Cal Poly Heliodon

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June 5, 2015

Statement of Disclaimer

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1. Introduction

The Heliodon Project is a Mechanical Engineering senior design project undertaken by students of the California Polytechnic State University San Luis Obispo. The goal of the Heliodon Project is to design, build, and test a rig to be used by students and faculty of Cal Poly. This final project report contains information about why Cal Poly needs a Heliodon, some background information about the Sun's motion and about Heliodons, the Heliodon's desired specifications and the objectives of this project, our methods of brainstorming and idea selection, our final designs, any technical content needed to help explain our designs and decisions, manufacturing process details, instructions for operation, and future suggestions if further iterations are to be made.

The purpose of the Heliodon project is to provide professors with a means to educate students about the movement of the sun and how that movement varies with location on earth and throughout the year. It may also be used to provide architecture, electrical engineering, and mechanical engineering students a means to accurately and physically model the sun's position and motion to better inform their design considerations. A custom designed rig is required in order to provide an accurate way to physically model shading and sun position for design testing and educational purposes. This custom designed rig must be easy to use, intuitive, relatable to the real world, and accessible by faculty and students. It must also be durable, transportable enough to move outdoors and move from building to building and from classroom to classroom.

The Heliodon Project team is composed of three senior mechanical engineering majors and one senior electrical engineering major: Greg Bucher, Lucas Carter, Jake Hamilton, and Robin Hubilla, respectively. We are excited to construct an educational tool to be used by our fellow students at Cal Poly for years to come and with our combined background in mechanical design, programming, motors, and mechatronics, we believe we are capable of doing so. Electrical engineering professor Dale Dolan is the project's sponsor and advisor.

2. Background

2.1 Heliodon Definition:

A Heliodon is a three-dimensional physical sun simulator with two essential components; a light to model the sun, and something for the light to strike (usually a building model). In essence, its purpose is to simulate the motion of the sun from the Earth's perspective. It can also simulate the relationship between the sun and anything that the sun's rays strike. The focus here is not on simulating the radiant heat from the sun's rays, but instead on simulating what the light rays strike and the shadows that are created on surfaces when the sun is in different locations in the sky throughout the year. It is limited to only simulating clear sky conditions. Other software is used to simulate weather changes and their effects on the sun's rays. The main advantage of a physical Heliodon is that it can demonstrate the sun's motion in the different months of the year and for the different seasons. A Heliodon should be able to simulate seasonal changes by changing solar declination, simulate changes in the Earth's rotation by modeling the sun's different positions in the sky throughout the day, and simulate changes in site location by latitude adjustment.

2.2 Earth-Sun Background:

To model the sun's relative motion, we must first understand the way the Earth moves about the sun. The Earth moves in an elliptical rotation about the sun and this rotation takes place in what is called the orbital plane. The orbital plane can be found by identifying only three points. One point would be the center of what is being orbited (the center of the sun), another would be the center of what is doing the orbiting at a specific time (the center of the Earth), and the third is the center of what is doing the orbiting at any other time. An expansion of these three points would identify the orbital plane of any object. This can be confirmed by looking at Figure 1 and imagining that the celestial body is Earth and it is rotating about the sun. By picking any two points the Earth will be located and picking the sun as the third point, the orbital plane would be defined.

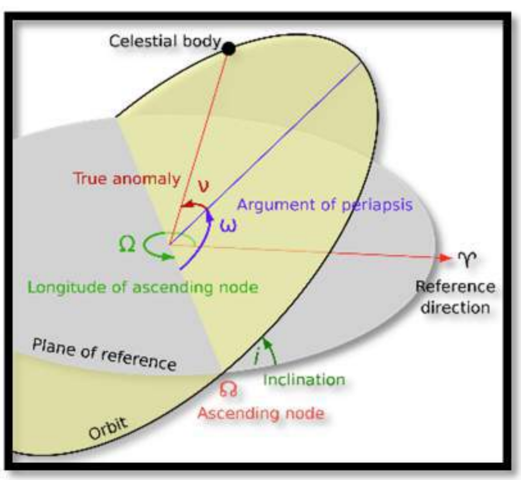


Figure 1. Orbital Motion

More formally however, the orbital plane of an object is defined by two parameters; Inclination and Longitude of the ascending node. These angles are also shown in Figure 1. Inclination of the orbit of a planet is the angle between the plane of the orbit of the planet and a reference plane. The reference plane is the plane containing Earth's orbital path. So for Earth the inclination angle is zero. A node is a point in which the orbit of an object passes through the reference plane. There are two nodes in Figure 1 because the orbit of the celestial object will cross the reference plane exactly twice. The ascending node is the angular position at which a celestial body passes from the southern side of a reference plane (below the plane of reference in Figure 1) to the northern side of the reference plane (above the plane of reference in Figure 1). This will not be important to understand as the reference plane is the Earth's orbital plane and so this will not be of use to us. The Longitude of the ascending node is the angle from a reference direction, called the origin of longitude, to the direction of the ascending node. The origin of longitude is specified differently for different applications but this will not be important for us to understand.

Figure 2 helps to visualize the motion of the Earth around the sun [1]. The important thing to take from Figure 2 is the notion that the Earth's equatorial plane is tilted at an angle of 23.45^{o} to the Earth's orbital plane. This tilt angle leads to a variation in the solar declination angle, δ, and this variation causes the changing seasons with their unequal periods of daylight and darkness. Solar declination angle is a measure of how many degrees North or South of the equator the sun is when viewed from the center of the Earth [2]. There are equations that calculate the declination angle based on what day in the year it is and these equations will be useful in our model. Figure 3 on the next page shows how solar declination varies throughout the year [2].

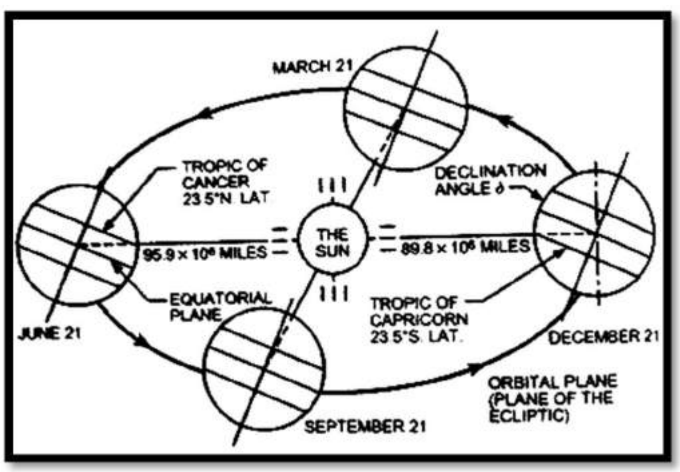


Figure 2. Motion of Earth around Sun

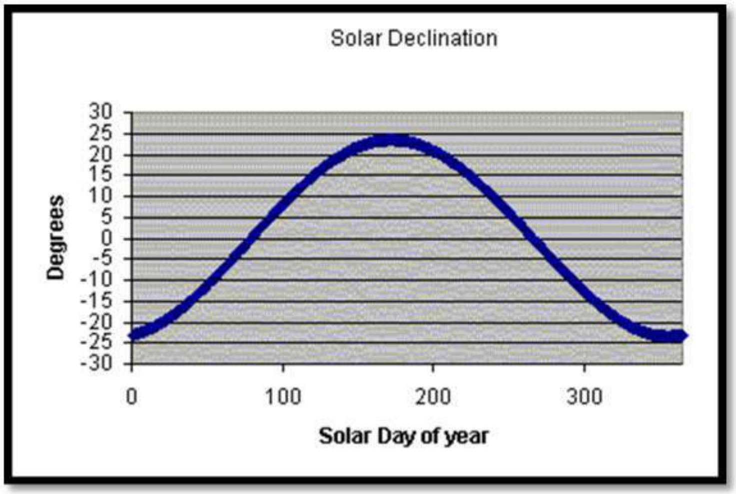


Figure 3. Solar Declination Daily Variation

The sun's position in the sky can be expressed in terms of the solar altitude angle, which is the angle above the horizontal, and the solar azimuth, which is an angle that sweeps across the earth and is measured from the south. In Figure 4, the solar altitude angle is the angle beta, β, and the solar azimuth is the angle phi, ϕ [1]. The other angles in Figure 4 are not important for our applications. The solar altitude angle is defined as the angle between the horizontal plane and a line emanating from the sun. The solar azimuth angle is defined as angular displacement from south of the projection, on the horizontal plane, of the Earth/sun line. Both of these angles are a function of the local latitude, the solar declination, and few other parameters that are not important to delve into [1].

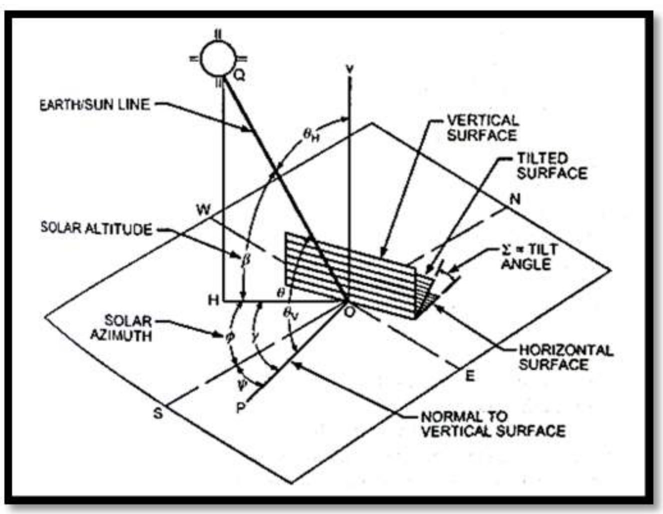


Figure 4. Solar Angles for Vertical and Horizontal Surfaces

Figure 5 shows the sun's position as expressed by the solar altitude and solar azimuth angles as a function of different dates for a latitude of $\pm 45^0$. As stated before, the sun's position varies by date due to the Earth's rotation about the sun and the tilt of the equatorial plane from the orbital plane. We can see from the figure that the range of the solar azimuth angle varies over the course of the year and goes well over a range of 180 degrees.

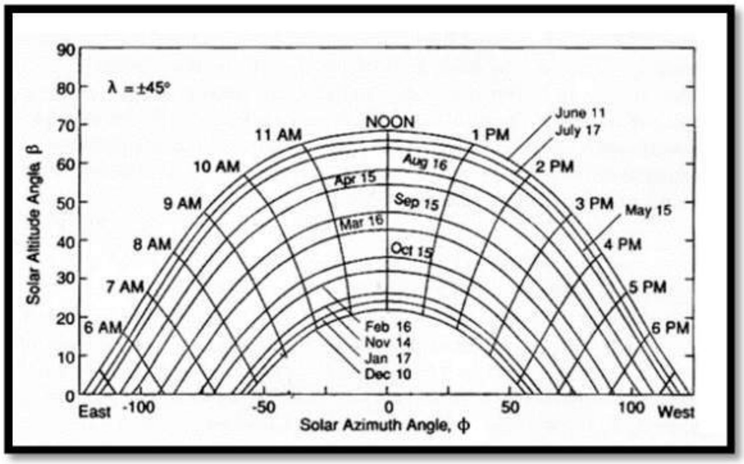


Figure 5. Sun Position for Various Dates

2.3 Research and other Models:

From what we have researched, Heliodons are the only physical models we have found for sun motion and position simulation. There are various software platforms available that can model the sun's motion and position, each meant for different applications. For example, architects may use Rhinoceros 3D to simulate shadows that the sun makes at different locations to better visualize designs; electrical engineers that design solar panels may use Solemetric devices such as SunEye and PV Analyzer to find sun angles at different times of the day and at different seasons in order to position solar panels most efficiently; mechanical engineers use HVAC programs such as Trace that account for sun angles in load calculations to help with HVAC designs.

The physical Heliodon model is one whose design varies extensively today. There are two main categories of Heliodon, each with its own advantages and disadvantages. First is the Fixed Sun Moveable Earth model, in which the model is moved while the light source remains fixed in order to create the appropriate sun angles and shadows on the model. Second is the Fixed Earth Moveable Sun model, in which the model stays fixed and the light source moves around the model to simulate sun motion, sun angles, and the shadows that the sun casts on the model. The Fixed Sun-Moveable Earth model is popular today and many industries or schools that have a Heliodon have one of this type.

PG&E in San Francisco has such a model that was designed and built by a three-person team. The team consisted of Professor Charles C. Benton of the University of California, Berkeley, Paul Leberge, a PG&E designer, and Ian Melody, a machinist. In their model, the motion of the model seems to be purely mechanical and it has knobs in which you can set the latitude, time of day, and time of year. The knobs adjust the various angles of the model. Their light source has been placed 30 feet from the model to simulate the sun's parallel rays in order to cast accurate shadows. There are two disadvantages associated with this Fixed Sun-Moveable Earth design. The first is that the model must be fixed securely to the rotating surface. The model must be able to maintain its own weight as it rotates to different orientations. Each model that is to be used with the Heliodon must be able to be fixed to the rotating surface as well. The second disadvantage is that because the model is moving, its simulation is inherently different from what is experienced on Earth. The shadows are hard to observe when the model is moving or even when it is fixed at a non-horizontal orientation. On Earth, even though we are moving around the sun (as the Fixed Sun-Moveable Earth model demonstrates), we see it the opposite and think that the sun is moving around us. So we are used to visualizing shadows as the sun moves and the object stays stationary. PG&E has accounted for this by attaching a Toshiba IK-M40A color CCD Point-of-View camera head and camera control unit to the moving table. This makes it so that when the video is watched, it appears that the model is not moving and that instead the shadows are changing due to sun motion. In our minds, this defeats the purpose of having a physical model because a video must be watched to observe the simulation [3].

Another type of Heliodon is a Sun Simulator. We analyzed the HPD Sun Simulator, and, later in the Ideation section of this report, we use this model as a benchmark to compare our ideas to. The HPD Sun Simulator falls under the category of Fixed Earth-Moveable Sun model. The table-top is usually fixed and the sun's path is simulated over the model and this is typically done by having multiple arches representing different sun paths. A different light along each arc represents one hour of the sun's movement relative to Earth. This type of Heliodon can only represent a single day of each month but only seven arches are needed for each month because certain months overlap. That is, for certain months, the sun's path is exactly the same. The main advantage of this design is that it simulates our everyday experience. It shows the physical movement of the sun relative to Earth. It is pretty accurate because the further the light source is away from the model, the more parallel the rays are when they strike the table-top. This particular Heliodon allows the top to rotate an additional five degrees allowing for more than one latitude without losing any clarity. The size allows for larger architectural models to be studied in addition to larger audiences, but this sacrifices ease of transportation. We may consider taking the principle of having a fixed table to increase accuracy [4].

Architects currently use 3D modeling software to see shadows caused by their buildings. A fixed light source is inserted somewhere in their model and then a rendering is done to see the desired result. Simulating a day takes time to set up and render. A physical system would benefit architect students by physically allowing them to see the movement instead of just looking at a rendered model where the light changes. Different features could be added without having to model anything in a computer program [5]. Both mechanical engineering and electrical engineering students would benefit from a physical model as well. If an electrical engineer wanted to install solar panels on a building, knowledge of the way the sun moves across the sky would be extremely helpful in panel placement. Mechanical engineers interested in calculating energy loads on a building (which are most impacted by radiation from the sun) and designing systems to cool or heat buildings would benefit from knowledge of the sun's motion as well. Currently, both electrical and mechanical engineers use programs that require little knowledge of the sun's motion to satisfy their needs.

2.4 Outside Effects of Operation:

Our final model will ideally not only demonstrate the motion of the sun, but also be able to simulate the sun's rays on an object. For that reason, it is important to consider the intensity of light that is emitted. We must consider if our Heliodon is to be as effective in daylight as it is in a darker setting.

We have recognized that previous senior projects have been stored outdoors and so we must consider weatherproofing our final model. We must decide if we want to create a covering to protect the Heliodon from the wind, the rain, and other debris or if we want to use weatherproof materials in manufacturing our final product.

3. Objectives

Our overall goal for this project is to deliver a fully functioning Heliodon that can be transported between different buildings and rooms and is capable of accurately and precisely modeling the position and overall motion of the sun throughout specific days and times at various locations on Earth.

To create the specifications for the Heliodon based on the needs of those who will use it, our team utilized the Quality Function Development (QFD) method. This involves creating a list of the people who will use the Heliodon and what their particular needs are from the device, followed by comparing those needs to a list of design specifications.

Various requirements like “lightweight”, “ease of use”, or “speed of operation” are all given an importance rating, ranking how important each customer requirement is to the overall product. These are then matched up with design specifications and given a relationship strength rating. For example, “lightweight” as a customer requirement and “weight” as an engineering specification would be given a “strong” relationship rating because it is very important that weight of final product is light. Each of the specifications are then given a weighted importance to help decide which have the highest priority and deserve the most consideration. Our QFD house of quality can be viewed in the appendix.

The highest ranked customer requirements for the Heliodon were to be able to model the sun’s position at precise dates and to accurately replicate the sun’s motion. Professor Dolan made it clear that the Heliodon’s primary purpose is to be a learning tool to help all students better understand sun’s relative motion and that its secondary function will be as a testing tool. This educational focus puts an emphasis on the Heliodon’s ability to accurately model the sun’s position and motion so that students learning from our model are not given false information. During the light’s movement, it is also desirable for the light to remain stable and to not vibrate too much. Ideally the light’s rays would remain fixed on the desired location as the light source moves to simulate the day.

Though the Heliodon is to be primarily used for educational purposes, it is also important that it also be usable for testing purposes. This means that it can be used by architecture students to model shadows, HVAC students to minimize sun radiation incident on surfaces, and electrical engineering students to optimize sun contact with solar panels. This is why the Heliodon’s ability to cast shadows well and output sun angle information are both ranked high on the importance scale.

To encourage students to use and learn from our Heliodon, a large importance ranking was given to the ease of using our interface. We want students to be able to quickly understand what the machine is and how to use it and then be able to operate it on their own with ease. A high importance was also placed on the operation speed of our machine as well. There are existing software that students can use as a tool to model the sun, so if our Heliodon moves slowly and is inconvenient to use, students will be more inclined to use such software.

While the Heliodon will be used primarily in the electrical engineering department, it must be able to be moved between rooms and buildings. This requires the Heliodon to be transportable and be able to fit through doors, which will dictate the sizing specifications. This also adds importance to the speed at which the machine can be set up so that it can be quickly used once being moved into a different room.

One last customer requirement is for the Heliodon's table to be fixed while the light source moves. A common trait amongst most Heliodons is for the light source to remain fixed while the model moves. This works well for use as a testing tool, but not when the primary focus is to help people learn about the sun's relative motion.

From our QFD analysis we were able to create a list of specifications. This list includes the specification targets and their tolerances, as well as the risk associated with trying to meet that specification that varies between Low (L), Medium (M) and High (H). It also includes the means by which we will check for our design's compliance with these specifications. These means are Analysis (A), Testing (T), Similarity to Existing Designs (S), and Inspection (I).

Table 1. QFD Specifications, Tolerances, Risks

Spec #	Description	Requirement/Target	Tolerance	Risk	Compliance
1	Explanation Time	5 min	±2 min	L	T
2	Height	78 in	Max	L	A,S,I
3	Width	36 in	Max	M	A,S,I
4	Length	90 in	±6 in	L	A,S,I
5	Weight	250 lbs	Max	L	A,T
6	Setup Time	5 min	±3 min	L	T
7	Light Movement speed	3 deg/ sec	Min	M	A,T
8	Angle precision	2 deg	Min	H	T,I
9	Settling Time	1 sec	Max	L	A
10	Angle Accuracy	1 deg	Min	H	T,I
11	Altitude Angle Range of Motion	180	Max	M	A,S
12	Latitude Angle Range of Motion	±50 deg	±.05 in	L	I

The explanation time ties in with the ease of usability of our Heliodon. We figured that if it took more than about five minutes for someone to become acquainted with how to use it then they would be more inclined to use another tool for their task. We can test this specification after it is built by running trials with students.

The height, width, length and weight all tie in to the transportability of the Heliodon. The height and width are both tied to dimensions of a typical door frame to allow for movement through doorways. The length is connected to an approximate hallway width so that it can be turned to go through a door without hitting the hallway walls. We will try make the Heliodon light enough so that pushing it will not be too strenuous for an adult of average strength. We should be able to approximate the size and weight of the model with SolidWorks and other CAD software and use other machine designs to see if we meet our specifications. We will also be able to inspect whether we'll be able to meet our targets once we have our materials.

The setup time is connected with the transportability of the Heliodon. We want the user to be able to move the model into a new room and then be able to set up and be able to operate the Heliodon within about five minutes. Again, we can conduct testing with various students and faculty after the Heliodon is built to determine whether we meet this target.

We chose a minimum angular light speed of about three degrees per second so that if our range of motion is from horizon to horizon, our Heliodon would be able to cover that in about a minute. Ideally this speed will be adjustable by the user, but we want it to be able to at least match this speed. We can figure out this speed through analysis once we have a motor selected and can also run tests once we have the Heliodon built.

The solar angles of our Heliodon need to be very precise and accurate so that they can model the true relative motion of the sun. We are aiming to have an accuracy of one degree and a precision of two degrees. To verify this, we can test the precision of our motors and the accuracy of our program. We can also measure the angle the light makes with the model or the distances of the light from the model. These distances may be used to calculate the angles and these angles may be compared with known angles for particular times.

Once the light reaches the desired position it needs to settle and stay there. We want to keep this settling time down to about one second. To check for this we can create a model and check its settling time, and then we can tweak it until we can get the response we desire. We also need to make sure that the light remains pointed at the model during its entire motion. We will be able to check this once the Heliodon is built and plan on troubleshooting if there are issues.

We are aiming for a range of motion (ROM) of the solar altitude angle of -5 to 185 degrees, which would be more than horizon to horizon. We are aiming for a full azimuth angle ROM corresponding to the azimuth angle ROM for our maximum latitude simulation. We want to make sure that we can model the sun's motion for at least all of the United States. Missing solar altitude ROM by a few degrees is not a huge issue as long as we get from horizon to horizon but we would like to be able to stick to our azimuth ROM. Our SolidWorks model of our design should be able to show how large our ROM is, and we can also view other Heliodon designs to see if we can achieve this.

It is important that our table is flat so that models can be placed on our table and the light will hit it in a true manner. The flatness of the whole table is not very important, but the flatness near the model's placement zone is. In this region we are aiming for a flatness of about 0.1 inches. We can only really test this flatness once we get our materials and assemble our table, after which we can make adjustments to get our desired flatness.

4. Ideation

The brainstorming for the project was an ongoing process. We divided the process into two phases; general brainstorming and detailed brainstorming. General brainstorming was completed for the overall look and operation of our Heliodon and the detailed brainstorming entailed the specifics of how the Heliodon as a whole would operate. Once the general brainstorming was completed, we had to pick our top concepts and select a final general design to go with before we started the detailed brainstorming.

4.1 General Brainstorming:

Our first brainstorming session was completed in class. We took a giant sheet of paper and wrote down different categories for different parts of a Heliodon. Our categories were transportation, material, light source movement, and user interface. With categories selected, we thought different aspects that could be used in the Heliodon that were related to those categories. For example, we thought of wheeling, sliding, dragging, and other things for transportation. We thought of wood, t-slot, aluminum, PVC pipe, and other things for material. And lastly, we thought of other relevant things for light source movement and user interface. An important aspect of this brainstorming session was to get every idea possible out there, even the farfetched and silly ones because clever and feasible ideas could spring from them.

Our second brainstorming session included brainstorming for specific parts of the Heliodon. For example, we first brainstormed the ways the light source could move. All four group members took out a blank piece of paper and had five minutes to individually write down their ideas for the light's movement. After the five minutes expired, each group member passed their paper to another person who would then build on those ideas. Figure 6 below shows one example of what a final piece of paper looked like after each group member added to the first idea. This brainstorming session inspired various possibilities for light movement, some of which included a rack and pinion system, a pulley and cable system, manually moving it along pegs or notches, or having rollers inside the arch.

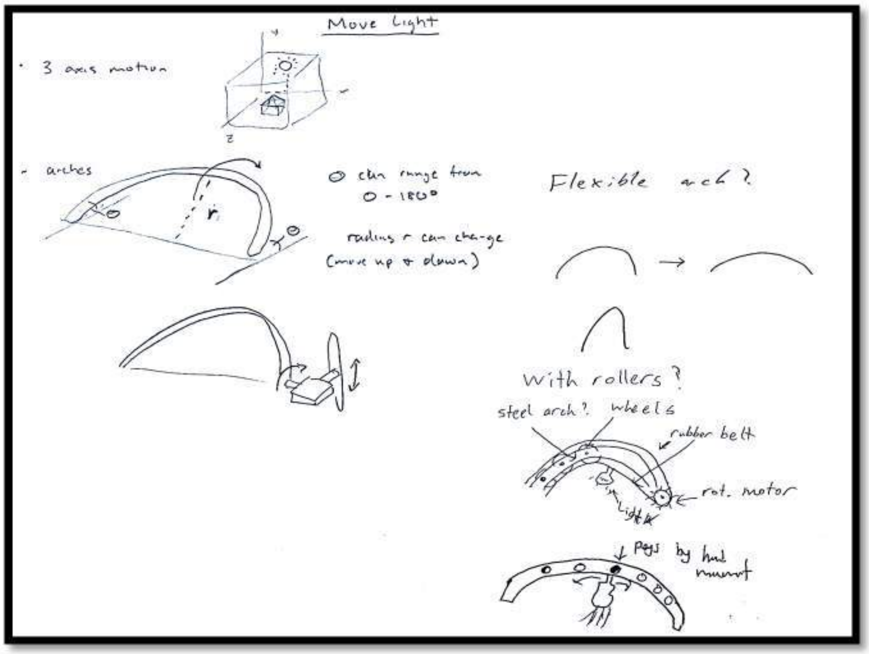


Figure 6. Brainstorming Example

During our third brainstorming session, we decided to visualize the movement of the sun through role play. This was an attempt to understand how the sun would actually move through the sky during different periods of the year. One group member stood in the middle of the room to play the role of the model while another played the role of the sun by holding a light and tracing the sun's path. This activity helped us realize that we needed to construct a rig that would be able to encompass all angles of altitude and azimuth. It also made us wonder whether the shape of the arch should be circular or ellipsoidal. We tried to visualize types of structures that would be able to achieve this movement and wrote our ideas on a white board. These white board sketches can be seen below in Figure 7.

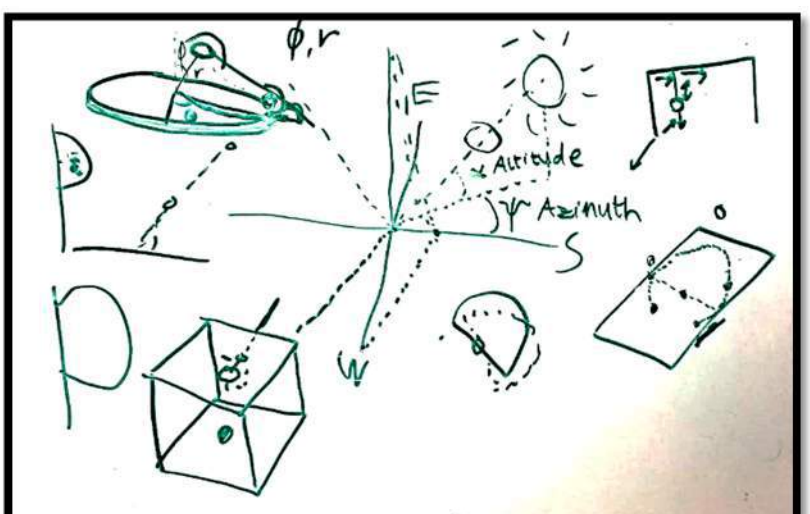


Figure 7. Angle Brainstorming

Next, we met up to sketch possible designs that could place a light at all altitude and azimuth angles. We also considered what kind of table or frame would be best for each light movement method. We used the category list from the first brainstorming session and made selections from each category to form combinations. We then made four combinations and had each group member sketch what the combination may look like. Figures 8 and 9 show a few sketches from the brainstorming session. The Figure 8 design utilized an x-y-z coordinate movement system to place the sun in each desired location while the Figure 9 design used more of an r-theta-z coordinate system. This brainstorming session helped us think about how we could make the Heliodon as large as possible but still fit it through a door. We came up with the idea of a folding table. The table could be folded when the Heliodon is being transported and unfolded when the Heliodon is going to be used.

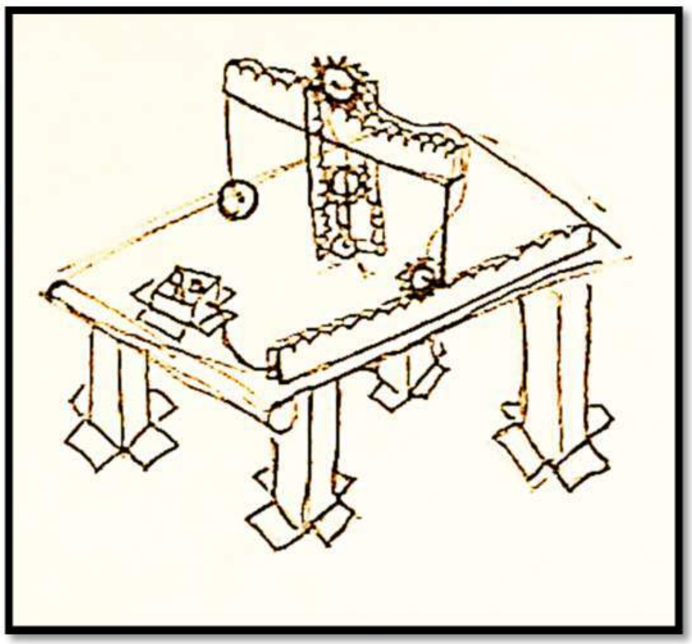


Figure 8. Possible Heliodon Constructed out of Cardboard

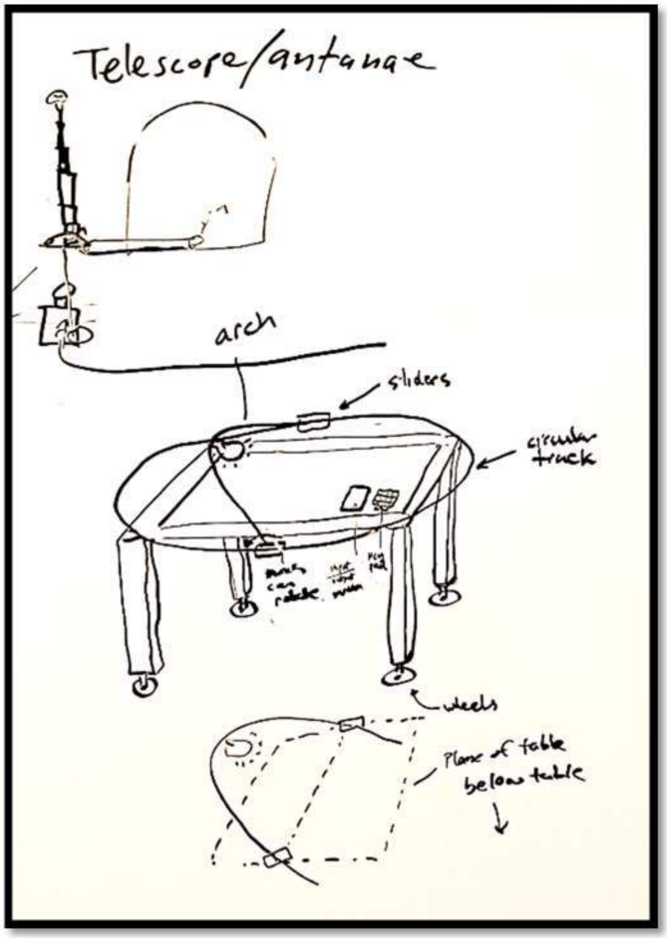


Figure 9. Rotating Arch with Centering Light

4.1.1 Modeling:

In our last brainstorming session we built small, crude models of prototype designs based on our ideas thus far. We made three designs and one concept design for an arch and folding table. These models helped us realize some otherwise overlooked problems with our designs. Figure 10 shows our original concept for the folding table Heliodon. The arch can pivot allowing for a full range of motion for the altitude angle. Even though we later found that this model would not give all the accuracy we wanted, the concept was the basis for later ideas.

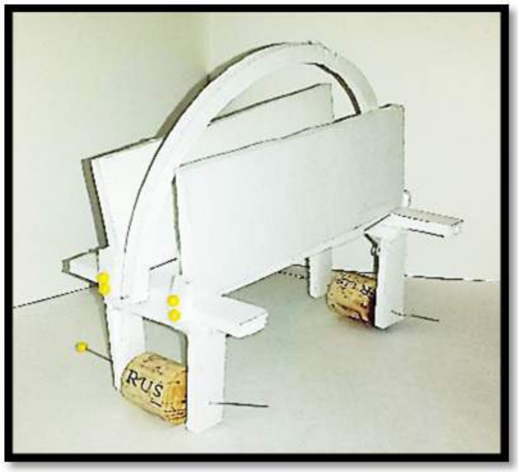


Figure 10. Folding Table Single Arch

Figure 11 shows the model Heliodon that operates similarly to a 3-D printer. It would ideally have full range of motion in the x, y, and the z plane and so it could model the sun's position in the sky at any time.

Figure 11. 3D Printer Model

Figure 12 shows a model of the cylindrical telescoping Heliodon. The arm, represented as a straw, would be able to telescope in and out while rotating around the table at 360^0.

Figure 12. Cylindrical Telescoping Heliodon Top Concepts and Design Selection

4.1.2 Top Concepts and Design Selection:

Out of all of the possible designs that were brainstormed, we considered five distinct designs to weigh against each other and against a datum existing Heliodon. The process by which we compared them all will be explained below.

The first of the five designs was labeled as the “3D printer” which can be seen in Figure 13. It would use Cartesian coordinates to model the sun’s movement in the x, y and z, plane. Servo motors would power each axis individually and vector equations would be used to move the sun in the orientation that a person would see while standing on earth. This would require all three motors working simultaneously to provide the correct path instead of the simpler design of having each motor work independently to get the sun in the correct position. The advantage of this design is that the overall principle of three axis motion has already been done with 3D printers. Instead of having a material injector, a light source would be attached. The overall design could fit through a doorway and be rolled around from classroom to classroom.

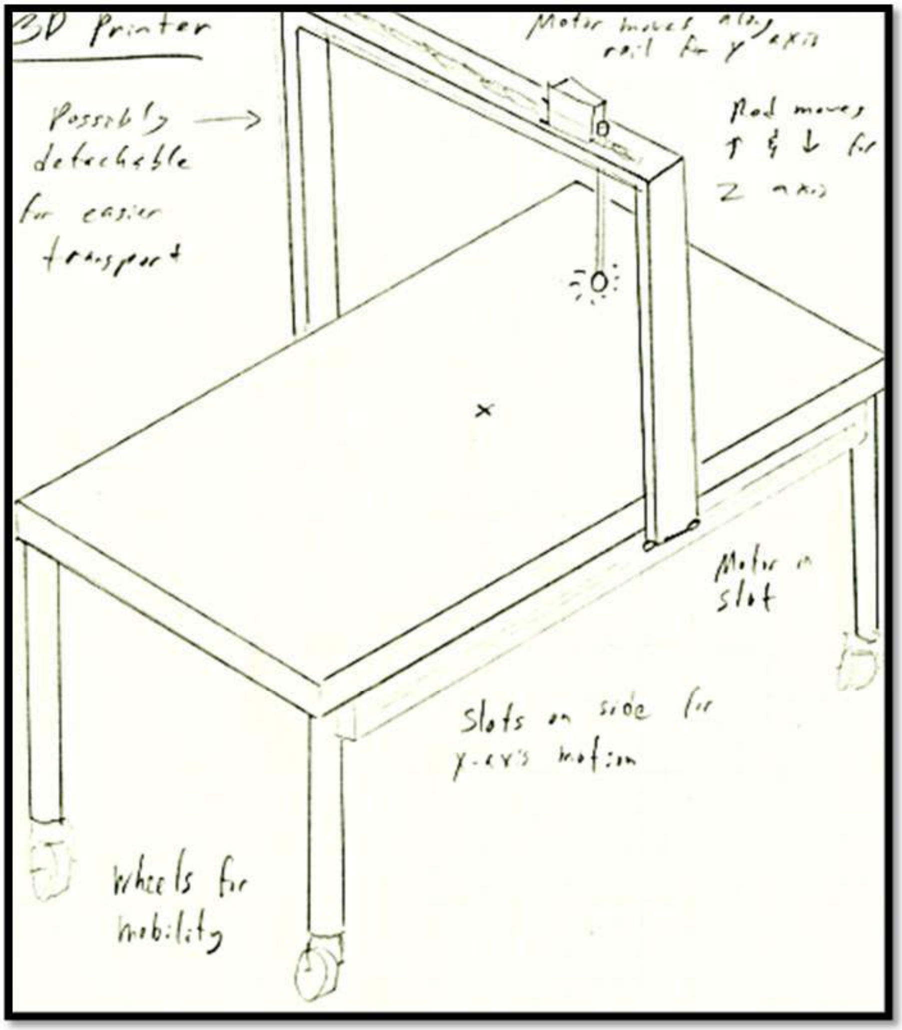


Figure 13. 3D Printer Heliodon

The second of the designs considered was the fixed light moving table. Out of all the designs, this was the simplest. A single light would be hung over a pivoting table that could be adjusted in any direction to achieve the range of motions necessary. The building model to be observed would be securely fastened onto the table to prevent it falling. This design is common due to ease of manufacture and operation. However, this design is unable to model the sun’s movement as we see it from Earth. This is one of our main design criteria given by our sponsor, Dale Dolan, and sacrificing this element is not acceptable. The fixed-light moving-table model is not intuitive and so it is not a good learning tool.

The third design better shows the sun’s movement relative to earth. This design is the rotating arch seen in Figure 14. This design incorporates a folding table to maintain the mobility and space criteria while making it as large as possible to increase accuracy. The further the light source is from the model, the more parallel the rays of light will be when they reach the model. A machined arch would be able to rotate and move along a slotted frame that is attached to the table. The slotted frame would also be able to rotate clockwise and counterclockwise as needed to simulate different latitudes of location on Earth. The arch position within the slot would represent the solar declination (the change in seasons). A wide azimuth range would be possible with this design. A moving light source would be attached to the arch to represent the sun's movement across the sky. This design could be fully automated or manual depending on the budget or the accuracy required. Each different angle would be driven by a single motor or manually before the next angle would need to be adjusted. The light movement along the arch would benefit most from having the motor because adjusting for the hour manually would be inaccurate. This design has the highest educational value because it shows the physical paths the sun would take.

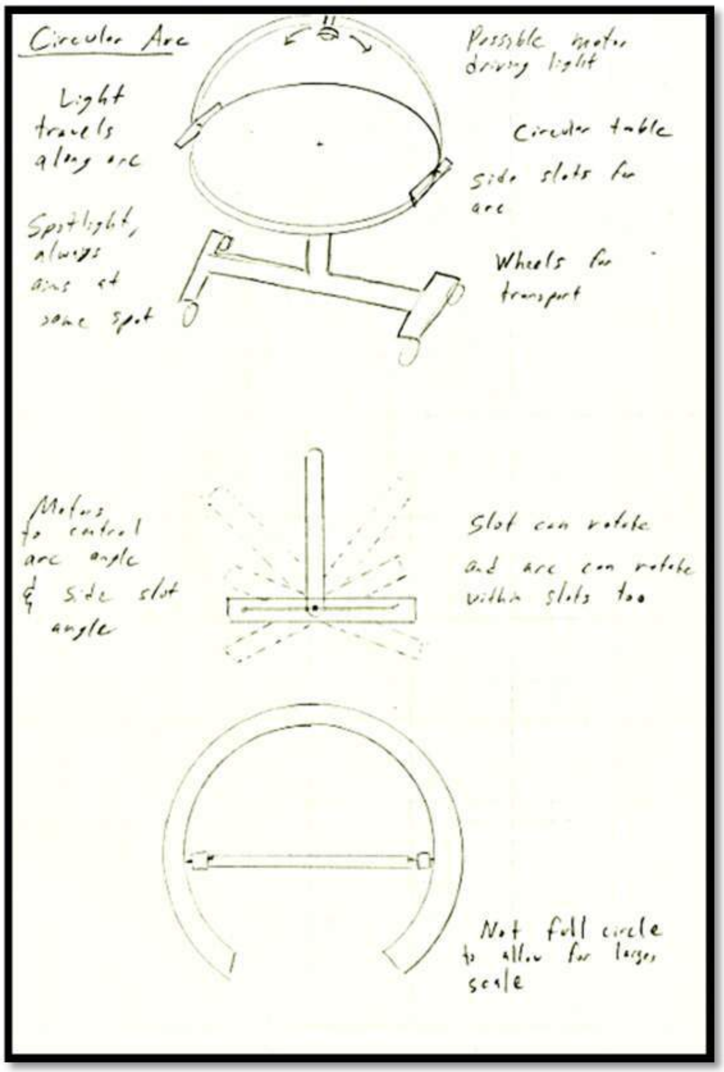


Figure 14. Circular Arch Heliodon

The fourth design uses cylindrical coordinates to model the sun's movement. This design can be seen in Figure 15. A collar that would rotate a full 360° would be attached underneath a folding table. A slotted frame would be attached to the end of the collar and would contain the light source. Inside the slotted frame would be a carriage that could either raise or lower the light source depending on the simulation. A telescoping mechanism would come off the carriage and would hold the light source. A wire feeder would expand or retract the telescoping piece. Three separate motors would be used to adjust the sun at any location or time. They would also be programed to simulate a full day's movement at various latitudes and times of year.

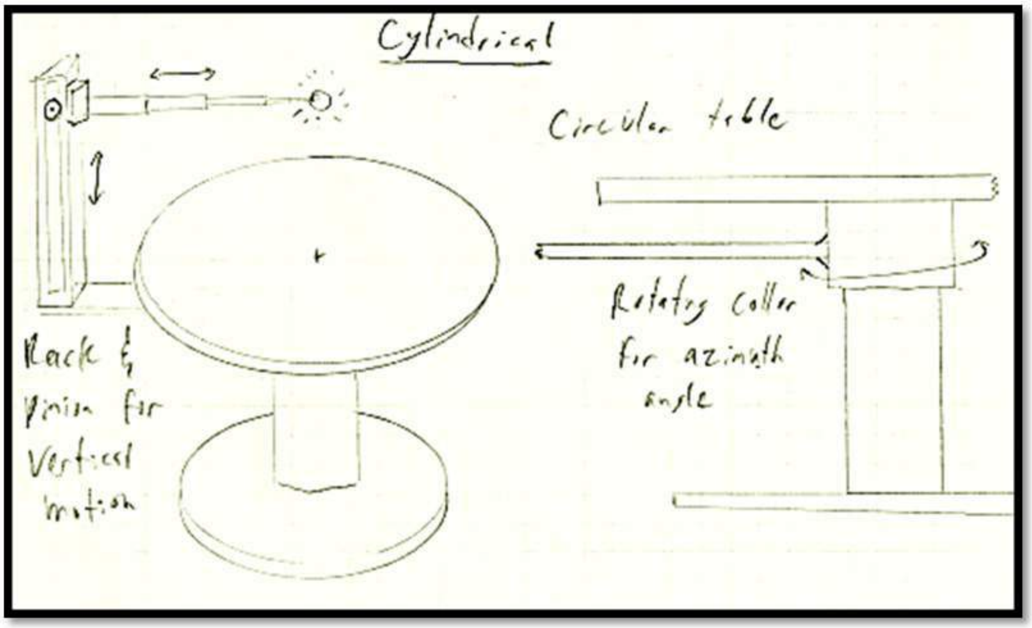


Figure 15. Cylindrical Heliodon

The last design would use spherical coordinates and may be seen in Figure 16. It is similar to the cylindrical design but instead of having a slotted member, it would have an extending rod with the light source attached at the end. The collar would rotate underneath the table while the rod would either extend or contract while bending from the end attached to the collar. The extended rod would also be able to pivot so that the light could extend even more.

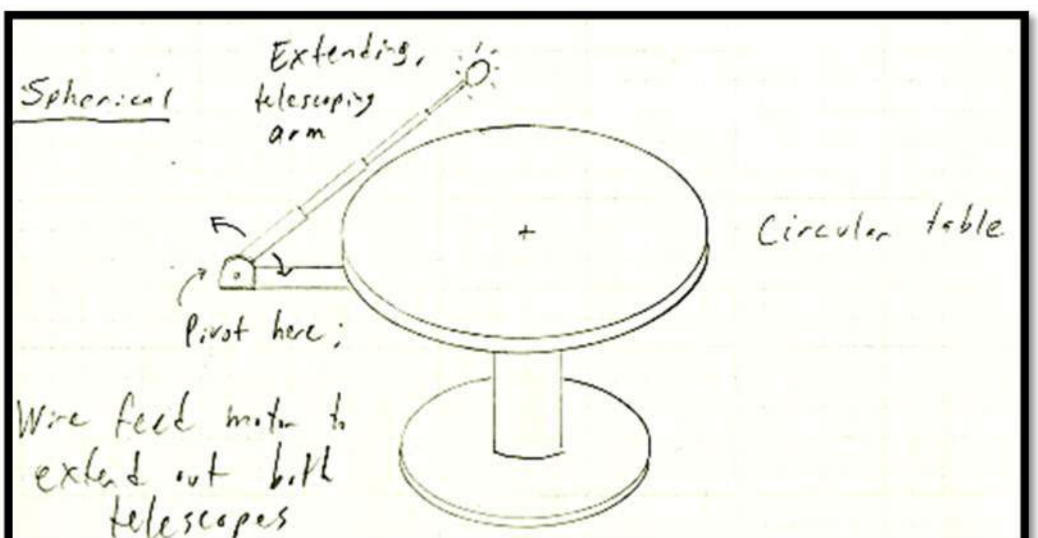


Figure 16. Cylindrical System

4.1.3 Selection Process:

Our team used a Pugh matrix to establish which ideas were better than the datum. The Pugh Matrix can be seen in Table 2. We chose the High Precision Devices Heliodon as our datum, as this is one of the few Heliodons we have come across that is available for purchase and that can model the motion of the sun. We ranked the 3D printer model, spherical and cylindrical telescoping models, and rotating arch model with differing numbers of motors.

For cost we ranked the cylindrical, spherical, 3D printer, and arch with 3 motors as all worse than the datum. All three of these will need three accurate and strong motors, which would likely set the cost higher than the datum. The arch with one motor would likely be about the same cost as we would need to manufacture only one arch as opposed to the seven that the datum has, but we would still need to buy a motor. The arch with no motors would be almost the same as the datum but would only need one arch as opposed to seven, making it cheaper.

The scale of all of these designs would be larger than the datum because we are planning on having a foldable table for each. This would allow us to make a large scale Heliodon while allowing for transportation and for passing through doors.

All but one of our designs would be able to simulate the sun's movement throughout the day better than the datum. The datum moves its light source by allowing the user to rotate the arches by hand. This shows the path of the sun, but doesn't accurately show the rate at which it moves through the sky. It also doesn't have a precise way of displaying a particular sun location at a particular time of the day. Our arch design without a motor would function similarly and come with the same disadvantages. Our arch designs that include a motor would also have a controller that would give the motor directions to provide for more precise movement of the light source.

All of our designs were equal to the datum for mobility, setup time, and ease of user interface. All of the designs, as well as the datum, have wheels and a small enough footprint to be able to be navigated through doors and hallways. They also all have the same setup time. The datum's setup involves rotating the table from vertical to horizontal, adjusting the dials until the arches rotate to the correct latitude, and then pulling the individual arch to select the month and the sun's motion for that day. Our arch design with no motor would function almost exactly like this, and our arch design with motors would involve unfolding the table, plugging the machine in, and using the user interface to input what date and time you would like to model. All of these designs would be very intuitive and would take little instruction before somebody could use it.

The resolution of all of our models would be better than the datum, with the exception of the arch with no motor. The datum is limited to only seven arcs, which greatly limits the range of dates that it can model. With seven fixed arches, the datum can only model one day of each of the 12 months. Our fully automated models with three motors theoretically should be able to simulate any day at any time, and thus give full resolution. Even the arch with a single motor would have more than seven possible positions, so while it would not have more resolution than the fully automated designs, it would still have more than the datum.

For the accurate positioning of the sun, the three designs with simultaneous three axis motion would have the most success. However, it would be extremely difficult to keep the motors coordinated with each other and thus it would be difficult to produce an accurate sun position. The datum has several fixed arches for the light to travel across, so as long as those arches are precise, the sun's position will also be precise. Though, as already stated, the datum has no way of very accurately simulating the sun's position at any given time as it is controlled by the user rotating the arches by hand. Our arch designs with motors would eliminate this problem as they would be able to more accurately model the sun's position at any time during the day.

While the Heliodon's main function is a learning tool, it is also important for it to be able to be used by students as a testing tool. This requires a light that can be shone directly at models to show sun contact. With our arch models, a spotlight could be used since the shape of the arch keeps the light shining at the center of the table at all times. For the non-arch models, separate control would be needed to aim the light directly at the model at all times, or a high intensity bulb would need to be used. This consideration made us decide that they were worse than the datum in that aspect.

For ease of manufacturing we believe all of our proposed models would be easier to manufacture than the datum, simply because of the seven accurate circular arcs that it uses. These arcs also need to serve as rails for the seven lights that it has, which would be much harder to create than any of the components in our designs.

Adding motors to a design means higher cost, more time spent programming, more power needed, and more variables to consider. The datum is completely manual and it doesn't need to deal with any of the previously listed factors. The spherical, cylindrical, and 3D printer designs would all need three motors running simultaneously, which would create many issues that could be difficult to foresee and could be difficult to resolve. The arch designs with motors would not need three motors all running at once, but they would still need motors that would need to be programmed and supplied with power. This made us give them a lower rank than the datum.

An automated Heliodon would require very little effort from the user and would help prevent against human error. All of our designs but one would involve automation, and of those, the one arch motor design would be the only one without complete automation. Though automation would be preferred, it is not necessary to make a functioning and accurate Heliodon, so its importance has not been given much weight.

The Heliodon is to be mainly used as an educational tool to help students of all ages understand the relative motion of the sun. For this reason, the design's educational value is highly important. The datum does a very good job of this, as do our arch designs, because the arch that the light travels on is actually viewable by the observer. The other three designs move the light source freely though the three axes, making the sun's actual path harder to visualize.

The last criterion on the matrix is the time required to build each design, including the time spent programming. The longer a design will take to manufacture and assemble, the greater the chance that it will not be completed before the deadline. Programming for the single motor arch will take a lot of time, and the designs with three motors will require even more time, making them all worse than the datum. Even though the single motor arch will take time to program, it will also only have a single arch that needs to be built and installed, which we believe makes it equal to the datum's seven arch assembly time.

After summing the weighted scores of each design and putting the scores in the "Total" row of Table 2, it is apparent that the 3D printer, spherical, and cylindrical models all scored lower than the datum. A design with three motors all being controlled simultaneously would lead to many headaches during programming, would lead to a high design cost, and would also sacrifice the educational value of the Heliodon.

Table 2. Pugh Matrix

Criteria	Weight (1 to 5)	HPD Sun Emulator	Cylindrical (Telescoping)	3D Printer (Folding)	Spherical (Telescoping)	Rotating Arc (3 motors)	Rotating Arc (No Motors)	Rotating Arc (1 motor)
Cost	4	Datum	-1	-1	-1	-1	1	0
Scale	3	Datum	1	1	1	1	1	1
Footprint (in storage)	2	Datum	0	0	0	0	0	0
Simulates Sun's movement	5	Datum	1	1	1	1	0	1
Mobile	4	Datum	0	0	0	0	0	0
Setup Time	1	Datum	0	0	0	0	0	0
Ease of User Interface	4	Datum	0	0	0	0	0	0
Resolution (how many dates)	3	Datum	1	1	1	1	0	1
Accurate Positioning	4.5	Datum	-1	-1	-1	1	0	1
Light Type?	2	Datum	-1	-1	-1	0	0	0
Ease of Manufacturing	3.5	Datum	1	1	1	1	1	1
Number of Motors	3	Datum	-1	-1	-1	-1	0	-1
Automation	2	Datum	1	1	1	1	0	1
Educational Value	5	Datum	-1	-1	-1	0	0	0
Assembly Time (including Programming)	2	Datum	-1	-1	-1	-1	1	0
TOTAL	**48**		-4	-4	-4	12	12.5	**18**

The top designs were all of the circular arch variations, which beat out all of the other completely automated designs as well as the datum. The circular arch design came out on top mainly due to the educational value that it holds. The arch shows the sun's path as the light moves along it, helping any student gain a better understanding of the sun's relative motion. Also, with all variations of the circular arch, it was the only design that would not require three motors being controlled simultaneously while still achieving all of the necessary angles.

The one motor variation of the circular arch came in first place at 18 points with the fully automated and fully manual designs nearly tying at 12 and 12.5 points respectively. This shows that the best design is actually a combination of the two. The one motor circular arch design captures the fluid sun movement and accurate time representation of the automated version as well as the lower cost and simplicity of the manual version. For this reason, we are selecting it as our top design choice.

4.2 Detailed Brainstorming:

Detailed brainstorming was the most ongoing portion of this project as the need to further brainstorm arose again and again as we began finding issues with manufacturing and assembling different parts. The brainstorming of each part is described below.

4.2.1 Frame and Wheels Considerations:

The size of the frame was limited by the requirement of fitting the Heliodon through the smallest door and in the smallest hallway of the EE building on campus. The height during transportation had to be less than six and a half feet, the total length had to be less than seven and a half feet, and the width had to be less than two and a half feet. The frame would also have to be strong enough to hold around 150 pounds. The inside dimensions of the frame were limited by considering the door and hallway restrictions and relating them to the dimensions of our table and our arch. The table and the arch had to fit within the inside dimensions of the frame without interfering with each other.

The wheels needed to be large enough to keep the frame off the ground and small enough to prevent the Heliodon's interference with the top of the door. They also needed to have braking or locking capability so the Heliodon would not roll on surfaces that aren't completely flat. We considered both hand brakes that could be used while the Heliodon was rolling around and "parking brakes" that would simply lock the wheels in place after the Heliodon was already held stationary. The price of the wheels was also a huge consideration as it was out of our budget to spend a few hundred dollars on each wheel. We considered different combinations of fixed wheels and casters. The requirement of getting through a door in a small hallway made us lean towards choosing casters for all four wheels.

4.2.2 Concept Evaluation: Frame and Wheels:

When we learned of Dr. Dolan's inclination towards T-slot and that Dr. Dolan's previous project team, the PV Trainer, got aluminum T-slot donated for their frame, we decided to use T-slot for our frame as well. T-slot is strong enough to support a lot of weight and it keeps the overall structure's weight low. Also, aluminum has good durability so that leaving the Heliodon outside would be possible. We decided that a system with four casters best suited the need to fit the Heliodon through a door. The difficulty of implementing hand brakes made us lean towards the simple wheel locking brakes.

4.2.3 Latitude Slots:

4.2.3.1 Latitude Slot to Frame Attachment:

The latitude slots had to be sized so that they were long enough to allow the full range of sunrises and sunsets at the different locations we chose to model and not too long so that they caused interference with the frame of the Heliodon or the frame of the door. The slot size was directly related to the size of our arch. We needed to decide both how they would attach to the frame while maintaining the ability to rotate and how the slots would interact with the slider in the slot.

The first idea for how the slots would connect to the frame while being able to rotate was what we called joint connections. This configuration may be seen in Figure 17. Each end of the slot would have a connecting rod extruding from it. The rod would be in two parts with a joint in the center to allow rotation of the slot. The end of the rod would be attached to the frame and would be able to slide up and down the frame to change the angle of the slot.

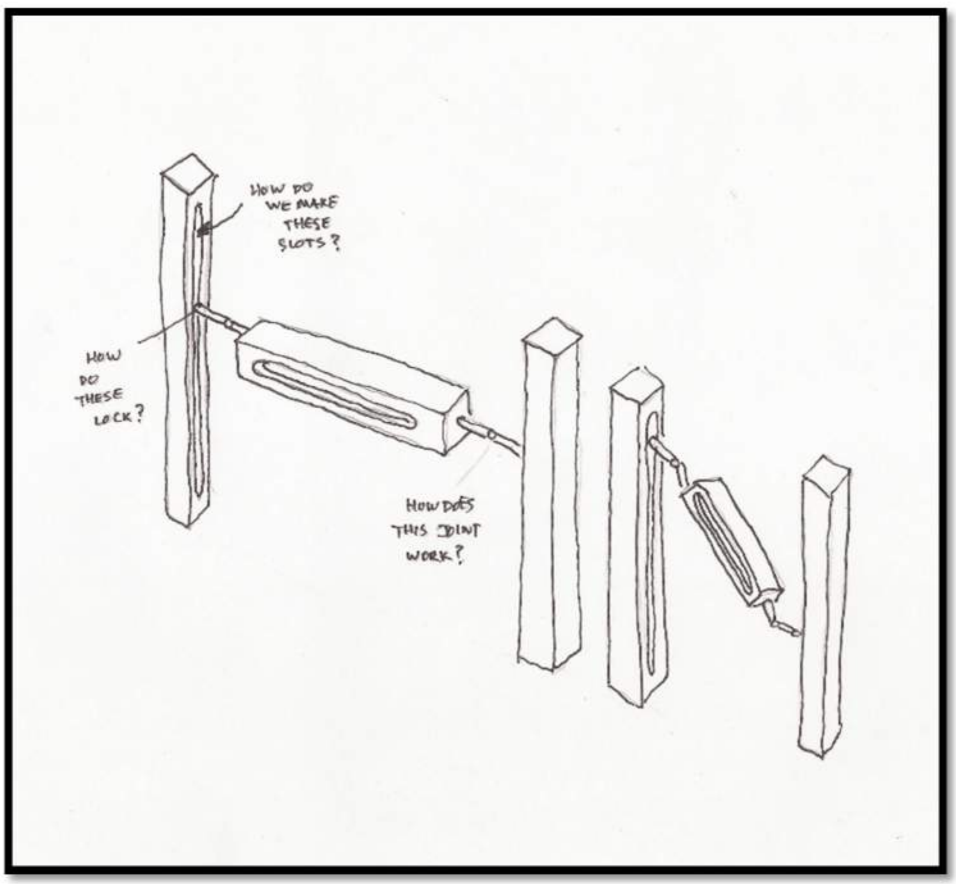


Figure 17. Joint Connections

The second idea for how the slots would connect to the frame while being able to rotate was what we called the adjustable height connections. In this design, which is shown in Figure 18, the slots would sit on the top of each of the columns coming up from the frame and the slot angle would change by adjusting the height of each individual column. The bottom columns could be hollow so that the columns connecting to the slot could dip into the hollow sections. The heights could be changed using pegs and adjusting each height differently would change the angle of the slots.

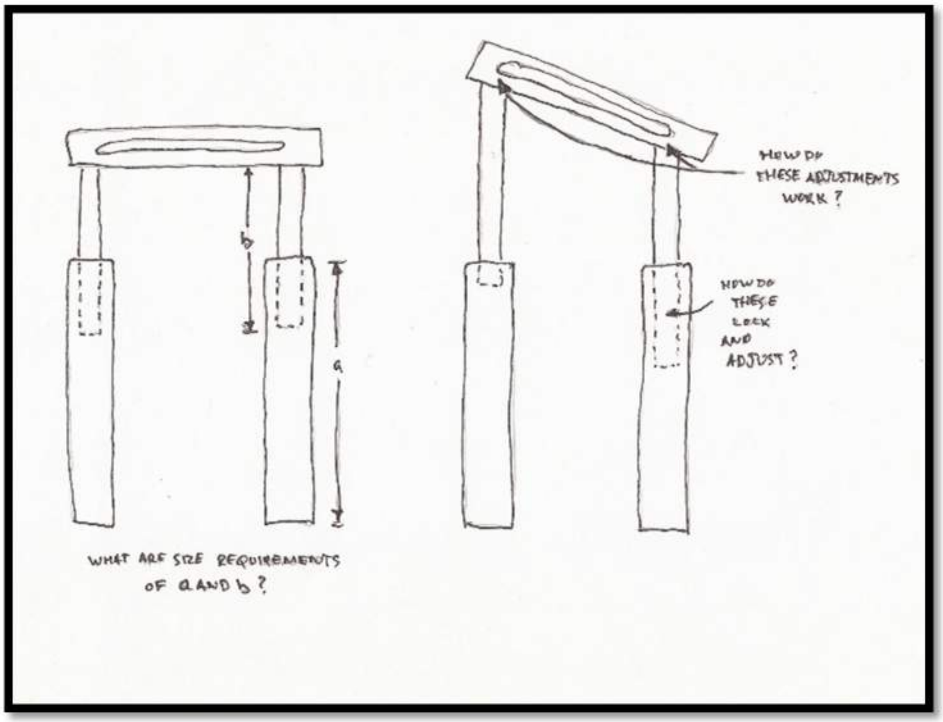


Figure 18. Adjustable Height Connections

The third idea for how the slots would connect to the frame while being able to rotate was the multiple slot configuration. This configuration is demonstrated in Figure 19. The latitude slot piece would have a main slot in which the arch would slide back and forth. It would have two secondary slots as well. These secondary slots would have pins in them and these pins would be connected to the columns coming up from the frame. Sliding the pins along these columns and within these secondary slots would change the angle of the latitude slots.

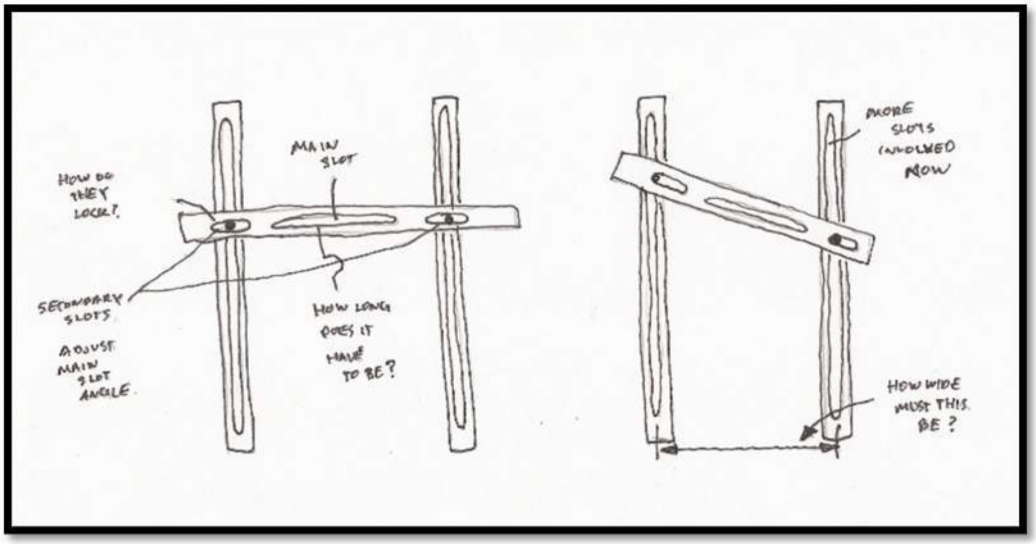


Figure 19. Multiple Slot Configuration

The fourth idea for the how the slots would connect to the frame while being able to rotate was a simple shaft connection. This is demonstrated in Figure 20. A shaft would connect the latitude slot to the frame and the latitude slot would be able to rotate about this shaft in order to change the angle of the latitude slot.

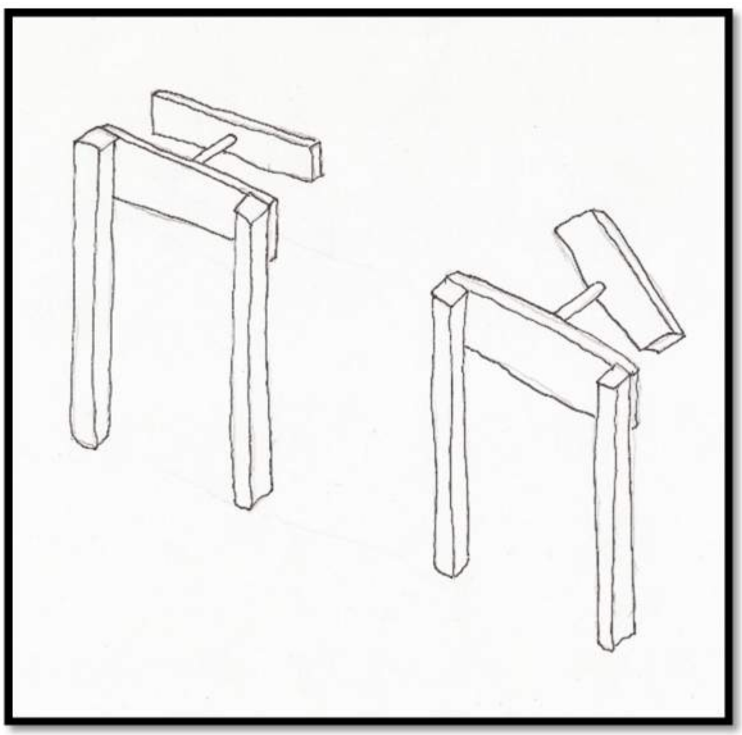


Figure 20. Shaft Connection

4.2.3.2 Latitude Slot – Slider Interaction: Motion and Locking:

The sliders needed to move freely within the slots so the arch could change position relative to the table. They also needed to have some way to lock in place so that when the latitude slots are angled, the sliders do not slide to the bottom of the slots. They will be holding the weight of the arches and so they will need to be structurally sound as well. One of the most challenging problems to tackle was the fact that both sliders would have to be moved at exactly the same time and move exactly the same distance. This was a difficulty because our sliders are six feet apart. In Figures 21 and 22 below, a sketch of how the sliders and the slot may interact is shown. The side plates would be attached to the slot after the slider is inserted, and both the slider and the slot could have rods coming out of them to connect to the Heliodon.

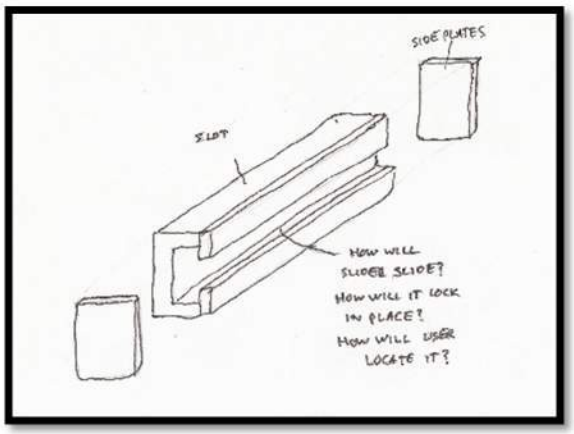


Figure 21. Slot Slider Interaction

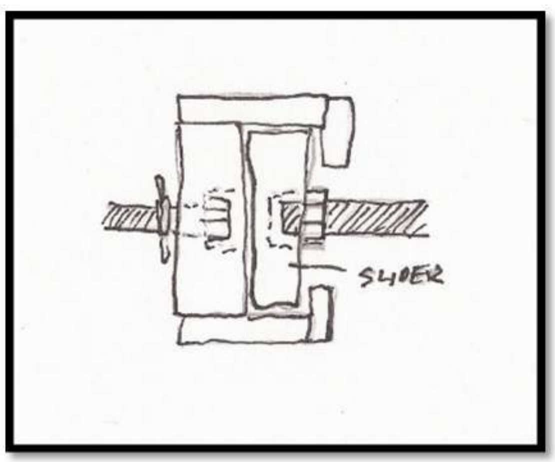


Figure 22. Slot Slider Interaction Side View

The materials we considered for the sliders were wood, aluminum, and some sort of plastic. Wood is a little cheaper than aluminum and it is more readily available with the dimensions we are considering. Aluminum is more structurally sound and it would probably look more aesthetically pleasing with the rest of the Heliodon. Aluminum would also last longer. We thought that plastic could be a good option because it may have the lowest friction and thus it may be the easiest to slide.

4.2.3.3 Motion:

Our first idea for slider motion was to have ball bearings within the slots. Ball bearings at the top and the bottom of the slider would create a smooth and easy motion for the slider. The sketch shown in Figure 23 is an idea of how this may work.

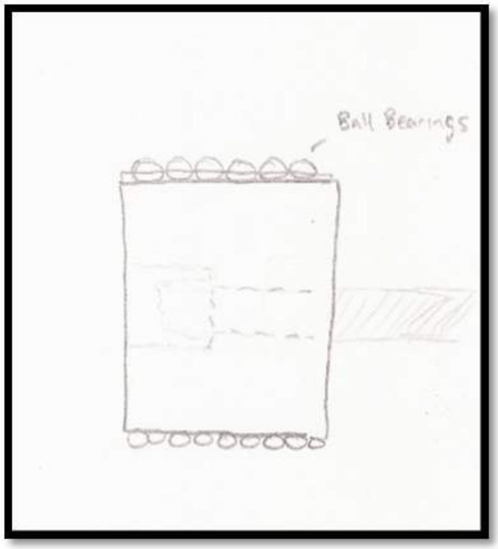


Figure 23. Ball Bearing Slider

Our second idea for slider motion was to have an internally threaded hole through the slider. A lead-screw would run through this hole so that turning the lead-screw would create linear motion in the slider. Figure 24 shows this design.

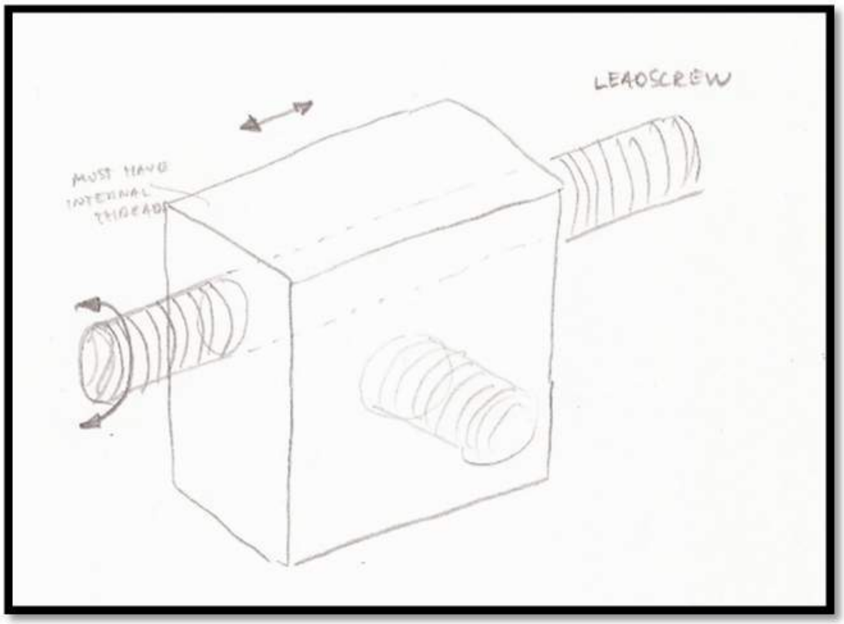


Figure 24. Lead-Screw Slider

Our third idea was to have guide-shafts running through each slider. Figures 25 and 26 below show this design. Figure 26 provides a side view showing a rod sticking out of the side. This rod could be a connection point to the rest of the Heliodon. These guide shafts would help to keep the sliders in line. Small wheels could be attached to the top and the bottom of each slider so that their motion would be more fluid.

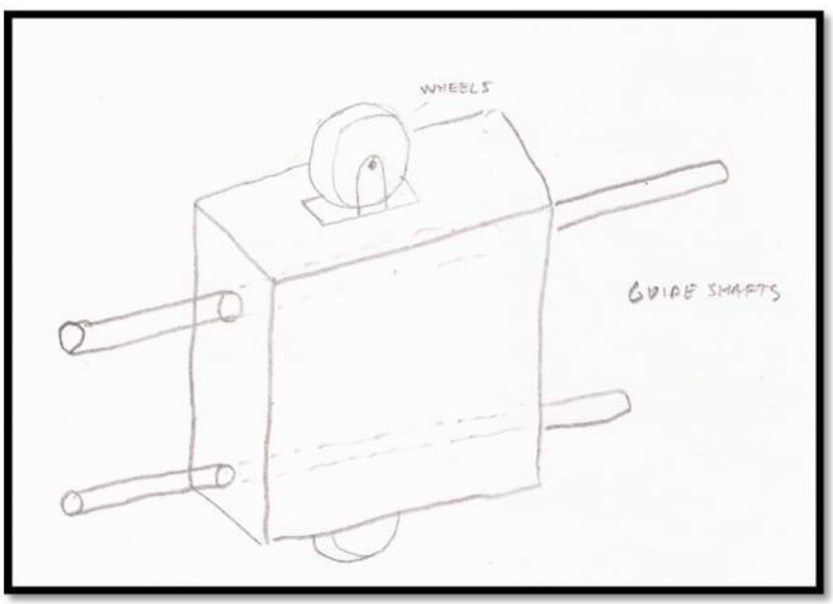


Figure 25. Guide Shafts and Wheels

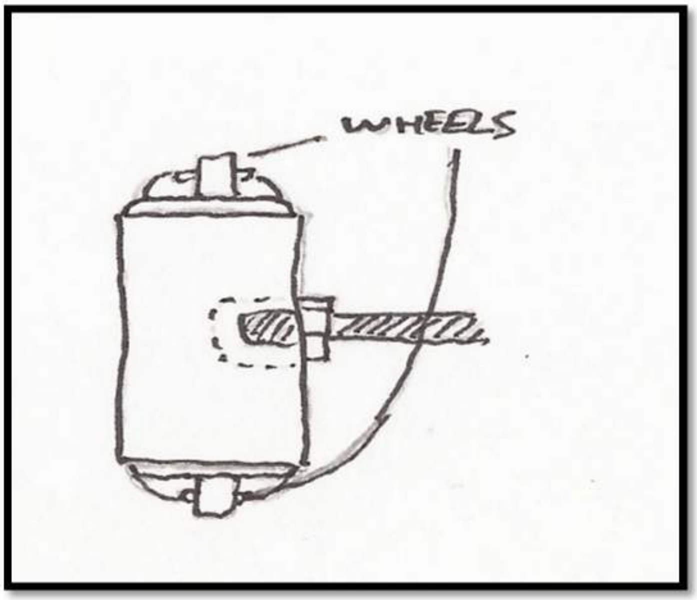


Figure 26. Wheels

4.2.3.4 Locking:

Our first idea for locking the slider in place was by installing a removable rod that could be placed through the slots and locked in place. Once the rod was locked in place, the slider would not be able to move past it. Nuts on the top and bottom of the slot could be loosened or tightened to provide sliding or locking. Figure 27 demonstrates this idea.

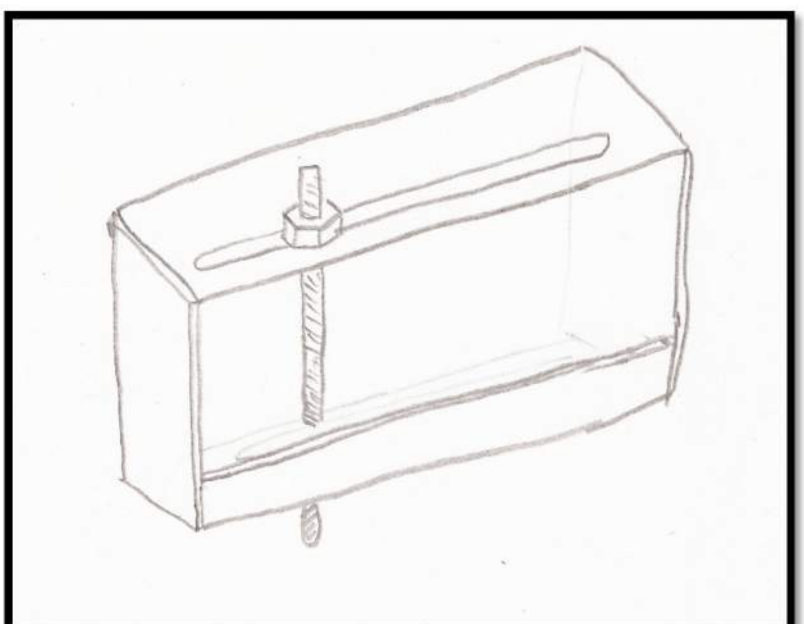


Figure 27. Removable Rod Locking

Another idea we had for locking the slider in place was by providing the user with an adjustable bar which could be placed between the slider and the side of the slot. This bar's length could be varied and once the correct length was selected, it would be wedged between the slider and the wall of the slot to prevent motion. Figure 28 demonstrates this idea.

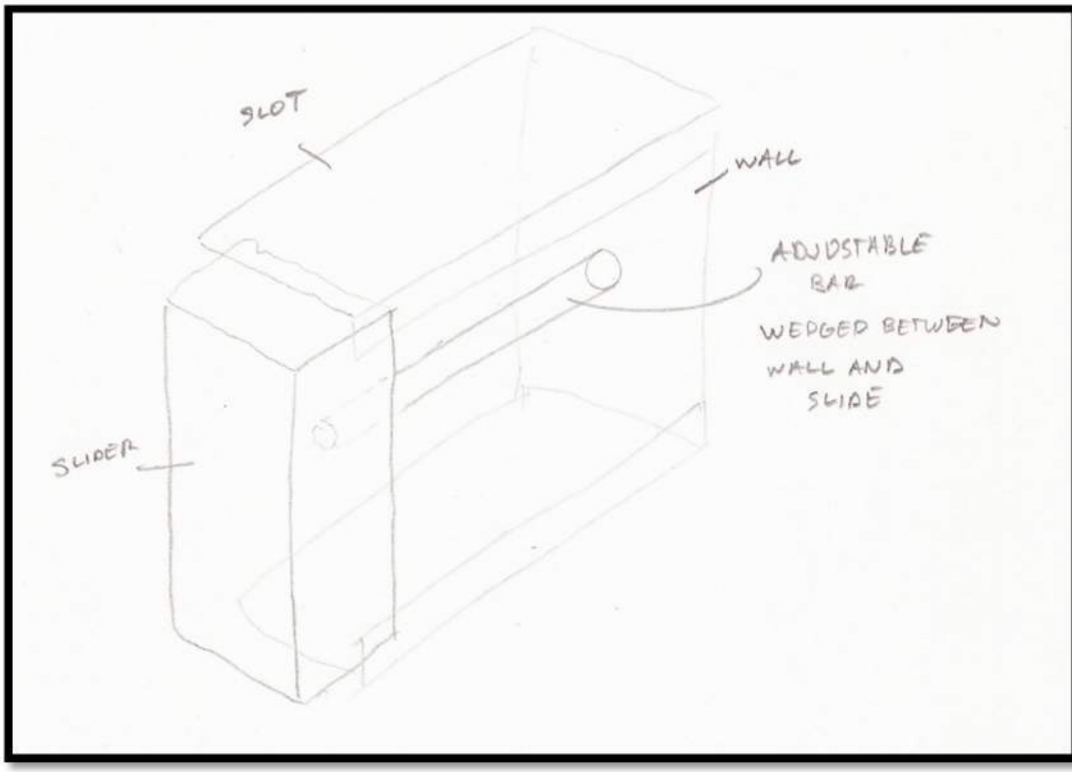


Figure 28. Adjustable Wedge

A third idea we had for locking the slider in place was to have a bar extruding from the slider that would slide with the slider along the slots. This bar would be threaded and would have a nut on the portion that is extruded from the slot. This nut could be loosened or tightened to allow for locking and unlocking of the slider. The bar could extrude from either the bottom of the slot, as seen in Figure 29, or the side of the slot as seen in Figure 30.

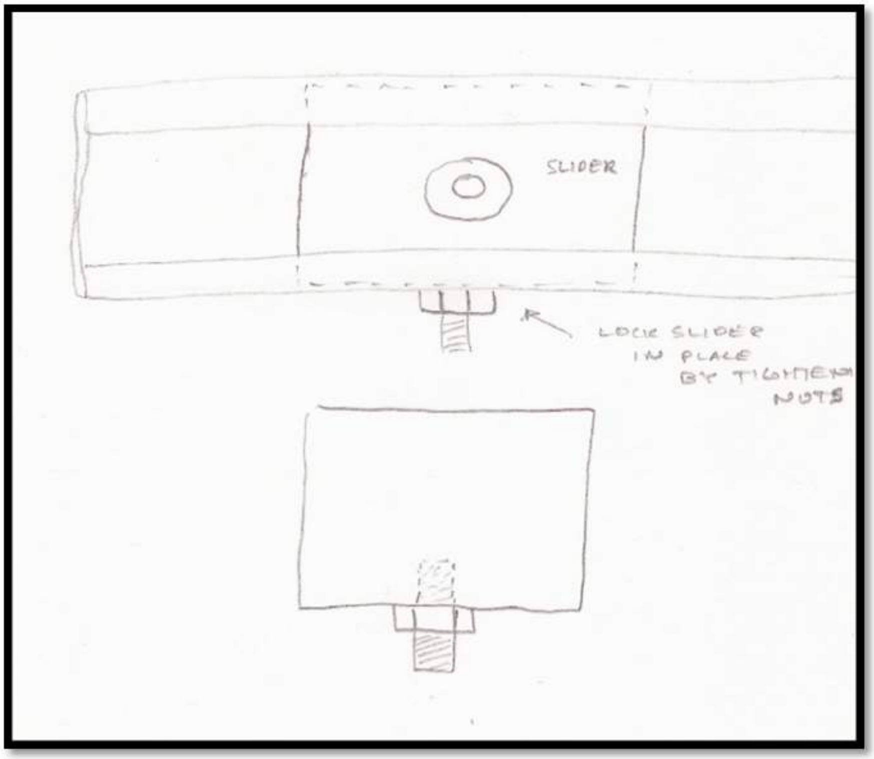


Figure 29. Bottom Extrusion

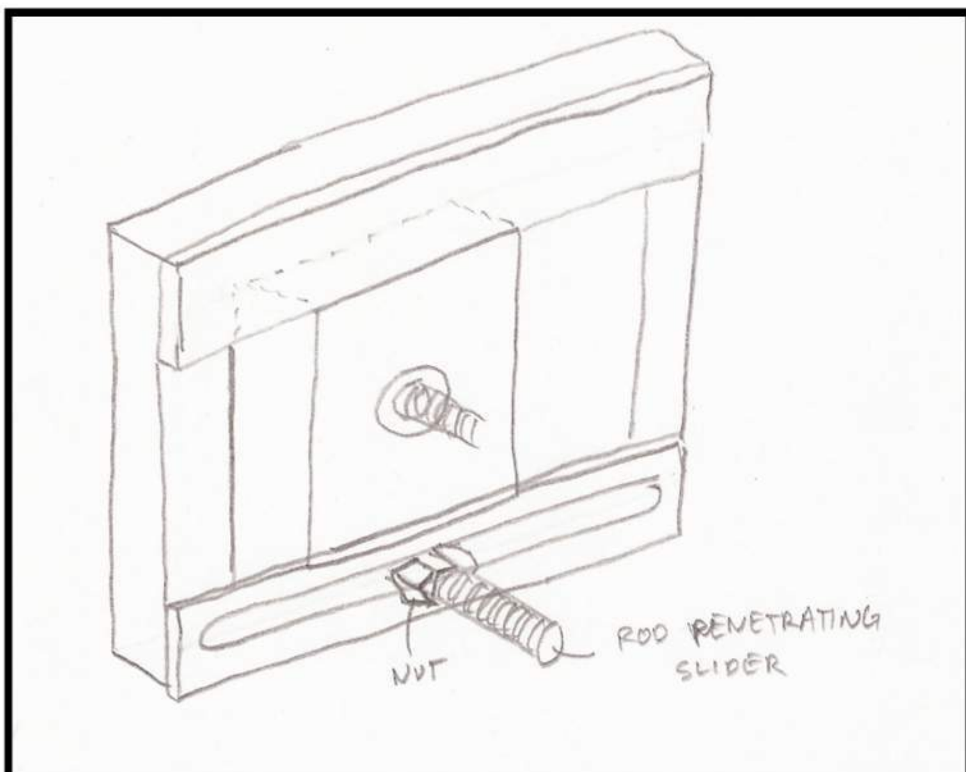


Figure 30. Side Extrusion

4.2.4 Concept Evaluation: Latitude Slots:

The joint connecters to move the latitude slots would effectively allow for the changing of the latitude slot angle. However, the way the joint would work could be very complicated. This design would also require the columns that support the latitude slots to have a slot down the side of the column. The adjustable height slots would also effectively allow for the changing of the latitude slot angle. However, the columns here would need to be hollow and a locking mechanism may need to be brainstormed to lock the slot in place. The connection between the slot and the columns could be complicated as well due to the way the contact surface changes with a changing angle. The multiple slot configuration would also work, but it introduces the need for many slots with many locking mechanisms. The shaft connection was the simplest design. The only foreseeable issue with this design was that the rod would have to be supporting a lot of weight, which could be an issue.

The ball bearings for the slider could work but the difficulty with this idea is thinking of a way to keep the ball bearings in place. The bearings may need to be replaced eventually as well. The lead-screw design seemed to be one of the most promising. The challenge of this idea was moving both sliders at the same time. We considered having a lead-screw through each slider, but then both lead-screws would have to be turned at the same time and the same rate. We then considered having a lead-screw in one slider while the other was free to move. This became complicated because we did not know whether the freely moving slider would move more or less than the lead-screw slider. The concept of using shafts to guide the slider could help this issue but any greater or lesser motion of the free slider would add a tilt to the arch and therefore decrease the Heliodon's accuracy. Some positive of this idea were that slider motion could be very precise and it would also be self-locking. The use of wheels on the slider would definitely ease their motion.

The removable rod would provide a good way to lock the slider in place, but locking it in exactly the right spot could prove difficult. There is also the possibility of losing the rod because it is removable, and in this case the Heliodon could not operate correctly without a replacement. The adjustable wedge rod would work to lock the slider in place, but it would probably be very tedious and difficult to both adjust the rod to the correct length and insert it into the slot. The extruding bar would provide a good way to lock the slider, but it may be difficult for the user to turn the bolt to the correct tightness.

4.2.5 Arch Design:

Before selecting an arch design, we had to learn what was feasible to be manufactured. We knew we needed a large arch that had a constant radius and we were thinking of using some sort of piping or tubing, but we didn't know if bending such a material to our desired radius was something that we could do ourselves or whether someone else could do it. The arch needed to have a light carriage traveling along it and this made us think of various cross sectional shapes for the arch. Some of these cross sections can be seen in Figure 31.

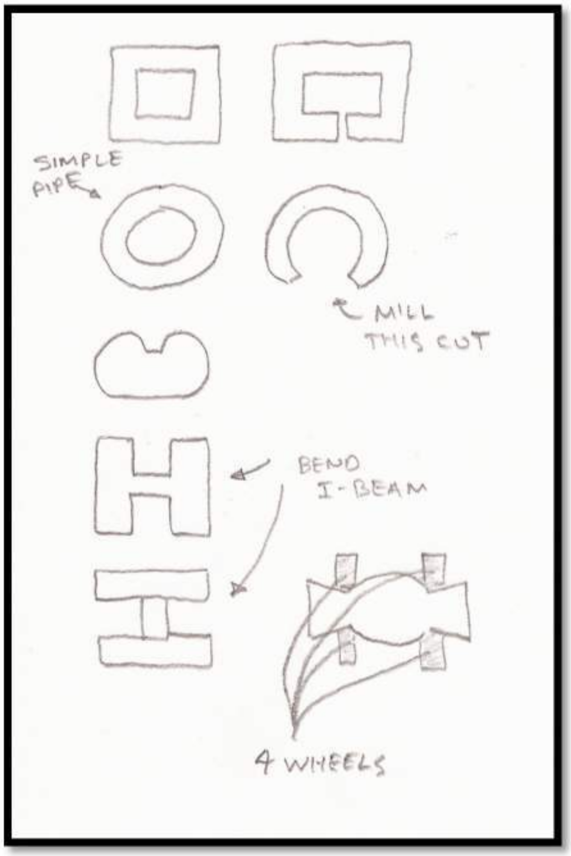


Figure 31. Cross Sections of Potential Arches

We started the brainstorming of the arch with the way the carriage may move along it in mind. However, we soon decided that it was more important to pick a design for the arch and then design a light carriage around it because the arch is the least customizable piece of the entire project. We considered using one arch as the track or using multiple arches for the track. We also considered a couple types of material to use for the arches including Aluminum, steel, and PVC pipe. Different manufacturing processes were analyzed for cost, efficiency, and feasibility.

4.2.6 Concept Evaluation: Arch Design:

After weighing the benefits and drawbacks of various arch cross sections, we decided that above all else the most important thing was to ensure that the arch be simple. We were most concerned about what was able to be manufactured and so choosing the simplest design was essential. In this case, a simple pipe with a circular cross section seemed to be the best. If the arch of our radius was to be produced, it would surely be most feasible with a circular cross section. We knew that our arch needed to be as light as possible, and this made us lean towards using PVC or aluminum over steel. We also leaned towards using multiple arches to simulate a track rather than only using one arch. We thought that having multiple arches to serve as a track could be beneficial for the light carriage because it could help with stability as it moved along the arch. We recognized that using two arches instead of one would require some way to lock the arches so there was a set distance between them. The use of brackets to lock them in place seemed to be the most feasible. The final design would really come down to what was possible to bend to the dimensions that we needed.

4.2.7 Light Carriage Design:

Only after the arch design was finalized could the detailed brainstorming for the light carriage begin. We knew that the carriage would have to be driven by a motor as it moved along the arches and most of our light carriage brainstorming assumed that the carriage was to be pulled by a cable attached to the shaft of the motor.

One of the initial ideas for the light carriage was to have its body being pulled by cables while being guided along the arches via two pieces of pipe that would slide onto the outside of the arches. A sketch of this design can be seen in Figure 32 and Figure 33. We called this the cut-pipe guide carriage design. This would allow the motor to pull the carriage and the arches to guide the carriage's path.

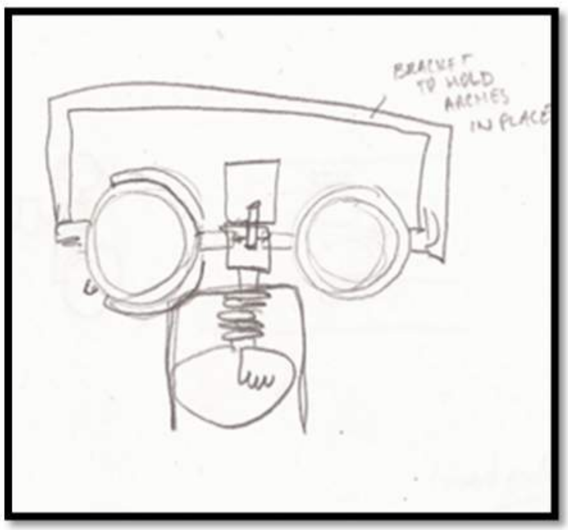


Figure 32. Carriage with Cut Pipe Guide Carriage

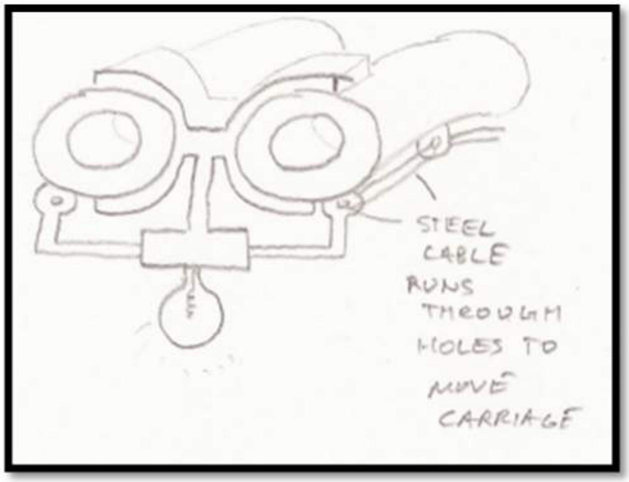


Figure 33. Side View of Carriage Movement

The other carriage design was inspired by a History Channel special on roller coasters. The arc will act like the roller coaster track and the carriage will have wheels surrounding it to guide it along it. A sketch of this mechanism can be seen in Figure 34.

