PolyCart

A Senior Project

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Bachelor of Science

by

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Final Design Report: PolyCart

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Introduction

For active people with disabilities it becomes difficult to participate in many sports. When organizing several different group activities, encompassing many different sports, moving the equipment becomes a difficult barrier to overcome. For our senior project, we have been asked to develop and build a prototype sports equipment cart to be used by those who participate in the activities organized by Bridge II Sports. Our senior project team, PolyCart, includes the following mechanical engineering students: Ryan Bolton, Vincent Contreras, and Rodrigo Sanchez. This team was advised by Professor Sarah Harding of the Mechanical Engineering Department, as well as by Dr. Kevin Taylor of the Kinesiology Department. Three kinesiology students, Jaime Santana, Kevin Crisfield, and Niki Spurgeon, also assisted the team. The goal for this project was to provide a working prototype of a sports equipment cart that was designed to be transported, and used by an individual who uses a wheelchair at Bridge II Sports. The clients for this project include Fiona Allen, representing the Organization Bridge II Sports, Dr. Kevin Taylor, who proposed the project, as well as the Research to Aid People with Disabilities Program who provided funding through a grant.

Background

Many people who have disabilities like to stay active by participating in sports and outdoors group activities. Bridge II Sports helps organize sports events for those with disabilities throughout the state of North Carolina. In order to run these events more effectively, an equipment cart is needed to carry the necessary equipment to participate in various sports and activities. Bridge II Sports strives to make enjoying these physical activities as easy as possible for as many people as possible.

The client, Bridge II Sports, has asked for an equipment cart to be designed so that it can be easily used by people who have limited mobility; specifically, those who use a wheelchair. The level of use of the cart includes: transporting the cart with equipment to a possibly remote location over varying terrain, easily accessing the equipment within the cart, loading the cart with equipment and supplies, and finally loading and unloading the cart from the back of a standard minivan. The equipment that the cart will be holding on a regular basis includes equipment for those participating in track and field activities, basketball, golf, gym activities, archery, volleyball, and tennis.

After an interview with the contact at Bridge II Sports, Fiona Allen, it was determined that the specific equipment that the cart will need to hold is as follows: javelins, shot put, discus, basketballs, golf clubs, golf balls, gym floor rolls of tape, cones, water coolers, cases of water bottles, bows and arrows, volleyballs, volleyball nets, tennis balls, tennis racquets, an air compressor, and quick start tennis

equipment. Along with the equipment listed, additional features that would be nice to include are a speaker system, remote controlling, and an integrated white board.

The basic concept for the project has been completed many times over by numerous different companies. The equipment cart has been designed around the need for physical education teachers to transport enough equipment from a storage room to the activity site for an entire class to participate. However, these carts were designed with the assumption that the user/teacher would have full use of their legs. The two most common types of equipment carts that are currently manufactured are the cage or basket style, and the skeleton style.

The cage or basket style employs an external frame, usually made of metal, which is then wrapped in a netting or cage, usually metal wire. This style is the more versatile of the two, as it has no restrictions as to what equipment can be used with the system as long as the equipment is bigger than the gaps in the cage, and is smaller than the dimensions of the frame. Because the tops are open, larger items can be transported with this cart by letting the equipment stick out of the opening. These carts usually have 4 rubber caster wheels, usually only used for either black tops or gym floors. Any rough surface would cause problems when trying to move the cart to another destination. Figure 1 shows a typical cage style equipment cart.

Figure 1: Basic Cage Style Cart

With this same style, another type of cart was found. This type of cart is similar in most ways to the basic cage style cart with two major differences. The first and biggest difference is that instead of using four rubber caster wheels, it uses four inflatable wheels. These inflatable wheels are much better suited for rough terrain that one might encounter while transporting equipment into fields and onto tracks. The second difference is that this type of cart can be pulled in a similar fashion to a wagon. The front wheels are connected by an axle that rotates in the center. This allows the user to pull the cart along using the handle that is connected to the center of the front axle. Figure 2 is an example of this type of cart.

Figure 2: Wagon Cart

The last common style of cart that was found was a skeleton type cart in which the equipment could be placed inside and outside of the structure. This skeleton cart can be seen in Figure 3. This cart has ideal accessibility due to the fact that all of the equipment is openly available at all heights and from all directions. However, the only skeleton style carts that were found were made strictly from PVC piping. This severely lowers the durability of the product simply because of the material choice. Also, because of the material choice, the arms for holding the hula hoops and jump ropes in the picture would be very limited on the weight they would be able to support. The wheels this system uses are simple rubber caster wheels for transportation of the cart. Therefore, similar to the basic cage style cart, the problem of limited mobility arises. Lastly, the narrow footprint of the wheels causes some concern regarding stability of the cart over bumps, rough terrain, or sudden stops and knocks.

Figure 3: Skeleton Style Cart

For the project, it was decided that there are some basic components that needed to be incorporated into the design. These include at least 4 wheels suitable for various surface conditions while maintaining stability. Sturdy materials were necessary to resist breaking under normal and extraneous conditions. A steering system needed to be employed for ease of transportation, as well as a large capacity for various sports equipment. Some of these requirements have already been solved in the designs seen above. These existing solutions were taken into account during the design process for the PolyCart design.

According to the team's sponsor and contact at Bridge II Sports, Fiona Allen, a wheelchair user has a towing capacity of at least 50 pounds. From this information it was determined that the cart should be made as light as possible so that a maximum amount of equipment can be pulled by the user.

Objectives

The overall goal for this project was to design and build a functional prototype of a sports equipment transportation device that is easily accessible and maneuverable for people that use wheelchairs.

From initial communication with Dr. Taylor and Fiona Allen from Bridge II Sports the team developed the following list of requirements and technical specifications for this project.

- The cart must be fit, either disassembled or complete, in the back of a minivan. This limits the external dimension of the cart to 7'3''L x 4'2''W x 3'10''H.
- The cart's internal storage must have minimum dimensions of 3'L x 2'W x 1.5'H in order to accommodate all of the equipment Bridge II Sports will be using.
- The cart must weigh no more than 30 pounds in order to be easily pulled, pushed, and loaded and unloaded from the back of a minivan.
- In order to facilitate easy maneuverability, the force required to move the cart will be at most 10 lbs.
- Stability is also a serious requirement. The cart must not tip over when 15lbs is put on the top edge of the cart.
- To ensure that the cart will not move with the brakes applied, the force required to move a stopped cart with the brakes applied will be at minimum 35 lbs.
- This cart will be used outdoors, so the cart must be able to roll over an obstacle 4 inches in height.

- If speakers are integrated into the design, the speakers must be capable of producing a volume level of at least 80 db.
- If a white board is incorporated into the cart, it will have a minimum writing surface of 18" x 24".

In order to meet all of these design requirements, every component of the cart was analyzed. As an assembly, the entire cart was also analyzed. After the prototype was built, it went through significant testing in order to ensure that it complies with all of the specifications. The specific design requirements can be seen in Table 1 below.

Table 1: Compliance Matrix for Equipment Cart Design Specification

Spec #	Parameter Description	Requirement/Target	Tolerance	Risk	Compliance
1	Exterior Height	3’10”	MAX	L	A, I
2	Exterior Length	7’3”	MAX	L	A, I
3	Exterior Width	4’2”	MAX	L	A, I
4	Interior Height	1'	MIN	L	A, I
5	Interior Length	3'	MIN	L	A, I
6	Interior Width	2'	MIN	L	A, I
7	Weight	30 lbs	MAX	H	A, T
8	Force to Move	10 lbs	MAX	H	A, T
9	Tipping Force	15 lbs	MIN	M	A,T
10	Braking Force	35 lbs	MIN	M	A, T
11	Obstacle Height	4"	MIN	M	T
12	Sound Level	80 db	MIN	L	T, S
13	Whiteboard Height	18"	MIN	L	I
14	Whiteboard Width	24"	MIN	L	I

For each design parameter there is a target or requirement for which each parameter must fulfill. The tolerance indicates whether the parameter must be lower, higher, exactly or within a specific amount of the target. The risk is related to the confidence in reaching these goals easily and it is listed as an H, M, or L, representing high, medium, and low risk respectively. The higher the risk, the harder it will be to meet the target requirement for a given parameter. The compliance matrix indicates the methods in which we made sure that a parameter meets the target specification. Analysis (A), testing (T), inspection (I), and comparison to similar designs (S) will all be used to measure each parameter. All of the parameters and requirements in Table 1 come directly from the quality function development (QFD) analysis that was performed based on the information given by Bridge II Sports and Dr. Taylor (Appendix A).

