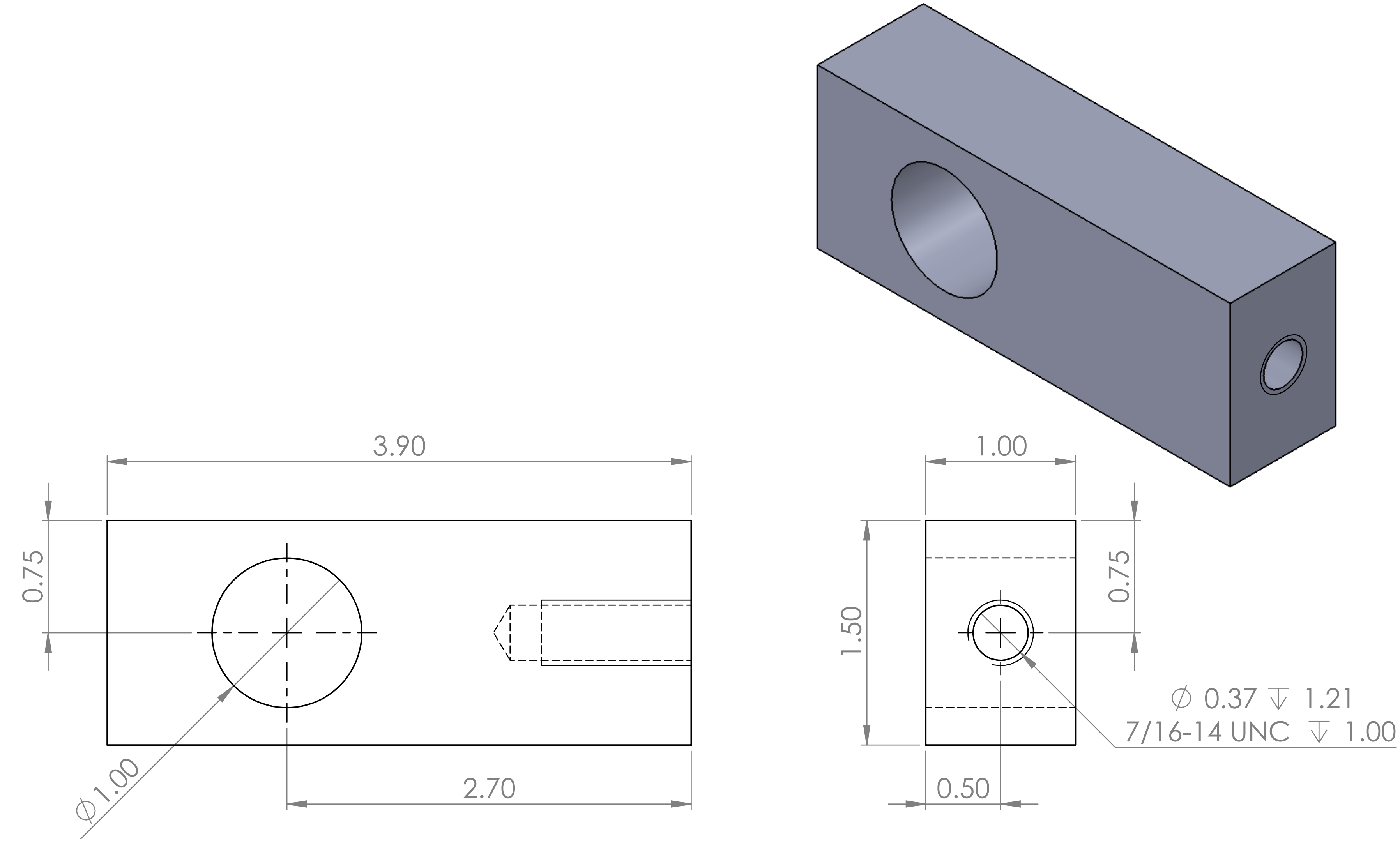
TITLE:

Rotational Shaft

SIZE A | DWG. NO. S-10-1 | REV B

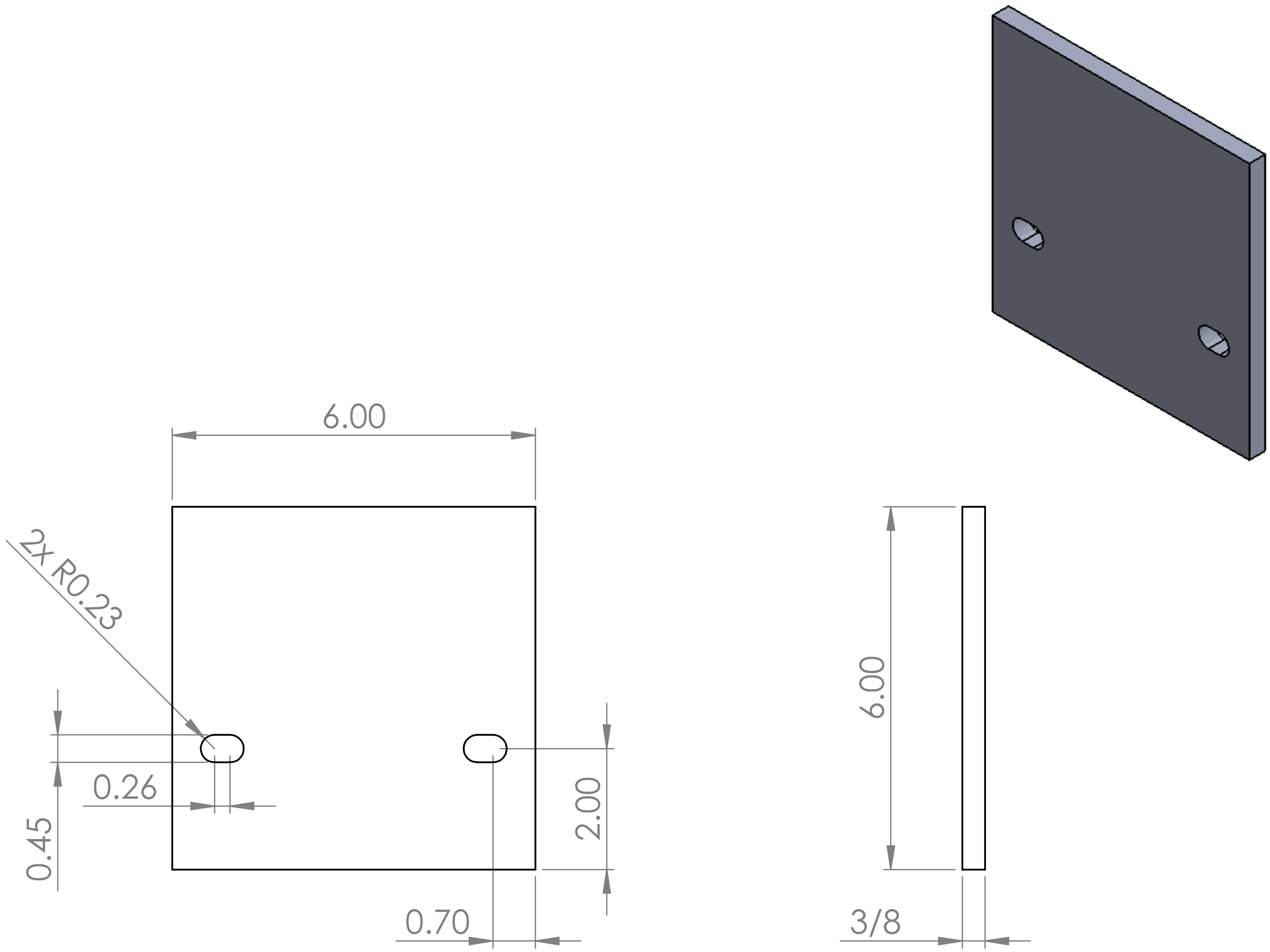
SCALE: 1:3 | WEIGHT: | SHEET 1 OF 1

5 4 3 2 1



		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	**Sunplanter**
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ±.05 ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.005	DRAWN	S. Hight	5/20/15	TITLE:
			CHECKED			Clevis Bar
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL 6061-T6 Al	COMMENTS:			SIZE A — DWG. NO. S-11-0 — REV A
NEXT ASSY	USED ON	FINISH				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:1 — WEIGHT: — SHEET 1 OF 1

5 4 3 2 1



NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±.05
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
6061-T6 Al

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	S. Hight	5/20/15
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

Sunplanter

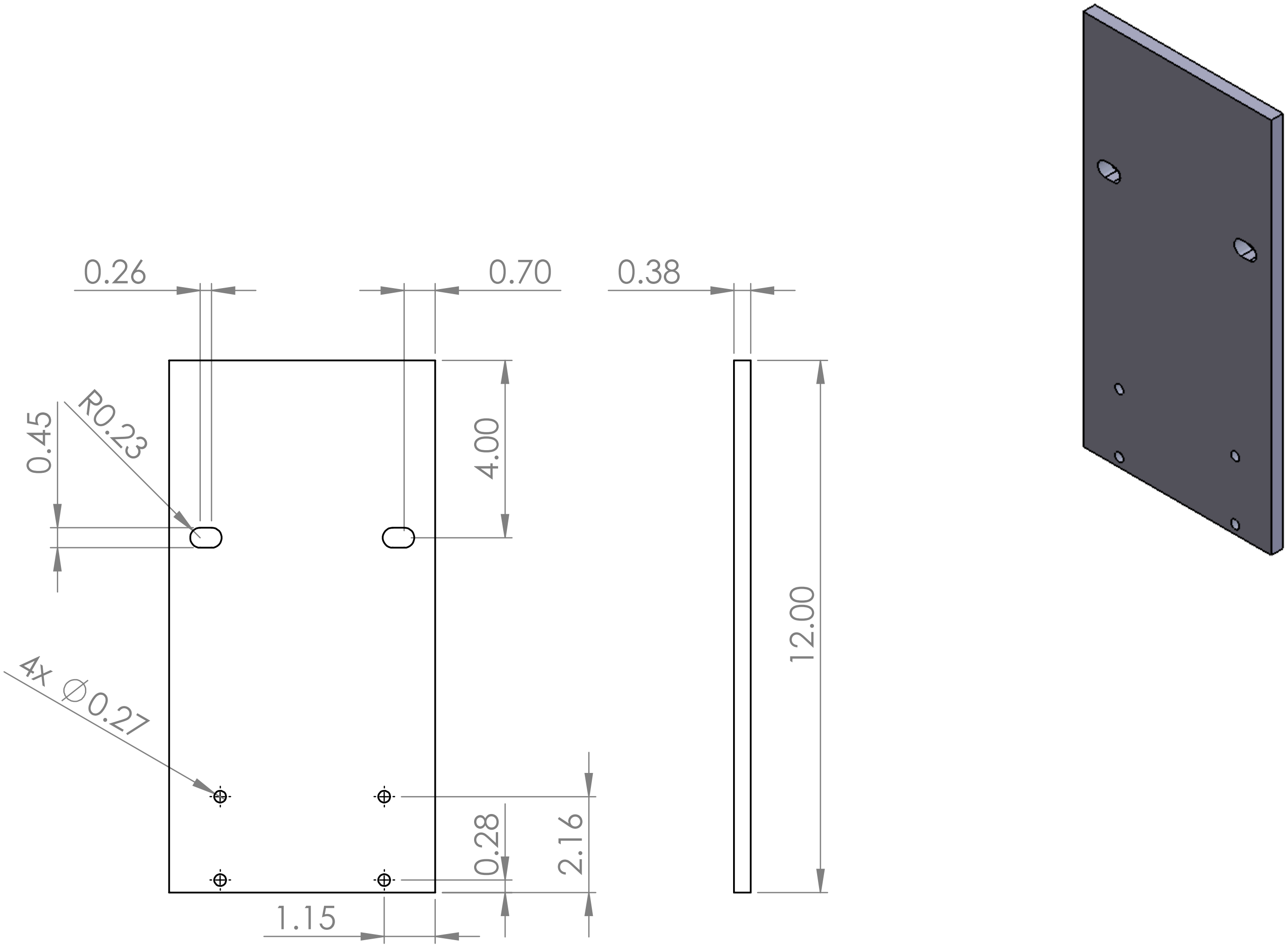
TITLE:

Pillow Block Support

SIZE	DWG. NO.	REV
A	S-12-0	A

SCALE: 1:3 | WEIGHT: | SHEET 1 OF 1

5 4 3 2 1



		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ±.05 ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.005	DRAWN	S. Hight	5/21/15
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL 6061-T6 Al	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

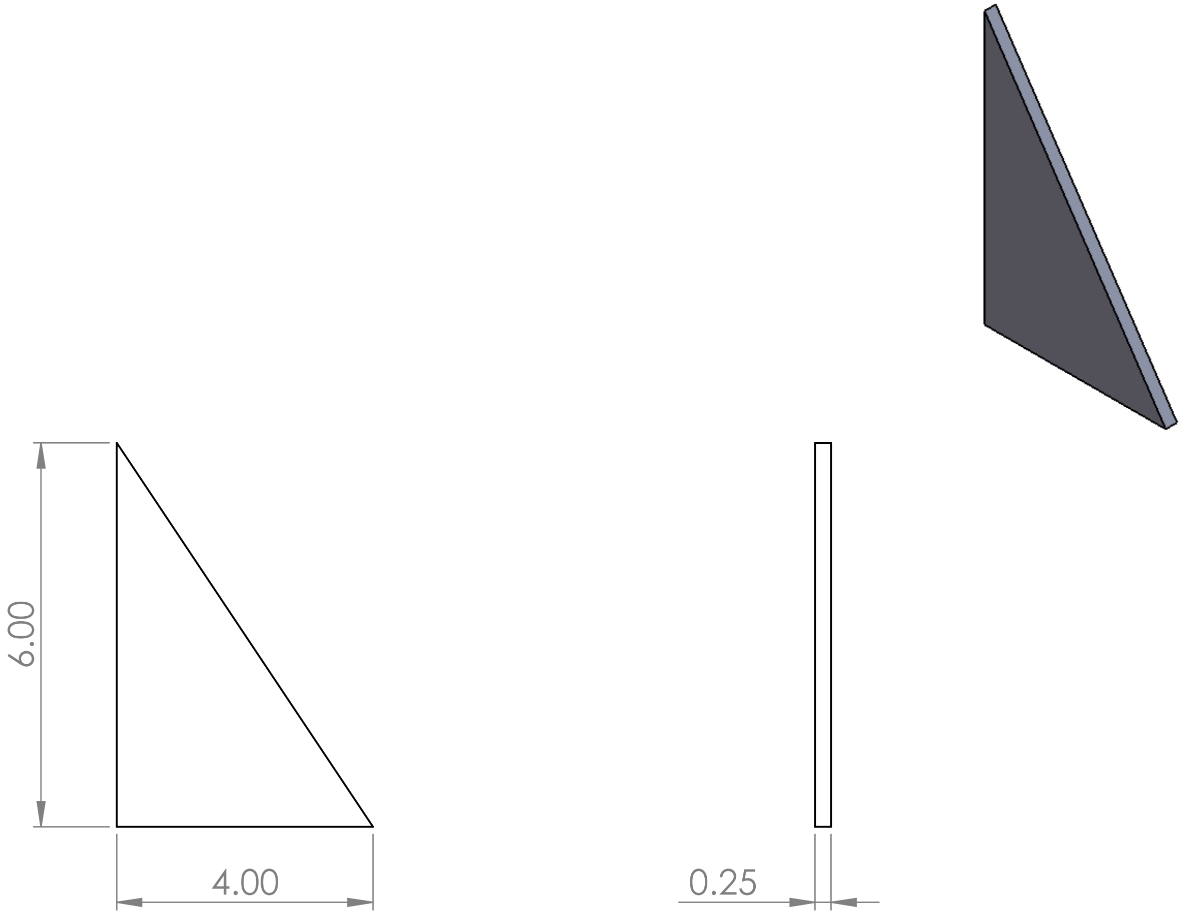
Sunplanter

TITLE:

Motor Mounting Plate

SIZE	DWG. NO.	REV
A	S-12-1	A
SCALE: 1:4	WEIGHT:	SHEET 1 OF 1

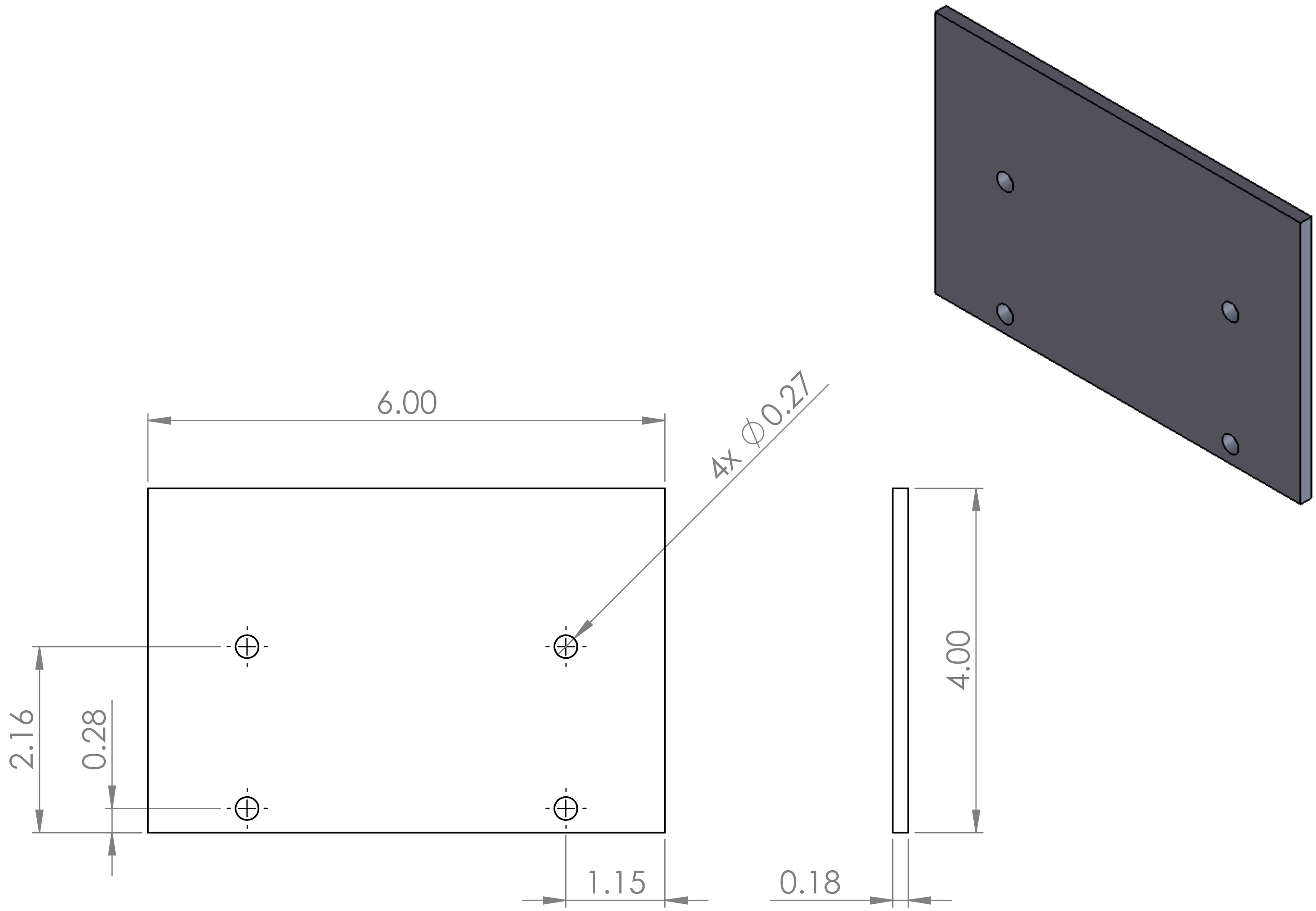
5 4 3 2 1



		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	**Sunplanter**
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ±.05 ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.005	DRAWN	S. Hight	5/21/15	TITLE:
			CHECKED			Motor Plate Gusset
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL 6061-T6 Al	COMMENTS:			SIZE A — DWG. NO. S-13-0 — REV A
NEXT ASSY	USED ON	FINISH				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:3 — WEIGHT: — SHEET 1 OF 1

PROPRIETARY AND CONFIDENTIAL

5 4 3 2 1



NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±.05
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
6061-T6 Al

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	S. Hight	5/21/15
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