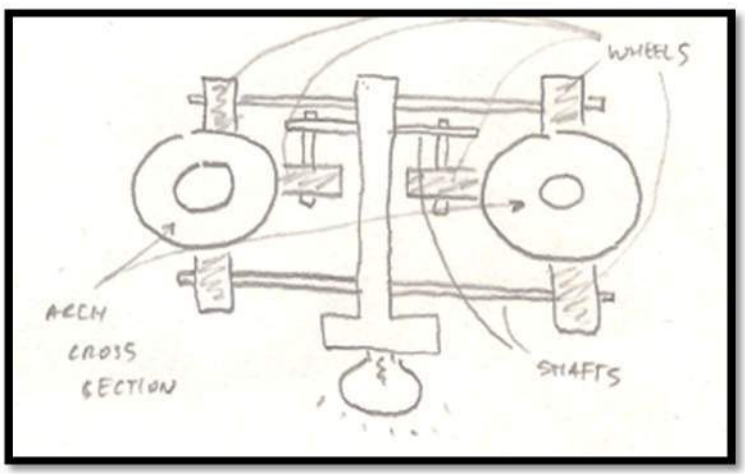


Figure 34. Early Sketches of Carriage Roller Coaster Concept

4.2.8 Concept Evaluation: Light Carriage Design:

There were two main concerns with the cut-pipe guide carriage. The first of these concerns would be manufacturing. To build this, we would need to get some pipe with an inner diameter similar to the outer diameter of our arch. We would then need to bend it to a similar diameter to the arc as well, because straight pipe will not slide well when mated against curved pipe. We would also have to cut out a portion of the outer pipe because free space on the arch piping is needed to attach the wire guides and the brackets. These pipe guides would also need to be attached to the main carriage body.

Another concern we had was the friction between the pipe guide and the arches. We would want the contact between them to be as great as possible, but this would also generate a lot of friction. This would make it difficult for the motor to pull the carriage along the arches without some sort of lubrication.

The benefits of this design is that it would be using the arches directly as the guide, so it would follow its path very well. It is also more limited in parts, so while it may take some time to assemble, it would not take very long, it would be cheap, and it would be less parts to worry about.

The roller coaster design's negatives are mainly the number of parts that are required. To make this idea work we would need to mount bearings for the wheels that we use, and these bearings would be relatively expensive. We also would want to use springs to force contact from the wheels to the arches, and because of the small amount of space there would be to work with, creating these spring attachments could prove difficult. All of the different components of this carriage would lead to greater manufacturing and assembly time, higher cost, and more places for the design to go wrong.

The pros of this design are that it is a proven concept that we know currently works with roller coasters. The wheels would provide smooth motion along the arches, which would better accomplish our goal of modeling the sun's motion accurately. The rotating shafts in this design may also be able to be coupled with an encoder, allowing us to directly track the carriage's position, if we wished to do so.

4.2.9 Motor:

We knew the carriage was going to be driven by a motor, but the placement of the motor on the Heliodon was up for discussion. We had the ideas to mount the motor to the arches, the frame, or to the carriage itself. We did not know how heavy our carriage would be and so we did not know how heavy the motor driving it would be. This made the notion of mounting the motor to the carriage seem a little unreasonable, but at the same time neglecting to mount the motor to the carriage made the need for some kind of cabling to pull the carriage.

We also had to decide what kind of motor to use. We had the option of using a stepper motor or a servo motor. We needed the motor to have enough holding torque to lock the carriage in place if it were to stop at some midsection of the arch. We also needed to decide whether the motor would be dual shaft or single shaft. That decision would depend on how the motor was going to interact with the cables and wiring. We also needed to consider whether or not the motor would need to be coupled with a gearing system to get the torque that we needed.

4.2.10 Concept Evaluation: Motor:

The concept of mounting the motor to the frame was weighed against the concept of mounting the motor to the arches. Mounting the motor to the frame would be very simple as far as supporting the motor, but the idea became complicated when we thought about how it would affect carriage motion. As the arches rotate, the carriage would move away from the motor and the cable connecting the two would be pulled on. We did not know exactly how this tension in the cable would affect the motor or how it would affect the accuracy of our simulations as a whole. When we considered mounting the motor to the arches, this problem disappeared because the motor and the carriage would move together. The difficulty of this idea was the actual mounting of the motor. We would need to design some kind of connection to the arches that the motor could be bolted to.

The chosen motor needed to be able to be controlled by the microcontroller and have enough torque to manage the cables. We found that servo motors only require three wires to control as opposed to stepper motors that require at least six. Servo motors are simpler to control and require less input and output pins on the microcontroller.

4.2.11 Carriage Motion:

We had to figure out how the carriage would move along the arches once the motor was driving it. We figured that the motor would have to be pulling a cable of some sort. We initially thought of using either 1/16th inch diameter steel cable or 1/32 inch Kevlar cable. This cable would be attached to the light carriage in some way, and would also be guided along by the arches so that it would pull the carriage in the needed direction. We also need to make sure that the carriage could move back and forth along the arches. Some initial "sleeve" design concepts are shown in Figure 35 below.

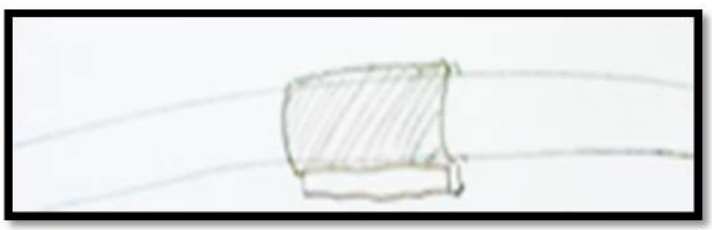


Figure 35. Cable Guides with Collar Attachment

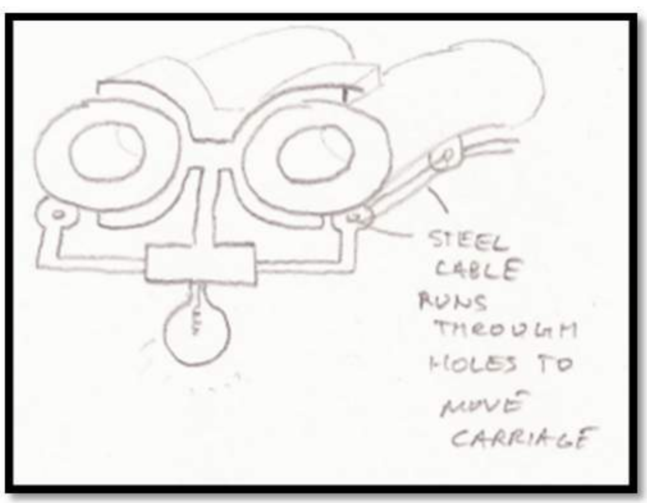


Figure 36. Cable Slit Sketch

One suggested method was to have cable guides attached to the arches at various places. They would have a slit in them that would be too small for the cable to slip out of, but large enough to allow for an attachment from the cable to the carriage without interfering with the guides. This method can be seen in Figure 36. The other idea was to use wire guides, but to have the cable directly attach to the carriage and to have the cable rest in the guides. As the carriage would approach a cable guide it would slightly lift the cable out of its guide, and as the carriage passed the guide, the cable would fall back into place. This method can be seen in Figure 37.

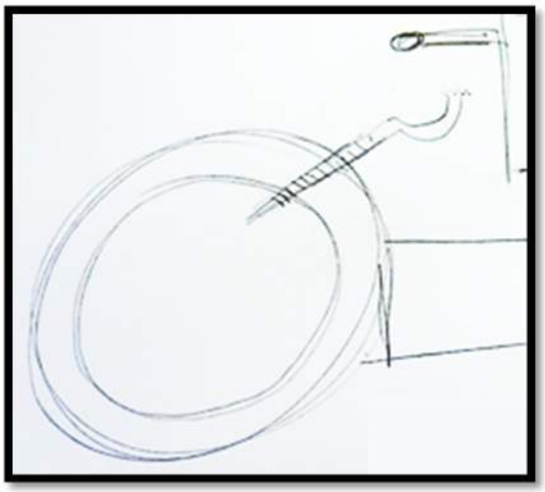


Figure 37. Cable Guides with Resting Cable

There were three main ideas that dealt with how to get the motor to draw in and release the cable to allow for the forward and reverse motion of the carriage. The first idea was to use a series of pulleys and tensioners to pull the cable, with the other end of the loop running through the inside of the arc. The next was to use a spool that the motor would rotate to take in one end of cable and let out cable on the other end, depending on the desired direction. This spool can be seen in Figure 38. The final option was to have two motors, one on each side of the arc, that would take in or give cable depending on the desired carriage motion.

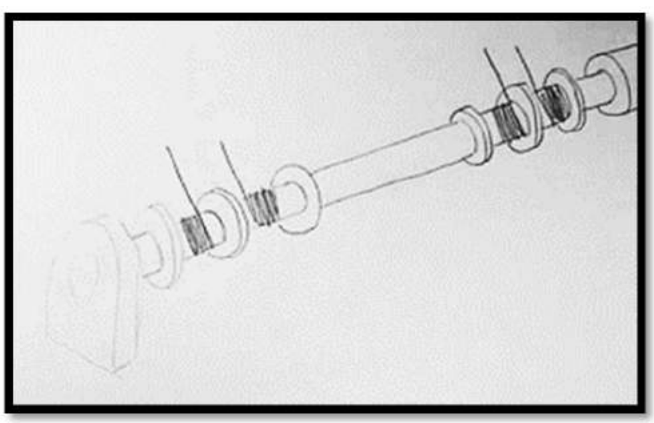


Figure 38. Cable Feed Spool

4.2.12 Concept Evaluation: Carriage Motion:

The cable guide with the collar attachment for the carriage would have some issues. It would be difficult to get the collar to go through the guides perfectly. It would be very easy for the collars to catch and bind and prevent the carriage from moving. The collar-carriage connection would have to line up with the slit in the cable guide or else it would not be able to get through. We would need to think of a way to secure the collar to the cable. A nut and bolt or a screw would likely cause interference with the guides while a weld would probably sever the cable.

Some difficulties we would face with the cable guide with resting cable would be ensuring that the cable settles back into the guides every time the carriage passes. We would also need to think of a way to join the cable to the light carriage. This design would be incompatible with the pipe-guide version of the light carriage and would be difficult to implement if we chose to go with the roller coaster design for the carriage

All of the methods for pulling the cable had issues. If we were to use the pulley and tensioner method, then we would need a lot of tension in the cable to be able to draw it in and feed it out, but would need as little tension as possible so that the cable's friction on the guides would not be so great that carriage motion would be prevented. This would eliminate the need to have a spool that accumulates wire, but it would also require us to create an adjustable pulley assembly.

The main con of the spool idea is that we would have to create a spool that can hold up to 20 feet of cable at a time on a limited amount of space. The spool shaft would require another bearing to support it, which would cost more money. There would also be the possibility of the cable overlapping on itself or spacing out while spooling, which would give inaccurate measurements when drawing in and letting out the cable.

The last idea was to have two spools and two motors on either ends of the arches. This seems like a simple solution, but it actually has many issues. The second motor would cost more money and we would have the same issue with creating a spool. Probably the biggest issue would be controlling both motors simultaneously, without letting up any of the tension in the cable, and keeping an accurate carriage position.

4.2.13 Light Power:

The method of powering the light was an iterative process. We needed to figure out how to effectively string power wires to the moving light fixture without bunching up the line, causing excessive bending, or allowing the line to dangle below the arches. A few ideas were thought up including using battery power, feeding wire from the top of the Heliodon, and spooling the power wire in tandem with the driving cables.

We quickly decided that battery power would be implausible; the LED light bulb, though efficient, would discharge a battery too quickly. A battery would be very inconvenient because it would need a recharge or a replacement very often and would add unnecessary volume to our light carriage.

Feeding the power wire through the top of the arches would not work either because it would add extra height to the Heliodon and risk interfering with the door frame. The addition of another spooling mechanism would require even more parts and design. This complexity ruled out that idea.

We decided that spooling the power wire in tandem with the driving cables would be the best option as we already had a spooling mechanism in place from the light carriage movement mechanism. The power wires would already have to be travelling with the light carriage driving cables.

The next problem with this method was keeping the cable up and out of the way of the Heliodon. We wanted the wires to have the orientation shown on the left in Figure 39 rather than the orientation on the right.

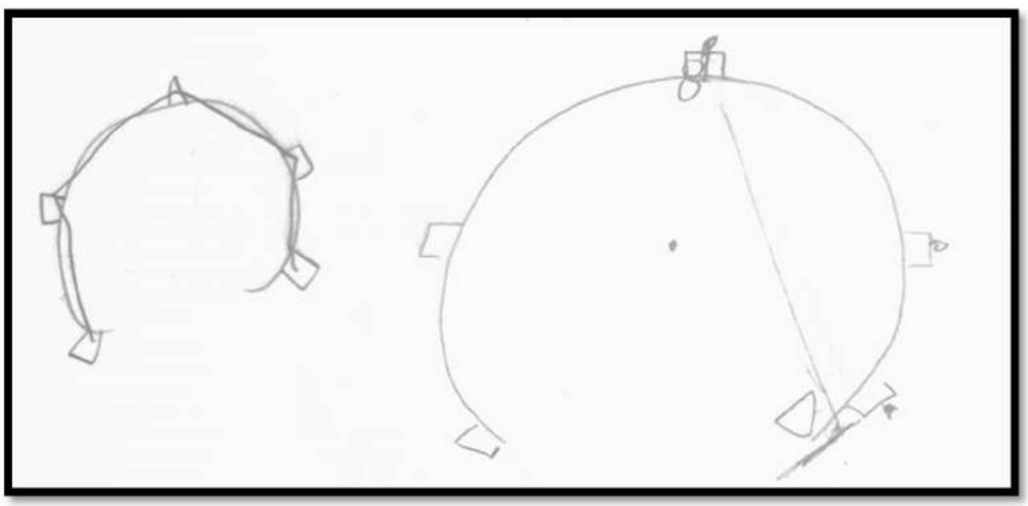


Figure 39. Potential Wire Locations

We thought of using wire guides with a method similar to the way a ski lift allows the lift to move past the supports and hooks as possible solutions to having the wires run along the arch.

4.2.14 Concept Evaluation: Light Power:

We determined that the best method to keep the power wires from interfering would be to run the wires through wire guides. These wire guides took many complex forms before reaching a simple effective solution. We first thought to use a sort of clamping mechanism similar to the way ski lift cables allow the lifts to pass through a pulley system. The power cable guides would open and close to let the light carriage pass through and rest the wire inside the enclosure. Though we were confident that this would work, these wire guides would require a lot of machining.

We finally thought to use a simple hook to string the wires through. An example of this hook may be seen in Figure 40. These hooks would be screwed in to each arch bracket and the hook would extrude from the bracket. This design requires that the light carriage has a bent tube to orient the power cable to be strung through the hooks. The design of the hooks to string the wires through was chosen for its simplicity, functionality, and low cost.

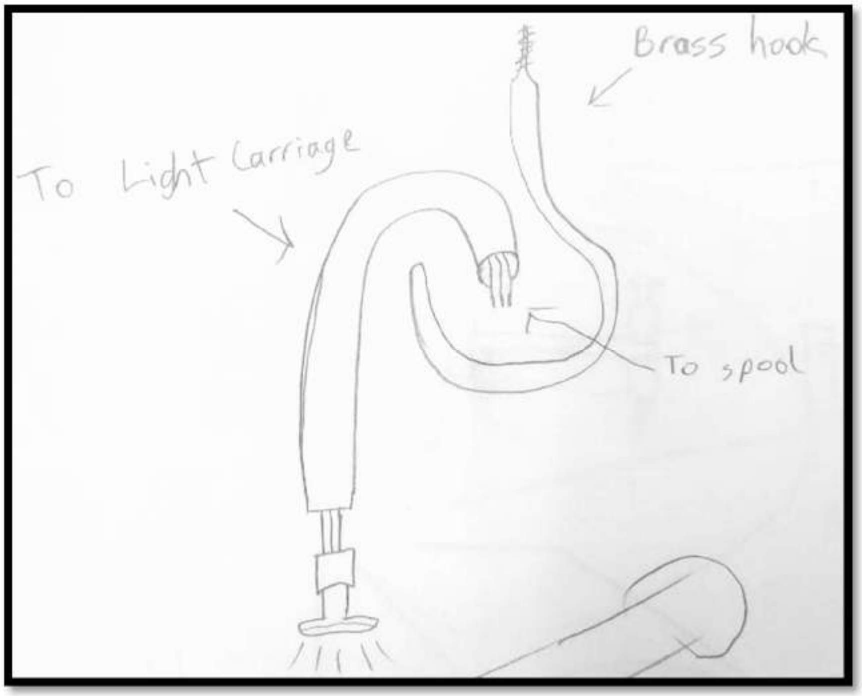


Figure 40. Wire Hanging Sketch for Hooks

4.2.15 Interface/Control System:

Our control system needed to accurately model the movement of the sun across the sky while providing an intuitive, user friendly interface. We decided that a user interactive interface would serve this purpose well. We wanted the interface to allow the users to input specific times and locations, control motor movement, and easily extract data. We thought of allowing the users to input specific latitudes or choose from a dropdown menu of pre-set major cities, and allowing the users to input specific days. We also thought of the idea of allowing the user to control the light carriage's motion and watch the screen output the time of day or of letting the user press a button that would run the carriage all the way across the arch to show the motion of the sun for that day. We also considered having the LCD screen output the sun angles for given inputs in case our Heliodon was not as physically accurate as we wanted. It was our hope that doing so would at least give the user some form of exact results.

The placement, housing, and location of the control system on the Heliodon needed consideration as well. Figure 41 below is an idea of how this control system may look.

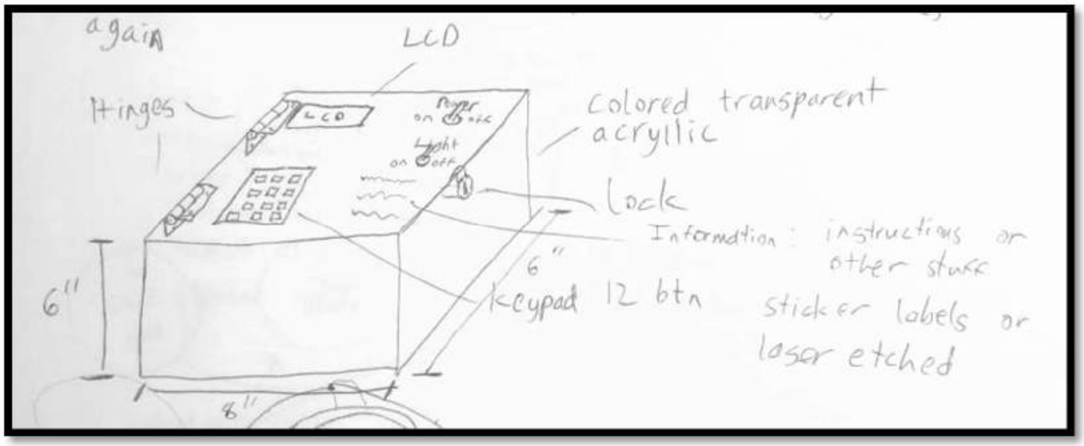


Figure 41. User Interface Keypad Sketch

Our first idea was to place the control system housing to the side of the frame for ease of access. The box would be protruding from the frame at around waist height so people could access the controls comfortably and out of the way of the arch's range of motion. This placement may be seen in Figure 42.

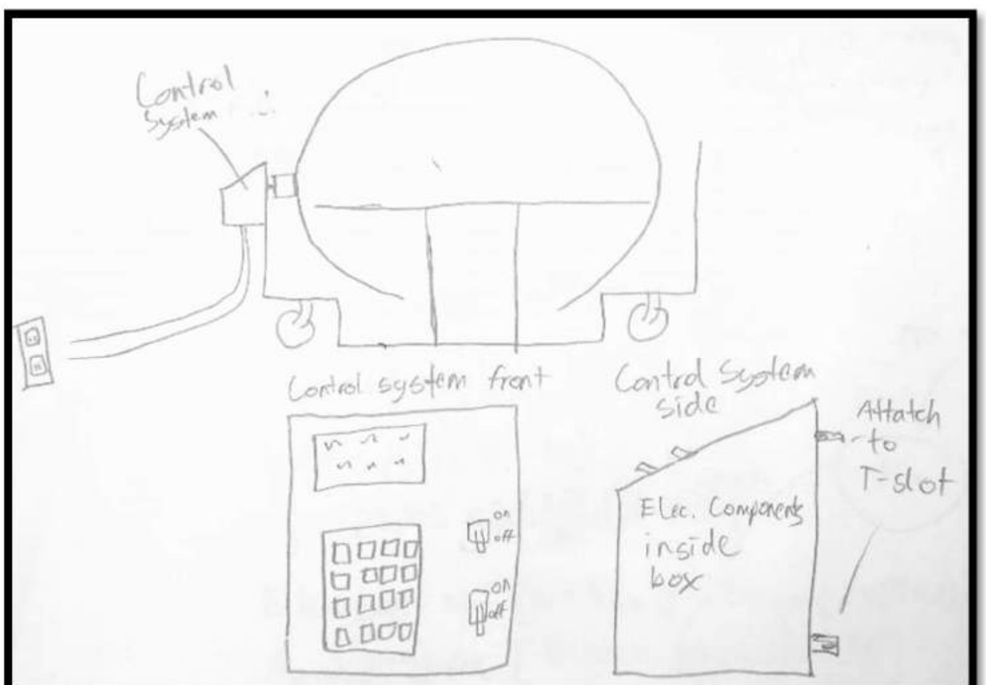


Figure 42. Control System Location Sketch

Our next idea was to place the control system out of the way and underneath the table. The issue with this placement is that the user would have to kneel and duck underneath the table to interact with the controls. This is obviously not a desirable option. With this placement, we needed a way for the user to easily access the controls. The solution to this problem was to make a wired handheld control interface for the user to operate comfortably and out of the way. This solution along with the placement of the control system can be seen in Figure 43.

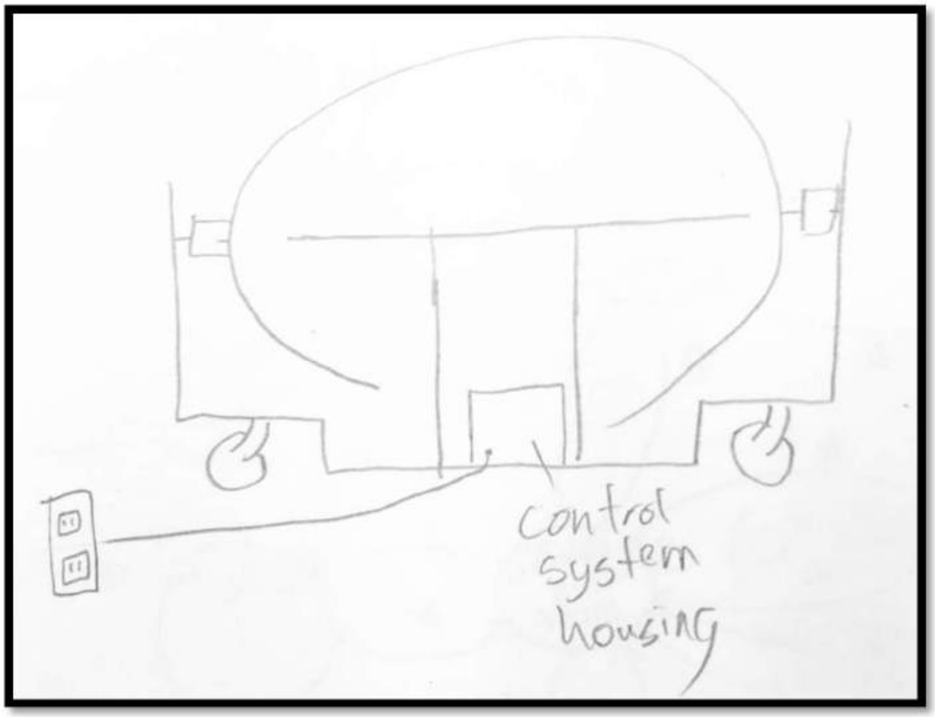


Figure 43. Alternate Control System Location

Figures 44 and 45 show an idea of the handheld user interface.

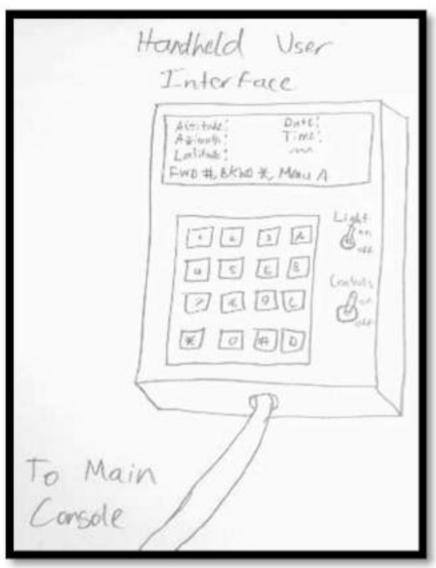


Figure 44. Handheld User Interface Sketch

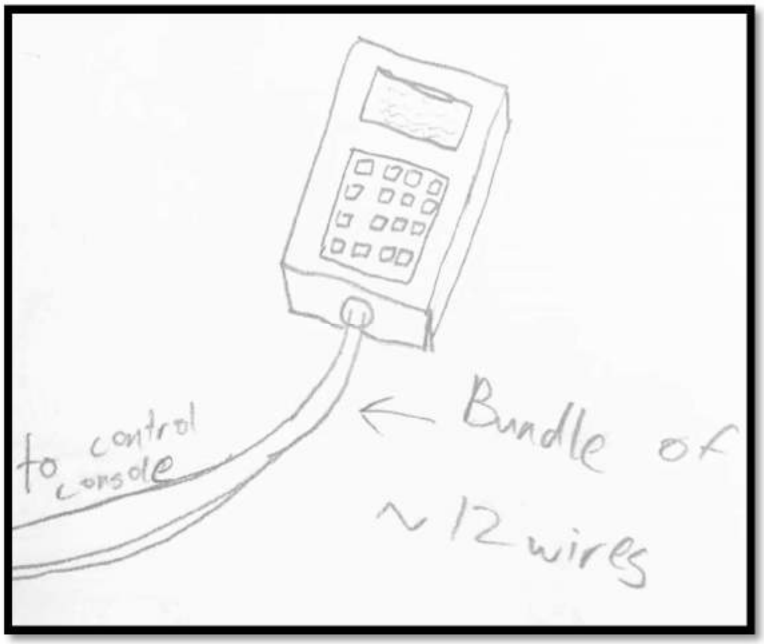


Figure 45. Keypad to Control System Wiring Sketch

4.2.16 Concept Evaluation: Interface:

The first idea for the placement of the control system housing which is depicted in Figure 42, though ideal, is problematic because it adds too much length to the Heliodon. The Heliodon needs to be able to fit in a hallway so its length is limited. We needed to place the control system elsewhere. This limitation made us lean towards a placement that is better depicted in Figure 43.

The handheld user interface seen in Figures 44 and 45 seem to be feasible systems to implement.

4.3 Prototyping:

Once the final general design was chosen, possible problems were identified and a few scaled prototypes were built using readily available material. Building a few prototypes allowed us to prove the feasibility of our design and it also helped us identify overlooked issues with our design. Tackling these issues before the final build was critical if the final Heliodon was to work as planned. The first prototype was made after the general brainstorming was completed and the top concept had been selected. The second prototype was made during the process of the detailed brainstorming in order to test some of the specifics of our detailed design.

4.3.1 General Heliodon Prototype 1:

The first prototype was completed before the Preliminary Design Report on November 18th. Foam core was used to build the frame, table top, and slots while a cut hula-hoop was used to model the arch. A threaded rod and wing-nuts secured the arch to the slots and duct tape secured the slots to the table top. A headlamp attached to the hula-hoop represented the sun. After completing the prototype we found problems that we did not anticipate with the design. The initial prototype is shown in Figure 46.

Figure 46. Initial Prototype

4.3.1.1 Unforeseen Issues:

Securing the arch to the outside of the slots prevented the light source from passing the slots, which meant the light source could not complete its full range of motion. We decided that an easy fix to this issue would be to secure the hoop to the inside of the slots so that the light could move past them. We would need to consider the way the slots are attached to the table though, as this attachment could be a hindrance to the movement of the arch within the slots. One other problem with the slots was that if the lamp had been able to pass by them, the light emitted by it would have been blocked by the slot. This would cast a shadow on the table and prevent the model from being lit. Another problem that we encountered was that the frame interfered with the arch circumference as the arch changed angle. To address this we would need to make sure the frame is out of the way of the arch when the arch is changing in angle. Another issue we encountered is that not all the latitudes could be modeled. The north and south poles have the most extreme latitudes and the only way to model these would be to have a full circle about the table which is not possible with this design.

4.3.2 General Heliodon Prototype 2:

A second prototype was created by February 1st. This prototype had a more detailed arch, arch brackets, working latitude slots, and a working carriage. The prototype can be seen in Figure 47.

Figure 47. Prototype Two

The arch was made up of two 3/4 inch diameter 10 feet long pieces of PVC pipe bent into a 1-1/2 foot radius circle. The two pieces were secured together with adequate spacing for the light carriage using the arch brackets which were made of wood 1 X 4s. The carriage was made of similar wood 1 X 4s and wheels were attached in a style similar to a roller coaster setup. Holes were made in the two arch brackets that attach to the latitude slots so that threaded rod could connect the brackets to the slots. The rod was threaded so that nuts could be used to loosen and tighten the brackets, thereby allowing for the independent adjustment of the arch angle relative to the latitude slot angle. This independent adjustment will be necessary in order to allow the final Heliodon to move through doors. The latitude slots were constructed using 2 X 4s with a countersink and a through hole for the threaded rod and the bolt.

4.3.2.1 Unforeseen Issues:

The construction of this prototype made it apparent that some of our parts were going to be very difficult to manufacture. Spacing out the arches and attaching all the brackets was very difficult and we would need to think of a better method of attaching the brackets to the arches when the final product is to be put together. We also realized that making the sliders for the slots and making the slots themselves was going to be difficult. The prototype really helped us comprehend how long and difficult manufacturing was going to be.

4.3.3 Spool Prototyping:

The spooling system that was a possibility for moving the light carriage was extensively explored. Six physical prototypes were made to test the feasibility of this carriage motion method.

The first prototype used a 1/16th inch steel cable to simulate the drive cable of the carriage. This cable was a consideration for the final design. The shaft used was a 1-1/4 inch PVC pipe and we used wood blocks with holes for bearings. These decisions were made to make the prototype cheap and easy to make. This prototype was made with the intention of testing ways to make the cable spool correctly. The cable was connected to the shaft by drilling a hole through both walls of the PVC, feeding the cable through, and tying it together. The cable was then spooled by hand in the fashion that it was hoped to spool on its own. That is, the cable was wound around the shaft so that each winding lined up directly next to the previous one, without space between the two and without overlapping any two windings. Once the cable was about two to three windings from being complete, the excess cable was fed through a pulley away from the shaft. This pulley was about three feet from the shaft. From this pulley, the cable was feed to the other end of the shaft (the side with no windings yet) and it was attached to the shaft in the same fashion. With this prototype we were not interested in building a rig that was to be to the precise dimensions that the final spool would be. We figured that this would increase the difficulty of the task. We were simply interested in experimenting with ways to get the wire to spool correctly and more importantly, if we would be able to even make this happen. This prototype can be seen in Figure 48.

Figure 48. Initial Spool Prototype

We found that the wire tended to want to spool towards the point on the shaft that was perpendicular to the pulley as show in Figure 48. We determined this point to be the settling point. This motion toward the settling point would not cause overlap, but it caused a lot of space between each winding. This was no good. We solved this problem by implementing a spring to pull each consecutive winding towards the previous one. This solution worked every time and that result was promising. We also noted that this rig worked really well even though the cable was not very tight. We wondered about the effects of having a tight cable and the effects of having a cable with more slack. Now that we knew that making it spool perfectly was possible, we wanted to create a prototype closer to the dimensions of the final design.

The second prototype used 1/32 in Kevlar cable as this was also a possibility for the drive cable. The rig was the same as prototype 1 with the exception of the distance from the shaft to the pulley. The pulley in this rig was about 6 inches from the shaft. The Kevlar wound in the same fashion as the steel cable. We noticed that the Kevlar thread was itself a winding of wire and that the ends of the wire would unwind if tampered with. We noted that this may affect the strength of the cable and that this possibility should be a factor to consider when choosing the final cable. The Kevlar wanted to wind to the point on the shaft that was perpendicular to the pulley. One thing that we observed that was because the pulley was so much closer to the shaft, the initial angle that the cable made with the shaft was way more extreme. This extreme angle caused the Kevlar to reach this perpendicular point on the shaft more quickly than in prototype one. In prototype one, most of the cable had been spooled by the time that the cable reached the perpendicular settling point. Now, that settling point would be reached in only two or three turns. This became a huge issue because the cable needed to be wrapped 20 to 30 times more than this to completely spool the cable. After only a few turns the cable would start to stack. Just as in prototype one, we tried implementing springs to pull the cable back. In prototype one this pulling back of the cable was to prevent the cable from spacing out, but in prototype two the springs hoped to prevent the cable from stacking. What we found was disconcerting. The springs helped slow the cables approach to the settling point, but before the cable could reach the settling point, it would be pulled back too much and stack over itself in the opposite direction. This result nullified the promising results from the first prototype as now we questioned whether a spring would work to make the cable spool the way we wanted. This second prototype can be seen in Figure 49.

Figure 49. Second Spool Prototype

From the first prototype to the second prototype, we had changed the thickness of the cable (from 1/16 in to 1/32 in) which we figured made the cable more likely to stack on itself and we also had changed the length of cable that was being spooled (20 feet of steel cable to 50 feet of Kevlar). This length change of the cable affected the final length of the spool that was wound up on the shaft. The spring would theoretically have to stretch this total wound up length and as the spring stretched more and more, the force that pulled the cable back up against the previous winding increased. This force increased more and more until it became too large and the cable jumped over the previous winding. Confused at how to fix this problem, we thought we should try the same rig with the steel cable.

The third prototype was made from the second prototype. We detached the Kevlar from the shaft of the second prototype, detached the steel cable from the first prototype, and attached that same steel cable to the previous second prototype (now the third). This steel cable had lost its original form from being wound over and over on the first prototype. It had kinks all along its length. We rigged the prototype up to test and soon found that these kinks were a huge problem. As soon as one of the kinks was wound around the shaft, it would either stack on the previous winding, or it would cause the next winding to stack. We determined that the final cable that was to be used had to be perfectly straight and free of kinks. The steel cable option was out. This prototype can be seen in Figure 50.

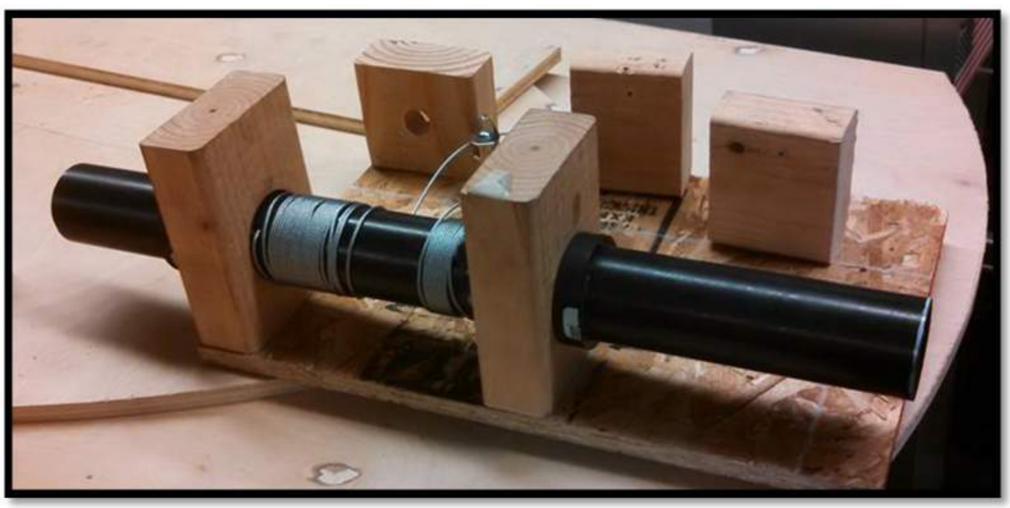


Figure 50. Third Spool Prototype

This prototype reverted back to the design of the second prototype with the Kevlar cable but now used two pulleys instead of one. The idea here was that there would be one pulley for each side of the winding; one for the feed and one for the return. We hoped that this might create two points that the cable would want to wind to (the perpendicular settling points discussed before) and that it would also reduce the angle in which the cable comes off of the feed and return sides. Although this worked well sometimes, new problems arose most of the time. For the pulleys to feed to each other they had to be at an orientation that was detrimental to the cable winding around the shaft. We also found that with these specific pulleys, the cable would sometimes get wedged between the rotating element of the pulley and the wall of the pulley housing. This created extra unwanted friction. We reverted back to one pulley to fix this problem. We then contemplated whether having the pulley below the shaft, about the shaft, or in line with the shaft had any effect on the spooling.

In this prototype we took the second prototype and tweaked a few things. First we realized that the angle that the cable came off of the shaft was related to stacking. We wanted to minimize this angle and so we determined that minimizing the distance between the shaft-cable connection points was essential. That is, we wanted the distance between the attachment points to equal the distance spanned by the cable when it was fully wound. We also tried to put the pulley on a spring as opposed to fixing the pulleys location and using a spring to pull the cable inwards. This produced the most promising results yet. The winding works perfectly sometimes and does not work other times. That is, sometimes we will wind it up perfectly, not change anything, and then rewind it and it will begin to overlap. As in previous prototypes this overlap causes huge issues and is very hard to reset. So far, it has not been determined what actually causes it not to work sometimes. Our theories so far are that it is caused by the inconsistency in the relative straightness of the cable in relation to the spool (it isn't spooling perfectly vertically, it is sometimes wavy, horizontal, etc) or that it is the non-constant speed that we are turning the shaft.

The final prototype incorporates the same elements of the fifth prototype, but it has been made somewhat modular. That is, we have set it up so that we can quickly test springs with different stiffness and we can test each spring at various locations. Figure 51 shows this prototype.

Figure 51. Spooling Prototype

4.3.4 Prototyping Conclusions:

Overall this design can be accurate, but we will need to find a way to put everything together and to make it user friendly while maintaining accurate results. The slots will need to rotate to the correct angles and the light will need to maintain its focus on the model as it moves along the arches. If we are to go with the spooling method for moving the carriage, it must work according to plan, otherwise accuracy will be sacrificed. A testing procedure must be developed to verify the accuracy of the light’s movement throughout various days of the year and through various times of the day.

5 Final Design Description:

5.1 Design Summary:

This section contains a detailed description of the final Heliodon design concepts. The final Heliodon has a maximum length of 88 inches, a maximum width of 30 inches, and a maximum height of 78 inches. The length allows for the motion in the smallest hallway of the EE building and the height allows for the Heliodon to be fit through the smallest door in the EE building. The maximum width is the width of the latitude slots and allows the Heliodon to fit through a door. The final arch that our Heliodon uses has a radius of 33 inches. This large radius should produce accurate results for the locations that we are modeling. According to the MATLAB code, our Heliodon should be able to model from 55 degrees North latitude to 55 degrees South latitude. To give a better idea of that latitude range, we have provided Figure 52 below**.** The lines of latitude are the horizontal lines bisecting the map and their degree values can be seen on the left and right sides of the map.

Figure 52. World Map with Latitudes

Figure 53 is the final assembly of the Heliodon. Please refer back to this figure while reading the following design sections.

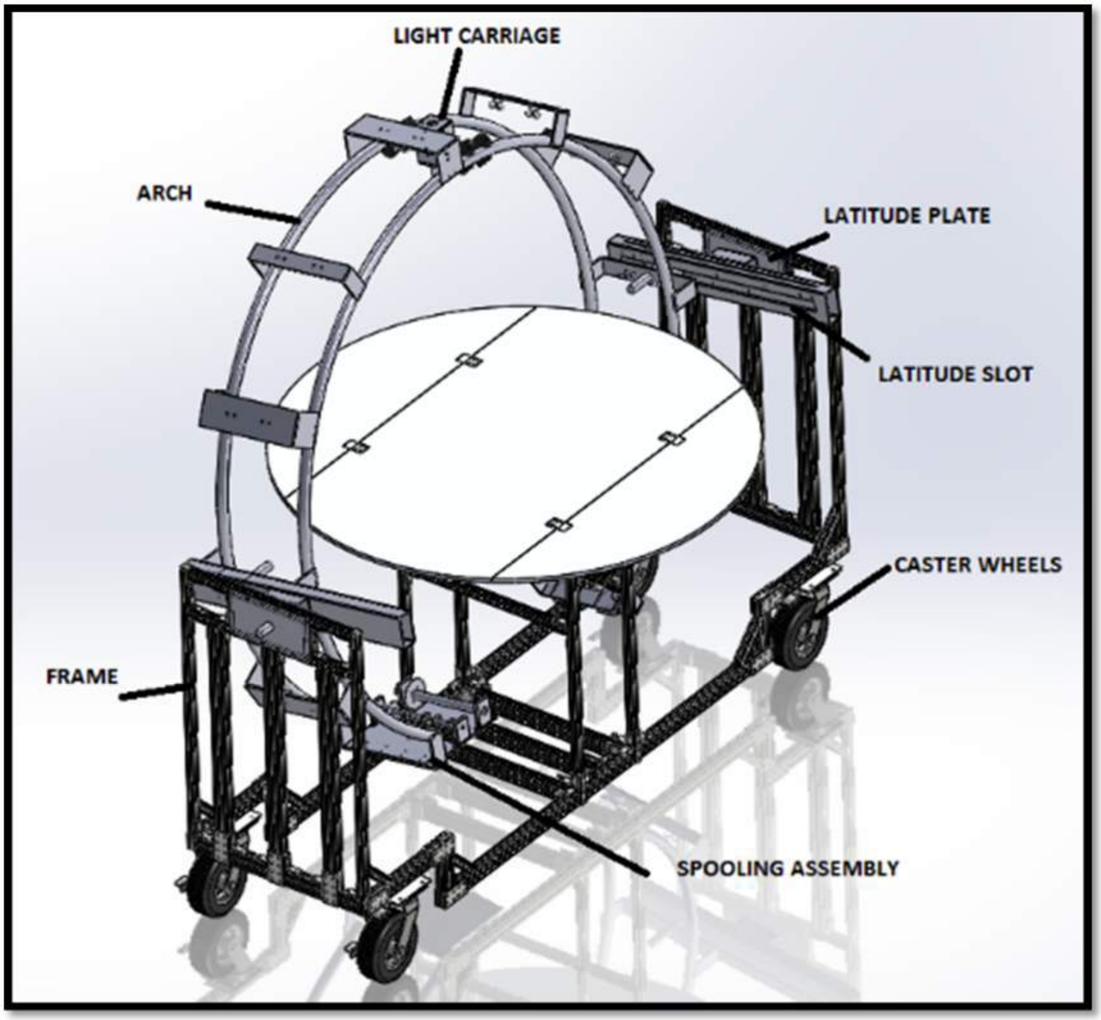


Figure 53. Final Heliodon Assembly

All part drawings and part lists can be seen in Appendix I.

5.2 Base and Structure:

5.2.1 Wheels:

The casters are connected to the frame with custom designed mounting plates. We manufactured these plates by cutting aluminum plate down to four inches by six inches and drilling 1/4 inch through holes. These plates were attached to the T-slot frame using four low-profiles T-slot fasteners and bolted to the wheel mounting plates using four 1/4 inch diameter carriage bolts with nuts and washers. This attachment can be seen in Figure 54.

Figure 54. Caster Wheel Assembly

These wheels allow a smooth ride on level surfaces while being able to travel over rough terrain (e.g. concrete, grass, dirt, gravel). All four wheels swivel to facilitate hallway navigation and lock to secure the Heliodon in place during normal operation and storage. The wheels don't add any length to the frame because the swivel radius is thirteen inches which is the length of the supporting T-Slot member. The overall wheel and plate height is 9-1/4 inches.

5.2.2 Frame:

The Heliodon's frame is constructed from 10-Series '8020' Aluminum T-Slot extrusion. The extrusion components are attached to one another by purpose-made hex-head fasteners and 8020 gusset plates. These fasteners may be seen in Figure 55. The frame's exact dimensions and parts may be seen in Appendix I.

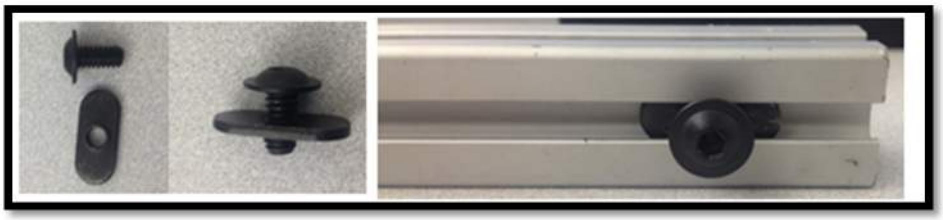


Figure 55. T-Slot Fasteners and Fastening Method

In the interest of maximizing the arch radius to increase the accuracy of the Heliodon, a two-level frame was chosen. This two-level frame is shown in Figure 56.

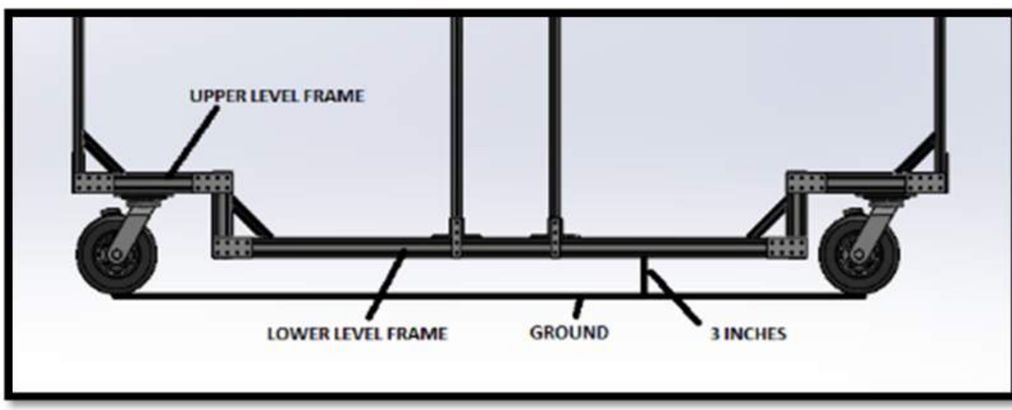


Figure 56. Two-Level Frame

With the addition of the lower frame level, we were able to lower the arches on the Heliodon without creating arch interference with the frame. The upper frame level allowed for us to use larger diameter wheels to transport the Heliodon. With this final design, there are 3 inches of clearance between the bottom of the bottom level frame and the ground.

We decided to use T-slot aluminum extrusions for multiple reasons. First, T-slot was recommended by our sponsor because of how simple it is to put together and how elegant it looks. It is easy to take apart, which allows the builder to modify the frame design during or after assembly without having to start from scratch. This opens up the design for more iterations. The T-slot fasteners simplify manufacturing and fabrication by guaranteeing right angles between components. In addition, no welding or special fastening tools are required other than standard 4 and 4.5 mm Allen wrenches. Since no welding is required, there is no risk of heat damaging the frame, creating unsightly weld defects, or burning through the walls of an extruded part. Aluminum is corrosion-resistant and so the frame will not be damaged if it is left outside or in a humid environment.

5.2.3 Latitude Plates and Latitude Angle Markers:

The latitude plates, whose front view is shown in Figure 57 are 1/8 inch thick. This is a 1/16 inch thinner than a typical T-Slot fastener piece so when the bolts are fully tightened into the T-Slot channel, the bolt head is not flush with the plates. In order to secure a flush, tight fit, a 1/4 inch washer is placed between each bolt head and hole before fastening. This extra thickness made all the fasteners mesh with our latitude plate design. The plates are made from stainless steel sheet metal and are machined so that they can connect to the T-Slot frame. The latitude plates have a 1 inch diameter hole in the plate's center so that the threaded rod that attaches the latitude plates to the latitude slot can be inserted.

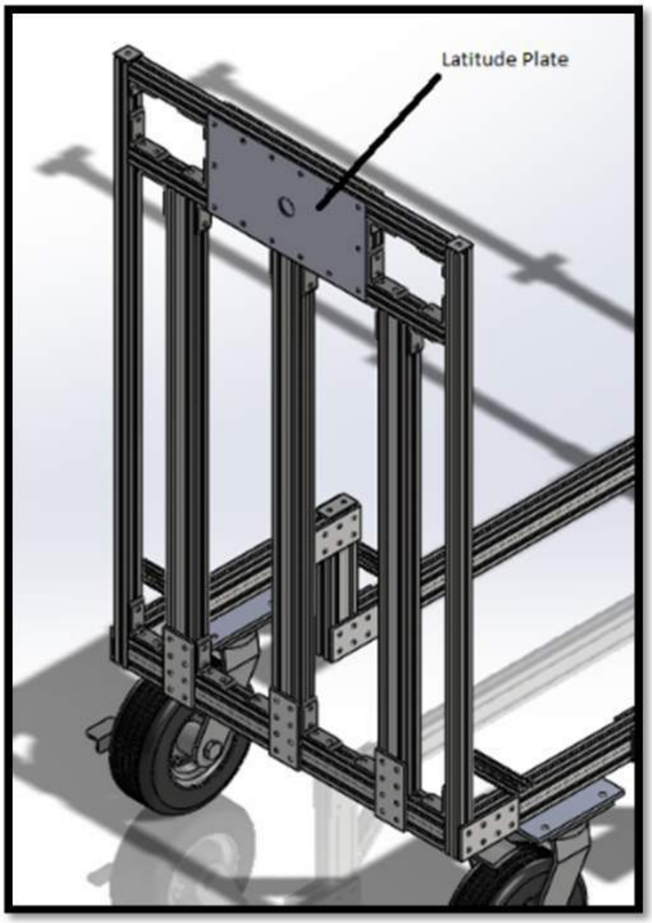


Figure 57. One Latitude Plate

The Latitude Angle Markers are fixed to the outside of the Latitude Plates. They remain fixed to serve as a reference when adjusting the latitude slots. They are laser cut from acrylic sheets. They display north and south latitudes from 0 to 90 degrees. Their smallest resolution markers are 5 degrees apart, their mid-resolution markers are 10 degrees apart, and their major resolution markings are 30 degrees apart. The final design may be seen in Figure 58.

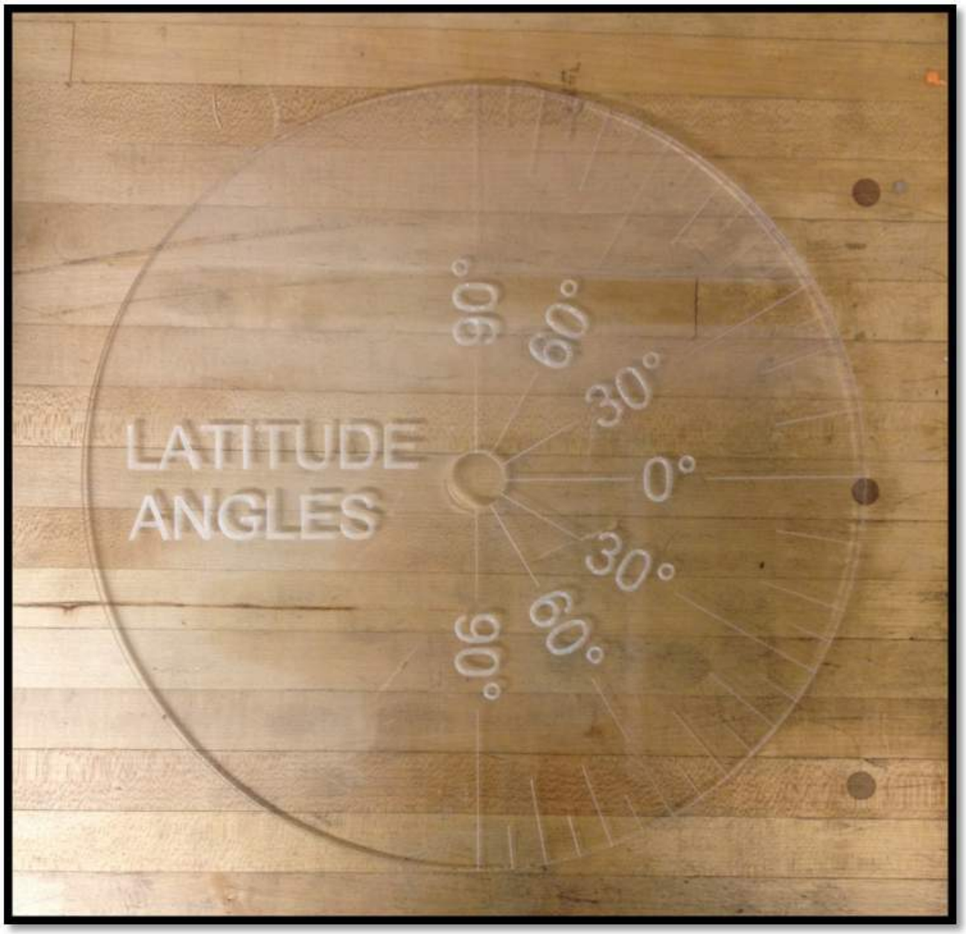


Figure 58. Latitude Angle Marker

5.2.4 Table:

The Heliodon's table-top is constructed from maple plywood. A single sheet was used to make the 4-1/2 foot diameter round table. It consists of three pieces; a center piece and two side pieces that fold upward in transportation mode. The center piece has a maximum width of 28 inches so that it can be directly supported by the frame. This allows the side pieces to fold because they are not connected to any other part of the frame. Standard T-slot fasteners attach the frame to the bottom of the table. This fastening is shown in Figure 59.

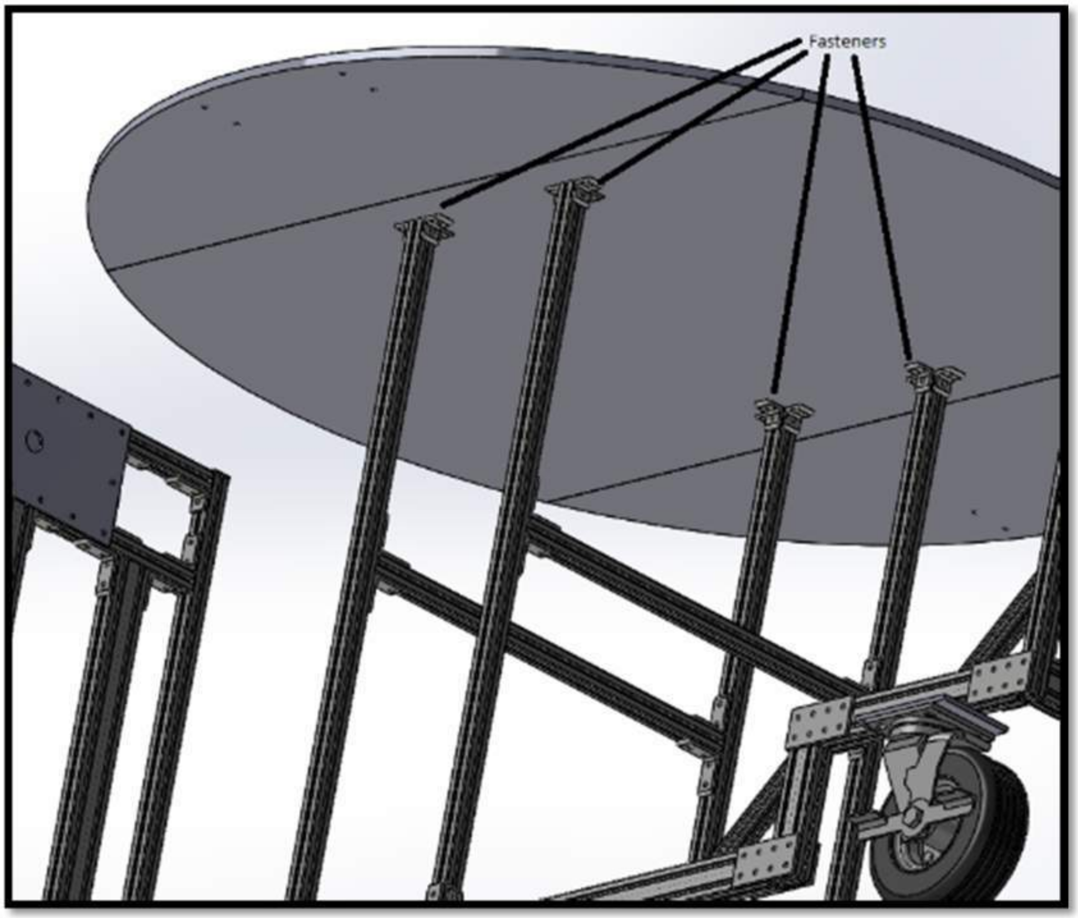


Figure 59. L Brackets Connecting Frame to Table

The sides of the table is attached to the center by butler table tray hinges. These hinges lay flush in the wood and allow the table's side pieces to rotate up 90 degrees to the storage and transport position. Two hinges on each of the table's side pieces support the weight of the table and prevent bending. The hinges are self-locking when rotated to a 90^{o} angle so that the user does not have to hold the side portions at 90 degrees when locking.

The Heliodon should be stored indoors and out of inclement weather. The tabletop is painted white to emphasize the shadows that are created by the light source and models and the table is finished with multiple layers of polyurethane for sealing purposes. If outdoor storage is required, we are recommending that a tarp be used to protect the electronics and tabletop.

5.3 Latitude Slots and Slider:

The latitude slots serve two purposes. The angle of the slots themselves represents the latitude angle that the user desires to model, while the slider's position inside of the slots determines the time of the year the user desires to model. Figure 60 below is a SolidWorks model of the slots while Figure 61 demonstrates the functions described above.

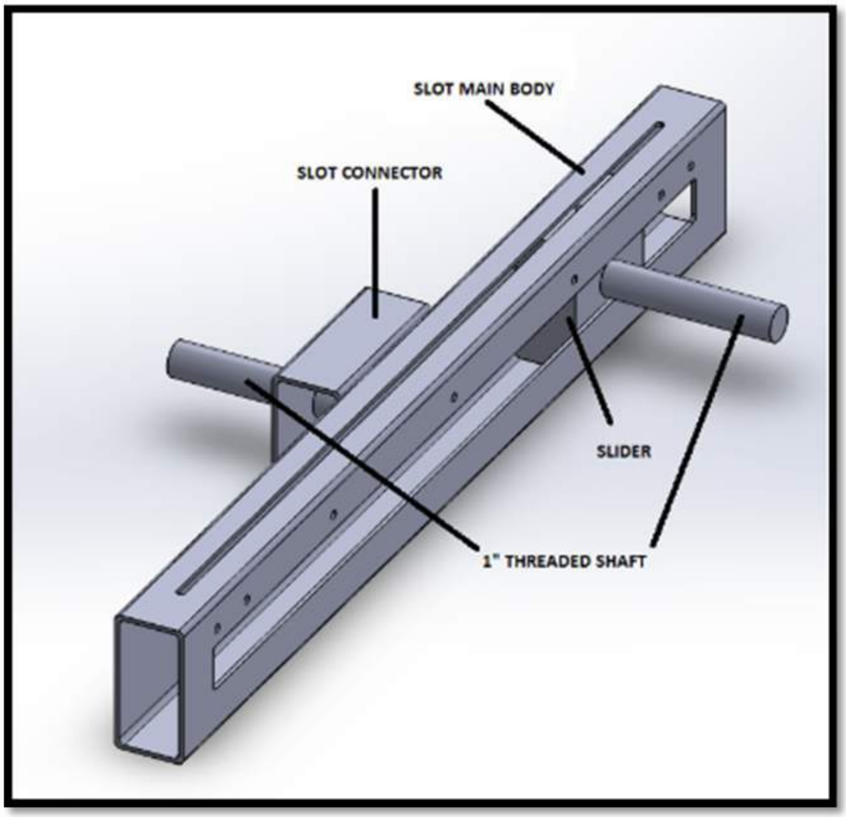


Figure 60. Latitude Slot

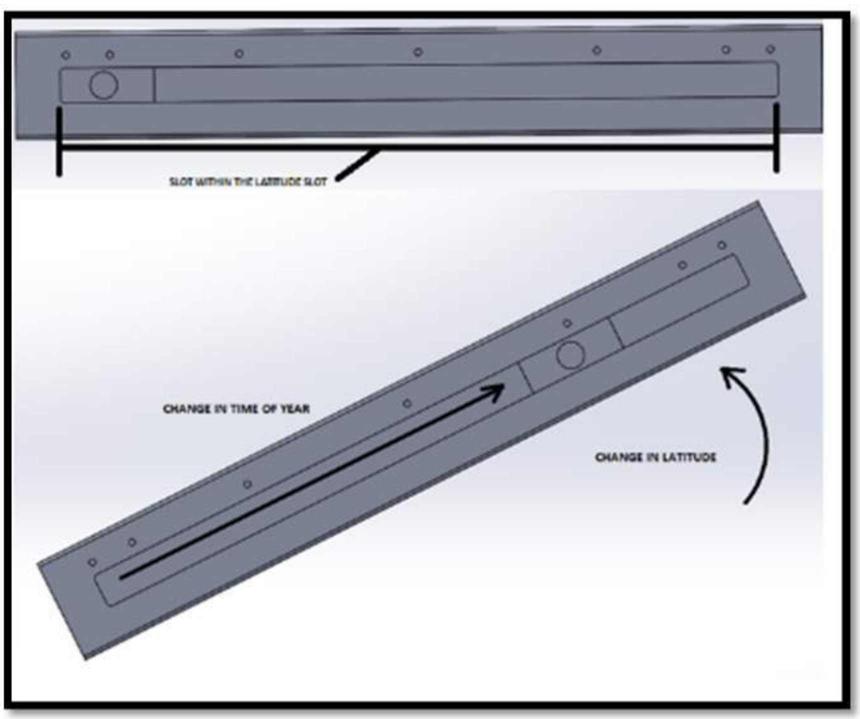


Figure 61. Latitude Slots Changing Heliodon Latitude and Time of Year

With the help of calculations that can be seen in Section 6.1 and Appendix G, we determined that the slot inside the latitude slot body that the slider slides in should be 27 inches long. This gives us enough room for our slider to cover all times of the year. The latitude slots were cut to 30 inches long in order to accommodate this slot.

The slot's main body is comprised of 1/8" X 2" X 4" rectangular aluminum tubing as shown in Figure 62.

Figure 62. Rectangular Aluminum Tubing Used

The initial design was comprised of several individual pieces of steel, but this proved nearly impossible to machine. The light weight of the aluminum combined with its ease of manufacturing made it the ideal material to work with. The main body had three main features: the front slot, the front holes, and the top slot. These features are highlighted in Figure 63.

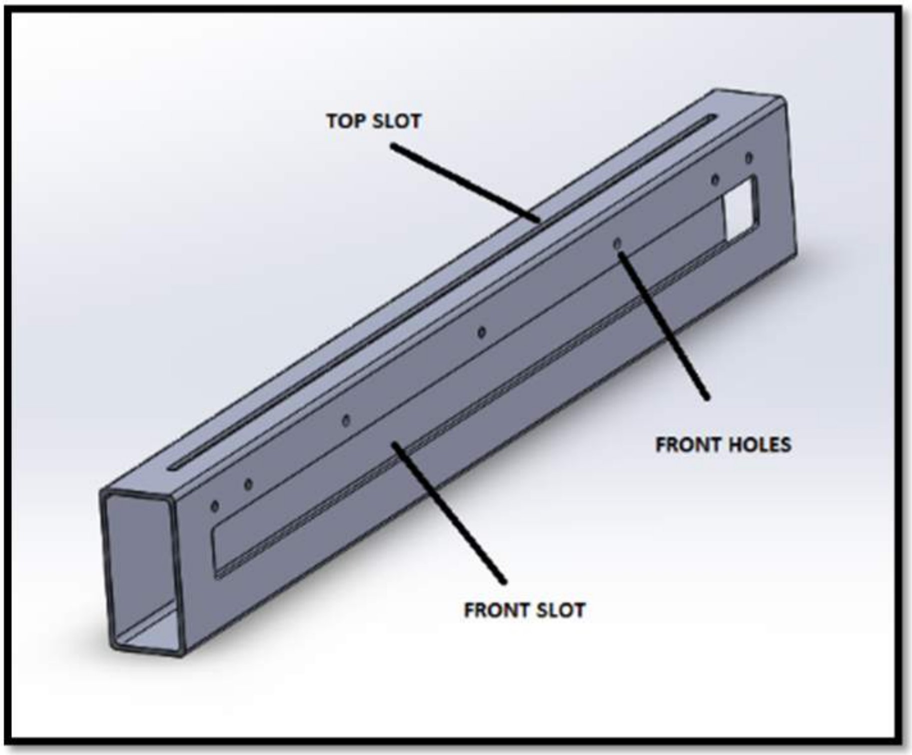


Figure 63. Slot Main Body Features

The front slot allows the threaded rod in the slider to protrude, while the other two features are used for locking. The front holes each represent the 21st day of each month. The two holes on each end of the slots represent the summer and winter solstices, while the very middle holes give the sun's position during the spring and fall equinoxes. A front hole in the slider allows the user to quickly and accurately place the slider in the correct position for these important dates. We have termed this feature the "quick adjustment feature". The top slot allows the user to lock the slider in position during any desired time of the year. All of these features can be seen in Figure 64.

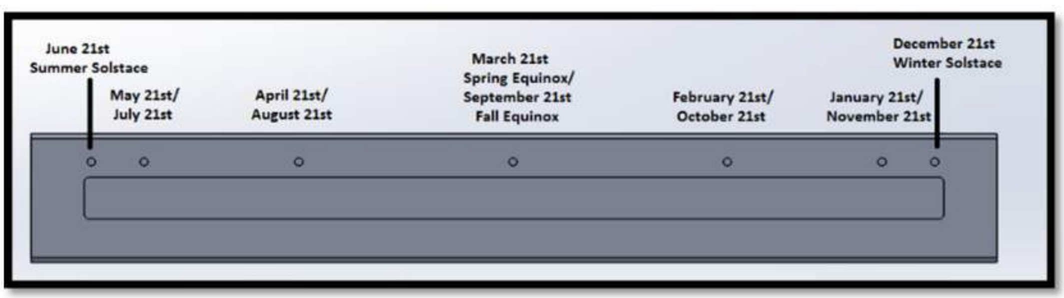


Figure 64. Slot Holes for Various Times of the Year

The back of the slots (the slot connector) can be seen in Figure 65. This is comprised of a small section of rectangular aluminum tubing with a single 1 inch hole drilled in the back of it to allow a threaded shaft to protrude. This back piece is welded to the main body.

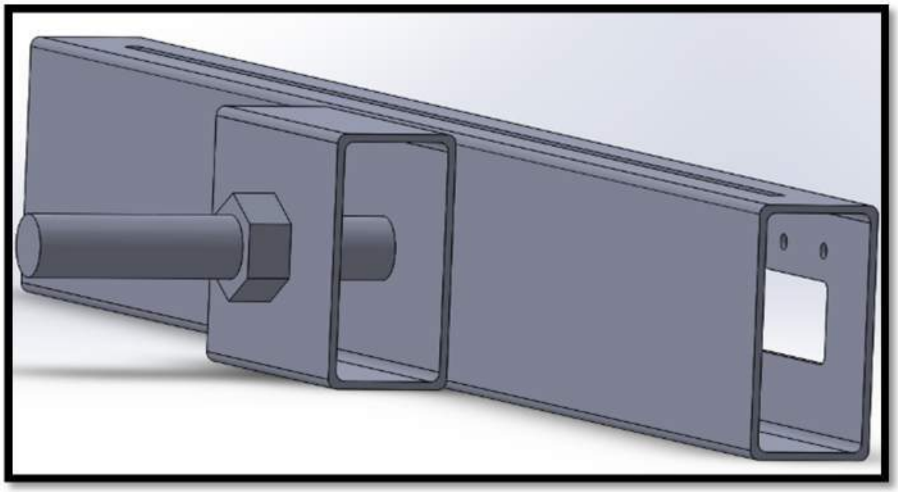


Figure 65. Isometric View of the Back Slot Connector

The threaded shaft in the back of the slot is secured using two hex nuts, as shown in Figure 66. The nut inside of the back connector is screwed on tight and will not be loosened, while the one outside of the back connector is loosened to allow for the rotation of the latitude slots. After the slot is rotated to the desired angle, the outside nut is tightened back in place to lock the latitude slots at the desired latitude.

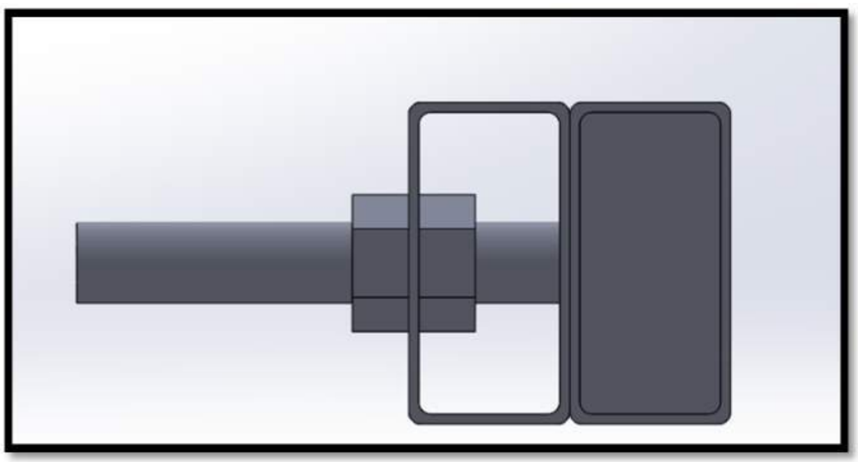


Figure 66. Side View of Hex Nuts

The slider itself is made of a 3-3/4" X 3-3/4" X 2" block of ultra-high molecular weight (UHMW) polyethylene. This material was chosen because of its low coefficient of friction, allowing for smooth sliding within the slots. It has a main hole in the center for another one inch threaded shaft, as well as a bore in the back that a hex nut can sit in, preventing the rotation of the threaded shaft inside of the slider. It has a hole in the front that allows it to be secured to the slot's front holes via a peg, and a hole on the top so that it can be locked in place with the latitude slot's top slot as shown in Figure 67.

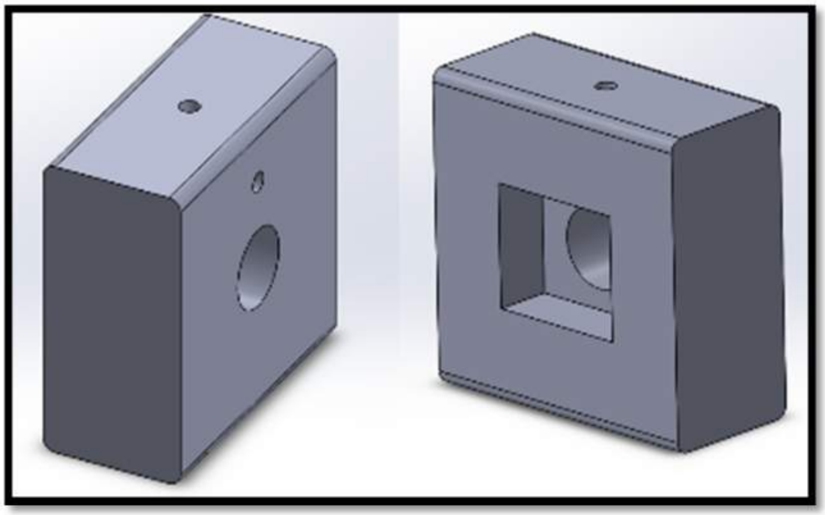


Figure 67. Slot Sliders

5.4 Arch Design:

After looking at the ideas that we came up with, we decided that the best solution was to have the arch made at a professional machine shop with a standard aluminum pipe. Each aluminum pipe has an outside diameter of 1-1/4 inches and a wall thickness of 3/16 in. The cross section is constant circle along the entire length of the arch. The arch is 300 degrees out of a full 360 degrees circle. We determined that this was the simplest design that could also be bent to our specifications. Aluminum provides enough structural stability to carry the light carriage and it is malleable enough to be bent without kinking or deforming. The two arches form a track and the light carriage travels along this track. The arches are connected on the inside of the latitude slots so that the slots do not interfere with the carriage or the light source as it passes the slots. The arches along with the latitude slots can be seen in Figure 68.

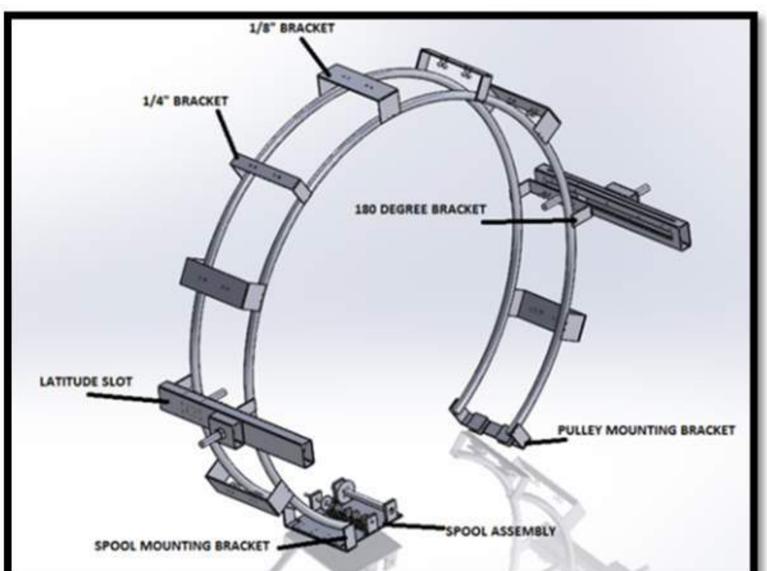


Figure 68. Arches with Brackets and Latitude Slots

5.5 Bracket Design and Drive Cable Hooks:

There are multiple types of brackets in our final design; the 0°/180° brackets, the spool bracket, the pulley bracket, the 1/4 inch thick brackets, and the 1/8 inch thick brackets. Each bracket is made of steel. Every bracket except the spool and pulley mounting bracket also house the drive cable hooks. These hooks allow the drive cable to run along the arches as they pull the carriage. Details on the drive cable and the carriage motion are further explained in section 5.7.

5.5.1 0 and 180 Degree Brackets:

The 0° and 180° brackets refer to the brackets that connect the arches to the sliders within the latitude slots. These brackets are made of three pieces of sheet steel that have a thickness of a quarter inch and can be seen in Figure 69.

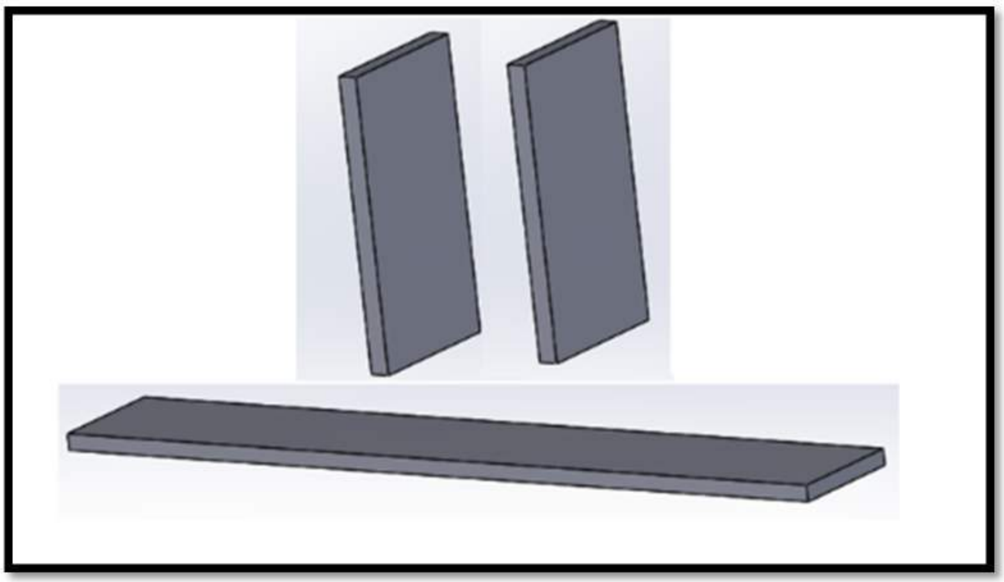


Figure 69. Quarter Inch Bracket Components

The top sheet steel piece is 13 inches long and 2 inches wide. The two pieces extruding down from this top piece are 3-3/4 inches long and 2 inches wide. These three pieces are fastened together via TIG (Tungsten Inert Gas) welding (this is also known as GTAW, Gas Tungsten Arc Welding). The two 3-3/4 inch long side pieces each have two holes of 3/16 inch diameter which are used to rivet the brackets to the arches. The 13 inch long top piece has five holes, one of 1 inch diameter, and four of 5/16 inch diameter. The 1 inch diameter hole allows a 1 inch diameter shaft to connect the bracket to the slider in the latitude slot. The four 5/16 inch diameter holes allow for the placement of the drive cable hooks. These hooks ensure that the drive cable will be guided along the arches. The full 0 and 180 Degree brackets can be seen in Figure 70.

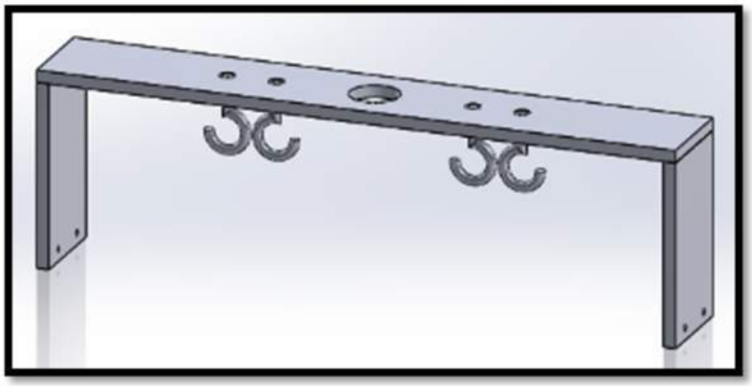


Figure 70. 0/180 Degree Bracket

5.5.2 Quarter Inch Thick Brackets:

The quarter inch thick brackets are also made of three pieces of sheet steel that have a thickness of a quarter inch. The top sheet steel piece is 13 inches long and 2 inches wide. The two pieces extruding down from this top piece are 3-3/4 inches long and 2 inches wide. These three pieces are fastened together via TIG welding. The two 3-3/4 inch long side pieces each have two holes of 1/8 inch diameter which are used to rivet the brackets to the arches. The 13 inch long top piece has four holes of 5/16 inch diameter to house the drive cable hooks. This design can be seen in Figure 71.

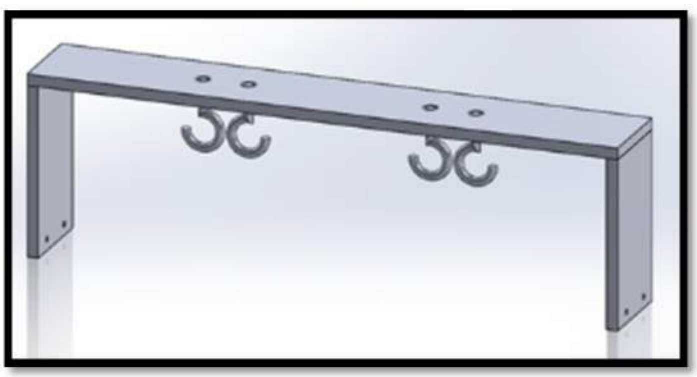


Figure 71. Quarter Inch Bracket

5.5.3 Eighth Inch Thick Brackets:

The eighth inch thick brackets are made of three pieces of sheet steel that have a thickness of 1/8 inch. These pieces can be seen in Figure 72.

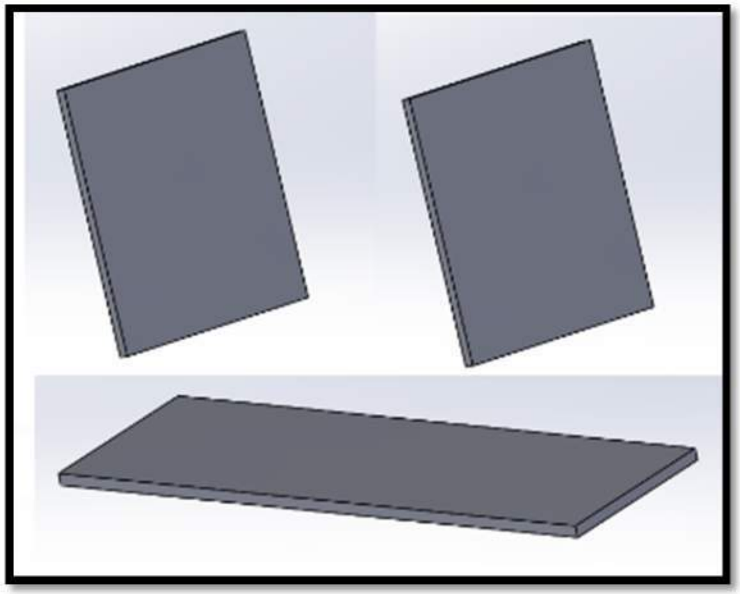


Figure 72. Eighth Inch Bracket Components

The top sheet steel piece is 12-3/4 inches long and 4 inches wide. The two pieces extruding down from the top piece is 3-3/4 inches long and 4 inches wide. These pieces are also fastened via TIG welding. The two 3-3/4 inch long side pieces each have two holes of 3/16 inch diameter which are used to rivet the brackets to the arches. The 12-3/4 inch long piece has four holes of 5/16 inch diameter to house the drive cable hooks. This design can be seen in Figure 73.

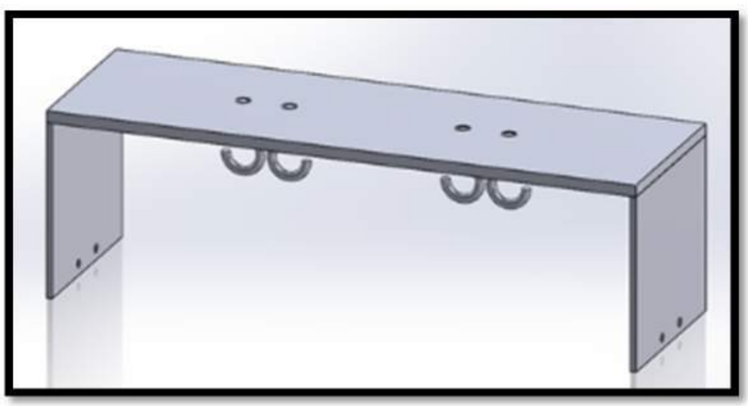


Figure 73. Eighth Inch Bracket

5.5.4 Spool Bracket:

The spool bracket is the bracket used to mount the spool to the arches. Figure 74 demonstrates this function.

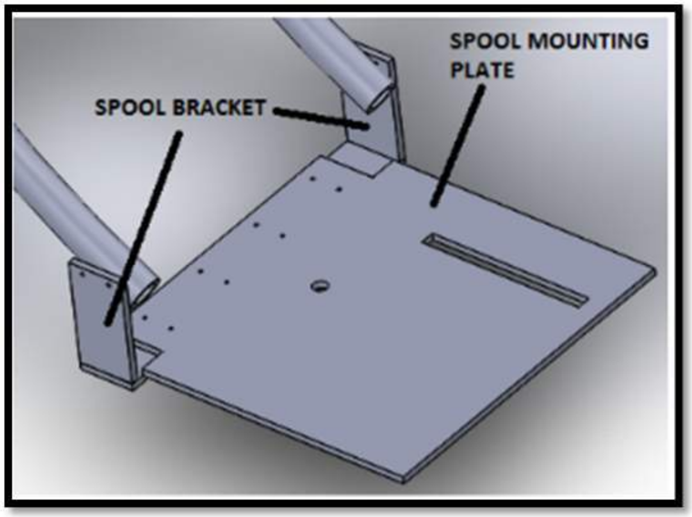


Figure 74. Spool Bracket with Spool Plate

This bracket is also made of three pieces of sheet steel have a thickness of a quarter inch. The top sheet steel piece is 13 inches long and 2 inches wide. The two pieces extruding down from this top piece are 3-3/4 inches long and 2 inches wide. These three pieces are also fastened together via TIG welding. The two 3-3/4 inch long side pieces each have two holes of 1/8 inch diameter which are drilled to rivet the brackets to the arches. The 13 inch long piece has eight holes of 1/8 inch diameter. These holes allow the spool bracket to be riveted to the motor mounting plate. The spool bracket can be seen in Figure 75.

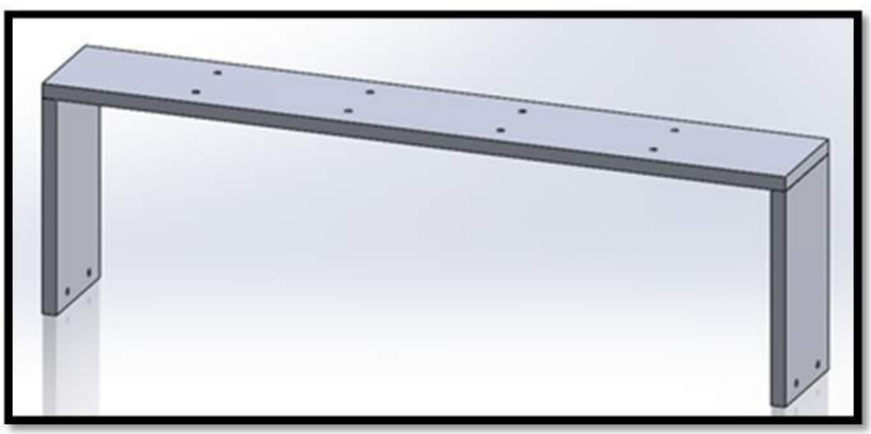


Figure 75. Spool Bracket

5.5.5 Pulley Bracket:

The pulley bracket is made of three pieces of sheet steel that have a thickness of a quarter inch. The top sheet steel piece is 13 inches long and 2 inches wide. The two pieces extruding down from this top piece are 3-3/4 inches long and 2 inches wide. These three pieces are fastened together via TIG welding. The two 3-3/4 inch long side pieces each have two holes of 1/8 inch diameter which are used to rivet the brackets to the arches. The 13 inch long top piece has four holes of 1/4 inch diameter which are used to fasten the pulleys to the bracket. This design can be seen in Figure 76.

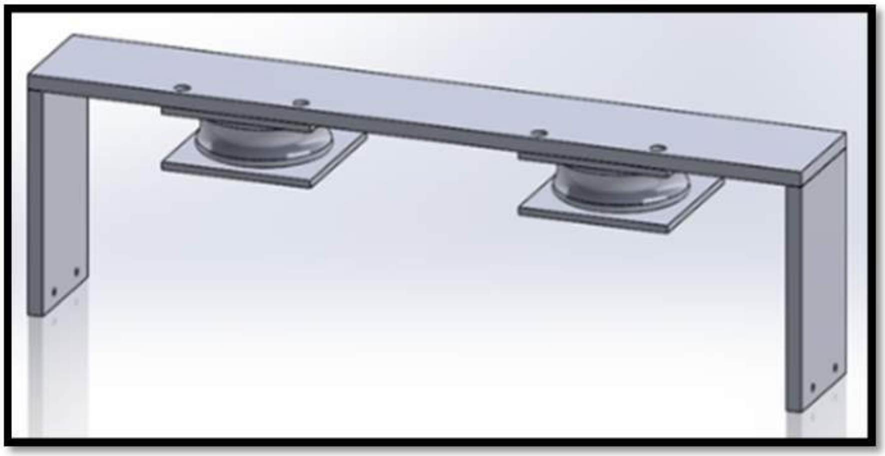


Figure 76. Pulley Mounting Bracket

5.5.6 Bracket Summary:

All of these brackets, with the exception of the spool and the pulley bracket, needed an additional hole in the 13 inch long piece to house a power cable hook. However, due to time constraints, these holes and therefor these hooks were never implemented. Refer to suggested improvements, section 9.1.4, for additional information.

5.6 Power Cable Spool:

The light bulb required 120 Volts at 60 Hertz (standard wall socket power) to be delivered while the carriage moved back and forth along the arches with the bulb. For this reason, we utilized a cord reel to feed and retract a thick insulated power cable that could move with the light carriage without posing any safety or shock hazards. The cord reel we used was the HDX 30 ft. retractable cord reel seen in Figure 77.

Figure 77. Cord wheel

The reel has a desired retracting force at all times that pulls the cable back into the housing. This is desired when the carriage is coming back along the arches. Some tampering with the reel was done in order to achieve this, and this process is detailed in manufacturing, section 7.1.11. For safety concerns regarding the cord reel, refer to section 6.4.2.

5.7 Light Carriage Design:

The light carriage was primarily designed around the arches. Our team decided to go with the roller coaster design of the carriage because despite it having more components to it, it is a more reliable design for our purposes.

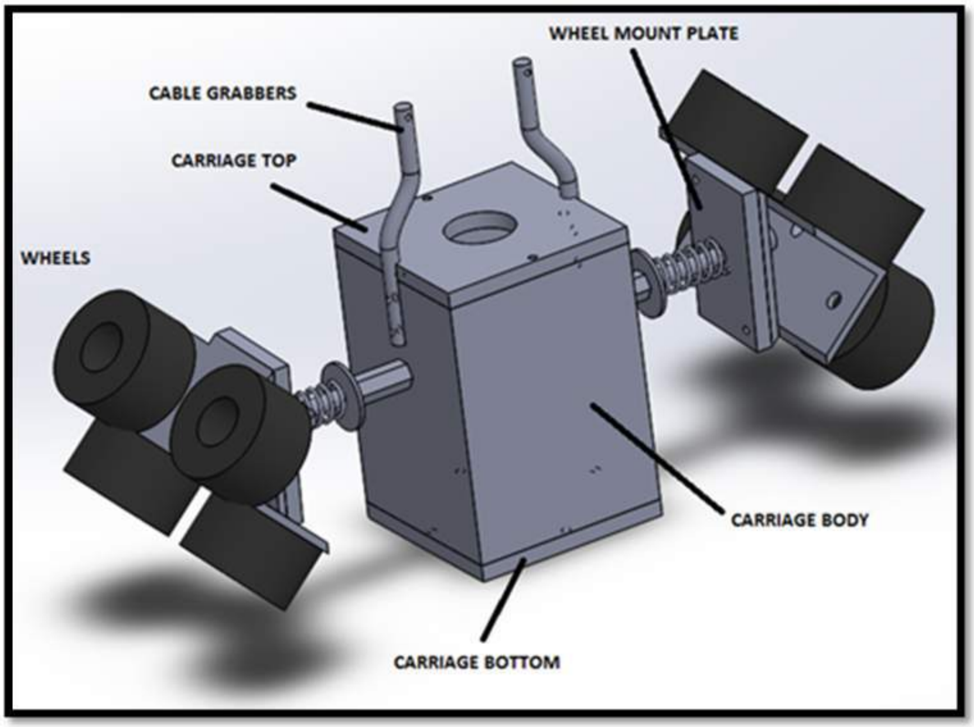


Figure 78. Light Carriage

The final light carriage can be seen in Figure 78. It is advised that the reader refer back to this figure when reading following sections. It consists of a square aluminum tube body with a top and bottom plate bolted on, two track dolly swivel wheels and two spring loaded shafts connecting the wheels to the body.

The center body is made out of 1/4” X 3” X 3” square aluminum tubing and is four inches long. The top plate has a center hole that is 1-1/32 inches diameter and it is secured to the body via two screws. This is to accommodate the cable strain relief grip that grabs the power cable. The bottom plate of the carriage has a 1-1/4” diameter hole so that the end of the light socket can rest in it. The bottom of the carriage can be seen in Figure 79.

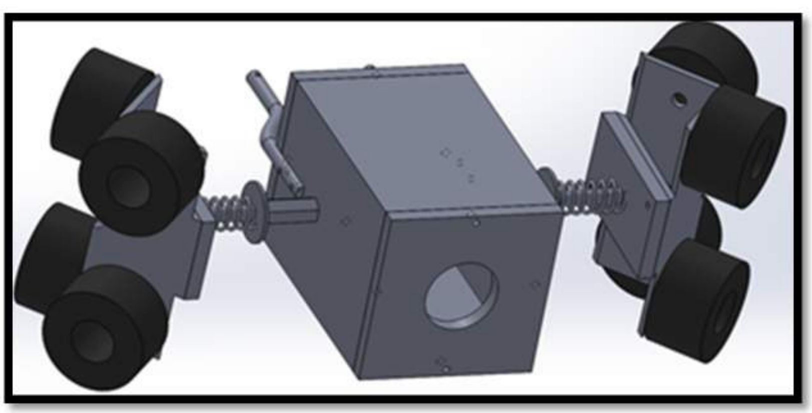


Figure 79. Light Carriage Bottom Plate

The end of the socket rests inside of this hole and it is secured in place by tightening two set screws on either side of the carriage body. This prevents the socket from moving around and becoming loose while the carriage is in motion. This can be seen in Figure 80.