Method of Approach

First of all, the team needed to methodically understand the needs and requirements of our costumers (sponsor) and based in this information the team defined the problem statement. The sponsor's requirements were converted into quantifiable engineering specifications. In order to meet the sponsor's needs, these specifications were closely monitored as the design process of the project progressed.

Communication with the sponsor is extremely important. Therefore, the team has communicated with our sponsor, Bridge II Sports, throughout the project. The team was assigned two kinesiology students to work with. They have been a method of communication with the sponsor as well as a good a resource for this project. The team received an etiquette lecture on how to professionally work with people with disabilities.

Once the team had a clear understanding of the problem, background research was performed on existing products and the difficulties that our clients have using them. The team checked out a wheel chair and an equipment cart from the kinesiology department via the kinesiology students that were assisting us in the project. This activity gave a feel of how difficult or impossible it is to push or pull an existing equipment cart while trying to move in the wheelchair simultaneously. In addition, the team conducted research on: types of suitable wheels for indoors and outdoors, braking mechanisms, structure geometry, and possible materials.

After the team performed thorough background research, the next step was to start the ideation process for possible solutions to the problem statement. Some of the brainstorming techniques that the team used for this process included a morphological attribute list and sketching many different designs in a short period of time. Once there were a good number of ideas, the team narrowed down to concepts that best met the requirements.

The team constructed conceptual design review report to ensure that the needs and requirements of the client were being satisfied. The team started formulation of tridimensional model in Solidworks along with the necessary two-dimensional drawings.

During the winter quarter 2012 a detailed design of the final concept was created. In addition, analysis was performed to ensure that the concept was functional. Design is an iterative process and the first design did not solve the problem. After a final design was approved, the team ordered the necessary components and material for manufacturing. The goal was to use the minimum amount of custom-made parts in

the design because it will be easier to maintain and replace those parts. Also, if the sponsor wants to build more of them it will be easier to get the parts.

The actual building and testing of the project began in the spring quarter 2012.

The goal to have a final working model by the end of the spring quarter was met, and the final model was presented at the senior project expo at the end of the spring quarter.

Design Development

Idea Generation

Two different kinds of brainstorming were used for idea generation for this project. A random attribute list was used as well as sketching as many ideas as possible in fifteen minutes. The idea generation process was done in two separate sessions. Since it is a good idea to have people from different fields in the brainstorming process, Jaime from the kinesiology department collaborated in one of the idea generation sessions. The ideas generated during the ideation process are listed in Figures 4-9.

Figure 4 shows a design that consists of three wheels. This design has two pivots on the front wheel. One pivot can turn on a horizontal plane to maneuver and the other on a vertical plane, which allows the linkage system to retract when the cart is stored.

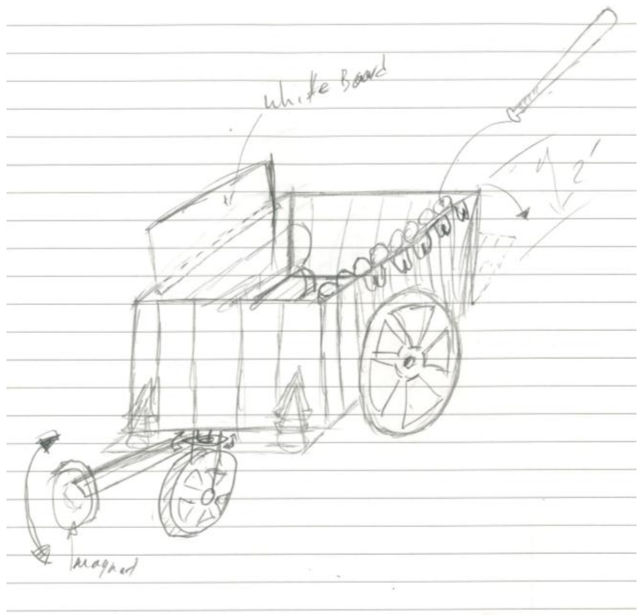


Figure 4: Thee wheel cage style cart

Figure 5 shows an idea with a trailer that is pulled by a wheelchair. The trailer consists of four wheels and the front two wheels with a wagon style steering system to allow the cart to follow behind the wheelchair easily. The cart is a cage style with metal bars holding all of the equipment securely. The top of the sides is hinged so that the cart can have a large holding capacity while maintaining accessibility while in a wheelchair. The back of the cart has rails with a whiteboard attached so that the whiteboard will remain lowered during transportation and can be lifted up to writing height when it is needed. The main disadvantage with this idea is the weight of the system. The entire cart would be made of metal, most likely steel causing the cart to put significant strain on the person pulling it. Also, with the hinged sides, only large items could be placed inside because when the side doors are opened, any small sports equipment will fall out.

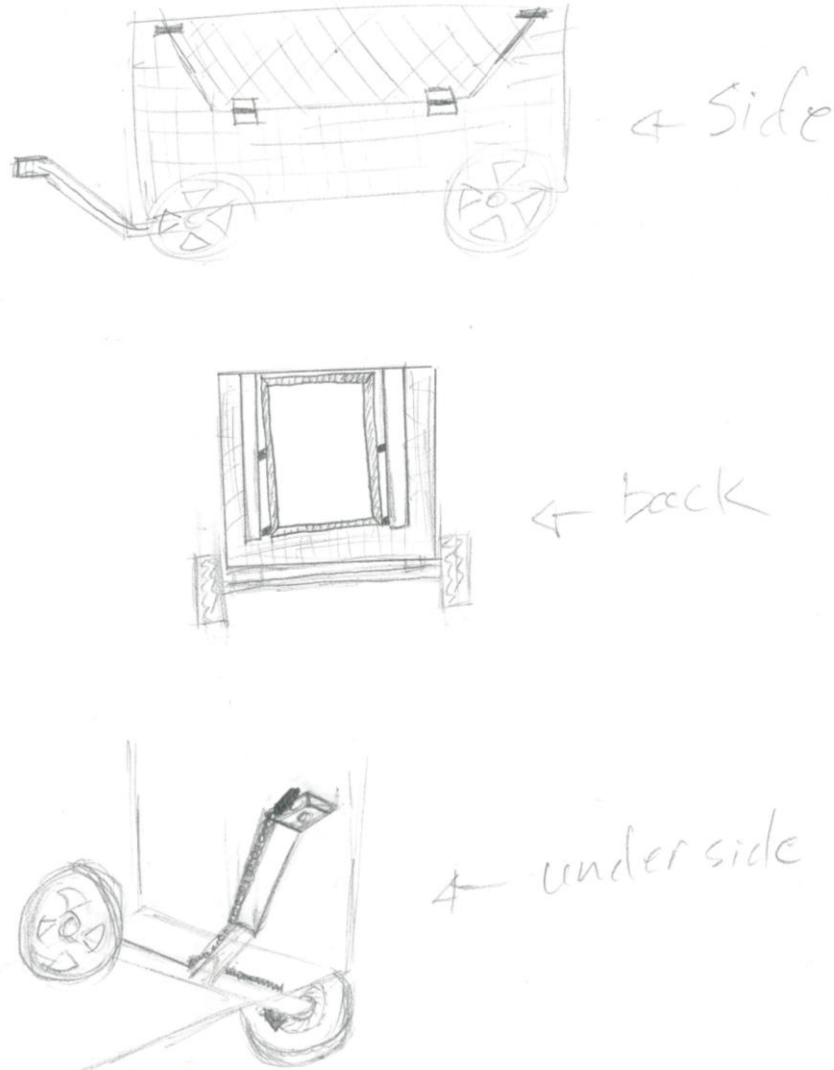


Figure 5: Trailer with folding sides

Figure 6 is an illustration of a three wheeled trailer equipment cart. This idea has a locking lid to keep all of the equipment secure when it is not in use or not under any supervision. The three wheels would provide great maneuverability while keeping the weight low. This design is limited by its lack of versatility. It can certainly hold a lot of equipment, but the interior is large and equipment can easily move around during transportation. Also, with an all-metal construction, the weight would most likely still be too heavy for the average person to tow along behind them. While the three wheels provide good maneuverability, they sacrifice stability. In tight cornering or sudden turns, the cart would be susceptible to accidental tip overs.