Sunplanter

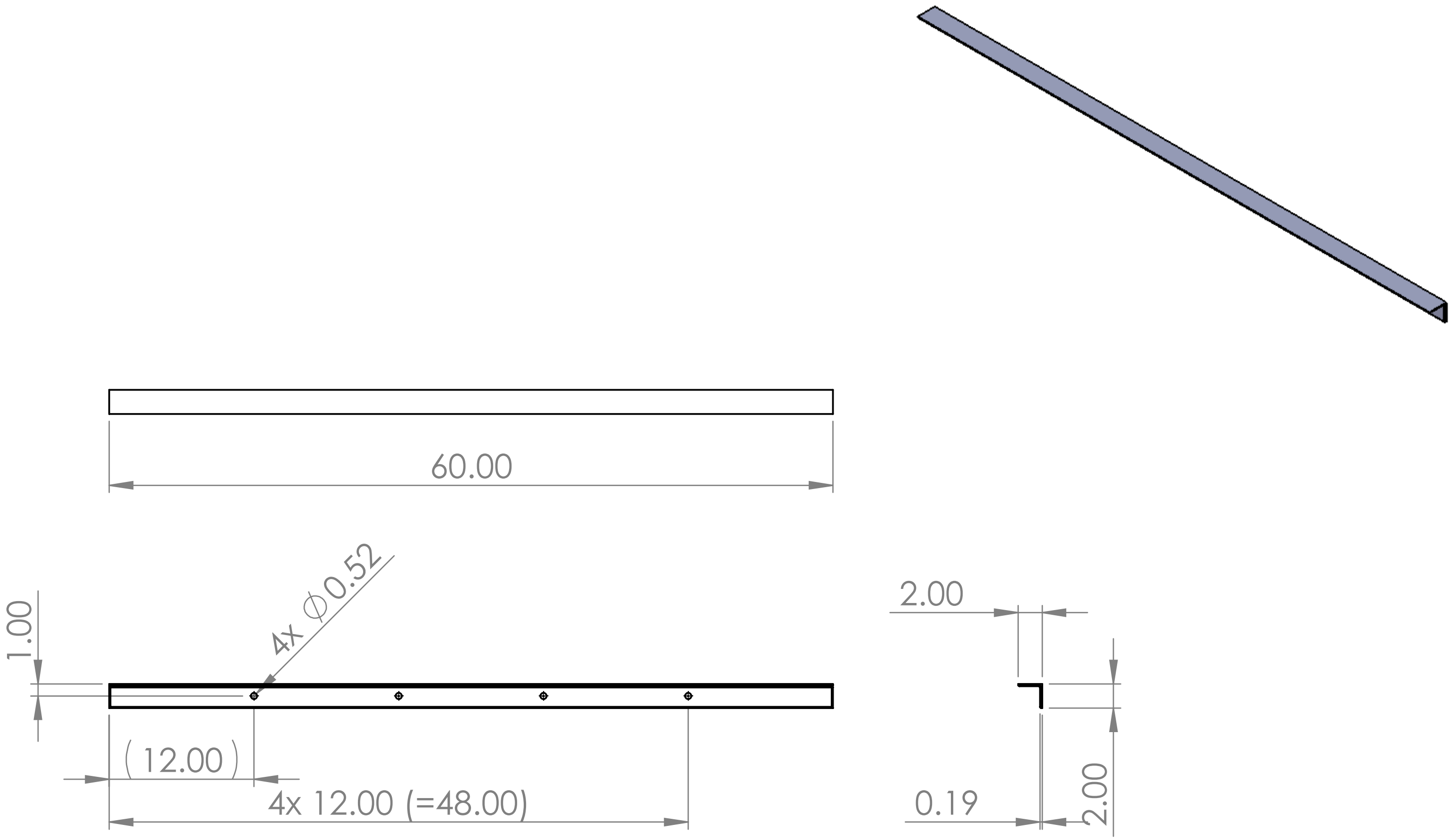
TITLE:

Motor Shim Plate

SIZE	DWG. NO.	REV
A	S-14-0	A

SCALE: 1:2 WEIGHT: SHEET 1 OF 1

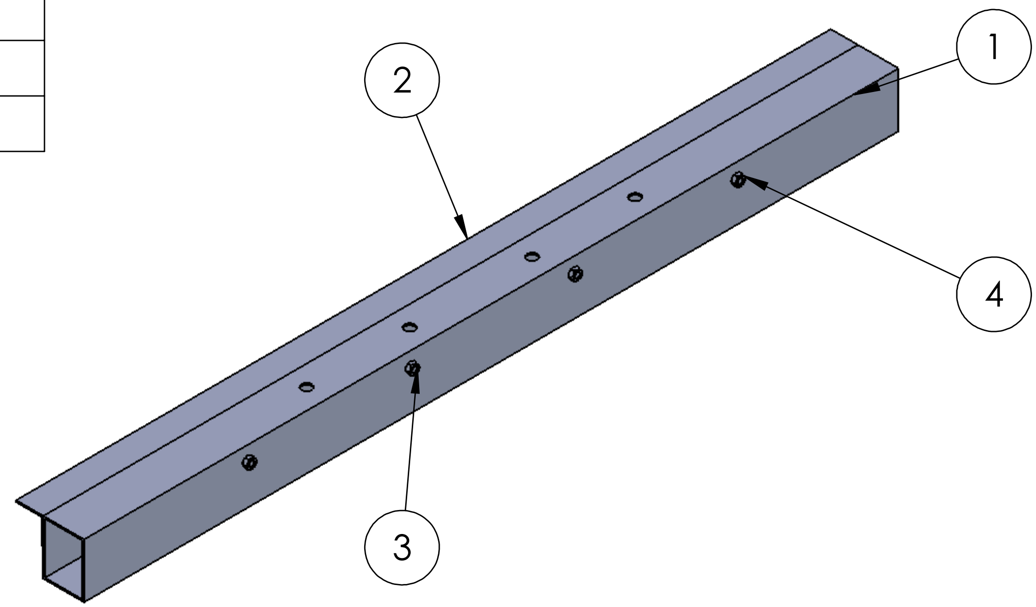
5 4 3 2 1

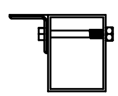


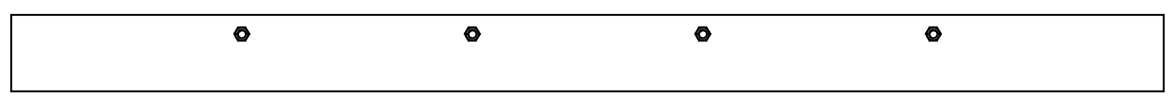
		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	Sunplanter
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ±.05 ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.005	DRAWN	S. Hight	5/21/15	TITLE:
			CHECKED			Angular Panel Shelf
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL 6061-T6 Al	COMMENTS:			SIZE A — DWG. NO. S-15-0 — REV A
NEXT ASSY	USED ON	FINISH				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:15 — WEIGHT: — SHEET 1 OF 1

5 4 3 2 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	S-08-1	Edge Support Rail	1
2	S-15-0	Angular Panel Shelf	1
3	7 16-14 Bolt	Length: 3.5"	4
4	7/16-14 Nut		4







PROPRIETARY AND CONFIDENTIAL

NEXT ASSY | USED ON

APPLICATION

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±.05
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Mixed

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	S. Hight	6/4/15
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

Sunplanter

TITLE:

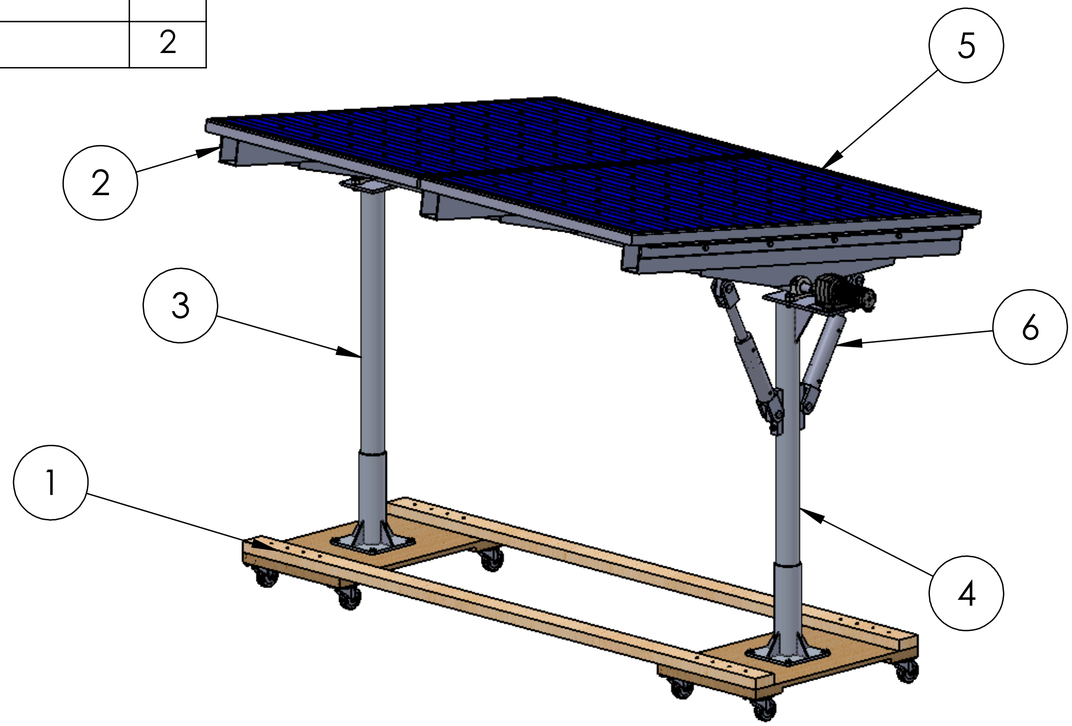
Edge Rail Assembly

SIZE	DWG. NO.	REV
A	S-16-0A	A

SCALE: 1:10 | WEIGHT: | SHEET 1 OF 1

5 4 3 2 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	F-06-0A	Mobile Foundation Assembly	1
2	S-05-0A	Panel Support Assembly	1
3	S-07-0A	Rotational Support Assembly	1
4	S-07-1A	Drive and Blocking Support Assembly	1
5	Bosch c-Si M60 NA 30119 250W	Photovoltaic Panel	2
6	HydraulicCylinder		2



NEXT ASSY	USED ON	
APPLICATION		

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±.05
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Mixed

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	S. Hight	6/4/15
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

Sunplanter

TITLE:

Full Assembly

SIZE	DWG. NO.	REV
A	SP-01-0A	C

SCALE: 1:25 WEIGHT: SHEET 1 OF 1

5 4 3 2 1

Appendix J: Senior Design Conference Handouts

SANTA CLARA UNIVERSITY
Department of Mechanical Engineering
Spring 2015

Problem Statement
Residential solar installations are expensive and time intensive to install. We seek to make a prefabricated, cost effective, easy to install, stand-alone solar-tracking system.

Purpose
The cost of solar panels has decreased by more than sixty percent over the last six years, and prices are still falling. However, even with the lower costs of solar panels, the demand for residential and commercial installations has not increased significantly. Installing solar systems on rooftops presents several challenges such as accommodating for different architectures, satisfying legal codes, and involving intensive labor processes. What will separate our system from existing technologies is that the installation process will be much simpler, and it will act as an additional living space adding value to the residence.