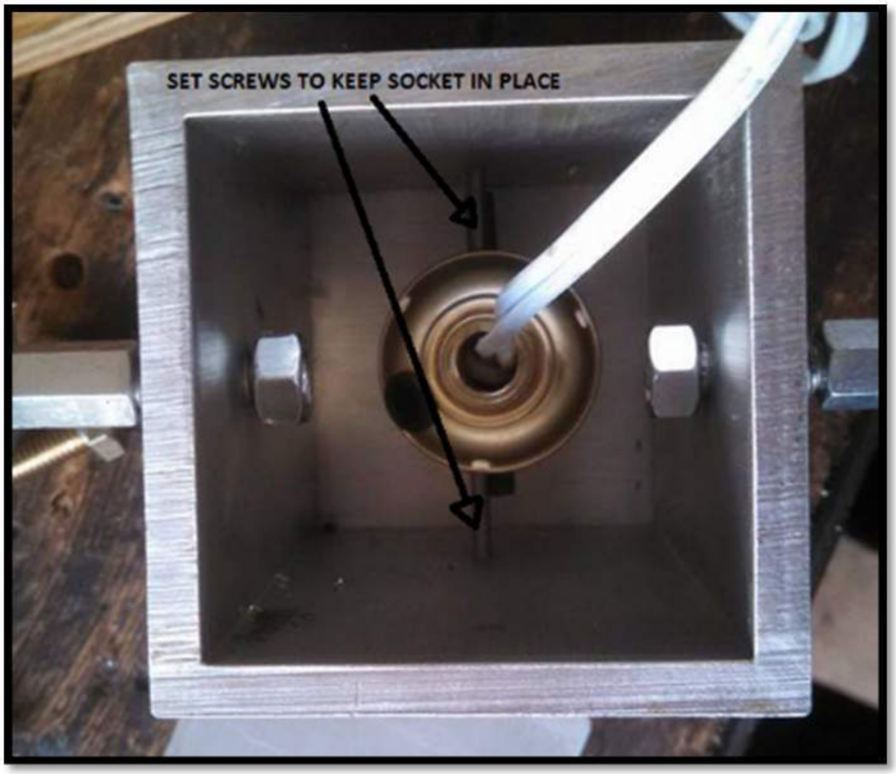


Figure 80. Set Screws in Carriage Body

The initial design of the light carriage used three wheels on each rail to keep the carriage in line. This design would require very precise machining of various parts and its assembly would be very difficult. After speaking with an aspiring movie director, it was recommended to us to try track dolly swivel wheels. These wheels are shown in Figure 81. These mechanisms use four wheels to contact each rail and come pre-made at a lower cost and higher quality than any wheels our team could have fabricated. The new and old wheel designs can be seen side-by-side in Figure 82.

Figure 81. Track Dolly Swivel Wheels

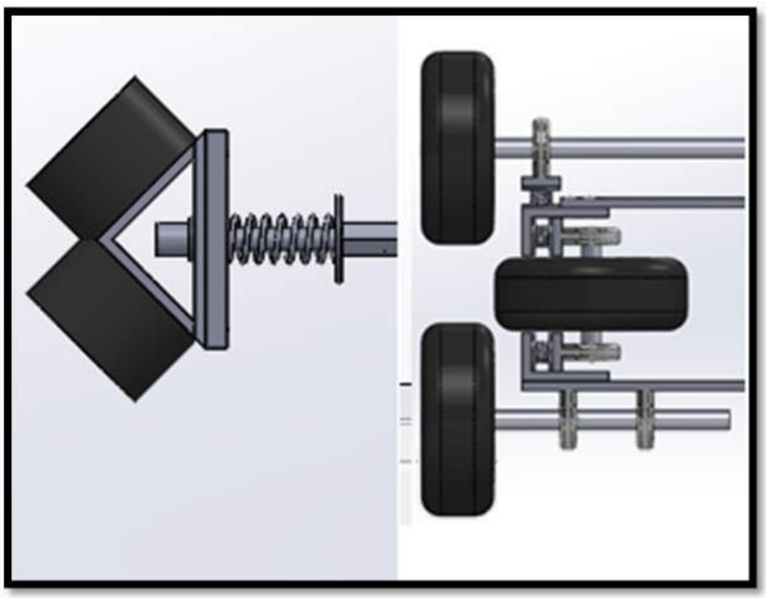


Figure 82. New (Left) and old (Right) Carriage Wheel Design

A labeled picture of the one side of the carriage can be seen in Figure 83. It is advised that the reader refer to this picture while reading the following paragraphs.

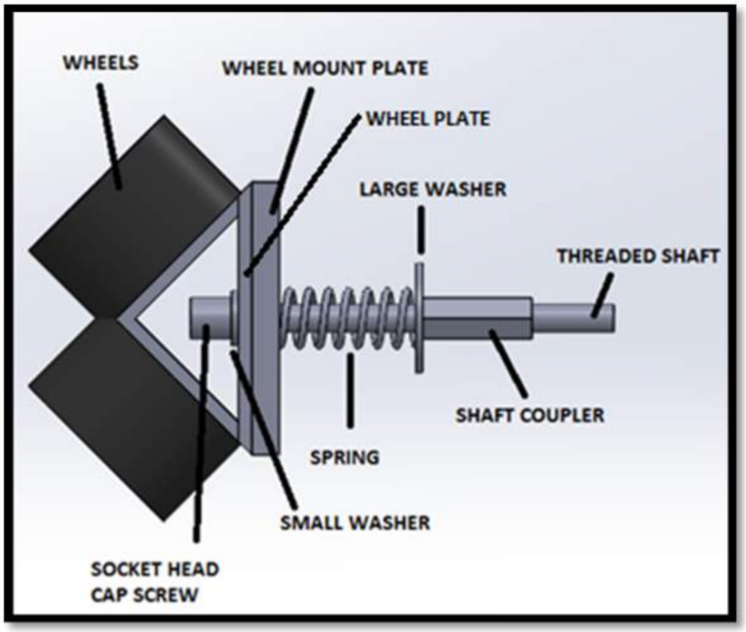


Figure 83. Spring-Loaded Shaft Mechanism for Carriage Wheels

To guarantee that the wheels remain in contact with the arches at all times, a spring loaded shaft mechanism is attached. This mechanism can be seen in Figure 83.

Ideally, the wheel plate that came with the track dolly swivel wheels would have a hole for the shaft to go through, but instead, this plate has a slot. This slot allows the shaft that goes through the hole and connects to the carriage to move both vertically and horizontally. We want to prevent this vertical motion because we want the shaft to only be able to move linearly in the horizontal direction as the spring compresses and extends. To solve this problem we made the wheel mounting plates. These plates are made out of 1/4 inch aluminum and are riveted onto the carriage wheels. It has a single hole in it which prevents the shaft from moving up or down, and the thickness of the plate prevents any wiggling of the shaft. One of the two wheel mount plates can be seen in Figure 84.

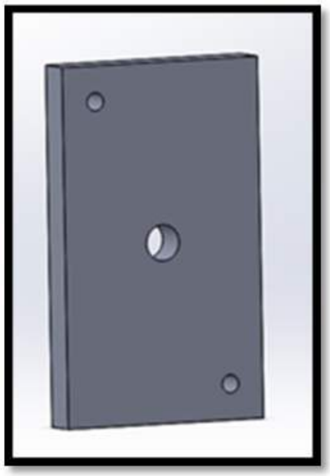


Figure 84. Wheel Mount Plate

The shaft itself consists of a 1/4-20 socket head cap screw joined to a threaded shaft via a shaft coupler. The shaft coupler is essentially an elongated nut with enough interior threads to house two different shafts. The cap screw has a large shoulder to allow more distance for it to slide through the wheel mount plate, so only about half an inch of thread actually goes into the shaft coupler. The threaded shaft is threaded into the carriage body through a tapped hole and secured with a hex nut inside the body. A previous figure is repeated in Figure 85 for convenience.

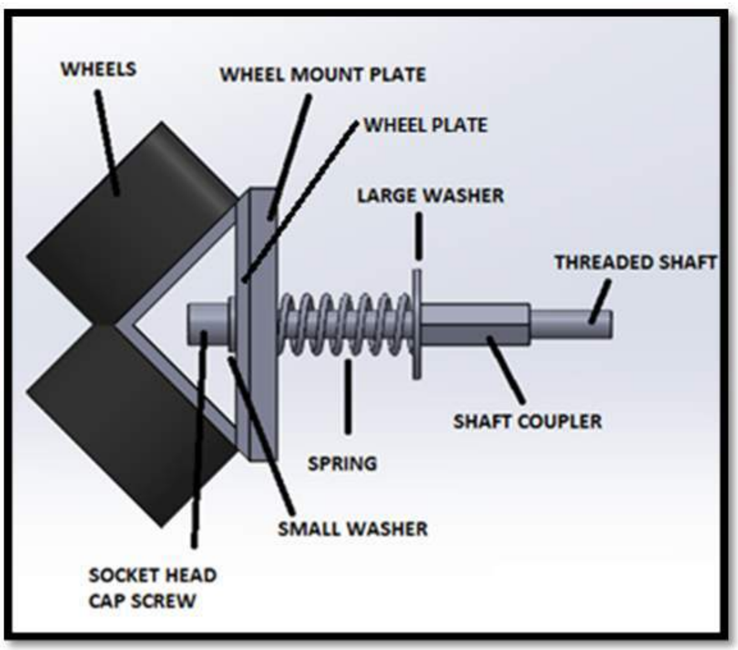


Figure 85. Spring-Loaded Shaft Mechanism for Carriage Wheels

A spring is used between the wheel mount plate and the shaft coupler to spring load the wheels and force wheel contact with the arches. A large washer is placed between the shaft coupler and the spring to ensure that the spring doesn’t slip over the coupler and become fully extended. When the wheels are pressed inwards towards the carriage body, the spring pushes them back out, ensuring contact on the rails. This motion is demonstrated in Figure 86.

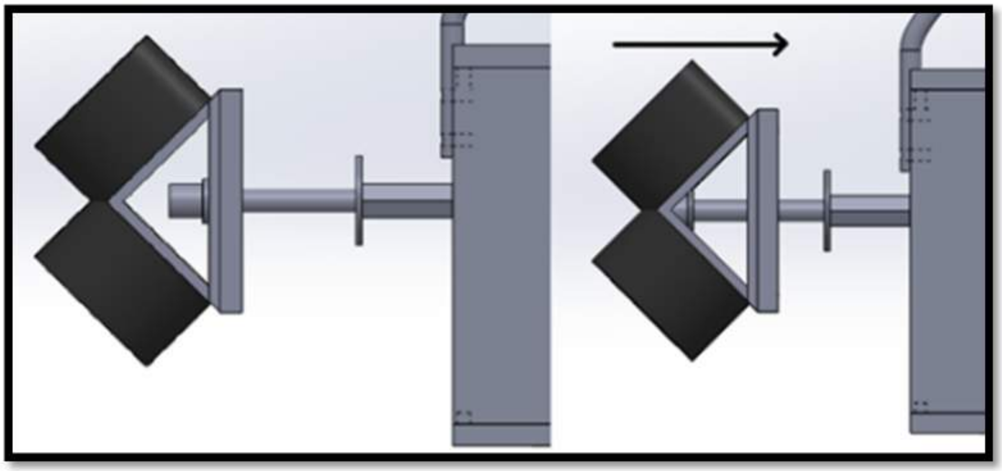


Figure 86. Carriage Wheel Spring Loading

The final component of the carriage are the cable grabbers. They can be seen in Figure 87. They are screwed onto the side of the carriage body and extend upwards, passing by the drive cable hooks in the brackets that carry the Kevlar thread.

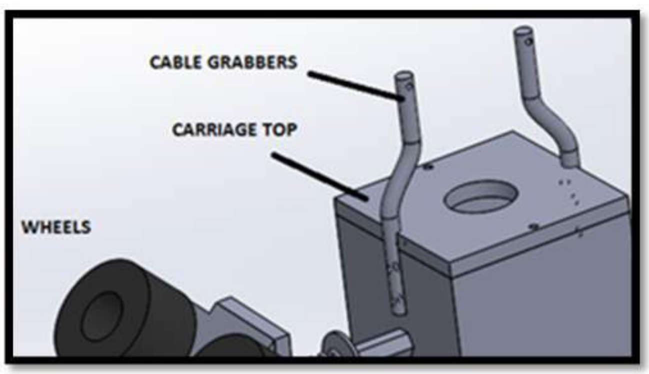


Figure 87. Carriage Grabbers

A small 3/32 inch hole in the top of the cable grabbers has Kevlar thread tied to it. As the Kevlar is reeled in by the motor, it pulls on the grabber, thus moving the carriage along the arch. The Kevlar tied to the grabbers can be seen in Figure 88.

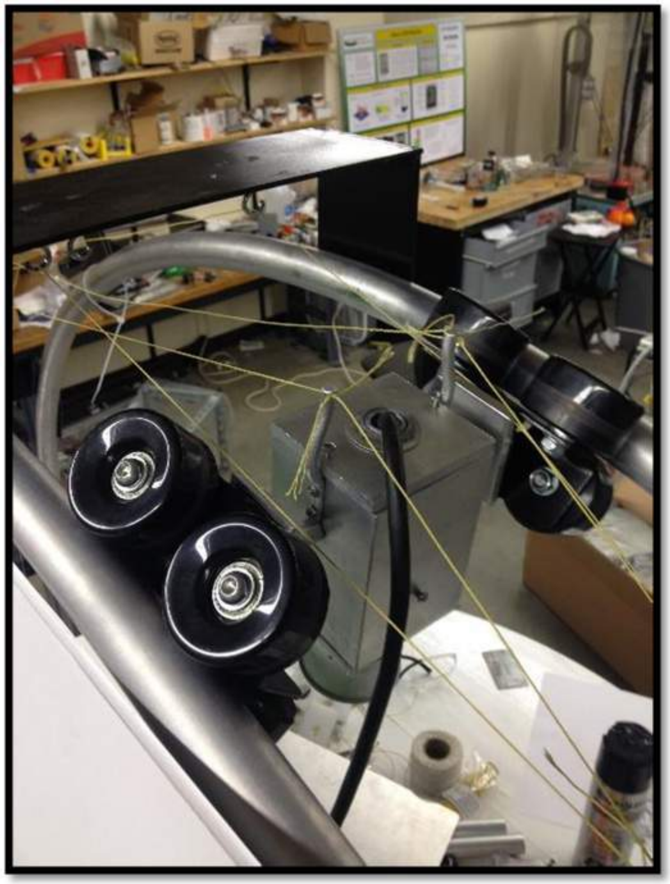


Figure 88. Kevlar Thread in Cable Grabbers

The grabbers are made out of 1/4 inch aluminum shaft and the ends connecting to the carriage body are ground down flat so they have a flat contact surface with the body. It is intended for the cable grabbers to lift the Kevlar thread from the drive cable hooks as the carriages passes them and lay them back into the hooks after the carriage has passed.

5.8 Spool Mounting Plate and Spooling Mechanism:

5.8.1 Spool Mounting Plate:

The spool mounting plate is made of 3/16 inch thick aluminum plate. It is 12 inches by 12 inches with two 2 inch by 1 inch cuts on one end so that it fits into the spool bracket. The dimensions of the plate were chosen after considering possible interference with the frame and possible deflection due to the motor and spooling mechanism. The deflection calculation can be seen in a MATLAB code in Appendix F**.** There are eight holes of 1/8 inch diameter at the top of the plate so that the plate can be riveted to the spool bracket. There is a 3/4 in wide 6 inch long slot that is cut along the plate as well as various holes for the spooling mechanism. The motor mounting plate can be seen attached to the spool bracket in Figure 89.

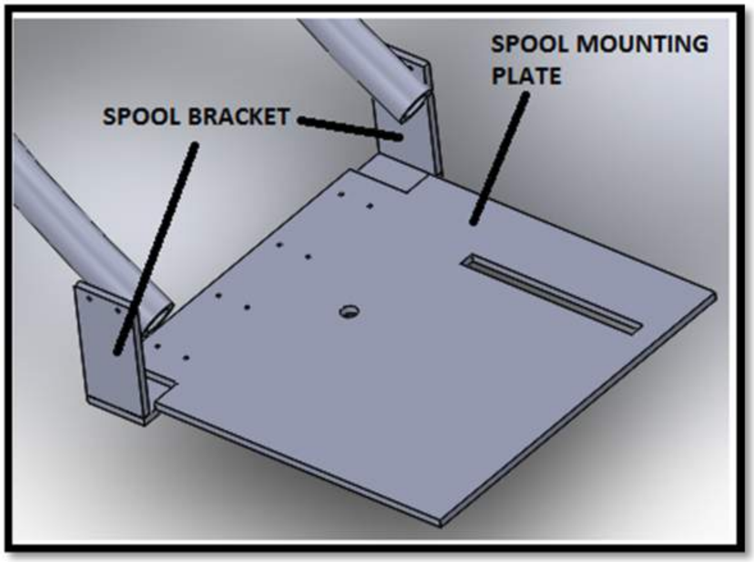


Figure 89. Spool Mounting Plate

5.8.2 General Spooling Mechanism:

In order for our Heliodon to be automated while maintaining accuracy, the motor has to move the light carriage very precise distances. Each turn of the motor must correspond to a specific distance traveled by the carriage along the arches. Since the carriage is pulled by the Kevlar thread drive cables, these cables must connect to the drive shaft. When the motor turns, these cables spool around the drive shaft, thereby pulling the carriage. In order to ensure that each turn corresponds to a specific distance traveled by the light carriage, the drive cables must not space out when spooling on the shaft, as is drawn in Figure 90, and they also must not stack on top of themselves, as is drawn in Figure 91.

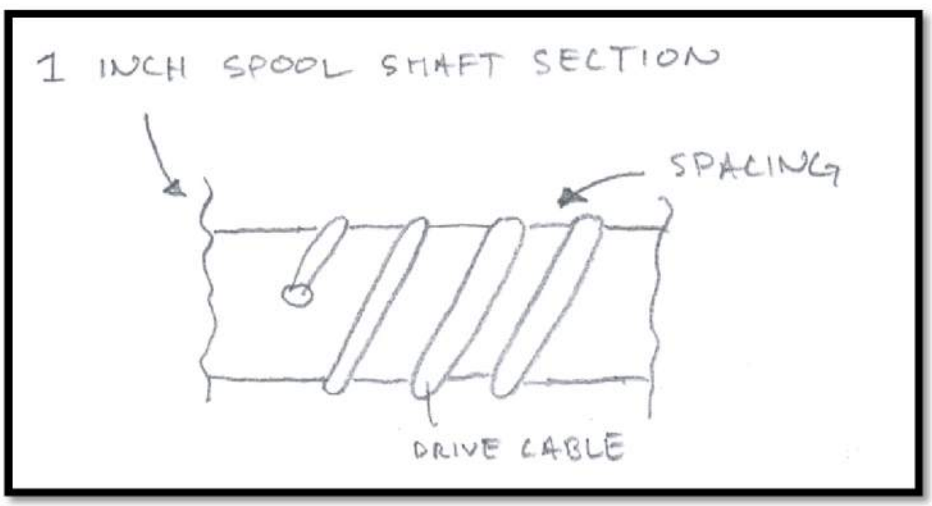


Figure 90. Spaced Out Thread on Spool

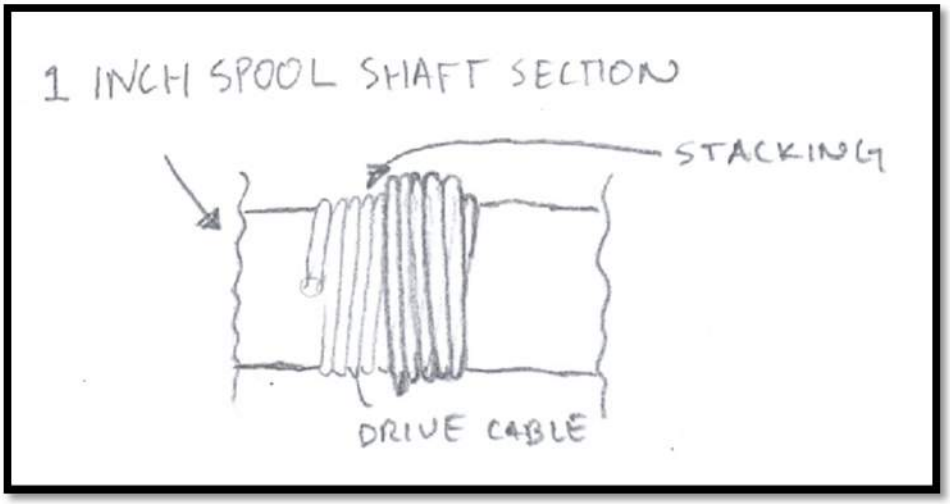


Figure 91. Stacked Thread on Spool

They must spool perfectly, with each subsequent wrap sitting directly against the previous one, as shown in Figure 92.

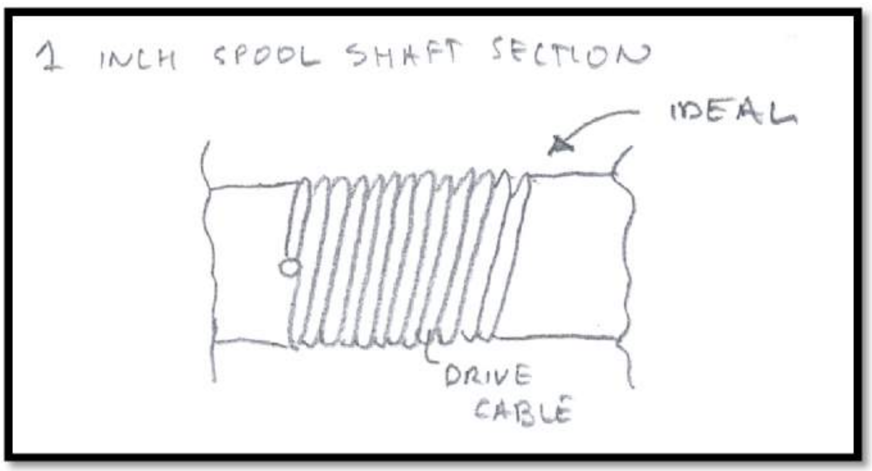


Figure 92. Ideal Thread Spooling

To accomplish this task, we contacted California Fine Wire Company in Grover Beach, California. They recommended using a lead-screw with wire guides that was coupled to the drive-shaft. This became our final design. A SolidWorks image of our final design can be seen in Figure 93.

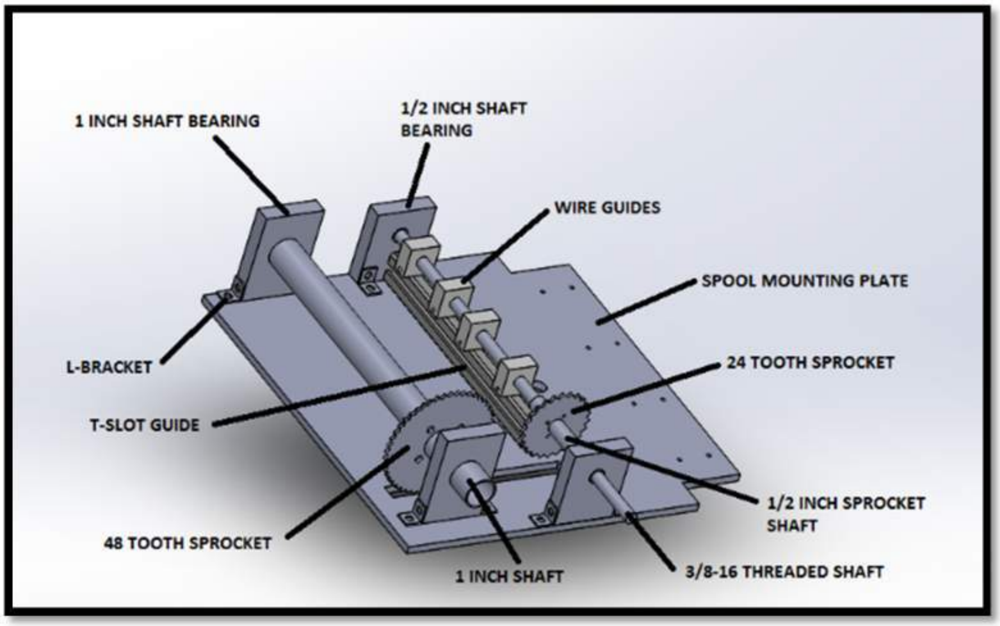


Figure 93. Spooling Assembly

The specifications for each component of the final spooling mechanism may be seen in Appendix I. A detailed explanation of considerations and choices for individual spool components may be seen in the following Detailed Spooling Mechanism section.

5.8.3 Detailed Spooling Mechanism:

With the help of a MATLAB code that we created, which can be seen in Appendix F, we sized the components of the spooling mechanism. We needed 173 inches of cable to span one arch length, and since the two arches each needed a supply and return cable, we needed four times this, or about 58 total feet of cable. With two 66 inch diameter arches of 300 out of 360 degrees, 173 inches of cable are needed to span one arch length. Each arch has a supply and return cable, so twice this amount, or 346 inches, is needed. We need this amount for each arch, so a total of 692 inches, or around 58 total feet of cable is necessary to pull the carriage back and forth along the arches.

Once the total length of cable was chosen, we needed to size the shaft that was to spool the cable. This shaft is referred to as the drive shaft because this is also the shaft connected to the motor. As the shaft diameter increases, so does the required torque to drive the carriage. We want this required torque to be as small as possible and so we chose to make the shaft hollow to decrease its moment of inertia. However, as the drive shaft diameter decreases, the number of rotations necessary for the carriage to traverse the arch increases, and thus the length of the spool increases. This is shown in Figure 94, where the smaller diameter shaft, D1, has longer spool, L1, and the larger diameter shaft, D2, has a shorter spool, L2.

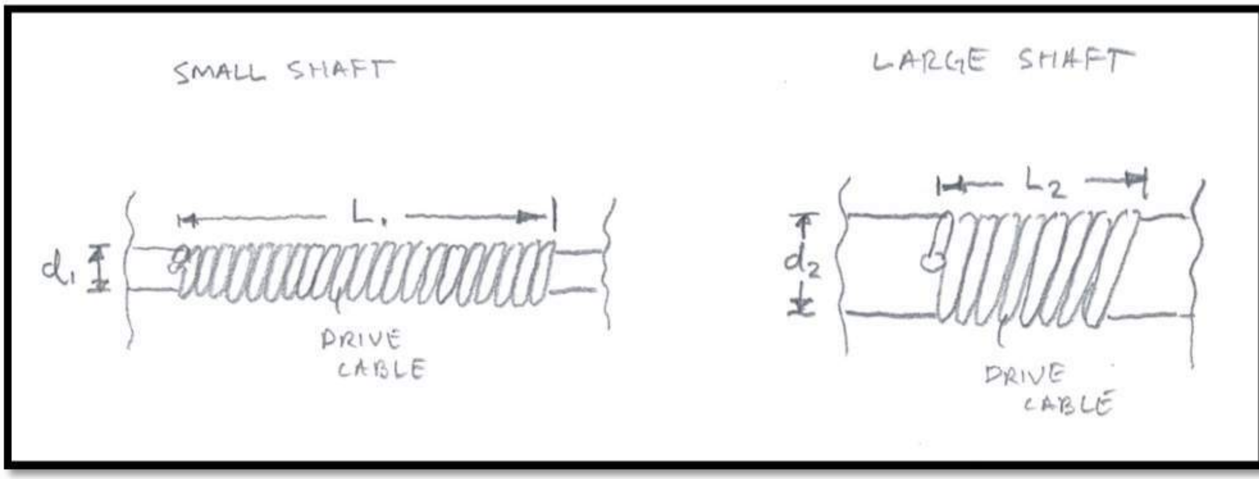


Figure 94. Kevlar Thread on Small vs. Large Shaft

This spool length cannot be excessive because the difficulty of spooling over a larger distance is immense. We experimented with input drive shaft sizes in the MATLAB code in Appendix F and found that a 1 inch diameter drive shaft yielded a spool length of about 1-3/4 inches. We decided that this was sufficient.

Once the drive shaft was chosen, we needed a way to get the cable to spool evenly along the shaft. Our Kevlar drive cable had a diameter of 1/32 inch, so for the cable to spool perfectly, it needed to move linearly 1/32 inch along the drive shaft for every rotation of the drive shaft. To accomplish this task, we elected to use a lead-screw that was coupled with the drive shaft. This lead-screw would have guides that move linearly along the lead-screw as it turns in order to guide the wire onto the drive shaft appropriately. These wire guides and their linear motion is illustrated in Figure 95.

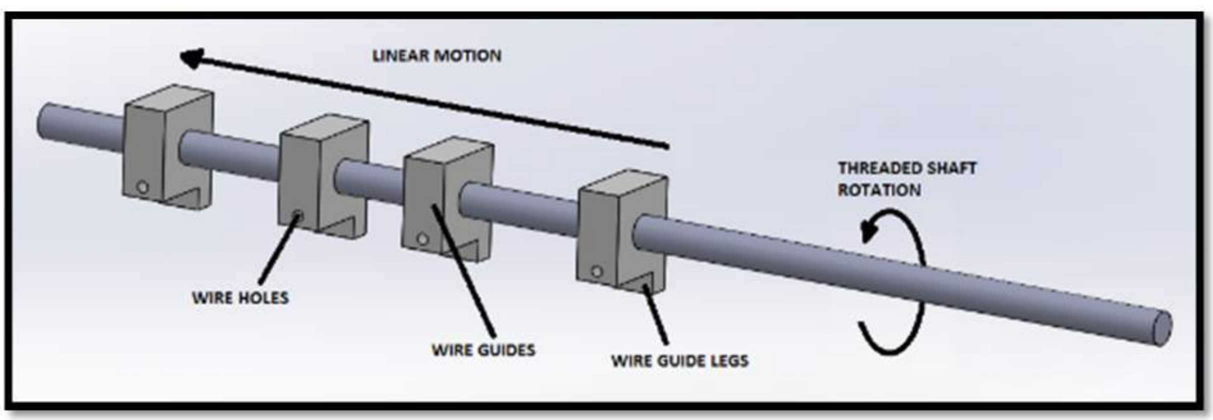


Figure 95. Cable Guide Motion Description

In order for the wire guides to work correctly, they have a 3/8 inch diameter, 16 threads per inch hole, a wire hole to feed the drive cables through, and a "leg" to fit into a T-Slot channel to prevent rotation (thereby creating the linear motion) with rotation of lead-screw. This “leg” and T-Slot channel interaction can be seen in Figure 96.

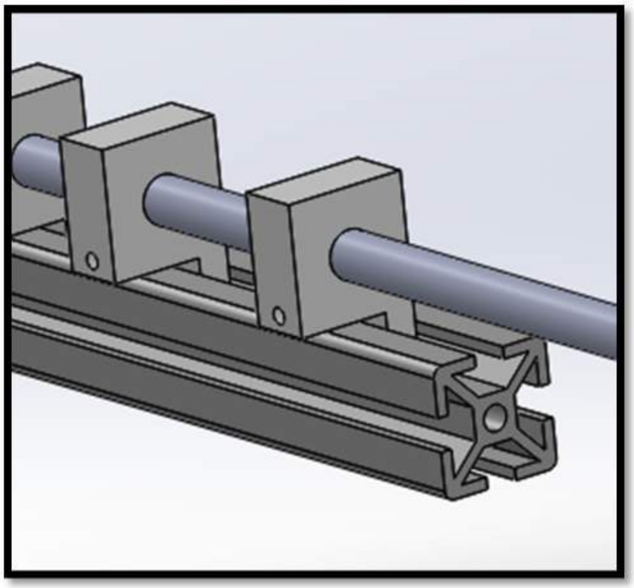


Figure 96. Cable Guide in T-Slot Rail

The wire guides are made Ultra-High Molecular Weight Polyethylene because the material is easy to work with. We could have used a lead-screw with 32 threads per inch, so that for every turn of the lead-screw, the wire guides would traverse the linear 1/32 inch, but this threads per inch is difficult to attain. Instead, we used a 3/8 inch diameter lead-screw of 16 threads per inch, and used a 2:1 gear ratio. This way, one turn of the drive shaft rotates the lead-screw half a turn, and so 32 turns of the drive shaft rotates the lead-screw 16 times. With 16 threads per inch, 16 turns of the lead-screw moves the wire guides 1 inch, and this 1 inch is traversed over 32 turns of the drive shaft as necessary.

Creating the 2:1 gear ratio was tricky, because our drive shaft and lead-screw did not have a 2:1 ratio (1 inch to ⅜ inch). We found two sprockets of 48 and 24 teeth on ServoCity that came with clamping hubs and a drive chain. The two sprockets and a clamping hub are shown in Figure 97 and the chain and exploded views of the chain sizing accessories are shown in Figure 98.

Figure 97. Spool Sprockets and Bore Clamping Hub

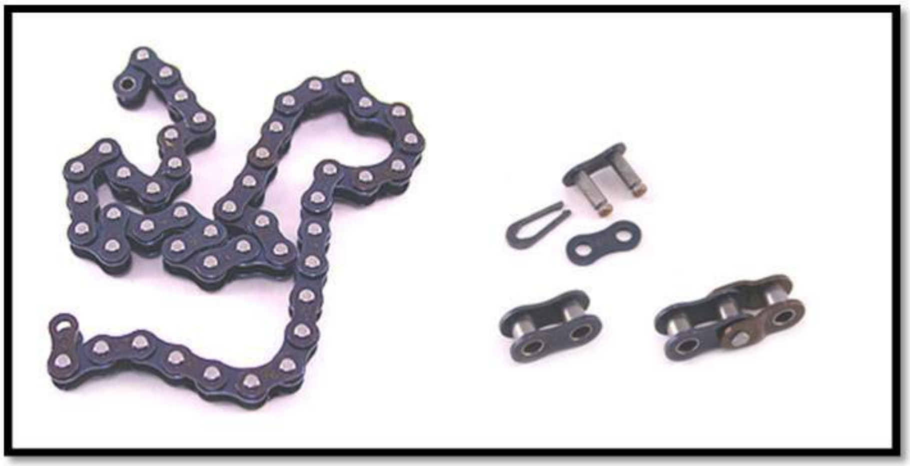


Figure 98. Spool Chain

The 48 tooth sprocket was for a 1 inch shaft and the 24 tooth sprocket was for a 1/2 inch shaft, so we needed to increase the diameter of our 3/8 inch shaft to the 1/2 inch shaft that fit the 24 tooth sprocket. We tried to accomplish this by purchasing a hollow 1/2 inch shaft and a shaft adapter that stepped a ⅜ inch shaft up to a 1/2 inch shaft. This adapter is shown in Figure 99.

Figure 99. Spool Shaft Coupler

Unfortunately, we found that this did not work because our ⅜ inch shaft was threaded and this made it too small to be clamped in the shaft adapter. To resolve this issue, we placed our hollow 1/2 inch shaft around our threaded 3/8 inch diameter shaft (like an annulus) and clamped the two together with two nuts. Two annuli were needed; one to mate with a bearing, and one to mate with a bearing and the 24 tooth sprocket. These annuli and the mating to their parts can be seen in Figure 100.

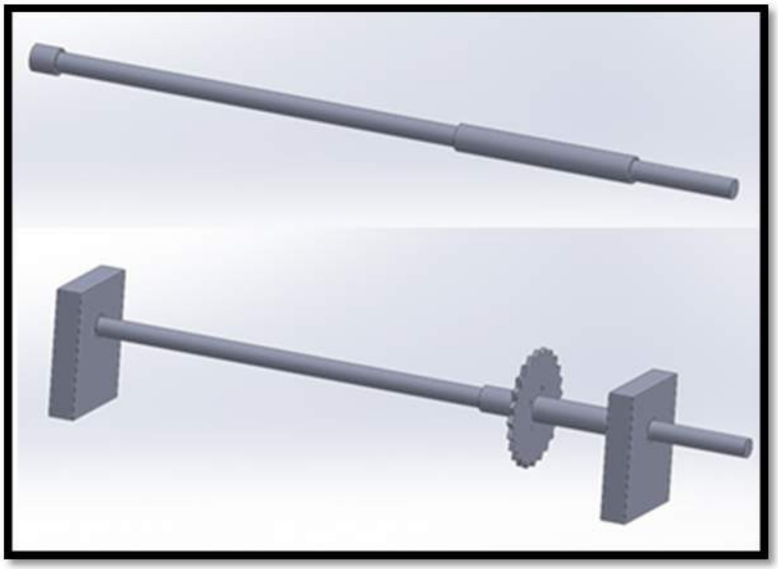


Figure 100. Spool Annuli with and Without Bearings

Once the sprockets fit the desired shafts, they were clamped to the shafts with their respective clamping hubs and the chain was applied. We decided to use Ultra-High Molecular Weight Polyethylene blocks to serve as the bearings for each shaft. The general design can be viewed in Figure 101, and the detailed dimensioned design may be seen in **Appendix I**.

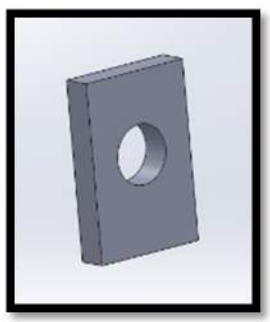


Figure 101. UHMW Shaft Bearing

To attach the bearings to the motor mounting plate, we used 3/4 inch Zinc plated corner braces, which can be seen in Figure 102.

Figure 102. L Brackets for Bearing Mounting

6 Design Considerations

6.1 Latitude Slot Length Requirement:

The required length of the slot within the Latitude Slot is a function of the radius of our arch. The slot has to be long enough to simulate the sunrise and sunset at the equator during the summer and winter solstices. That is, the light arch has to move far enough within the slot so that when the light passes the plane of the table it appears to be doing so at the azimuth angle corresponding to sunrise and sunset at the winter and summer solstices at the equator. These sunrises and sunsets occur at azimuth angles of $+23.45^{\circ}$ and -23.45°. Figure 103 provides further explanation.

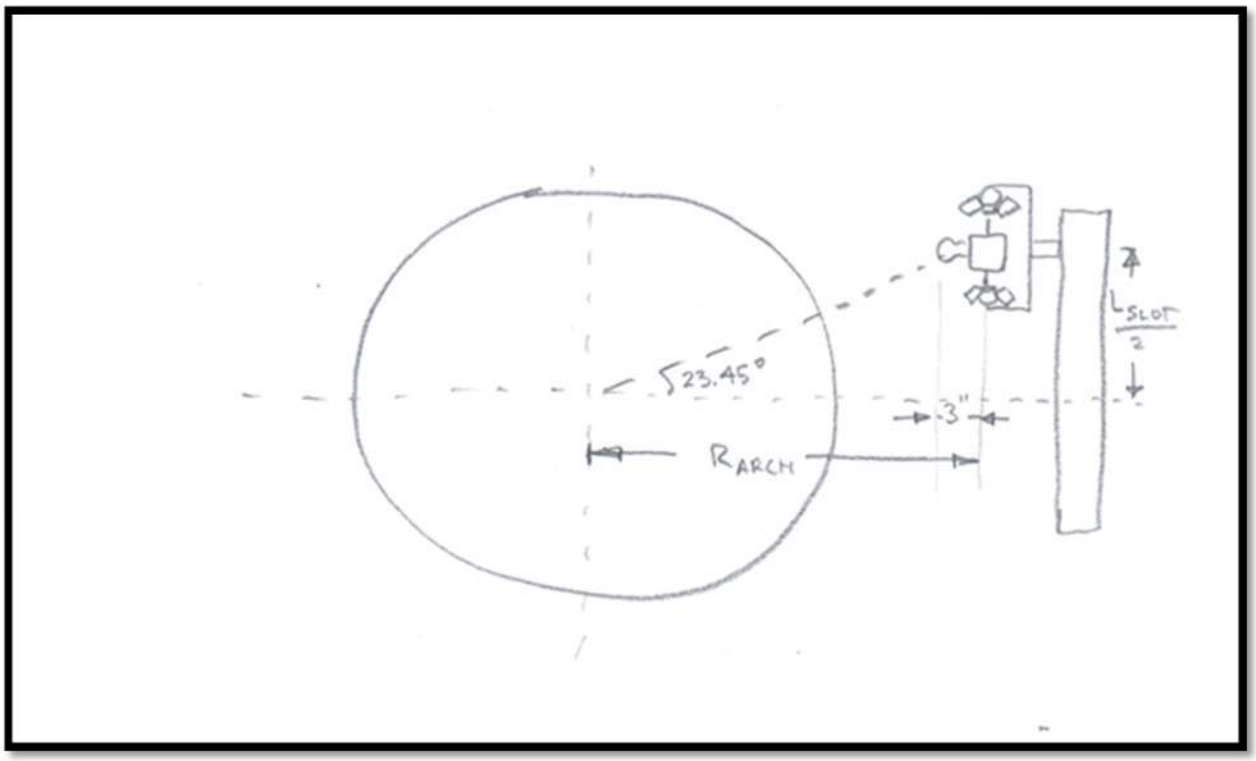


Figure 103. Slot Length Schematic Diagram

Figure 103 shows the location of the light at sunrise of the summer solstice at the equator. This is the max distance the light will have to move from the center of the slot and it is equal to the distance it would have to move to get to the sunrise for the winter solstice. Therefore, the length of the slot needs to allow for two times this max distance. The geometry and calculation for the length that the slot would need to allow the light to move, L_s, is in Figure 104.

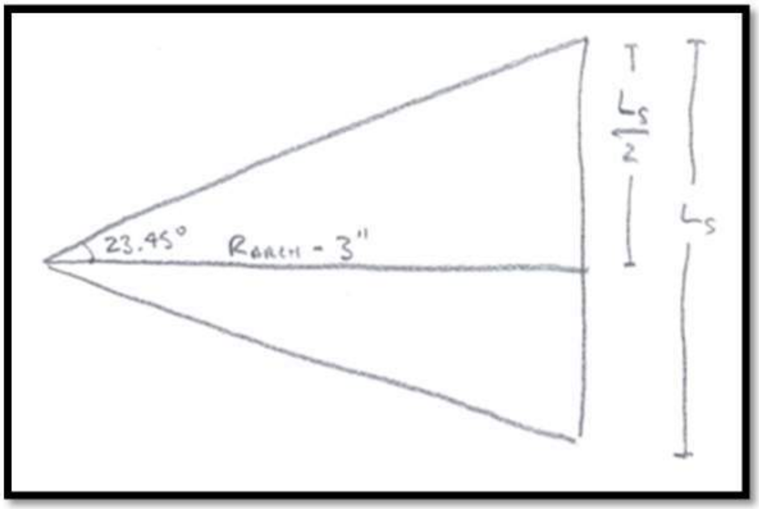


Figure 104. Slot Triangle

$$\tan(23.45^{o}) = \frac{\frac{L_S}{2}}{(R_{ARCH} - 3)}$$

$$L_S = 2\,(R_{ARCH} - 3)\tan(23.45^{o})$$

$$R_{ARCH} = 33\ in$$

$$L_S = 26\ in$$

The actual length of the slot would need to allow for this L_S to be traversed by the center of the 1 inch diameter shaft in the slider. This means that the slot has to be this length, plus the radius of this shaft, 1/2 inch, on each end of the slot. This put the final length required of the slots at 27 inches, and we made our slot a round 30 inches.

6.2 MATLAB System Modeling:

The MATLAB code served a few purposes for our team. First, it helped us relate the size limitations of the Heliodon (its ability to be transported in hallways and through doors) to the latitude simulation limitations (the range of latitudes that could be simulated). It helped us experiment with different arch sizes and frame dimensions by letting us know what combinations would be feasible. Some combinations would create interference in transportation, some combinations caused the arches to interfere with the frame, and some combinations delivered very limited latitude ranges. The code helped us pick the optimum combination – one that gave us door frame clearance and clearance between the arch and the frame while maximizing the latitude simulation range.

6.2.1 Deriving the Equations:

In order to create the code, we first had to determine the governing equations of our system. Figure 105 is a side view of the Heliodon that shows the latitude slots, table, frame, and arches of the Heliodon. The latitude slots are rotated to an arbitrary latitude angle Θ_L.

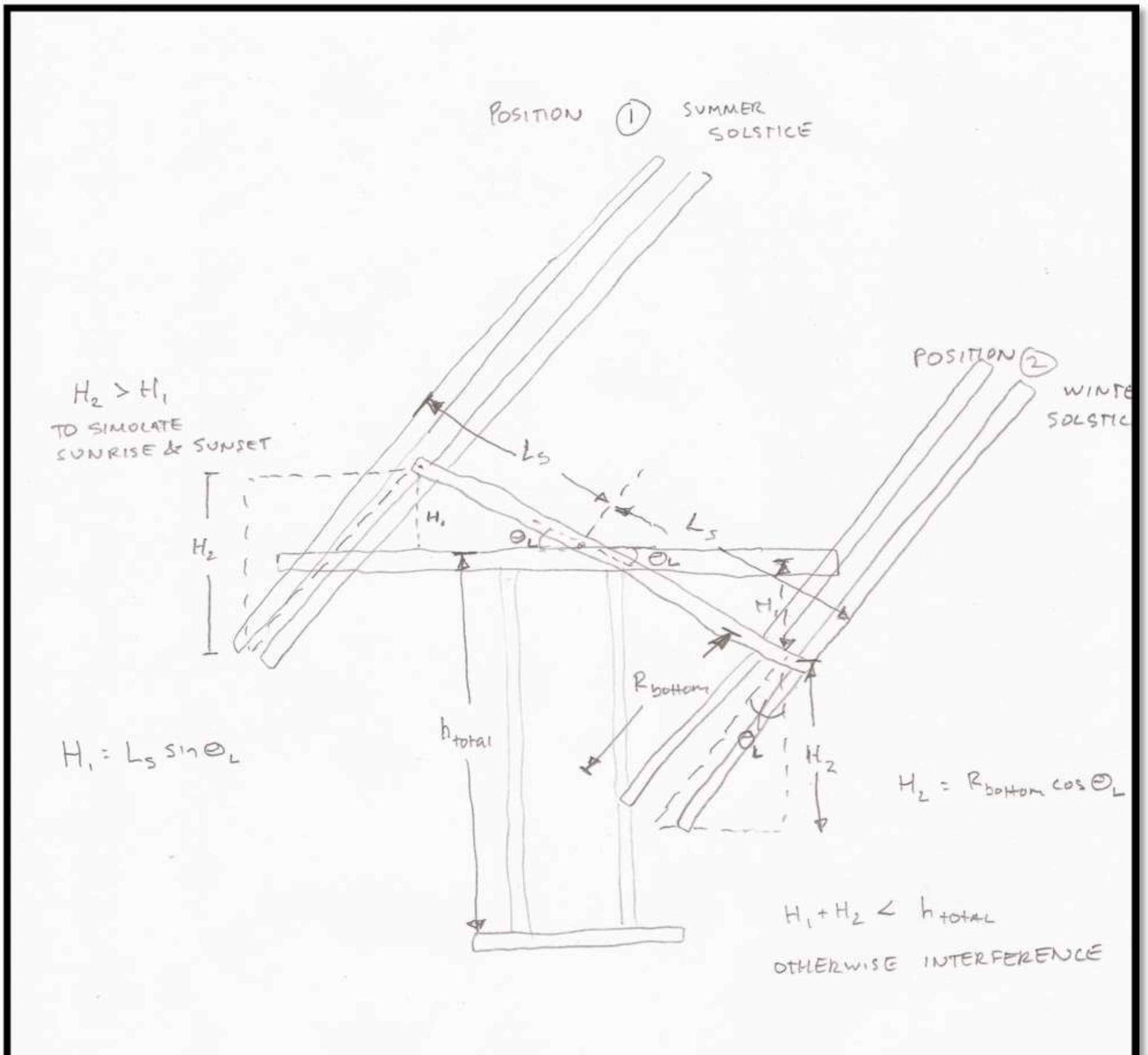


Figure 105. MATLAB Schematic Diagram

The length L_s is the length from the center of the slot to the outermost point on the outer arch. The calculation for L_s is provided in Figure 106 and has been typed up as well for convenience.

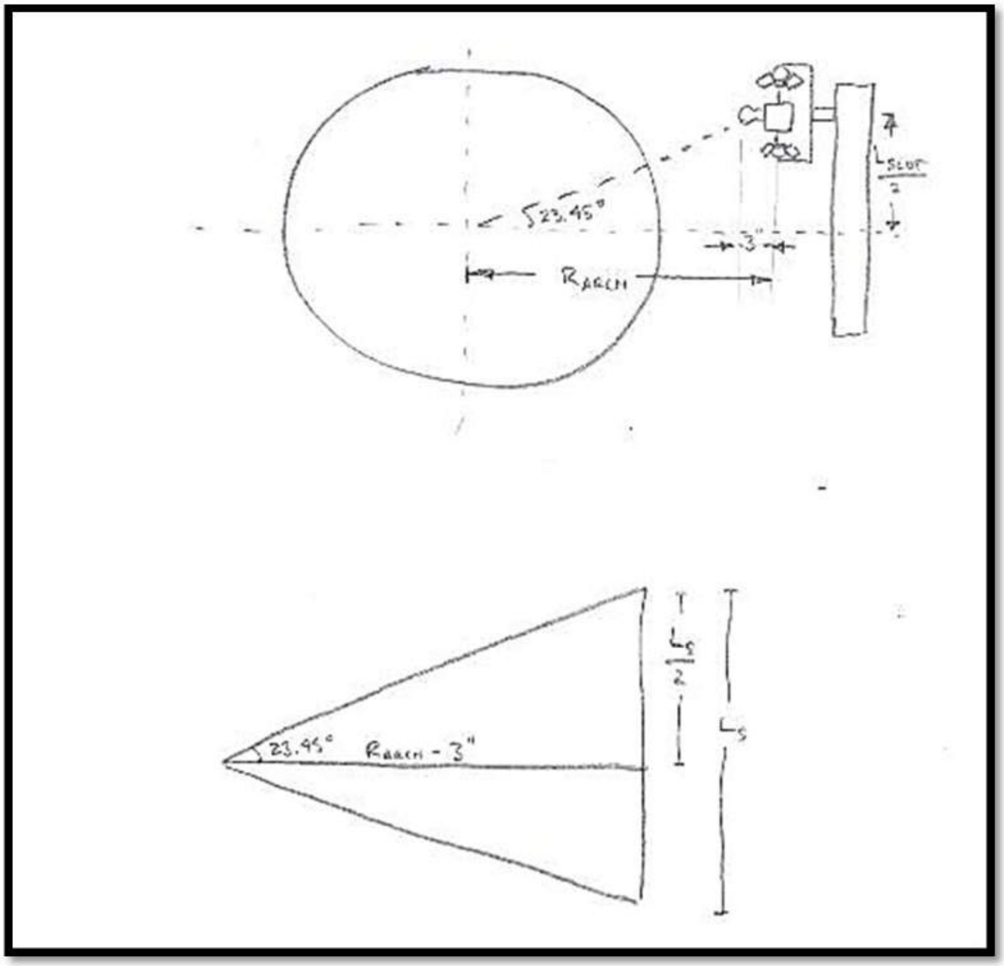


Figure 106. True Slot Length Math

$$L_s = \frac{27}{2}in + \frac{13.5}{2}in$$

$$L_s = 20\ in$$

This length is a function the slot length (which is in itself a function of the radius of our arch), the distance between the two arches (which affects the distance between the outermost point on the outer arch and max point the slider has to slide to) , and the cross sectional diameter of the arches.

The height, H_1, is the perpendicular distance from the top (or bottom) of the slot to the bottom (or top) of the table. It is found by the equation,

$$H_1 = L_S \sin(\Theta_L)$$

as derived from the triangle highlighted by Figure 107.

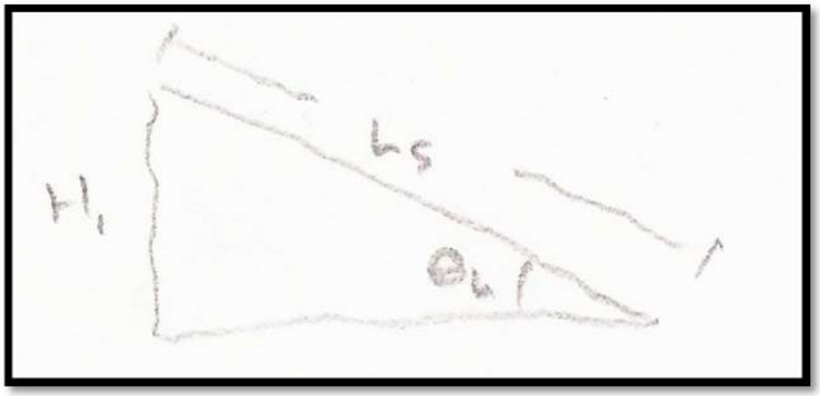


Figure 107. H1 Derivation Triangle

This distance is important because we need to make sure that the bottom portion of the arch is long enough for the light to pass the horizontal plane of the table and therefore simulate sunrise and sunset. This bottom portion of the arch has been called R_{bottom}, and it is a parameter that is chosen by us. As shown in Figure 108, we choose how full of a circle we want and this choice changes the value for R_{bottom}. We chose to have a 300 degree arch which gave a value of 28 inches for R_{bottom}.

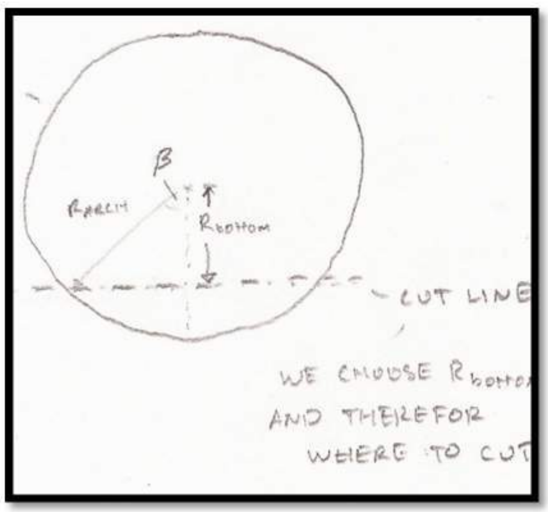


Figure 108. Rbottom Schematic

The parameter, H_2, is related to R_{bottom} by the equation below as derived from the triangle highlighted by Figure 109.

$$H_2 = R_{bottom}\cos(\Theta_L)$$

Figure 109. H2 Derivation Triangle

We want to make sure H_2 is always greater than H_1 so that the Heliodon will be able to simulate sunrise and sunset. At the point where H_1 becomes larger than H_2, we will not be able to simulate the sunrise and sunset because the light source be unable to pass below the plane of the table. This could occur when the Heliodon is simulating the summer solstice at extreme latitudes. The point at which this condition does occur is the maximum latitude that our Heliodon can simulate. This operation point can be seen back in Figure 105 when the arches are in position 1, at the top left of the slot. Since H_1 and H_2 are functions of the latitude angle, Θ_L, there are some latitudes that make H_1 larger than H_2 and these latitudes cannot fully be modeled by our Heliodon. This is the first limitation that the code is checking.

The variable h_{total} is the distance from the top of the table to the top of the bottom of the T-Slot frame. We chose this distance when we designed the frame. For our design h_{total} = 36.5 in. The second limitation that we are checking for is whether or not the arch will interfere with the frame. This interference may occur when the Heliodon is operating at the winter solstice for certain latitudes. This operation point is shown back in Figure 105 when the arch is at position 2, the bottom right slot position.

The governing equations for the MATLAB simulation are simply,

$$H_1 = L_S\sin(\Theta_L)$$

$$H_2 = R_{bottom}\cos(\Theta_L)$$

We choose the radius of our arch, R_{arch}, which determines the length, L_s, and we choose the amount we cut off which affects R_{bottom} and therefor H_2 as well.

6.2.2 Justifying Our Final Dimensions:

The full MATLAB code that was written can be seen in Appendix G**.** The code displays our final chosen inputs. The radius of our arch is 33 inches, the distance between the top of the table to the top of the bottom beam of the frame is 36.5 inches, and the final arch is 300 degrees which makes the lower portion of the arch 28 inches. The code was run for latitudes from 0 degrees to 90 degrees North latitude, which would produce the same results from 0 degrees to 90 degrees South latitude. The output plot of our graph can be seen in Figure 110.

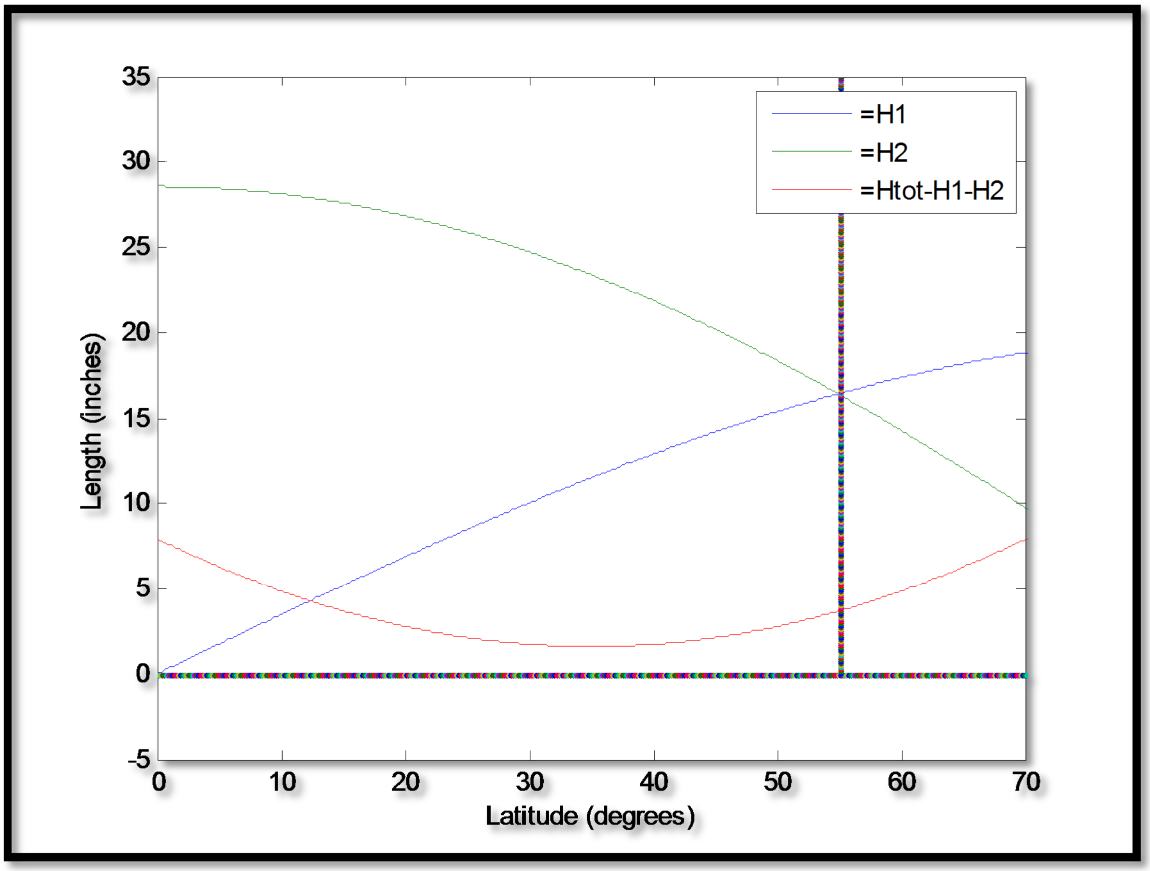


Figure 110. MATLAB Code Output

The plot is an overlay graph of H_1 versus Θ_L, H_2 versus Θ_L, and H_{tot} which is equal to (h_{total}-H_1-H_2) versus Θ_L. Remember, the limiting factors for Heliodon operation are if H_1 becomes larger than H_2 (limiting sunrise and sunset simulations) or if H_1+H_2 becomes greater than h_{total} (creating arch interference with the frame at certain latitudes). In our plot, the latter limitation is displayed by the red line. If the red line, H_{tot}, dips below zero, then there is arch interference with the frame at that latitude. For all latitudes shown, H_{tot} is positive and so there should never be arch interference with the frame. H_1 becomes larger than H_2 at a latitude of around 51 degrees, and so this should be the maximum latitude in which our Heliodon can display all sun paths throughout the year.

6.3 Design Analysis:

In order to justify all of the sizing of the load-bearing components of our design we turned to hand calculations and analysis. We analyzed the deflection of two different beams of the frame, the stresses in the threaded rods, and the possibility of tipping during both general operation and during transportation. We sized the parts according to rough estimations and then used the dimensions to calculate the stresses and deflections that a given component might experience. We overestimated the weights of components in order to over-design in the interest of safety.

6.3.1 Weight Estimations:

Before any analysis was done, the weights of all the components in the Heliodon system had to be estimated. All of part's weights that were not pre-ordered (the wheels, the motor, etc.) were estimated using the density of the material they were made from and the volume of the individual materials. These calculations can be seen in Appendix G, and here we have included the weight estimations for each component in Table 3.

Table 3. Weight Estimations

Part	Number of Parts	Material	Density (lb/ft^3)	Volume (in^3)	Volume (ft^3))	Weight Per Part (lbs)	Total Estimated Weight (lbs)
Casters	4	Mixed	-	-	-	9	40
Frame	1	Aluminum	169	700	0.4	65	70
Table	1	Maple Plywood	-	-	-	20	20
Latitude Plates	4	Steel	491	5	0.003	1.5	6
Steel Rods	4	Steel	491	5	0.003	1.5	6
Latitude Slots	2	Aluminum	169	175	0.1	16.9	35
Sliders	2	UHMW	58.75	32	0.019	1.5	5
Brackets	11	Steel	491	16	0.009	5	55
Arches	2	Aluminum	169	111	0.06	11	25
Carriage	-	-	-	-	-	-	10
Motor Mounting Plate	-	-	-	-	-	-	5
Spool	-	-	-	-	-	-	5
Motor	-	-	-	-	-	-	1
Total Estimated Weight							283

6.3.2 Threaded Rod Analysis:

We knew that the threaded rod would have to hold the weight of the arches, slots, carriage, cables, wiring, brackets, and motor, and so we assumed that it would have to be strong. We first decided to use a 3/4 in diameter steel threaded rod. Analysis was done by transmitting the forces and the moments created by the forces to the very end of the rod. These forces may be seen in Figure 111 and have been translated to the rod in Figure 112.

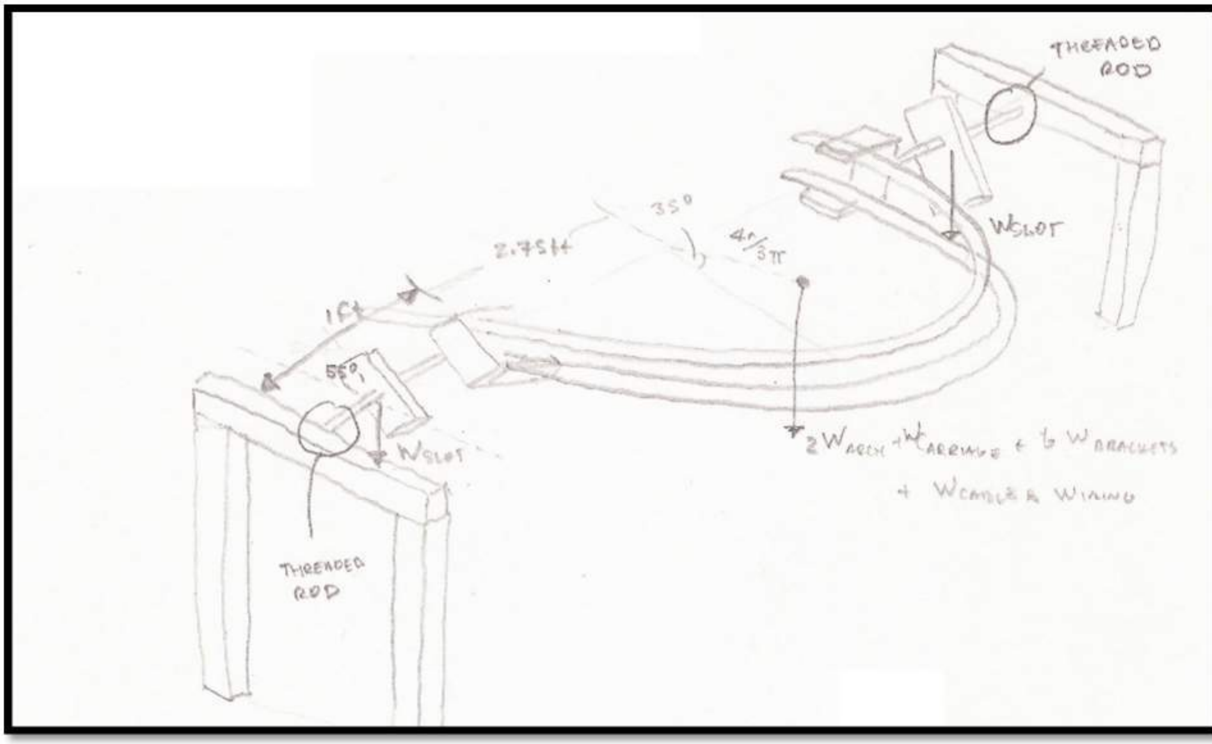


Figure 111. Threaded Rod Analysis Schematic.

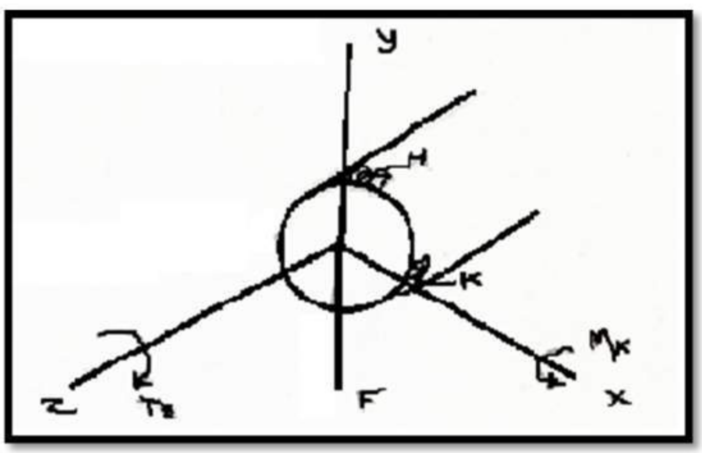


Figure 112. Forces and Moments in Threaded Rod

The stresses caused by these moments, torques, and shear forces were then found using governing equations. The stress diagram for point H and the governing equations can be seen in Figures 113 and 114, respectively.

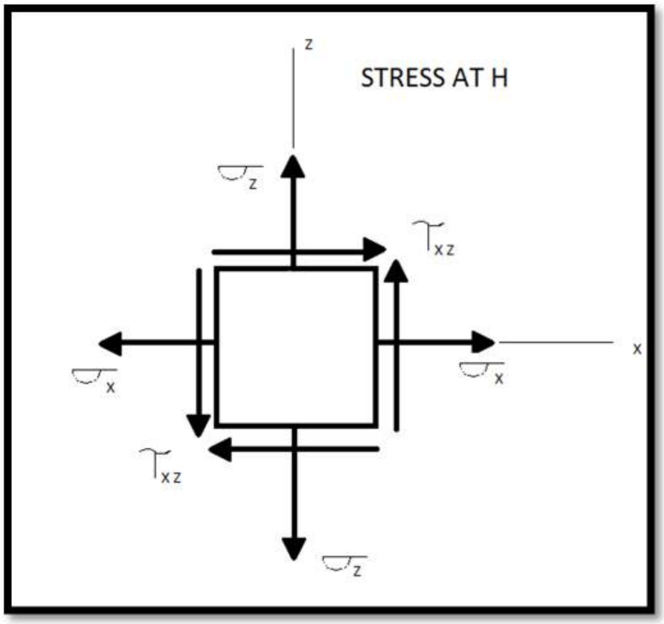


Figure 113. Stress Diagram

1-D Stress Components			
$\sigma = \frac{P}{A}$	$\sigma = -\frac{My}{I}$	$\tau = \frac{VQ}{It}$	$\tau = \frac{Tr}{J}$
$\tau_{\max} = \frac{3V}{2A}$ rectangle	$\tau_{\max} = \frac{4V}{3A}$ solid circle	$\tau_{\max} = \frac{2V}{A}$ thin tube	$q = \frac{\Delta H}{\Delta x} = \frac{VQ}{I}$
Shear stress distribution in a rectangle: $\tau = \frac{3V}{2A}\left[1-\left(\frac{y}{c}\right)^2\right]$ where y is measured from the neutral axis and c is the half-height of the beam ($c = h/2$)			

Figure 114. Governing Equations

Once these stresses were known, Mohr's circle of stresses was drawn so the maximum shearing stress and the maximum stress could be found and compared to the yield strength of steel. These calculations can be seen in detail in Appendix G. To our surprise, we found that using 3/4 inch diameter rod created a maximum stress of 42.46 ksi. This exceeded the yield strength of steel of 36 ksi. This told us that a 3/4 in diameter steel rod was not feasible. Redoing the calculations with a 1 inch diameter steel rod gave us a maximum stress of 12.1 ksi which was acceptable.

6.3.3 Frame Deflection: Columns:

There were two parts of the frame which we considered may deflect. The first part was the columns that extrude up from the bottom of the frame and attach to the latitude plates. The columns of interest are shown in Figure 115 below.

Figure 115. Initial Column Design

We recognized that these columns would have a large moment as they would be supporting the arches weight and the moment they created. We modeled the extruding columns as a cantilevered beam with a moment acting at the free end of the beam. This analysis can be seen in Appendix G. This analysis told us that using 1” X 1” T-slot would create a 1.2 inch deflection at the top of the column inward towards the table. This deflection was not acceptable so a different solution was necessary. We decided that we needed either more 1 x 1 inch T-slot to distribute the weight and moment more, or 2” X 1” inch T-slot for the columns instead. Using 2” X 1” inch T-slot reduced the deflection to 0.16 inches and using four columns on each side instead of only two on each side reduced the deflection to 0.30 inches. It is important to note that this analysis did not take into account the two 45 degree bracings at the bottom of the columns. It also overestimated the weights of each component that adds to the moment.

Each of these facts indicate that the calculated deflection should be more that the actual deflection. Figure 116 shows our final design with the extra columns that should prevent drastic deflection.

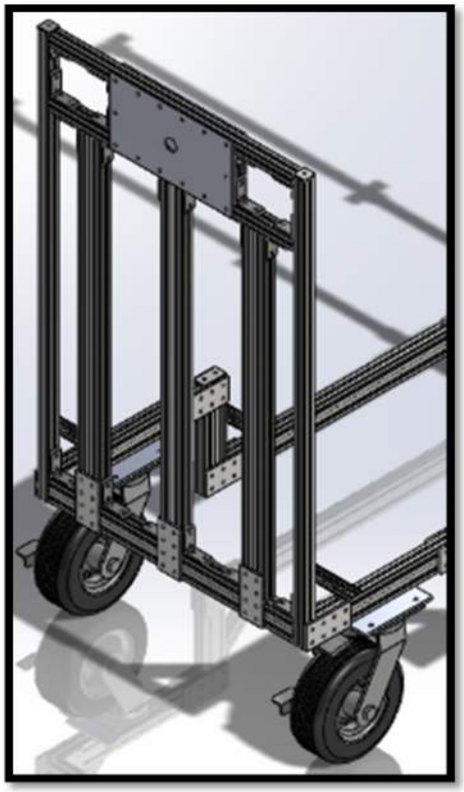


Figure 116. Final Column Design

6.3.4 Frame Deflection: Bottom Beam:

The forces in the bottom beam were determined by creating free body diagrams of each part of the Heliodon. The bottom beam can be seen in Figure 117 and the free body diagram of the bottom beam can be seen in Figure 118.

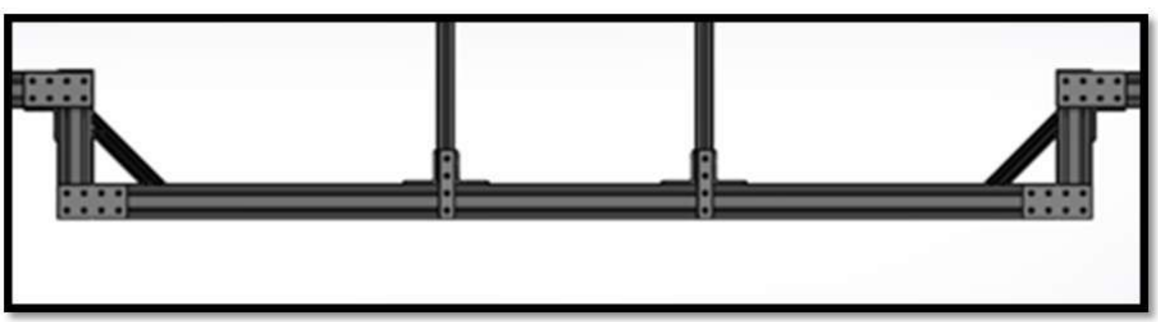


Figure 117. Bottom Beam

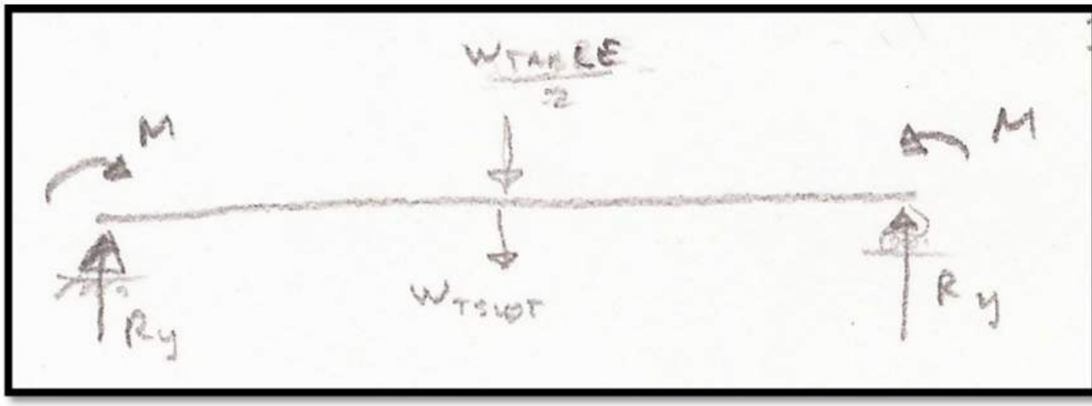


Figure 118. Bottom Beam FBD

The R_y forces were modeled as reaction forces from the supports that bottom beam would be resting on even though the R_y forces are truly from the vertical columns holding the bottom beam up. The full calculation showing how these forces were determined is extensive and can be seen in Appendix G**.** The deflection in the center was found by using the beam deflection equations and the principle of superposition. Figure 119 below shows the two cases that were superimposed on the beam. The first case was used twice, once for each moment, and the second case was used once. Figure 120 shows the governing equations used.

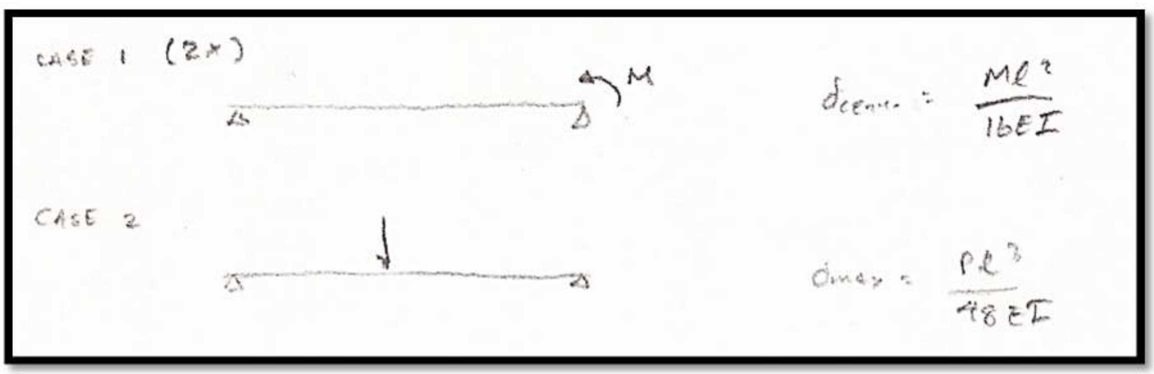


Figure 119. Superposition Cases

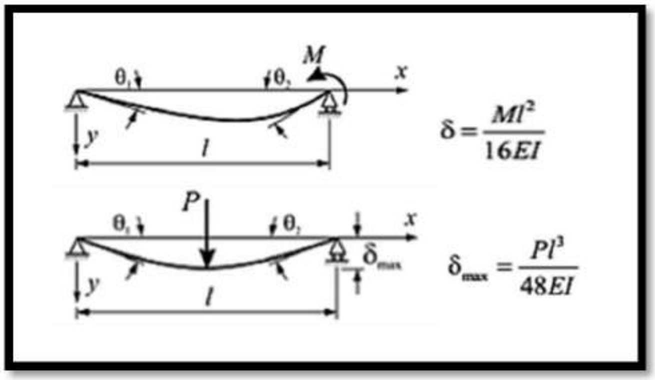


Figure 120. Governing Equations

Using the moment of inertia of 2” X 1” T-slot provided from the T-slot website, the deflection was determined to be only six one hundredths of an inch [7]. This amount of deflection was negligible to our design.

6.3.5 Tipping At Extreme Operating Conditions:

For safety purposes and in the interest of keeping the Heliodon operational, we needed to determine whether the Heliodon would tip over at the extreme modeling conditions. We first determined whether the biggest moment from the arches would occur at the equator on either solstice or on either solstice at the maximum latitude we are modeling. We found that the maximum moment would occur at the latter condition. The weight of the arches at the solstice on the equator acts at a distance equal to half of the length of the slots while the weight of the arches at the solstice at our maximum latitude acts at a distance greater than half the length of the slots. These distance calculations can be seen in Figure 121, Figure 122 and in Appendix G.

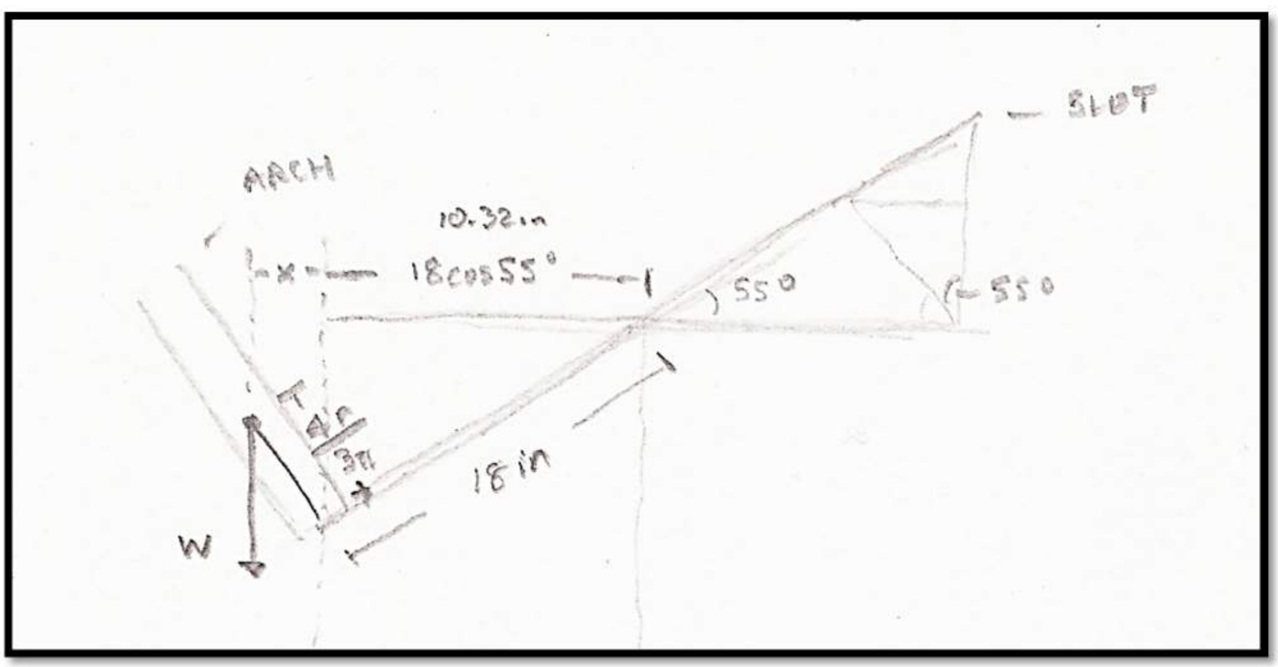


Figure 121. Max Moment Calculation Diagram

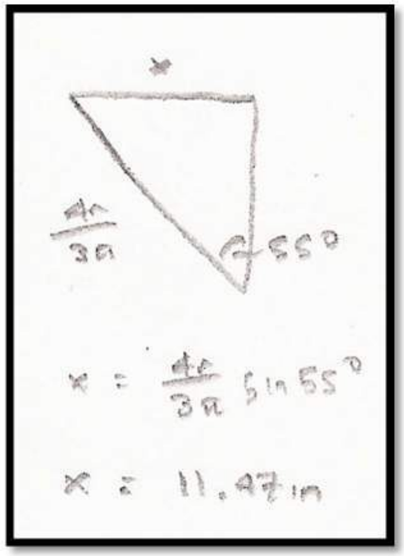


Figure 122. Tipping Calculation Triangle

A free body diagram was constructed with the weight of the arches, carriage, brackets, cables, and motor placed at the maximum distance that the weights would act during operation. Normal forces were drawn at each wheel and the weight of the frame, slots, table, wheels, and rods was lumped in the middle of the Heliodon. This free body diagram can be seen in Figure 123.

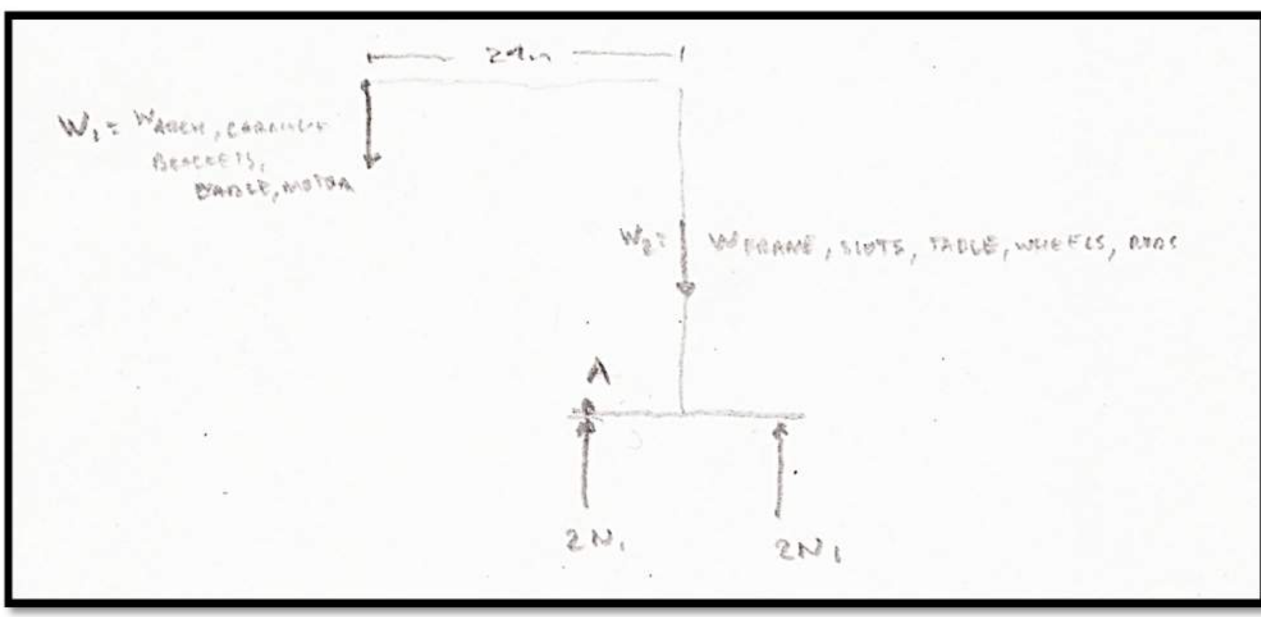


Figure 123. Free Body at Max Tip Condition

Summing the moments about one of the wheels told us whether or not the Heliodon would tip. If the normal force that we solved for was less than zero that would mean that the ground would need to pull down on the Heliodon to prevent tipping. This is impossible when the support is a wheel, and so the Heliodon would tip. If the normal force was greater than zero that would mean that the ground would be pushing up on the Heliodon indicating that it would not tip. The normal force we solved for was greater than zero and so we determined that tipping would not occur.

6.3.6 Tipping Due to Wind During Transportation:

For safety purposes and in the interest of keeping the Heliodon operational, we needed to see what kind of wind force would tip the Heliodon. We determined that the Heliodon was most likely to tip from wind when in transportation mode, with the sides of the tables folded up. A free body diagram was drawn with the weight of the Heliodon acting in the center and the normal forces on the wheels. We decided that the wind force would act at over half the maximum height of the Heliodon, a distance we called 45 inches. This diagram can be seen in Figure 124.

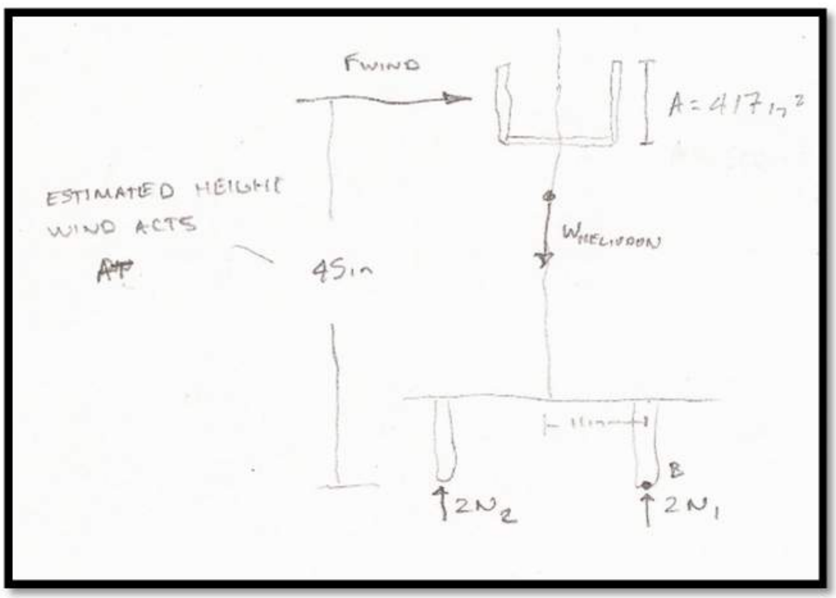


Figure 124. Wind Tipping FBD

We summed the moments about the wheel at B and said that when the Heliodon tipped, the normal force N_2 would be equal to zero. We solved for the greatest value the wind force could be before the Heliodon tipped. We determined that a force of greater than 62.5 lbs. would tip the Heliodon over.

We would like to note that many assumptions were made in this calculation and we are hesitant to say that it is accurate. We do not know the true location that a wind force would act at and we were not able to determine what a reasonable wind force would be. The wind force is determined by the equation,

$$F_{WIND} = \frac{1}{2} C_d \rho_{AIR} V_{AIR}{}^2 A$$

C_d is the drag coefficient, ρ_{AIR} is the density of air, V_{AIR} is the wind velocity and A is the area that is acted upon. The drag coefficient is dependent upon the shape and orientation of what the wind is acting upon, in this case the shape and orientation of the Heliodon. This was not able to be accurately determined or estimated. The area that the wind acts upon was also not able to be accurately determined or estimated. Without these two parameters, we were unable to estimate a reasonable wind force and so we have come to the conclusion to not transport the Heliodon when it is windy.

6.4 Safety Considerations:

This section will examine the safety of the final design for the Heliodon. We will discuss the potential safety hazards and the measures we have taken to eliminate or reduce them. Areas of discussion include the mechanical and electrical systems.

6.4.1 Mechanical Safety:

Although the light carriage moves automatically, it moves slowly enough so that body parts such as hair and fingers will not get caught and dragged under the wheels. Also, because of how closely the carriage passes underneath the brackets, it would be very difficult to build some sort of guard around the wheels.

Our final design utilizes a chain and sprocket to drive two shafts with a single motor. The Heliodon does not currently have a working motor, so no cage or protective barrier is needed around the spooling mechanism. If a motor is implemented in the future, this will create a major pinch point and will need to be covered accordingly. There are also small pinch points on the folding portions of the table and the sliders in the slots. While these can be easily avoided, caution should still be taken.

One of the greatest safety concerns with the Heliodon in its current state is its inability to lock its arches and the latitude slots in place properly. The current method of locking is tightening two hex nuts together and having the friction between them act as the locking mechanism. This is demonstrated in Figure 125. After speaking with Jim Gerhardt, he recommended adding some sort of pegs to allow for locking. This would reduce the resolution of our Heliodon by limiting simulations to very specific latitudes, but it would allow effective locking.

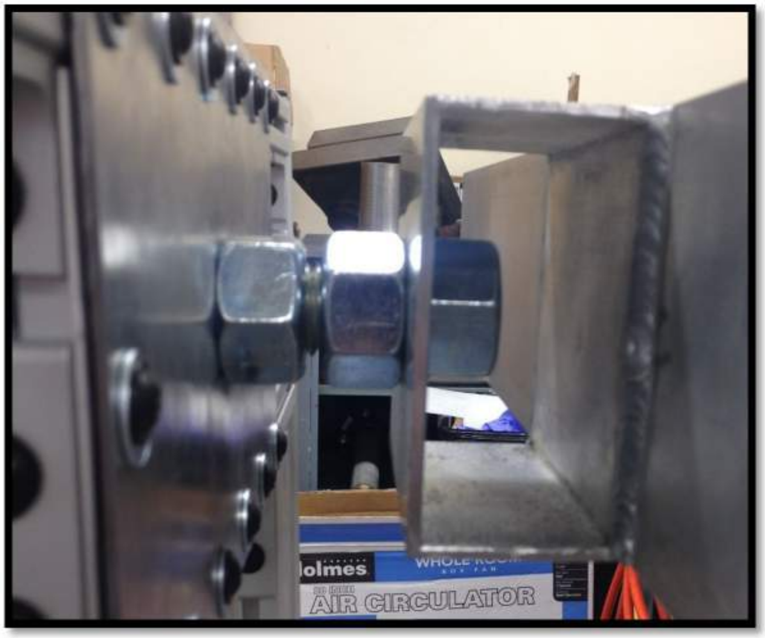


Figure 125. Current Locking Mechanism

To test for tipping, the Heliodon was taken out to the hill beside building 20 on the Cal Poly campus. It was turned horizontally and the wheels were locked. The Heliodon did not tip in this extreme scenario, so any tipping occurring is very unlikely. Figure 126 shows the conducted testing.

Figure 126. Heliodon Horizontal on a Hill Not Tipping

One last concern about the Heliodon was it possibly rolling down a hill out of control. One member of our team pushed the Heliodon up and down a hill and was able to maintain control of the device with ease, despite how large it is. This reassures us that transporting the Heliodon will be of little concern.

6.4.2 Electrical Safety:

The only electrical shock hazards present on the Heliodon are within the light carriage and along the power cord. Shock hazards can be caused by cutting or abrading the power cord as it passes through the brackets or hooks. Wearing away the insulation of the cord could expose energized wires, posing an electrocution hazard. This hazard has been eliminated by ensuring that the power cord only contacts smooth surfaces and no sharp edges.

The light bulb socket inside the light carriage does not have a grounding wire, but the power cord from the cord reel does. If any of the energized wires were to break and contact the light carriage, someone touching the carriage and any other conductive surface would be electrocuted. We solved this shock hazard by connecting the ground wire to the metal body of the light carriage. This prevents the light carriage from being electrified in the event of a broken energized wire. Ben Johnson, electric shop supervisor of Cal Poly, had recommended that we take further safety precautions by using a cable strain relief grip in the light carriage to prevent the power cord from bending, flexing, and tearing. This was also implemented and may be seen in Figure 127.

Figure 127. Strain Relief Grip with Internal Grounding Wire

6.5 Cost Analysis:

Several major changes occurred to our budget over the course of the project. We were given a flexible budget that varied based on whether or not our sponsor liked our design. After the preliminary design review, we came up with a budget of around $2,000 for prototyping and final design.