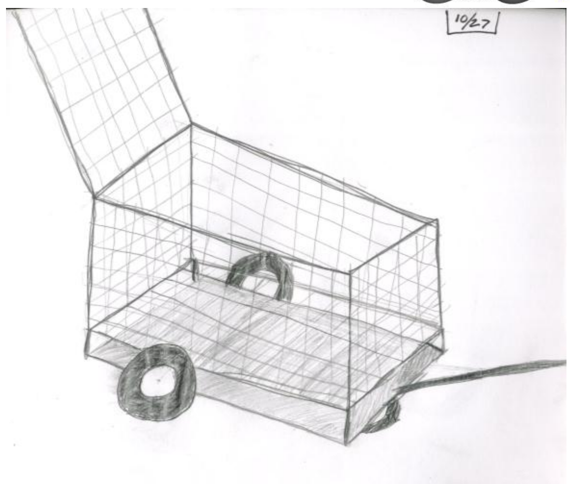


Figure 6: Tri-Wheel Cage

Figure 7 shows a four wheel cart that is pushed by a person that uses a wheel chair. This is a feasible design; however, it will be harder for a wheelchair user to push a cart than to haul it. In additon, this design is harder to manuever around corners. Also, it would be hard to drive on grass.

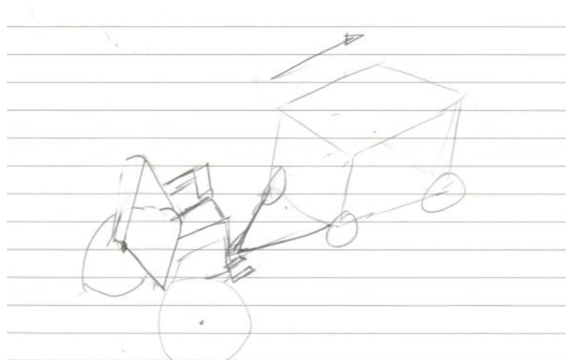


Figure 7: Push Cart

Dr. Taylor provided the sketch in Figure 8. It shows some of the features that the sponsor would like to have in the cart in addition to carrying sports equipment. Speakers and a white board are some of those features.

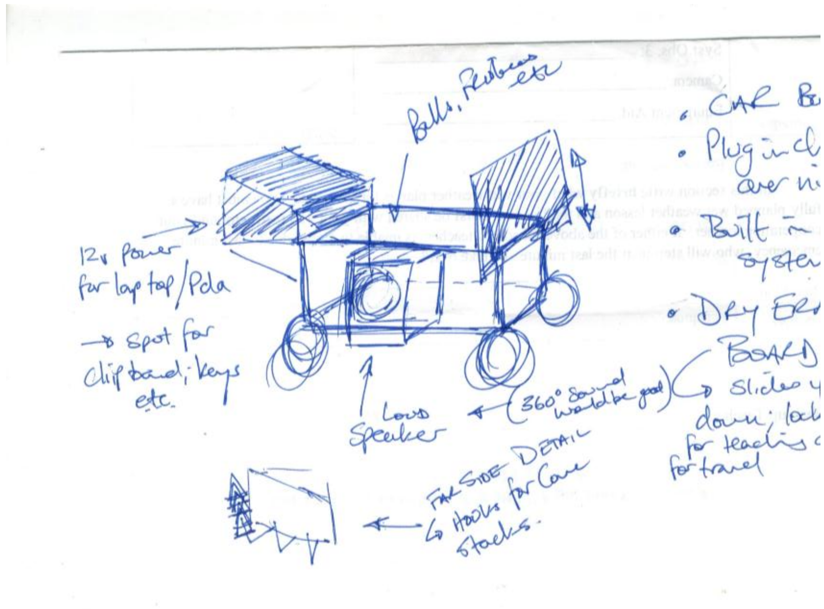


Figure 8: Cart Accessories

Ideal Selection

In order to narrow down the number of ideas, the team discussed the feasibility of each idea and eliminated the ones that were not feasible based on the time constraints to design, build and test the project. For the top ideas, decision matrices were created to select the final design. Furthermore, a decision matrix was created for the type of material and the steering system.

The choice of the materials used to manufacture the cart was the first decision that needed to be made in order to start designing the cart. The materials that were considered consisted of aluminum, titanium, PVC, carbon fiber, and steel. A decision matrix (see Table 2) was used to help decide the best material for the cart. Steel was used as a datum because it is the most common material and it was logical to compare each of the other materials to steel. Five criteria were used in the selection process, which consisted of cost, weight, strength, durability, and manufacturability. These five criteria were ranked by importance and given a weight, ranging from one to five, with five being the most important and one being the least important. The weight of each material was determined to be the most important criteria because it is important for the cart to be below the weight specification of 30 pounds so that a person will be able to pull the cart when it is attached to his or her wheelchair. Durability was the next most important criteria because it is important for the cart

to be able to hold up under use for a long period of time. On the other hand, manufacturability was determined to be the least important criteria because the team has access to a large selection of tools and machinery in the machine shop on campus. Additionally, a dual weighting system was used to distinguish between larger and smaller disparities between each material and the datum for a particular criterion. For instance, for cost, aluminum was assigned a negative one-half because it is only slightly cheaper than steel, but titanium was assigned a negative three because it is much more expensive than steel. The data to determine how each material related to the datum was found by researching online. The results of the decision matrix showed that aluminum was the best material to use to manufacture the cart because it is both lighter than steel, and is not significantly less strong, less durable, or more costly than the alternative materials.

Table 2: Cart Material Decision Matrix

Criteria	Weight	Aluminum	Titanium	PVC	Carbon Fiber	Steel
Cost	2	-0.5	-3	1	-2	0
Weight	5	1	1	1.5	1	0
Strength	3	0	1	-1	0	0
Durability	4	0	0	-2	0	0
Manufacturability	1	-1	-1	1	-1	0
	Total	3	1	-0.5	0	0

The second decision that needed to be made was how the linkage system would be arranged for attaching the cart to the wheelchair. A quick release clamp was used to attach the cart to an existing bar on the back of the wheelchair. This allows the user to easily attach and detach while sitting on the wheel chair. In order for the cart to track behind the wheelchair properly either caster wheels or a wagon style steering system would need to be used. The caster system would use two stationary wheels in the rear and two caster wheels in the front to allow the cart to rotate. The wagon style steer system would use two stationary wheels in the rear and two stationary wheels in the front connect by a single axle. This axle would pivot underneath the cart to allow the cart to rotate. Along with these two steering systems, the number of links needed to allow tight turns to be made needed to be decided. A decision matrix (see Table 3) was created with several combinations of the two steering styles and the number of pivot points. The criteria used is listed in the table; the accessibility refers to the ability to access the contents of the cart while still attached to the cart and the ease of connection refers to how easy it would be to attach the wheels or steering system to the cart. Solid/single link with the wagon style steering was used as the datum as it is the most popular form of steering in existing carts. The only criteria that were assigned more than a plus or minus 1 were the 2 pivot-steer regarding accessibility, the 1 pivot-steer regarding maneuverability, and the 2 pivot-caster for collapsibility. These criteria were awarded double weighted points because they were significantly better than not only datum but also all of the other

options. A physical model was made and used to test each of the options with an existing wheelchair. Each of the model carts and steering linkages were tested by the same person, and were pulled around the same obstacles as well as pulling forward, stopping, and reversing the cart while in the wheelchair. The option that was significantly better than all of the rest during testing was the 1 pivot-steer. This option uses wagon style steering with a single pivot between two linkages that connect the wheel chair to the cart. The maneuverability was decided to be of the most important criteria and the 1 pivot-steer option excelled in this area due to its tight turning radius without allowing the wheelchair to crash into the cart. Compared to our datum of a solid link steering option, the 1 pivot-steer had better maneuverability, better accessibility of the contents of the cart, and could be more easily collapsed to save space when not in use. The only flaws with this option are that it would be slightly more expensive and complicated to manufacture. These flaws were outweighed by benefits this system will provide.