Goals
Our system solar tracks in order to increase the power output from the panels. In addition, structural codes have been satisfied to ensure the safety of the structure, and to guarantee that the structure is weatherproof. The system was also made to be cost effective so that it acts as a reasonable approximation of an affordable full-sized system. We created a prototype that, when scaled, can reasonably be installed in a single day.

System Design
The structure is a stand-alone two pole foundation that can withstand any expected environmental loads that it may be subjected to. The rotation is driven by a DC gearmotor. The gearbox incorporated in the motor serves as both a speed and torque reducer, since the electric motor will spin faster than the desired rotation, and the wind loads on the solar panels will cause incredible torque through the rotational axes attempting to throw it off angle. In order to keep the angle of the panels stationary, a blocking system utilizing hydraulic pistons is being used, allowing movement only when desired. The system also includes an Arduino based program, allowing not only for efficient solar tracking, but also for user override when desired, as well as other useful features.

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Team Sunplanter

Matthew Diaz, Joseph Gaither, Stephen Hight, and J. Brandon Suehiro
Mechanical Engineering, Class of 2015

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Contents

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Problem Statement

- Residential solar installations are expensive and time intensive to perform. We seek to design a prototype version of a prefabricated, cost effective, easy to install, stand-alone solar-tracking system.

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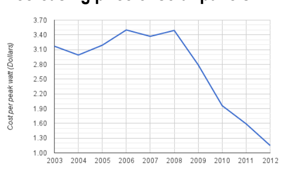
Background Information

- Solar Technology 35% efficiency improvement in the last 8 years
- Decreasing price of solar panels



Source: http://www.eia.gov/renewable/annual/solar_photo/.

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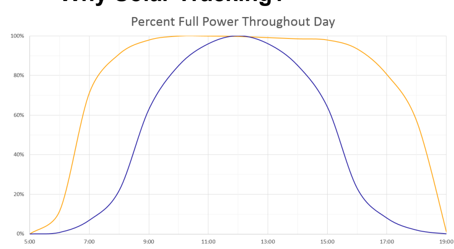
Why Solar Tracking?



Source: http://www.lauritzen.biz/products/pumping/pvvfd/graph.png.

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Existing Technologies

AllSun Tracker Series 20

Array Tech Inc. DuraTrack DA Solar Tracker

Sources: http://www.backspinrenewables.com/.

Sources: http://arraytechinc.com/residential/duratrack-da-tracker/

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Sunplanter

- Newly founded company focusing on practical incorporations of solar technology
- Two pole, single axis tracking system, that creates a functional shaded space beneath the panels
- Senior Design Project
  - Create a working, scaled down, mobile prototype of the system

Initial Project Goals

- Cost Effective
- Simple and Fast Installation / Pre-fabrication
- Fulfill Codes and Regulations in California
- Solar Tracking
- Weatherproof/Waterproof
- Customizable

Codes and Regulations

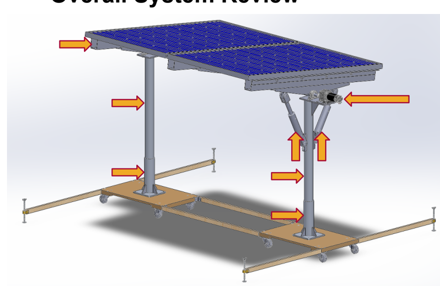
- ASCE: Minimum Design Loads for Buildings and Other Structures
  - Earthquake, Wind, Precipitation loads
  - Open structure with slanted roof
- Large Wind Loads
  - Max wind speed ~115 mph
  - Significant torque

ASCE American Society of Civil Engineers

Prototype vs. Full Scale Model

- Full Scale
  - Support Height: 11.5 ft
  - 16 panels
  - Permanent Foundation
- Prototype
  - Support Height: 4 ft
  - 2 panels
  - Mobile
  - Design and Testing

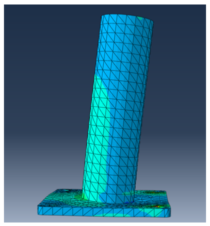
Overall System Review

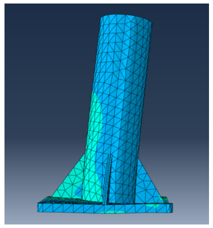


Structure

- 6061-T6 Aluminum Structure
  - Lightweight
    - Total Weight ~175 lbs.
  - Strong and Cost Effective
  - Simple Manufacturing Techniques
- Subsystems
  - Base Supports
  - Vertical Supports
  - Rotational Axis Assembly

Structure: Base Supports



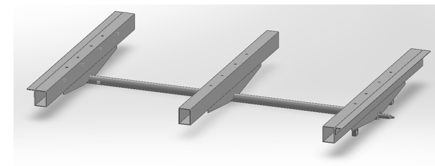


Structure: Vertical Supports

- **Initial Designs**
  - 1.5" inner diameter, 2" outer diameter
  - Drive system and blocking system on separate supports
- **Improved Design**
  - 2" inner diameter, 3" outer diameter
  - Motor and hydraulics on same side of structure
  - Gussets added to support motor

Structure: Rotational Axis Assembly

- **6'5" tube**
- **Racking rails and supports**
- **Solid shafts supported by pillow blocks**