The largest expense of the project was the T-Slot framing. It cost around $900. The fasteners to connect all the individual pieces of T-Slot made up about two thirds of that $900. After contacting the manufacturer, Futura Industries, we found that they would donate all the T-Slot and fasteners to help the school funded project.

The final cost of the components required to build the Heliodon was $1,631.94. This amount neglected the T-Slot that was donated. A detailed parts list with the costs and the source list can be found in Appendix H.

7. Manufacturing and Assembly

7.1 Manufacturing:

The following sections are an account of the manufacturing of individual components in our Heliodon. All of the components were manufactured by the team members in the Mustang 60 machine shop or the Hangar. The manufacturing of the Heliodon took over 300 hours of combined shop time.

7.1.1 Frame:

The frame is made of T-Slot because it is easy to assemble, non-corrosive, and lightweight. Futura Industries was gracious enough to donate all the T-Slot extrusions and fasteners used for the project. We placed a bulk order that specified the length of each extrusion and how many fasteners were needed to construct the frame. Upon arrival each piece was laid out according to the drawings so that individual sections could be constructed before assembling the final frame. The fasteners to put the T-Slot together consisted of t-nuts, locking plates, and individual fastener plates. Pictures of the T-Slot, the t-nuts, the locking plate, and how the three combine has been provided in Figure 128. Pictures of the different individual fastener plates can be seen in Figure 129.

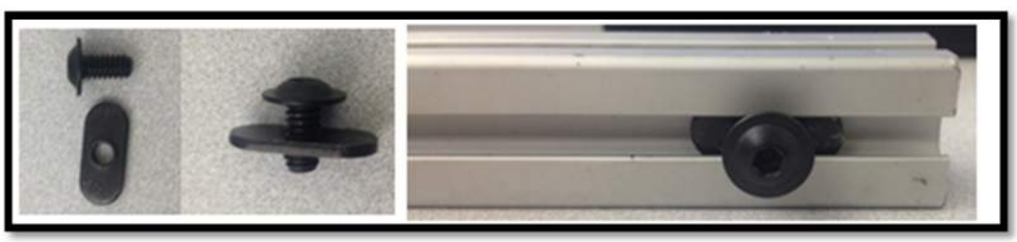


Figure 128. T-Slot Fasteners

Figure 129. T-Slot Connecting Fasteners

The t-nuts were placed into each fastener and the locking plate was lightly screwed on so that each fastener can be inserted by sliding them into the extrusion channels as shown in Figure 130.

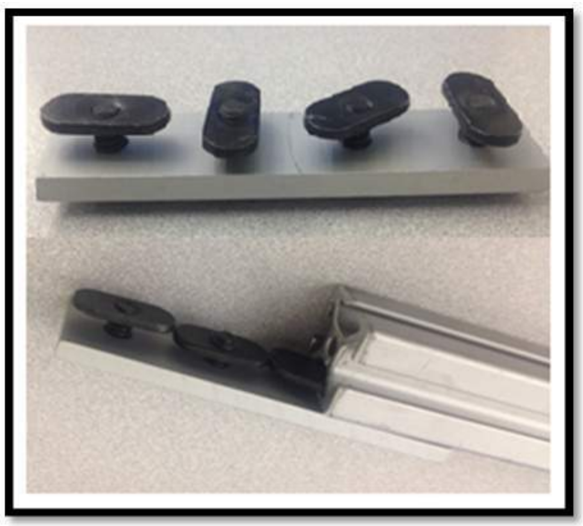


Figure 130. Ideal Fastening Method

Assembling each T-Slot and fasteners with this method made the assembly much simpler. It is more difficult to place the locking plates in the T-Slot channel, place the fastening plate on the T-Slot and then feed the t-nuts through the fastening plate while trying to find the hole in the locking plate within the channel. This method is shown in Figure 131.

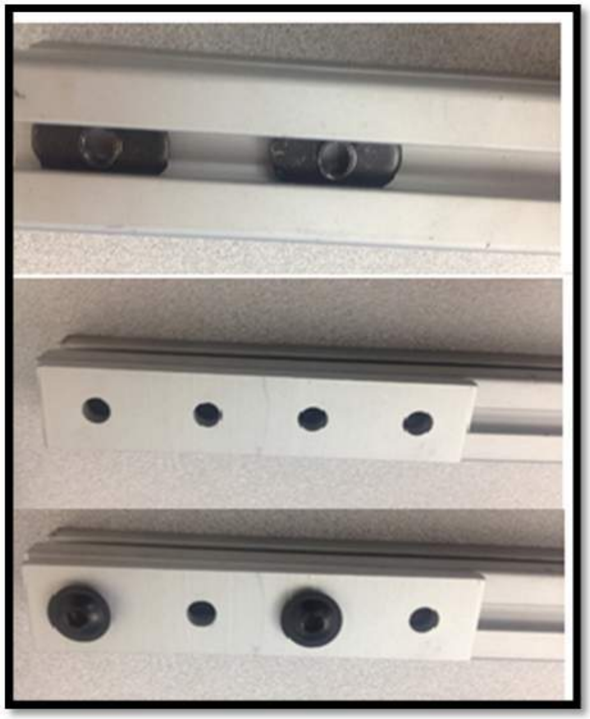


Figure 131. Non Ideal Fastening Method

Due to late changes in the design, some of the T-Slot extrusions needed to be cut down. We first attempted to cut the T-Slot to length with the Chop Saw in the Mustang 60 machine shop. Despite the shop techs advice, we do not recommend using this machine as even though it cut to the desired length, it left the cross section of the T-Slot marred and disfigured. We did a re-cut on the horizontal band saw and this cut the T-Slot to a precise length and left the cross section in good order. A picture of the horizontal band saw in the Hangar is shown in Figure 132.

Figure 132. Horizontal Band Saw Cutting T-Slot

There were only a few pieces that needed cutting. The 1” X 1” T-Slot table supports needed to be lengthened to 36-1/4 inches, so we had to cut down some of our extra T-Slot to this length. We also needed to cut down four 1” X 1” T-Slot to 4 inch lengths for in the latitude plates. An image of Jake (left) and Luke (right) working on the frame in the early stages is shown in Figure 133.

Figure 133. Two Cool Dudes Assembling the Frame

7.1.2 Caster Wheels:

In order to provide mobility to the Heliodon, we purchased four large 8 inch diameter locking casters. The mounting plates that were provided with each caster were too large to interface with the aluminum T-slot. Our solution was to machine a 1/4 inch thick aluminum plate to connect the casters and the T-slot.

Fabrication of these plates took place in the Mustang 60 machine shop. We began with a 1/4 inch thick strip 4” X 24” inch long aluminum stock. We used the vertical band saw to cut the metal down into four 4” X 6” inch rectangular pieces. We did not take into account the fact that with every cut, material is removed from the total length, so not all the pieces turned out to be exactly 6 inches. One of the pieces was measured using calipers and rulers to get proper placements for the holes. A vertical drill press was used to drill six, 1/4 inch diameter holes in the proper locations. One plate was manufactured first and then this was used as a template for the other three plates. Once all the plates were drilled, deburring took place using files and other deburring tools. The completed caster mounting plate is shown in figure 134.

Figure 134. Caster and Wheel Mounting Plate

7.1.3 Table:

Our table was fabricated from a large sheet of maple plywood. Fabrication of the tabletop took place in Mustang 60 and the Hangar. The maple plywood was cut into the three sections using the table saw. In order to achieve a perfect circle, a large compass was constructed using a piece of scrap plywood and the desired final radius of the circular table was marked. Two holes were drilled into the compass; one for a pencil to trace the circle on the plywood and the other for a screw to anchor the compass in the center. Laying the three pieces of maple plywood on the ground, the compass was screwed onto the center of the circle. A circle was traced using the pencil. This process is shown in Figure 135.

Figure 135. Tracing Outline for Table Top

The pieces were cut using the vertical band saw and then finished using the vertical belt sander.

The hinges had to lie on top of the table in order to achieve the folding we required. The hinge outline was traced on the bottom of each piece. Using the table router and a 1/4 inch bit, the hinge holes were cut. The hinges had two separate levels that had to be accounted for. The first was 1/16 inch and the other was 3/16 inch. The bit on the router was raised to accommodate the deeper cut. The router was not able to create a perfect channel for the hinges to sit in so we planned on using wood glue to fill any gaps after the hinges were applied. The hinge screws would go all the way through the table so to prevent any injuries, small wood blocks were cut and glued underneath where the hinges screws would have otherwise protruded.

To achieve the darkest shadows, we decided to use a white table top. Once all the cutting on the three pieces was done, a fine sanding was performed starting at 60 grit and repeating until 400 grit. After all of the sanding, the three pieces were painted. Once dry, a second light sand job was performed to ensure the paint coat was evenly distributed. After this, another layer of paint was applied. To protect the table from the elements, a spray on sealant was used on the bottom of the table. This was also sanded for even distribution and a second coat was applied.

Once dry, the pieces were flipped and the hinges were screwed into place. Wood filler was applied to any excess cuts in the table. An intermediate picture of the table and a location where filler was applied can be seen in Figure 136.

Figure 136. Table Top Mid-Finishing

After the wood filler was dry, the table-top was sanded, painted twice, and a final layer of the sealant was applied again.

The center part of the table dimensions is 26” X 48”. Using this information, the table was centered on the frame by using a table measure and measuring from each corner of the frame. Once centered, a pencil was used to mark where the fasteners holes should go. The fasteners used were the standard T-Slot bolts. A countersunk pilot hole was required to prevent the bolt from going all the way through the tabletop. To ensure that the pilot holes drilled did not go through the tabletop, we marked the drill bits that were used to drill the pilot holes with blue painters tape. This marking was made from the tip of the drill bit to a length that was shorter that the thickness of the table. Once this marking was reached, the hole was not drilled any deeper. An image of this drill marking method may be seen in Figure 137.

Figure 137. Hole-Depth Marking Method

The tabletop was flipped upside down and this process was repeated for the twelve marked holes to secure the table to the frame. Once these hole were complete, the table was turned right side up and placed back on the frame. The bolts were inserted and tightened using a standard 4 mm Allan wrench.

7.1.4 Latitude Plates and Angle Markers:

To create the Latitude Plates, we used 1/8 thick, 4 inch stock stainless steel plate. The latitude plates were created in the Mustang 60 shop. The chop saw was used to cut down the stock stainless steel to four, 6” X 4” pieces. Each plate was wire brushed to provide a clean finish.

The plates use standard T-Slot bolts to attach to the frame. Since these plates were to be load bearing, it was decided that there needed to be many connection points to the frame. All the 1/4 inch holes for the T-Slot bolts need to be drilled into the steel plate in locations that were as precise as possible so that all the fasteners could fit in the T-Slot channel. To achieve this precision we used the Bridgeport Mill. The vise on the mill was squared using the dial gage and rubber mallet. The plate was placed in the mill and zeroed to the top left corner. Parallel bars and wood were placed under the plate in order to increase accuracy by preventing the warping of the metal. A picture of the latitude plates in the vise can be seen in Figure 138.

Figure 138. Milling Spool Mounting Plate

Each hole was aligned using the digital readout. The 1/4 inch holes were drilled first using a two flute end mill. The center 1 inch hole was drilled progressively, starting with a 1/8 inch and increasing drill size by 1/8 inch until 1 inch was reached. We repeated this process for the other three plates. All four of the plates were deburred using files and the circular deburring tool.

To make the latitude angle marker, we used the laser cutter in Mustang 60 machine shop. We used AutoCAD to make the two different circular angle markers. The laser cutter uses an RGB color scheme to distinguish between full cuts and rasters (etchings). From previous experience, it was determined that the majority of the circle would be laser cut and not rastered to save time. Three colors were chosen, red for the thru cut, yellow for the shallow cut, and green for the rastering. Both circles would be cut at the same time to give accuracy and to save time. An image of one of these drawings is shown in Figure 139.

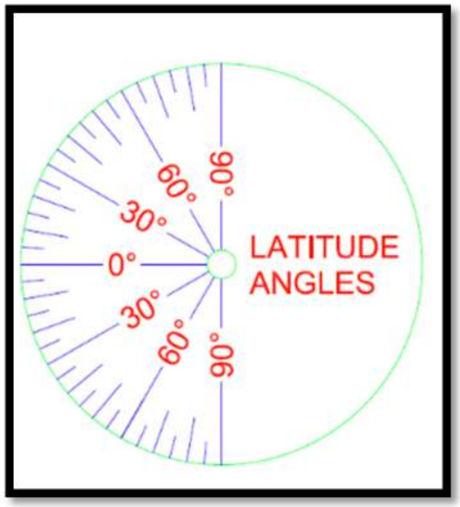


Figure 139. AutoCAD Drawing Used in Laser Cutter

The acrylic came with a white protective sheet which was left on during the manufacturing. Leaving the white sheet on prevented the acrylic from acquiring unwanted burn marks during the cutting. The table saw was used to cut down the stock acrylic to a piece that would fit in the bed of the laser cutter. This final sheet was roughly 17" by 31". The cut piece was centered in the laser cutter and the height of the laser was checked using the height gage. The through cut used a power rating of 100 with a speed rating of 6 while the shallow cut used a power rating of 50 and a speed rating of 7. Three passes had to be used to cut all the way through the material. The final result can be seen in Figure 140.

Figure 140. Final Latitude Angle Marker

7.1.5 Latitude Slots:

Our initial slot design was made of steel and utilized various pieces of angle and plate steel. Many pieces of angle steel needed to be cut down to uneven "L" dimensions, requiring cutting along the length of the steel. These required cuts can be seen in Figure 141.

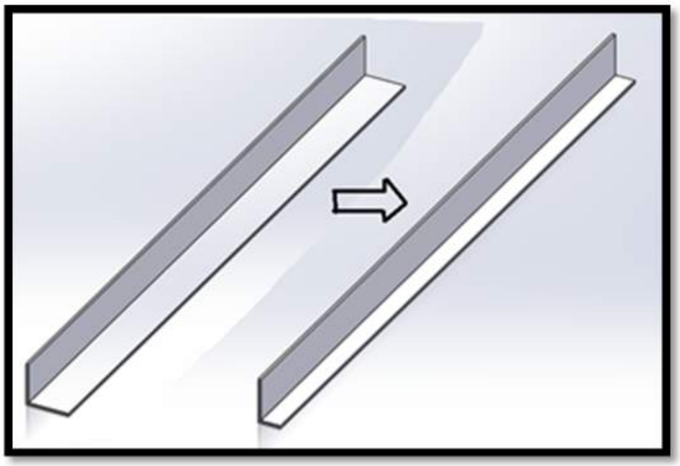


Figure 141. Needed Steel Angle Cut with Initial Slot Design

After purchasing the steel from B&B Steel, our group tried many methods to cut down the steel angle. First, our team tried to cut it on the vertical band saw. This seemed to work well initially, until we got to the end of the cut and realized that the guide was loose and we had slowly drifted over the length of the cut so that the cut was no longer straight. Another attempt at cutting the steel ended up breaking the teeth of the band saw, rendering the machine useless.

Next, we tried using the mill to make these cuts. It was difficult to do so because the length of the slots caused a lot of vibration of the part. The length also required us to remove the material from the vice and move it over multiple times which led to a non-uniform cut. Cutting the steel produced so much heat that several bottles of coolant were required to finish just a single piece. It ended up damaging several end mills as well. The heat required us to cut slowly, taking about three hours to machine a single piece. These attempts can be seen in Figure 142.

Figure 142. Attempting to Mill Steel Angle

Lastly, our team tried oxyacetylene cutting. This was by far the fastest and easiest method of cutting, but it also yield the roughest cuts. The finished product was so rough that it was unusable, even after grinding down the cuts for a better finish.

After all of these issues working with the steel, Greg found out that B&B Steel also supplied specialty aluminum parts, including rectangular aluminum pipe. This was perfect for what we wanted our slots to be, so our team scrapped the steel angle and purchased 1/8" X 4" X 2" rectangular aluminum tubing, as seen in Figure 143.

Figure 143. Rectangular Aluminum Tubing

The first step in creating the slots was to cut them to length according to the slot length calculations in Appendix G. This was done using the horizontal band saw in the Hangar. After cutting it to length it was placed on the mill to cut the front slot. We had to use two vices because of the length of the piece and we had to square both the vices because of the length of our cut. After squaring the two vises, we used the edge finder to zero the mill on one of the corners of the tubing. We then located the center of the edge finder and set the digital readout to zero. After going in the correct X distance, an initial pass was made with a 1/4 inch end mill. This was done to ensure the tool wasn't damaged by removing too much material. This end mill was used to complete the initial pass of the front slot. This first pass can be seen in Figure 144.

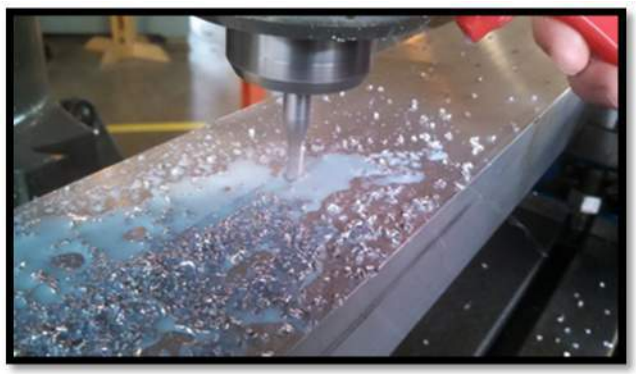


Figure 144. First Pass While Milling the Front Slot in the Latitude Slots

After making this initial pass a 1/2 inch end mill was used to make the final cuts of the front slots. The initial pass with the smaller end mill made this cut very easy with the auto feed engaged.

Next, the front holes were made in the slots on the mill using a chuck and a 1/4 inch drill bit. After zeroing the mill on the corner of the slots, the Y position was adjusted and locked. After this, we moved into the correct X positions for each of the seven required holes.

Lastly, the top slot had to be made. The slot was repositioned in the vise as shown in Figure 145. The mill was zeroed and, using a 1/4 inch end mill, the slot was machined in the center of the top of the slot. This completed the machining required for the latitude slot main body.

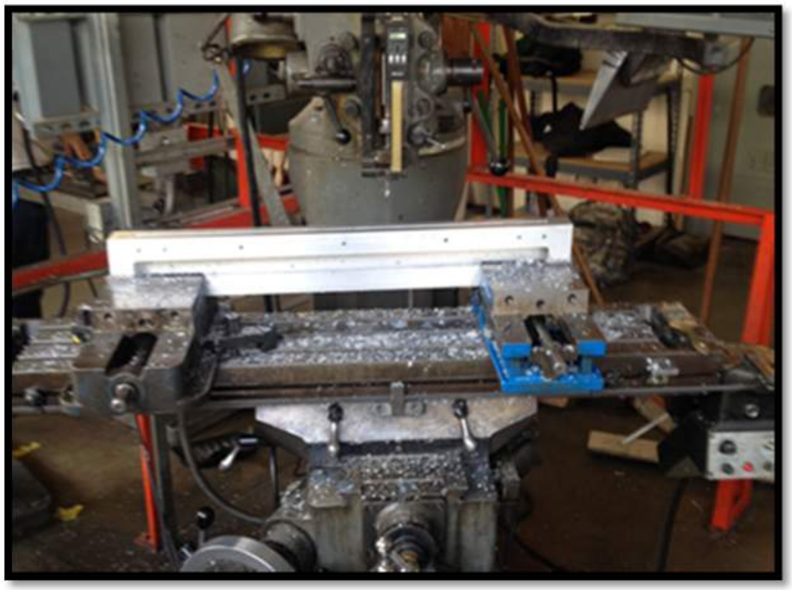


Figure 145. Milling the Top Slot in the Latitude Plates

Each slot required a back piece to connect to the frame. Each back piece was made of the same rectangular aluminum tubing as the slot itself. The length was achieved using the horizontal band-saw and then the piece was deburred. A one inch hole was drilled in the center of the back of the connecter. We used the drill press to drill an initial 1/4 inch hole and then we increased the drill bit size by 1/4 inch intervals until the 1 inch hole was achieved. This back connector was welded to the main slot body to join the two. The weld locations are demonstrated in Figure 146.

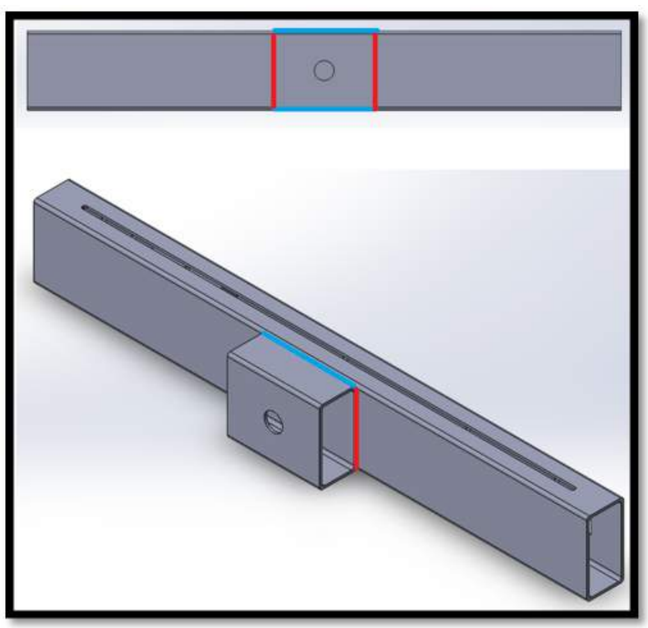


Figure 146. Slot Weld Location

One latitude slot has welds in the locations illustrated by the blue lines (top and bottom) and the other has welds in the locations illustrated by the red lines (sides). The first slot was welded horizontally on the top and bottom of the latitude slots. These welds deformed the aluminum by causing the top slot of the latitude plates to pinch in and become thinner. After seeing this result, he decided to weld the next slot vertically on the sides. This weld did not deform the top slot, but we later discovered that it deformed the inner channel where the slider moves. The weld made the center section of the inner channel thinner and created some difficulty in moving the sliders within the tubing. The final welds may be seen in Figure 147.

Figure 147. Final Slot Welds

7.1.6 Sliders:

The sliders were made of ultra-high molecular weight polyethylene (UHMW). It was ordered in a single length with a 2” X 4” cross section. It was first cut on the horizontal band saw in the Hangar into two four inch long pieces. One quarter of an inch was then milled off the front and side with a half inch end mill using the mini-mill in Mustang 60 so that they could fit inside of the latitude slots.

After the sliders were completely cut to length, a 31/32 inch hole was cut in the center of them to accommodate the threaded shaft that connects them to the arch assembly. This was done using the digital readout on a mill and a mill- compatible drill chuck.

After this hole was complete, the sliders were inserted into the slots. Marks were made on the top and side of the sliders where it lined up with the front holes and top slot on the latitude slots. After these marks were made, the sliders were placed back in the vise on the mill and a 3/16 inch it was used to drill about one half inch into the material. This work can be seen in Figure 148.

Figure 148. Drilling Front and Top Holes into UHMW Slider

To get the size of the bore in the back of the slider for the hex nut to rest in, the inch threaded shaft was threaded into the slider as shown in Figure 149. It is important to note that using a vise to clamp the shaft, as shown in the figure, ruins the threads of the rod and renders the clamped portion unusable.

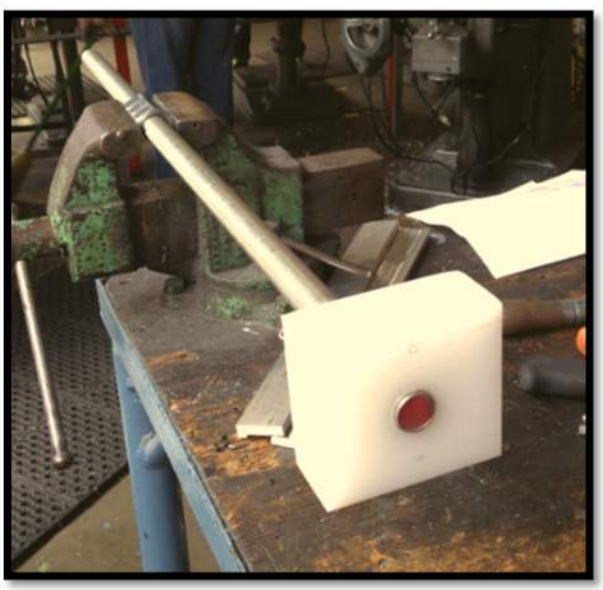


Figure 149. Threading Rod into UHMW Slider

After this was done, a hex nut was threaded onto the rod and its outline was traced on the slider. It was then placed on the mill where the outline was milled out using a 1/2 inch end mill. The bore was milled to be the exact depth of the nut, which was approximately 0.85 inches.

7.1.7 Brackets

The different brackets were made from welded steel. The 0 and 180 degree brackets, the 1/4 inch thick brackets, the spool bracket, and the pulley bracket were all made from 2 inch wide, 1/4 inch thick steel. The top and side pieces of each 1/4 inch thick bracket were cut to length on the chop saw and then faced on the mill using another vise acting like a part stop to ensure that all lengths were the same. This process can be seen in Figure 150.

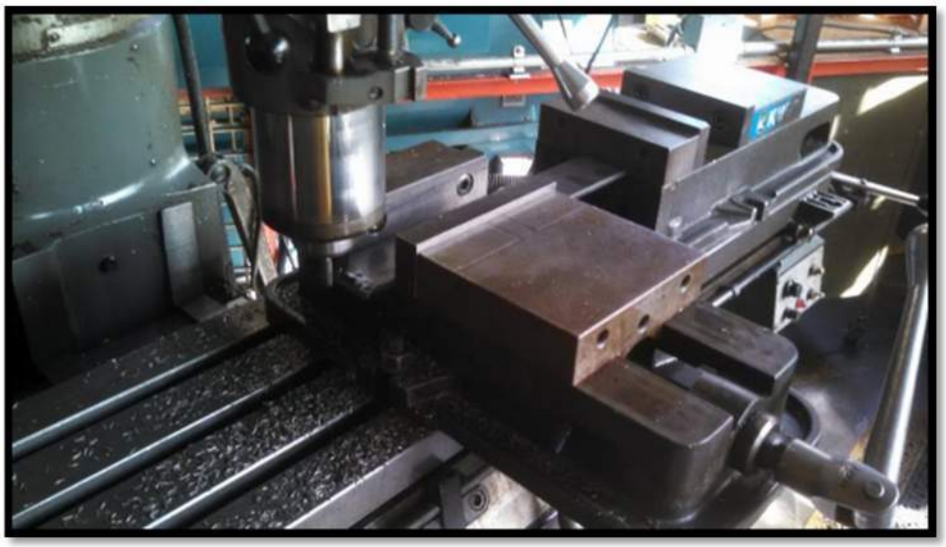


Figure 150. Facing Bracket Tops to Length

After all bracket components were faced to length the rivet holes were drilled. Two 1/8 inch holes were drilled in the 1/4 inch thick bracket side plates, while two 3/16 inch holes were drilled in the 1/8 inch brackets to accommodate the different rivets used.

Once the pieces were faced down and the rivet holes were drilled, they were run through a wire wheel to remove any contamination before welding. We decided to TIG weld the steel together and the welding was performed in Mustang 60 and in the Hangar. Before welding the final pieces, practice brackets were welded with scrap steel provided by the shops. The practice bracket welds helped us make sure that our final welds would look nice.

Once we determined that additional brackets would be needed to house the drive cable hooks, we decided to use 1/8 inch thick, 4 inch wide steel for the addition. These new brackets were cut to length and welded in the same fashion as the thicker brackets.

After all the brackets were welded, four 5/16 inch holes were drilled in the tops of nine of the brackets to allow placement of the cable drive hooks. The brackets were secured on the manual drill press to complete this action.

Two of the brackets were selected to be the 180 degree brackets. These brackets are the same as the others, just with one inch holes drilled in the center. A 1 inch hole-saw was used on the manual drill press in the Hangar to accomplish this.

To make the pulley mounting plate, the two pulleys being used were placed on the bracket and holes were drilled with a hand drill corresponding to the mounting holes on the pulleys.

After all of the brackets were fully made, black Rust-Oleum spray paint was used to finish them. An example of a finished bracket can be seen in Figure 151.

Figure 151. Finished Bracket on Arch

Lastly, the spool bracket was made by lining up the rivet holes on the spool plate with the bracket. Once they were both aligned to our liking, we went through and drilled 1/8 inch holes in line, riveting the holes as we went.

7.1.8 Carriage:

The carriage's main body was the first part of the carriage that was manufactured. It was found in the scrap storage container in the back of Mustang 60. It was cut to 4 inches in length in Mustang 60 on the horizontal band saw. After this, two 1/4 inch holes were drilled in the sides of the carriage body. These holes were then tapped to allow the wheel shafts to feed into the carriage.

Six more holes were drilled in the carriage main body: two on top, two on the bottom, and two in the side. The two on top allow the top plate to be screwed on to the main body. The two on the bottom allow the bottom plate to be screwed on. The two in the side allow two set screws to secure the socket inside of the carriage body. All of these holes were tapped with a #6-32 tap.

The top and bottom plates of the carriage are very similar. We used 1/4 inch thick aluminum to cut 3” X 3” plates. The top plate was secured in a vise and a hole was drilled in the center starting with a 1/2 inch bit, stepping up to a 1-1/32 inch bit. This was to accommodate the cable strain relief grip that sits in the hole. The bottom plate had a 1-1/4 inch hole drilled in its center to accommodate the end of the light socket. Both of these plates had two holes drilled in their sides to become compatible with the screw holes in the carriage body. These are the same screw holes that are mentioned in the previous section.

The cable grabbers were cut from a quarter inch aluminum shaft. They were cut to about 3 inches long using the horizontal band saw in the Hangar. They were then secured in a vise about an inch from the end and struck with a rubber mallet until they were bent to an approximate 20 degree angle. The actual numerical value of the angle was not important, but instead, the angle needed to be attained that would allow the grabbers to interact with the drive cable hooks properly. The grabbers were then secured again and bent back vertically about an inch from that bend. The initial end of the cable grabbers were then taken on the wheel grinder and ground down flat so that they could sit flush against the carriage body. Two holes were drilled and tapped in this bottom section to attach it to the carriage body and a hole was drilled in the top to allow the Kevlar thread to be fed through. These cable grabbers can be seen in Figure 152.

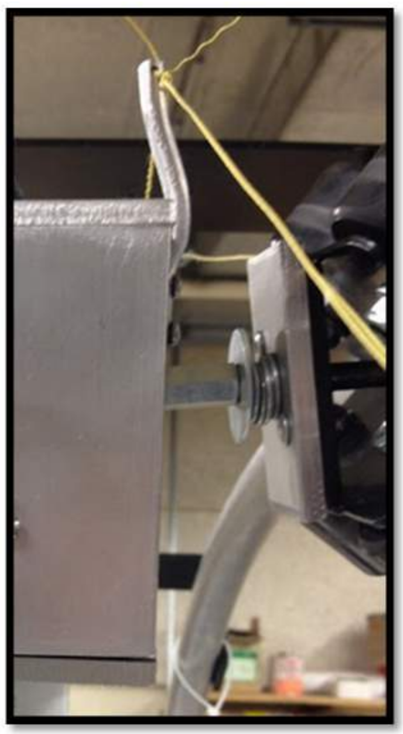


Figure 152. Cable Grabbers

For the spring-loaded shafts, we had to manufacture the wheel mount plates, the spring, and the threaded shaft connecting them to the main body.

The wheel mount plates were cut from 1/4 inch aluminum to mirror the dimensions of the plates on the track dolly swivel wheels. A single 1/4 inch hole was drilled in the center to allow the socket head cap screw to feed in, as well as two 1/8 inch holes to allow the plates to be riveted to the wheels.

After the mounting plate was riveted on, the screw was fed though and the amount of free space was measured. We took a spring purchased from Ace Hardware and used wire cutters to cut it to this appropriate unstretched length. We then pressed the cut end against a grinding wheel to give it a flat surface to sit on. Lastly, we used a hacksaw to cut a 1/4 inch threaded shaft about an inch and then ground down the ends to allow it to be threaded into the carriage hole. The entire spring loaded shaft was then assembled as shown in Figure 153.

Figure 153. Spring Loaded Shaft

7.1.9 Spool Mounting Plate:

The spool mounting plate was made from a 12” X 12” X 3/16” inch thick plate of aluminum. A picture of this plate is shown in Figure 154.

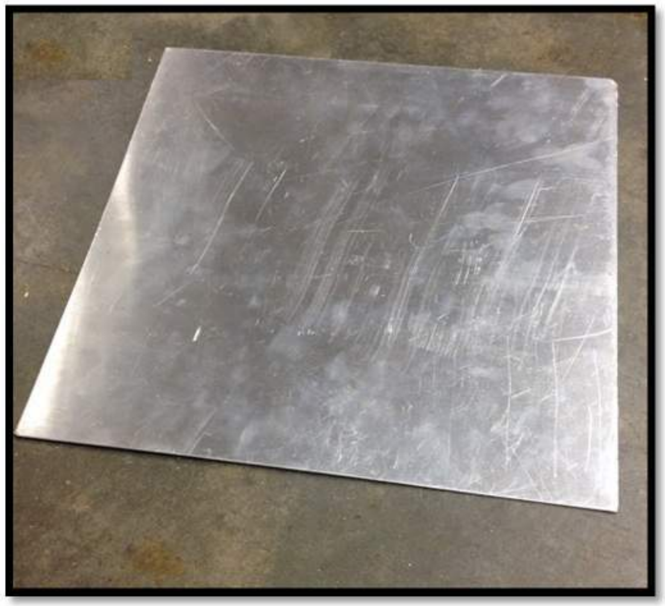


Figure 154. Aluminum Plate

The entire plate was manufactured on the mill in the Mustang 60 machine shop. Due to its size, the piece could not fit in the vise and be zeroed on the mill. This made the manufacturing process extremely difficult. To solve this clamping issue, we used scrap lengths of 2” X 4” wood blocks to support the plate on the mill’s worktable. We clamped the aluminum plate to the wood and the worktable with toe-clamps. The most difficult part of the manufacture was the process of squaring the aluminum plate to the worktable. This was accomplished after a few hours of meticulous adjustment. Once the plate was square, an edge-finder was used to zero a corner of the plate. Due to the plate’s size, only one side of the plate could be manufactured at a time. A 1/2 inch end mill was used to cut the 1” X 2” inch portions (that allows for the plates meshing with the spool bracket) out of the plate. The same end mill drilled the 1/2 inch diameter hole for the power cable to run through. A 1/8 inch drill bit was used to drill the rivet holes in the plate. Once all of these cuts were made, the toe-clamps were loosened, the plate was flipped over and the part was re-squared and re-zeroed. After another tedious hour, the remaining cuts were ready to be made. Multiple passes with the 1/2 inch end mill was used to make the 3/4 inch wide 6 inch long slot for the sprockets and chain to sit in.

7.1.10 Spooling mechanism:

The order of part manufacture for the spool was a big issue. We had been getting conflicting advice from valid sources and we ended up blindly following one source’s advice. If we were to do it again, we would do it differently.

The bearings on the spooling mechanism were made from UHMW Polyethylene. They were cut the appropriate size using the horizontal band-saw and any flaky pieces that remained were ground off using the wood belt sander. To precisely make the bearings the same height, we placed them on the Bridgeport mill in the Hangar and faced the sides. Using the mill, a 1 inch diameter hole was drilled in two of the bearings, and a 1/2 inch diameter hole was drilled into the other two. To ensure that the bearings slid smoothly on their respective shafts, we used the rotary sander in the Mustang 60 machine shop to slightly enlarge the previously drilled holes. Holes for the screws used to fasten the bearings to the spool mounting plate were drilled in the appropriate sides of each bearing with a cordless power drill,

The 3/8 inch diameter, 16 threads per inch shaft, was cut to length by clamping the shaft in a vise and using a hand saw to cut the desired portion. We made sure that the piece that were planned on using was not clamped in the vise, as this would have ruined the threads.

The 1 inch and the 1/2 inch outer diameter shafts were cut to length on the vertical band-saw in the Hangar. They were then placed on the grinding wheel to face flat and to taper the outer edges. The 1 inch shaft needed holes to connect the Kevlar drive cables to the shaft. We marked the location of the holes with sharpie, and before we could drill the holes, we had to use a hole-punch to flatten the drill surface. Without the hole-punch, the drill bit used to drill the holes would slip along the arch of the shaft and the bit would break. Once the punch was used to flatten the drill surface, these holes were drilled using a 3/32 inch drill bit on a drill press.

The wire guides were made out of half inch thick UHMW. First, four 1” X 2” sections were cut on the horizontal band saw. After this they were placed on the mill and were zeroed to their top right corners. Their bottom “leg” was machined with a half inch end mill. This was difficult because the legs on the guides were so thin that the force of the end mill pressing against them caused them to deflect before actually removing material. This required some finishing on the sander after the milling process was complete.

After the legs were milled out, a hole was drilled in the center of each guide. This was done on the mill as well using a chuck and a 5/16 inch fractional drill bit. This size bit was used to accommodate the 3/8-16 lead screw they would be sliding on. A 3/8-16 TPI tap was used to thread the holes.

Once that hole was made and threaded, the guides were placed on the drill press and given 1/8 inch holes in their sides to allow the Kevlar thread to travel through.

The guides were actually quite difficult to move along the lead screw as it rotated. We wanted motion with little resistance so it was recommended to us to connect the lead screw to a drill to allow us to linearly move the wire guides on the screw. We ran the drill forward and in reverse so that the wire guides moved back on forth on the threads. We hoped that this would wear the internal threads in the wire guides and produce low resistance spinning. After hundreds of runs, little progress was made, so instead we ran the 3/8-16 TPI tap through the holes again. This ended up doing a better job of lowering the spinning resistance.

The T-Slot channel that prevented the rotation of the wire guides was cut to length on the horizontal band-saw. Once its position on the spool mounting plate was finalized, holes were drilled in the plate so that the T-Slot fasteners could lock the T-Slot to the plate.

We forgot to order the piece that allows for easy adjustment of chain length, so to adjust the length we had to place the chain in a vise and use a punch and hammer to try and remove individual pegs. It is advised that in future designs, this device is purchased. The device that would mesh with our chain is the ServoCity chain breaker. This device is shown in Figure 155.

Figure 155. ServoCity Chain Breaker

Once the desired pegs were removed, the pieces indicated by Figure 156 were applied to fix the chain at the final length.

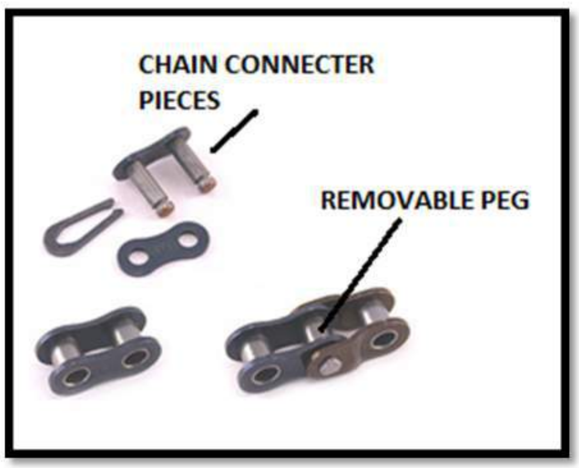


Figure 156. Chain with Removed Links

7.1.11 Power Cable Spool:

The HDX cord reel has a ratcheting gear mechanism that prevents the retraction of the cord once the cord is pulled out of the reel. For our purposes, the reel needed to retract the cord at all times so that the cord could move forward and backward along the arches with the light carriage effectively. Our solution was to open the cord reel and break the ratcheting gear mechanism to force the reel to retract the cord at all times. We also had to cut off the outlet at the end of the reel cable and use the remaining wires to splice it with the light bulb socket wires in order to power the light bulb without the use of bulky socket and plug connections.

7.2 Final Assembly:

The majority of assembling parts together was fairly straightforward. Frame assembly was not complicated, and assembling the caster wheels to the frame was simple as well. After manufacturing, the sliders slid into the latitude slots as planned. All of the sections of the threaded rods fit in their necessary holes and were easily clamped in place using crescent wrenches and 1 inch nuts.

There were four parts of the assembly that were particularly challenging. They were the arch assembly, the carriage assembly, the spooling mechanism assembly, and the drive cable hookup. These assembly methods are described in the sections in the

7.2.1 Arch Assembly

Assembling the arches together was one of the hardest parts of the project. The arches had a natural tendency to bow out due to the bending process. Since the two arches had to be perfectly centered with each other a pseudo-brace was developed before trying to attach the brackets. To keep the arches our specified distance apart and perfectly parallel, five wooden braces were constructed. These braces are as shown in Figure 157.

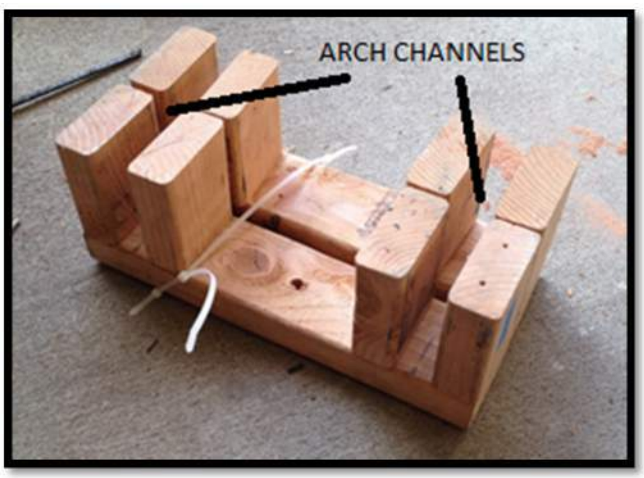


Figure 157. Braces for Holding Arches in Place

We made a 2-1/2 foot wide protractor in AutoCAD and printed it on the plotter in 13-107. This protractor was essentially a drawing of a 300 degree circle with markings at the specified angles that the brackets were to be attached. Figure 158 provides a representation of the protractor.

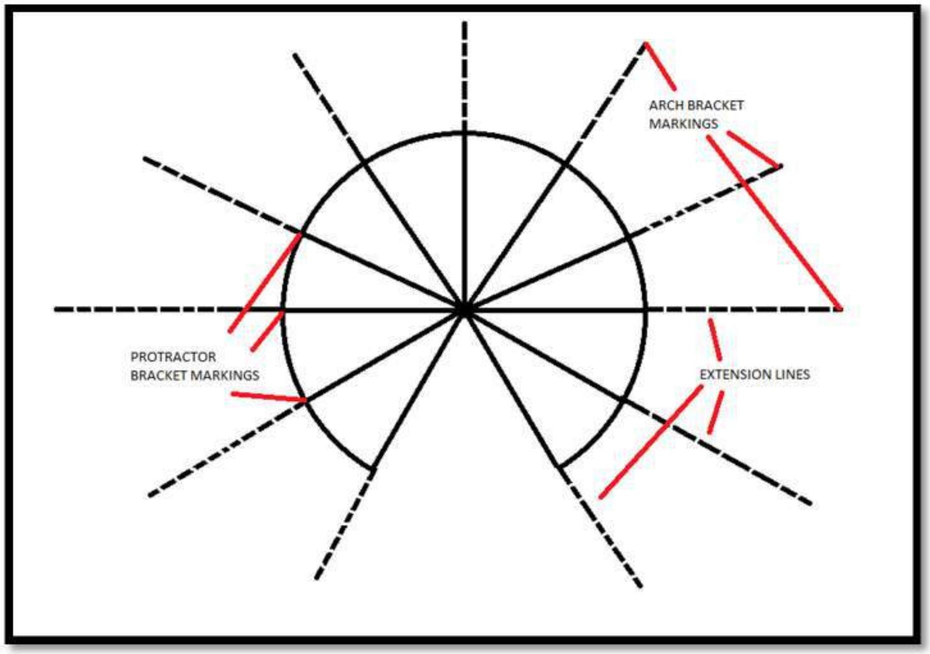


Figure 158. AutoCAD Protractor Printed on Plotter

We laid the protractor on the floor of the bay in Bonderson and set the braces up around the protractor. We placed the arches in the braces so that they were "stacked" above the protractor. To ensure the arches were concentric with the protractor, we made sure each point on the arch was equidistant from the center of the protractor. We did this using a tape measure. Once concentricity was attained, we used yardsticks to extend the lines of the protractor in order to line up the bracket markings on the protractor with the desired bracket locations on the arches. Once these locations were found we marked the locations on the arches.

Once all the markings of where the arches should go on the arches were made, they needed to remain in the braces each of the brackets was matched with a location on the arches. After we matched specific brackets to specific locations, we thought it'd be a good idea to label each bracket to indicate where it had been on the arches. We used blue painter's tape and pencil markings to keep track of the pieces. The 0 degree and 180 degree brackets were the most important because they needed to remain level after the fastening for the Heliodon to be accurate. We laid one side plate of each bracket flush with its respective arch location and we used a small nail and rubber mallet to line up the holes in the side plate of the bracket to where the holes should be located on one of the arches. Once all the hole locations were marked, this arch was brought to the drill press and a 1/8 inch bit was used to drill the necessary holes. The 0 degree and 180 degree brackets were then riveted into the one arch. The second arch was lined up to the unfastened side plates of the brackets and C-Clamps were used to secure the arch to the unfastened side plates. This guaranteed a tight fit between the arches and the unfastened side plates and allowed the rivets to fasten the two securely. This process was repeated with all of the other brackets. The only difference in this process was that the 1/8 inch thick brackets required a 3/16 hole instead of a 1/8 inch hole. We used an electric drill for these holes because it was easier than bringing the two arches in on the drill press.

7.2.2 Carriage Assembly:

The carriage was assembled in the Hangar and the Mustang 60 machine shop. The first part of the carriage that was assemble was the spring loaded shafts. The socket head cap screw was put through the small washer, then through the slot in the back of the track dolly swivel wheels, and then through the wheel mount plate. After this, the spring was placed over the shoulder of the cap screw with the ungrounded end in contact with the wheel mount plate. The large washer was placed over the screw and the shaft coupler was threaded on to slightly compress the spring. The threaded shaft was then threaded into the other end of the shaft coupler. This process was repeated for the other spring loaded shaft.

Before placing the spring loaded shafts on the carriage, the cable grabbers need to be attached. This was done by screwing the two holes on each cable grabber. These holes corresponded to two holes on the carriage body so that the two could be attached with a screw.

After the carriage grabbers were attached, spring loaded shafts were connected to the body of the carriage. This was done with threaded shafts and shaft couplers. The connection was made so that the shaft couplers were flush against the carriage body. Once this was ensured, nuts were placed on the threaded shaft inside the light carriage and tightened to complete the fastening of the wheels to the carriage body.

The next step was to place the light socket inside of the light carriage body. We did this by placing the end of it through the hole in the carriage bottom plate. Once the socket was in the hole, the carriage bottom plate was screwed onto the body. Next, we used the two small holes on the carriage body to tighten two set screws to hold and lock the socket in place inside of the carriage body. After this was done, the carriage top plate was placed on the top of the carriage body and was secured down with two screws.

7.2.3 Spooling Mechanism Assembly:

Assembling the spooling mechanism components together was tricky. We continually ran into issues with chain length, sprocket spacing, shaft alignment, and bearing friction. The mechanism was assembled and disassembled of the mechanism.

To make sure the sprockets fit on each shaft, we had to sand down the outside diameter of each shaft. This was done by hand at first, but after realizing how much time this would take, we put each shaft on a lathe and held sandpaper against the shaft as it spun. This was done until each sprocket and its pair bore clamping hub fit tightly on each shaft. We removed the sprockets and clamping hubs before continuing.

Another thing we needed to ensure was that the threaded rod and the 1/2 inch shaft that was sleeved over were concentric. To do this, we wrapped painter’s tape around the threaded shaft until its outer diameter could be press fit to the 1/2 inch shaft’s inner diameter. This can be seen in Figure 159.

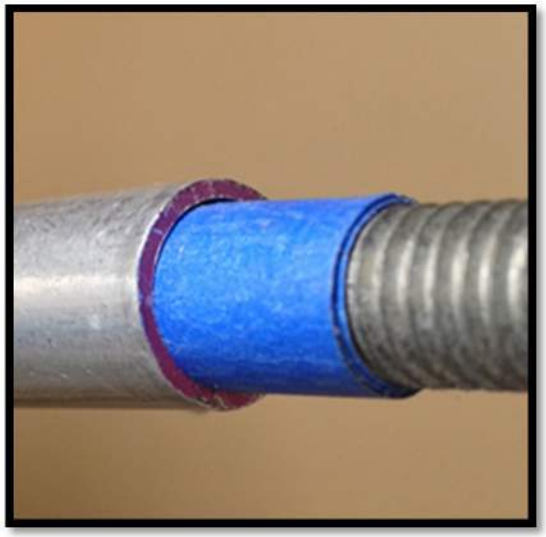


Figure 159. Painter's Tape Sleeve

Once this was done, the two shafts were concentric, and the bearings and the 24 tooth sprocket and bore clamping hub were applied. We applied the 48 tooth sprocket and its bore clamping hub to the 1 inch shaft as well. We spaced the wire guides to their appropriate spacing, 2 inches apart from one another. It is important that they were placed correctly, as once everything is tightened down and connected, adjustment is very difficult.

We placed the T-Slot so that the wire guides would have a channel to traverse. We now had two aligned shafts on bearings, wire guides in the correct position on threaded shaft and in the T-Slot channel, and the chain around the sprockets. All that was left was to fasten the bearings and the T-Slot to the spool mounting plate.

The hole location for the bolts that connect the bearings to the spool mounting plate were then marked on the plate. Their location was marked through the L-brackets that fasten the bearings to the plate. Once marked, each component was removed, and the holes were drilled on a drill press with a #36 drill bit. These holes were then tapped with a 6-32 tap.

Once all the holes were drilled, everything was re-assembled and fastened down.

7.2.4 Drive Cable Hookup:

Attaching the Kevlar drive cables to the Heliodon was a challenge. Each cable needed to be attached simultaneously, so two people needed to be working in tandem accomplish the task. Two uncut spools of Kevlar cable were used to hook up the drive cables to the Heliodon. The carriage was at rest at the top of the arches upon hooking up the cables.

The initial spool setup without the drive cables attached is sketched in Figure 160. The wire guides should be spaced evenly, with 2 inches separating each guide.

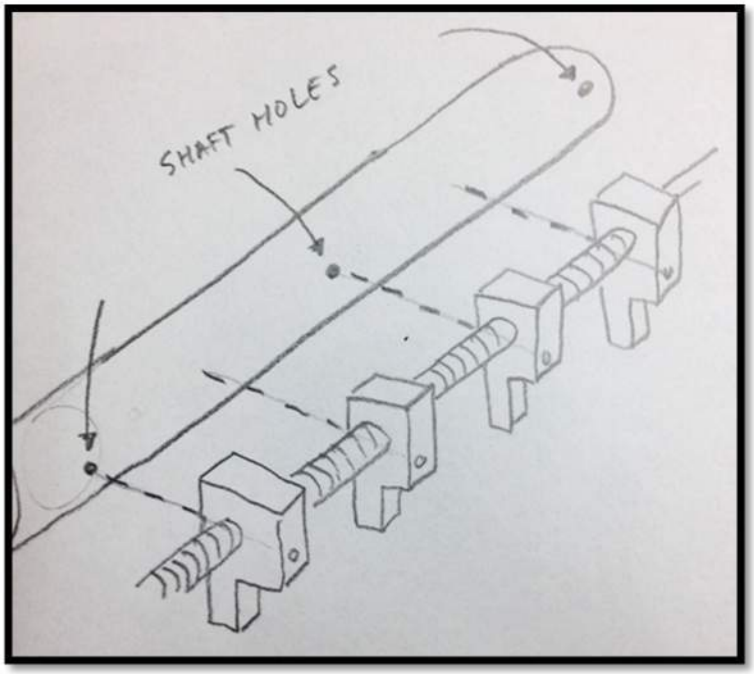


Figure 160. Initial Wire Guide Positioning

First, we rotated the threaded rod so that the wire guides reached their max displacement. The desired direction of wire guide motion is sketched in Figure 161. By comparing Figure 160 and 161, it can be seen that the wire guides have moved in relation to the shaft holes. The goal was to get the two guides to line up with the two holes as shown in the figure.

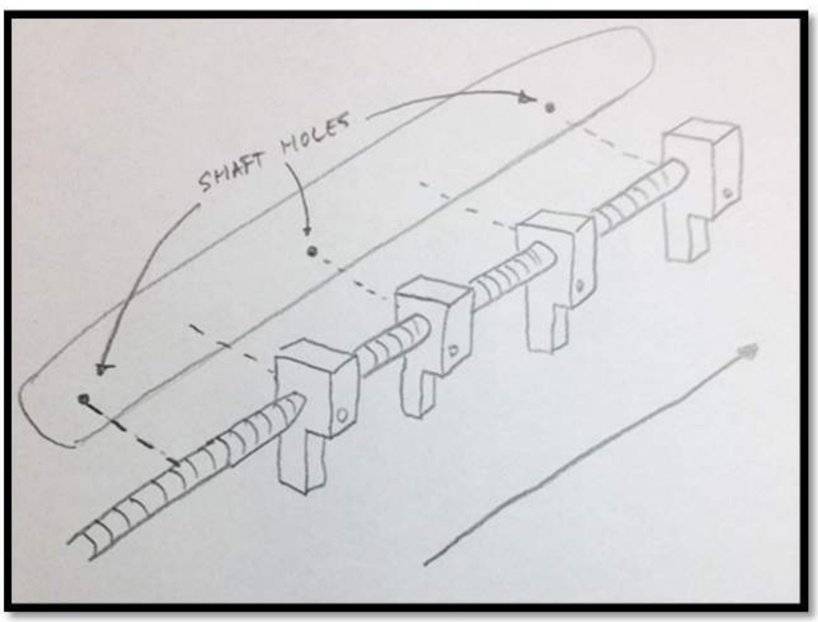


Figure 161. Wire Guides in Max Displacement Positions

Next, we wanted to thread the drive cables through the two wire guides that were aligned with the holes and through the holes in the 1 inch shaft that the guides were aligned with. This was difficult due to the small diameter of the Kevlar cable. To feed the cables through the holes, they were first carefully fed through standard sewing needles. This was difficult because the eye of the needle was smaller than the diameter of the thread. Individual strands of the Kevlar thread had to be fed through the eye of the needle one by one until the entire thread was through. This needle provided the cables with a rigid structure to ease the feeding through the 1 inch shaft. Once drive cable was through each needle, the cables were fed through each wire guide and shaft hole. They were looped around the shaft and tied to themselves. This is shown in Figure 162.

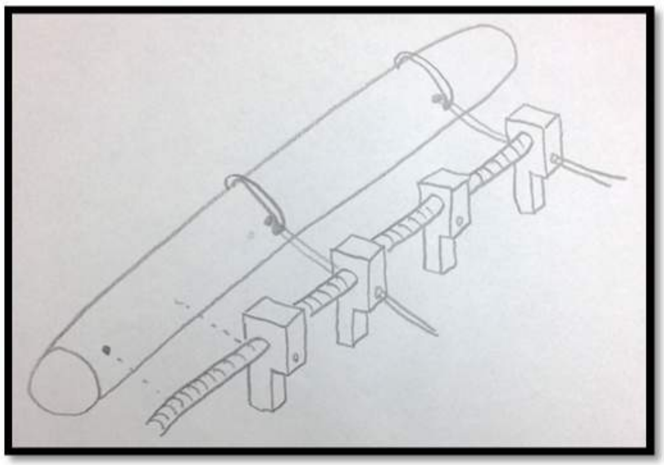


Figure 162. Wire Guide Set Up

Before feeding the drive cables around the arches, they needed to be wound around the shaft tightly and without stacking. To do this, the threaded shaft was rotated so that the wire guides moved back to their original position. This final winding is shown in Figure 163. The arrows next to each wire indicate the Kevlar drive cables untied end. The other arrow indicates the motion of the wire guides in the process previously described.

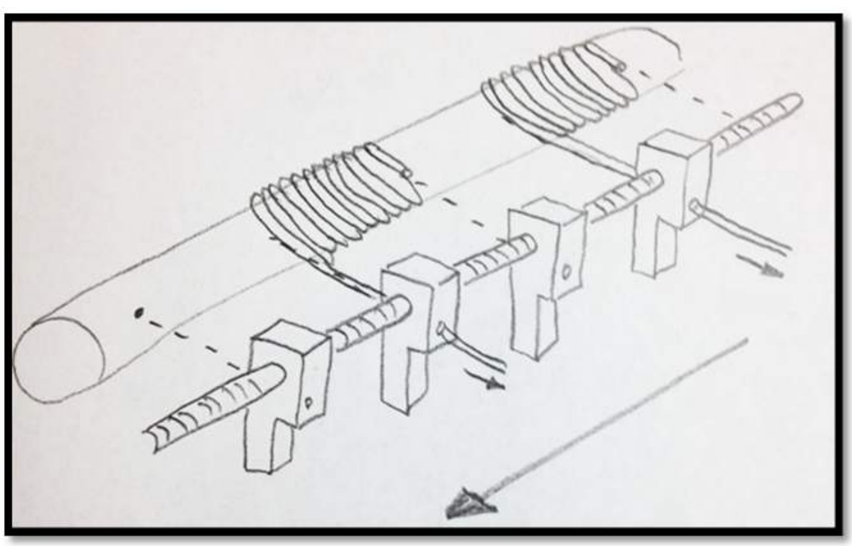


Figure 163. Second Step in Wire Guide Set Up

Next, from each cable's untied end (which was still on the full purchased spool of Kevlar), the cable was run around the arches of the Heliodon until the carriage at the top of the arches was reached. Moving one bracket at a time, the cable was placed in its respective feed drive cable hooks. When each cable reached the carriage, the cable was cut and each cable was tied to its respective cable grabber on the carriage. Now the need for two new lengths of cable arose. The new cables were needed to for the Kevlar to span the arch length. One cable was tied to one cable grabber, and one cable was tied to the other. This connection would allow the carriage to be pulled as the spool rotated. The connection is shown in Figure 164.

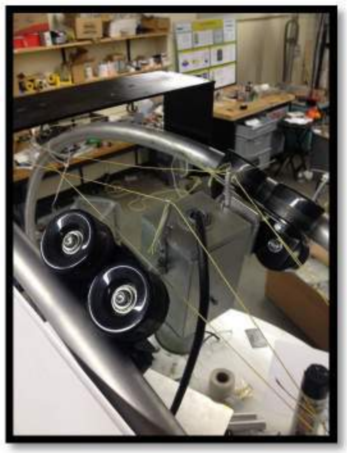


Figure 164. Spool-Kevlar Connection

Next, we used the remaining length of Kevlar to reach the other end of the arches. Moving one bracket at a time, the cable was placed in its respective feed drive cable hooks. This was repeated until the pulley bracket was reached. When the pulley bracket was reached, each cable was looped around its respective pulley. An image of the threads wrapping through the pulleys is shown in Figure 165.

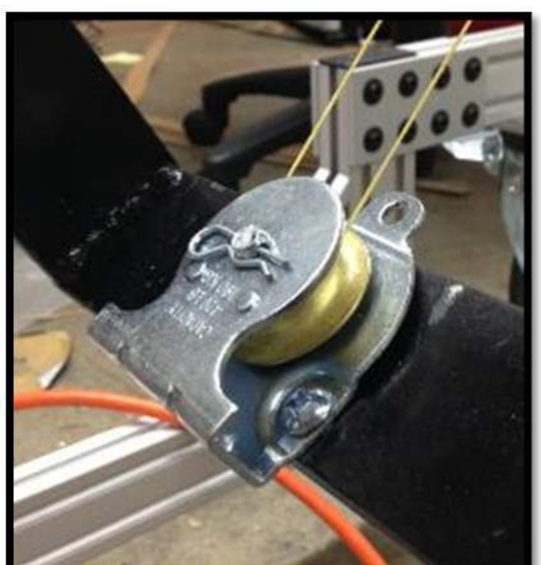


Figure 165. Thread Running Through Pulley

After this the cables were once more fed about the length of the arches. Now, moving one bracket at a time, the cables were placed in their respective return drive cable hooks. This was repeated until they were back to the spool mounting plate.

Once the spool mounting plate was reached the wires were fed through the wire guides labeled “return” in Figure 166. They were then threaded through the holes in the 1 inch shaft and tied off. This completed hookup can be seen in Figure 166.

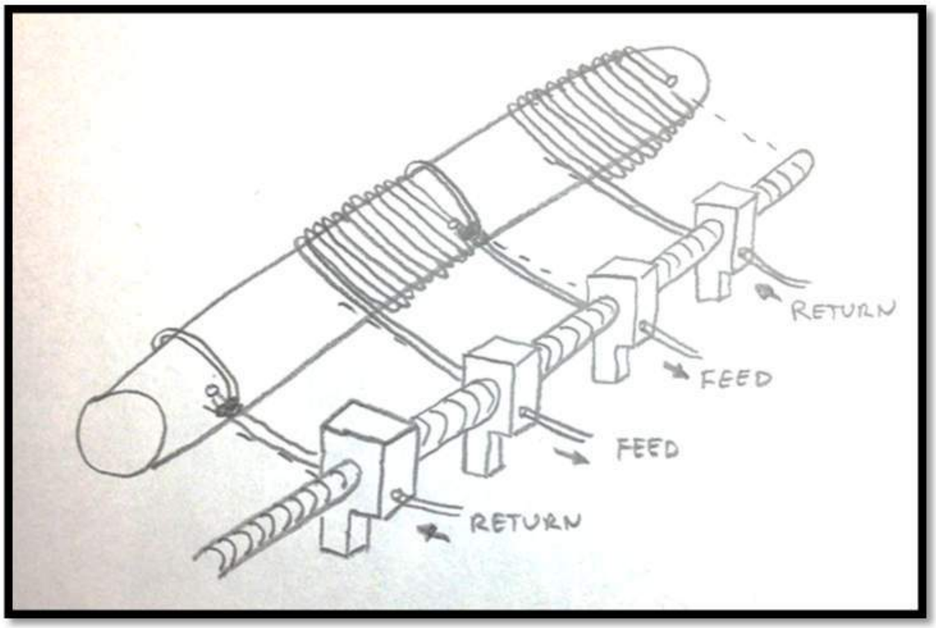


Figure 166. Final Spool Setup with Feed Directions

7.3 Operating Guide:

Operation of the Heliodon requires two people and a tool that is able to grip the large hex nuts on the threaded rods. We recommend large vice grips or a crescent wrench. Before making adjustments to the Heliodon’s position, ensure that all four brakes are engaged on the caster wheels. While one person is making adjustments to the Heliodon’s simulation, ensure that at least one other person is holding on to the arches to ensure that they do not tip over.

To adjust the latitude of the Heliodon, the latitude slots should be tilted by first loosening the hex nuts that are locking the latitude slots in place. The slots may then be tilted to the desired position in reference to the latitude angle marker. It is important to ensure that the arches rotate with the latitude slots so the arches always form a perpendicular angle with the latitude slots. Once the slots are tilted into position, retighten the hex nuts.

To adjust the date that is wished to be simulated, slide the slider within the latitude slots to the desired location. There should be one person at each end of the frame working together to move each of the two sliders in tandem. Avoid sliding the arches in one latitude slot without doing the same in the other latitude slot. For the most accurate simulations, use the front holes in the latitude slot to line up the sliders in the latitude slots. All slider position adjustments should be done symmetrically.

To adjust the position of the light carriage, the spooling mechanism must be driven either by hand or by a motor. Whatever method is used, the rotational force should be applied to the smaller of the two spooling shafts. See Section 9.1.3 for future modifications that should be done in order to make a motorized spooling mechanism possible.

Once the Heliodon is adjusted to the desired position, plug in the cord reel to a wall socket to power the light bulb and illuminate the table.

To transport the Heliodon from room to room, the Heliodon must first be returned to standard position in order to fit through doors. This means that the latitude slots should be parallel to the ground, the arches should be centered in the latitude slots, the arches should be perpendicular to the ground, and the two wings of the table should be folded up. Unlock the four caster wheels and push the Heliodon to its destination.

7.4 Disassembly, Maintenance, and Repair:

In the case of faulty operation of the Heliodon, parts may become loose, worn, or even broken. The following sections will recommend how to disassemble, maintain, and repair parts of the Heliodon.

7.4.1 Disassembly:

Disassembly could be an important part of troubleshooting if an issue with the Heliodon occurs. We recommend that before disassembly, the user fully understand the difficulty of putting the Heliodon back together. We also recommend that at least four people are present to disassemble the Heliodon. The arches are heavy and if they were to unlock and swing downward, they could pose a serious safety hazard.

The first thing to be done upon disassembling would be to cut the Kevlar drive cables and remove the carriage from the arches. The drive cables can be cut with scissors and the carriage can be removed with some force.

Next, with multiple people to help out, the nuts on the 1 inch shaft should be loosened and removed. One person should hold the arches on the 0 degree bracket side and another person should hold the arches on the 180 degree bracket side. The other two people should help preventing the arches from tipping. One person at a time should remove the threaded rod from the latitude plates while keeping the latitude slots connected to the arches. Once this is complete, the other should repeat the process. Next the sliders should be disconnected from the 1 inch threaded shaft. This will disconnect the latitude slots from the arches. Once the threaded shaft is removed, the slider and latitude slot can be separated. The arches should be laid down carefully, and at this point the rivets can be removed from the brackets if necessary.

The remaining disassembly of the Heliodon can be done with one person if desired. All that is needed to take apart the latitude plates, T-Slot frame, table, spooling mechanism, and caster wheel mounting plates is a 4mm Allan Wrench and a Philips Head screwdriver.

Once the Heliodon has been taken apart, individual components can be modified for upgrades or repaired.

7.4.2 Maintenance and Repair:

In this section we have identified the components on the Heliodon that are most likely to fail or need maintenance.

With the final decision to use epoxy to fasten the drive cable hooks to the brackets, we have discovered that the epoxy is susceptible to failure. If this happens we recommend getting a new hook instead of trying re-epoxy the old one. It is difficult to get the old epoxy out of the hole in the bracket where the hook previously laid, and if an old hook is reapplied with new epoxy it may sacrifice strength. We recommend clearing the hook hole of epoxy by using a drill. Slather the new hook with epoxy and insert into the now clean hole. Apply epoxy to the back of the bracket to ensure that the hook and hole are covered thoroughly. Once dry, peel off the excess epoxy and spray paint to obtain a clean finish. If this continues to be an issue, see section 9.1.4 for further recommendations.

During typical use, the Heliodon's frame fasteners may become loose due to the vibrations from transportation. We recommend to check the fasteners every so often and see if any T-Slot bolts have become loose. If upon checking it is discovered that any of the fasteners can be tightened, these fasteners are susceptible falling off the frame. Use a 4 mm Allan wrench to tighten the loose bolts.

The chain and sprocket assembly will require light lubrication every so often to function properly and to maintain the life of the chain. Lubricate the chain every four months to prevent early onset fatigue and to ensure a working Heliodon.

The tabletop was sealed with a polyurethane type substance. These types of finish wear off over time. We recommend that every year the tabletop is sealed to prevent weather and UV damage. This will prevent wood rot from occurring

The electrical connections need to be maintained as well. It is recommended that the wiring is checked every so often for frays or kinks. No maintenance should be done on the electric components unless the Heliodon is unplugged.

8. Design Verification, Testing, and Future Test Plan

Upon the deadline for completing the Heliodon, only the mechanical portion of the project was finished. The electrical and automation goals were not reached and therefore, many of our desired tests could not be performed. In the following subsections we will discuss the status of our goals, show results from the testing that we were able to perform, and provide a possible test plan for future iterations of the design.

8.1: Design Verification:

At the beginning of the design process we set various specifications and goals for the final design to meet. Table 4 shows the specifications and whether or not we delivered on those specifications.

Table 4. Specification Evaluation

Spec #	Description	Requirement/Target	Tolerance	Pass/Fail/Not Tested
1	Explanation Time	5 min	±2 min	P
2	Height	78 in	Max	P
3	Width	36 in	Max	P
4	Length	90 in	±6 in	P
5	Weight	250 lbs	Max	F
6	Setup Time	5 min	±3 min	F
7	Light Movement speed	3 deg/ sec	Min	Not Tested
8	Angle precision	2 deg	Min	Not Tested
9	Settling Time	1 sec	Max	Not Tested
10	Angle Accuracy	1 deg	Min	Not Tested
11	Altitude Angle Range of Motion	180	Max	P
12	Latitude Angle Range of Motion	±50 deg	±.05 in	P

We gave ourselves a pass on explanation time, height, width, and length. It seems that explaining the purpose of the Heliodon as well as the way to operate it is fairly straightforward. With only three inputs to perform a simulation, it take the user significantly less than five minutes to understand the Heliodon's purpose and how it is operated.

The Heliodon fit through the doorways of the EE building and it was easily maneuverable through hallways and across campus. All of our dimensions were within our specifications.

We gave ourselves a failing grade for the weight of the Heliodon. As can be seen in section 6.3.1, we have estimated the Heliodon weight to be 283 lbs. We believe that we failed on this specification because we changed our bracket design from aluminum to steel at the last minute. We were willing to sacrifice weight for structural integrity. One of the reasons that we came up with the weight specification maximum of 250 lbs was because we thought anything heavier than that would be hard for one person to transport. Upon testing however, it is surprisingly easy to push around and so we are happy with the final weight.

We gave ourselves a fail on the setup time as well. This failure was more a result of not being able to set up as opposed to not being able to do it in a certain time. The locking mechanisms that we went with were not up to par with the locking mechanism that is required to operate the Heliodon effectively.

We did not test the light movement speed, angle precision, light source settling time, or the angle accuracy. All of these tests were intended for a motorized design. Our final Heliodon did not have a motor and so we could not test these specifications.

We gave ourselves passing scores on the altitude angle range of motion and the latitude angle range of motion. The light source was able simulate sunrise and sunset and latitudes of 50 degrees north and 50 degrees south.

8.2 Testing:

The first round of testing we conducted was to verify that the Heliodon was able to fit through a doorway. Once the final Heliodon was assembled, it was measured with a tape measure. The final length was 88 inches, the width was 30 inches, and the height was 78 and 3/4 inches. These values are within the design specifications. The Heliodon was wheeled to the Electrical Engineering building and brought inside. It cleared the large doorframe to enter the building and it was able to maneuver through the small hallways with ease. It was able to rotate a full 360 degrees in the hallway. A variety of different classrooms were chosen to test if the Heliodon could fit through the doors and each test was successful. Pictures of the test are shown in Figure 167 to Figure 169.

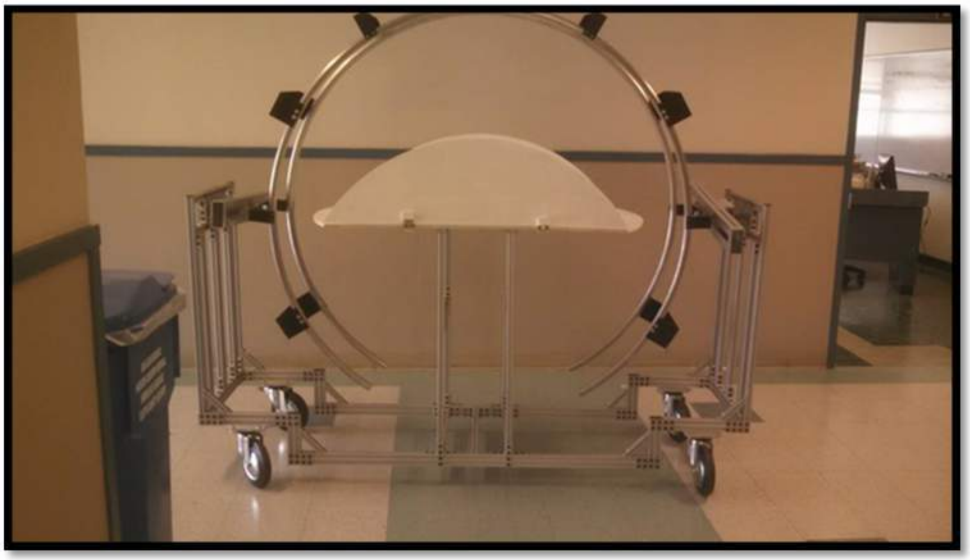


Figure 167. Heliodon in the Electrical Engineering Building Hallway

Figure 168. Heliodon in a Doorway

Figure 169. Heliodon Top Bracket Clearance

The second round of testing consisted of testing the accuracy of the "quick adjustment feature" of the slots (locking the slider in the slots using the holes in the front of the latitude slots). The center of the table coincides with the center of the circle traced by the arches and this is supposed to be the most accurate position for simulations on the Heliodon. Our latitude angle marker served as a protractor that we placed on the center of the table. We lined up the 90° line on the latitude angle marker with the "North" side of our table. This is shown in Figure 170.

Figure 170. Angle Accuracy Test Setup

A string was tied to the summer solstice hole and was brought to the compass to measure the angle formed. The angle recorded was 22.4° which is only 1.05° off from the actual angle of 23.45°. A sketch of the test set up and the desired angle is shown in Figure 171.

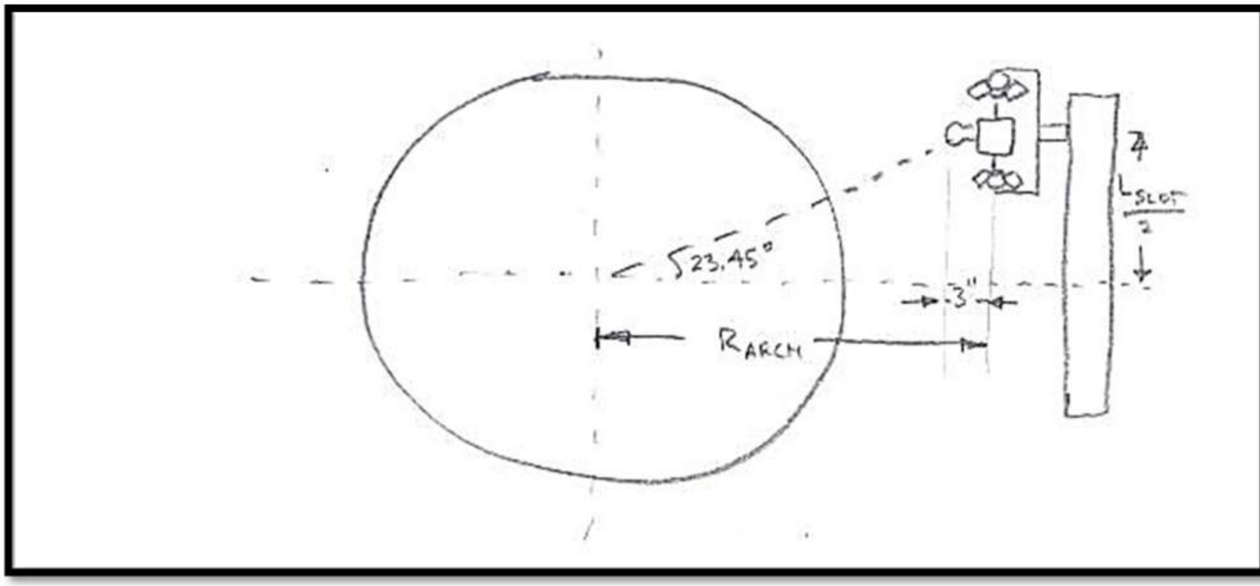


Figure 171. Desired Heliodon Angle

One concern that we had was the Heliodon may tip during use or if was on a steep hill. The first tipping test was set up by moving the arches to the summer solstice and moving the light carriage to the farthest point away from the center of the frame. These settings provide the greatest moment. The Heliodon did not tip and so it passed this test. The other tipping test consisted of the Heliodon being moved on a hill parallel to the incline. It did not tip on the hill either.

The setup time, light movement speed, angle precision, settling time, angle accuracy and altitude range of motion were not tested. All of these specifications were for the automation of the Heliodon which wasn't complete. These tests will have to be performed in a future iteration.

8.3 Future Testing Recommendations:

The most important test for a Heliodon is ensuring that the simulation of times, dates, and locations, is accurate. The sun angles that are created by the Heliodon at different simulations should match given sun angle data for the same simulation parameters. The best way to test these sun angles is to test the angles at sunrise and sunset for different months at the equator. If these angles are accurate, then angles during other simulations can also be accurate. If these angles are slightly off, then all of the simulated angles will be slightly off as well.

The accuracy of the angles just described is entirely dependent on the mechanical system. Inaccuracy could be the result of the table not being centered in the arches, the latitude slot not angled to the correct latitude, the slider not being in the precise location in the latitude slots, or just misalignment created through assembly in general. Alignment and locking accuracy should be a huge concern for future iterations of this project. There is no point of automating the day to day simulation if the latitude and date parameters cannot be made accurate in the first place.

If the Heliodon is sufficiently dimensioned and aligned, then there needs to be extensive testing to calibrate the control system. In our design, our spooling system would have to work perfectly for any automated carriage to have the change to accurately demonstrate times of the day. Any stacking or spacing of our driving cables during the spooling process would create inaccuracies.

We recommend inputting sun calculation equations to a micro-controller that can communicate with the motor. Tests various times should be run at specified latitude and date simulations. For example, the light source could be told to move to 3PM in San Luis Obispo on October 21st. After this motion, the tester would measure the altitude and azimuth angle formed by the light source and compare these values to the values predicted by sun equations. These tests should be run at numerous times, dates, and latitudes, until the motor and micro-controller are calibrated.

9. Suggested Improvements

Our project is largely mechanical, but there is also a huge potential for an electrical side. We have split our suggested improvements section into mechanical improvements and electrical improvements. The following sections detail our suggestions.

9.1 Mechanical Improvements:

9.1.1 Alignment:

Despite our best efforts, not everything on our final design was as aligned and level as we wanted. The latitude slots are not quite parallel to the ground. The 1 inch holes in the latitude plates are not all in line with each other. The table is not quite square with the frame. The 0 and 180 degree brackets are not perpendicular to the ground.

All we can recommend is investigating better manufacturing methods to ensure alignment and leveling. We recognize that we were not experienced manufacturers and we also recognize that future teams may also lack experience. The best recommendation that we can offer is to continue searching for manufacturing and assembly advice.

9.1.2 Motion and Locking:

For future considerations, multiple components need a better way to lock in place. Specifically, locking the latitude slots at desired angles and locking arches and the latitude slots so that they rotate together must be improved.

In regards to the locking the latitude slots at required latitude angles, a design other than tightening nuts needs to be thought of. A possible solution to this is shown in Figure 172.

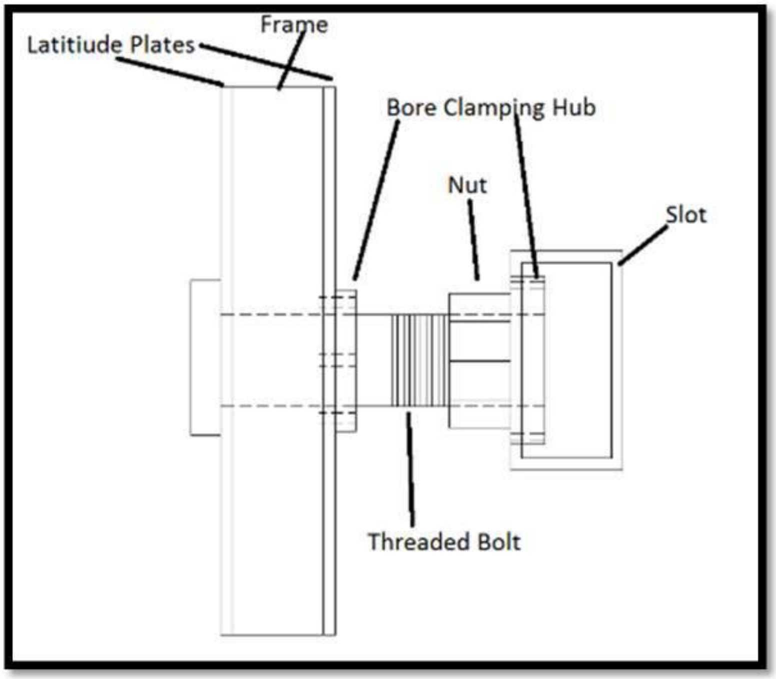


Figure 172. Possible Solution to Heliodon Locking Issue

First, a partially threaded bolt would need to be purchased. The unthreaded, or shoulder, section of the bolt would go through both the latitude plates and the latitude slot connector, but a bore clamping hub and nut would be placed in between the latitude plates and slot. The bore clamping hub would screw into the latitude plates, making the shaft unable to rotate. The end of the bolt would have another bore clamping hub attached to the inside of the slot. This prevents the slots from moving in the axial direction and provides a surface for the nut to press into once tightened. Rotating the slots with this method only requires loosening the one nut.

The current design doesn't have a safe place for the acrylic angle markers due to the six nuts. If the above design is implemented the angle marker could go between the bolt head and latitude plate. This location will allow a user specified amount of force on the plate, preventing it from cracking.

Another locking issue is that the arches can rotate independently of the slots. While designing the Heliodon, we wanted to keep this rotation possible due to its mobility and being able to fit through a door. If the Heliodon ended up being too large to fit through a door, we wanted to be able to orient the slots vertically so that we could slide the arches to a lower point. Once built and tested, the overall height was just short enough to fit through a door.

To eliminate this rotation, a double shaft design could be implemented into the slider. The center one inch shaft would be removed, new sliders would be fabricated to fix the hole and two, 1/2 inch shafts would take its place. The length of the slider would not change but the slot length would need to increase by an enough to allow the center of the slider to reach its necessary position. The two 1/2 inch shafts would go straight from the slider to the 0 and 180 degree brackets. This would effectively lock the slot's rotation with the arches and keep the arches perpendicular to the slots as necessary. A sketch of the design is shown in Figure 173.

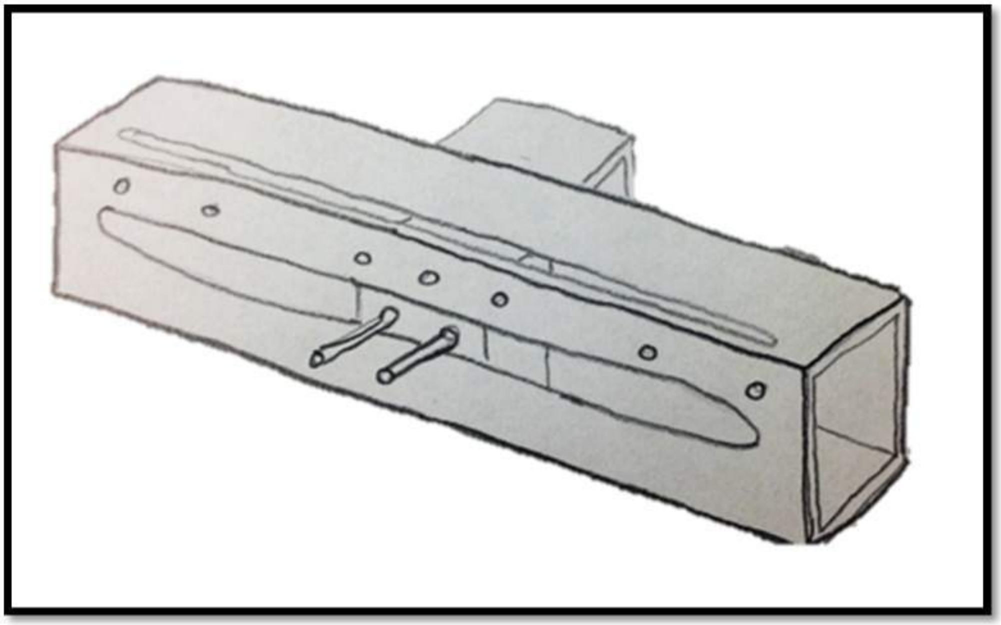


Figure 173. Slot Shaft Rotation Solution

9.1.3 Spooling Mechanism:

The general idea for the spooling mechanism is sound. The two shafts coupled with a chain and wire guides that run along a lead screw is the best way to spool the wire as necessary. However, the individual parts of the spooling mechanism can be greatly improved. The use of small journal bearings, like the ones seen in Figure 174, will help with shaft alignment and bearing life.

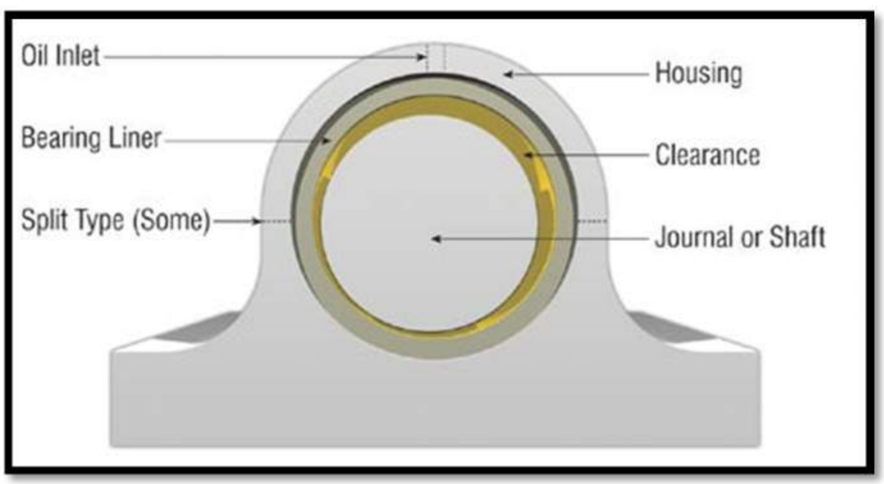


Figure 174. Shaft Bearing Improvement

The largest problem that we failed to realize was the coupling between the spooling shaft and the lead screw shaft. Despite the requirement of spooling shaft to spin twice as often as the lead screw shaft, we used a gear ratio that actually did the opposite of this. In our assembly, the lead screw spins twice as often as the spooling shaft. We failed to realize this until the day that we assembled the final Heliodon and we did not have enough time to fix this error. If a future team is to modify our Heliodon, this is the first problem that should be fixed. It is important to note that there are other gear ratios that could be used if different threads per inch are used on the lead screw. Future teams must also understand that the gear ratio, the threaded shaft TPI, the shaft diameters, the shaft lengths, and the drive cable diameter are all dependent variables in the spooling design.

Placement of a motor on the spooling mechanism and possibly a force or torque measurement system on the spooling mounting plate or mechanism must also be considered.

9.1.4 Drive Cable and Power Cable Hooks:

The current design of attaching the drive cable hooks to the brackets is not effective. The epoxy that holds the drive cable hooks to the brackets cannot support the tension created by the Kevlar drive cable and so they pop out of the brackets when tensioned. We recommend a bolt style hook with matching nuts and washers. The bracket holes wouldn't need to be threaded because the two nuts would prevent the movement of the hook. This idea provides easy maintenance in the case that a hook has to be replaced.

The shape of the hook should also be changed. The current hooks do not allow the cable grabbers to replace the Kevlar thread in the hooks after lifting them out. There is a product called a J-Bolt that we recommend using. Figure 175 shows the J Bolt with the two nut idea.

Figure 175. J Bolt

With these J-Bolts, the cable grabbers could be remade to similar J shapes and this would lift and replace the cable as necessary when the carriage passes the hooks. A sketch of the theorized cable grabber, J-bolt interaction is shown in Figure 176.

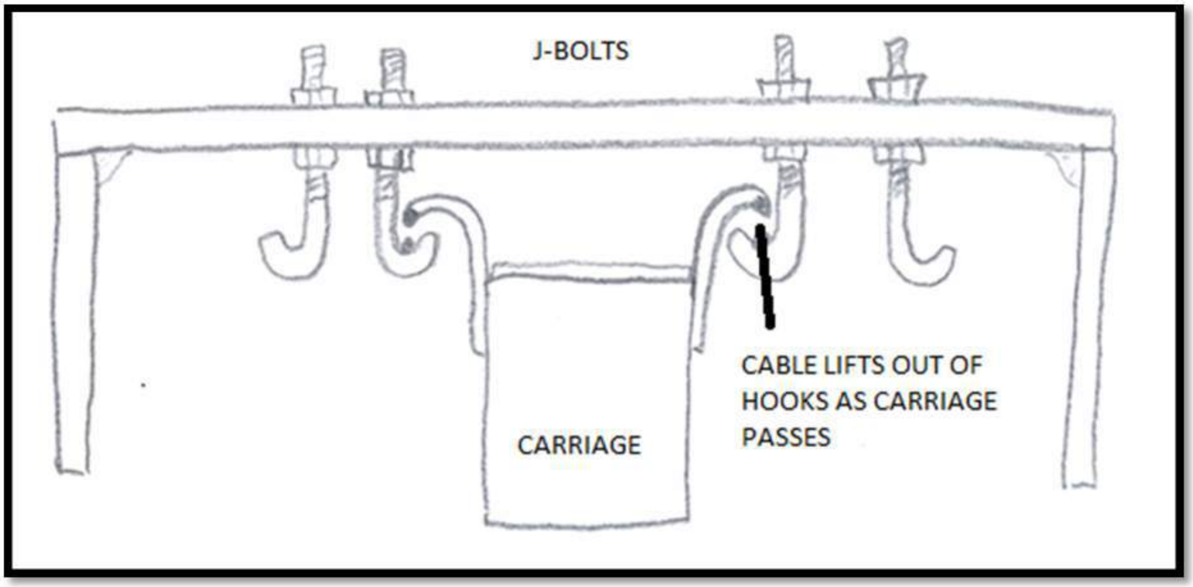


Figure 176. J Bolt Solution to Cable Drive Hook Issue

To better accommodate the power cable and to prevent it from dangling as the carriage runs along the arches, we recommend power cable hooks. These hooks are similar to the drive cable hooks, but they only require one hook per bracket. This design requires that the locking mechanism between the latitude slots and the arches be implemented, because ideally the power cable would lay in the center of each bracket. As of now, this is not possible at the 0 and 180 degree brackets because of the 1 inch threaded connecting shaft. With the new locking mechanism proposed, there would be no shaft in the middle of the brackets (as shown previously in Figure 173) and so a power cable hook could lie there instead. A third cable grabber could be implemented to the carriage and the same mechanism for lifting the wire out of the hooks as the carriage passes could be implemented.

9.2 Electrical Improvements:

9.2.1 Power Cable Management:

The power cable needs proper management to reduce friction, to keep the cable out of the way of the light, and to properly travel along with the moving light carriage. Larger cable hooks attached to each bracket could be utilized to guide the power cord in a similar way that the drive cable hooks guide the Kevlar drive cable string. The cord reel could also be modified so that the internal torsion spring pulls with reduced force, lowering the required torque of the motor. Whatever method is employed, it must be ensured that the cord does not come into contact with sharp or abrasive edges to protect the integrity of the wire insulation.

9.2.2 User Interface:

The design of the user interface should encourage accessibility and ease of use. At the very least, there should be a screen and a keypad for the user to input and read out information. This design could utilize on screen instructions or have an accompanying instruction booklet.

One concept of the user interface can be seen in Figure 177 below. With this handheld device, the user could interact with the control system through the keypad and receive information (i.e. menu displays, instructions, sun angle information) from the LCD screen. Refer to Appendix E for a concept of the control system's function state diagram. Switches could be used as well to turn on and off the light bulb and/or the control system.

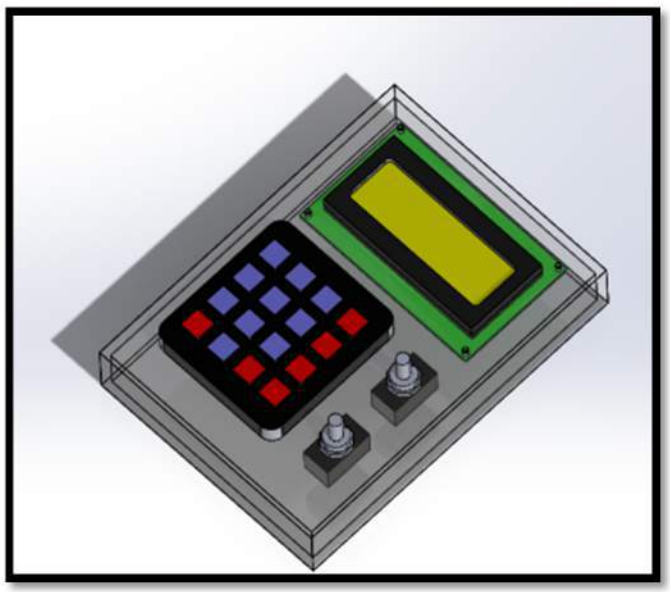


Figure 177. Handheld User Interface Concept

9.2.3 Sun Angle Calculator:

Regardless of how accurate the physical Heliodon is, the control system should be able to calculate and output the simulated sun angles accurately. This will require the use of a robust microcontroller or PLC due to the complex nature of the sun angle equations. Trigonometric functions (i.e. sine, cosine, arccosine, arcsine) must be utilized. The future project leaders should be advised to select a controller that is capable of performing these complex calculations well. Users should be able to input latitude, date, and time and receive accurate sun angle information. We recommend talking to Dr. Jesse Maddren of the Mechanical Engineering department, as he has an excel code that already does this. We also recommend talking to Dr. Kim Shollenberger, as she teaches a solar course at Cal Poly as well.