Table 3: Linkage Decision Matrix

Criteria	Weight	Solid-Caster	1 Pivot-Caster	2 Pivot-Caster	1 Pivot-Steer	2 Pivot-Steer	Solid-Steer
Cost	1	1	0	-1	-1	-1	0
Weight	2	1	1	1	0	0	0
Maneuverability	5	-1	0	1	2	1	0
Accessibility	2	0	0	1	1	2	0
Ease of Connection	4	1	0	-1	-1	-1	0
Collapsibility	3	0	1	2	1	1	0
Reliability	4	0	-1	-1	-1	-1	0
Stability	5	-1	-1	-1	0	0	0
	Total	-3	-4	1	6	3	0

The next choice that was made involved how the storage compartment was to be enclosed. A decision matrix (see Table 4) was developed to aid this decision. The group determined that the best shape for the storage enclosure was rectangular due both to the amount of useable volume and how easily the contents could be accessed from outside. A design involving a cage that formed a single basket to hold all equipment was chosen as the datum because it is the most common design already in production. The designs that were compared to the datum were comprised of a cage with a separate tray underneath, a net supported by a frame with a bottom tray, a net supported by a frame with a single compartment, a net without supports, and a solid walled single compartment. The net with supports and tray was derived from combining the cage with a bottom tray and the net with supports bringing the benefits of the two designs together. Unfortunately, it was determined that the cage

with the bottom tray was still a better option due its increased rigidity and durability over the net with supports and tray. Weight was again chosen to be the highest weighted criteria because the cart would be most useful if it could be easily pulled by any number of people. Because this cart will not undergo substantial loading, rigidity was weighted the lowest. The cage with a bottom tray ended up receiving the best results from the decision matrix due to improved accessibility by having a bottom tray and its maintained rigidity and durability.

Table 4: Storage Enclosure Decision Matrix

Criteria	Weight	Cage w/ Bottom Tray	Net w/ Supports & Tray	Net w/ Supports	Net w/o Supports	Solid	Cage
Cost	1	0	-0.5	-0.5	1	-1	0
Weight	5	0	0.5	0.5	1	-1	0
Accessibility	4	1	1	-0.5	-0.5	-0.5	0
Rigidity	1	0	-1	-1	-2	0	0
Versatility	3	1	1	1	-0.5	1	0
Durability	2	0	-1	-1	-1	0	0
Volume	3	0	0	0	-0.5	0	0
	Total	7	6	0	-3	-5	0

Analysis

The maximum cart dimensions given by the sponsor were 4’Wx5’Lx3’H. A cart with this size would be too heavy and hard to maneuver for a person that uses a wheelchair. Furthermore, it would be hard for a wheelchair user to reach inside the entire cart and it would not fit through standard size doors. A quick test was performed and it was concluded that the dimensions shown in Figure 9 gives a good reach span and the user would still be able to carry the necessary equipment. The front view in Figure 10 shows a more clear view of the arm span with an average arm length of approximately eighteen to twenty inches. Therefore, the final dimensions of the cart are 2’Wx3’Lx1.5’H. The final dimensions reduced the cage weight by forty percent.

A standard size basketball has a diameter of 0.7825 ft and a volume of 0.251 ft^3. Therefore to fit a basketball inside a cube, the cube must have sides of 0.7825 ft and a volume of 0.479 ft^3. With nine cubic feet of storage volume the cart is able to hold eighteen basketballs. The weight of one basketball was researched and found to be 20 ounces. The weight of a full load of basketballs will add 22.5 pounds to the tow weight. This weight, added to the maximum allowable weight of the cart (30 pounds), is 52.5 pounds, which, according to our research, can be towed by a wheelchair user.

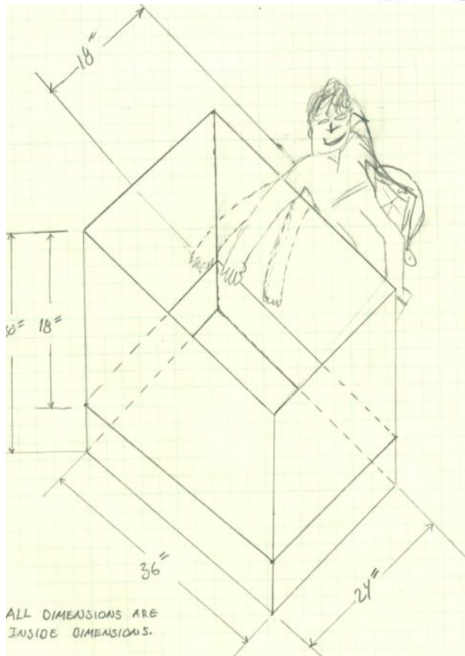


Figure 9: Reaching into cart from side

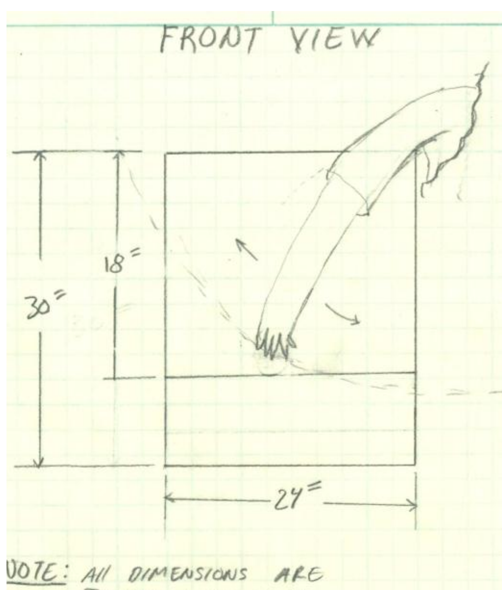


Figure 10: Reach distance inside cart

A basic stress analysis was performed for the longest angle aluminum members at the center on the bottom of the cart. It was assumed a conservative load of 50 lbs at the middle of the member. Figure 11 shows a diagram of the forces exerted on the member along with the corresponding shear and bending moment diagram. The calculations for this analysis can be found in Appendix C. For simplicity, pure and symmetrical bending was assumed. The load provided a maximum deflection of 0.615 inches. However, this deflection will be significantly smaller because the actual cart design has more members, thus reducing the total deflection. There is another parallel member to the one analyzed, so this member will take half of the load, thus reducing the maximum deflection by one half. In addition, there are three angle aluminum members perpendicular to the previous two, so this will reduce the maximum deflection even more because the members are shorter and the shorter the member is, the less it will deflect. Additionally, the expanded aluminum at the bottom of the cart will take some of the loading and distribute the load across multiple members. One of the longest square members that form the enclosure was analyzed as well. It was assumed that a person will push down on the member exerting a force of 200 lbs at the middle of the member. The force was assumed to be at the center because that is the location where the maximum normal stress and deflection will occur. With the chosen, Aluminum 6061 T6, there is a maximum deflection of 0.5 inches with a safety factor of 1.4. In addition, the attached expanded aluminum will reduce the stress and deflection on all the members by taking some of the load. Lastly, the vertical members were analyzed for buckling and the critical buckling load is significantly greater than the worst case loading conditions the cart is going to experience. Engineering Equation Software (EES) was used to find the minimum bar size that would withstand the loading conditions. The EES code used for this analysis can be found in Appendix D.

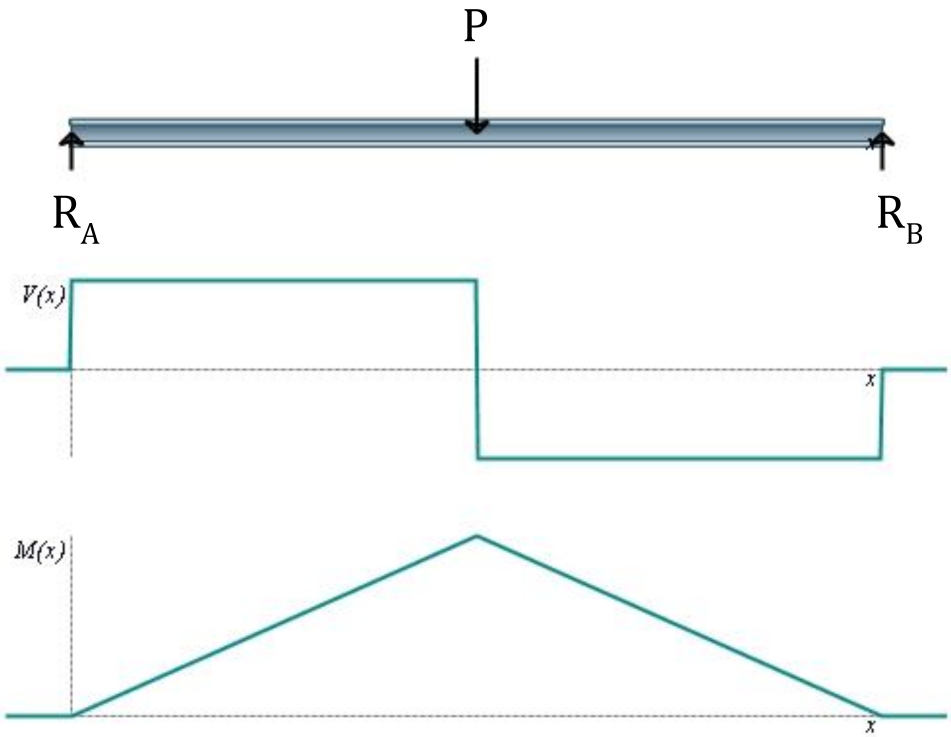


Figure 11: Member loading conditions and shear and bending moment diagram.