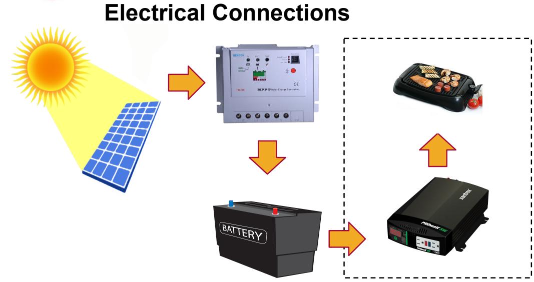


Drive System: Bison DC Gearmotor

Stock	BQS
Input HP	1/20
Torque (in-lbs)	160
Amps	0.2
Approx Weight	9
OHL	115
Ratio:1	1369.3
Stages	5
Speed (RPM)	1.3
Voltage	90-130
Speed 130V	1.3

Source: http://www.bisongear.com/011-175-1369.html

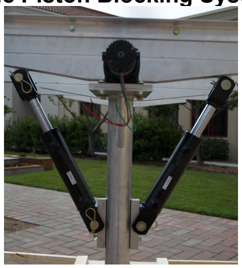
Electrical Connections



Blocking/Damping Design Process

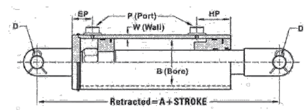
- **Initial design considerations**
  - Dual-pin
  - Ratchet and Pawl
  - Torsion bar
- **Requisites**
  - Dampen rotational motion
  - Stop system at desired location
  - Withstand largest loads
  - Hard-stop at full rotation

Hydraulic Piston Blocking System



Hydraulic Piston Blocking System

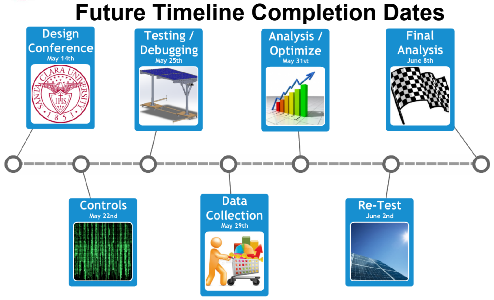
- **Stronger than required**
  - Max column load: 9,420 lbs
    - Factor of Safety >5
    - Sufficient for 16 panel system
  - 6" Stroke
    - Allows for 17 degrees of rotation in either direction



Controls

- **Arduino based**
- **Controls motor rotation and valve function**
  - Quick, intermittent motion
- **Prototype**
  - Time based
- **Full-size system**
  - Advanced method of solar tracking

Future Timeline Completion Dates



Impact Over 25 Years

Single Home Savings	
Estimated Monthly Savings	$165
Rough Cost of Sunplanter System	$12,000
Lifespan Net Savings	$37,000
CO2 Emission Reductions	
C02 produced per kWh (Natural Gas)	~1.2 lbs
C02 mitigated by Sunplanter 4 kW system over lifetime	~115,000 tons

Conclusion

- **System**
  - Cost effective, Simple and Fast Installation
- **Design**
  - 2 pole structure
  - DC gearmotor
  - Hydraulic blocking/damping
- **Results**

Conclusion

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Acknowledgements

- Dr. Timothy Hight
  - Faculty Advisor
- Alain Poivet
  - Industrial Advisor
- Alan Owens and the Versaco Team
- Don MacCubbin
- Calvin Sellers
- Joe Soares
- Jim Reites S.J
- Dr. Tonya Nilsson
- The Residents of Power House
- Friends and Family

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Questions

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Appendix Slides

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Feature Comparison

Features/Specifications	Array Tech. Inc. (DA Tracker)	All Earth Renewables (All Sun Series 20)	**SUNPLANTER (Proposed)**
Min. Height	3.25 ft.	2 ft.	**8 ft.**
Support Column Height	8 ft.	11 ft.	**11.5 ft.**
Tilt from Horizontal	5° to 60°	0 to 60°	**∓25°**
Tracking Accuracy	∓2°	Not Specified	**∓3°**
Max Array (Panels)	16	20	**16**
Drive System	Gear drive/Linear Actuator	¼ hp hydraulic power unit	**DC Gearmotor**
Tracking Axes	Dual Axis	Dual Axis	**Single Axis**

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Customer Needs

	Customer Need	Importance
PERFORMANCE		
	Quiet operation	7
	Aesthetically pleasing	8
	Come close to maximization of power outpu	9
	Easy user interface (UI)	5
	Waterproof	9
	Able to have added accessories	6
SAFETY		
	Withstand wind load	10
	Withstand earthquake load	10
	Withstand precipitation loads	10
	Minimum allowable height	10
	Electrical	10
	"Lock" position	10
TIME SCALE		
	Preparation period (surveying/landscaping)	7
	Installation	8
	System longevity	8
	Maintenance frequency	7
COST		
	Initial system	10
	Installation	9
	Maintenance	8

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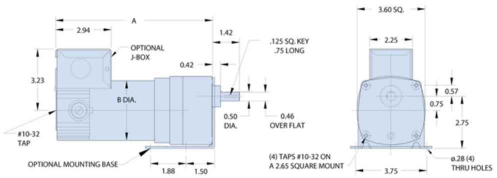
Drive System: Bison DC Gearmotor



Source: http://www.bisongear.com/011-175-1369.html

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Cost Analysis

Subsystem Breakdown	Actual Cost (To Date)	Estimated Cost To Team
Drive/Blocking	$1,043.24	$1,150.00
Structure	$831.17	$800.00
Racking	$261.44	$150.00
Electronics	$0.00	$880.00
Total	**$2,135.85**	**$2,980.00**

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