9.2.4 Motor and Motor Control:

The selected motor must be able to effectively mobilize the entire light movement system including the spooling mechanism, driving cables, and power cable management systems. In order for proper motor selection to be made, the entirety of the light movement system must be designed and tested to determine how much torque is needed in the motor. The fixture should be rigged up, and strain gauges or other force transducing devices should be used to extract the required torque. The motor should be sized accordingly. The motor control system should also be determined after the selection of the motor. Motor, motor power supply, and controller selection should be considered carefully.

10. Conclusion

Over the course of this capstone project, team Heliodon succeeded in making a functional prototype of the Heliodon. We are proud to say that the mechanical systems work and with a further iteration, automation and fully functioning, accurate Heliodon is possible.

We hope that once the final iteration of the Heliodon is complete, it will be a valuable contribution to the Cal Poly Electrical Engineering department and the students and faculty of Cal Poly as a whole. This project has helped us learn about how the Sun moves relative to the Earth and the Heliodon is definitely a helpful teaching tool. Throughout this project, we encountered challenges that required us to push ourselves to complete.

We would like to thank Dr. Dale Dolan for being a helpful sponsor, Dr. O'Neil and Dr. Maddren for helping us learn about Sun motion and Sun angles, Kevin Williams for teaching and practical welding help, Hans Meyer for spooling advice, Dr. Shollenberger for providing us with a small scale Heliodon, Futura Industries for donating the T-Slot, California Fine Wire for providing us with the idea for our final spooling method,, and Advanced PipeBending for the arches.

We would especially like to thank Professor Sarah Harding, our advisor. She always guided us in the right direction, pushed us to be our best, and never gave up on us.

Finally, we wish the best of luck to future students working on the Heliodon. It's a challenging but rewarding process.

11. References

[1] "14.8 Climatic Design Information." *2013 Ashrae Handbook: Fundamentals*. Atlanta, GA: Ashrae, 2013. N. pag. Print.

[2] "Solar Declination." *Solar Declination*. Sunlit Design, n.d. Web. 19 Oct. 2014.

[3] "The PEC Heliodon." *The PEC Heliodon*. PG & E, n.d. Web. 20 Oct. 2014.

[4] "Sun Simulator Heliodon." *Sun Simulator Heliodon.* Auborn, n.d Web. 19 Oct. 2014.

[5] Shwartz, Stefan. "Modeling the Sun." Personal interview. 18 Oct. 2014.

[6] Pelletier, Matt. "Servo Motor Sizing Concepts." Design News. Design News, 15 June 2009. Web. 9 Nov. 2014.

[7] T-Slot, Futura Industries, 10 Series. http://www.tslots.com/product-category/fractional/extrusions/tslotsfractionalextrusions10-series/

Appendices

Appendix A: QFD Analysis:

▽ = "PG&E fixed light"
□ = "Large scale fixed table design"
○ = "Sun modeling software"

⬡ = "Professor Dolan"
△ = "Cal Poly Students"
◇ = "K-12 students"

Strong - 9
Medium-3
Weak - 1

Customer	Voices	Item No.	Importance	Explanation Time (A)	Height (B)	Width (C)	Length (D)	Weight (E)	Setup Time (G)	Light Angular Speed (I)	Angle precision (J)	Settling Time (K)	Angle Accuracy (N)	Range of Motion (O)	Flatness (P)	Customer Ratings 1 (Bad)	2	3	4	5 (Good)
⬡△	Easy to use interface	1	8	9					1							○		□	▽	
⬡△	Transportable	2	9		3	3	3	9	3							▽○	□			
⬡△	Fast setup time	4	3						9								○	□▽		
⬡△	Fast operation time	5	4		1	1	1			9		3		1				□▽		○
⬡△	Can fit through a door	7	8		9	9	9									▽	□			
⬡△◇	Precise dates	8	10								9		9	9				□	▽	○
⬡△	Minimal light source vibration	9	3							3		9								□○▽
⬡△	Able to cast shadows well	11	8		3	3	3			1									□	○▽
⬡△	Outputs sun angle information	12	8	3												□▽				○
⬡△◇	Can model sun's motion	13	10							3	9		9	9		▽		□	○	
⬡	Fixed Table	14	8												9	▽				□

Company Ratings		A	B	C	D	E	G	I	J	K	N	O	P
Good	5							○	○▽	○	□○▽	□○▽	○
	4	▽					□▽						□▽
	3	□	▽	▽	▽								
	2		□	□	□	▽	○						
Bad	1	○				□		▽					

	A	B	C	D	E	G	I	J	K	N	O	P	Total
Targets	5 minutes	6.5 ft	2ft 10in	5.5ft	200lbs	5 minutes	45 seconds	2 degrees	5 seconds	1 degree	180 degrees	.1in	
Weighted Importance	96	127	127	127	81	62	76	180	39	180	184	72	1351
% Importance	7.1	9.4	9.4	9.4	6	4.6	5.6	13	2.9	13	14	5.3	100

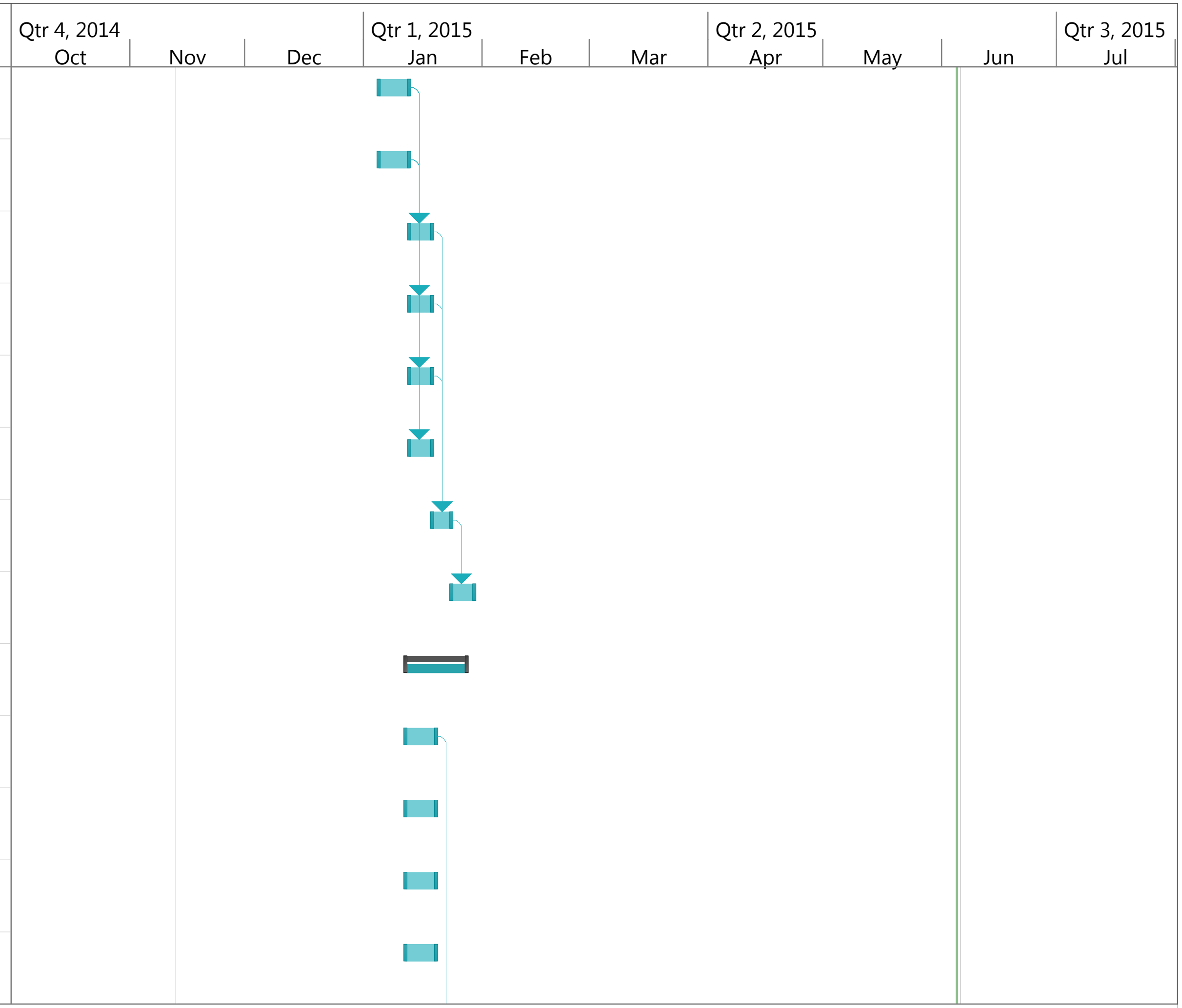
Appendix B: Gantt Charts:

ID	Task Mode	Task Name
1		**QUARTER 1: PROJECT DESIGN**
2		YELLOW TAGS
3		DESIGN TABLE
4		DESIGN LIGHT MOVEMENT
5		DESIGN INTERFACE
6		DESIGN FRAME
7		WORK ON PDR
8		PRESENTATION PREP
9		PDR DUE
10		PRESENTATION
11		RESEARCH MANUFACTURING
12		
13		**QUARTER 2: ENGINEERING DESIGN**

Project: GANTT
Date: Fri 6/5/15

Task	Inactive Summary	External Tasks
Split	Manual Task	External Milestone
Milestone	Duration-only	Deadline
Summary	Manual Summary Rollup	Progress
Project Summary	Manual Summary	Manual Progress
Inactive Task	Start-only	
Inactive Milestone	Finish-only	

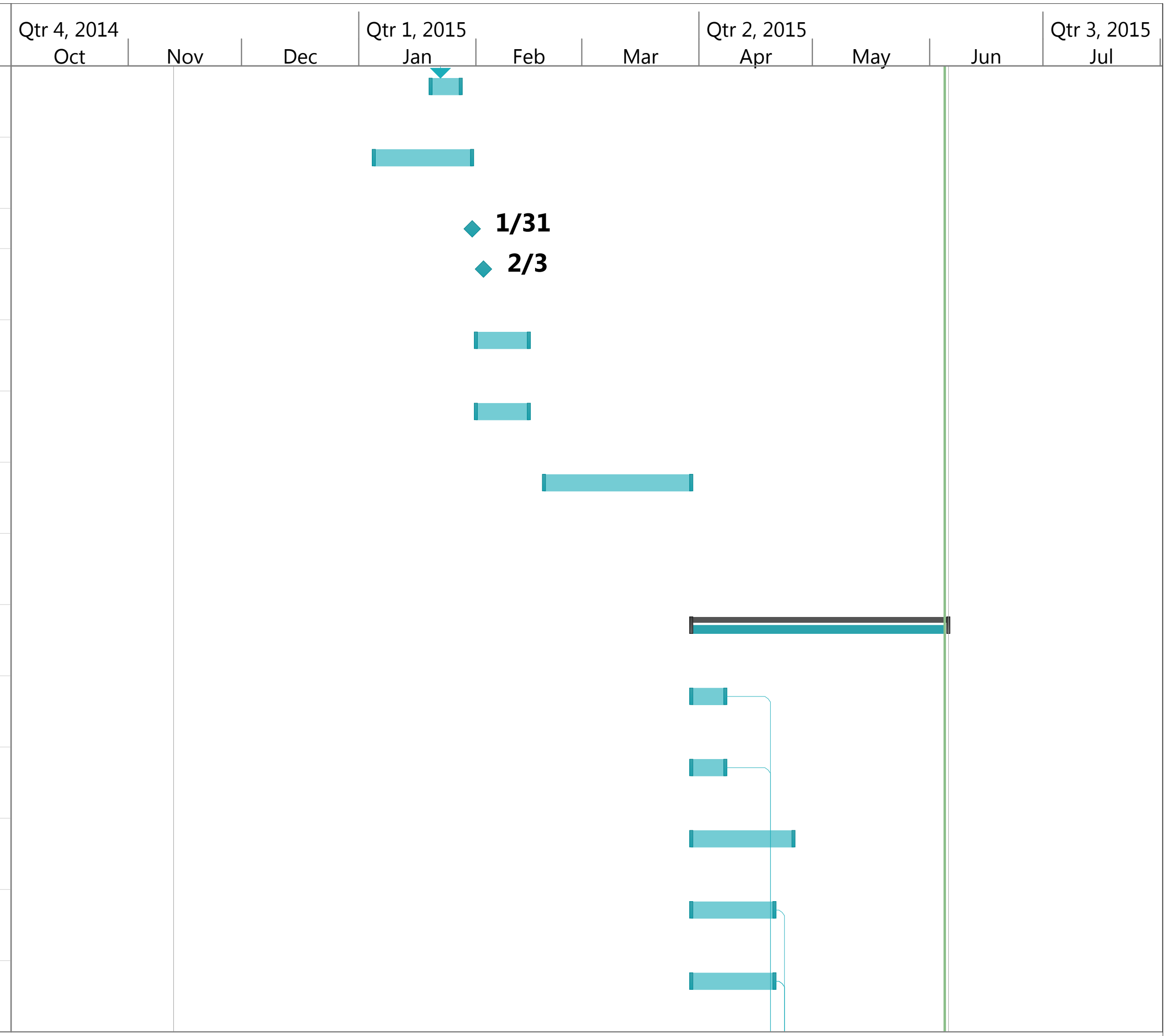
ID	Task Mode	Task Name
14		STRESS ANALYSIS
15		DYNAMIC ANALYSIS
16		TABLE SIZE AND MATERIAL
17		FRAME SIZE AND MATERIAL
18		ARCH SIZE AND MATERIAL
19		CHOOSE MOTORS
20		DETAIL DRAWING
21		CAD ASSEMBLY
22		**ELECTRICAL DESIGN**
23		MICROCONTROLLER SELECTION
24		USER INPUT
25		DISPLAY
26		ENCODER



Project: GANTT
Date: Fri 6/5/15

Task	Inactive Summary	External Tasks
Split	Manual Task	External Milestone
Milestone	Duration-only	Deadline
Summary	Manual Summary Rollup	Progress
Project Summary	Manual Summary	Manual Progress
Inactive Task	Start-only	
Inactive Milestone	Finish-only	

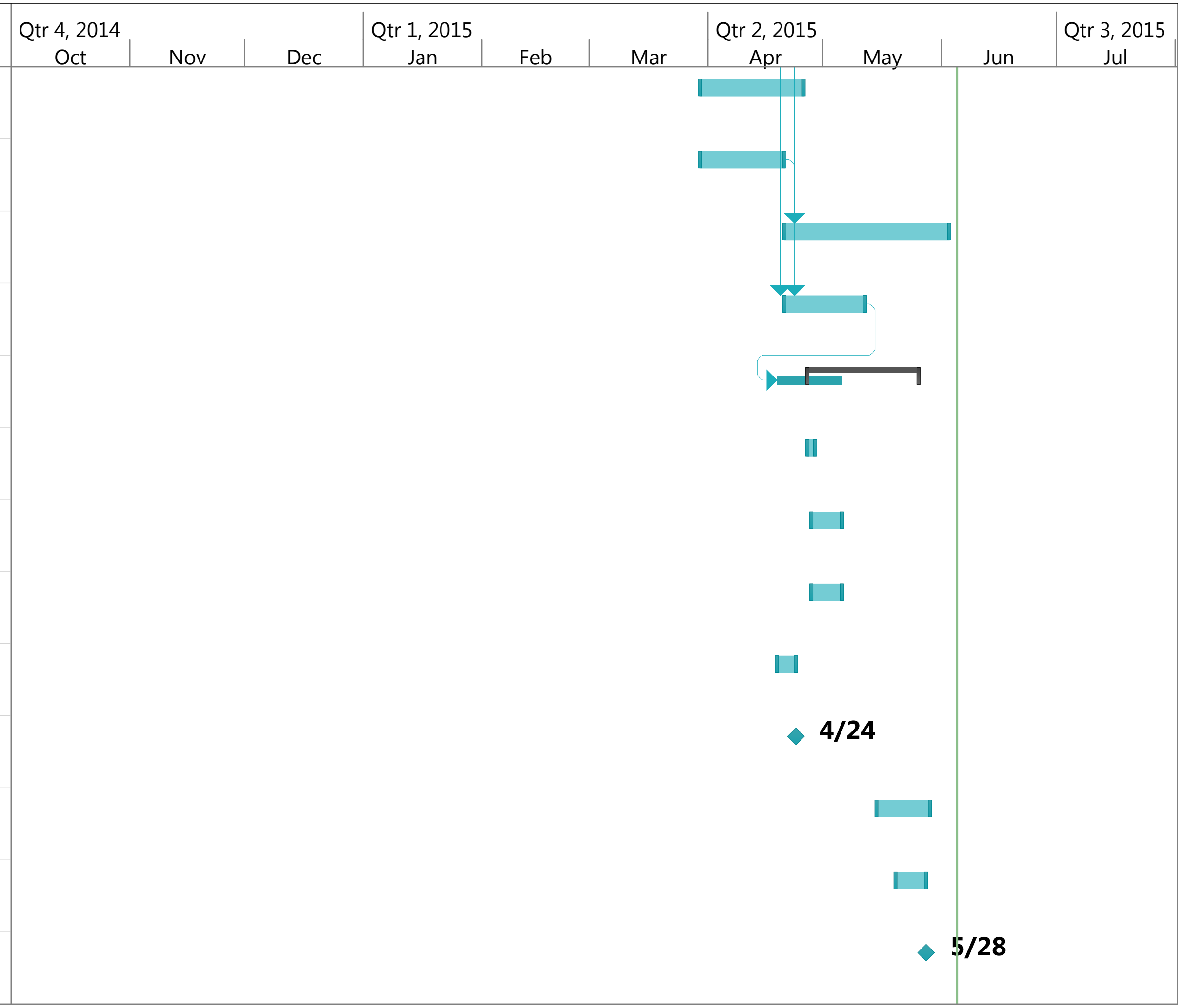
ID	Task Mode	Task Name
27		PROGRAM OUTLINE
28		WORK ON CDR
29		CDR DUE
30		CDR PRESENTATION
31		TEST PROCEDURE OUTLINE
32		MANUFACTURING AND TEST REVIEW
33		ORDER MATERIALS
34		
35		**QUARTER 3: ASSEMBLY AND TESTING**
36		FRAME BUILD AND ASSEMBLY
37		TABLE BUILD AND ASSEMBLY
38		PROGRAMMING
39		BUILD AND ASSEMBLE ARCH
40		BUILD AND ASSEMBLE LIGHT CARRAIGE



Project: GANTT
Date: Fri 6/5/15

Task	Inactive Summary	External Tasks
Split	Manual Task	External Milestone
Milestone	Duration-only	Deadline
Summary	Manual Summary Rollup	Progress
Project Summary	Manual Summary	Manual Progress
Inactive Task	Start-only	
Inactive Milestone	Finish-only	

ID	Task Mode	Task Name
41		INSTALL SAFETIES
42		INSTALL INTERFACE
43		TROUBLESHOOT PROGRAMMING WITH ARCH AND LIGHT CARRIAGE
44		ASSEMBLE FULL STRUCTURE
45		**TESTING**
46		CHECK FULL ASSEMBLY MOBILITY
47		TEST ACCURACY AND PRECISION
48		TEST EASE OF USE
49		SETUP DEMO MATERIAL
50		PROJECT HARDWARE DEMO
51		VERIFY ENGINEERING SPECIFICATIONS
52		SETUP EXPO MATERIAL
53		SENIOR EXPO



Project: GANTT
Date: Fri 6/5/15

Task	Inactive Summary	External Tasks
Split	Manual Task	External Milestone
Milestone	Duration-only	Deadline
Summary	Manual Summary Rollup	Progress
Project Summary	Manual Summary	Manual Progress
Inactive Task	Start-only	
Inactive Milestone	Finish-only	

ID	Task Mode	Task Name	Qtr 4, 2014: Oct, Nov, Dec — Qtr 1, 2015: Jan, Feb, Mar — Qtr 2, 2015: Apr, May, Jun — Qtr 3, 2015: Jul
54		FINAL REPORT DUE	**6/5**

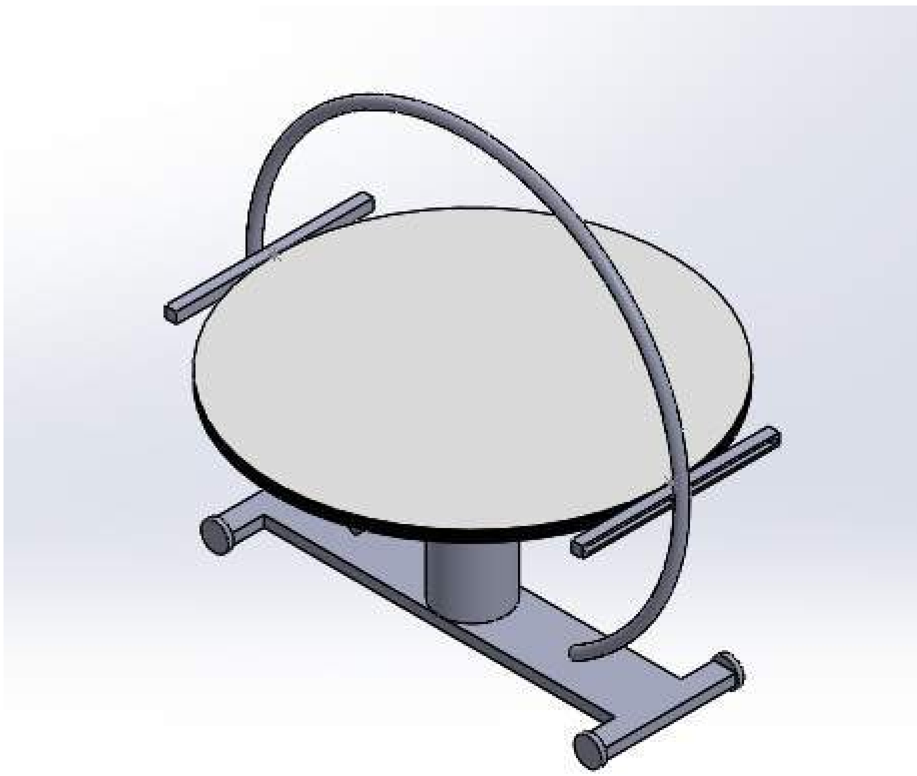
Project: GANTT
Date: Fri 6/5/15

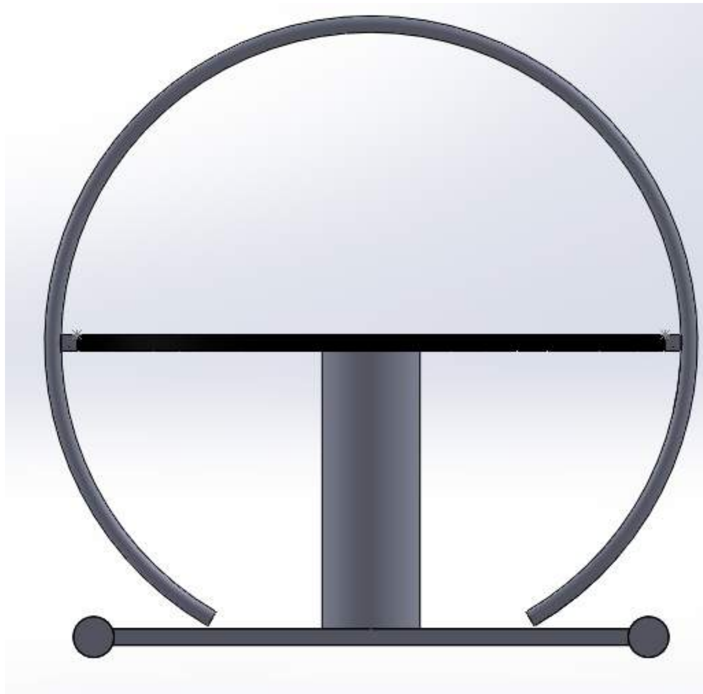
Task	Inactive Summary	External Tasks
Split	Manual Task	External Milestone
Milestone	Duration-only	Deadline
Summary	Manual Summary Rollup	Progress
Project Summary	Manual Summary	Manual Progress
Inactive Task	Start-only	
Inactive Milestone	Finish-only	

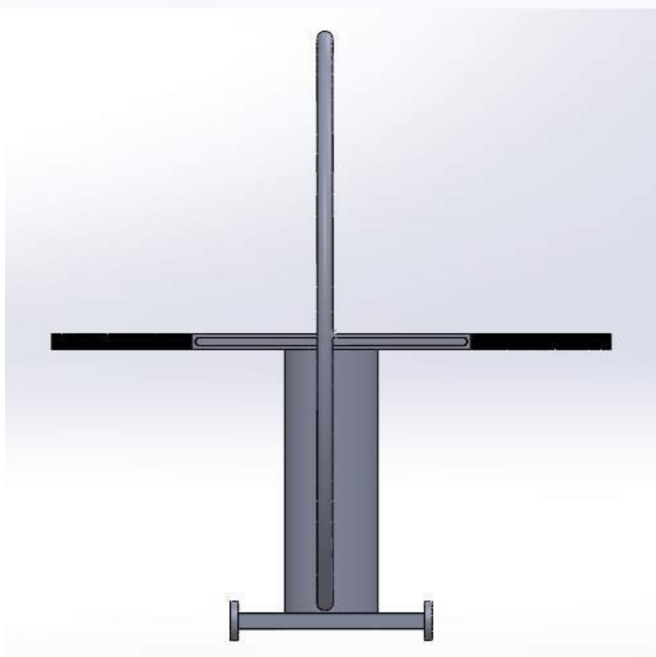
Appendix C. Initial Heliodon Designs:

The following appendix displays SolidWorks images from previous design iterations. None of these designs were adopted, but it can be seen how each initial design developed into the final design.

Initial SolidWorks Designs:

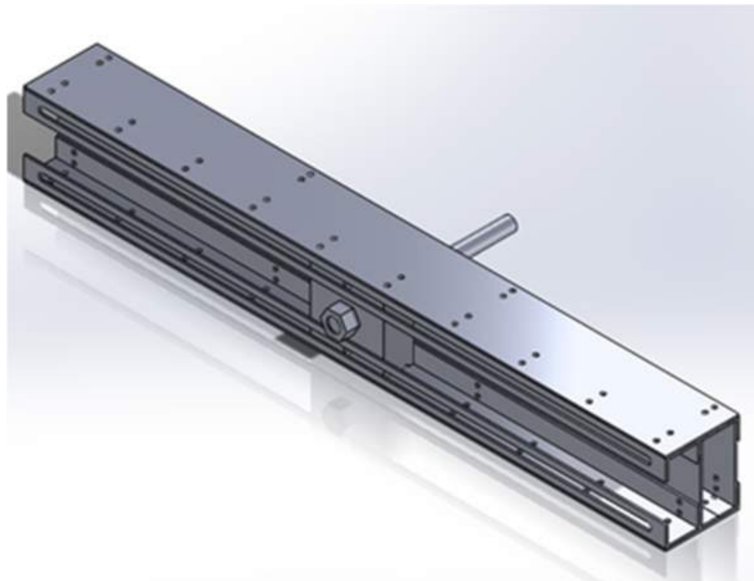


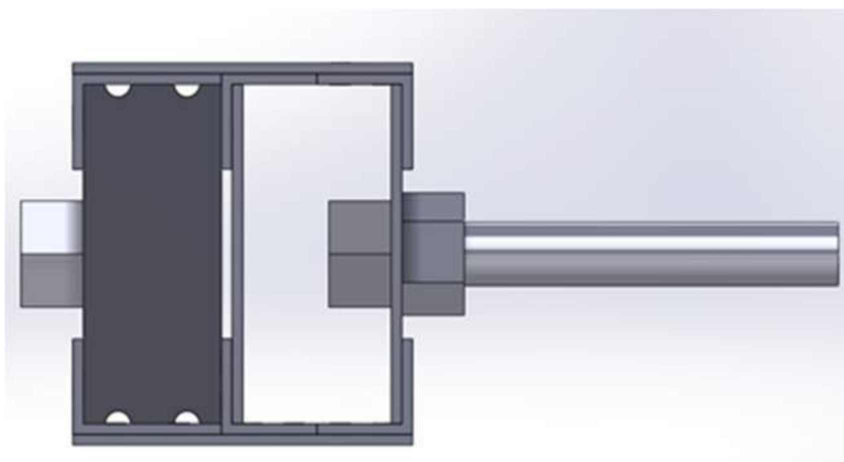




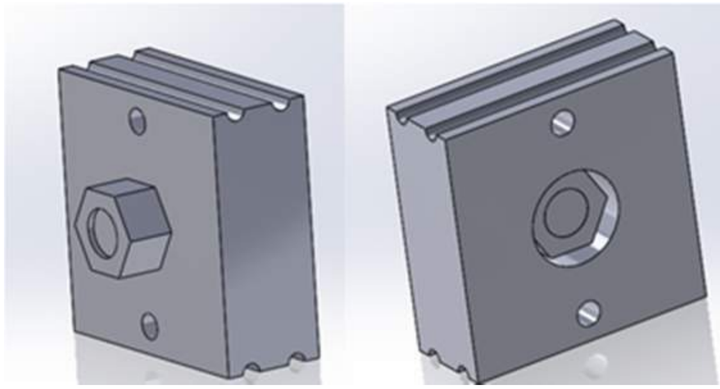
First Iteration Designs:

Latitude Slots:



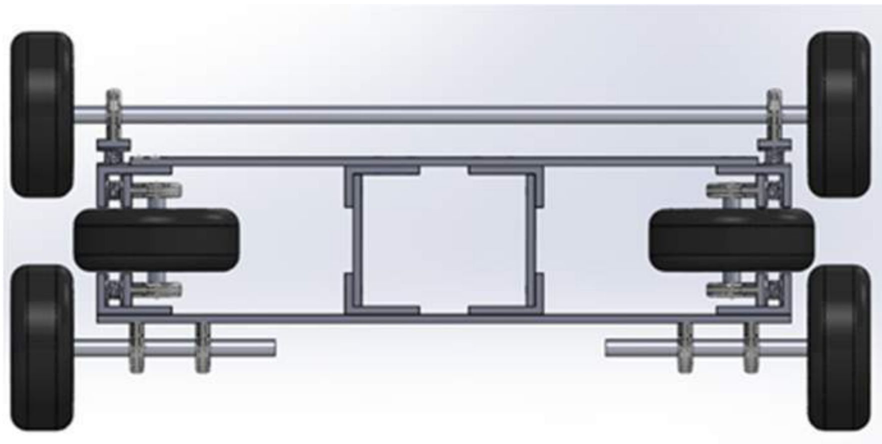


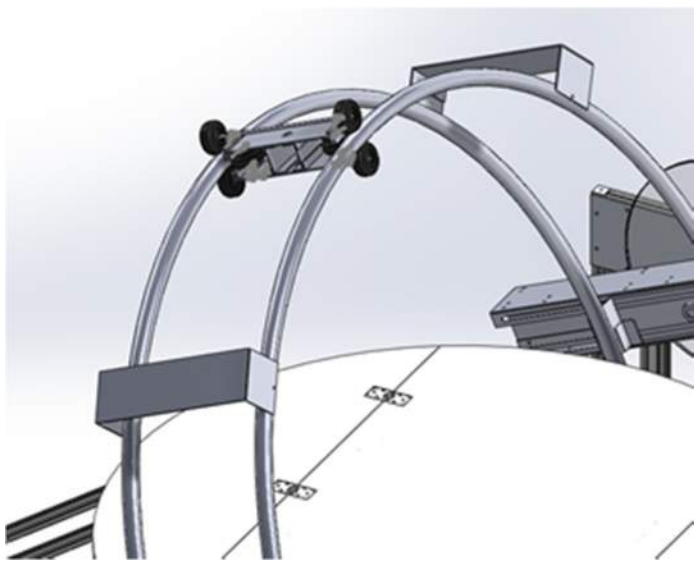
Latitude Slot Sliders



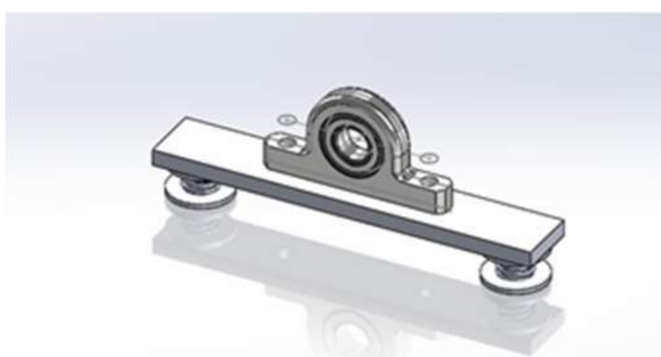
Arch Assembly

Carriage Design

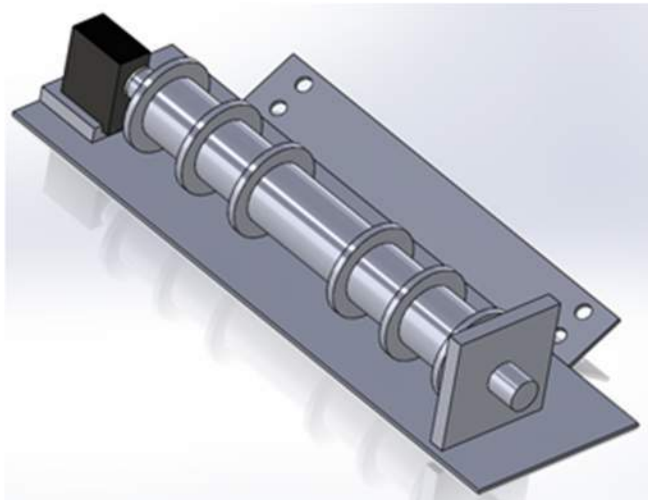




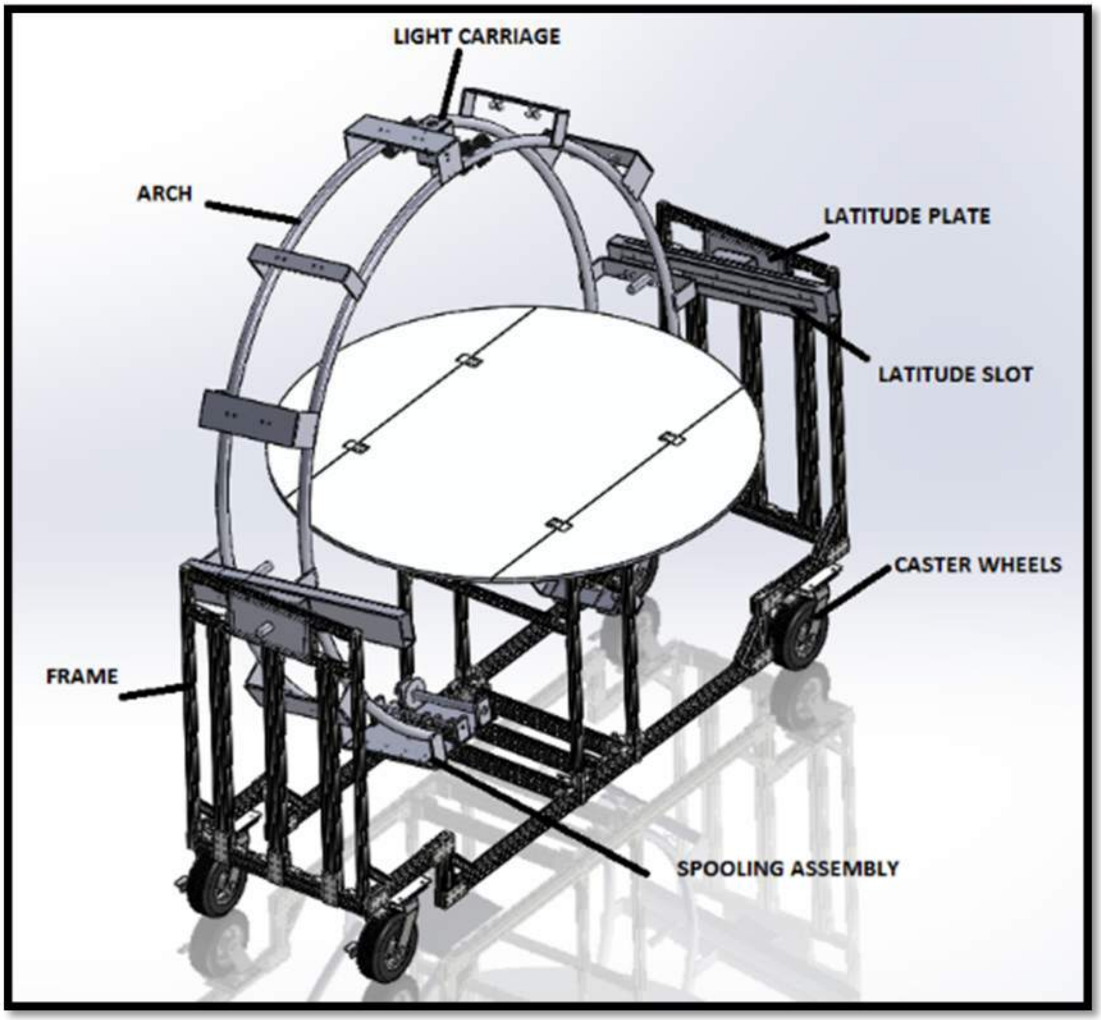
Carriage Bearings



Spool Design

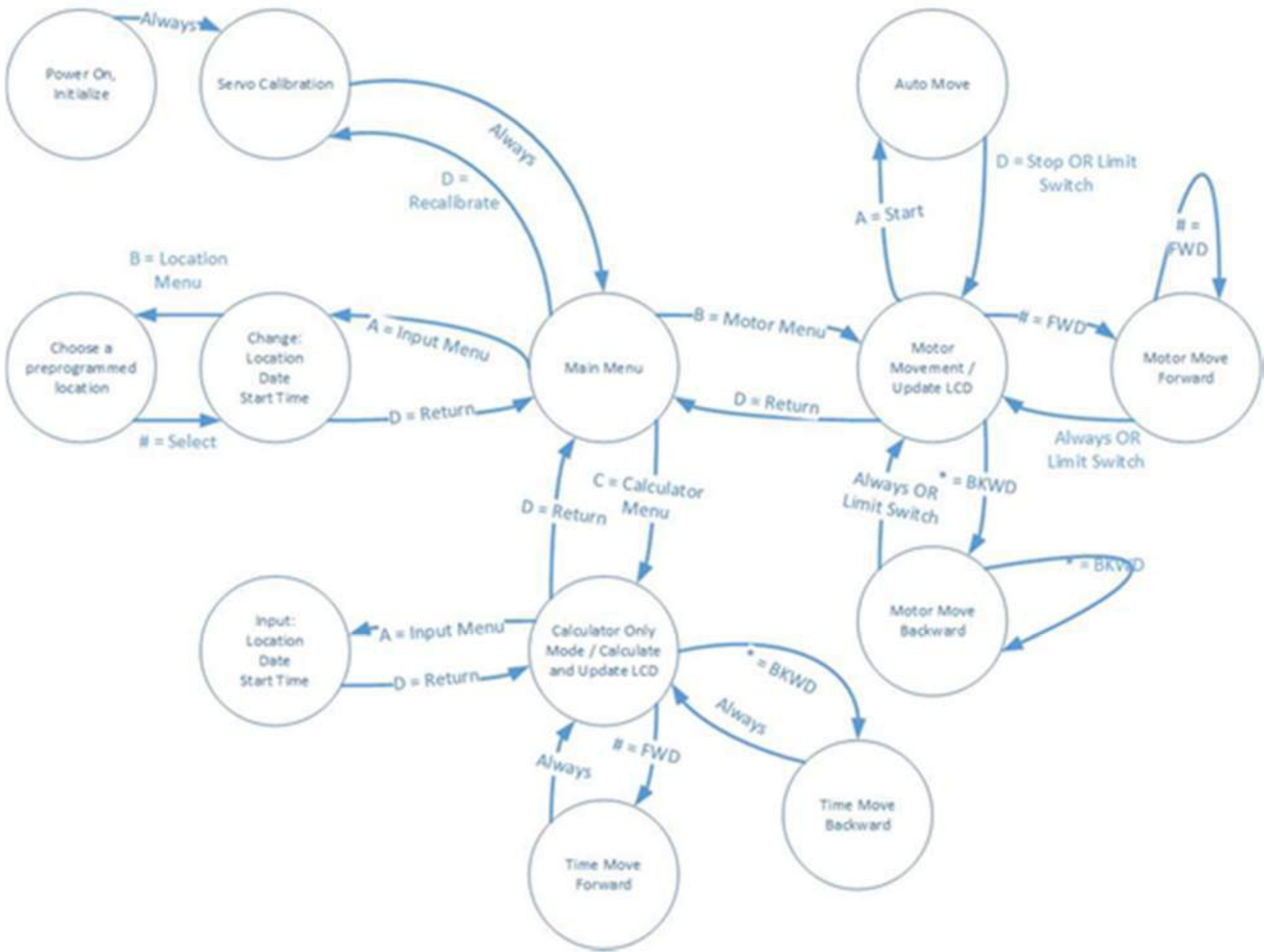


Appendix D: Final Heliodon Design:



Appendix E: Function State Diagram:

This function state diagram outlines the user's interaction with the planned (but not implemented) control system.



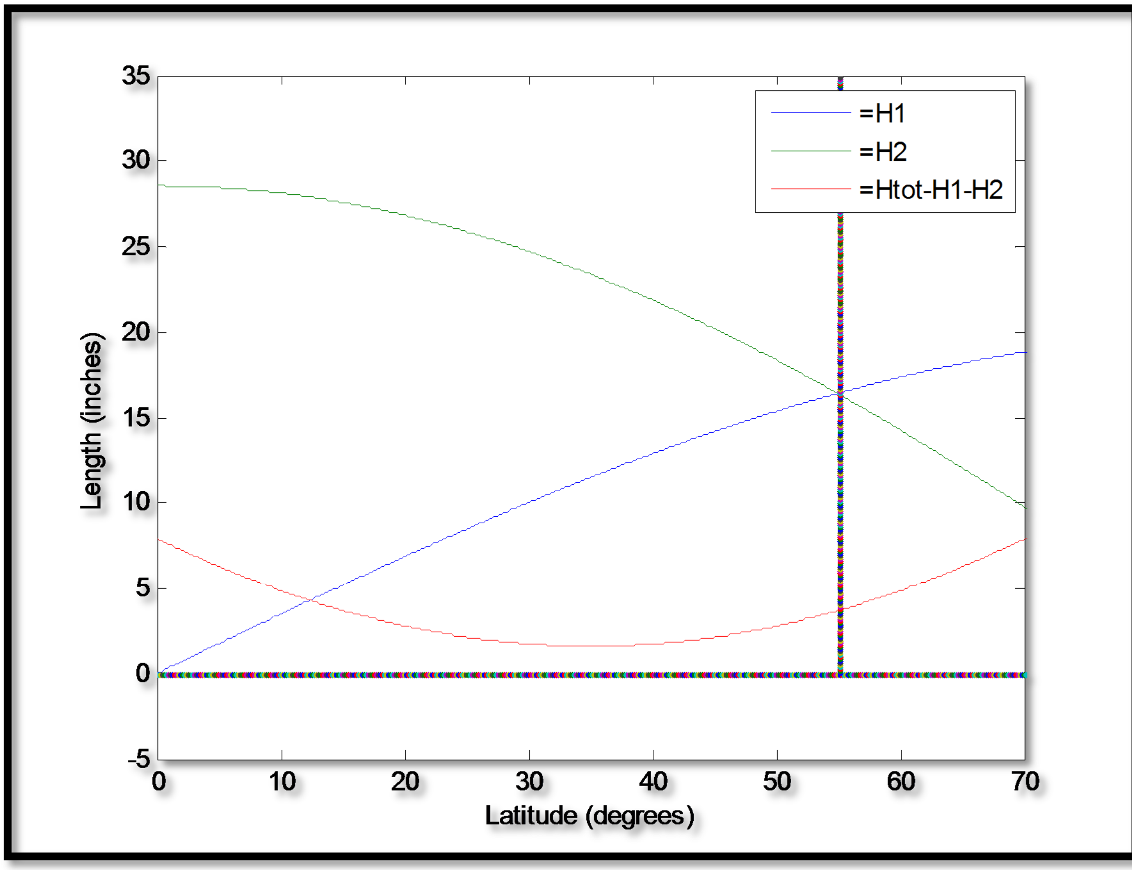
Appendix F. MATLAB Codes:

This appendix shows the MATLAB codes for the latitude simulations, for the spool and drive cable calculations, and for the spool mounting plate deflection.

Latitude Simulation Code:

Our inputs are a 300 out of 360 degree arch of radius 33 inches and a frame to table height of 38 inches. The output graph showing the results is on the following page.

```
% MATLAB CODE WITH A 5.5FT ARCH, 38IN HTOTAL, AND 300O ARCH (RBOTTOM=28
INCHES)

Rarch = 33;                      % Arch radius (minus light), inches
Ls = (Rarch-3)*tand(23.5)+7;     % Half slot length + extra, inches
Htotal = 36.5;                   % Max table to top of bottom of frame, inches
Rbottom =28.57;                  % Length of bottom half of arch, inches

arch_angle = asind(Rbottom/Rarch)*2+180; % Angle of the arc, degrees

thetaL =zeros(900,1);        % Latitude range, degrees
H1 = zeros (900,1);          % Table to slot at max latitude, inches
H2 = zeros (900,1);          % Slot bottom to bottom of arch, inches


% Calculating values for H1 and H2 for ThetaL from 0 to 90 Degrees

for i = 1:900
thetaL(i) = i/10;
H1(i)=Ls*sind(thetaL(i));
H2(i)=Rbottom * cosd(thetaL(i));
H=H1(i)-H2(i);

% Latitude angle at which sunset and sunrise cannot be shown

if (H>-.1 && H<.1)
    ThetaPrime = thetaL(i);
end

end

% plot(thetaL,H1+1,thetaL,H2),legend('H1','H2');

plot(thetaL,H1,thetaL,H2,thetaL,Htotal-H1-H2,thetaL,0,ThetaPrime,thetaL)
xlabel('Latitude (degrees)'),ylabel('Length (inches)')
legend('=H1','=H2','=Htot-H1-H2')
axis([0,70,-5,35]);
```



=H1
=H2
=Htot-H1-H2
Length (inches)
Latitude (degrees)
35
30
25
20
15
10
5
0
-5
0
10
20
30
40
50
60
70

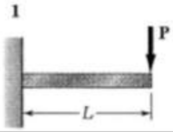
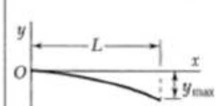
Spool and Drive Cable Calculations

```
%Spool Shaft Diameter Calculation

d_cable = 1/32;                %cable diameter [in]

ratio = 2;                     %Gear Ratio:1

TPI = 32/ratio;                %Threads per inch needed

d_arch = 5.5*12                %arch diameter [in]

L_cable = pi()*d_arch*5/6      %cable length to span one way of one arch [in]

d_spool = 1;                   %input spool diamter [in]

N = L_cable/(pi()*d_spool)     %number of turns to move carriage all the way across the arch

Cable_travel = N * d_cable     %linear length the cable will spool along the arch [in]

Total_cable_in = 4*L_cable

Total_cable_yards = Total_cable_in*1/12*1/3
```

Spool Mounting Plate Deflection:

```
%Mounting Plate Deflection Calculator
```

This calculator uses a beam of length L = L1+L2 with force P at 2(L)/3 from the fixed end of the beam. This is for a sudo - superposition method. This model coincides with case seen in the figure below.

Beam and Loading	Elastic Curve	Maximum Deflection	Slope at End	Equation of Elastic Curve
1 		$-\frac{PL^3}{3EI}$	$-\frac{PL^2}{2EI}$	$y = \frac{P}{6EI}(x^3 - 3Lx^2)$

This calculator calculates the deflection due to a lumped force P which is not at the end of the beam L, but is at some middle position L1. This deflection has been called D1 and its equation coincides with the maximum deflection for case 1. The calculator also finds the deflection D2, which is the additional deflection after the application of P due to the slope at point L1 from P and the additional length L2 to reach the free end of the beam. The total deflection is the sum of D1 and D2.

Parameters such as width, b, length, L, and thickness, h, component weight, the placement of the lumped force at L1, total length L, can be modified below.

```
E_Al=10*10^6;                 %Modulus of Elasticity of Aluminum [psi]
rho_Al=0.0975;                %Denisity of Aluminum [lb/in^3]
b=8;                          %Width of Aluminum plate [in]
L1=8;                         %Length 1 [in]
L2=4;                         %Length 2 [in]
L = L1+L2;                    %Total Length of Aluminum plate [in]
h=.25;                        %Thickness [in]
W_plate = b*L*h*rho_Al        %Weight of Aluminum Plate [lbs]
I = (1/12)*b*(h^3);           %Moment of Inertia of Rectange about x-centroidal
axis [in^4]
component_weight = 10;        %Weight of all spool equipment [lbs]
P =component_weight + W_plate;              %Weight of everything assuming
component weight of 10 lbs [lbs]

d1=(P*(L1^3))/(3*E_Al*I)    %Deflection from force of Case 1 [in]

d2=(L2*(sin((P*L1^2)/(2*E_Al*I)))) %Deflection from slope in case 1 and
additional length [in]

d_max = d1+d2
```

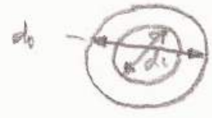
Appendix G. Full Hand Calculations:

Weight Estimations:

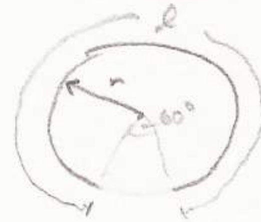
WEIGHT ESTIMATIONS

ARCHES: $W = \rho V$

ALUMINUM $\rho = \frac{169\,lb_f}{ft^3}$



$d_i = 0.88\,in$
$d_o = 1.25\,in$



$\ell = 2\pi r\left(\frac{5}{6}\right)$

$\ell = 2\pi(2.75\,ft)\frac{5}{6}$

$\ell \approx 14.39\,ft$

$V = \frac{\pi}{4}\left((1.25\,in)^2 - (0.88\,in)^2\right)\left(\frac{1\,ft}{12\,in}\right)^2(15\,ft)$

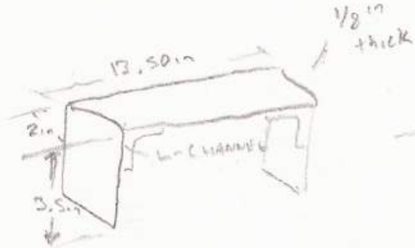
$V = 0.0644\,ft^3$

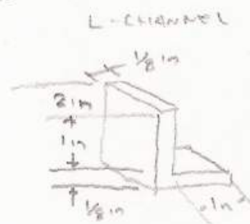
$W = 10.89\,lb$

$\boxed{\text{2 ARCHES} \approx 25\,lbs}$

BRACKETS

ALUMINUM $\rho = \frac{169\,lb_f}{ft^3}$





$V = \left[2(2\,in)(3.5\,in) + (2\,in)(13.5\,in) + 2\left[(1.125\,in)(2\,in) + (1\,in)(2\,in)\right]\right]\frac{1}{8}\,in$

$V = [41\,in^2 + 8.5\,in^2][\tfrac{1}{8}\,in]\left(\frac{1\,ft}{12\,in}\right)^3$

$V = 0.00358\,ft^3$

$W = 0.605\,lb$

$\boxed{\text{6 BRACKETS} \approx 5\,lb}$

$\boxed{\text{CABLES \& WIRING} \approx 10\,lb}$

$\boxed{\text{CARRIAGE} \approx 5\,lb}$

$\boxed{\text{MOTOR} \approx 1\,lb}$

CABLES

$V = \pi(\underbrace{0.137795\,in}_{3.5\,mm})^2(30\,ft)\left(\frac{1\,ft}{12\,in}\right)^2$

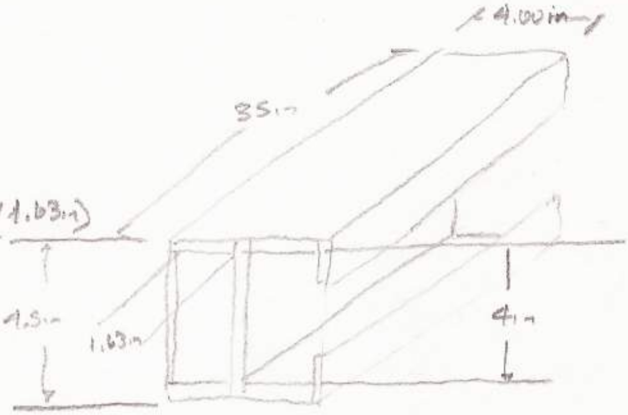
$V = 0.012427\,ft^3$

$\rho_{steel} = 0.284\,lb/in^3 \times \left(\frac{12\,in}{1\,ft}\right)^3 = 490.75\,lb/ft^3$

$W = 6\,lb$

SLOTS

ALUMINUM $\rho = \frac{169 lb}{ft^3}$



$V = (4.5in)(35in)(4in) - 2(4in)(35in)(1.63in)$

$V = 175in^3 \times \left(\frac{1ft}{12in}\right)^3$

$V = 0.100 ft^3$

$W = 16.9 lb$

$\boxed{2 \text{ SLOTS} \approx 35 lb}$

THREADED ROD

STEEL DENSITY : $0.284 lb/in^3$

2 (1ft rods) $V = l\pi r^2$

$(12in)(\pi)(0.5in)^2 = V$

$V = 4.71 in^3$

$W = 1.34 lb$

$\boxed{2 \text{ RODS} \approx 3 lb}$

FRAME → ALUMINUM

$V = [2(88in) + 4(9in)][0.824in^2] + [4(37.25in) + 4(34.50in) + 6(24in)][0.457$

$+ 3(24in)[0.824in^2]$

$V = 175in^3 + 200in^3 + 60in^3$

$V = 435in^3 \left(\frac{1ft}{12in}\right)^3$

$W = \rho_{ALUM} V + W_{FASTENERS}^{20lbs}$

$\boxed{\text{FRAME} \approx 70 lbs}$

$\boxed{\text{4 WHEELS} \approx 36\text{lbs}}$

TABLE

$\rho_{WOOD} = 2.60 lb/ft^2$ for .75in thick

$A = \pi r^2 = \pi \left(\frac{4.5ft}{2} \right)^2$

$A = 16 ft^2$

$\boxed{\text{TABLE} = 45\text{lb}}$

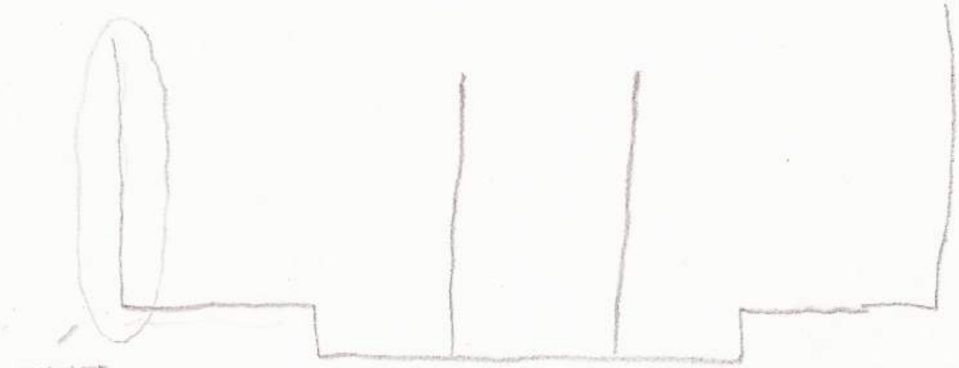
$\boxed{\text{INTERFACE} \approx \quad}$

$\boxed{\text{HELIODON TOTAL WEIGHT} \approx 250\text{lb}}$

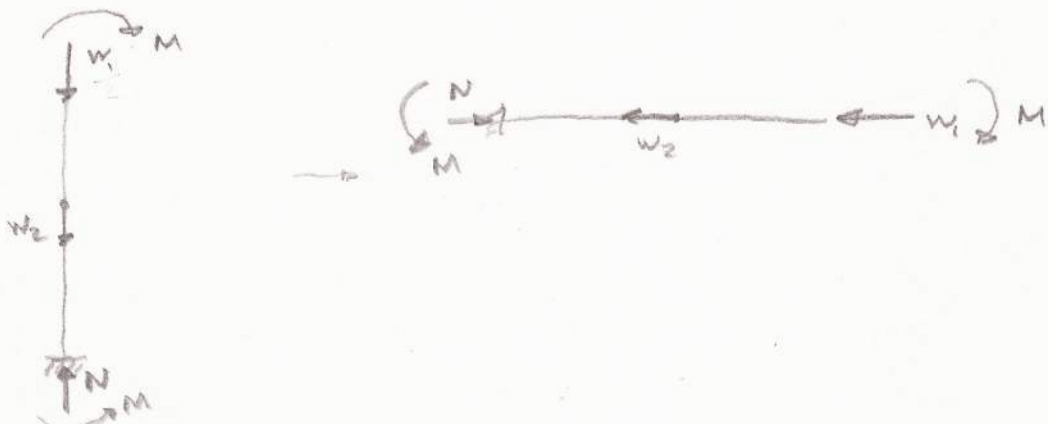
Frame Deflection Calculations:

Upright Columns:

FRAME DEFLECTION



ANALYZED LIKE CANTILEVER



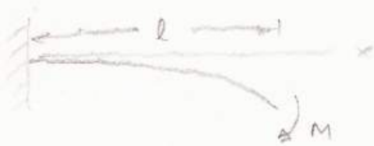
$W_2 = \left(\frac{169\,lb}{ft^3}\right)\left(\frac{1\,ft}{12\,in}\right)^3(0.457\,in^2)(34.5\,in)$

— $W_2 = 2\,lbs$

$W_1 = \frac{1}{4}\left[\overset{25\,lbs}{W_{ARCHES}} + \overset{35\,lbs}{W_{SLOTS}} + \overset{3\,lbs}{W_{RODS}} + \overset{5\,lbs}{W_{BRACKETS}} + \overset{5\,lbs}{W_{CARRIAGE}} + \overset{10\,lbs}{W_{CABLES\,\&\,WIRING}} + \overset{1\,lb}{W_{MOTOR}}\right]$

— $W_1 = 21\,lbs$

— $M = W_1(3.75\,ft) = 78.75\,lb\,ft$



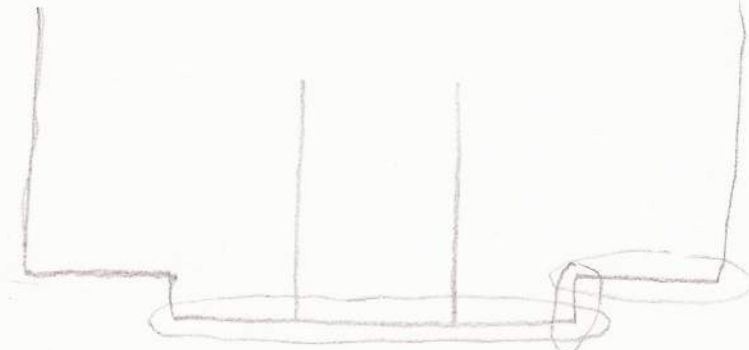
$d_{max} = \frac{Ml^2}{2EI}$ $E_{ALUM} = 10\times10^7\,lb/in^2$

I 1×1 T-SLOT $= 0.046\,in^4$

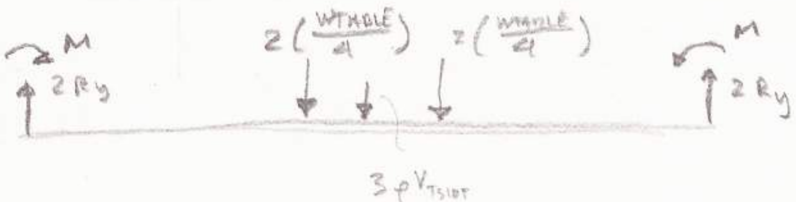
$$d_{max} = \frac{\left(78.75\,lbft \times \frac{12\,in}{1\,ft}\right)(34.5\,in)^2}{2(10^7\,lb/in^2)(0.046\,in^4)}$$

$d_{max} = 1.22\,in$ — TOO MUCH DEFLECTION, NEED TO USE EITHER 2×1 T-SLOT OR HAVE MORE SUPPORTS

FRAME DEFLECTION



FBD



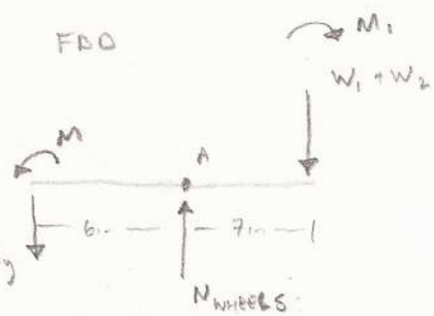
$$4R_y = W_{TABLE} + 3\left(\frac{164\,lbs}{ft^3}\right)\left(\frac{1ft}{12in}\right)^3(0.824\,in^2)(74\,in)$$

$$4R_y = 45lb + 20lb$$

$$R_y = 16.25lb$$

FBD

FBD



$+\circlearrowleft \Sigma M_A = 0$

$$R_y(6in) + M = (W_1 + W_2)(7in) + M_1$$

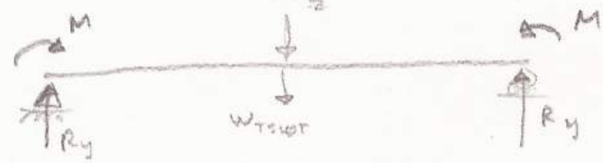
$$M = 161\,lb\cdot in + 995\,lb\cdot in = 97.5\,lb\cdot in$$

$$M = 1000\,lb\cdot in$$

Bottom Beam:

BOTTOM BEAM
DEFLECTION

USE SUPERPOSITION



CASE 1 (2x)

$$\delta_{center} = \frac{Ml^2}{16EI}$$

CASE 2

$$\delta_{max} = \frac{Pl^3}{48EI}$$

$$\delta_{CENTER} = \underbrace{\frac{2Ml^2}{16EI}}_{2\text{ CASE }1} + \underbrace{\frac{Pl^3}{48EI}}_{\text{CASE }2}$$

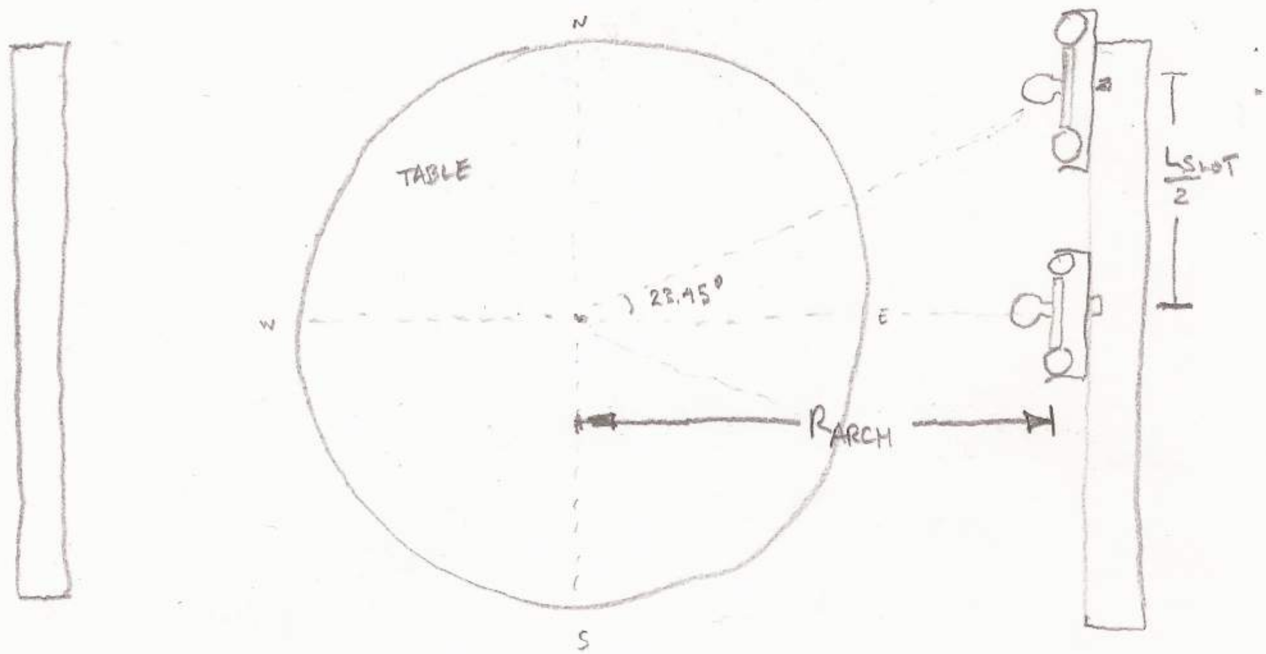
$$\delta_{CENTER} = \frac{1}{8}\left[\frac{(1000\,lb\,in)(56\,in)^2}{16(10^7\,lb/in^2)(0.341\,in^4)}\right] + \frac{(50\,lb)(56\,in)^3}{48(10^7\,lb/in^2)(0.341\,in^4)}$$

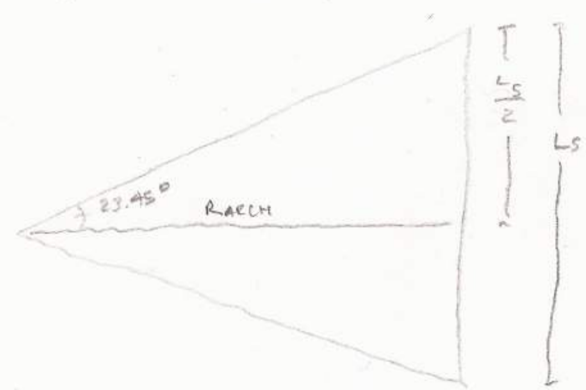
$$\delta_{CENTER} = 0.00619\,in + 0.0536\,in$$

$$\delta_{CENTER} = 0.0598\,in$$

Slot Length Calculation:

SLOT LENGTH CALCULATION



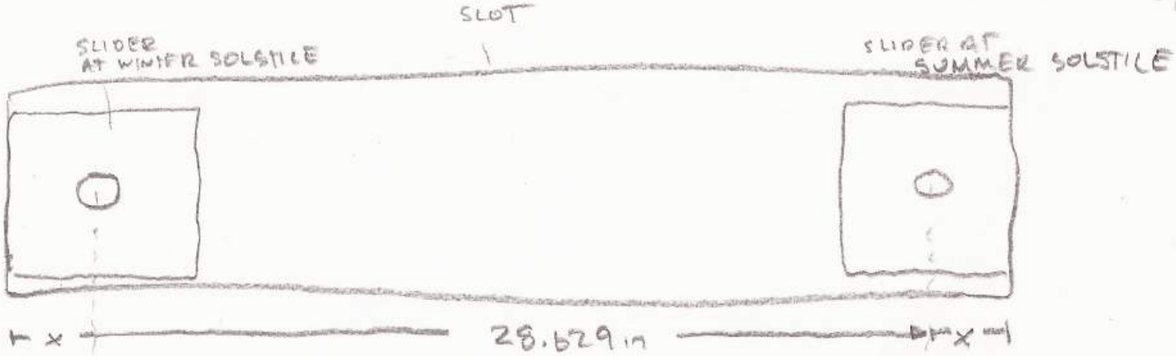


$$\tan 23.45 = \frac{\left(\frac{L_{SLOT}}{2}\right)}{R_{ARCH}}$$

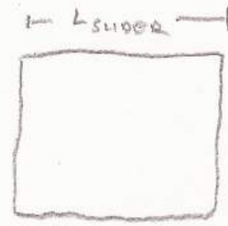
$$L_{SLOT} = 2 R_{ARCH} \tan 23.45$$

R_{ARCH} : 2.75 ft , 33 in

L_{SLOT} = 28.629 in



$x = \frac{L_{SLIDER}}{2}$

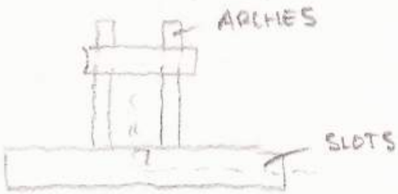


SLOT LENGTH → 28.629 in + L_{SLIDER}

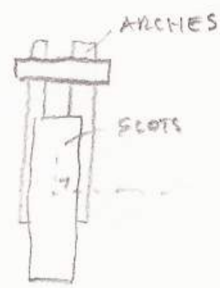
DOOR FRAME ≈ 34 in

$L_{SLIDERMAX}$ = 5.371 in — IF WE DO NOT ROTATE ARCHES INDEPENDENT OF SLOTS

WE NEED TO ROTATE SLOTS TO GET THROUGH A DOOR ∴ ARCHES WILL NEED TO ROTATE INDEPENDET OF SLOTS



OPERATING MODE



TRANSPORT MODE

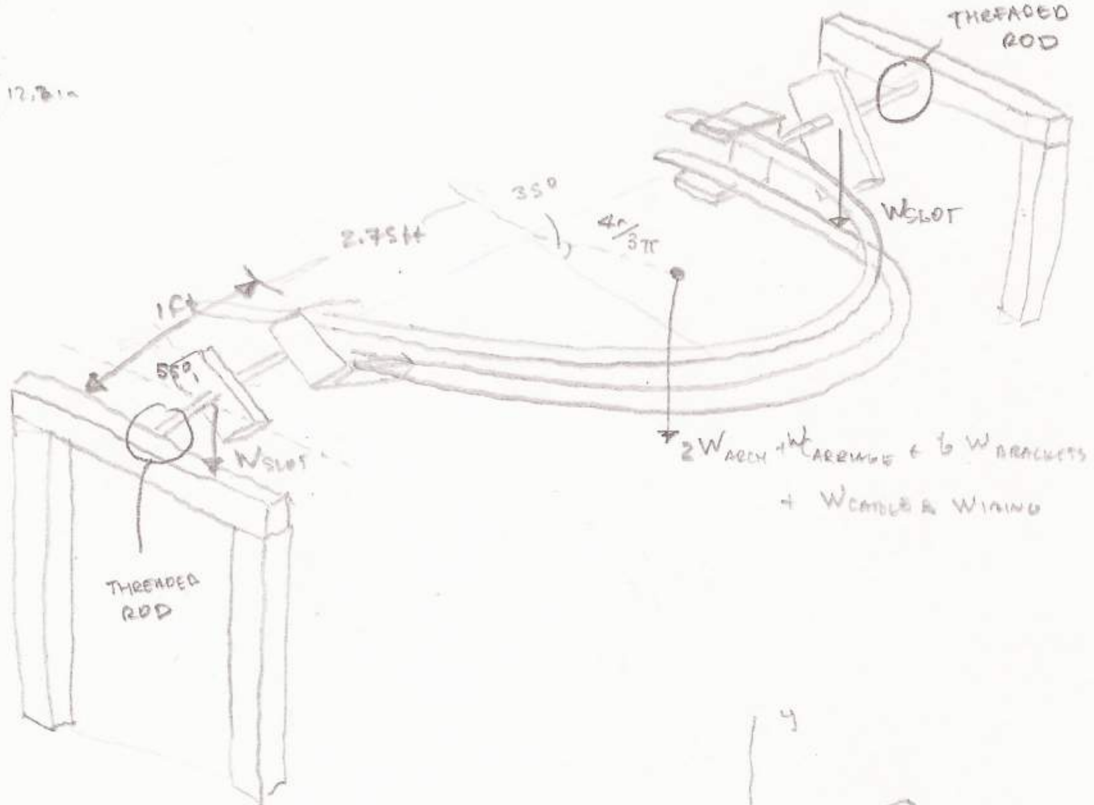
DECIDE

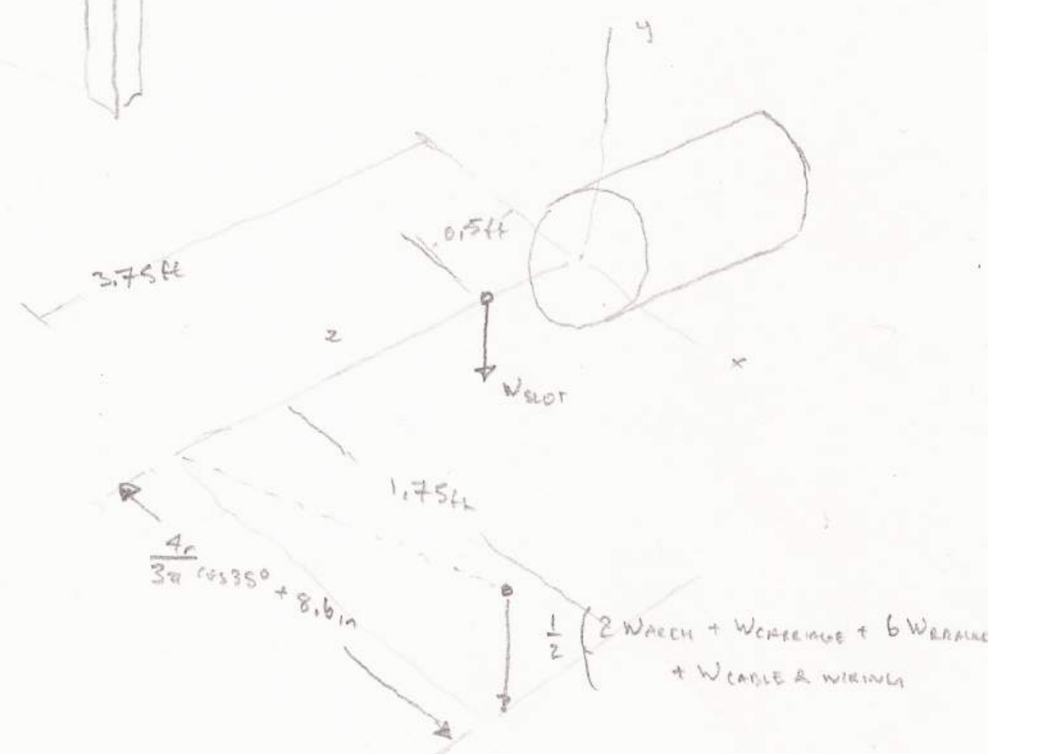
$$\boxed{\begin{aligned} L_{SLIDER} &= 6\text{ in} \\ L_{SLOT} &= 35\text{ in} \end{aligned}}$$

Threaded Rod Stress Analysis:

THREADED ROD

STRESS ANALYSIS



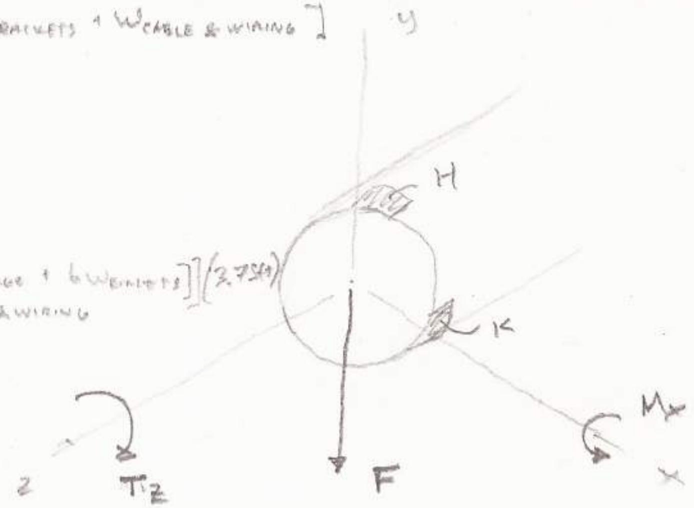


$$F = W_{SLOT} + \frac{1}{2}\left[2W_{ARCH} + W_{CARRIAGE} + 6W_{BRACKETS} + W_{CABLE\ \&\ WIRING}\right]$$

$$F = 17.5\,lb + \frac{1}{2}\left[46\,lb\right]$$

$$\boxed{F = 40.5\,lb}$$

$$M_x = (W_{SLOT})(0.5ft) + \left[\frac{1}{2}\left[2W_{ARCH} + W_{CARRIAGE} + 6W_{BRACKETS} + W_{CABLE\ \&\ WIRING}\right]\right](3.75ft)$$



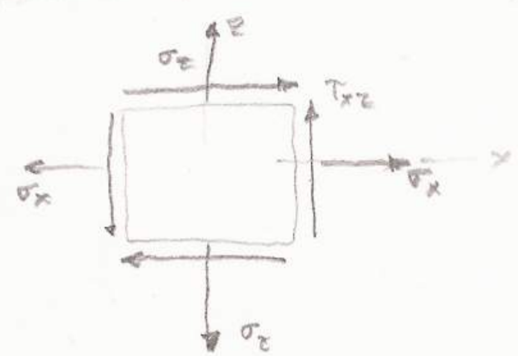
$$M_x = 8.75\,lb\text{-}ft + 86.25\,lb\text{-}ft$$

$$\boxed{M_x = 95\,lb\,ft} \rightarrow \boxed{1140\,lb\,in}$$

$$T_z = (1.75ft)\left(\frac{1}{2}\right)(46\,lb)$$

$$\boxed{T_z = 40.25\,lb\text{-}ft} \rightarrow \boxed{483\,lb\text{-}in}$$

STRESS AT H



$$\sigma_z = \cancel{\frac{F_{AXIAL}}{A}}^{\,0} + \frac{Mc}{I}$$

$$\sigma_z = \frac{M_x(r_{rod})}{\frac{\pi}{4}(r_{rod})^4}$$

$$\sigma_z = \frac{4M_x}{\pi(r_{rod})^3}$$

$$\sigma_x = \cancel{\frac{F_{AXIAL}}{A}}^{\,0} + \cancel{\frac{Mc}{I}}^{\,0}$$

$$\sigma_x = 0$$

$$\tau_{xz} = \cancel{\frac{VQ}{It}}^{\,0} + \frac{Tr}{J}$$

$$\tau_{xz} = \frac{T_z(r_{rod})}{\frac{\pi}{2}(r_{rod})^4}$$

$$\tau_{xz} = \frac{2T_z}{\pi(r_{rod})^3}$$

STEEL

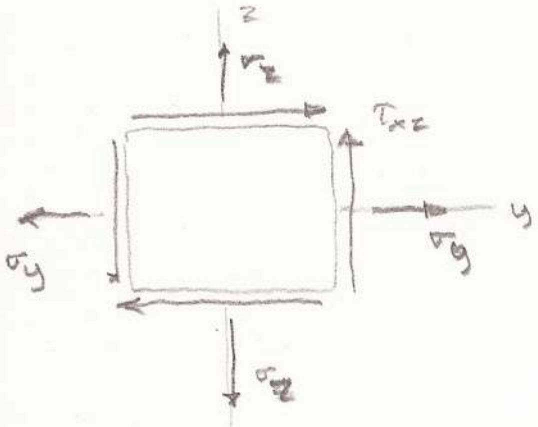
USING 0.75 in DIAMETER ROD

$r_{rod} = 0.375\,in$

$\sigma_z = 27.524\,ksi$

$\tau_{xz} = 5.83\,ksi$

STESS AT K



$$\sigma_y = \cancel{\frac{F_{AXIAL}}{A}}^{\,0} + \cancel{\frac{Mc}{I}}^{\,M=0}$$

$$\sigma_z = \cancel{\frac{F_{AXIAL}}{A}}^{\,0} + \cancel{\frac{Mc}{I}}^{\,c=0}$$

$$\tau_{xz} = \frac{VQ}{It} + \frac{Tr}{J}$$

$$\tau_{xz} = \frac{3V}{2A} + \frac{2T_z}{\pi (r_{rod})^3}$$

USING 0.75in DIAMETER ROD (STEEL)

$r_{rod} = 0.375\text{in}$

$$\tau_{xz} = \frac{3(40.5\text{lb})}{2(\pi(.375\text{in})^2)} + \frac{2(483\text{lb}\cdot\text{in})}{\pi(0.375\text{in})^3}$$

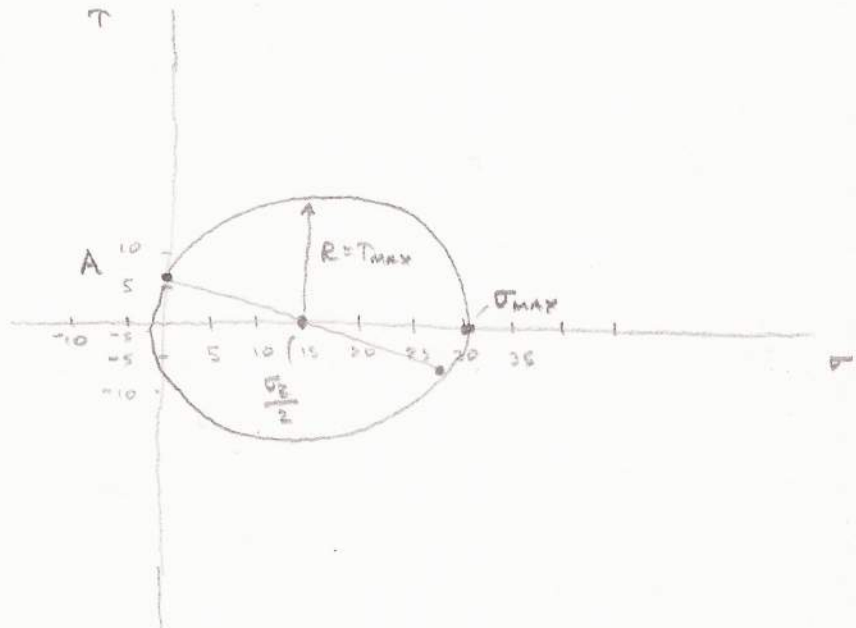
$\tau_{xz} = 5.967\text{ksi}$

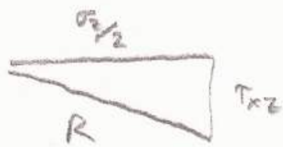
Mohr's Circle

$A = (0, \tau_{xz})$

$B = (\sigma_z, -\tau_{xz})$

VALUES AT POINT H





$$R = \tau_{max} = \sqrt{\left(\frac{\sigma_z}{2}\right)^2 + \tau_{xz}^2}$$

$\tau_{max} = 14.94\text{ ksi}$

$$\sigma_{MAX} = \frac{\sigma_z}{2} + R$$

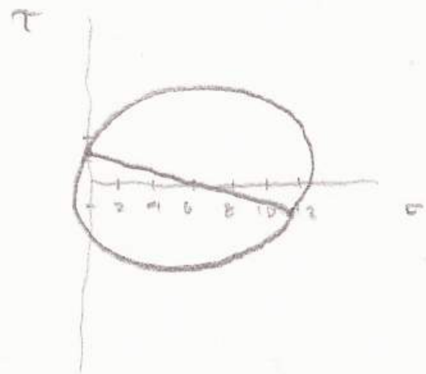
$\sigma_{MAX} = 42.46\text{ ksi}$

$\sigma_{max} > \sigma_{yeild}$ FOR STEEL

$\sigma_{yeild} = 36\text{ ksi}$

USE 1 in DIAMETER ROD

$r_{rod} = 0.5\,in$



$\sigma_z = 11.61\,ksi$

$\tau_{xz} = 2.46\,ksi$

$A = (0, \tau_{xz})$

$B = (\sigma_z, -\tau_{xz})$

$$\tau_{max} = \sqrt{\left(\frac{\sigma_z}{2}\right)^2 + \tau_{xz}^2}$$

$\tau_{max} = 6.3\,ksi$

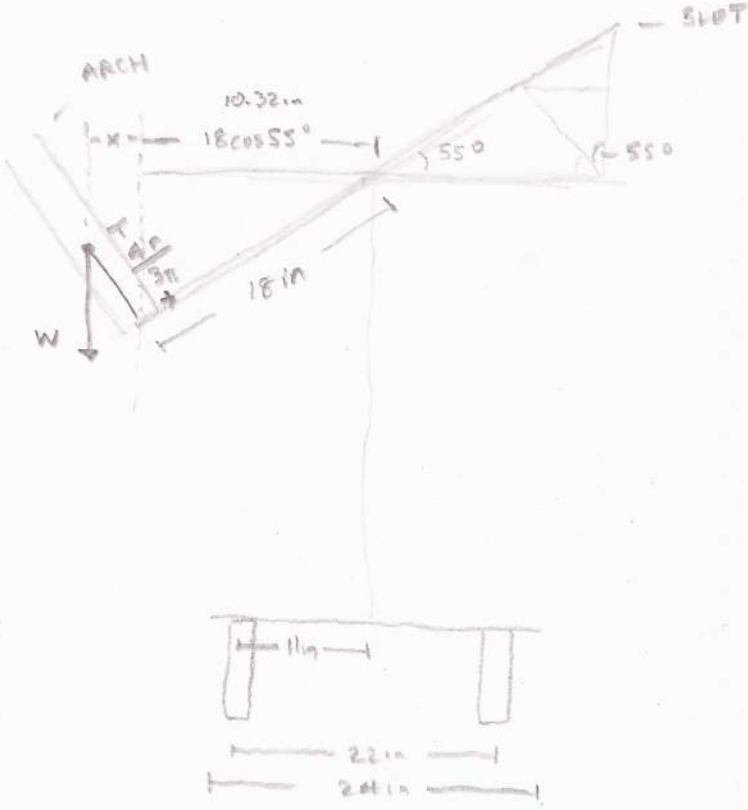
$\sigma_{max} = \tau_{max} + \frac{\sigma_z}{2}$

$\sigma_{max} = 12.105\,ksi$

$\boxed{\text{USE 1 IN DIAMETER ROD}}$

Tipping Analysis:

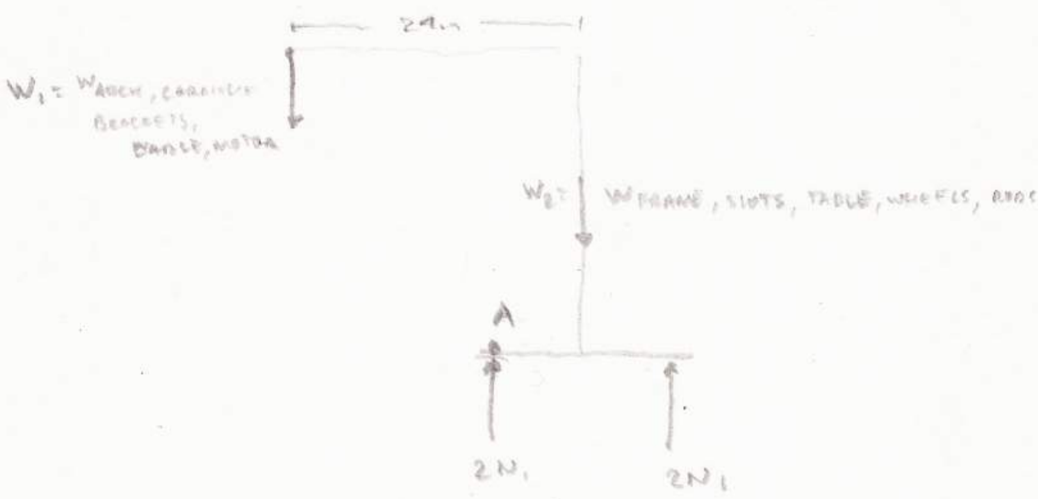
Extreme Operating Conditions:



$x = \frac{4r}{3\pi} \sin 55°$

$x = 11.47\,in$

MAX TIPPING MOMENT OCCURS AT OUR MAX LATITUDE AT EITHER SUMMER OR WINTER SOLSTICE



$W_1 = 46\,lbs$

$W_2 = 189\,lbs$

$(+\circlearrowleft)\ \Sigma M_A = 0$

$W_1(24in - 11in) + 2N_1(22in) - W_2(11in) = 0$

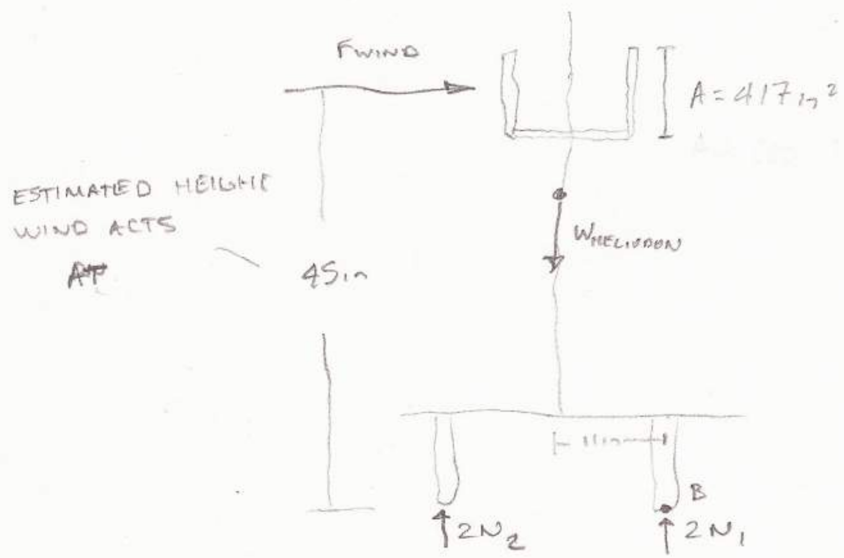
$(46lb)(13in) - (189lb)(11in) + (44in)N_1 = 0$

$N_1 = 33.7\,lb$

$\boxed{N_1 > 0 \quad \text{SO NO TIPPING}}$

Tipping From Wind:

TIPPING FROM
WIND
WHEN TRANSPORTING



WHAT IS
TOTAL SIDE AREA
OF HELIODON
IF WE MODEL ENTIRE
HELIODON AS FLAT
PLATE ?

$$F_{WIND} = \frac{C_d \rho_{AIR} V_{AIR}^2 A}{2}$$

C_d for Flat plate $\perp$ to flow $1.2 \rightarrow 2.0$

$C_d = 2.0$

$\rho_{AIR} = 4.61 \times 10^{-5}\ lb_f/in^3$

$V_{AIR} = 26.4\ in/s$

FIND F_{WIND} THAT WILL TIP HELIODON

$\curvearrowright + \; \Sigma M_B = 0 \qquad N_2 = 0$ AT TIPPING POINT

$$F_{WIND}(45in) = (W_{HELIODON})(11in)$$

$$F_{WIND} = \frac{W_{HELIODON}}{4}$$

$F_{WIND} \geq 62.5 lb$ IT TIPS

- LOTS OF ESTIMATIONS
- DON'T TRANSPORT IN WIND !!