Final Design

The final design is shown in Figure 12. The final weight of the cart is estimated to be 21 pounds according to the Solidworks model of the entire system. The cart has various features that have been incorporated to fit the needs of the customer. The cage, steering system, and attachment method are the critical components in the design and are explained in detail below. Figure 13 shows a model of the final design with properly sized basketballs placed inside the cage to show the size and capacity of the cart.

Figure 12: Empty cart.

Figure 13: Cart holding several basketballs.

Cage

The cage structure is made of 1 inch square aluminum tubes with 0.065 wall thickness. On the bottom of the cage, there is a tray for storage of miscellaneous items. The tray is equipped with a plastic drawer for easier accessibility. The cage has expanded aluminum on the sides and bottom which adds rigidity to the cart as well as keeping the payload in the cart and not allowing small items to escape. The expanded aluminum on the bottom of the cart is rigidly supported by five angle bars. A whiteboard is attached to the back of the cage with a rail system that is attached to the vertical square tubing of the cart. This rail system allows the user to raise and lower and lock the white board in place for better usability and visibility. The rail system also permits the user to completely remove the whiteboard if desired. The cage is shown in Figure 14. The interior of the cage can be divided into multiple

sections by attaching stretchable netting to the expanded aluminum with built-in hooks.

Figure 14: Cart Cage

Since wheelchair users use different types of wheels whenever they play sports, the regular wheels have to be stored while not in use. The cart is able to hold a total of eight wheels (four sets). The two shorter horizontal bars on the top of the cage have one telescoping round bar that pulls out on each side of the cart. These telescoping bars will be extended to hold the wheelchair wheels, and whenever they are not in use, they can be fully retracted. Figure 15 shows the cart carrying two sets of wheels on one side. The other two pairs, not shown in the figure, will go on the other side of the cart.

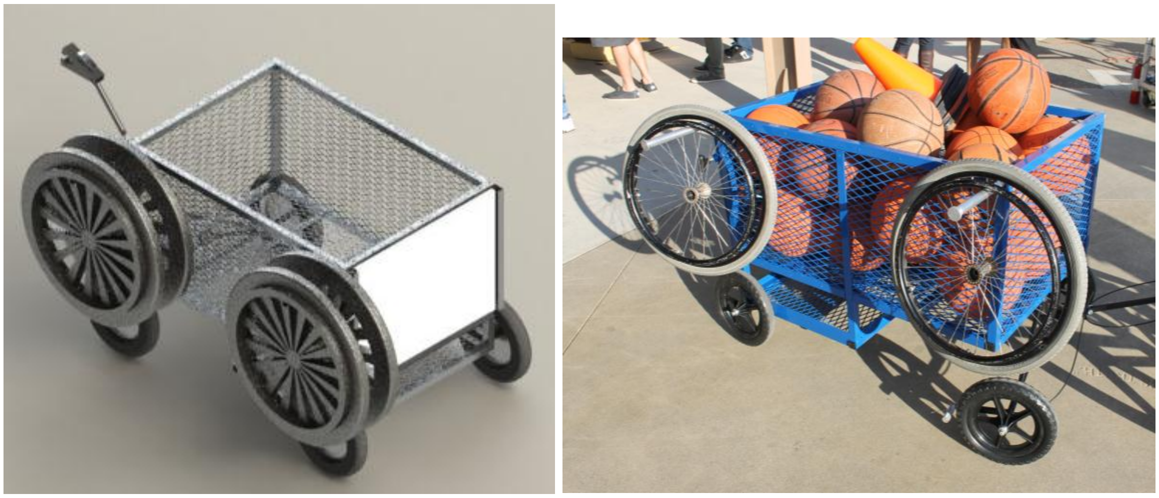


Figure 15: Wheel holders

One bar that contains the telescoping tubes has been isolated from the cart in Figure 16 to better demonstrate its operation. As seen in Figure 16, a round tube comes out of the square bar on each side of the cart. The square bar contains four holes on the

face that will be facing up when the cart is assembled. The two holes at the middle correspond to the bars fully retracted. The other two are located at each end.

To keep the pairs of wheelchair wheels from sliding off of the bars, rectangular caps will be securely attached to the ends of the bars. These caps will serve two main purposes; they will keep the wheelchair wheels from sliding off of the end, and to provide an easy-to-grasp tab so that the bars can be pulled out with ease. In order to prevent these tabs from being a safety hazard, they will have smooth, rounded tops.

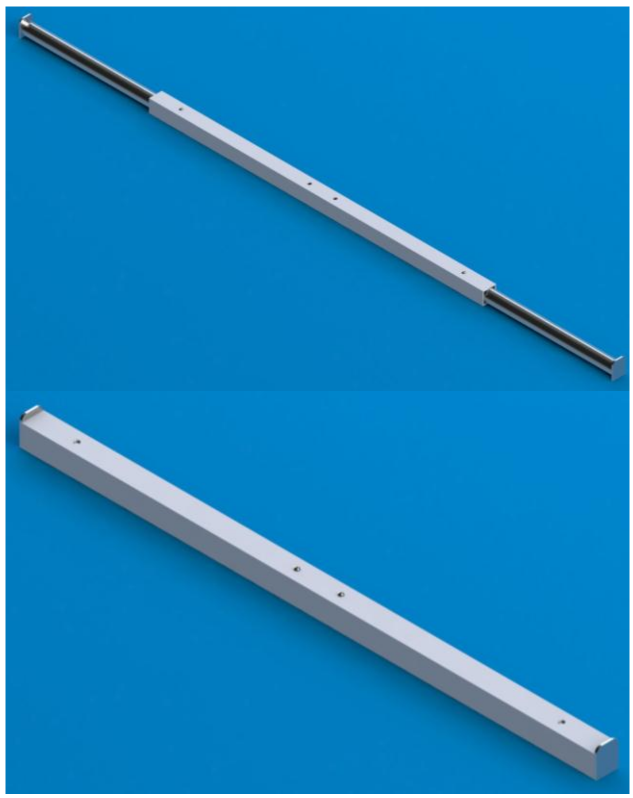


Figure 16: Telescoping Tubes

In order to keep the telescoping bar in a retracted or extended position, a snap pin will be used in the interior of the round bar. The round hollow bar will have a hole at one end and the head of the V-shape snap pin will come through the hole. The pin will be go through the holes on the square bar and will lock the round bar in place. This locking mechanism can be seen in the cross-sectional view of the bar in Figure 17.

Figure 17: Cross-section of square tube for wheel holder.

Figure 18 shows a closer view of the telescoping bar locking mechanism. The colors of the square and round bar have been changed to enphaisze the features more clearly. The v-shape pin is in tension and whenever the pin head comes concentric to the holes on the square bar (green) the pin will snap in place locking the bars. In order to unlock the bars, the pin head is simply pushed down while the round bar (yellow) is pushed or pulled.