Appendix H. Bill of Materials and Source List:

Bill of Materials:

CATEGORY	ITEM DESCRIPTION (Part #)	Qty	COST/ UNIT	TOTAL COST	SHIPPING	TAX
T-Slot Framing	T-Slot, 10-Series, 1x1 (4 inches required) (211)	2	Donated by T-Slots		$0.00	$0.00
	T-Slot, 10-Series, 1x1 (36.5 inches required) (211)	4	Donated by T-Slots		$0.00	$0.00
	T-Slot, 10-Series, 1x1 (22 inches required) (211)	6	Donated by T-Slots		$0.00	$0.00
	T-Slot, 10-Series, 1x1 (37 inches required) (211)	4	Donated by T-Slots		$0.00	$0.00
	T-Slot, 10-Series, 1x1 8 inches required) (211)	1	Donated by T-Slots		$0.00	$0.00
	T-Slot, 10-Series, 1x2 (13 inches required) (212)	4	Donated by T-Slots		$0.00	$0.00
	T-Slot, 10-Series, 1x2 (22 inches required) (212)	5	Donated by T-Slots		$0.00	$0.00
	T-Slot, 10-Series, 1x2 (28.5 inches required) (212)	6	Donated by T-Slots		$0.00	$0.00
	T-Slot, 10-Series, 1x2 (56 inches required) (212)	2	Donated by T-Slots		$0.00	$0.00
	4 Hole Inside Corner Bracket (213)	48	Donated by T-Slots		$0.00	$0.00
	8 Hole Inside Corner Bracket (214)	12	Donated by T-Slots		$0.00	$0.00
	4 hole Joining Strip (215)	8	Donated by T-Slots		$0.00	$0.00
	Right Angle Brace 1x1 6 inch (216)	8	Donated by T-Slots		$0.00	$0.00
	8 Hole Joining Plate (217)	32	Donated by T-Slots		$0.00	$0.00
	1" X 2" End Cap Black (218)	4	Donated by T-Slots		$0.00	$0.00
	1" X 1" End Cap Black (218)	4	Donated by T-Slots		$0.00	$0.00
	Compact Head Fasteners (219)	300	Donated by T-Slots		$0.00	$0.00
	Standard Fasteners (219)	324	Donated by T-Slots		$0.00	$0.00
	3 Hole Inside Corner Bracket (220)	4	Donated by T-Slots		$0.00	$0.00
	2 Hole Inside Corner Bracket (221)	16	Donated by T-Slots		$0.00	$0.00
Light Carriage	Dolly Track Swivel Wheels (297)	2	$29.97	$59.94	$0.00	$0.00
	Light Carriage Body (291)	1	Donated	Donated	$0.00	$0.00
	Carriage Top Plate (292)	1	Donated	Donated	$0.00	$0.00
	Carriage Bottom Plate (293)	1	Donated	Donated	$0.00	$0.00
	Wheel Mount Plate (295)	1	Donated	Donated	$0.00	$0.00
	Springs	2	$2.39	$4.78	$0.00	$1.13
	Threaded Shaft (294)	1	$7.49	$7.49	$0.00	$0.60
	Cable Graber shaft (296)	1	Donated	Donated	$0.00	$0.00
Arches	Arches 5.5' Diameter (281)	2	$175.00	$350.00	$0.00	$0.00
Portability	Casters (241)	4	$22.99	$91.96	$0.00	$7.60
	Caster Mounting Plate 24" (242)	1	$19.00	$19.00	$0.00	$0.00
Table Top	Maple Plywood (4 ft x 8 ft) (231, 232)	1	$40.34	$40.34	$0.00	$3.20
	Hinges (233)	4	$9.59	$38.36	$5.95	$3.48
	Sand Paper	3	$3.97	$11.91	$0.00	$1.35
	White Paint (234)	4	$3.48	$13.92	$0.00	$0.60
	Painters Touch 2X Gloss Clear (235)	2	$3.98	$7.96	$0.00	$0.32
	Paint Brush	1	$2.48	$2.48	$0.00	$1.47
	Wood Filler	1	$6.48	$6.48	$0.00	$0.00
	Painters Tape	1	$3.93	$3.93	$0.00	$0.00

Stock Metal	L Channel 2" x 2" x 1/8" , 140" long	1	$29.00	$29.00	$0.00	$14.92
	L Channel 1.25" x 1/8" , 2" long	2	$10.62	$21.24		
	1/8 x 4" H.R. Strip 20' (263, 264)	2	$31.28	$62.56		
	1/8 x 3" H.R. Strip 20"	1	$13.00	$13.00		
	1/8 x 2" H.R. Strip 6"	1	$11.00	$11.00		
	1/4 x 2" H.R. Flat 126" (261, 262, 265, 266, 267)	1	$25.00	$25.00		
	Latitude Plates (253)	1	$4.50	$4.50	$0.00	$0.37
Motor	Motor (301)	1	$120.00	$120.00	$10.00	$10.00
Spooling Mechanism	Mounting plate (302)	1	$24.00	$24.00	$0.00	$2.00
	48 tooth gear (303)	1	$7.19	$7.19	$6.99	$0.00
	24 tooth gear (304)	1	$4.79	$4.79		
	1 inch bore clamping hub (305)	1	$5.99	$5.99		
	1/2 inch bore clamping hub (306)	1	$7.99	$7.99		
	metal chain (307)	2	$8.99	$17.98		
	3/8 inch threaded shaft (314)	1	$7.99	$7.99	$0.00	$2.24
	1/2 Aluminum tube (313, 316)	1	$5.99	$5.99		
	1 inch Aluminum Tube (312)	1	$9.99	$9.99		
	Rubber Cap	1	$3.59	$3.59		
	1" Corner Bracket (311)	1	$7.48	$7.48	$0.00	$0.88
	UHMW (308, 309, 315)	1	$24.17	$24.17	$0.00	$0.00
Arch Wires	Kevlar Thread (317)	1	$12.00	$12.00	$0.00	$2.86
	Drive Wire Guides (268)	1	$9.99	$9.99	$0.00	$0.85
	Power Cable Guide Hooks	5	$1.92	$9.60	$0.00	$1.55
Power Supply	Light Bulb (321)	1	$20.97	$20.97	$0.00	$1.68
	Light Bulb Socket (322)	1	$12.47	$12.47	$0.00	$3.97
	Extension Cord (323)	1	$11.73	$11.73		
	Cable Spooler (324)	1	$31.97	$31.97		
	Junction Box 8x8x4	1	$22.64	$22.64	$0.00	$4.53
Slots	Alum Rec Tube (251, 252,)	1	$61.20	$61.20	$0.00	$0.00
	UHMW (256)	1	$39.44	$39.44	$18.82	$5.00
	1 Inch Threaded Shaft (257)	1	$23.99	$23.99	$0.00	$3.00
Hardware	Box of 1 Inch Nuts	1	$14.49	$14.49	$0.00	$1.16
	1 Inch Hex Nut	6	$1.99	$11.94	$0.00	$0.00
	Spray Paint Primer (270)	1	$6.99	$6.99	$0.00	$1.20
	Black Spray Paint (271)	1	$7.99	$7.99		
	Nuts for 3/8 16 tpi shaft	4	$0.12	$0.48	$0.00	$0.00
	Bolts for spooling	20	$0.26	$5.20	$0.00	$1.22
	Nuts for spooling	20	$0.16	$3.20		
	Washers for Spooling	30	$0.23	$6.90		
	Rivet ST1/8X1/2 100PK	1	$7.99	$7.99	$0.00	$1.28

	Rivet STL 3/16X3/8" 25PK	1	$3.99	$3.99		
	Bolt Eye w/Nut	4	$0.99	$3.96		
	Light Carriage Screws	8	$0.19	$1.52	$0.00	$0.00
	Wheel Mounting Plates Bolt 5/16x3/4	16	$0.16	$2.56	$0.00	$0.54
	Wheel Mounting Plates Nut 5/16	16	$0.11	$1.76		
	Wheel Mounting Plate 25 pack washer 1/4	1	$2.46	$2.46		
	Brass Hinge Screws #4x1/2"	3	$1.18	$3.54	$0.00	$0.00
	Flat Head Brass screws	4	$1.29	$5.16	$0.00	$0.00
	Wall/Pulley Ceiling 1 1/2" (269)	2	$4.28	$8.56	$0.00	$0.00
	1/4" 100 Box Washers	1	$8.88	$8.88	$0.00	$0.72
	Bolts 20X3/4"	1	$1.18	$1.18	$0.00	$0.00
	.4375 in L x 6-32 Cap screw (298)	1	$2.09	$2.09	$0.00	$0.00
	6-32x3/8 inch cap screw	4	$0.35	$1.40	$0.00	$0.00
	.220 Acrylic Sheet (254)	1	$54.97	$54.97	$0.00	$0.00
	Shaft Coupler (299)	2	$1.61	$3.22	$0.00	$0.00
	Epoxy	2	$5.59	$11.18	$0.00	$0.85
Summation Of Each Cost:				$1,509.61	$41.76	$80.57
Total Cost:						$1,631.94
Prototyping	Fasteners Springs	2	$3.19	$6.38	$0.00	$0.00
	Fasteners Springs	2	$1.49	$2.98		
	24" 3/4 inch threaded rod	1	$7.49	$7.49	$0.00	$2.10
	1-1/2" Rubber Wheel Caster	6	$2.47	$14.82		
	3/4 inch hex nut	8	$0.50	$4.00		
	Cable 3/16" 7X9	22	$1.29	$28.38	$0.00	$4.40
	Conduit	2	$2.99	$5.98		
	Screw ete .098X1	1	$1.71	$1.71		
	Flat HR Plain 1/8X2X48"	1	$13.99	$13.99	$0.00	$1.12
	Fastener	2	$3.54	$7.08	$0.00	$0.75
	Light Carriage screw	4	$0.17	$0.68	$0.00	$0.08
	Light Carriage screw	4	$0.08	$0.32		
	Sheet Screw	1	$1.18	$1.18	$0.00	$8.45
	Wood Screw #6x3/4"	2	$1.18	$2.36	$0.00	$0.00
Summation Of Each Cost:				$97.35	$0.00	$16.90
Total Cost:						$114.25

Part Source List:

Item Description	Part Number	Supplier
T-Slot, 10-Series, 1x1 (8 inches required)	650000	http://www.tslots.com/
T-Slot, 10-Series, 1x1 (10 inches required)	650000	http://www.tslots.com/
T-Slot, 10-Series, 1x1 (22 inches required)	650000	http://www.tslots.com/
T-Slot, 10-Series, 1x1 (34.50 inches required)	650000	http://www.tslots.com/
T-Slot, 10-Series, 1x1 (37.25 inches required)	650000	http://www.tslots.com/
T-Slot, 10-Series, 1x1 (40 inches required)	650000	http://www.tslots.com/
T-Slot, 10-Series, 1x2 (8.50 inches required)	650002	http://www.tslots.com/
T-Slot, 10-Series, 1x2 (13 inches required)	650002	http://www.tslots.com/
T-Slot, 10-Series, 1x2 (22 inches required)	650002	http://www.tslots.com/
T-Slot, 10-Series, 1x2 (28.5 inches required)	650002	http://www.tslots.com/
T-Slot, 10-Series, 1x2 (56 inches required)	650002	http://www.tslots.com/
4 Hole Inside Corner Bracket	653045	http://www.tslots.com/
8 Hole Inside Corner Bracket	653051	http://www.tslots.com/
4 hole Joining Strip	653054	http://www.tslots.com/
Right Angle Brace 1x1 6 inch	650000	http://www.tslots.com/
8 Hole Joining Plate	653098	http://www.tslots.com/
1" X 2" End Cap Black	655010	http://www.tslots.com/
1" X 1" End Cap Black	655000	http://www.tslots.com/
Compact Head Fasteners	651220	http://www.tslots.com/
Standard Fasteners	651221	http://www.tslots.com/
T-Slot Pivot	653000	http://www.tslots.com/
T-Slot Level Feet	651531	http://www.tslots.com/
2 Hole Inside Corner Bracket	653047	http://www.tslots.com/
Dolly Track Swivel Wheels	None	http://www.glidegear.net/
Light Carriage Body	Stock Metal	Cal Poly Shops
Springs	In Store	http://www.acehardware.com/
Threaded Shaft	In Store	http://www.acehardware.com/
Cable Graber shaft	Stock Metal	Cal Poly Shops
Arches 5.5' Diameter	Stock Metal	http://www.advancepipebending.com/
Casters	46819	http://www.harborfreight.com
Caster Mounting Plate 24"	Stock Metal	http://bbsurplus.com/

Maple Plywood (4 ft x 8 ft)	730232001628	http://www.homedepot.com/
Hinges	286260	http://www.hardwaresource.com/
Sand Paper	205415923	http://www.homedepot.com/
White Paint	205362565	http://www.homedepot.com/
Painters Touch 2X Gloss Clear	100670438	http://www.homedepot.com/
Paint Brush	100626363	http://www.homedepot.com/
Wood Filler	203211477	http://www.homedepot.com/
Painters Tape	1000085823	http://www.homedepot.com/
L Channel 2" x 2" x 1/8" , 140" long	Stock Metal	http://bbsurplus.com/
L Channel 1.25" x 1/8" , 2" long	Stock Metal	http://bbsurplus.com/
1/8 x 4" H.R. Strip 20'	Stock Metal	http://bbsurplus.com/
1/8 x 3" H.R. Strip 20"	Stock Metal	http://bbsurplus.com/
1/8 x 2" H.R. Strip 6"	Stock Metal	http://bbsurplus.com/
1/4 x 2" H.R. Flat 126"	Stock Metal	http://bbsurplus.com/
Latitude Plates	Stock Metal	http://bbsurplus.com/
Motor	HS-7954SH	https://www.servocity.com
Mounting plate	Stock Metal	http://bbsurplus.com/
48 tooth gear	615126	https://www.servocity.com/
24 tooth gear	615106	https://www.servocity.com/
1 inch bore clamping hub	545352	https://www.servocity.com/
1/2 inch bore clamping hub	545600	https://www.servocity.com/
metal chain	C250	https://www.servocity.com/
3/8 inch threaded shaft	Stock Metal	http://www.acehardware.com/
1/2 Aluminum tube	Stock Metal	http://www.acehardware.com/
1 inch Aluminum Tube	Stock Metal	http://www.acehardware.com/
Rubber Cap	In Store	http://www.acehardware.com/
1" Corner Bracket	202034303	http://www.homedepot.com/
UHMW	UHMW	https://www.interstateplastics.com
Kevlar Thread	KEV346NATL00B	http://www.thethreadexchange.com/
Drive Wire Guides	In Store	http://www.acehardware.com/
Power Cable Guide Hooks	202305418	http://www.homedepot.com/

Light Bulb	203553312	http://www.homedepot.com/
Light Bulb Socket	204835997	http://www.homedepot.com/
Extension Cord	100661440	http://www.homedepot.com/
Cable Spooler	204379332	http://www.homedepot.com/
Junction Box 8x8x4	100404099	http://www.homedepot.com/
Alum Rec Tube	stock metal	http://bbsurplus.com/
UHMW	UHMW	https://www.interstateplastics.com
1 Inch Threaded Shaft	stock metal	http://www.acehardware.com/
Box of 1 Inch Nuts	In Store	http://www.acehardware.com/
1 Inch Hex Nut	In Store	http://www.acehardware.com/
Spray Paint Primer	1495498	http://www.acehardware.com/
Black Spray Paint	1096056	http://www.acehardware.com/
Nuts for 3/8 16tpi shaft	In Store	http://www.acehardware.com/
Bolts for spooling	In Store	http://www.acehardware.com/
Nuts for spooling	In Store	http://www.acehardware.com/
Washers for Spooling	In Store	http://www.acehardware.com/
Rivet ST1/8X1/2 100PK	In Store	http://www.acehardware.com/
Rivet STL 3/16X3/8" 25PK	In Store	http://www.acehardware.com/
Bolt Eye w/Nut	In Store	http://www.acehardware.com/
Light Carriage Screws	In Store	http://www.acehardware.com/
Wheel Mounting Plates Bolt 5/16x3/4	In Store	http://www.homedepot.com/
Wheel Mounting Plates Nut 5/16	In Store	http://www.homedepot.com/
Wheel Mounting Plate 25 pack washer 1/4	204276388	http://www.homedepot.com/
Brass Hinge Screws #4x1/2"	202705647	http://www.homedepot.com/
Flat Head Brass screws	135212	http://www.hardwaresource.com/
Wall/Pulley Ceiling 1 1/2"	203001587	http://www.homedepot.com/
1/4" 100 Box Washers	203639697	http://www.homedepot.com/
Bolts 20X3/4"	In Store	http://www.acehardware.com/
.4375 in L x 6-32 Cap screw	In Store	http://www.acehardware.com/
6-32x3/8 inch cap screw	In Store	http://www.acehardware.com/
.220 Acrylic Sheet	202038052	http://www.homedepot.com/
Epoxy	100670610	http://www.homedepot.com/

Appendix I. Drawing List and Part Drawings:

100 – Top Level Assembly
200 – Frame Assembly
- **201 –** Frame Dimensions
- **210 –** Frame Cut List
- **210A –** Frame (T-Slot) Assembly (1)
- **210B –** Frame (T-Slot) Assembly (2)
- **210C–** Frame (T-Slot) Assembly (3)
  - **211 –** 1010 T-Slot 8020 Aluminum Data Sheet
  - **212 –** 1020 T-Slot 8020 Aluminum Data Sheet
  - **213 –** T-Slot 4 Hole Inside Corner Bracket Data Sheet
  - **214 –** T-Slot 8 Hole Inside Corner Bracket Data Sheet
  - **215 –** T-Slot 4 Hole Joining Strip Data Sheet
  - **216 –** T-Slot Right Angle Brace Data Sheet
  - **217 –** T-Slot 8 Hole Joining Plate Data Sheet
  - **218 –** T-Slot End Cap Data Sheet
  - **219 –** T-Slot Low Profile Hammerhead Bolt Data Sheet
  - **220 –** T-Slot 3 Hole Inside Corner Bracket Drawing
  - **221 –** T-Slot 2 Hole Inside Corner Bracket Data Sheet
- **230 –** Table Top Assembly
  - **231 –** Center Table Drawing
  - **231A –** Center Table (Table Mounting) Drawing
  - **232 –** Side Table Drawing
  - **233 –** Hinges Data Sheet
  - **234 –** Paint Data Sheet
  - **235 –** Polyurethane Finish Data Sheet
- **240 –** Caster Assembly
  - **241 –** Caster Data Sheet
  - **242 –** Caster Mounting Plate Drawing
- **250 –** Latitude Slots Assembly
  - **251 –** Slot Main Body Drawing
  - **252 –** Slot Connector Drawing
  - **253 –** Latitude Plates Drawing
  - **254 –** Latitude Angle Marker Drawing (AutoCAD Drawing. Not featured)
  - **255 –** Laser Cutter PDF File
  - **256 –** Sliders Drawing
  - **257 –** Threaded Shaft Drawing
- **260A –** Arch ¼ Bracket Assembly
- **260B –** Arch ⅛ Bracket Assembly
- **260C –** Arch 0°/180° Bracket Assembly
- **260D –** Arch Spool Bracket Assembly
- **260E –** Arch Pulley Bracket Assembly
  - **261 –** Steel Plate ¼ Side Drawing
  - **262 –** Steel Plate ¼ Top Drawing
  - **263 –** Steel Plate ⅛ Side Drawing
  - **264 –** Steel Plate ⅛ Top Drawing
  - **265 –** Steel Plate ¼ Pulley Mounting Drawing

- **266 –** Steel Plate ¼ Spool Mounting Drawing
- **267 –** Steel Plate 0°/180° Top Bracket Drawing
- **268 –** Wire Guides Data Sheet
- **269 –** Pulley Data Sheet
- **270 –** Spray Paint Primer
- **271 –** Black Spray Paint

280 – Arch Assembly

- **281 –** Arch Drawing

290 – Carriage Assembly

- **291 –** Carriage Body
- **292 –** Carriage Top Plate
- **293 –** Carriage Bottom Plate
- **294 –** Threaded Shaft Drawing
- **295 –** Slider Plate Drawing
- **296 –** Cable Grabbers Drawing
- **297 –** Carriage Wheels Data Sheet
- **298 –** Socket Head Cap Screw Data Sheet
- **299 –** Shaft Coupler Data Sheet

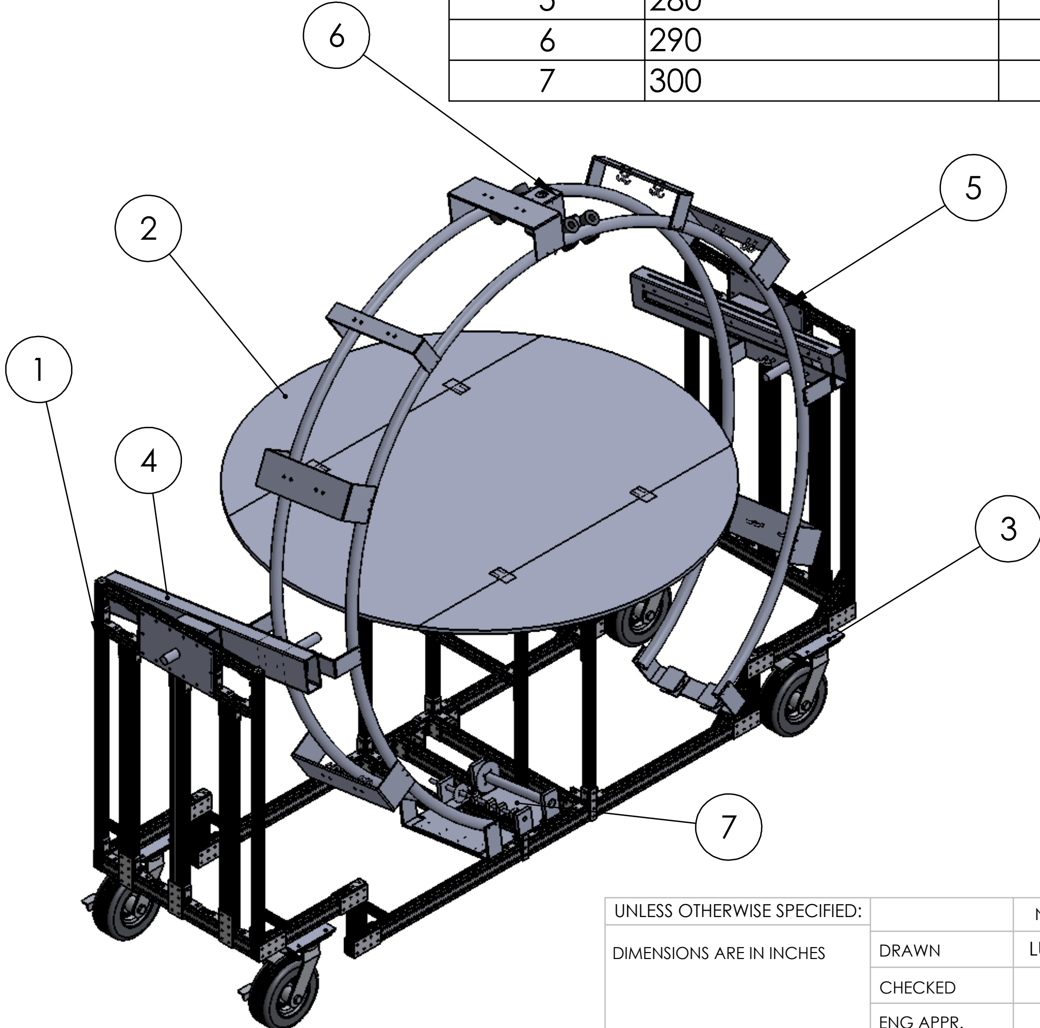
300– Spooling Assembly

- **301 –** Motor Data Sheet
- **302 –** Motor Mounting Plate Drawing
- **303 –** 48 Tooth Sprocket Data Sheet
- **304 –** 24 Tooth Sprocket Data Sheet
- **305 –** 1 Inch Bore Clamping Hub Data Sheet
- **306 –** ½ Inch Bore Clamping Hub Data Sheet
- **307 –** Chain Data Sheet
- **308 –** Wire Guides UHMW Drawing
- **309 –** 1 Inch Bearing Drawing
- **310 –** T-Slot Wire Guide Track Drawing
- **311 –** L Bracket Data Sheet
- **312 –** 1 Inch Shaft Drawing
- **313 –** ½ Inch Bearing Shaft Drawing
- **314 –** ⅜ Inch 16 TPI Threaded Shaft Drawing
- **315 –** ½ Inch Bearing Drawing
- **316 –** ½ Inch Sprocket Shaft Drawing
- **317 –** Kevlar Thread Data Sheet

320 – Power System

- **321 –** Light Bulb Data Sheet
- **322 –** Light Bulb Socket Data Sheet
- **323 –** Extension Cord Data Sheet
- **324 –** Cable Spooler Data Sheet

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	200	FRAME	1
2	230	TABLE TOP	1
3	240	CASTER	4
4	250	LATITUDE SLOTS	2
5	280	ARCH	1
6	290	CARRIAGE	1
7	300	SPOOLING	1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES	DRAWN	LUCAS	5/13/15	
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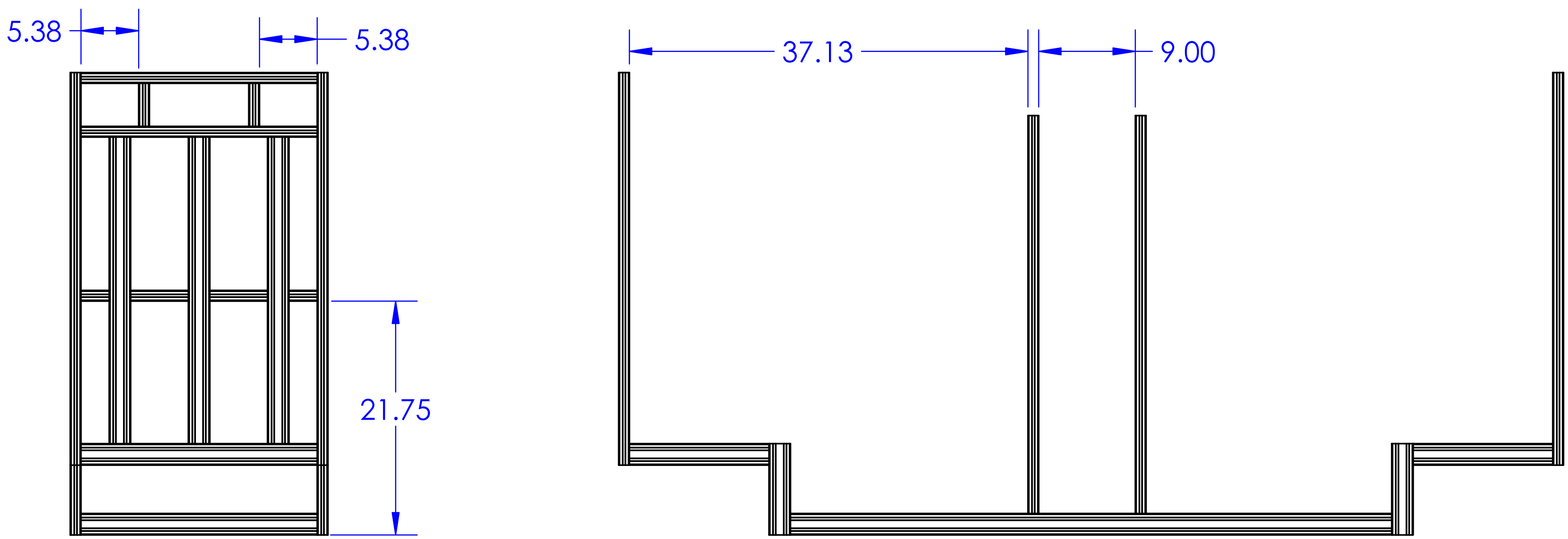
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL	COMMENTS:			SIZE A — DWG. NO. 100 — REV
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:20 — WEIGHT: — SHEET 1 OF 1

5 4 3 2 1



UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
6061 T-SLOT

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	GREG	5/3/15
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

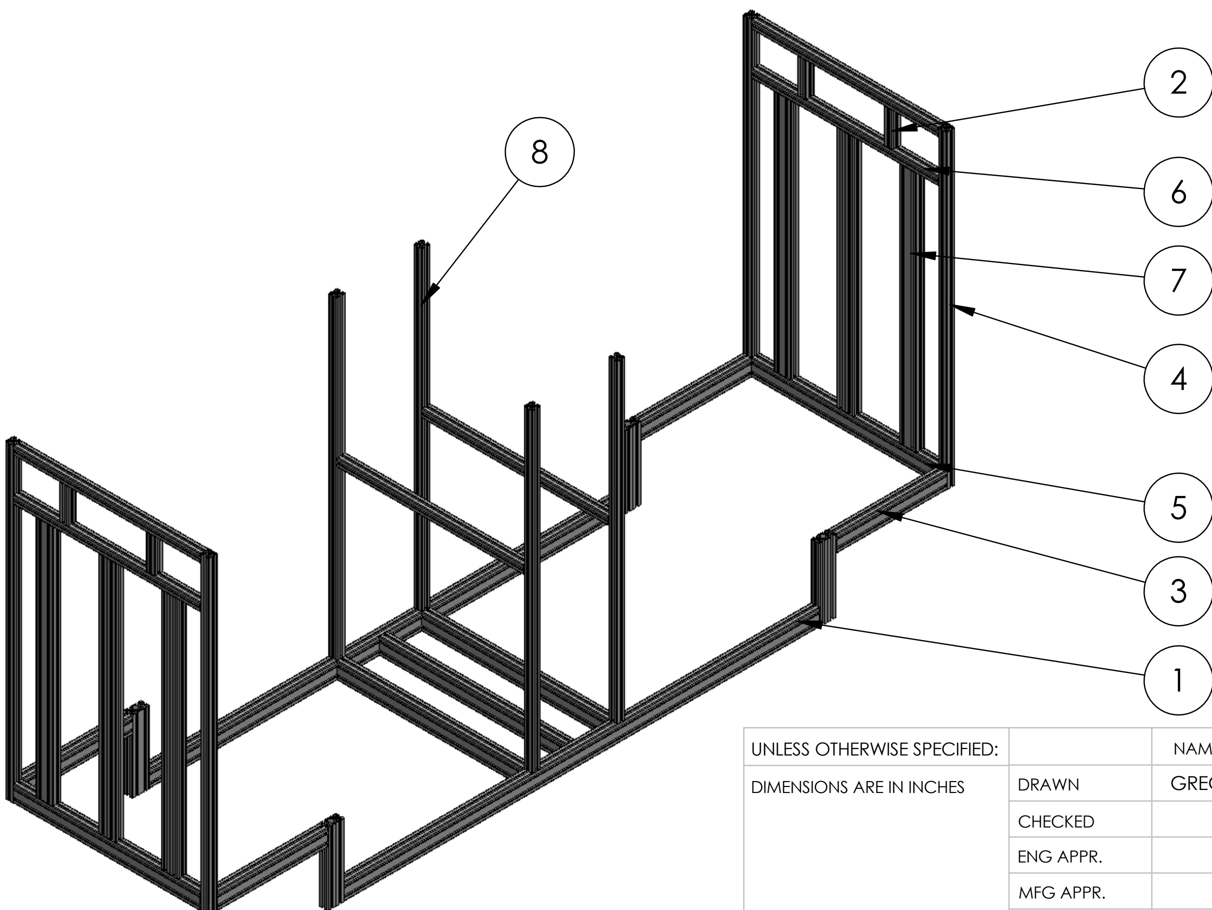
TITLE:
FRAME DIMENSIONS

SIZE A | DWG. NO. 201 | REV

SCALE: 1:32 | WEIGHT: | SHEET 1 OF 1

5 4 3 2 1

ITEM NO.	LENGTH	DESCRIPTION	QTY.
1	56	10-SERIES 1020 T-SLOT	2
2	4	10-SERIES 1010 T-SLOT	4
3	13	10-SERIES 1020 T-SLOT	4
4	36.5	10-SERIES 1010 T-SLOT	4
5	22	10-SERIES 1020 T-SLOT	5
6	22	10-SERIES 1010 T-SLOT	6
7	28.5	10-SERIES 1020 T-SLOT	6
8	37	10-SERIES 1010 T-SLOT	4



		NAME	DATE
UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES	DRAWN	GREG	5/3/15
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL 6061 T-SLOT	COMMENTS:		
FINISH			
DO NOT SCALE DRAWING			

TITLE:

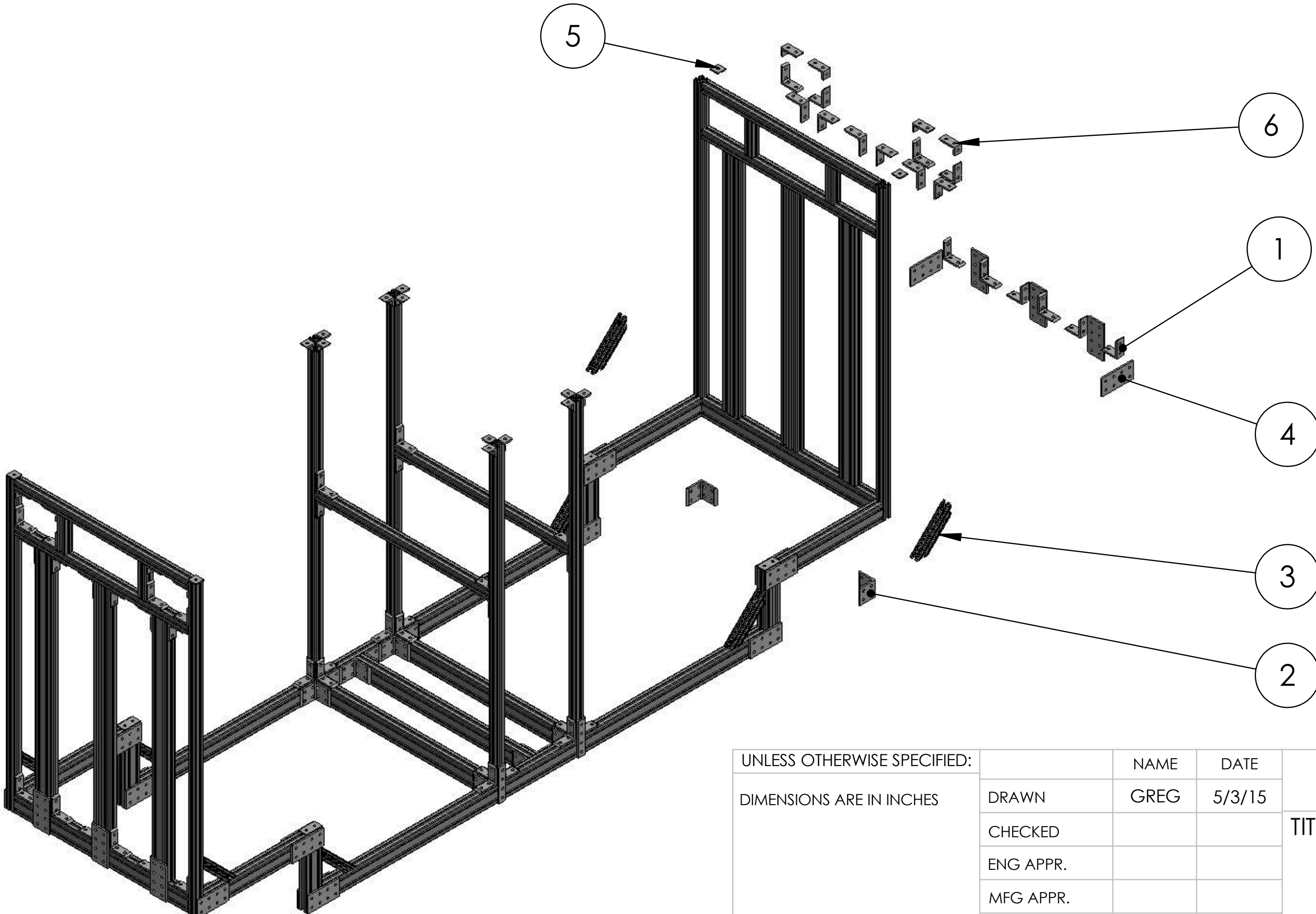
FRAME CUT LIST

SIZE A | DWG. NO. 210 | REV

SCALE: 1:16 | WEIGHT: | SHEET 1 OF 1

5 4 3 2 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	213	T-SLOT 4 HOLE INSIDE CORNER BRACKET	16
2	214	T-SLOT 8 HOLE INSIDE CORNER BRACKET	2
3	216	T-SLOT RIGHT ANGLE BRACE	2
4	217	T-SLOT 8 HOLE JOINING PLATE	5
5	218	T-SLOT END CAP	2
6	220	T-SLOT 3 HOLE INSIDE CORNER BRACKET	4



UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES	DRAWN	GREG	5/3/15
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL VARIOUS	COMMENTS:		
FINISH			
DO NOT SCALE DRAWING			

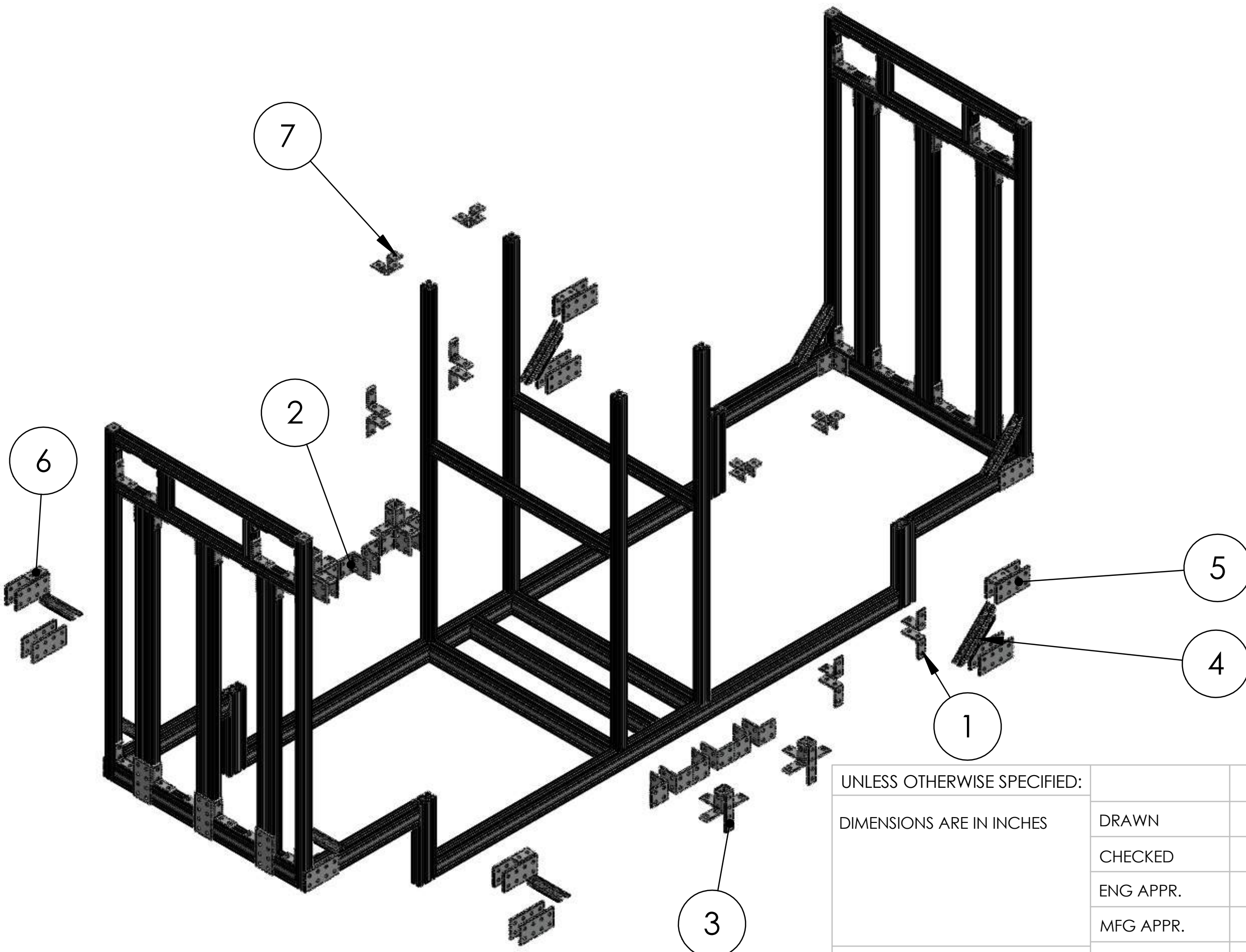
TITLE:
FRAME (T-SLOT) ASSEMBLY (1)

SIZE	DWG. NO.	REV
A	210A	

SCALE: 1:16 WEIGHT: SHEET 1 OF 1

5 4 3 2 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	213	T-SLOT 4 HOLE INSIDE CORNER BRACKET	20
2	214	T-SLOT 8 HOLE INSIDE CORNER BRACKET	12
3	215	T-SLOT 4 HOLE JOINING STRIP	4
4	216	T-SLOT RIGHT ANGLE BRACE	4
5	217	T-SLOT 8 HOLE JOINING STRIP	16
6	218	T-SLOT END CAP	4
7	221	T-SLOT 2 HOLE INSIDE CORNER BRACKET	12



UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES	DRAWN	GREG	5/3/15
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL VARIOUS	COMMENTS:		
FINISH			
DO NOT SCALE DRAWING			

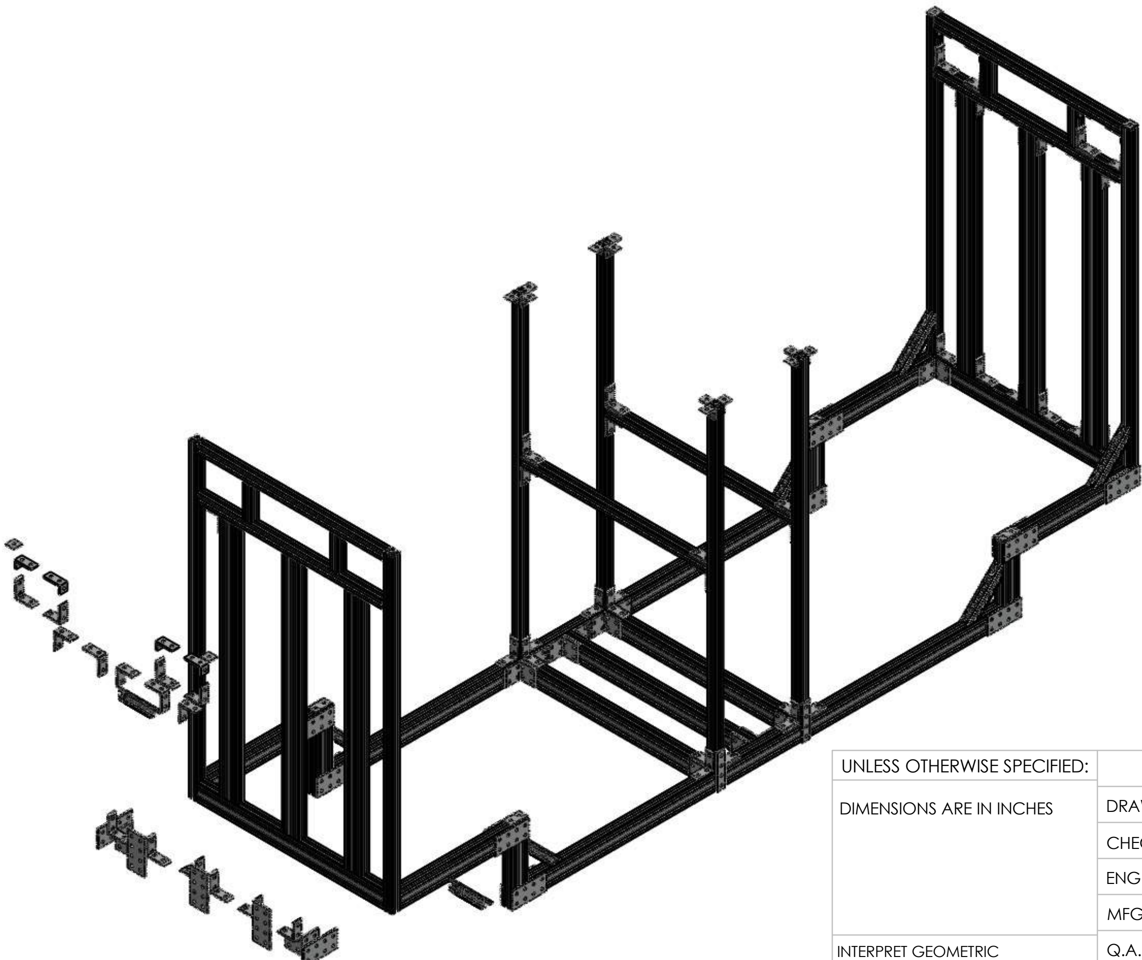
TITLE:

FRAME (T-SLOT) ASSEMBLY (2)

SIZE	DWG. NO.	REV
A	210B	
SCALE:1:16	WEIGHT:	SHEET 1 OF 1

5 4 3 2 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	213	T-SLOT 4 HOLE INSIDE CORNER BRACKET	15
2	214	T-SLOT 8 HOLE INSIDE CORNER BRACKET	2
3	216	T-SLOT RIGHT ANGLE BRACE	2
4	217	T-SLOT 8 HOLE JOINING STRIP	5
5	218	T-SLOT END CAP	2
6	220	T-SLOT 3 HOLE INSIDE CORNER BRACKET	4



UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES	DRAWN	GREG	5/3/15
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL VARIOUS	COMMENTS:		
FINISH			
DO NOT SCALE DRAWING			

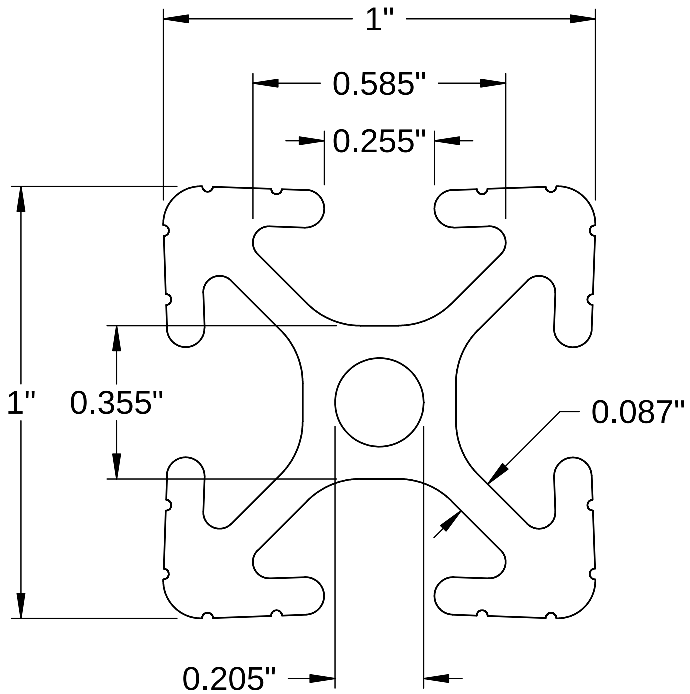
TITLE:

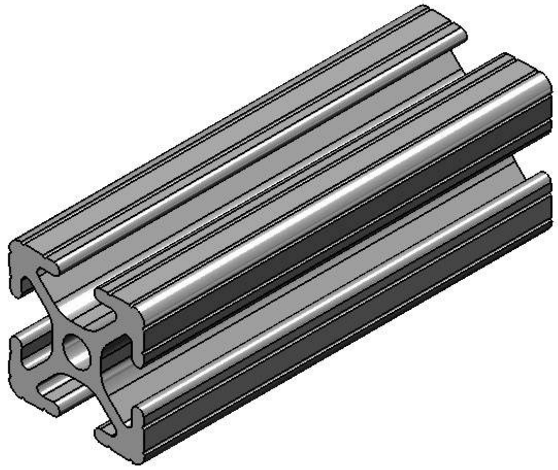
FRAME (T-SLOT) ASSEMBLY (3)

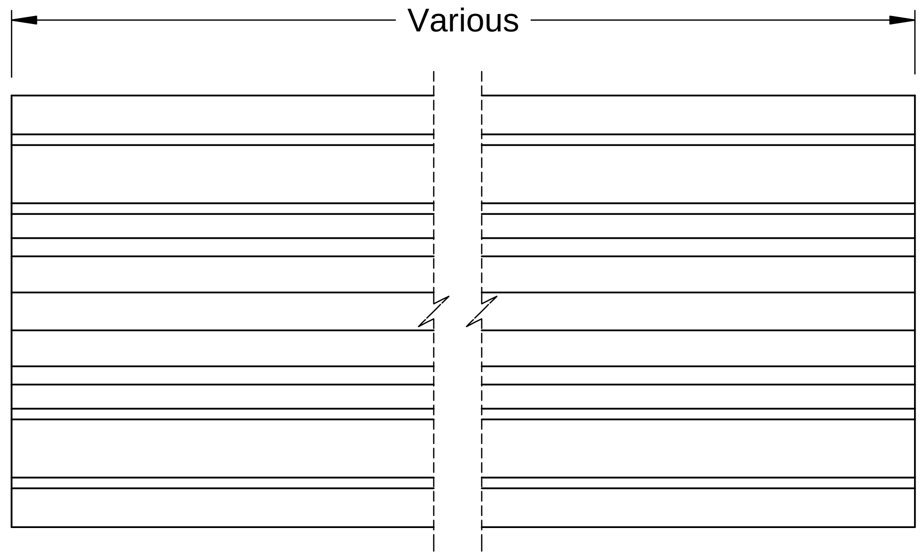
SIZE	DWG. NO.	REV
A	210C	

SCALE: 1:16 WEIGHT: SHEET 1 OF 1

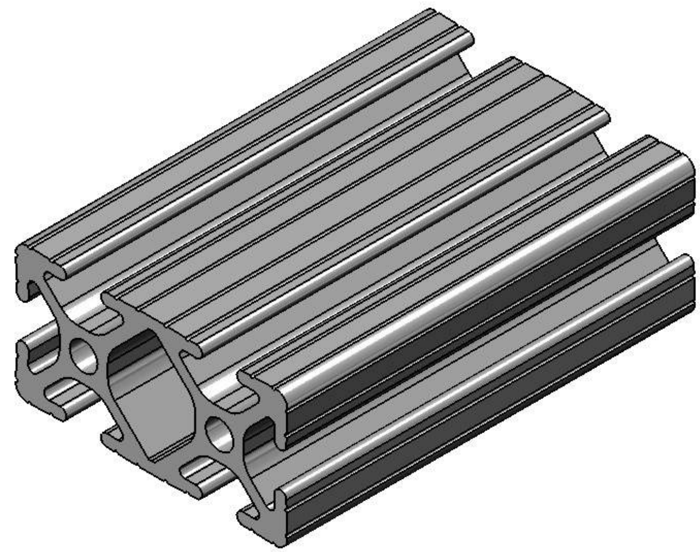
5 4 3 2 1

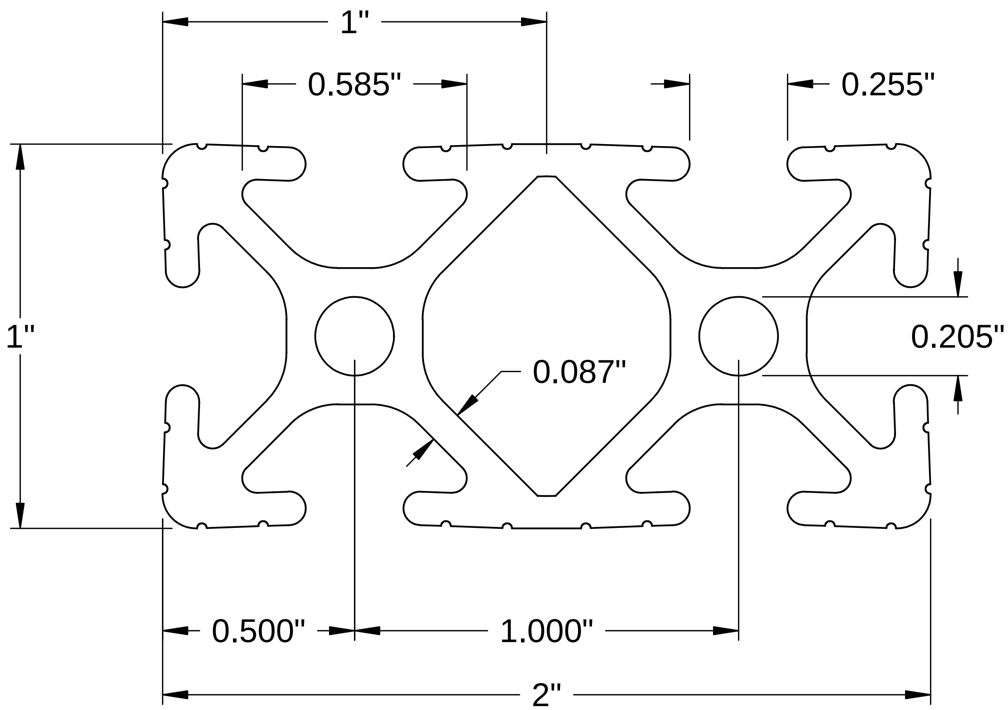


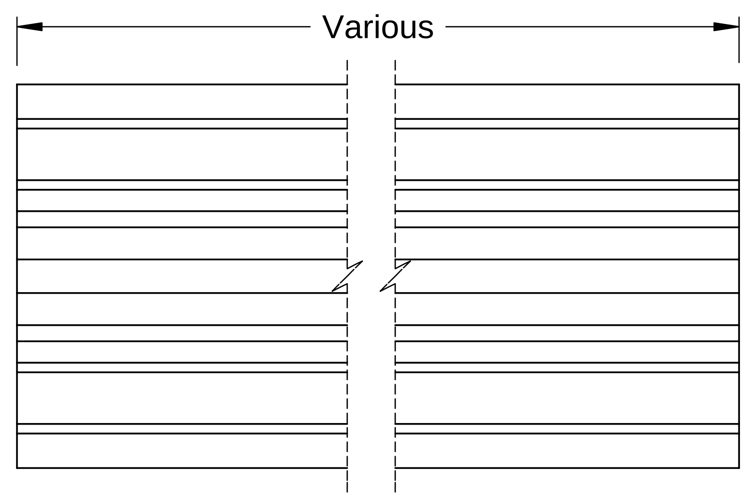




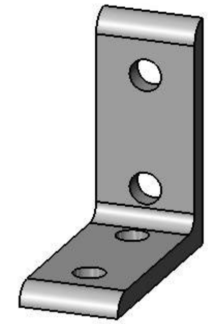
McMASTER-CARR® CAD	PART NUMBER	211
http://www.mcmaster.com © 2010 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	Aluminum Four-Slot Single Extrusion	

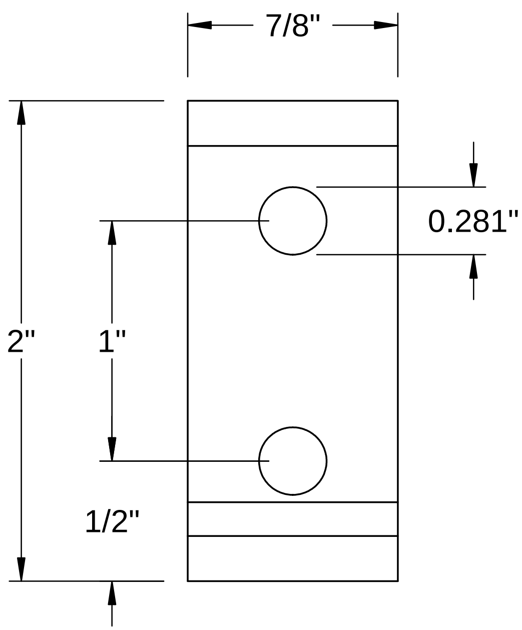


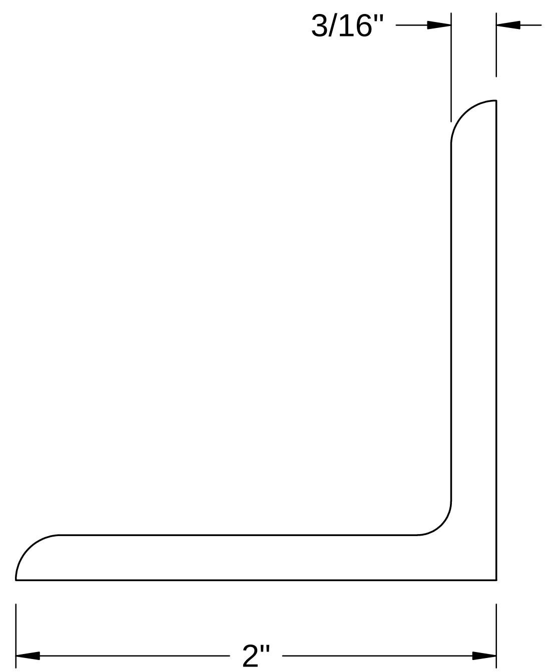




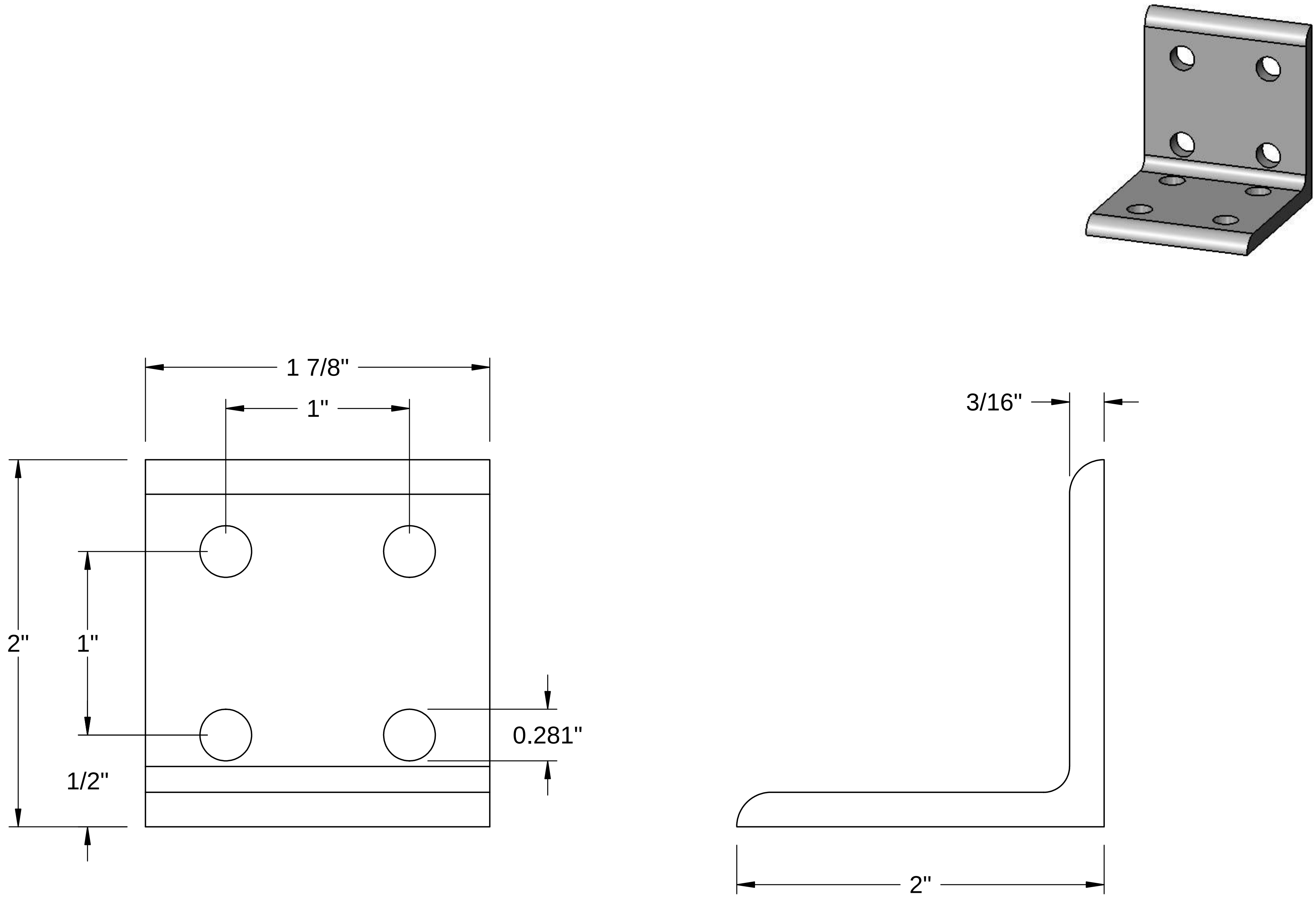
McMASTER-CARR® CAD	PART NUMBER 212
http://www.mcmaster.com © 2010 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	Aluminum Six-Slot Double Extrusion



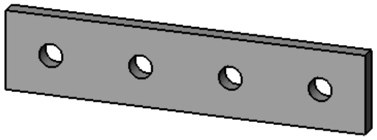


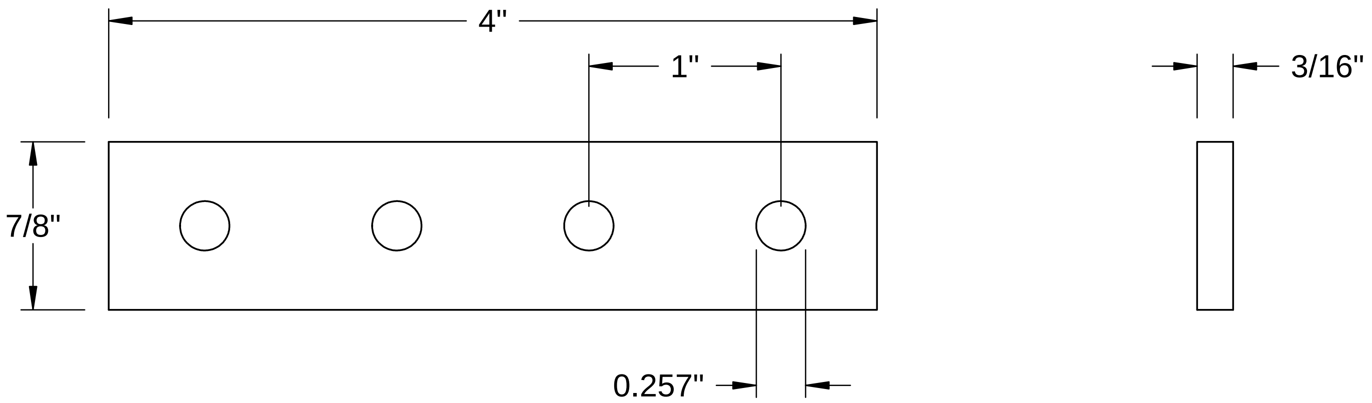


McMASTER-CARR® CAD	PART NUMBER	213
http://www.mcmaster.com © 2012 McMaster-Carr Supply Company	Aluminum Single Extended 90° Bracket	
Information in this drawing is provided for reference only.		



McMASTER-CARR® CAD	PART NUMBER	214
http://www.mcmaster.com Information in this drawing is provided for reference only.	Aluminum Double Extended 90° Bracket	



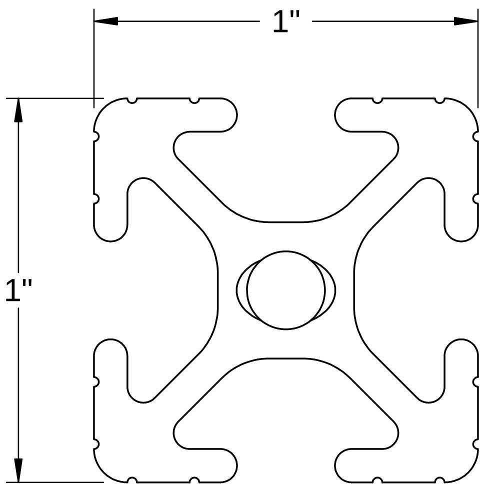


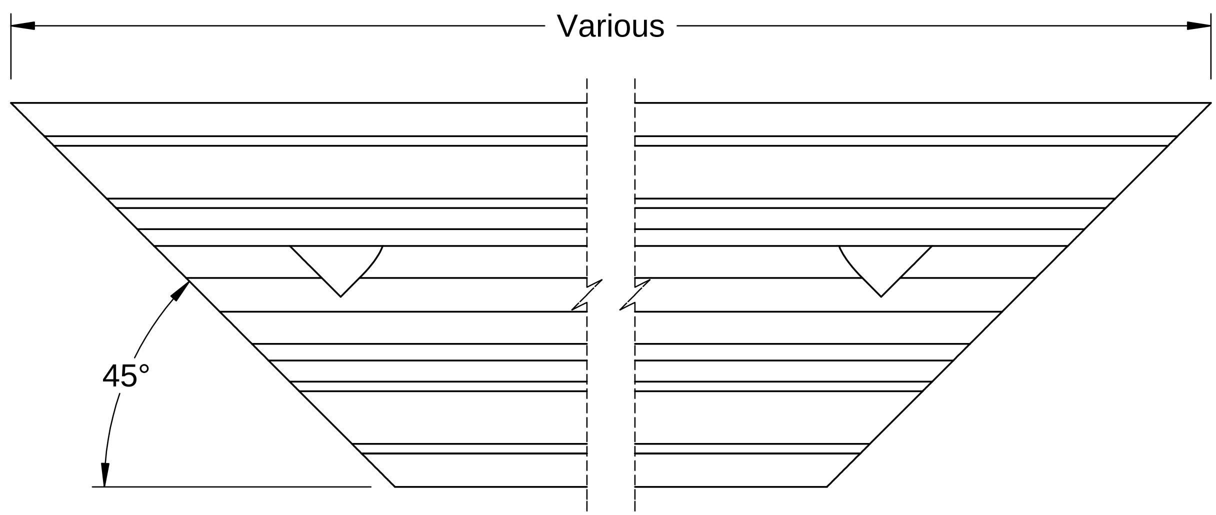
McMASTER-CARR® CAD

PART NUMBER **215**

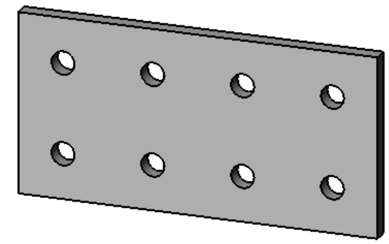
http://www.mcmaster.com

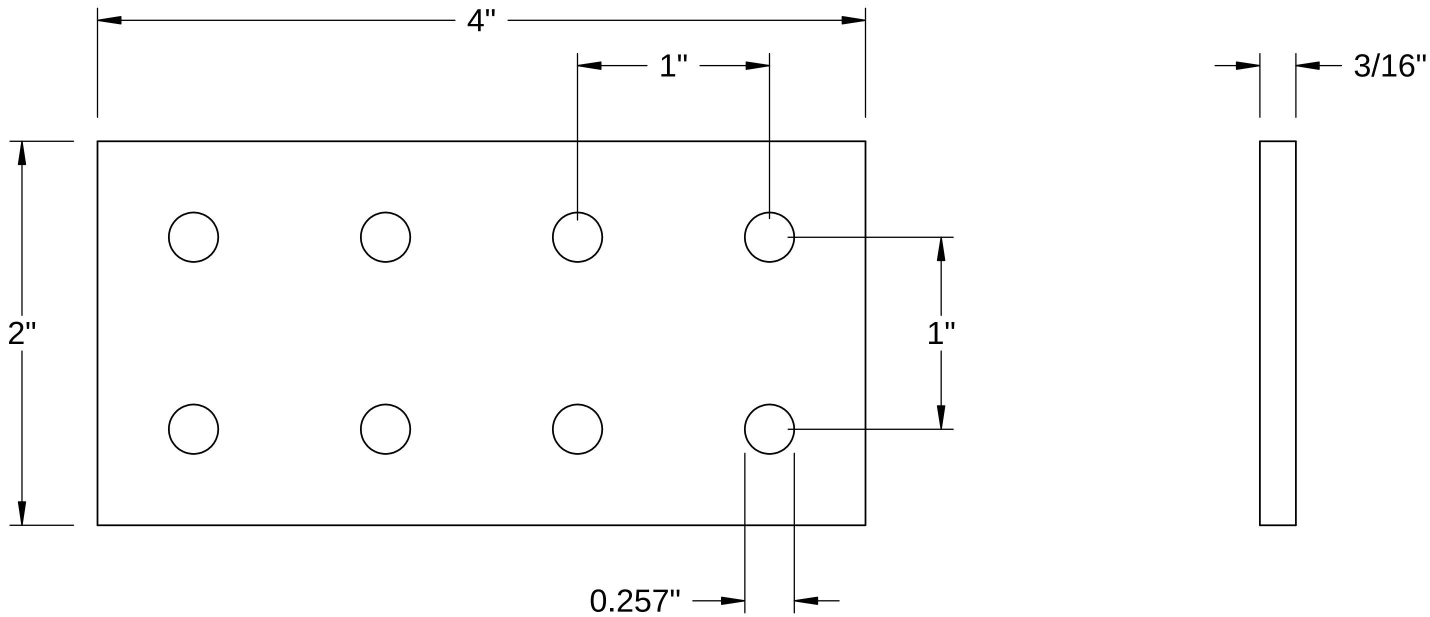
Aluminum Single Extended Plate



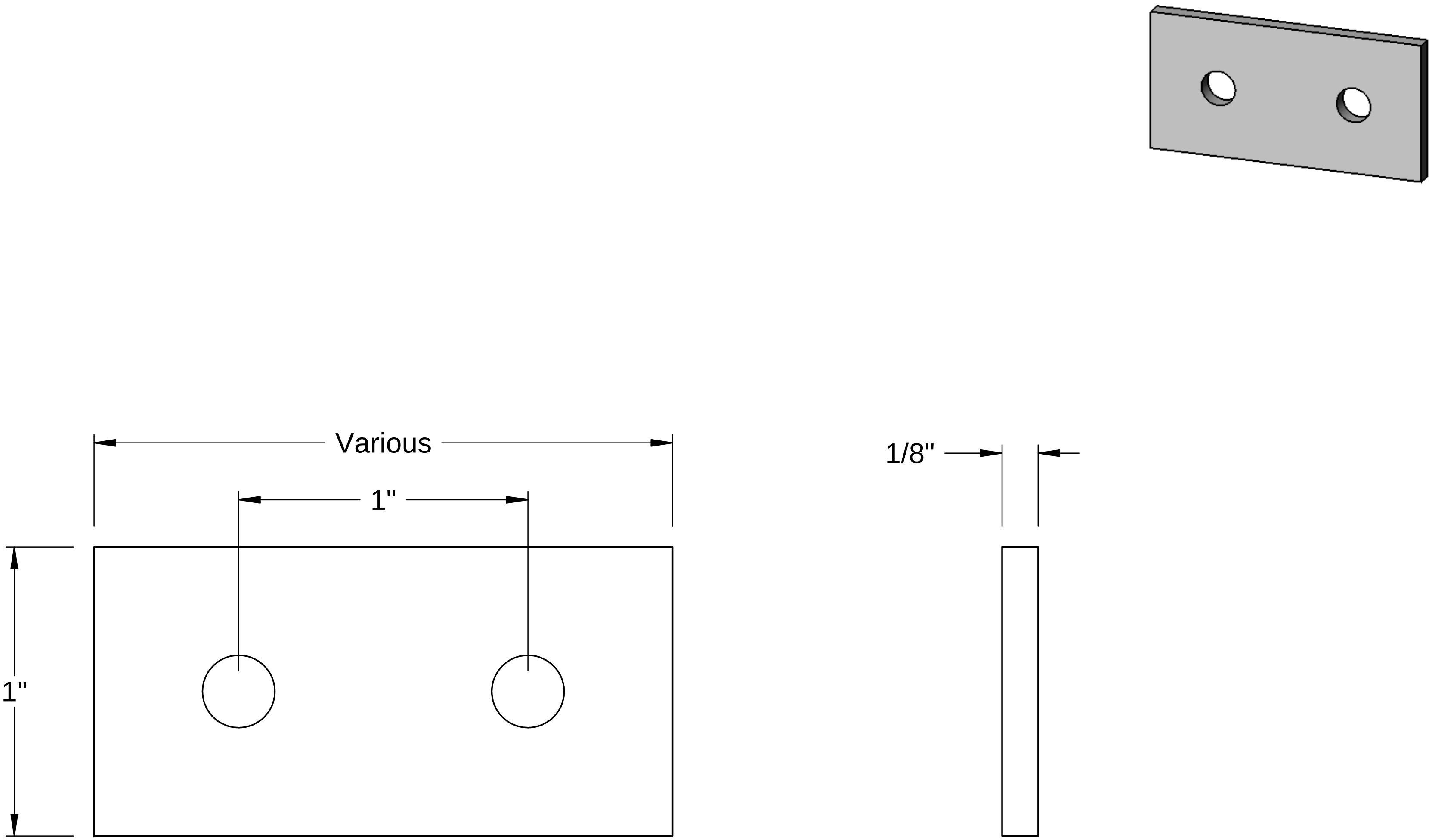


McMASTER-CARR® CAD	PART NUMBER	216
http://www.mcmaster.com © 2011 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	Aluminum Heavy Duty 90° Brace	

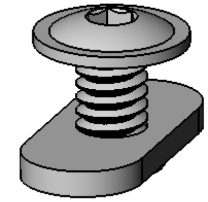


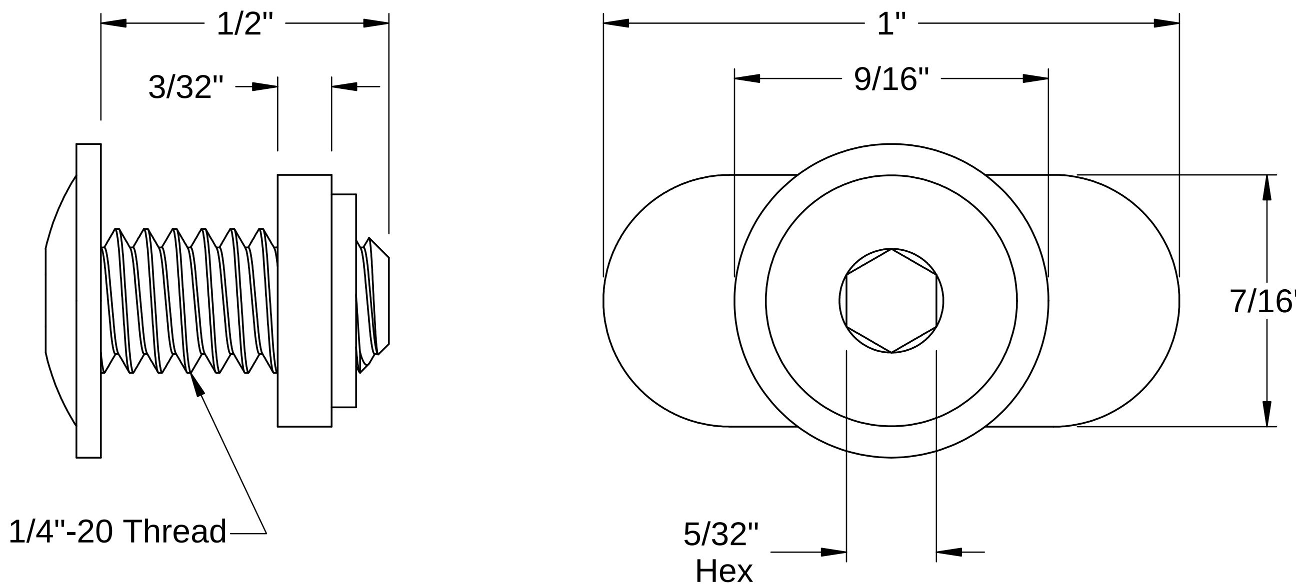


MCMASTER-CARR® CAD	PART NUMBER **217**
http://www.mcmaster.com © 2011 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	Aluminum Double Extended Plate

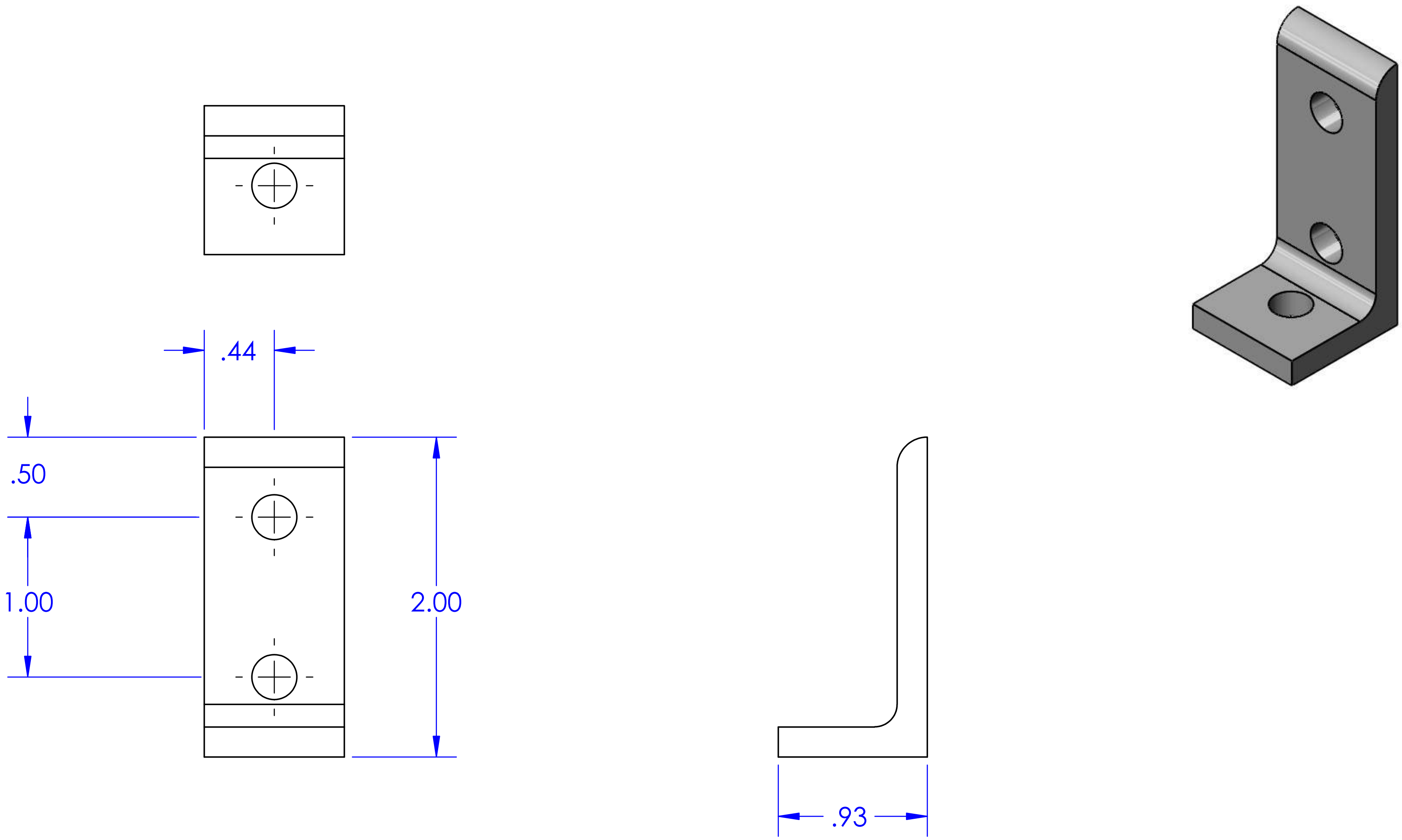


McMASTER-CARR® CAD	PART NUMBER	**218**
http://www.mcmaster.com © 2010 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	Black Plastic Double End Cap	



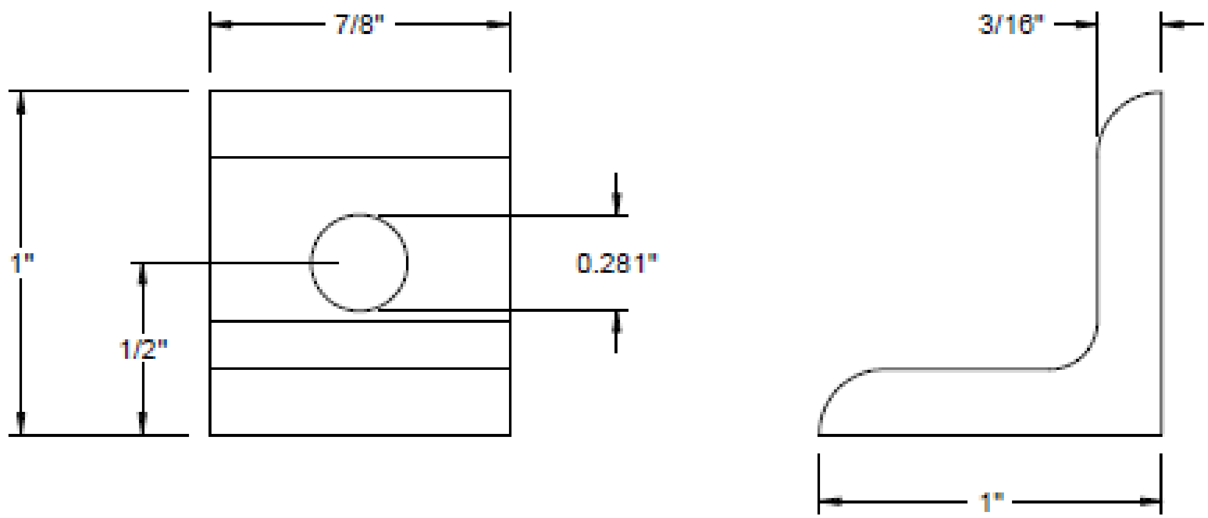


McMASTER-CARR® CAD	PART NUMBER	219
http://www.mcmaster.com © 2010 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	Zinc-Plated Steel End-Feed Slotted Framing Fastener	



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES	DRAWN	GREG	5/3/15	TITLE:
	CHECKED			3 HOLE BRACKET
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL 6061 AL	COMMENTS:			SIZE A / DWG. NO. 220 / REV
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:1 / WEIGHT: / SHEET 1 OF 1

5 4 3 2 1



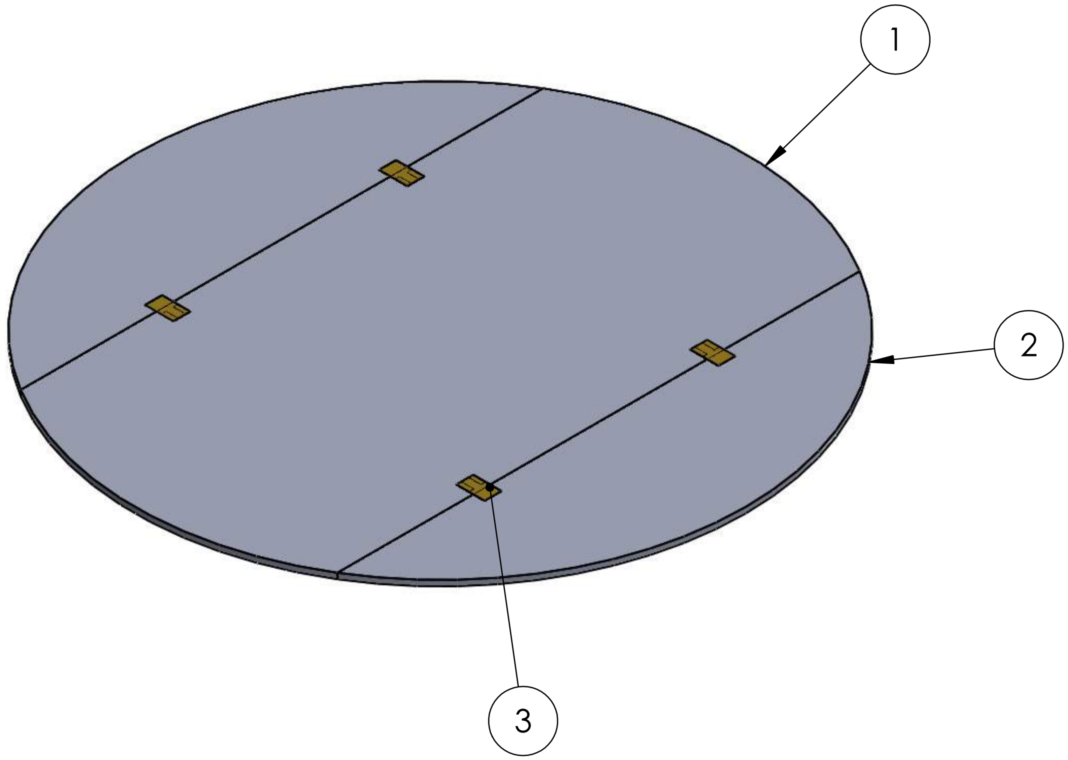
McMASTER-CARR CAD

PART NUMBER 221

http://www.mcmaster.com

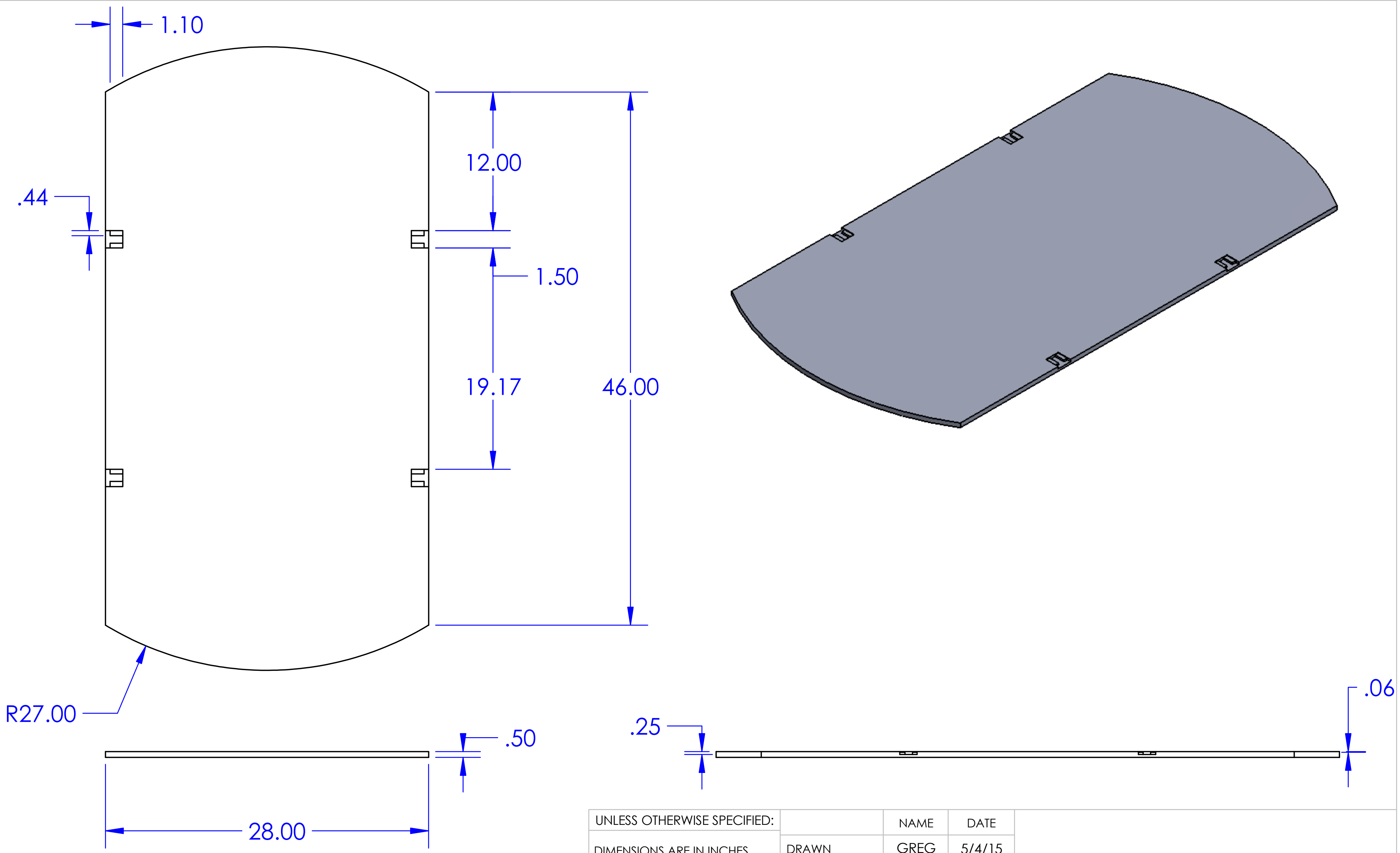
Aluminum
Single 90° Bracket

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	231	CENTER TABLE	1
2	232	SIDE TABLE	2
3	233	HINGES	4



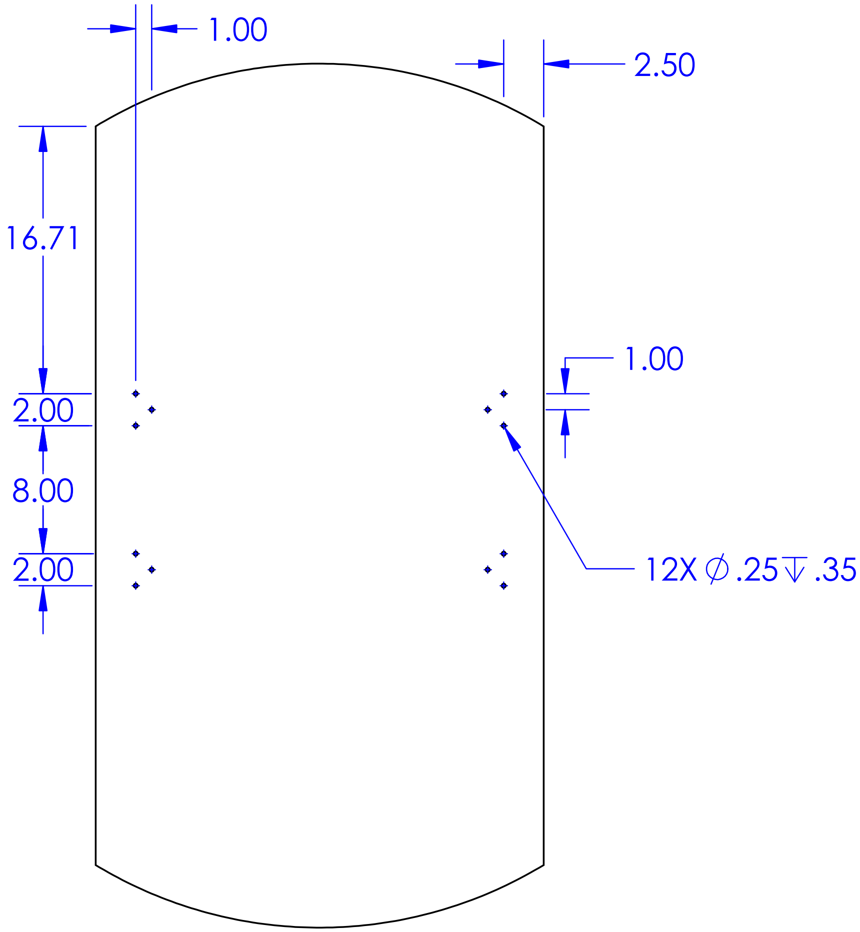
UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES	DRAWN	GREG	5/3/15	TITLE:
	CHECKED			TABLE TOP ASSEMBLY
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL	COMMENTS:			SIZE A · DWG. NO. 230 · REV
FINISH 234 WHITE PAINT 235 POLYURETHANE				SCALE:1:12 · WEIGHT: · SHEET 1 OF 1

5 4 3 2 1



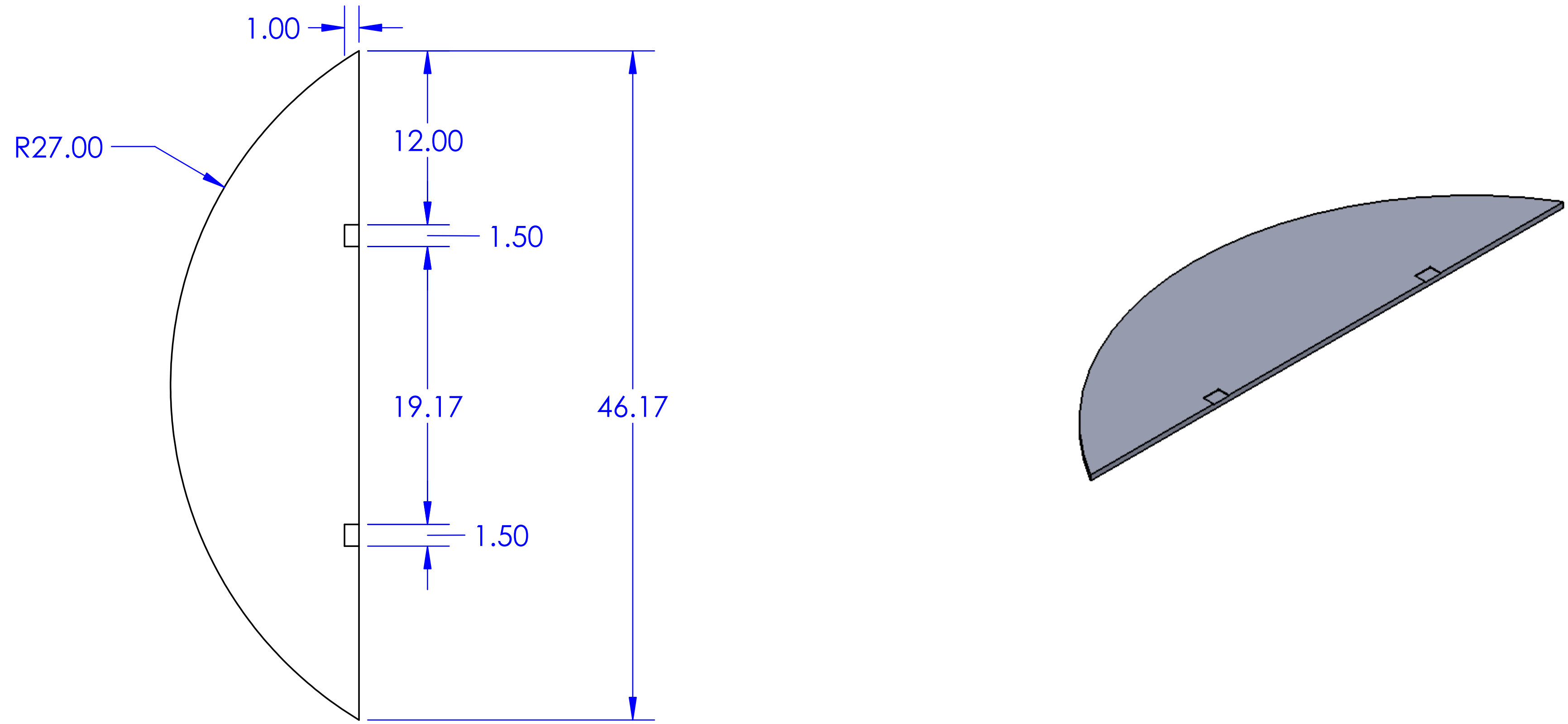
UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES	DRAWN	GREG	5/4/15	TITLE:
	CHECKED			CENTER TABLE
	ENG APPR.			
	MFG APPR.			
	Q.A.			
MATERIAL MAPLE PLYWOOD	COMMENTS:			SIZE A / DWG. NO. 231 / REV
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:12 / SHEET 1 OF 1

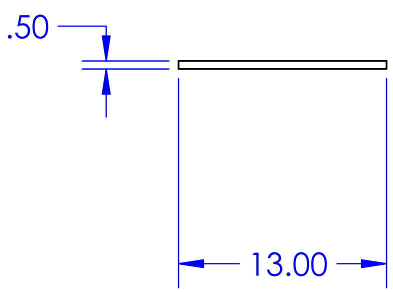
5 4 3 2 1

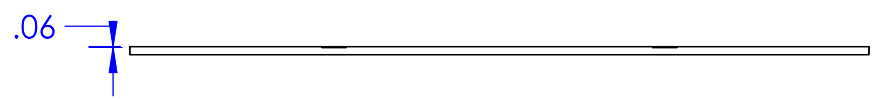


UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES	DRAWN	GREG	5/3/15	TITLE:
	CHECKED			CENTER TABLE (1)
	ENG APPR.			
	MFG APPR.			
	Q.A.			
MATERIAL MAPLE PLYWOOD	COMMENTS:			SIZE A — DWG. NO. 231(A) — REV
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:12 — SHEET 1 OF 1

5 4 3 2 1







UNLESS OTHERWISE SPECIFIED:		NAME	DATE			
DIMENSIONS ARE IN INCHES	DRAWN	GREG	5/3/15	TITLE: SIDE TABLE		
	CHECKED					
	ENG APPR.					
	MFG APPR.					
	Q.A.					
MATERIAL MAPLE PLYWOOD	COMMENTS:			SIZE A	DWG. NO. 232	REV
FINISH						
DO NOT SCALE DRAWING				SCALE: 1:12		SHEET 1 OF 1

5 4 3 2 1

Butler Tray Table Hinge, Solid Brass

Product Information & Specifications

Hinge is an English reproduction.
Locks open in flat position.
Holds vertical at 90 degrees.
Square ends.
Hinge measures 2-1/2" long x 1-1/2" wide.
Hinge is 1/8" thick (3/8" at the thickest point). Thickest point measurement is taken with the hinge in its flat position.
Solid brass base material.
Uses #5 flat head screws (not included). Flat head brass screws are offered for purchase during checkout.
Finishes:

Satin Brass

Finish	SKU	Price	Qty	Unit
Satin Brass	286260	$9.59		Each

Home > Paint > Paint Colors & Trim > Interior Paint, Exterior Paint & Paint Samples

BEHR Premium Plus Ultra | Model # UL22016 | Internet # 205362565 | Store SKU # 1000403472

8 oz. #220 UPW Interior/Exterior Paint Sample

★★★★★ | Write the First Review + | Ask a Question +

PRODUCT OVERVIEW

Model # UL22016 | Internet # 205362565 | Store SKU # 1000403472

Before delving into a big painting project, preview the color with the BEHR Premium Plus Ultra 8 oz. Sample. Formulated with both paint and primer, this sample allows you to conveniently apply paint to interior or exterior surfaces and accurately envision coverage. See the beautiful paint color on an actual surface under different lighting conditions. California residents: see Proposition 65 information

- 8 oz. ready-to-go sample for a convenient way to test colors
- Satin appearance
- Covers up to 16 sq. ft. depending on surface porosity
- Low VOC
- Paint and primer in one featuring NANOGUARD technology
- Liquid samples are not returnable but are an invaluable resource to help you select the right paint color
- Actual paint colors may vary from on-screen and printer representations

Info & Guides

MSDS

You will need Adobe® Acrobat® Reader to view PDF documents. Download a free copy from the Adobe Web site.

SPECIFICATIONS

DIMENSIONS

Container Size	8 OZ-Sample	Coverage Area (sq. ft.)	16

DETAILS

Base	Base 1	Paint Features	No additional features
Cleanup	Soap & Water	Paint Type	Acrylic
Color Family	Multi	RGB Value	255:255:255
Color/Finish	UPW	Returnable	Non-Returnable
Dry to touch (min.)	60	Sheen	Satin
Interior/Exterior Paint	Interior Paint	Time before recoating (hours)	2
Minimum Temperature for Use (F)	50	Transparency	Solid
Paint & Primer in One	Yes		

Rust-Oleum Painter's Touch 2X | Model # 249117 | Internet # 100670438 | Store SKU # 617046

12 oz. Gloss Clear General Purpose Spray Paint

★★★★★ (4) | Write a Review + | Ask a Question +

PRODUCT OVERVIEW Model # 249117 | Internet # 100670438 | Store SKU # 617046

Rust-Oleum Painter's Touch Ultra Cover 2X 12 oz. Gloss Clear General Purpose Spray Paint delivers twice the coverage as other competitive brands. Double Cover Technology provides ultimate hiding power and is a Paint and Primer in One allowing projects to be completed quickly. A great value.
California residents: see Proposition 65 information

- Interior/exterior use on wood, metal, plastic and more
- Designed to provide long lasting protection and durability
- Covers up to 50 sq. ft.
- Glossy finish provides a fresh shine to surfaces
- Comfort spray tip with wider finger pad reduces finger fatigue and offers 360-degree, any-angle spray technology
- Dries to the touch in 20 minutes
- Oil based formula contains breakthrough technology, delivers twice the coverage
- Paint and primer in one
- Clean up with mineral spirits

SPECIFICATIONS

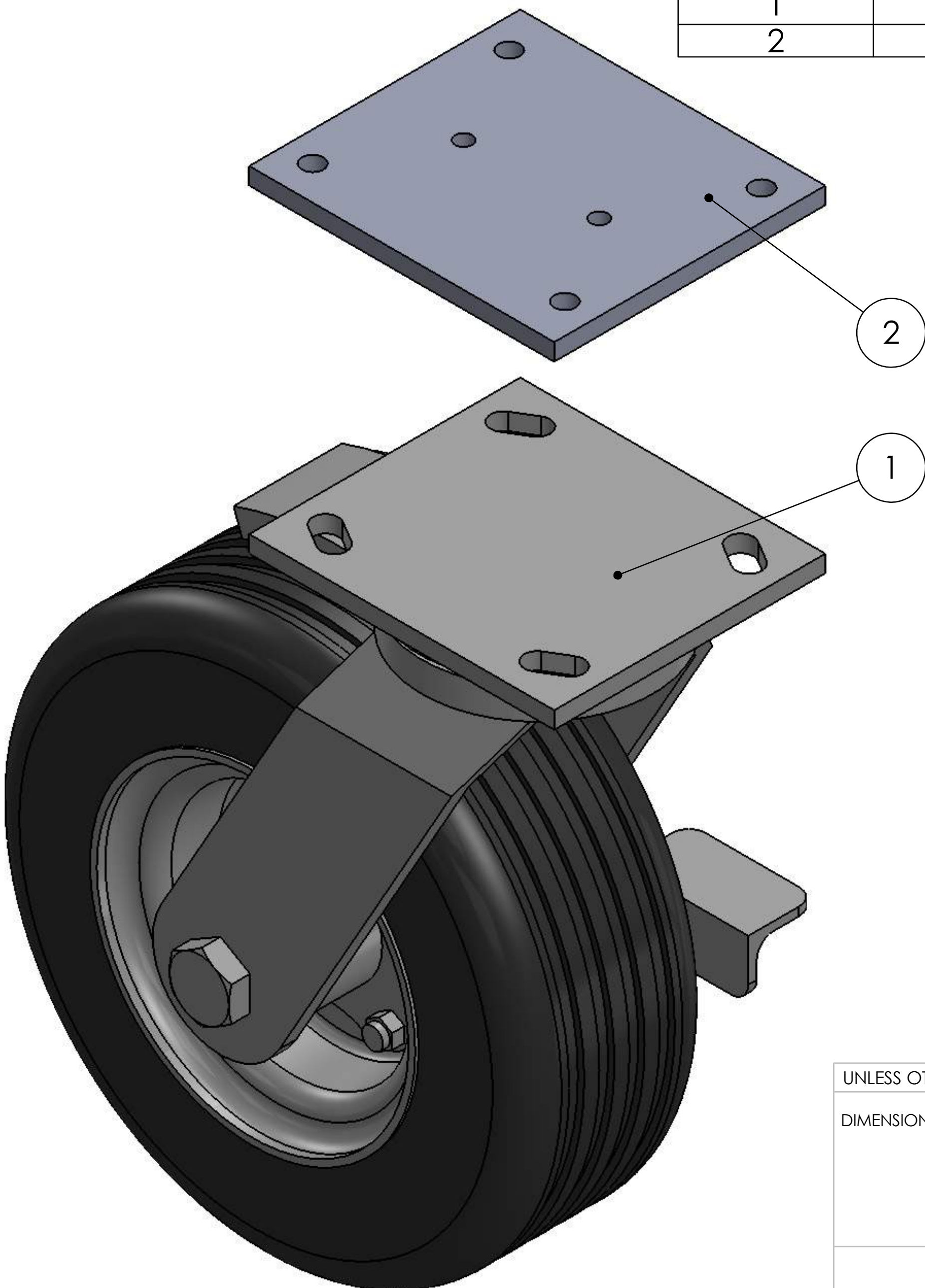
DIMENSIONS

Coverage Area (sq. ft.)	50	Product Size (oz.)	12

DETAILS

Cleanup	Mineral Spirits	Primer required	No
Color Family	Clear	RGB Value	255:255:255
Color/Finish	Clear	Sheen	Gloss
Dry to touch (min.)	20	Spray Paint/Stain Type	General Purpose
Interior/Exterior	Interior/Exterior	Spray Product Type	General Purpose
Inverted spray ability	Yes	Transparency	Clear-Crystal Clear
Paint Product Type	General Purpose Spray Paint	Type	Oil

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



UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES	DRAWN	GREG	5/3/15
	CHECKED		
	ENG APPR.		
	MFG APPR.		
	Q.A.		
MATERIAL VARIOUS	COMMENTS:		
FINISH			
DO NOT SCALE DRAWING			

TITLE:

CASTER ASSEMBLY

SIZE	DWG. NO.	REV
A	240	
SCALE: 1:1	WEIGHT:	SHEET 1 OF 1

5 4 3 2 1

Double click on above image to view full picture

8 in. Rubber Heavy Duty Cushion Tire Swivel Caster with Brake

- Item#46819

Read 1 Review Write A Review

Move your cart or table and lock it in place with this swivel caster

SHARE

Only: $24.99

Qty: 1 ADD TO CART

This item may be available at your local Harbor Freight Tools Store FIND STORE

Add to Wishlist View Shipping Rates

Product Overview | Customer Reviews | Warranty

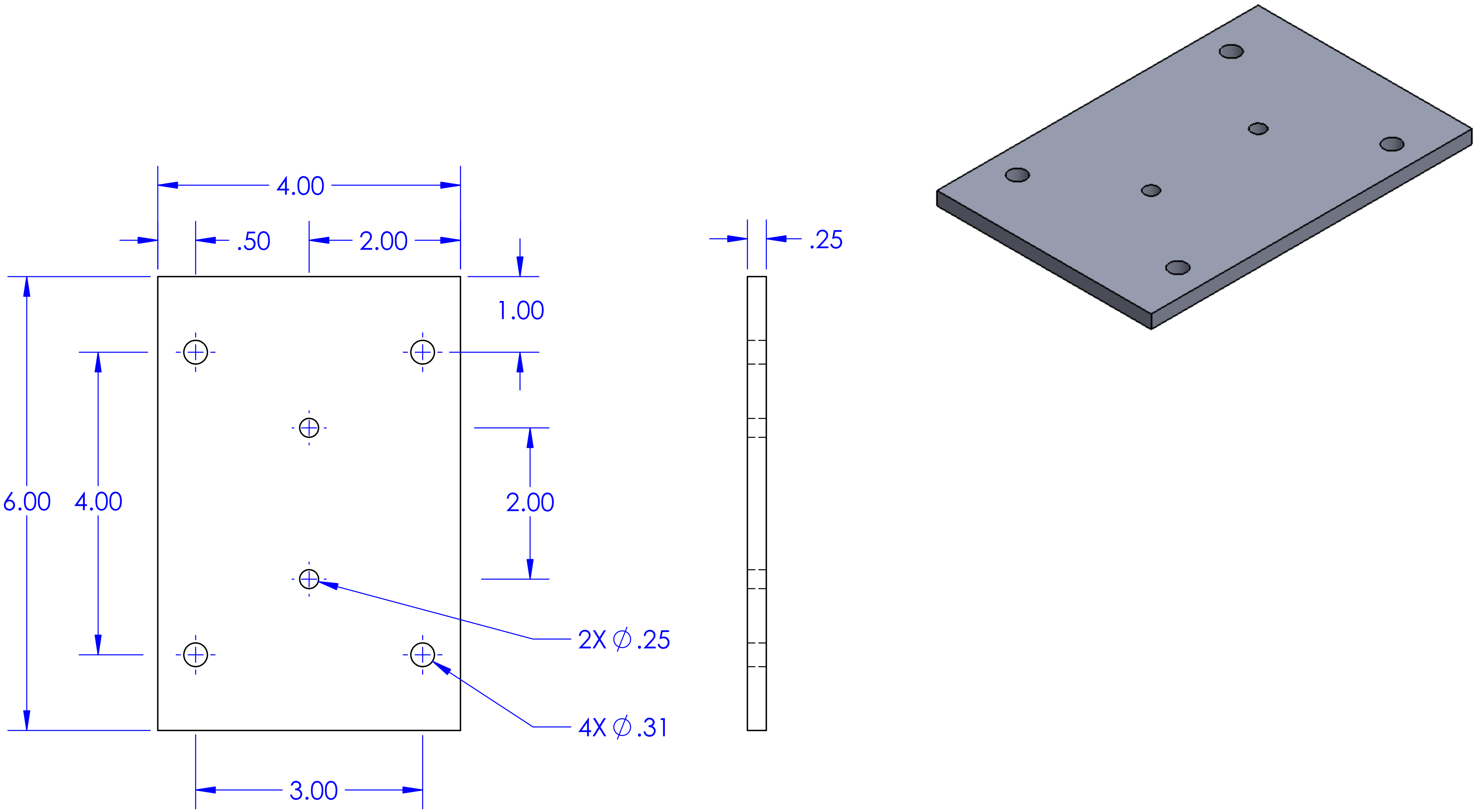
Description

This solid rubber cushion caster rolls smoothly and silently thanks to the ball bearing 360 degree swivel. This tire swivel caster won't damage your flooring and is ideal for transporting tools and equipment around your shop or garage. This tire swivel caster features a pressed steel hub with needle bearings and a weight capacity of 450 lbs.

- Easy step-on locking brake
- Cushioned solid rubber tire with grooved tread
- 450 lb. load rated
- Needle bearing hub
- Ball bearing 360° swivel
- Zinc plated steel yoke and plate

Specifications

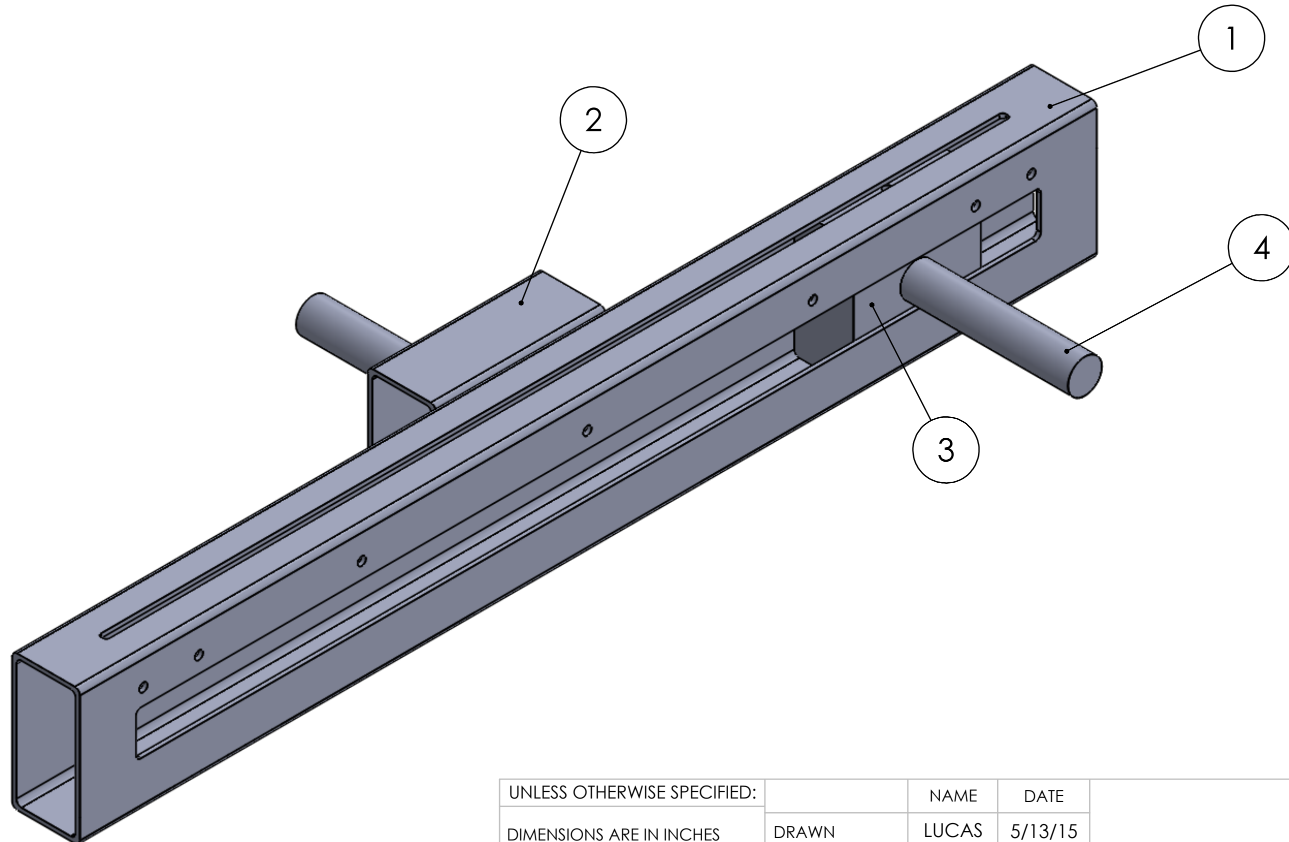
Name	8 in. Rubber Heavy Duty Cushion Tire Swivel Caster with Brake
SKU	46819
Brake	Yes
Material	Rubber, steel
Maximum Working load (lbs.)	450 lb.
Mounting type	Plate
Quantity	1
Swivel base (deg)	360°
Wheel thickness (in.)	2 in.
Fits tire size (in.)	8 in.
Mounting plate size (in.)	4-1/4 in. x 5-1/8 in.
Product Height	9-1/2 in.
Product Length	8 in.
Product Weight	9 lbs.
Product Width	4-1/4 in.
Shipping Weight	8.95 lb.
Tire size (in.)	8 in.



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES	DRAWN	GREG	5/3/15	TITLE:
	CHECKED			CASTER MOUNTING PLATE
	ENG APPR.			
	MFG APPR.			
	Q.A.			
MATERIAL 6061 T6 AL	COMMENTS:			SIZE A DWG. NO. 242 REV
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:2 SHEET 1 OF 1

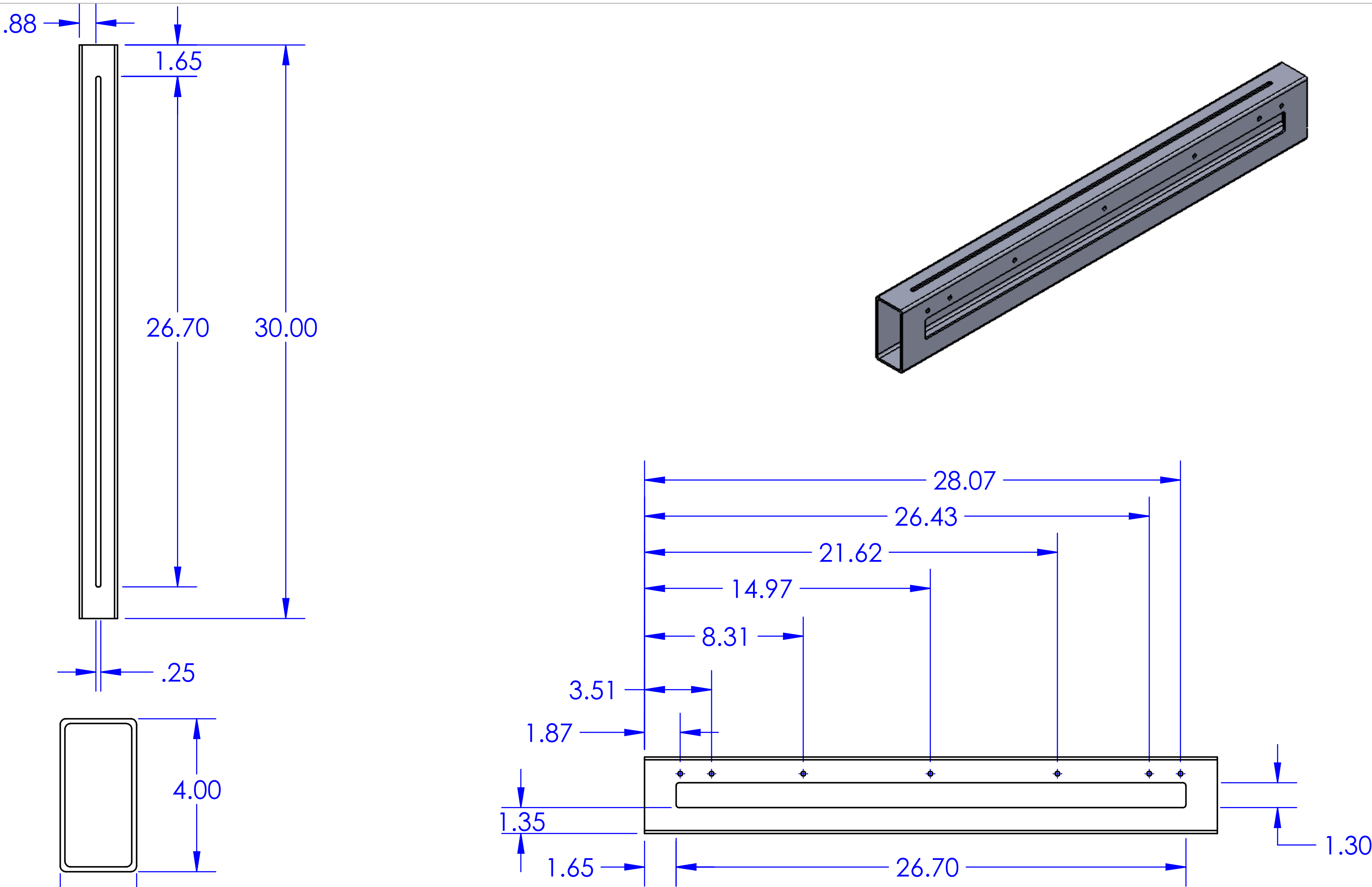
5 4 3 2 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	251	LATITUDE SLOT BODY	1
2	252	SLOT CONNECTOR	1
3	256	SLIDER	1
4	257	1 INCH THREADED SHAFT	2



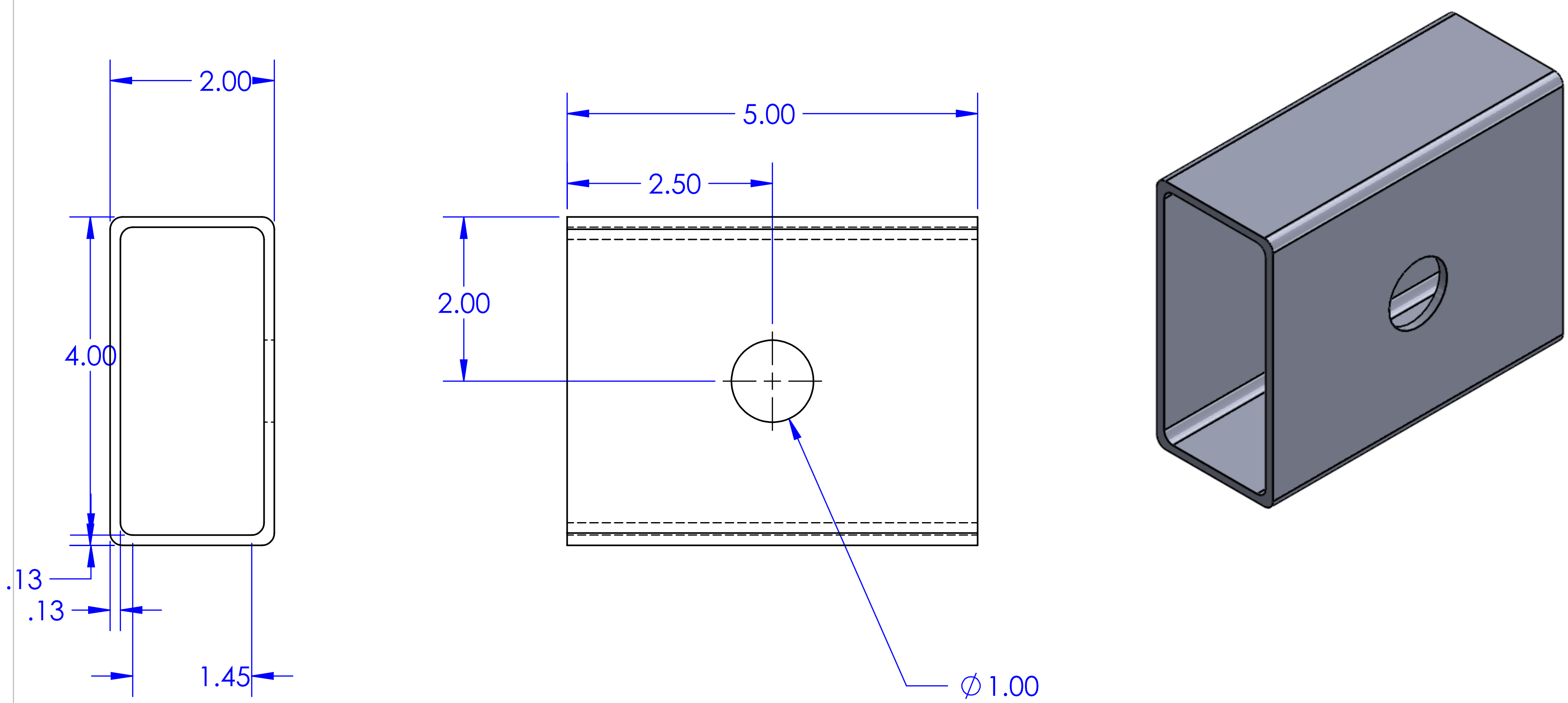
UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES	DRAWN	LUCAS	5/13/15	
	CHECKED			TITLE: LATITUDE SLOT
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL:	COMMENTS: SLOT CONNECTOR AND MAIN BODY ARE CONNECTED VIA TWO WELDS, ONE ON TOP AND BOTTOM			SIZE A — DWG. NO. 250 — REV
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:4 — WEIGHT: — SHEET 1 OF 1

5 4 3 2 1



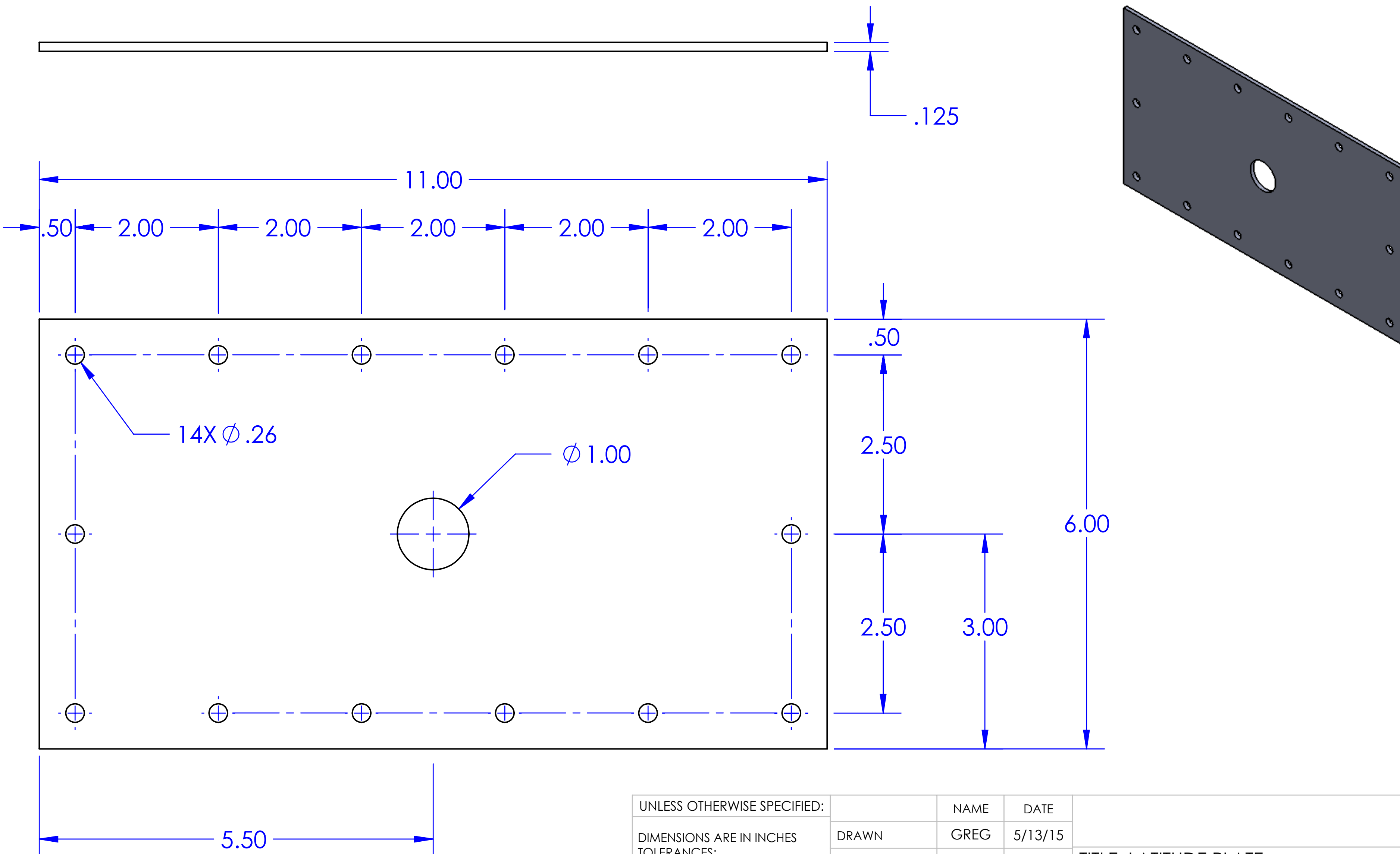
UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	LUCAS	5/13/15	TITLE: LATITUDE SLOT BODY
	CHECKED			
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL: ALUMINUM	COMMENTS:			SIZE A — DWG. NO. 251 — REV
FINISH DO NOT SCALE DRAWING				SCALE: 1:16 — WEIGHT: — SHEET 1 OF 1

5 4 3 2 1



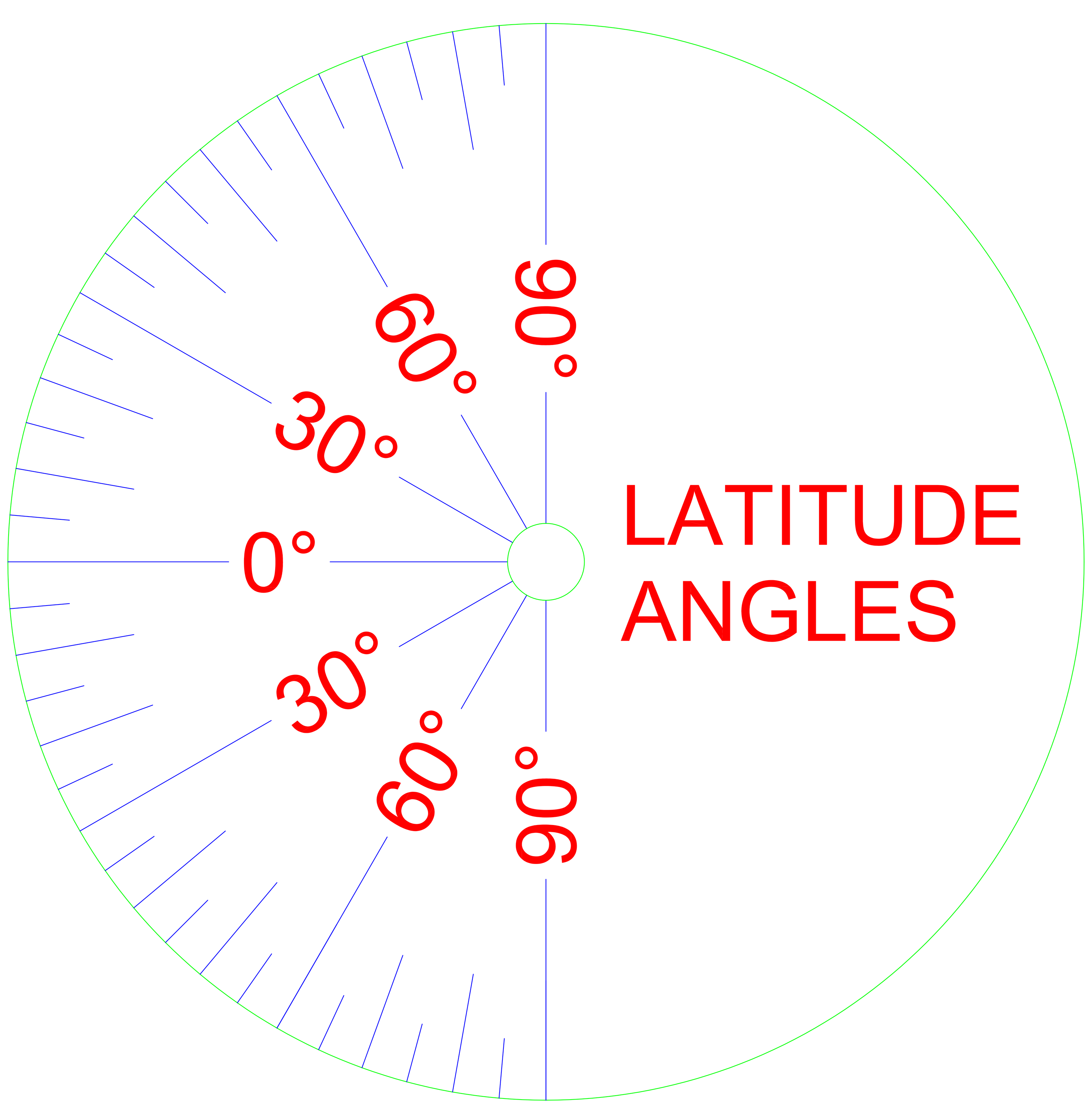
UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES	DRAWN	LUCAS	5/13/15	TITLE: SLOT CONNECTOR
	CHECKED			
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL: ALUMINUM	COMMENTS:			SIZE A	DWG. NO. 252	REV
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:2	WEIGHT:	SHEET 1 OF 1

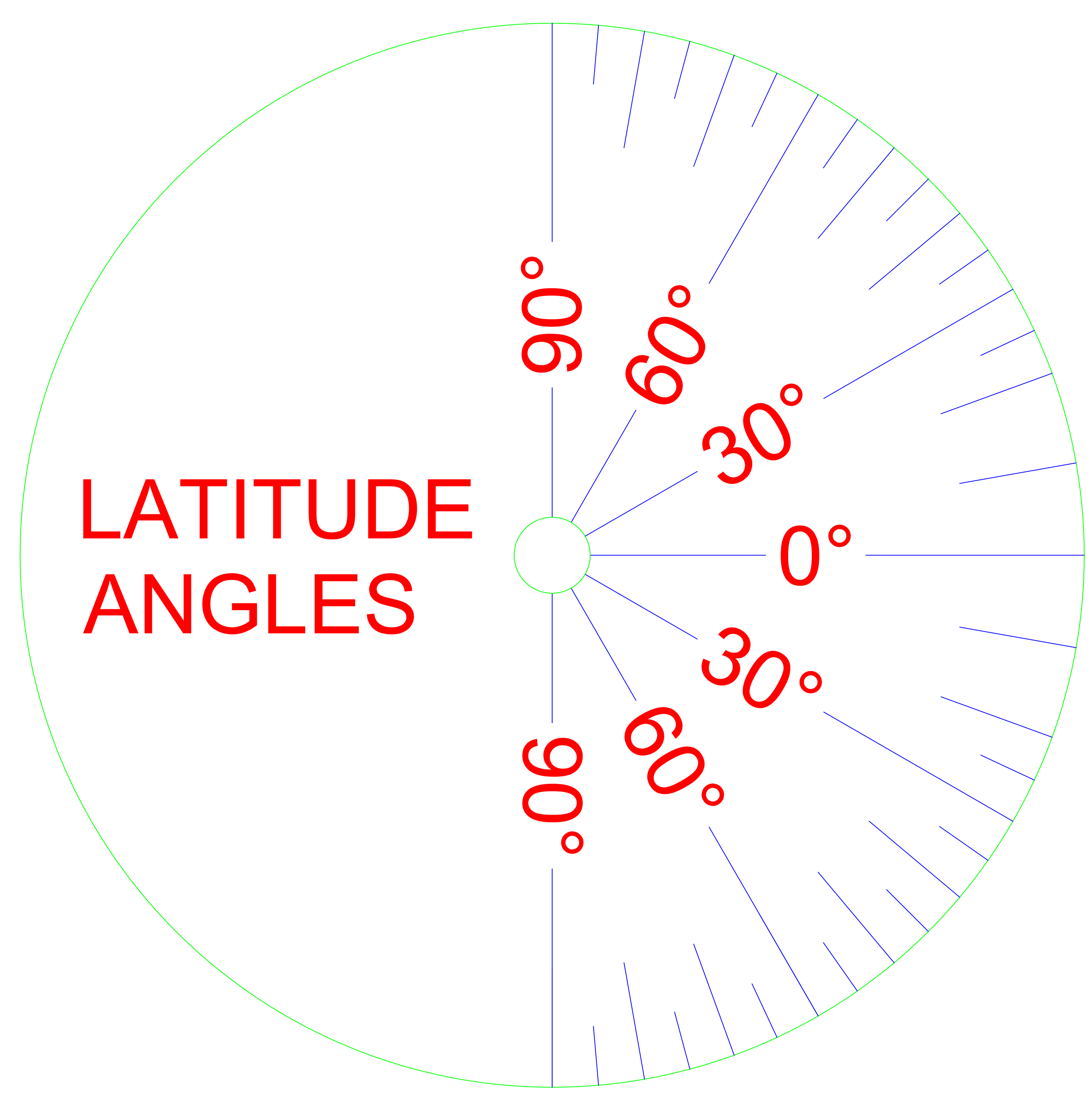
5 4 3 2 1

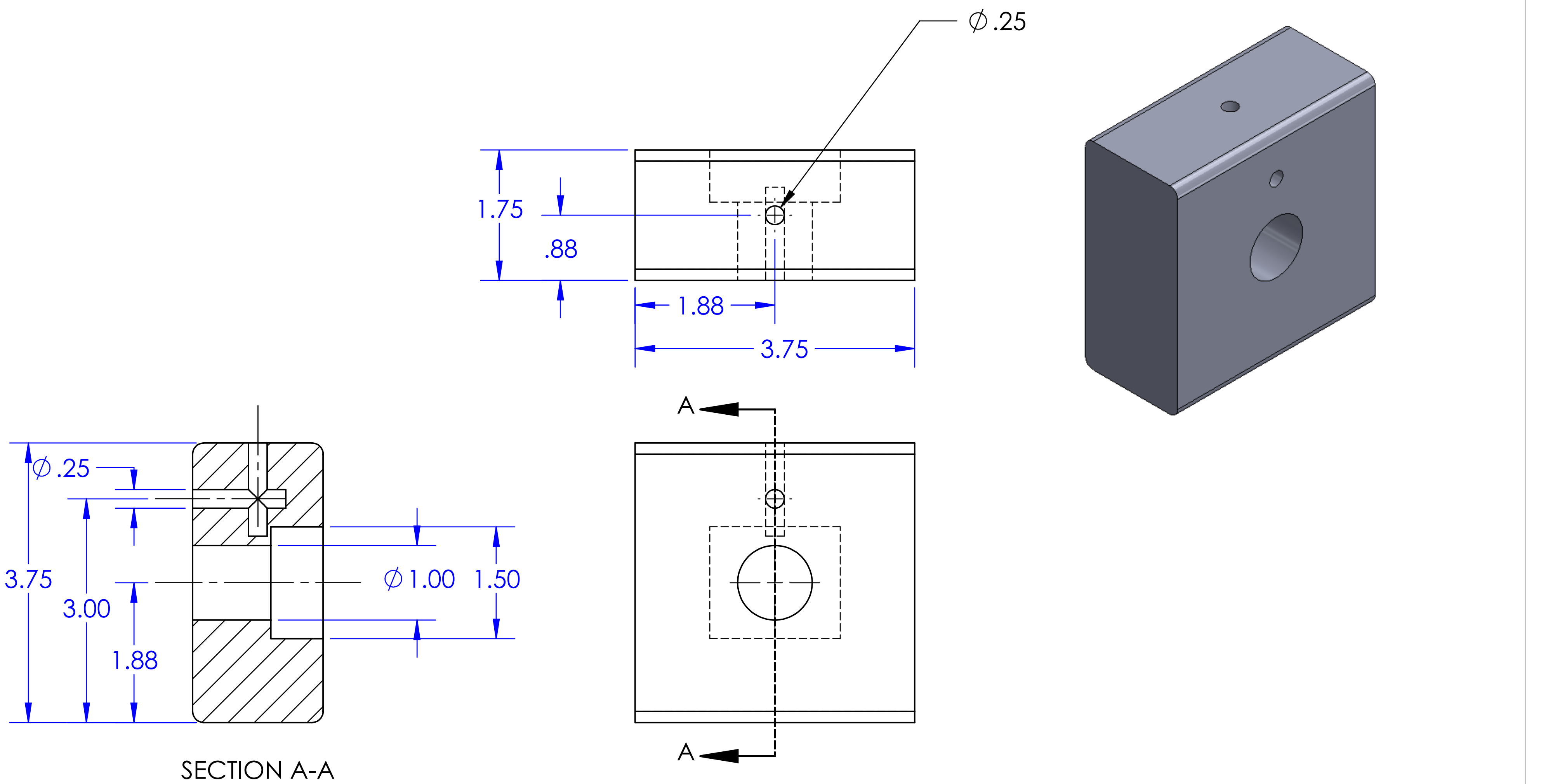


UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	GREG	5/13/15	TITLE: LATITUDE PLATE
	CHECKED			
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL: STEEL	COMMENTS:			SIZE A · DWG. NO. 253 · REV
FINISH				SCALE: 1:4 · WEIGHT: · SHEET 1 OF 1
DO NOT SCALE DRAWING				

5 4 3 2 1


90°
60°
30°
0°
30°
60°
90°
LATITUDE
ANGLES


LATITUDE
ANGLES
90°
60°
30°
0°
30°
60°
90°



UNLESS OTHERWISE SPECIFIED:		
DIMENSIONS ARE IN INCHES		
INTERPRET GEOMETRIC TOLERANCING PER:		
MATERIAL: UHMW		
FINISH		
DO NOT SCALE DRAWING		

	NAME	DATE
DRAWN	LUCAS	5/13/15
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

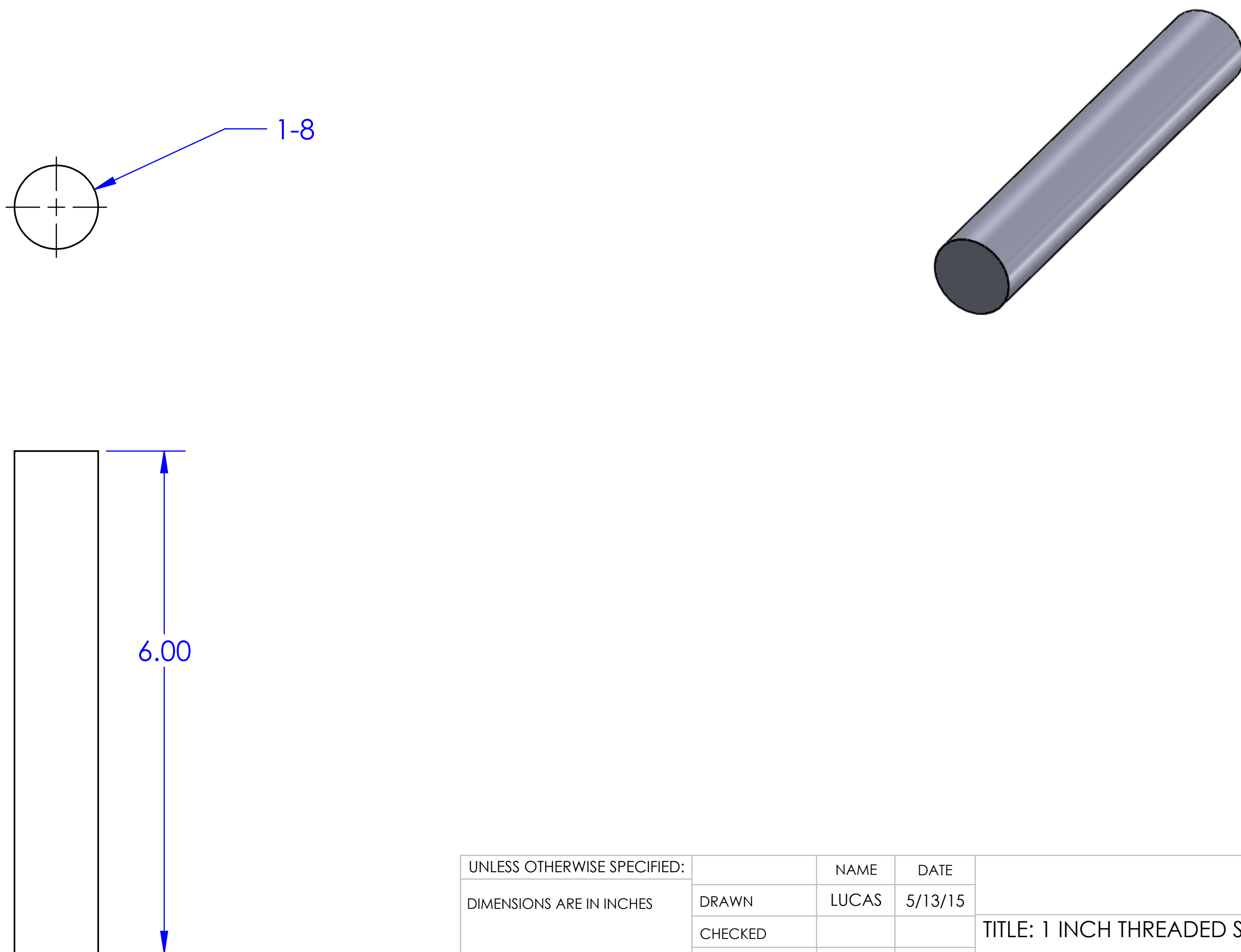
COMMENTS: BACK SQUARE HOLE IS SO THAT A NUT CAN SIT IN THE BACK OF THE SLIDER

TITLE: SLIDER

SIZE	DWG. NO. 256	REV
A		

SCALE: 1:2 WEIGHT: SHEET 1 OF 1

5 4 3 2 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES	DRAWN	LUCAS	5/13/15
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL: STEEL	COMMENTS:		
FINISH			
DO NOT SCALE DRAWING			

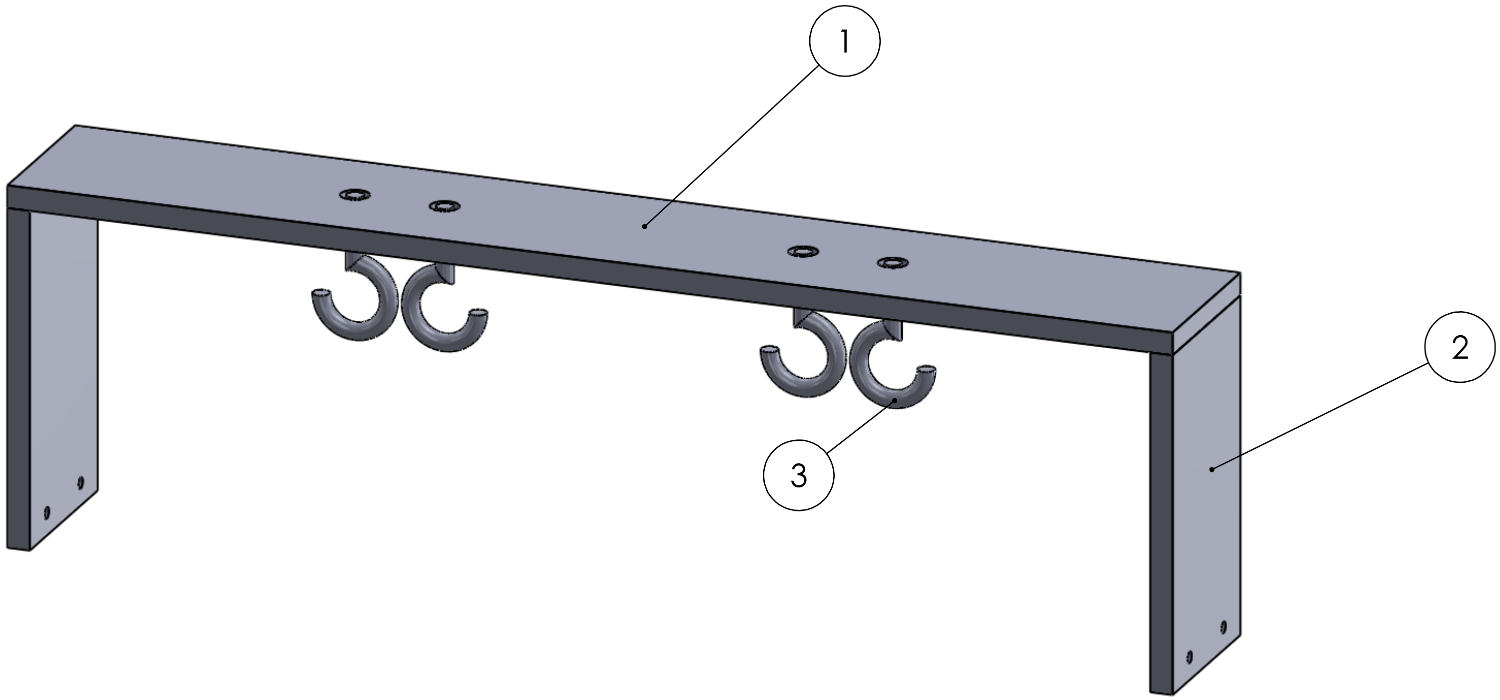
TITLE: 1 INCH THREADED SHAFT

SIZE	DWG. NO. 257	REV
A		

SCALE: 1:2	WEIGHT:	SHEET 1 OF 1

5 4 3 2 1

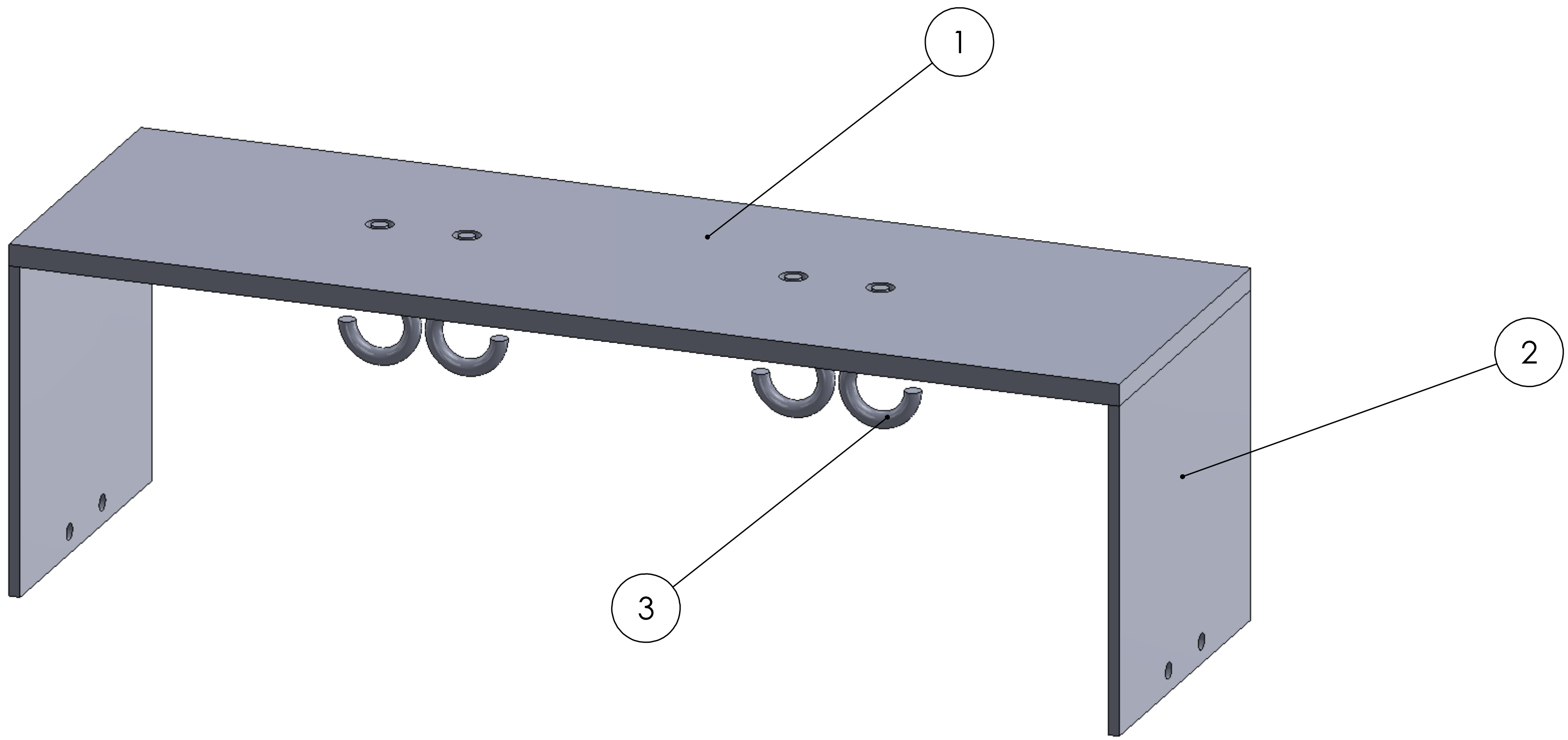
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	262	1/4" BRACKET TOP	1
2	261	1/4" BRACKET SIDE	2
3	268	HOOK	4



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES	DRAWN	LUCAS	5/3/15	TITLE: 1/4" BRACKET
	CHECKED			
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL:	COMMENTS:			SIZE A
FINISH				DWG. NO.
DO NOT SCALE DRAWING				REV
				SCALE: 1:2
				WEIGHT:
				SHEET 1 OF 1

5 4 3 2 1

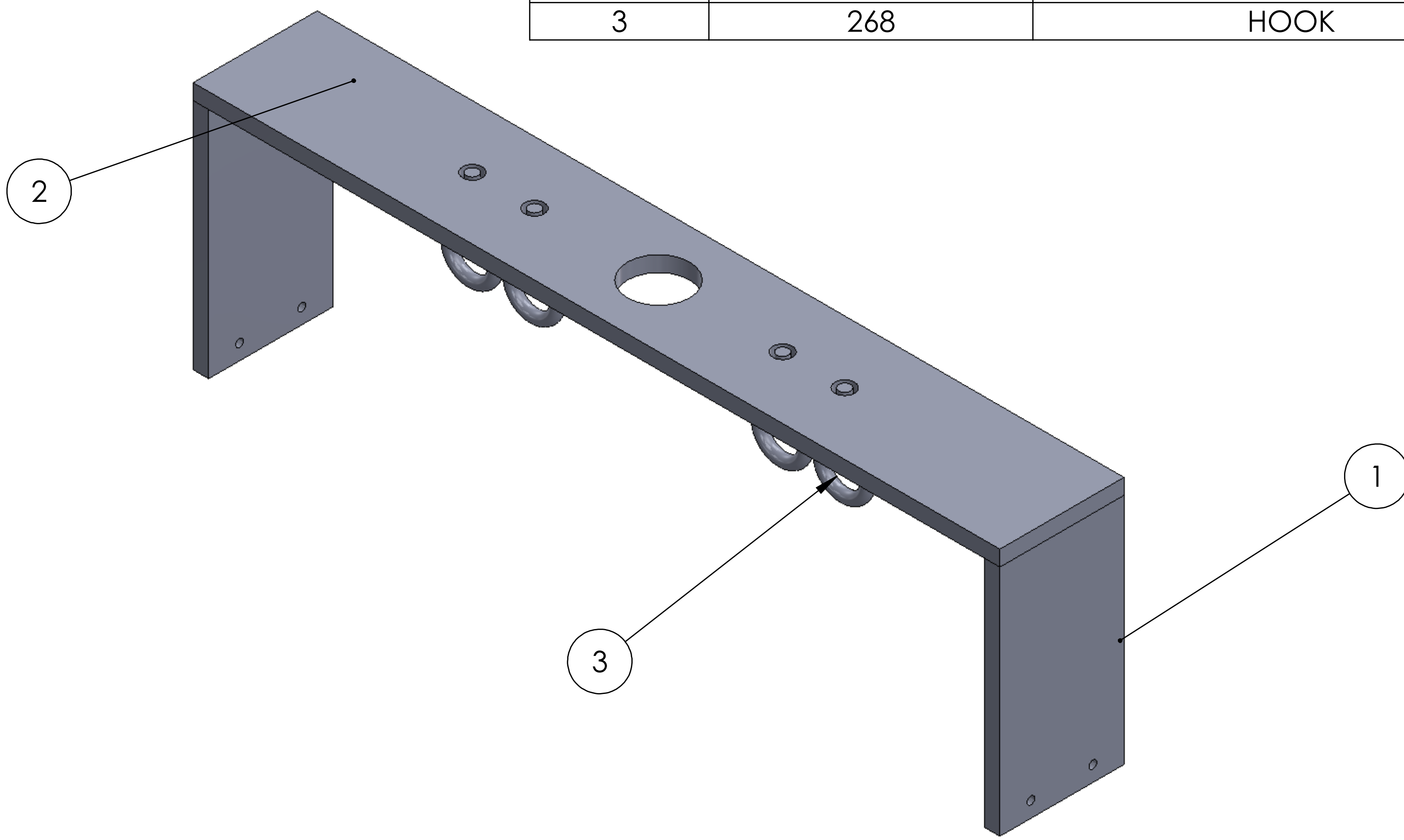
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	264	1/8" BRACKET TOP	1
2	263	1/8" BRACKET SIDE	2
3	268	HOOK	4



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES	DRAWN	LUCAS	5/3/15	TITLE: 1/8" BRACKET
	CHECKED			
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL	COMMENTS:			SIZE A — DWG. NO. 260B — REV
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:2 — WEIGHT: — SHEET 1 OF 1

5 4 3 2 1

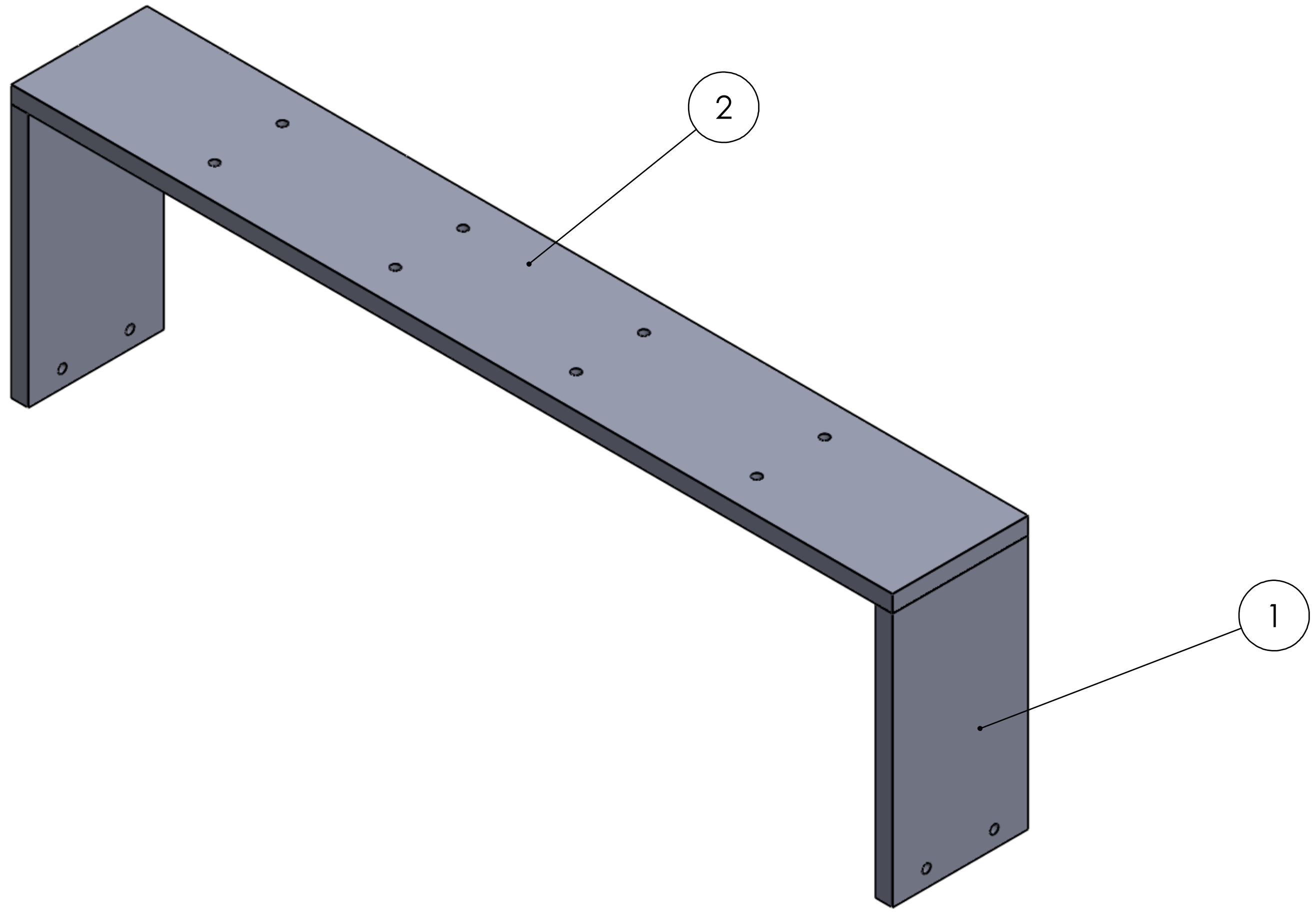
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	261	1/4" BRACKET SIDE	2
2	267	180 BRACKET TOP	1
3	268	HOOK	4



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES	DRAWN	LUCAS	5/3/15	
	CHECKED			TITLE: 180 DEGREE BRACKET
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL:	COMMENTS:			SIZE A — DWG. NO. 260C — REV
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:2 — WEIGHT: — SHEET 1 OF 1

5 4 3 2 1

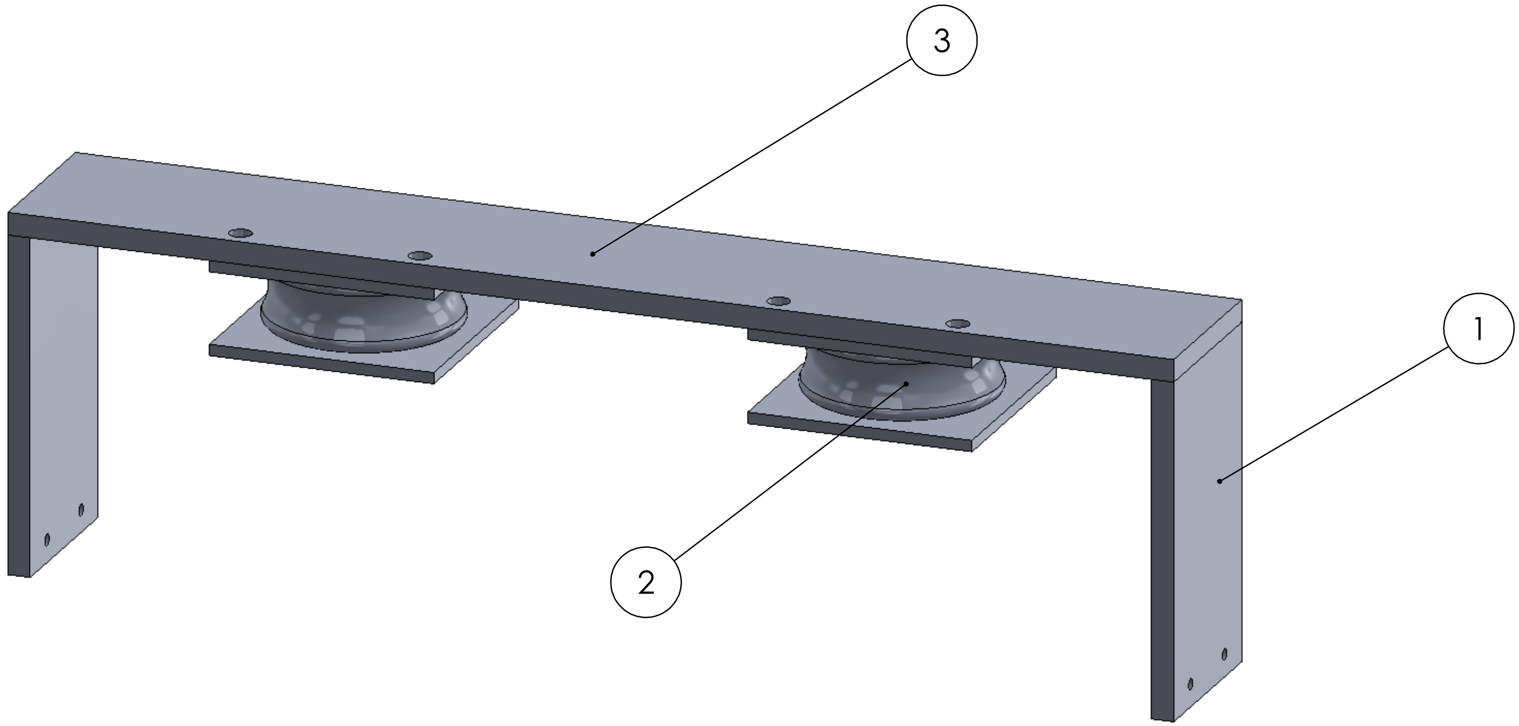
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	261	1/4" BRACKET SIDE	2
2	266	MOTOR PLATE BRACKET TOP	1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES	DRAWN	LUCAS	5/3/15	
	CHECKED			TITLE: SPOOL BRACKET
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL	COMMENTS:			SIZE A · DWG. NO. 260D · REV
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:2 · WEIGHT: · SHEET 1 OF 1

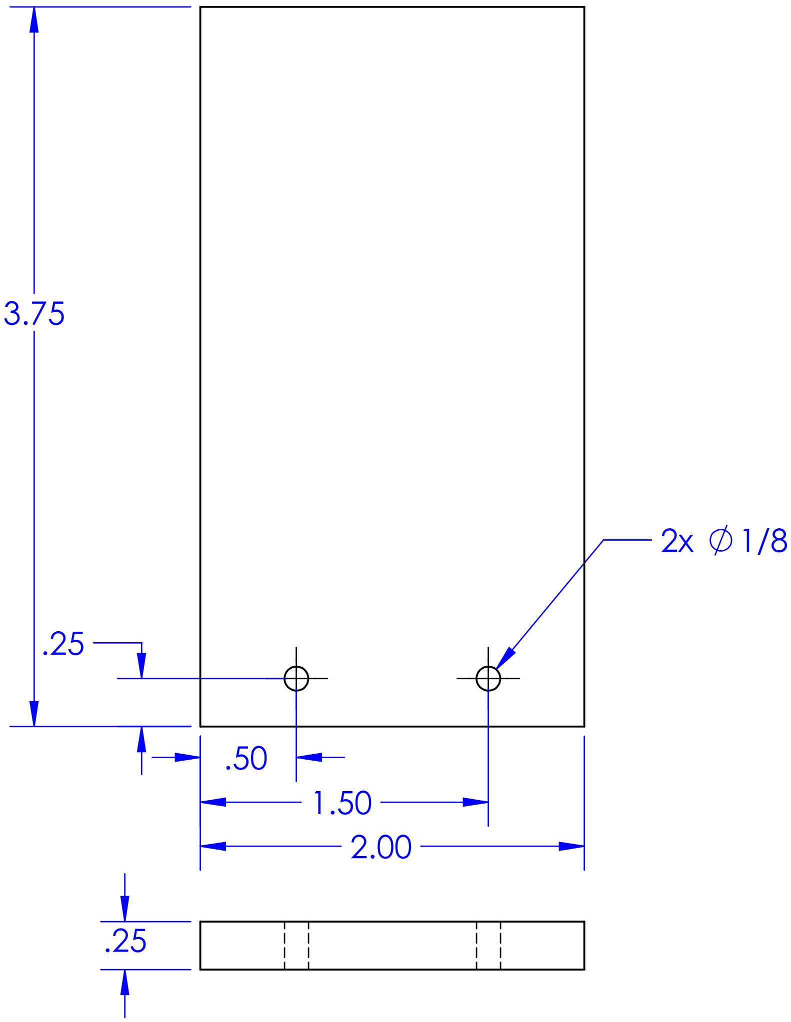
5 4 3 2 1

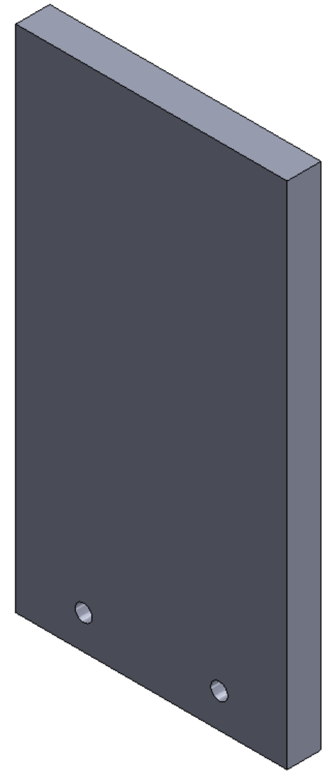
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	thick bracket side	1/4" BRACKET SIDE	2
2	pulley	PULLEY	2
3	pulley bracket top	PULLEY BRACKET TOP	1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES	DRAWN	LUCAS	5/3/15	
	CHECKED			TITLE: PULLEY BRACKET
	ENG APPR.			
	MFG APPR.			
	Q.A.			
INTERPRET GEOMETRIC TOLERANCING PER:	COMMENTS:			
MATERIAL				SIZE A — DWG. NO. 260E — REV
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:2 — WEIGHT: — SHEET 1 OF 1

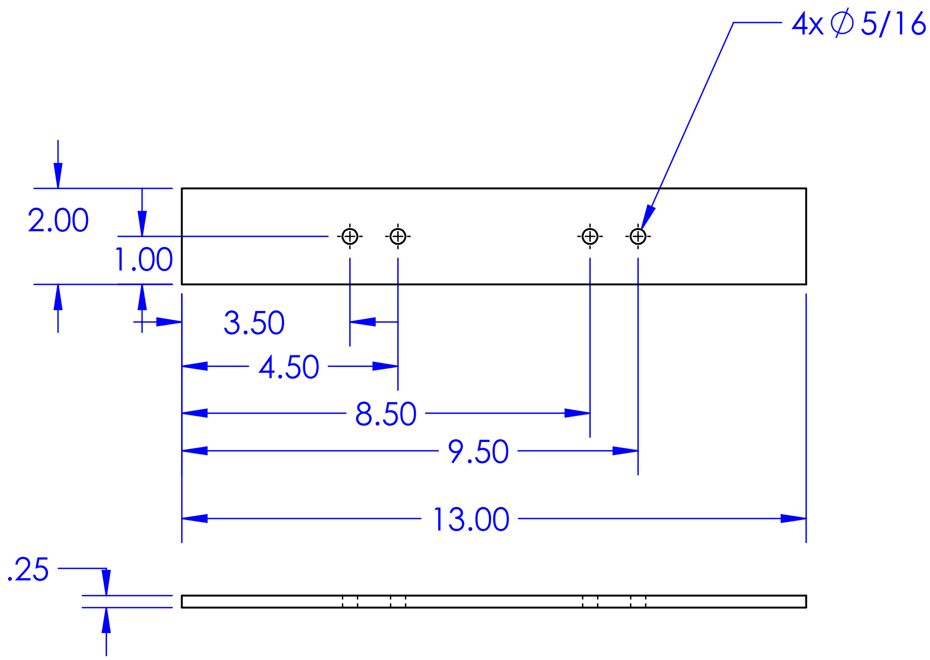
5 4 3 2 1

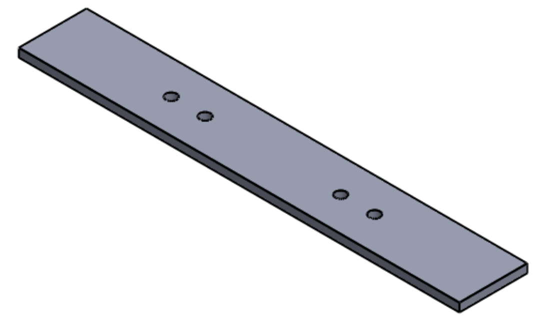




UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES	DRAWN	LUCAS	5/3/15	TITLE: 1/4" BRACKET SIDE
	CHECKED			
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL: STEEL	COMMENTS:			SIZE A · DWG. NO. 261 · REV 2
FINISH: PAINTED BLACK				
DO NOT SCALE DRAWING				SCALE: 1:1 · WEIGHT: · SHEET 1 OF 1

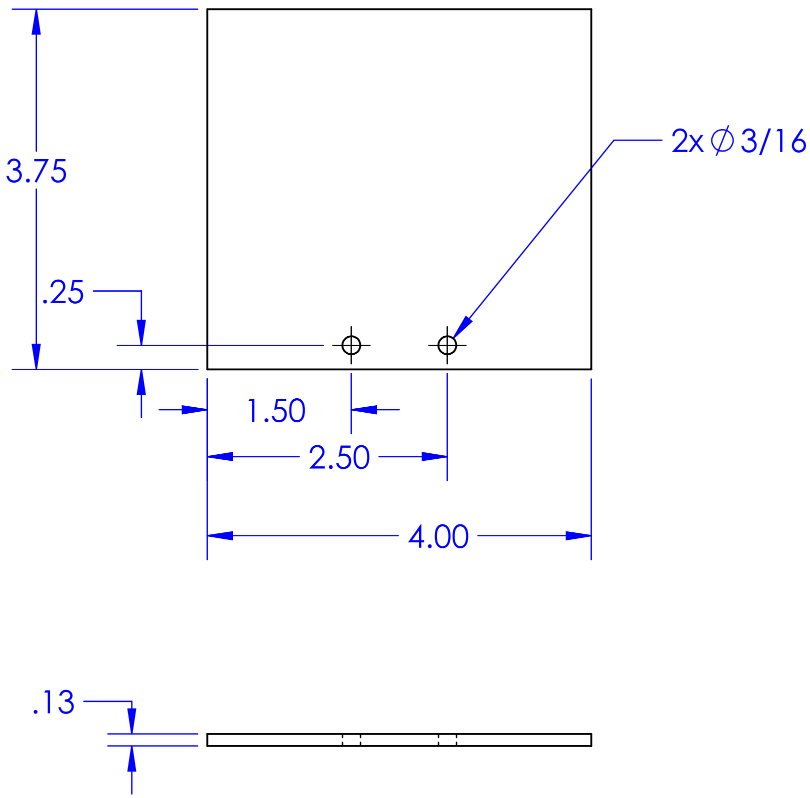
5 4 3 2 1

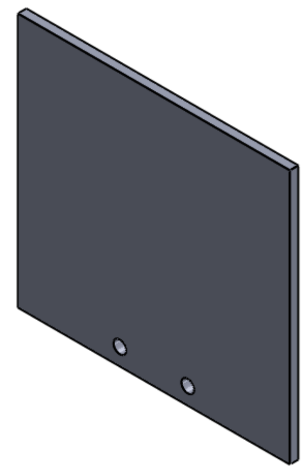




UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES	DRAWN	LUCAS	5/3/15	
	CHECKED			TITLE: 1/4" BRACKET TOP
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL: STEEL	COMMENTS:			SIZE **A** — DWG. NO. 262 — REV
FINISH: PAINTED BLACK				
DO NOT SCALE DRAWING				SCALE: 1:4 — WEIGHT: — SHEET 1 OF 1

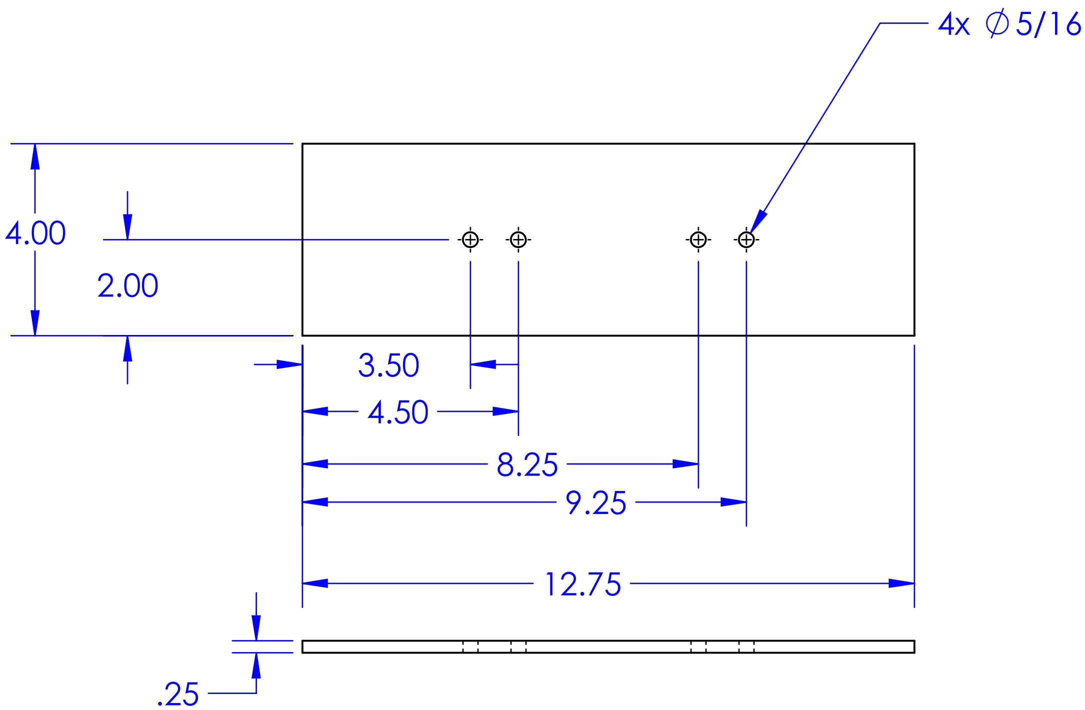
5 4 3 2 1

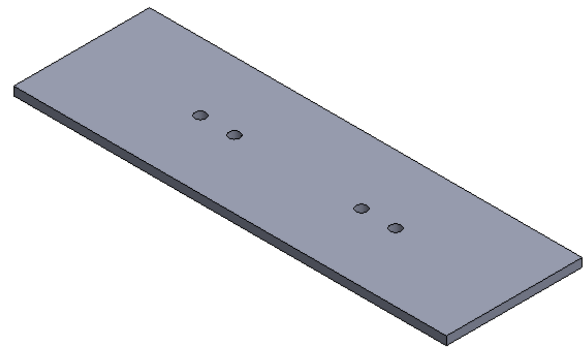




UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES	DRAWN	LUCAS	5/3/15	TITLE: 1/8" BRACKET SIDE
	CHECKED			
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL: STEEL	COMMENTS:			SIZE A · DWG. NO. 263 · REV
FINISH: PAINTED BLACK				
DO NOT SCALE DRAWING				SCALE: 1:2 · WEIGHT: · SHEET 1 OF 1

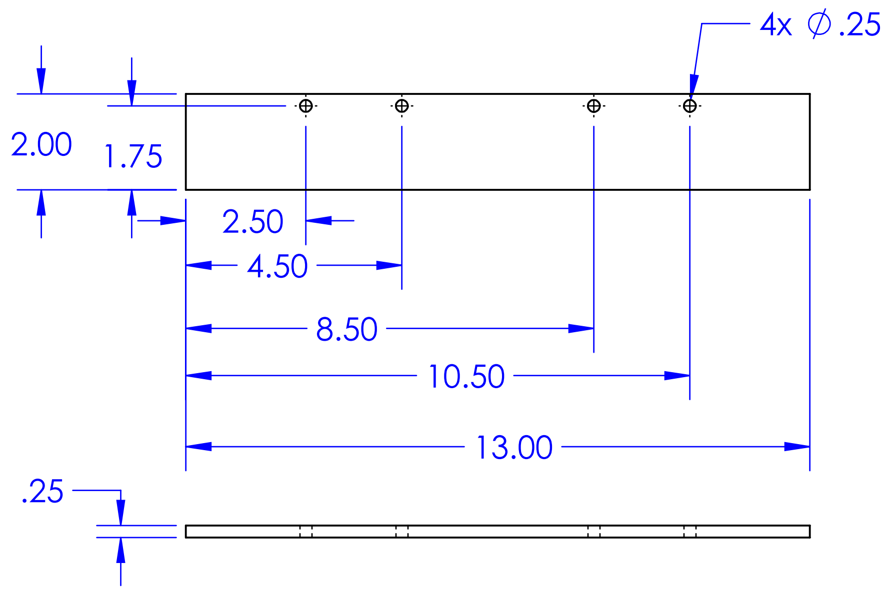
5 4 3 2 1

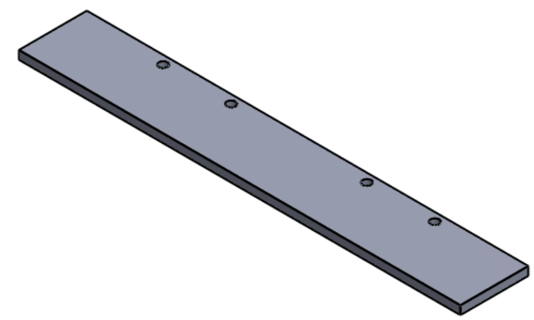




UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES	DRAWN	LUCAS	5/3/15	TITLE: 1/8" BRACKET TOP
	CHECKED			
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL: STEEL	COMMENTS:			SIZE A — DWG. NO. 264 — REV
FINISH: PAINTED BLACK				SCALE: 1:4 — WEIGHT: — SHEET 1 OF 1
DO NOT SCALE DRAWING				

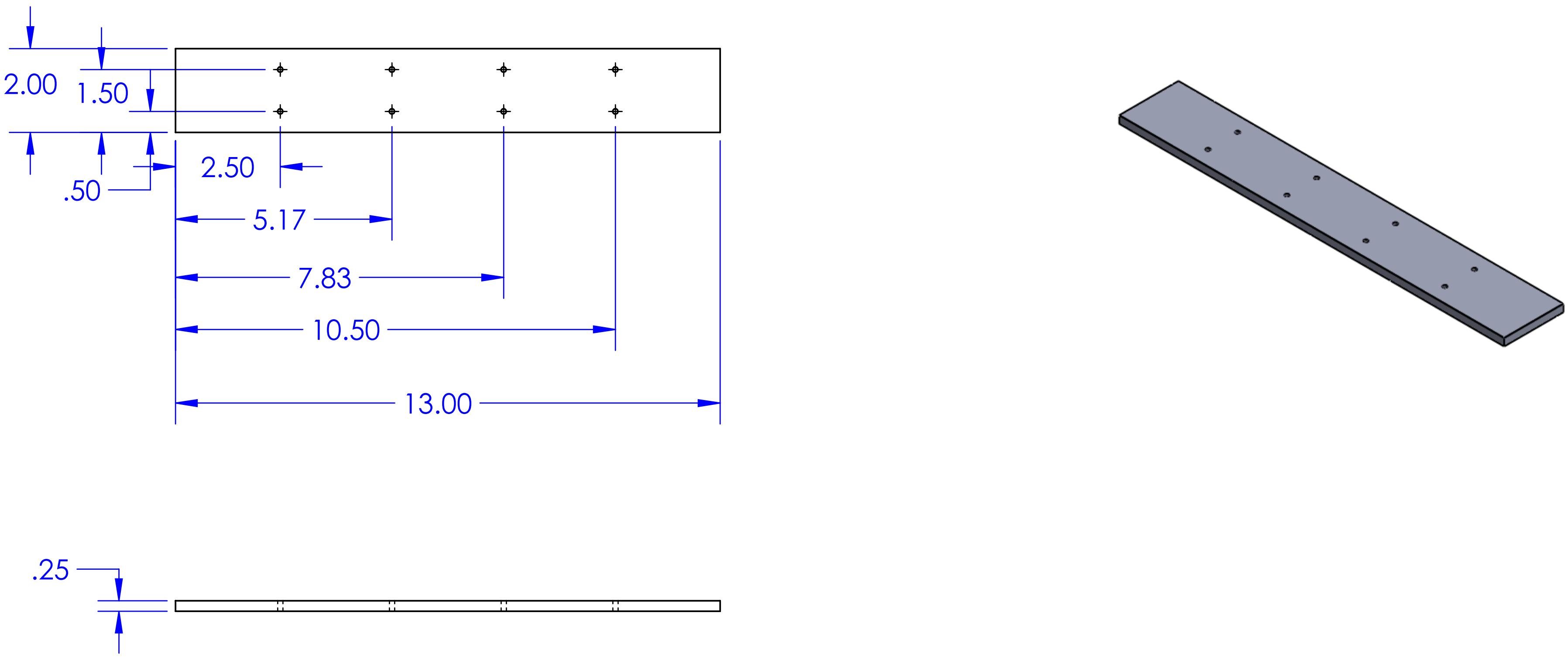
5 4 3 2 1





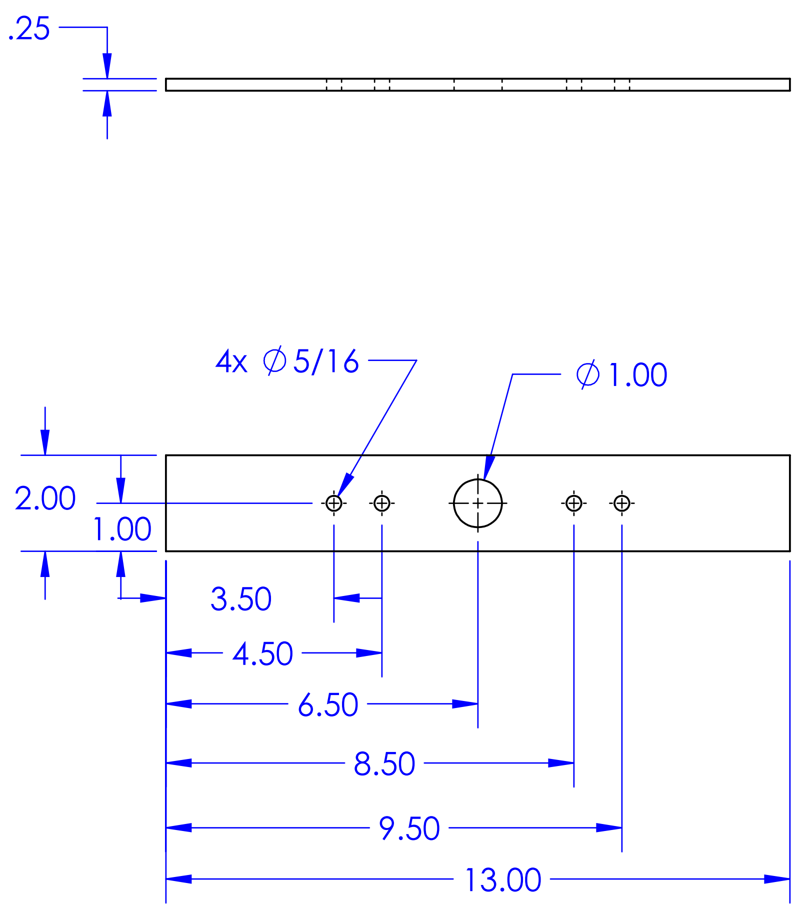
UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES	DRAWN	LUCAS	5/3/15	TITLE: PULLEY BRACKET TOP
	CHECKED			
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL: STEEL	COMMENTS:			SIZE A DWG. NO. 265 REV
FINISH: PAINTED BLACK				
DO NOT SCALE DRAWING				SCALE: 1:4 WEIGHT: SHEET 1 OF 1

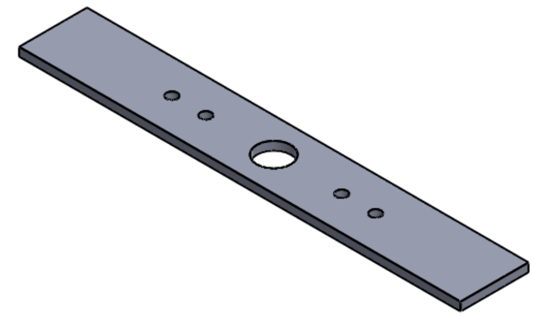
5 4 3 2 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES	DRAWN	LUCAS	5/3/15	
	CHECKED			TITLE: MOTOR PLATE BRACKET TOP
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL: STEEL	COMMENTS: RIVETS ARE SPACED 8/3" APPART HORIZONALLY			SIZE A DWG. NO. 266 REV
FINISH: PAINTED BLACK				
DO NOT SCALE DRAWING				SCALE: 1:4 WEIGHT: SHEET 1 OF 1

5 4 3 2 1





UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES	DRAWN	LUCAS	5/3/15
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL: STEEL	COMMENTS:		
FINISH: BLACK PAINT			
DO NOT SCALE DRAWING			

TITLE: 180 BRACKET TOP

SIZE	DWG. NO. 267	REV
A		2
SCALE: 1:4	WEIGHT:	SHEET 1 OF 1

5 4 3 2 1

Lehigh | Model # 7229S-6 | Internet # 100111333 | Store SKU # 439509

3-5/8 in. x 3/4 in. Zinc-Plated Screw Eye Hooks (2-Pack)

PRODUCT OVERVIEW

Model # 7229S-6 | Internet # 100111333 | Store SKU # 439509

3-5/8 in. x 3/4 in. Zinc-Plated Screw Eye Hooks (2-Pack) are great for use with rope up to 1/2 in. in diameter. The hooks can be used with snap hooks and rope clamps for increased versatility.

- All-purpose hooks
- Great for use with rope up to 1/2 in. in diameter
- Can be used with snap hooks and rope clamps for increased versatility
- Made of steel
- Zinc plated

SPECIFICATIONS

DIMENSIONS

Assembled Depth (in.)	.66 in	Hook length (in.)	3.625
Assembled Height (in.)	6 in	Hook opening (in.)	1.0
Assembled Width (in.)	3 in	Projection (in.)	2.0
Hook diameter (in.)	1.0		

DETAILS

Fastener Type	Eye Bolt	Maximum Weight Capacity (lb.)	10.0
Finish Family	Metallic	Package Quantity	2
Magnetic	No	Product Weight (lb.)	0.17 lb
Material	Steel	Self-adhesive	No

NOTE: SIMILAR PRODUCT, NOT EXACT PURCHASED PART

Crown Bolt | Model # 64634 | Internet # 203001587 | Store SKU # 430803

1-1/2 in. Zinc-Plated Wall/Ceiling Mount Pulley

Write the First Review + | Questions & Answers (2) +

PRODUCT OVERVIEW

Model # 64634 | Internet # 203001587 | Store SKU # 430803

1-1/2 in. Swivel Wall/Ceiling Mount Pulley can safely support up to 420 lbs. for heavy duty applications. The wheel is free to rotate and easily lifts loads by applying little force. Direction of the force can easily be changed. Use with Crown Bolt rope up to 3/8 in. Mount using three 1/4 in. machine screws. (Screws are not included).