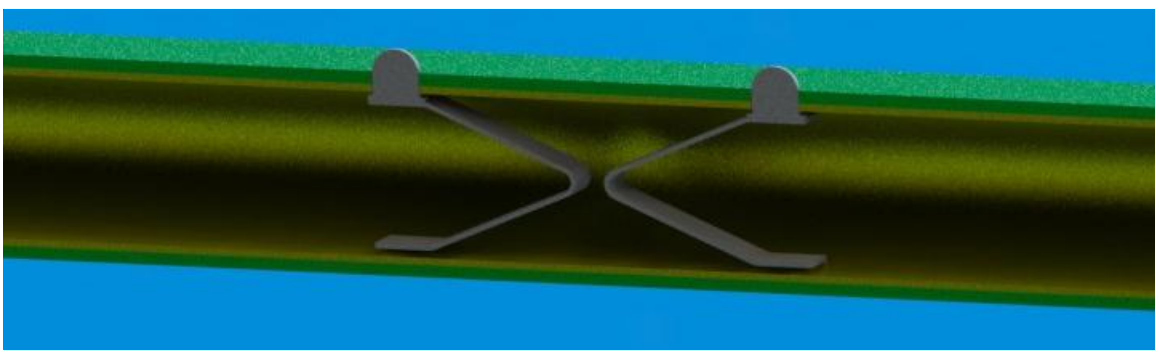
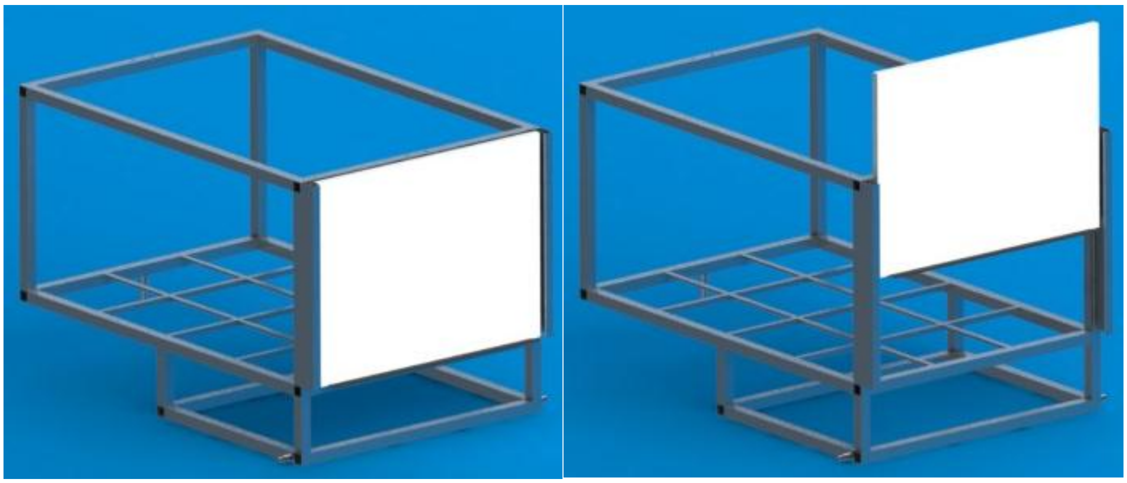


Figure 18: Telescoping tubes locking mechanism

Whiteboard Attachment:

As seen in Figure 19, the cart is equipped with a rear mounted sliding whiteboard. The whiteboard has a writing surface of 18 inches by 24 inches. Two lengths of C-channel are welded facing each other to the rear vertical frame rails of the cart. The whiteboard is mounted between the C-channels and is able to slide up and down between the C-channels. Caps are welded on the bottom of each C-channel to limit the whiteboard's downward travel. In order to limit the longitudinal slack between the whiteboard and the C-channel, plastic inserts are used between the whiteboard and the C-channel. Because the whiteboard will be mounted relatively low during transportation, the whiteboard will be able to be lifted into a higher position for presenting the contents of the whiteboard to a large audience. For this to be accomplished, T-Handle pull-pins are mounted to the side of each C-channel. When retracted, these pull pins allow the whiteboard to travel to its lowest point in the

channels. With the pull-pins engaged, the whiteboard can rest on the pins at a higher elevation. Alternately, the whiteboard can be completely removed from the cart so it can be cleaned, taken to a new/remote location for further instruction, or for the ease of writing. When the pins are not needed to hold the whiteboard up, they can be locked in the retracted position by being pulled out and rotated 1/4 turn.



Figures 19: Whiteboard lowered and raised.

Steering System

The steering system linkage has three pivot points. However, only two are used to maneuver the cart. The third pivot point is used to retract the linkage whenever the cart is not in use, and it only allows movement on a vertical plane. The pivot where the linkage is attached to the cart, by a bearing, only allows movement on a horizontal plane. On the other hand, the ball joint allows movement on both vertical and horizontal planes. The steering system without the wheels is shown in Figure 20. The ball joint gives flexibility to the clamping mechanism for different height bars on the back of the wheelchair and also allows the cart to be towed across uneven terrain.

Figure 20: Steering system.

In order to reduce the space needed to store the cart, the linkage folds back. The folded linkage can be seen in Figure 21. Additionally, in order to reduce the weight of the cart, it was important to select wheels that were lightweight. Therefore, lightweight foam-filled wheels were found and selected. An added benefit of these wheels is that they will not go flat since they are filled with foam instead of air.

Figure 21: Folded-up steering system attached to cart.

Attachment Method

The attachment method is shown in Figure 22. It consists of a clamp with grooves to hold the bar that is attached to the wheelchair. The clamp tightens using a cam lever as show in Figure 22. The cam lever allows the user to easily and quickly attach and detach the cart while seated on the wheelchair. In addition, the clamp is able to attach to different sized bars that may be on the back of other wheelchairs.

Figure 22: Wheelchair clamp attachment mechanism.

A cable is attached to the end of the cam lever to allow the user to quickly detach the cart without reaching to the back of the wheelchair. The red arrow, shown in Figure 23, shows the direction of the needed force to open the clamp.

Figure 23: Clamp with linkage

Brakes

This cart is equipped with a parking brake for the front axle to prevent unwanted cart movement. When the cart is attached to a wheel chair and the clamp is secured, there is no tension on the brake cables, and the brakes are disengaged. When the clamp is opened, the movement of the clamps pulls two cables in tension, which pulls the brake pins into the two front wheels. These aluminum pins are knurled to provide sufficient friction between wheel and the pin to prevent the cart from rolling. In order to ensure ease of repair/replacement, bicycle shifter cables and housings were used for the brake actuation. To prevent the brakes from accidently engaging during normal use there is a light spring that preloads the brake pins away from the wheels. If the cart needs to be moved with the wheel chair not attached, simply closing the clamp will disengage the brakes and allow the cart to roll freely.

Figure 24: Brake on front right wheel

Management Plan

Most of the major tasks associated with the project were worked on by the entire team. These tasks include research, documentation, design, fabrication, and testing. However, certain tasks were assigned separately to individual team members. Ryan Bolton was responsible for communication both external and internal to the team, Vincent Contreras was in charge of the fabrication process, and Rodrigo Sanchez was the lead for both research and documentation. Each week, smaller tasks were assigned to individual team members such that the work load was balanced and each team member worked according to his strengths.

The mechanical engineering department has set up several important dates to monitor the project's progress. The first major milestone, the critical design report and review, was on January 31, 2012, and the design was reviewed and finalized. Once the design had been approved parts were ordered and fabrication can began. Fabrication was completed and testing began in the second week of May 2012. The final project report was completed by the June 1, 2012 deadline. For a more detailed description, progression, and timing of the project schedule, a Gantt chart, showing all processes and milestones, is attached (Appendix B). The team used Microsoft Project and this Gantt chart to monitor progress and manage timing.

Manufacturing Process

The manufacturing plan consisted of five main sections. The first section included the ordering of all of the necessary material and parts. This was scheduled and

completed before the end of January for all parts initially needed for manufacturing. As manufacturing of the cart was completed, more material was purchased as was necessary.

The second section, the cutting/preparing section, began in February. The square aluminum tubes for the frame of the cart, the angle aluminum for the supports in the cart, and the steel tubes for the steering system were all cut to length. Before the expanded aluminum was cut to size, a panel was tested (see test plan) to ensure that the expanded aluminum would have the strength for the bottom and side panels of the cart. The last pieces that needed to be cut to length were the telescoping tubes for the wheel chair wheel holders and the c-channel for the whiteboard sliders. Part of the second section included the fabrication of the quick release clamp. This piece was made from sheet metal, and was cut, bent, and then drilled.

Figure 25: Tubes and angle cut to length

Figure 26: Sheet metal quick release clamp

The third section, the machining section, began in March. For the cart subsystem, two aluminum axle stubs and the aluminum steering stub were machined entirely on a lathe. Also for the cart subsystem, the telescoping tubes were turned down to a smaller diameter on the lathe so they would slide in the top rails of the cart, and their end caps were also machined using a lathe.

Figure 27: End cap and Steering stem

For the steering system, more pieces needed to be machined than for the cart. Two axle stubs, similar to the ones made for the cart, were made from steel using a lathe. The weldable threaded insert for the ball joint was made on a lathe with only one setup, while the hinge insert required one lathe setup, one mill setup, and one drill press setup to manufacture. The last piece that was machined for the steering system was the bearing housing. This piece was also made from steel and was machined on a lathe and was made so the bearing race could be press fit into it.

Figure 28: Turning down steel axle stubs

Figure 29: Top Left: Threaded insert, Top right: Hinge insert, Bottom: axle stubs

The fourth section of the manufacturing process was started in April and completed in May. This was the most critical and difficult part of the manufacturing process. This cart was welded together using a TIG (tungsten inert gas) welding process. In order to ensure that this section was completed correctly a welder was hired to weld the cart and steering system. The aluminum cart was welded in pieces then the pieces were connected with the vertical supports in order to keep the cart square. Due to the minimal thickness of the expanded aluminum, only the bottom panel was welded to the cart, the rest of the panels were riveted onto the cart using angle aluminum to hide the edges of the panel. The last pieces to be welded to the frame included the white board c-channel, axle stubs and steering stem.