California residents: see Proposition 65 information

- Zinc-plated finish
- Working load limit 420 lbs.
- Makes moving and lifting items easier
- Mount directly to wall or ceiling
- Removable sheave pin for easy installation
- Do not use for overhead lifting, do not exceed the working load limit

SPECIFICATIONS

DIMENSIONS

Product Depth (in.)	0.3543307086614173	Product Width (in.)	2.75
Product Height (in.)	5.5625		

DETAILS

Chain/Rope Accessory Type	Other Accessory	Package Quantity	1
Fastener Type	Chain/Rope Accessory	Product Weight (lb.)	0.357 lb
Finish Family	Other	Returnable	90-Day

ENLARGE

Krylon 12 Oz Black Hammered Dual Paint + Primer Spray Paint (K08841000)

Item no: 1495498 | 724504088417

$6.99

(No reviews)

Be the first to Write a Review

70 Estimated ACE Rewards points

1

FREE Store Pickup! Find my Ace. (details)

+ ADD TO CART   TO-DONE LIST

FREE PICKUP at Your Local Ace   CHECK AVAILABILITY

PayPal CREDIT No Payments + No Interest if paid in full in 6 months. On orders over $250. Subject to credit approval. See terms.

PRINT   EMAIL

This item can be purchased on-line, however, due to shipping restrictions, ITEM PICKUP IS ONLY AVAILABLE AT YOUR LOCAL ACE STORE.

Rust-Oleum 11oz Stops Rust Metallic Spray Paint in Black (7250-830)

Item no: 1096056 | 020066725082

$7.99

★★★★★ (No reviews)

Be the first to Write a Review

80 Estimated ACE Rewards points

− 1 +

FREE Store Pickup! Find my Ace. (details)

+ ADD TO CART TO-DONE LIST

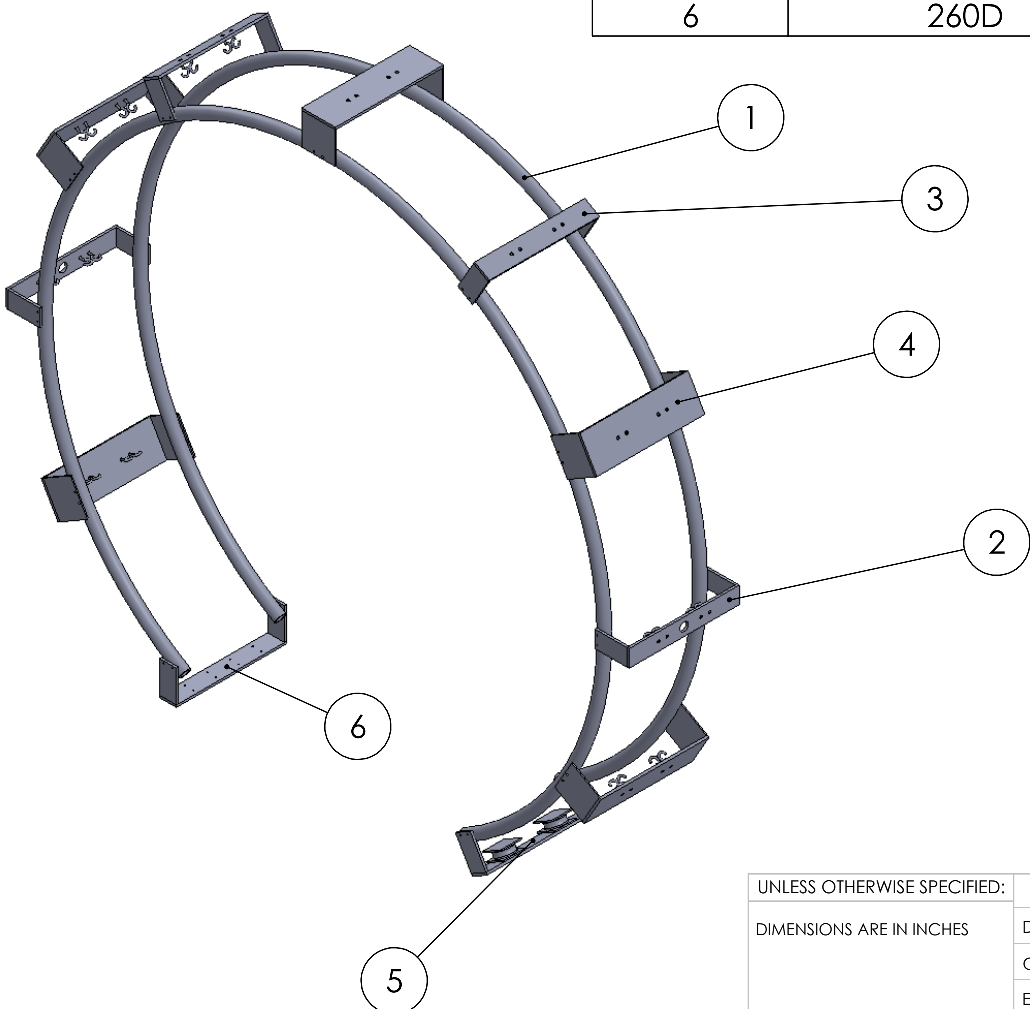
FREE PICKUP at Your Local Ace CHECK AVAILABILITY ›

PayPal CREDIT No Payments + No Interest if paid in full in 6 months. On orders over $250. Subject to credit approval. See terms.

PRINT › EMAIL ›

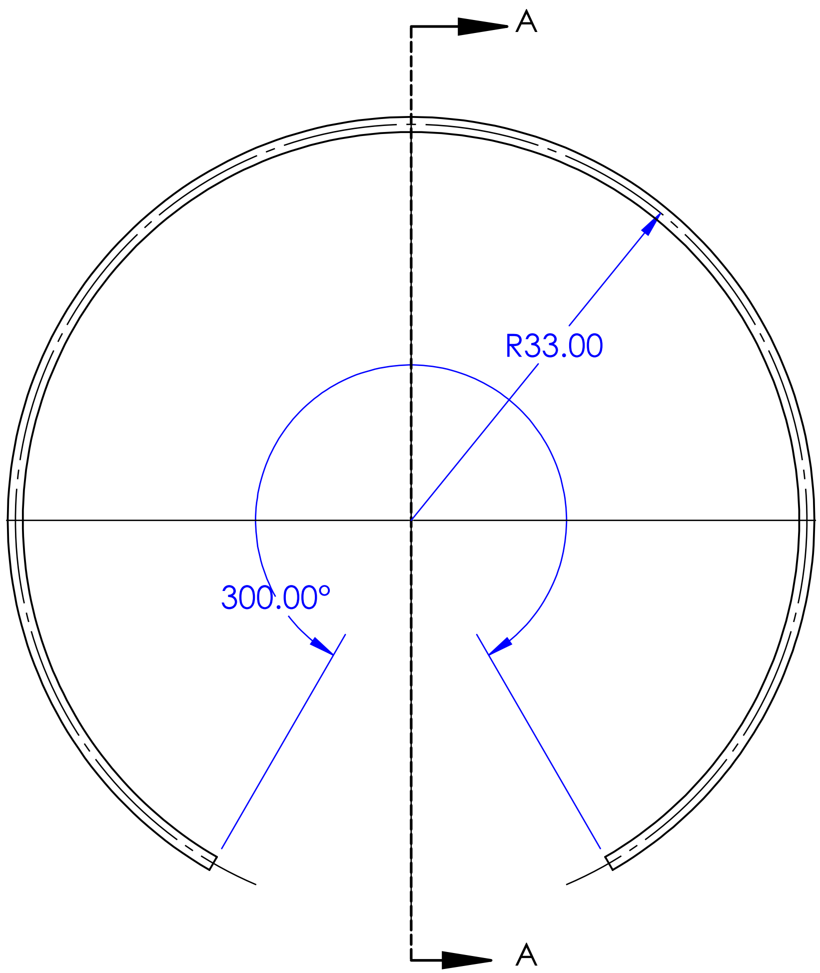
This item can be purchased on-line, however, due to shipping restrictions, ITEM PICKUP IS ONLY AVAILABLE AT YOUR LOCAL ACE STORE.

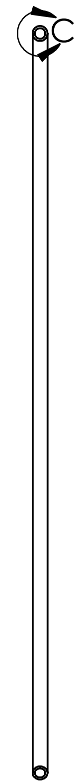
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	281	ARC	2
2	260C	180 BRACKET	2
3	260A	1/4" BRACKET	2
4	260B	1/8" BRACKET	5
5	260E	PULLEY BRACKET	1
6	260D	SPOOL BRACKET	1



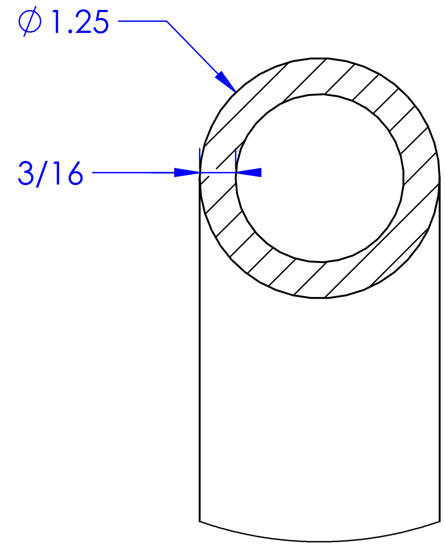
UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES	DRAWN	LUCAS	5/13/15	
	CHECKED			TITLE: ARCH ASSEMBLY
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL:	COMMENTS: 180 BRACKETS ARE ACCROSS FROM ONE ANOTHER. THE THICK AND THIN BRACKETS ARE STAGGERED ALONG THE ARCH			SIZE A — DWG. NO. 280 — REV
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:16 — WEIGHT: — SHEET 1 OF 1

5 4 3 2 1





SECTION A-A

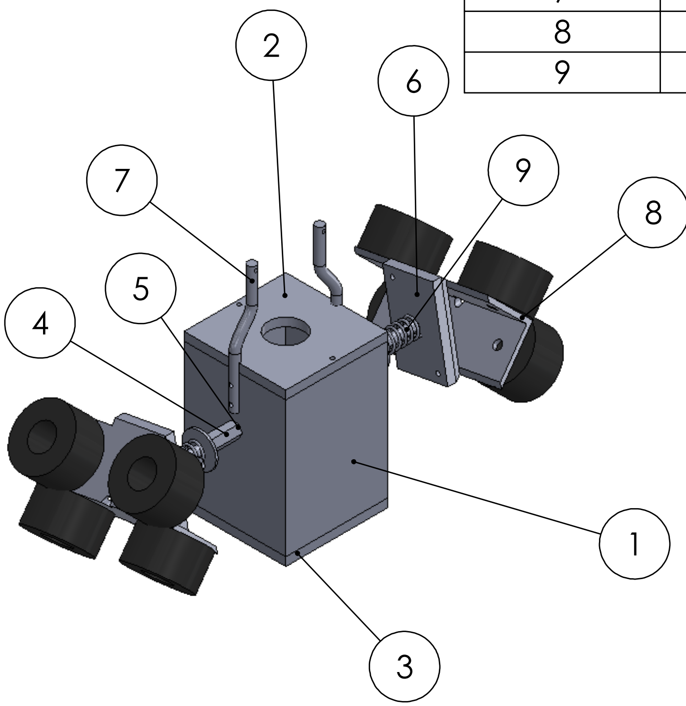


DETAIL C
SCALE 1 : 1

UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES	DRAWN	LUCAS	5/13/15	TITLE: ARCH
	CHECKED			
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL: ALUMINUM	COMMENTS:			SIZE A · DWG. NO. 281 · REV 2
FINISH: SCOTCH BRITE RUB				
DO NOT SCALE DRAWING				SCALE: 1:16 · WEIGHT: · SHEET 1 OF 1

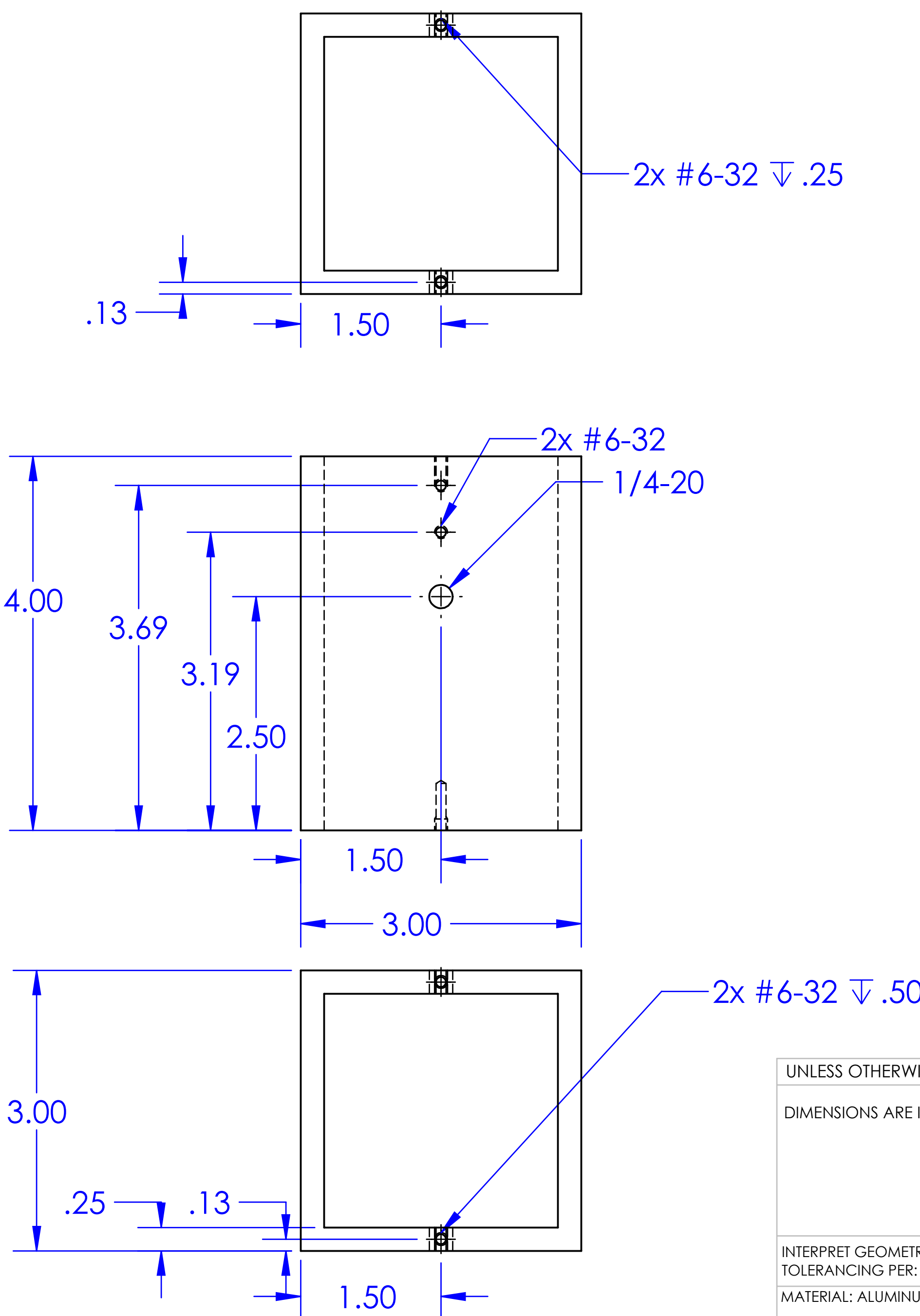
5 4 3 2 1

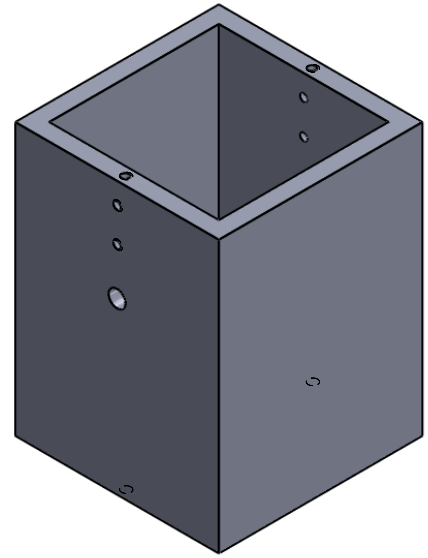
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	291	CARRIAGE BODY	1
2	292	CARRIAGE TOP PLATE	1
3	293	CARRIAGE BOTTOM PLATE	1
4	299	SHAFT COUPLER	2
5	294	THREADED SHAFT	2
6	295	SLIDER PLATE	2
7	296	CABLE GRABBERS	2
8	297	WHEELS	2
9	298	SOCKET HEAD CAP SCREW	2



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES	DRAWN	LUCAS	5/3/15	
	CHECKED			TITLE: CARRIAGE ASSEMBLY
	ENG APPR.			
	MFG APPR.			
	Q.A.			
INTERPRET GEOMETRIC TOLERANCING PER:	COMMENTS:			
MATERIAL:				SIZE A, DWG. NO. 290, REV
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:4, WEIGHT:, SHEET 1 OF 1

5 4 3 2 1



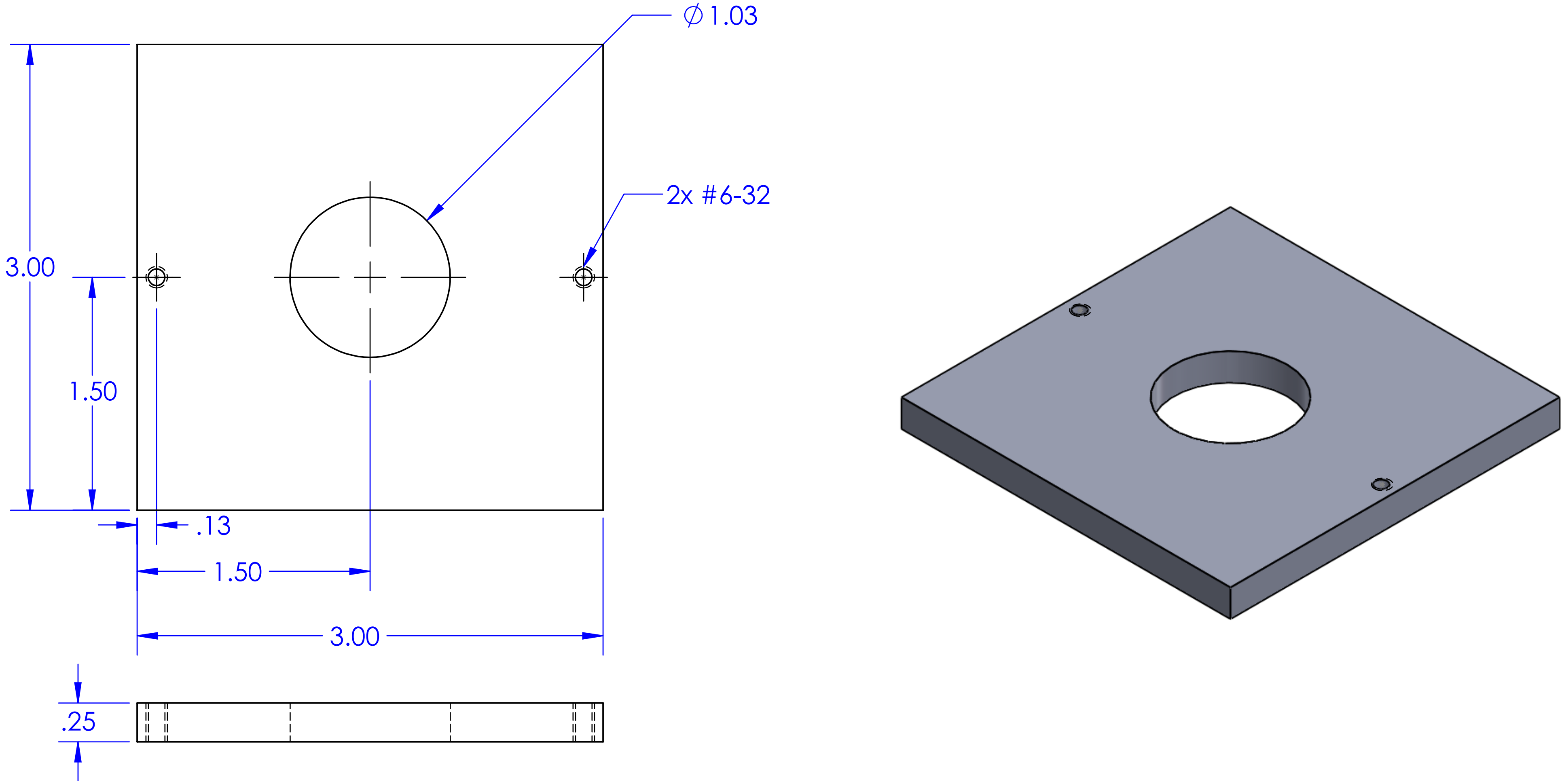


UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES	DRAWN	LUCAS	5/3/15
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL: ALUMINUM	COMMENTS: ALL HOLES REFLECTED ON OTHER SIDE OF BODY AS WELL. DEPTH FOR HOLES ON TOP AND BOTTOM ARE NOT VERY IMPORTANT.		
FINISH			
DO NOT SCALE DRAWING			

TITLE: CARRIAGE BODY

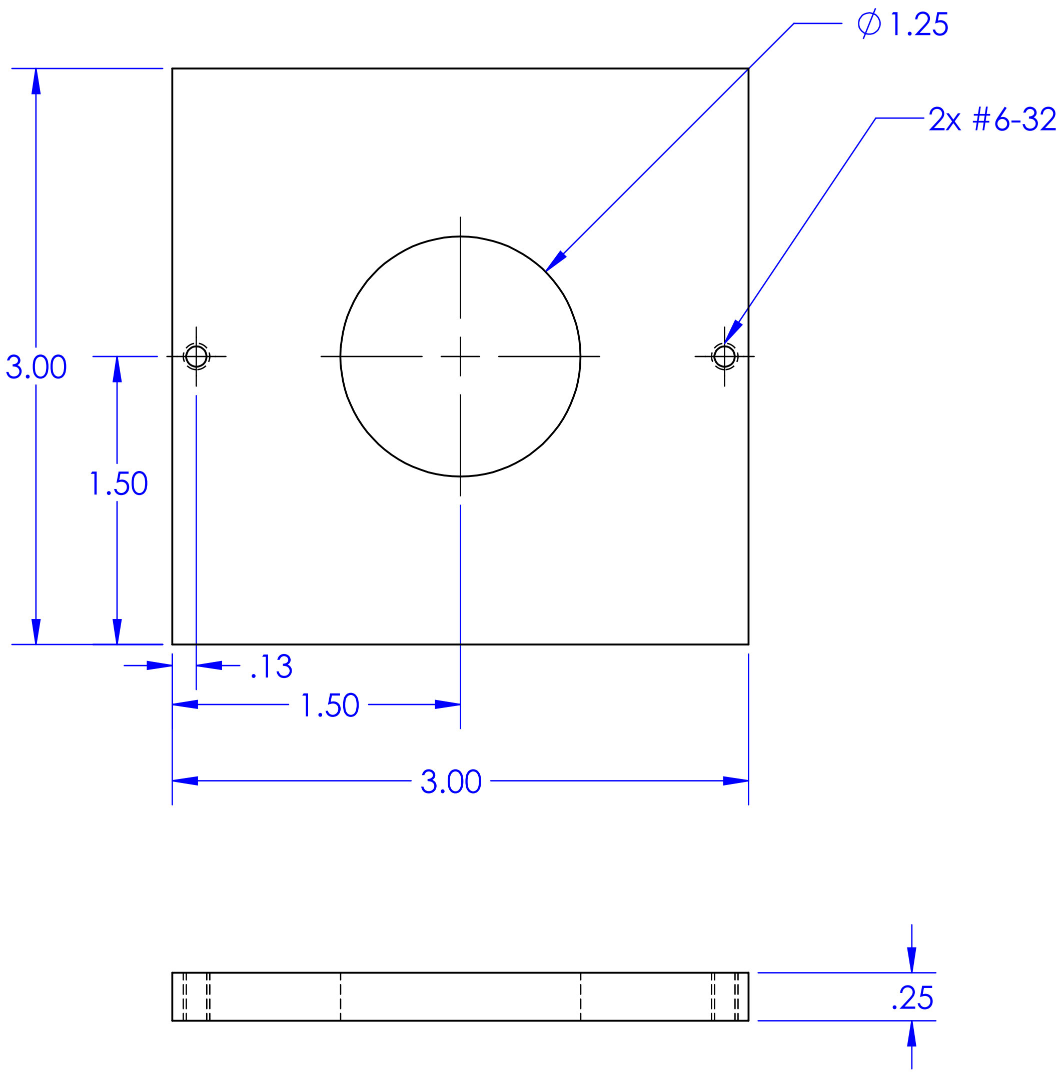
SIZE A	DWG. NO. 291	REV
SCALE: 1:2	WEIGHT:	SHEET 1 OF 1

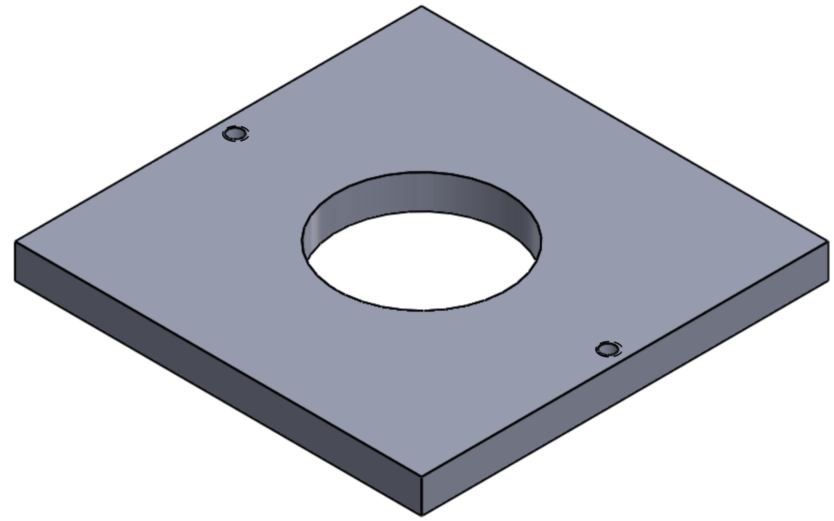
5 4 3 2 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES	DRAWN	LUCAS	5/3/15	TITLE: CARRIAGE TOP PLATE
	CHECKED			
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL: ALUMINUM	COMMENTS: MIDDLE HOLE IS FOR CABLE TIGHTENER TO GRAB POWER CABLE			SIZE A — DWG. NO. 292 — REV
FINISH				SCALE: 1:1 — WEIGHT: — SHEET 1 OF 1
DO NOT SCALE DRAWING				

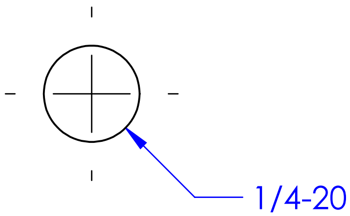
5 4 3 2 1

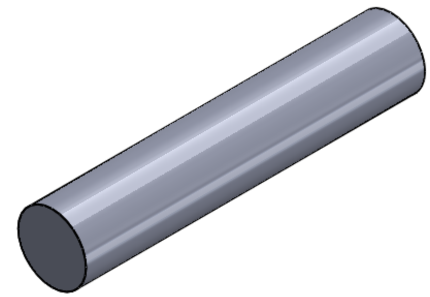


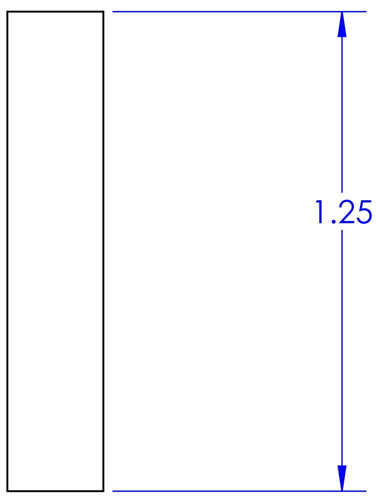


UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES	DRAWN	LUCAS	5/1/15	TITLE: CARRIAGE BOTTOM PLATE
	CHECKED			
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL: ALUMINUM	COMMENTS:			SIZE A — DWG. NO. 293 — REV
FINISH				SCALE: 1:1 — WEIGHT: — SHEET 1 OF 1
DO NOT SCALE DRAWING				

5 4 3 2 1

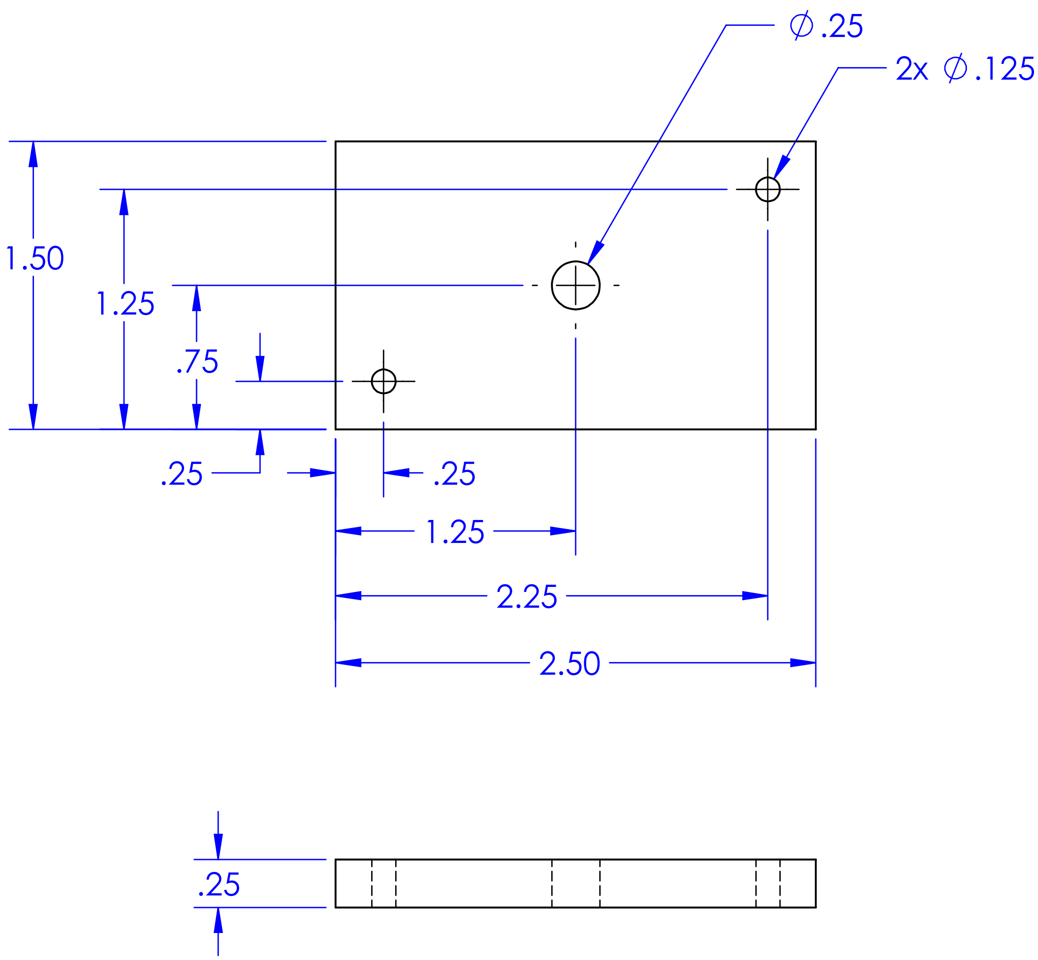


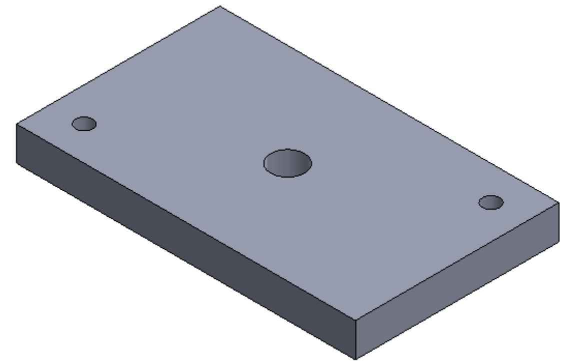




UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES	DRAWN	LUCAS	5/3/15	
	CHECKED			TITLE: CARRIAGE THREADED SHAFT
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL: STEEL	COMMENTS: 1/4-20 THREADED ROD CUT DOWN TO LENGTH. BOTH ENDS NEED TO BE THREADED, SO GRIND BOTH ENDS TO ALLOW NUTS TO BE SCREWED ON.			SIZE A — DWG. NO. 294 — REV
FINISH				
DO NOT SCALE DRAWING				SCALE: 2:1 — WEIGHT: — SHEET 1 OF 1

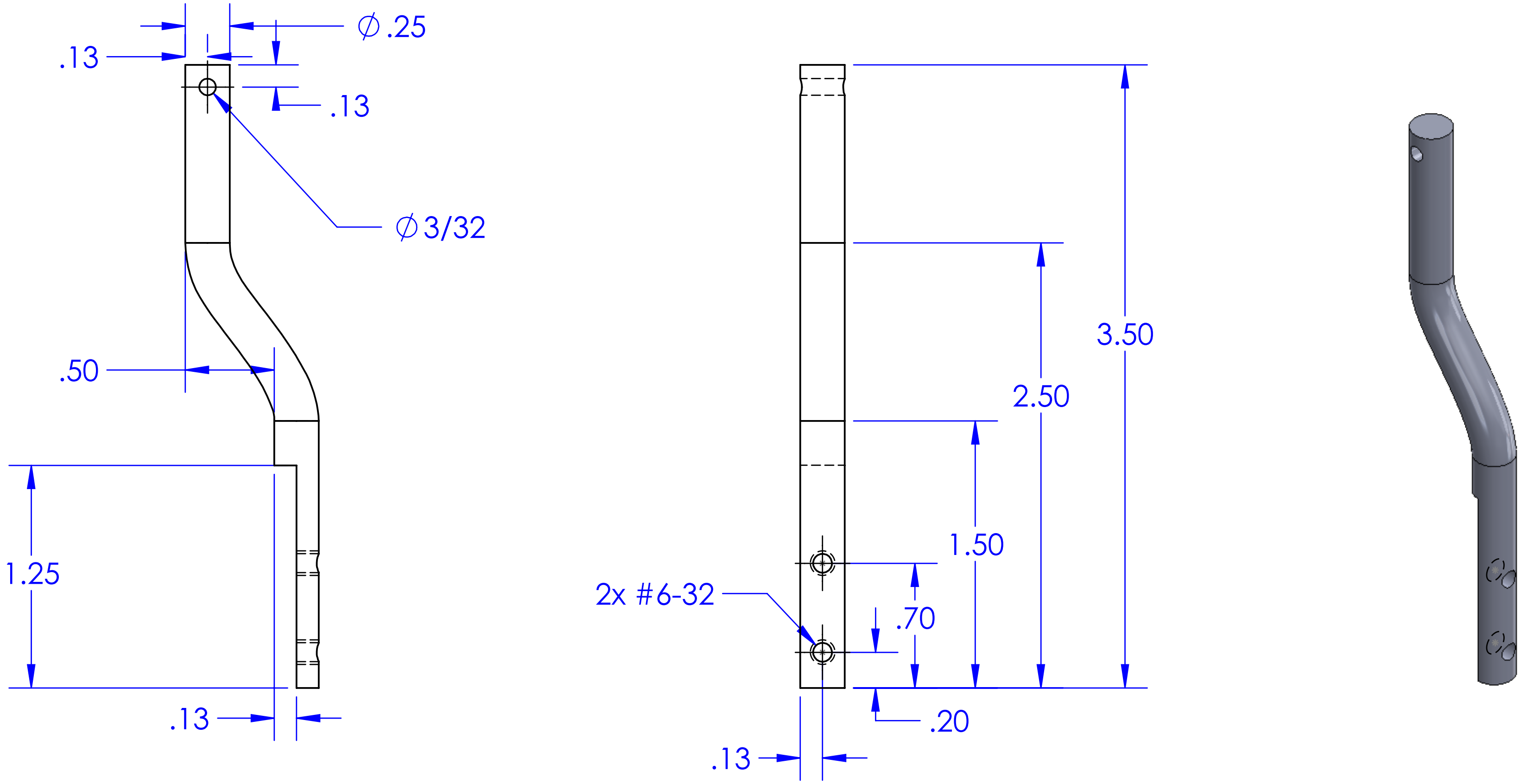
5 4 3 2 1





UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES	DRAWN	LUCAS	5/3/15	TITLE: WHEEL MOUNT PLATE
	CHECKED			
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL: ALUMINUM	COMMENTS: NO HOLES ARE THREADED, JUST STRAIGHT THROUGH. MIDDLE IS FOR CAP SCREW, SIDES ARE FOR RIVETS			SIZE A — DWG. NO. 295 — REV
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:1 — WEIGHT: — SHEET 1 OF 1

5 4 3 2 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES	DRAWN	LUCAS	5/3/15	TITLE: CABLE GRABBER
	CHECKED			
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL: ALUMINUM	COMMENTS: EXACT SHAPE OF CURVE ISN'T IMPORTANT.			SIZE A · DWG. NO. 296 · REV
FINISH				SCALE: 1:1 · WEIGHT: · SHEET 1 OF 1
DO NOT SCALE DRAWING				

5 4 3 2 1

Dolly Track Swivel Wheels

$39.97

- 1 +   Add to cart

Categories: Camera Accessories, Camera Dolly & Track Systems.

Description | Reviews (0)

Product Description

NEW TRACK DOLLY SWIVEL WHEELS

Each swivel track wheel assembly comes with four track wheels (4-wheels) for maximum stability and each castor wheel has 360° swivel and locking mechanism.

These wheels are not only full 360° swivel, but also able to freely slide within the wheel housing in any direction by an extra 1". This means that the track can be as uneven as 2" in places and still not effect the smooth operation.

1/4"-20 x 1-3/4" Grade 18-8 Stainless Steel Socket Cap Screw

Fastenal Part No. (SKU): 1173465
UNSPSC : 31161518
Manufacturer: HOLO-KROME INTERNATIONAL
Category: Fasteners > Sockets > Socket Cap Screws
Technical Specifications for Part: Fastenal Product Standard

Product Details

Compliance:
3TG: Does not contain 3TG
Contract Catalog Item: Y
Diameter: 1/4"
Diameter - Thread Size: 1/4" - 20
Drive: Hex
Drive Size: 3/16"
Finish: Plain
Grade: 18-8
Length: 1-3/4"
Material: Stainless Steel
REACH: Y
RoHS: Y
Specification: ASTM F837
System of Measurement: Imperial (Inch)
Thread: Coarse
Thread Size: 20
Type: Socket Cap Screw
Product Weight: 0.6375 lbs.
Notes:
HOLO-KROME® International is our high-quality globally sourced fastener line which competes with all other import Brands. Socket Head Cap screws are ideal for precision work with close tolerances and applications needing a well tooled appearance. Socket Head Cap screws supply greater tensile strength than equivalent Hex Head Caps screws, while requiring less surface area to counterbore. Resists corrosion even when submerged in salt water. Stainless Steel material. Grade 18-8 has the same design advantages as a low carbon bolt, however can be used in environments that require greater atmospheric corrosion resistance.

NOTE: SIMILAR PRODUCT, NOT EXACT PURCHASED PART

Simpson Strong-Tie | Model # CNW1/2 | Internet # 202092467

1/2 in. Witness Coupler Nut

★★★★★ (1) | Write a Review + | Customer Images (1) | Ask a Question +

PRODUCT OVERVIEW

Model # CNW1/2 | Internet # 202092467 | Store SO SKU # 592854

Simpson Strong-Tie coupler nuts are a tested and load-rated method to join threaded rod and anchor bolts. "Witness" holes in the nut provide a means to verify when rods are properly installed. The positive stop feature helps ensure even threading into each end of the nut.

- Tighten the 2 rods until each all-thread rod is visible in the witness hole
- For non-hot-dip galvanized all-thread rod only
- Rod Dia. 0.500
- Height: 1-1/2 in.
- Zinc plated

SPECIFICATIONS

DIMENSIONS

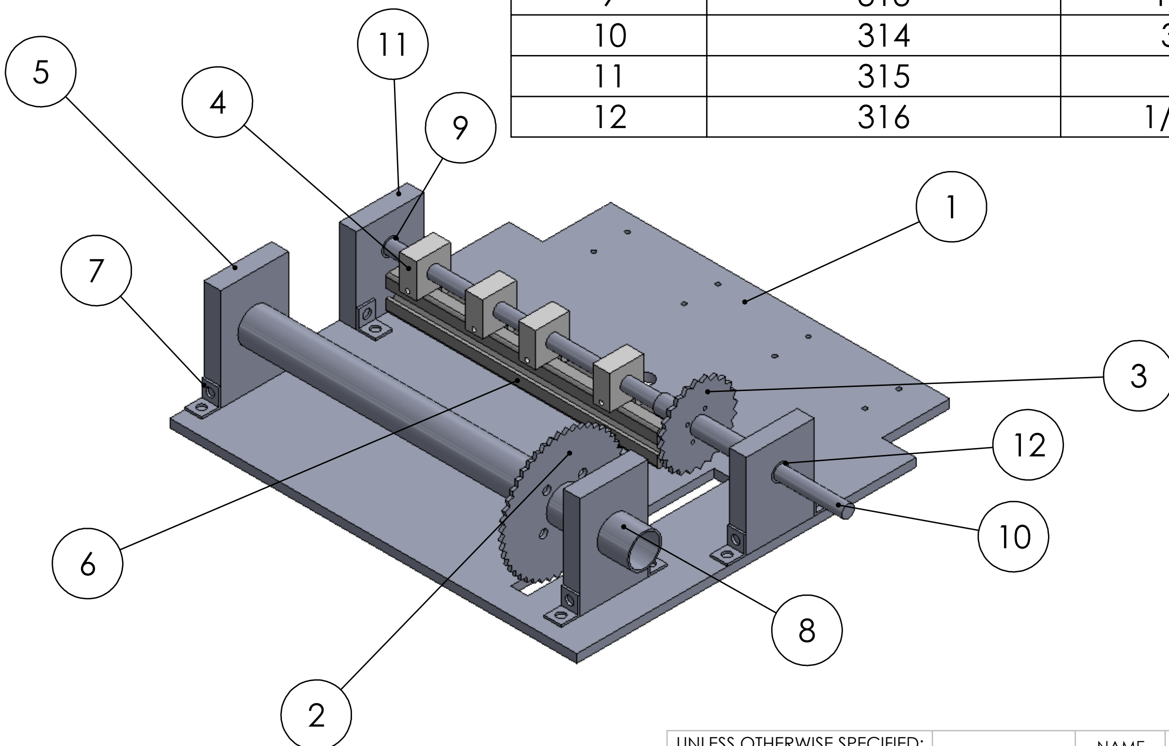
Assembled Depth (in.)	.866 in	Inside Diameter	.5 in
Assembled Height (in.)	1.5 in	Outside Width	.75 in
Assembled Width (in.)	.75 in		

DETAILS

Fastener Callout Size	1/2 in.	Package Quantity	1
Fastener Thread Type	Coarse	Product Weight (lb.)	0.06 lb
Fastener Type	Rod Coupling Nut	Returnable	90-Day
Finish Family	Metallic	Thread pitch	0.45
Material	Metal	Threaded	Yes
Measurement Standard	SAE		

NOTE: SIMILAR PRODUCT, NOT EXACT PURCHASED PART

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	302	MOTOR MOUNTING PLATE	1
2	303	48 TOOTH SPROCKET	1
3	304	24 TOOTH SPROCKET	1
4	308	WIRE GUIDE	4
5	309	1 INCH BEARING	2
6	310	T-SLOT WIRE GUIDE TRACK	1
7	311	L BRACKET	8
8	312	1 INCH SHAFT	1
9	313	1/2 INCH BEARING SHAFT	1
10	314	3/8-16 THREADED SHAFT	1
11	315	1/2 INCH BEARING	2
12	316	1/2 INCH SPROCKET SHAFT	1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES	DRAWN	LUCAS	5/3/15	
	CHECKED			TITLE: SPOOLING ASSEMBLY
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL:	COMMENTS:			SIZE A / DWG. NO. 300 / REV
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:4 / WEIGHT: / SHEET 1 OF 1

5 4 3 2 1

HS-7954SH Servo

Shopping Cart

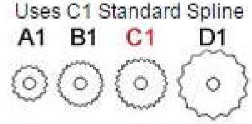
MAXIMUM TORQUE **403 oz-in.** **MAXIMUM SPEED** **0.12 sec/60°**

Introducing the next generation Ultra performance servos from Hitec. The "Ultra Torque" HS-7954SH features our second generation "G2" programmable digital circuit, steel gear set, heatsink case, and ultra power coreless motor making it arguably one of the best R/C servos ever produced! This new circuit has twice the resolution of our original circuit while adding programmable overload protection. The HS-7954SH has been designed for the most demanding hobby applications including the largest aircraft and monster trucks. Featuring a titanic 402oz./in. of torque at 7.4 volts, all this power is harnessed by incorporating steel gears for great durability and two strong hardened steel gear pins and axial brass bushing mounted in the servo case. We offer the HS-7954SH servo in several configurations, 90° stock rotation, 180° modified rotation, continuous rotation (potentiometer is left outside the servo case) and reverse rotation.

Digital Servo Programmable

Share with friends! 234

Uses C1 Standard Spline



Click for more information

*Digital servos do not need to be programmed to operate. They work great right out of the box and purchasing a programmer is not necessary.

Price: **$99.99**

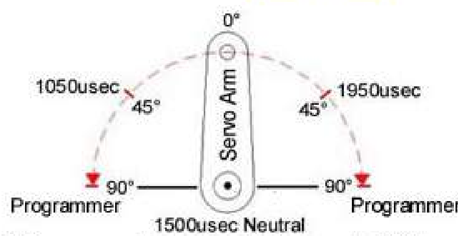
Part: **37954S**

Status: **In-Stock**

Rotation: Continuous +$20

Direction: Counter Clockwise +$10

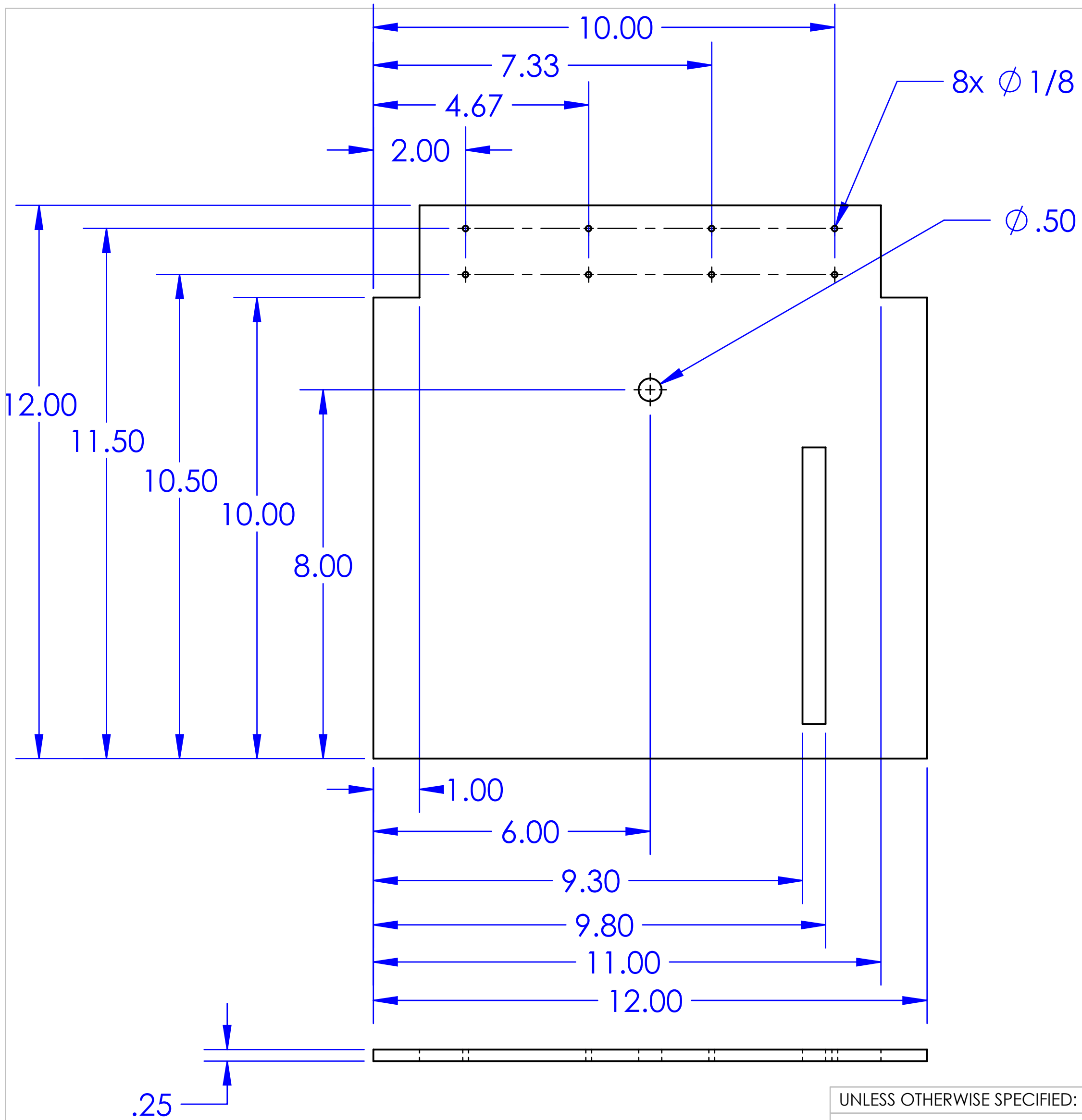
Qty: 1 **Add to Cart**

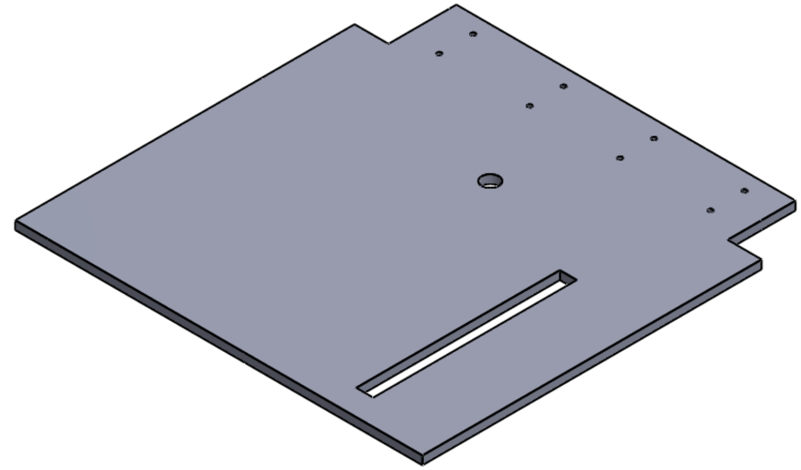


This servo can be configured to operate 180° by using any of the following servo programmers: Hitec HFP-25, HPP-21, HPP-21+

Detailed Specifications

Control System: +Pulse Width Control 1500usec Neutral
Required Pulse: 3-5 Volt Peak to Peak Square Wave
Operating Voltage Range: 4.8-7.4 Volts
Operating Temperature Range: -20 to +60 Degree C (-4F to +140F)
perating Speed (4.8V): **0.18 sec/60° at no load**
Operating Speed (6.0V): **0.15 sec/60° at no load**
Operating Speed (7.4V): **0.12 sec/60° at no load**
Stall Torque (4.8V): **275oz/in. (20kg.cm)**
Stall Torque (6.0V): **333oz/in. (24kg.cm)**
Stall Torque (7.4V): **403oz/in. (29kg.cm)**
Operating Angle: 45 Deg. one side pulse traveling 400usec
Continuous Rotation Modifiable: Yes
Direction: Clockwise/Pulse Traveling 1500 to 1900usec
Dead Band Width: 2usec
Motor Type: Coreless Carbon Brush
Potentiometer Drive: 6 Slider Indirect Drive
Bearing Type: Dual Ball Bearing MR106
Gear Type: Steel Gears
Connector Wire Length: 7" (178mm)
Dimensions: 1.57" x 0.78"x 1.45" (40 x 20 x 37mm)
Weight: 2.40oz (68g)





UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES	DRAWN	LUCAS	5/3/15	TITLE: MOTOR MOUNTING PLATE
	CHECKED			
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL: ALUMINUM	COMMENTS:			SIZE A
FINISH				DWG. NO. 302
				REV
DO NOT SCALE DRAWING				SCALE: 1:4
				WEIGHT:
				SHEET 1 OF 1

5 4 3 2 1

#615126 - 48T

48	**615126***	1"	3.823"	3.979"	1.7 oz.

#615106 - 24T

24	**615106**	1/2"	1.955"	2.049"	.40 oz.

The 1" Bore Aluminum Clamping Hub A is perfect for standard applications that require 1" shafting and great holding power. This clamping hub has 4 equally spaced 6-32 tapped holes. The side clamping machine screw is a 6-32 x 1/2" socket head machine screw and accepts a 7/64" hex key.

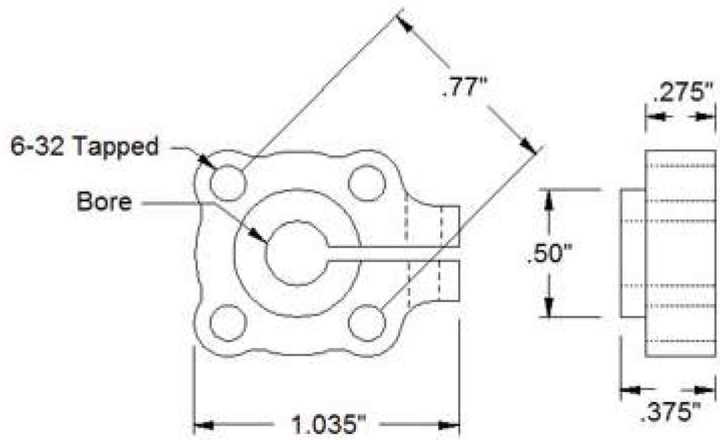
Fig. 1


Fig. 2

Price: **$5.99** / each
Part: **545352**
Status: **In-Stock**
Qty: 1 **Add to Cart**

This hub works great with our 1" bore 32P gears and our 1" Aluminum Tubing.

Weight: 0.45 oz (each)



1/2" (.500")	**545600**

Fig. 1

Metal Chain (.250)

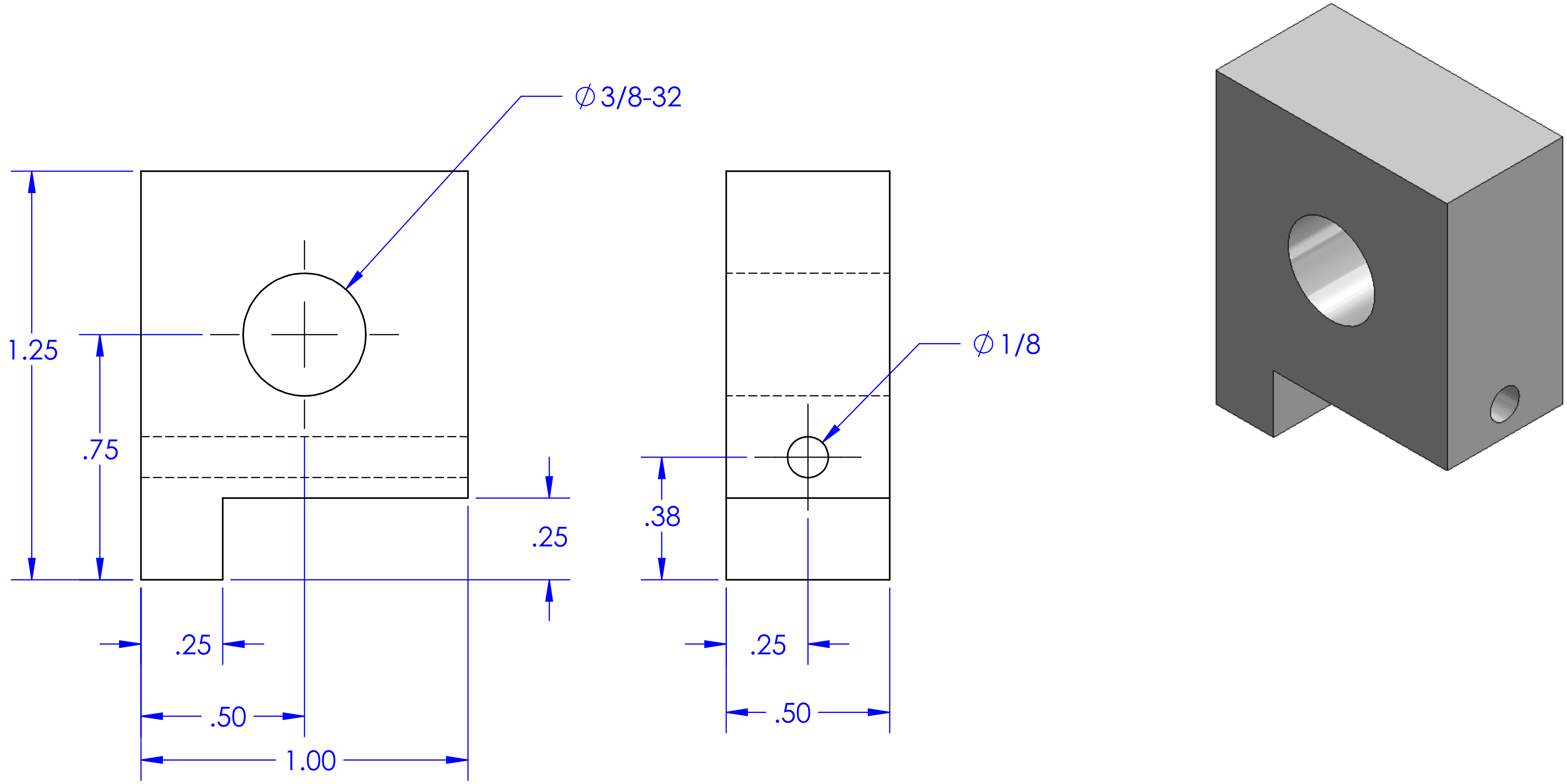
Extremely strong precision chain can take tremendous abuse. When used with our chain breaker, length can be changed quickly and easily for various applications. Rated for a 114lb working load. **Sold in pre-cut 1 foot sections.**

1 foot = 39g

Price: **$8.99**
Part: **C250**
Status: **In-Stock**
Feet: 1 **Add to Cart**

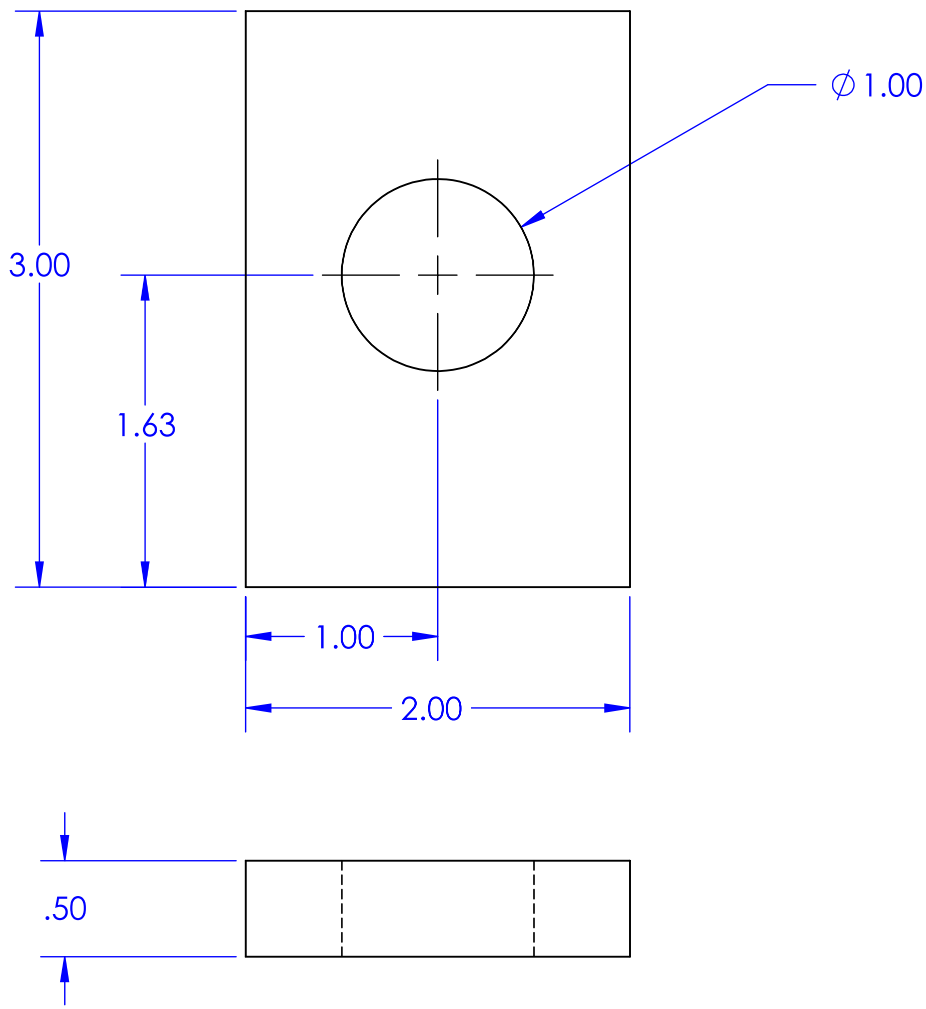
1/4" Pitch
1/8" Roller Width
0.130" Roller Diameter

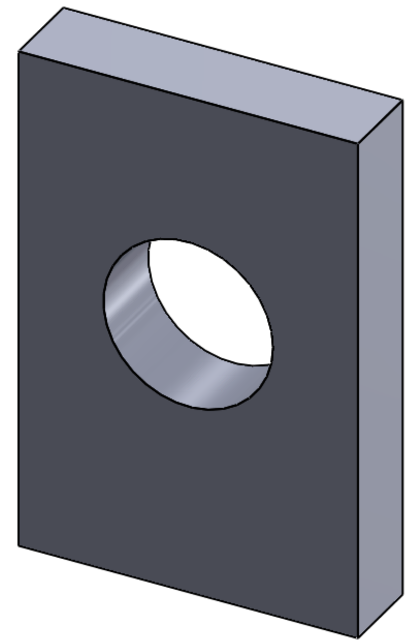
Includes (1) connecting link
(additional connecting links can be purchased below)



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES	DRAWN	LUCAS	5/3/15	TITLE: WIRE GUIDE
	CHECKED			
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL: UHMW	COMMENTS:			SIZE A — DWG. NO. 308 — REV
FINISH				
DO NOT SCALE DRAWING				SCALE: 2:1 — WEIGHT: — SHEET 1 OF 1

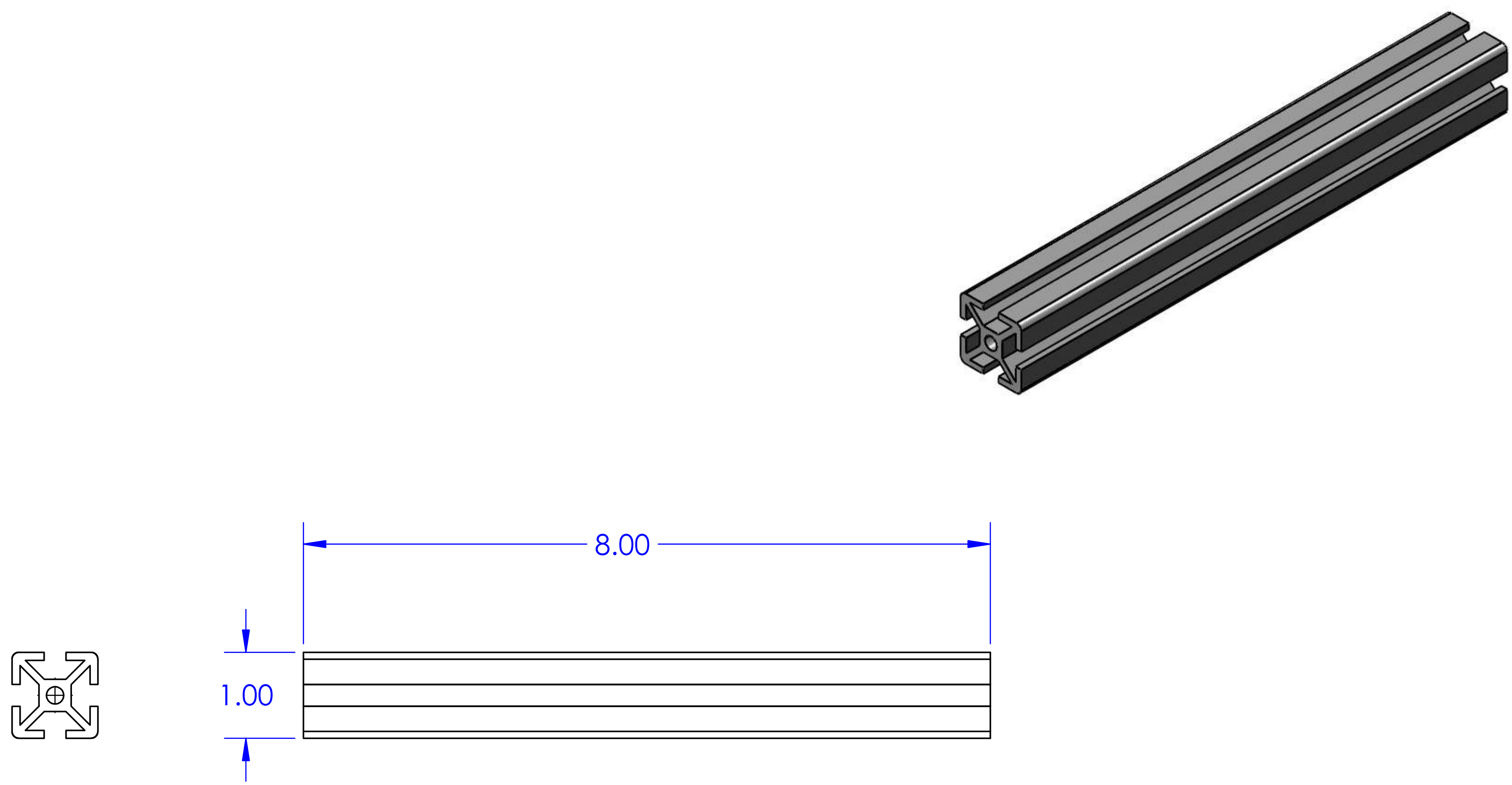
5 4 3 2 1





UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES	DRAWN	LUCAS	5/3/15	TITLE: 1 INCH SHAFT BEARING
	CHECKED			
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL: UHMW	COMMENTS: USE ROTARY SANDER TO GET HOLE BIG ENOUGH FOR SHAFT			SIZE A — DWG. NO. 309 — REV
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:1 — WEIGHT: — SHEET 1 OF 1

5 4 3 2 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES	DRAWN	GREG	5/3/15	
	CHECKED			TITLE:
	ENG APPR.			T-SLOT WIRE GUIDE
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL 6061 AL.	COMMENTS:			SIZE A · DWG. NO. 310 · REV
FINISH				SCALE: 1:2 · WEIGHT: · SHEET 1 OF 1
DO NOT SCALE DRAWING				

5 4 3 2 1

Model # 18589 | Internet # 202034303 | Store SKU # 610949

1 in. Zinc-Plated Corner Brace (20-Pack)

★★★★★ (1) | Write a Review + | Questions & Answers (1) +

PRODUCT OVERVIEW

Model # 18589 | Internet # 202034303 | Store SKU # 610949

The Everbilt 1 in. Corner Braces (20-Pack) are ideal for reinforcing inside of right-angle corner joints. Countersunk design allows screws to sit flush with material. Easy to install. California residents: see Proposition 65 information

- Made of steel
- Zinc-plated finish
- Ideal for use with wood on indoor and outdoor applications
- Screws are not included
- 2 hole design

Info & Guides

Installation Guide

You will need Adobe® Acrobat® Reader to view PDF documents. Download a free copy from the Adobe Web site.

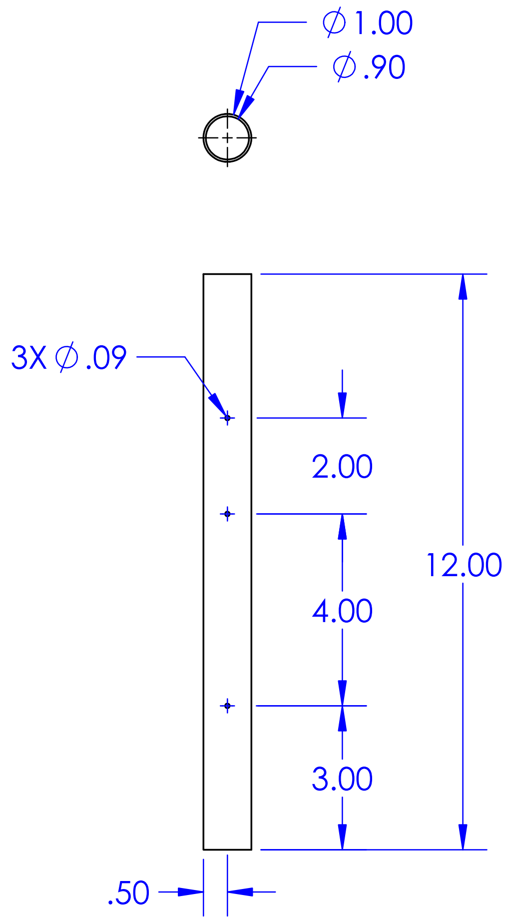
SPECIFICATIONS

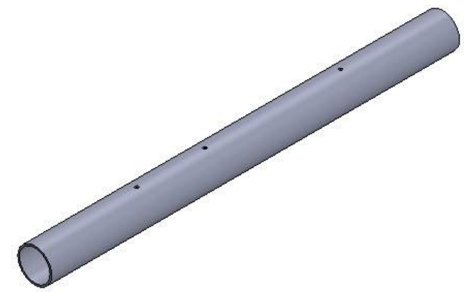
DIMENSIONS

Assembled Depth (in.)	0.06 in	Product Height (in.)	1
Assembled Height (in.)	1 in	Product Thickness (in.)	0.06 in
Assembled Width (in.)	0.5 in	Product Width (in.)	0.5
Product Depth (in.)	0.06		

DETAILS

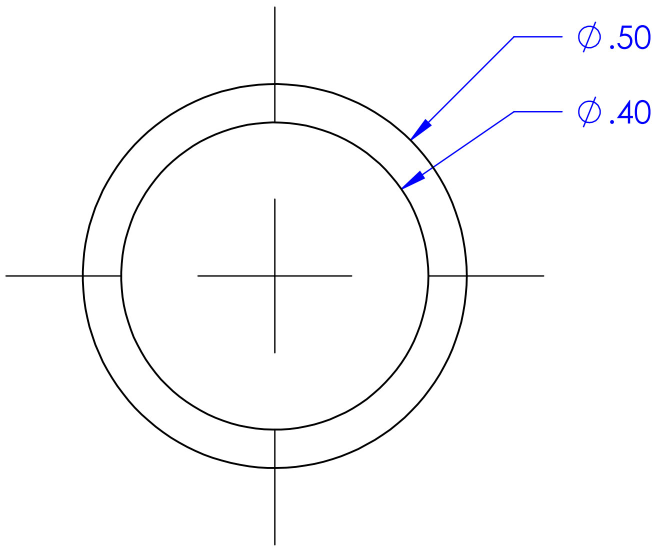
Brace type	Inside corner	Material	Steel
Builders Hardware Product Type	Braces	Number of Pieces	20
Color	Zinc	Number of mounting holes	2

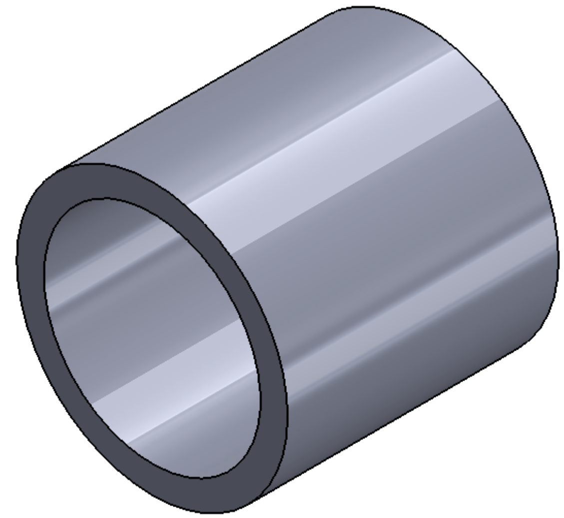


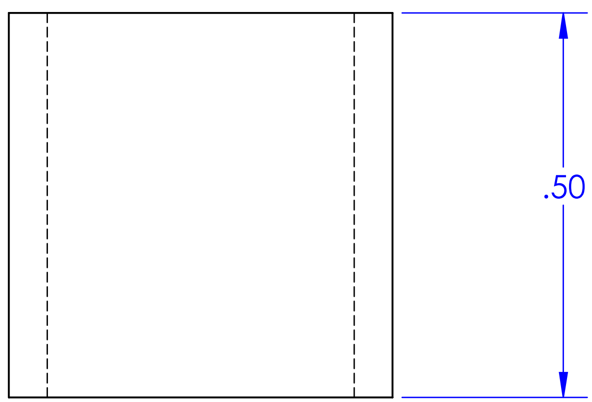


UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES	DRAWN	LUCAS	5/3/15	TITLE: 1" SHAFT
	CHECKED			
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL: ALUMINUM	COMMENTS:			SIZE A · DWG. NO. 312 · REV
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:4 · WEIGHT: · SHEET 1 OF 1

5 4 3 2 1

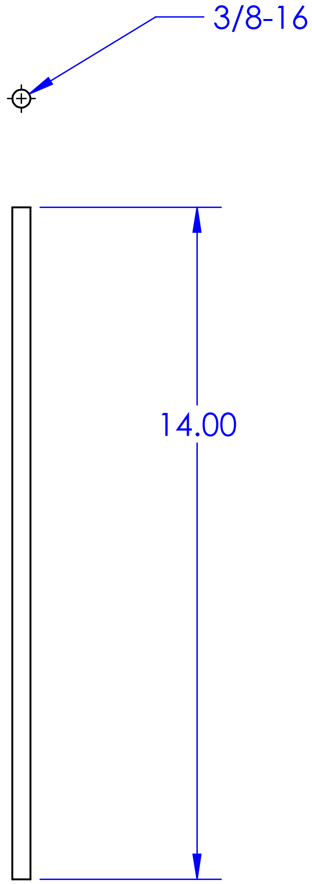


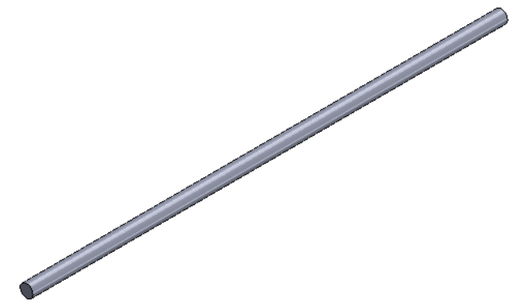




UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES	DRAWN	LUCAS	5/3/15	
	CHECKED			TITLE: 1/2" BEARING SHAFT
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL: ALUMINUM	COMMENTS:			SIZE A · DWG. NO. 313 · REV
FINISH				
DO NOT SCALE DRAWING				SCALE: 4:1 · WEIGHT: · SHEET 1 OF 1

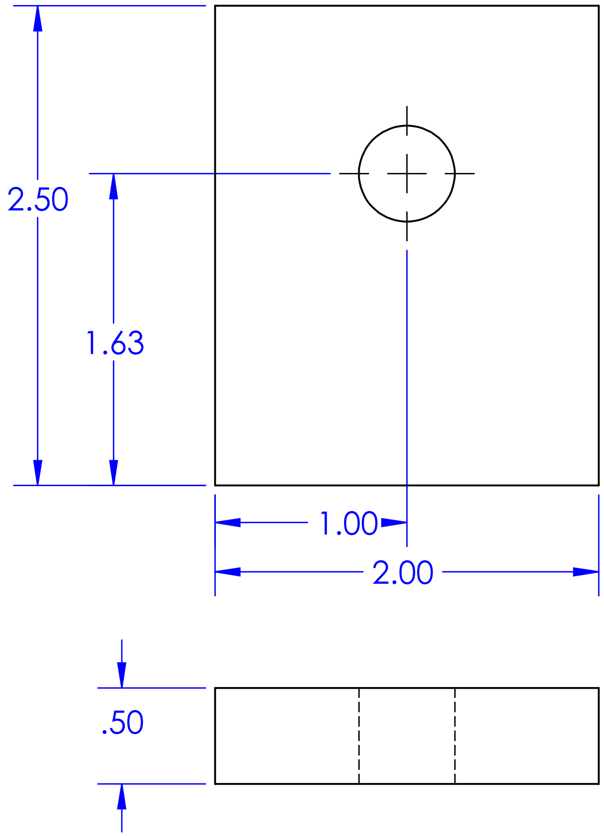
5 4 3 2 1

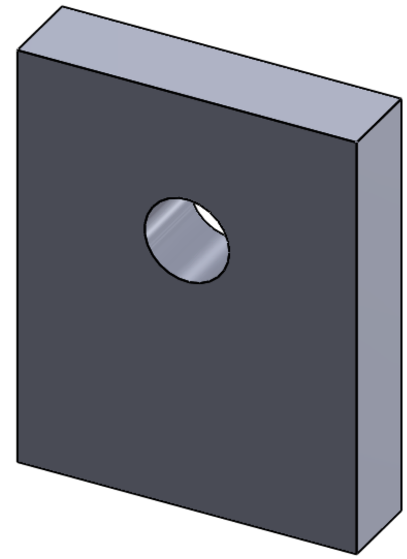




UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES	DRAWN	LUCAS	5/3/15	TITLE: 3/8-16 THREADED SHAFT
	CHECKED			
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL: STEEL	COMMENTS:			SIZE A
				DWG. NO. 314
FINISH				REV
DO NOT SCALE DRAWING				SCALE: 1:4
				WEIGHT:
				SHEET 1 OF 1

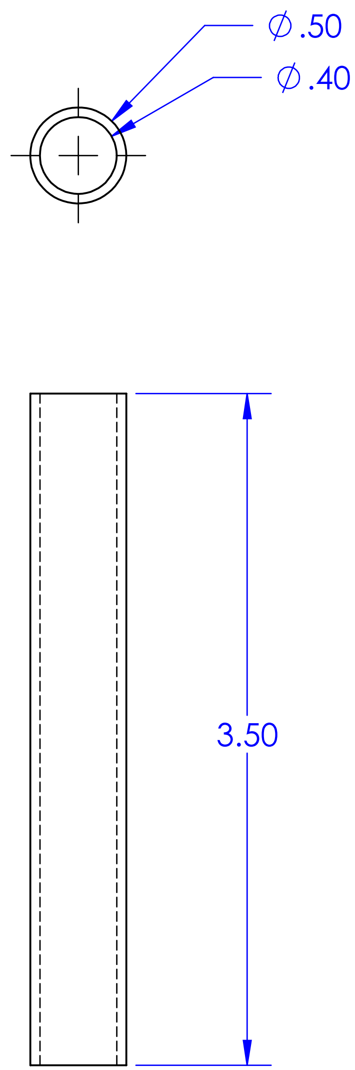
5 4 3 2 1

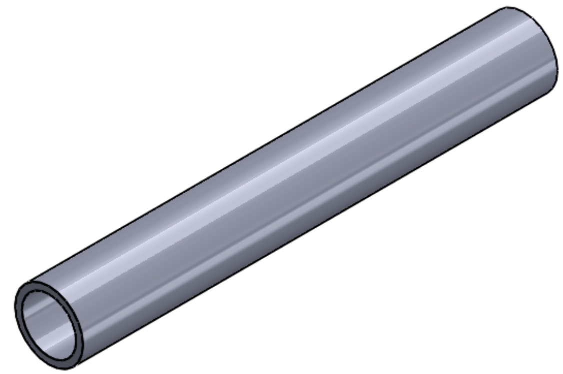




UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES	DRAWN	LUCAS	5/3/15	TITLE: HALF INCH SHAFT BEARING
	CHECKED			
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL: UHMW	COMMENTS: USE ROTARY SANDER TO GET HOLE BIG ENOUGH FOR SHAFT			SIZE A / DWG. NO. 315 / REV
FINISH				SCALE: 1:1 / WEIGHT: / SHEET 1 OF 1
DO NOT SCALE DRAWING				

5 4 3 2 1





UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES	DRAWN	LUCAS	5/3/15	
	CHECKED			TITLE: 1/2" SPROCKET SHAFT
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL: ALUMINUM	COMMENTS:			SIZE A — DWG. NO. 316 — REV
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:1 — WEIGHT: — SHEET 1 OF 1

5 4 3 2 1

Kevlar - Size 346 - (Tex 400) - Natural - Bonded - Nominal 1/2 Oz Tube - 33 Yards - Strength 135 Lbs

Quantity in Basket: *None*
Code: **KEV346NATL00B**
Price: **$12.00**
Shipping Weight: **0.34** pounds
...16 In Stk
Great for Small Jobs

Quantity: 1 Add To Cart

Philips | Model # 426114 | Internet # 203553312 | Store SKU # 790398

50W Equivalent Bright White (3000K) PAR20 Dimmable LED Flood Light Bulb (E*)

★★★★ (22) | Write a Review + | Customer Images (2) | Questions & Answers (1) +

Was ~~$22.97~~
$20.97 / each (limit 12 per order)
Save $2.00 (9%)

Pick Up In Store FREE
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Atascadero, CA 93422
Change Pick Up Store +

5 In Stock
Aisle 06, Bay 001

PRODUCT OVERVIEW

Model # 426114 | Internet # 203553312 | Store SKU # 790398

Philips Energy Saving LED 8-Watt PAR20 indoor flood light is ideal for use in kitchens, living rooms and dining rooms. It provides a bright, white light and is perfect for general room lighting. Fully Dimmable, this medium base flood light replaces your current 50-Watt halogen PAR20, saving you up to $118.25 in energy costs. Philips Energy Saving LED PAR20 flood light can be used in recessed cans and track light fixtures.

- Brightness: 470 lumens
- Estimated yearly energy cost: $.96 (Based on 3 hrs/day, 11/kWh. Costs depend on rates and use)
- Life hours: 22.8 years (based on 3 hours/day)
- Light Appearance: 3000K (bright white)
- Energy Used: 8 Watts (equivalent to a 50 watt standard incandescent light bulb)
- Lumen per Watt: 58.75
- Uses 84% less energy compared to a standard incandescent light bulb
- Ideal for use in kitchens, living rooms and dining rooms in your track light or recessed fixtures
- Contains Mercury: No
- Meets federal minimum efficiency standards for Energy Star certification

Info & Guides

MSDS

Warranty

You will need Adobe® Acrobat® Reader to view PDF documents. Download a free copy from the Adobe Web site.

DIMENSIONS

Bulb Diameter (In.)	2.5	Product Height (in.)	8.11
Product Depth (in.)	3.35	Product Width (in.)	4.49

DETAILS

Actual Color Temperature (K)	3000	Light Bulb Shape Code	PAR20
Average Life (hours)	25000	Light Color	Bright White
Bulb Shape	Reflector	Light Output (lumens)	470
Bulb Type	Flood and Spot	Lighting Technology	LED
Color Rendering Index	80	Number in Package	1.0
Indoor/Outdoor	Indoor	Returnable	90-Day
Light Bulb Base Code	Medium	Specialty Bulb Type	Flood & Spot
Light Bulb Base Type	Medium	Watt Equivalence	50
Light Bulb Features	Dimmable	Wattage (watts)	8

Westinghouse | Model # 7002500 | Internet # 204835997 | Store SKU # 215449

Electrified Candlestick and Bottle Adapter Kit

★★★★★ (5) | Write a Review + | Questions & Answers (1) +

$12.47 / each

Ship to Home FREE with $45 Order
Estimated Arrival: JUN 10 - JUN 12
See Shipping Options +

Pick Up In Store FREE
Available for Pick Up: Today

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OR Buy now with PayPal

Item cannot be shipped to the following state(s): AK,GU,HI,PR,VI

IN STOCK AT YOUR SELECTED STORE

PRODUCT OVERVIEW Model # 7002500 | Internet # 204835997 | Store SKU # 215449

The Electrified Candlestick and Bottle Adapter Kit make the process of creating and building your own lamp design simple and efficient. The three included rubber bottle adapters make it possible for you to turn a special vase or an attractive bottle into an original, working lamp base. A push-through socket attaches to correct size bottle adapter with the included nipple, check ring, and lock nut hardware. Along with the socket, bottle adapters, and included hardware, this Make-A-Lamp kit includes an 8 ft., 18-gauge cord set. The socket is rated at 660-Watt – 250-Volt and takes a standard-base bulb with a 150-Watt maximum. Each piece of the set fits together efficiently to allow you build the lamp design you want without any hassle of installation. Westinghouse is a global brand with a simple philosophy: make life easier for everyone who buys its products. The company offers ceiling fans, lighting fixtures, lighting hardware, lighting accessories, and light bulbs for both consumer and commercial applications. Westinghouse products are designed for exceptional quality, reliability, and innovation. Product reference number 70025.
California residents: see Proposition 65 information

- Silver finish sheath complements a variety of fixtures
- 18-2 SPT-2 wire is excellent for use with table and floor light fixtures
- 8 ft. of length offers generous reach for connecting to sockets
- Split, stripped, and tipped free ends for easy installation

SPECIFICATIONS

DIMENSIONS

Product Depth (in.)	1.75	Product Width (in.)	5.75
Product Height (in.)	8.75		

DETAILS

California Title 20 Compliant	No	Returnable	90-Day
Product Weight (lb.)	.4737 lb	Switch Mechanism	Toggle Button

Husky | Model # AW62616 | Internet # 100661440 | Store SKU # 448156

9 ft. 16/3 Banana Tap Extension Cord

★★★★★ (8) | Write a Review + | Questions & Answers (1) +

$11.73 / each

CORD LENGTH (FT.)
9

Ship to Home FREE with $45 Order
Estimated Arrival: JUN 8 - JUN 10
See Shipping Options +

Pick Up In Store FREE
Available for Pick Up: Today

1 | ADD TO CART | SAVE TO MY LIST

OR Buy now with PayPal

Item cannot be shipped to the following state(s): AK,GU,HI,PR,VI

IN STOCK AT YOUR SELECTED STORE

PRODUCT OVERVIEW

Model # AW62616 | Internet # 100661440 | Store SKU # 448156

The Husky 9 ft. 16/3 Black Extension Cord is a light duty indoor extension cord for use with such devices as appliances and consumer electronics. This cord was made with vinyl jacket and molding plug. It has a durable strain relief to make sure the plug securely connected with cable.
California residents: see Proposition 65 information

- NEMA 5-15P and NEMA 5-15R 3-wire extension cord, it can be used for indoor in between temperature range -40°C to 75°C (-40°F to 167°F)
- Rated at 125-Volt/13-Amp/1625-Watt and listed by UL approval, ideals for use with light duty output devices
- Available in 3-conductor, these cords feature molded plugs for added strength and durability
- Our light-duty power supply cords are made to replace used and worn out cords on some portable power tools
- Maximum 1,625 Watt
- Unplug when not in use
- Note: Product may vary by store.

SPECIFICATIONS

DIMENSIONS

Cord Thickness (In.)	0.03	Product Height (in.)	9
Product Depth (in.)	2.5	Product Width (in.)	1.25

DETAILS

Application	General Purpose	Number of Conductors	3
Cord Length (ft.)	9	Number of Outlets	3
Electrical Product Type	Electrical Cords & Cord Management	Product Weight (oz.)	13.87
Indoor/Outdoor	Indoor	Returnable	90-Day
Maximum Amperage (amps)	13	Voltage (volts)	125

HDX | Model # HD-800 | Internet # 204379332 | Store SKU # 109098

30 ft. 16/3 Heavy-Duty Retractable Reel with 3-Outlets

(8) | Write a Review + | Questions & Answers (1) +

$31.97 / each

- Product may Vary by Store

Ship to Home FREE with $45 Order
Estimated Arrival: **JUN 10 - JUN 12**
See Shipping Options +

Pick Up In Store FREE
Available for Pick Up: **Today**

1 | ADD TO CART | SAVE TO MY LIST

OR Buy now with PayPal

Item cannot be shipped to the following state(s): AK,GU,HI,PR,VI

IN STOCK AT YOUR SELECTED STORE

PRODUCT OVERVIEW

Model # HD-800 | Internet # 204379332 | Store SKU # 109098

The HDX retractable cord reel has a 30 ft. 16/3 SJT cord. With 3 separate grounded outlets and a 10 Amp rating, powering your projects is quick and easy. Simply pull out what you need and when you're done, all the cord winds back up inside the heavy-duty metal housing.

- Retractable cord reel with 30 of integrated extension cord
- 3 separate grounded outlets
- LED status light on outlet bar
- 10 Amp rating
- Includes mounting brackets to attach the reel to the wall or ceiling
- Product may vary by store

SPECIFICATIONS

DIMENSIONS

Cord Thickness (In.)	.325	Product Height (in.)	11.25
Product Depth (in.)	4.25	Product Width (in.)	10.06

DETAILS

Cord Included	Yes	Number of Conductors	3
Cord Length (ft.)	30	Number of Outlets	3
Electrical Product Type	Electrical Cords & Cord Management	On/Off Switch	No
GFIC	No	Product Weight (oz.)	123 oz
Indoor/Outdoor	Indoor	Resettable circuit breaker	No
Maximum Amperage (amps)	10 A	Returnable	90-Day
Minimum Temperature (F)	0	Voltage (volts)	120

Carlon | Model # E989N-CAR | Internet # 100404099 | Store SKU # 500015

8 in. x 4 in. Junction Box

★★★★★ | Write the First Review + | Ask a Question +

$22.64 / each

Pick Up In Store FREE
Available for Pick Up: Today

5 In stock at:
Atascadero #1031
Change Pick Up Store

1 ADD TO CART | SAVE TO MY LIST

OR Buy now with PayPal

IN STOCK AT YOUR SELECTED STORE

Atascadero #1031
Atascadero, CA 93422
Change Pick Up Store +

5 In Stock
Aisle 05, Bay 009

PRODUCT OVERVIEW Model # E989N-CAR | Internet # 100404099 | Store SKU # 500015

The Carlon Junction Box is manufactured from plastic moulding compound and features a foam-in-place gasketed lid fastened with stainless-steel screws. It protects electrical wiring from falling dirt, hose-directed water, entry of water from prolonged submersion and external ice formation. It is UL listed with a NEMA 6P rating per section 314.29, Exception of the National Electrical Code. It is ideal for indoor and outdoor use.

- Protects electrical wiring from falling dirt, hose-directed water, entry of water from prolonged submersion and external ice formation
- Ideal for indoor and outdoor use
- Manufactured from plastic moulding compound that will not rust or corrode
- Foam-in-place gasketed lid fastened with stainless-steel screws
- Fire-rated junction box has CSA and UL listings for safety
- NEMA Type 6P and Type 4/4 ratings
- Note: Product may vary by store
- Note: Product may vary by store.

SPECIFICATIONS

DIMENSIONS

Product Depth (in.)	8.38	Product Width (in.)	8.38
Product Height (in.)	4.48	Trade Size (in.)	Other

DETAILS

Box Type	Junction box	Number of Gangs	0
Color Family	Gray	Number of Knockouts	0
Electrical Product Type	Box	Package Quantity	1
Material	Thermoplastic	Packaging Type	Consumer Packaging
Metallic/Non-Metallic	Non-Metallic	Power Distribution Features	Fire Rated
Mounting	Nail On	Product Weight (lb.)	1.998 lb