The steel steering system was welded together using the same welding process as the cart. All of the supports for the front axle were notched to fit together before welding, and a rotary table was used to ensure the weldable inserts remained concentric during welding.

The fifth and final section of the manufacturing plan consisted of only assembly. Once welding was completed, the cart was fully assembled. After final assembly of

the cart, the testing wheelchair was modified to accept a ¾" tow bar along the back of it for pulling the cart. After initial assembly and testing of the cart, it was disassembled and sent out for powder coating, with final assembly following its return.

Economics

The required materials that were purchased were found from various vendors and a list showing the cost and source of each component can be found in Appendix F. The total cost for the project was $1270.44, which was $370.44 over the previous estimate of $900. However, the cost was still below the project budget of $1500.

Testing

Testing of this cart has been completed over the entire design process, instead of just after manufacturing had been completed.

The first test that was completed was done during the initial design phase. This test compared the maneuverability, stability, and ease of towing of various types of steering types and number of linkages. A wagon style steering system was compared with a system that uses two front casters for steering. For each of these steering systems one, two, and three steering link systems were compared. The turning radius, the ability to load the cart without unhooking from the wheel chair, and the ease of backing up were all tested to decide which system would work best for the cart. From these tests, it was determined that a wagon steering system with one steering link would be optimal for maneuverability as well as the capability of backing up. This final design technically has two steering links but the limited degrees of freedom of the lower link provide the same towing characteristics as the single link that was tested.

Figure 30: Steering options test

The second test that was performed during the design process was to explore the possible use of plastic corner connectors for the cart as an alternative to welding it together. Plastic connectors were ordered and then press fit into the existing aluminum tubes. These connectors developed significant amount of play in their fitment after minimal use, and yielded with less force than they would see during normal operation. Because of these results, welding was the preferred method of manufacturing the cart.

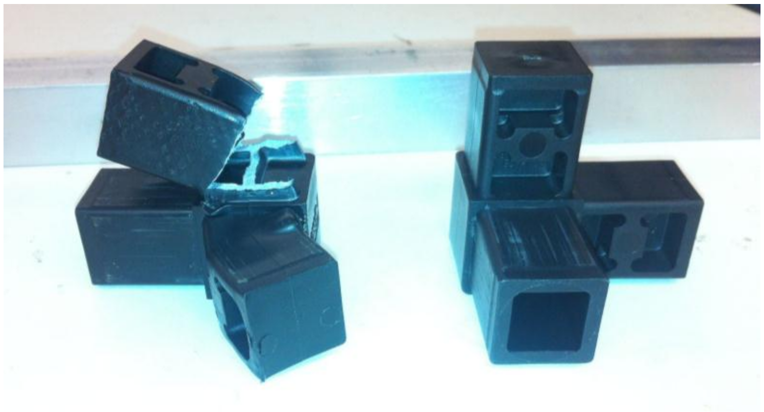


Figure 31: Failed plastic corner connector

Due to some concerns regarding the thickness of the expanded aluminum, a test panel was made to resolve the concerns. A 2ft by 3ft frame was made, and the .040" expanded aluminum was attached to it. Various loading conditions of typical sporting equipment were applied until failure was achieved. It was determined that the .040" thick expanded aluminum would be more than satisfactory for the side panels, and that .070" thick expanded aluminum should be used for the bottom panel, and the tray panel.

Figure 32: Shot put on expanded aluminum test panel

Welding was initially going to be used to attach the expanded aluminum to the frame. However, due to the thickness of panels, welding was no longer an option. Instead, angle aluminum covers were used in conjunction with rivets to secure the panels to the cart. A test piece of square aluminum tubing, angle aluminum, and expanded aluminum was made to determine the minimum distance between rivets need for a secure attachment. It was found that a distance of approximately 5 inches would be ideal to minimize the number of rivets needed while maintaining a rigid connection.

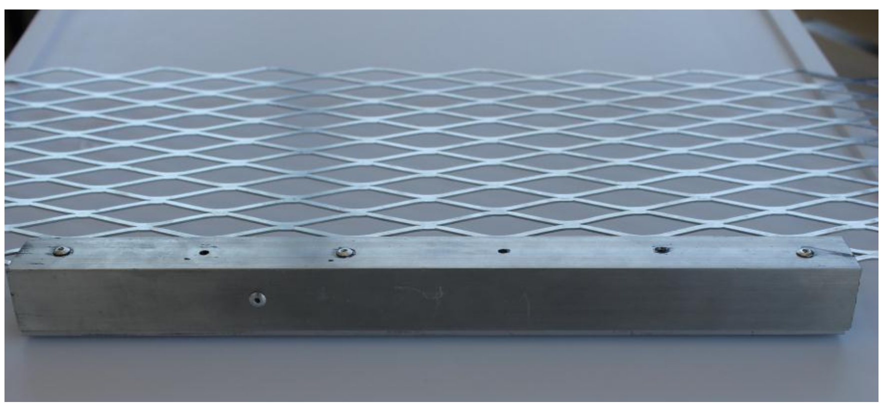


Figure 33: Riveted test section

The last set of testing followed the completion of the cart. In order to validate the design based on the initial design criteria, four different tests were completed. The first two tests were the measurements of the dimensions and complete weight of the cart. The internal dimension measure at 30”L x 24”W x 18”H. The external dimensions 39 7/8”L x 33 ¾”W x 31 ¼”H. With these dimensions, the cart will hold over 20 basketballs, and still fit in the back of a minivan. Along with these two measurements, the weight of the whole cart was measured to be 40 pounds. This does not meet the initial design criteria of less than 30 pounds; however, it is an acceptable weight for the cart’s intended use. The third test that needed to be completed was the lateral stability of the cart. The initial design criteria called for a

15 pound load at the top of the cart in the lateral direction and the cart could not tip over. The actual load that could be applied to the cart before tipping occurred was 19 pounds; this exceeds the initial design criteria of at least 15 pounds. This also met our initial design requirements. The fourth quantitative test that was performed on this cart was the obstacle clearance test. The cart needed to be able to clear a 4-inch obstacle without getting stuck. A 4-inch block was used and all 4 wheels were able to traverse the obstacle independently and the cart can straddle the same obstacle without getting stuck. This also met our initial design goals.

The final tests that were performed were qualitative physical tests. The cart was towed behind the test wheel chair for 1.2 miles over various terrains to test the maneuverability, and the ease of pulling the cart up and down hills. Because this cart will be used over different terrains, this test was able to ensure that this cart can handle these conditions with ease. The capacity of the cart was tested by loading it with various sporting equipment. First, a collection of racquets, cones, and sports balls were unevenly loaded and the cart was pulled through a cone slalom. The cart was then loaded with the maximum number of basketballs, 25, and then pulled through the same slalom. These two tests provided minimal added resistance to pulling the cart, and maneuverability and stability remained consistent with an empty cart. It was also determined that with experience, the cart can be backed up successfully into elevators and around corners. These tests qualitatively support the design decisions that were made.

Figure 34: Cone Slalom

Figure 35: Various equipment loading

Conclusion

PolyCart has designed, built and tested an equipment cart that can easily be used by a person who uses a wheelchair. The final cart can be seen in figure 36. The project has been completed within the allotted budget, and meets all of the customer's requirements. Although this may not be the optimal design possible, it is a strong base for any future revisions, and is robust enough to be used as a working prototype.

Figure 36: Final Product

Appendix A

QFD

	Customer
1	Bridge II Sports
2	Instructor
3	Dr. Taylor

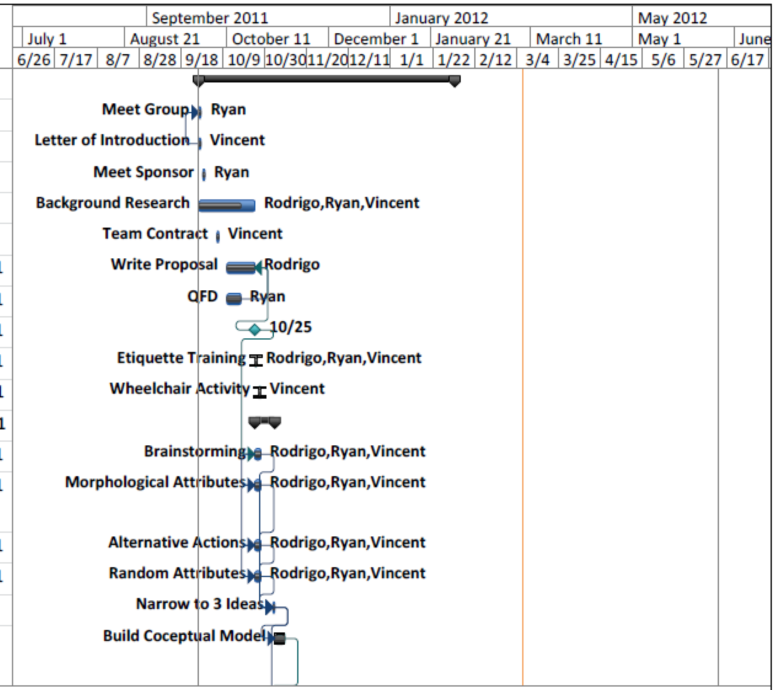
Grouping	Voices	Item No.	Importance	Height (Exterior)	Length (Exterior)	Width (Exterior)	Height (Capacity)	Length (Capacity)	Width (Capacity)	Weight	Force (To move)	Force (To tip over)	Force (Braking)	Obstacle Height	Sound Level	Height (whiteboard)	Width (whiteboard)
				A	B	C	D	E	F	G	H	I	J	K	L	M	N
	Used outside	1	5								3	3	9	9	1		
	Used indoors	2	5								3	3	3	1	1		
	Travel 1/4 mile	3	4								9						
	Fit through gym door	4	5	9	9	9											
	Fit in back of minivan	5	5	9	9	9				9							
	Loaded into van by wheelchair	6	1	3	3	3				9							
	Hold 2 bags of basketballs & c	7	3				9	9	9								
	Hold first aid kit	8	4				9	9	9								
	Hold helmets	9	3				9	9	9								
	Hold paddles	10	4				9	9	9								
	Hold golf clubs	11	3				9	9	9								
	Hold track field equipment	12	4				9	9	9								
	Has whiteboard	13	2	1	1	1										9	9
	Has iPod speakers	14	1												9		
	Brakes	15	5							3		3	9				
	Targets			3'10"	7'3"	4'2"	2'	5'	4'	30 lb	10 lb	15 lb	35 lb	4 in	80db	18"	24"
	Weighted Importance			95	95	95	189	189	189	69	66	45	105	50	19	18	18
	% Importance			8	8	8	15	15	15	6	5	4	8	4	2	1	1

Measures: columns A–N

Appendix B

Gantt Chart

ID	Task Name	Duration	Start
1	**Design**	**92 days**	**Tue 9/27/11**
2	Meet Group	1 day	Tue 9/27/11
3	Letter of Introduction	1 day	Tue 9/27/11
4	Meet Sponsor	1 day	Thu 9/29/11
5	Background Research	4 wks	Tue 9/27/11
6	Team Contract	1 day	Thu 10/6/11
7	Write Proposal	2 wks	Tue 10/11/11
8	QFD	1 wk	Tue 10/11/11
9	Proposal Due	0 days	Tue 10/25/11
10	Etiquette Training	1 day	Tue 10/25/11
11	Wheelchair Activity	1 day	Thu 10/27/11
12	**Idea Generation**	**8 days**	**Tue 10/25/11**
13	Brainstorming	3 days	Tue 10/25/11
14	Morphological Attributes	3 days	Tue 10/25/11
15	Alternative Actions	3 days	Tue 10/25/11
16	Random Attributes	3 days	Tue 10/25/11
17	Narrow to 3 Ideas	1 day	Thu 11/3/11
18	Build Coceptual Model	3 days	Fri 11/4/11

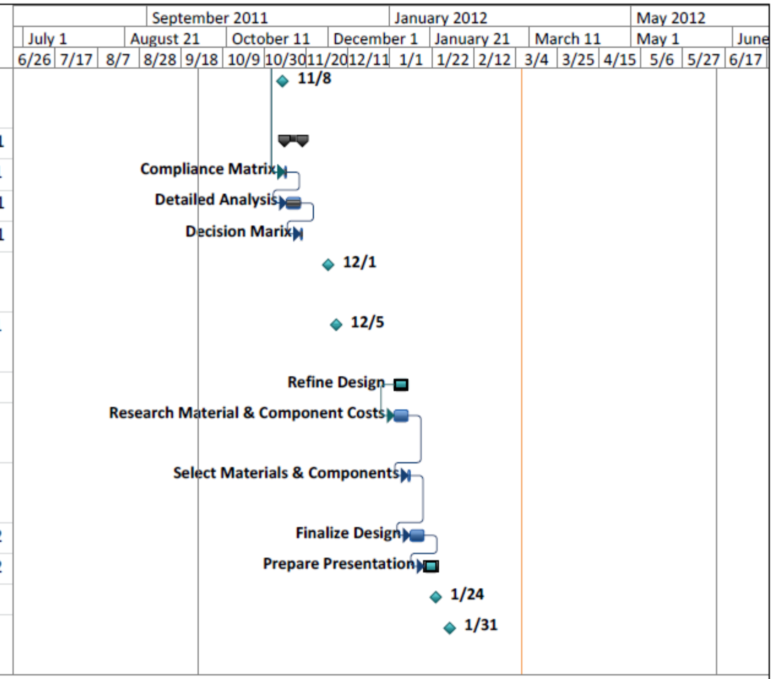


Project: !PolyCartTimeline11-03-1
Date: Wed 3/7/12

Task		External Milestone	◆	Manual Summary Rollup	
Split		Inactive Task		Manual Summary	
Milestone	◆	Inactive Milestone	◇	Start-only	[
Summary		Inactive Summary		Finish-only	]
Project Summary		Manual Task		Deadline	⇩
External Tasks		Duration-only		Progress	

Page 1

ID	Task Name	Duration	Start
19	Conceptual Model Due	0 days	Tue 11/8/11
20	**Analysis**	**7 days**	**Wed 11/9/11**
21	Compliance Matrix	1 day	Wed 11/9/11
22	Detailed Analysis	1 wk	Thu 11/10/11
23	Decision Marix	1 day	Thu 11/17/11
24	Conceptual Design Report Due	0 days	Thu 12/1/11
25	Conceptual Design Review	0 days	Mon 12/5/11
26	Refine Design	1 wk	Tue 1/3/12
27	Research Material & Component Costs	1 wk	Tue 1/3/12
28	Select Materials & Components	1 day	Tue 1/10/12
29	Finalize Design	1 wk	Wed 1/11/12
30	Prepare Presentation	1 wk	Wed 1/18/12
31	Practice CDR	0 days	Tue 1/24/12
32	Critical Design Report Due	0 days	Tue 1/31/12

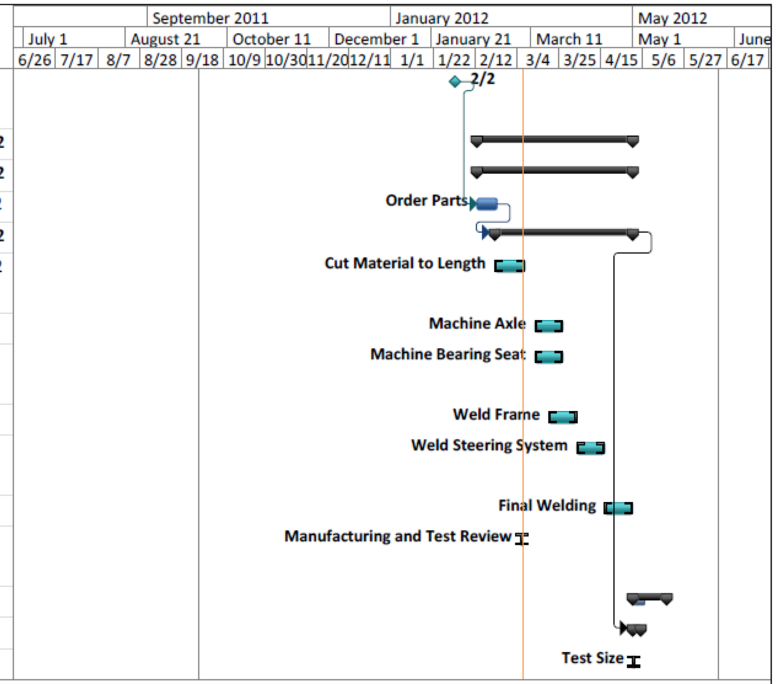


Project: !PolyCartTimeline11-03-1
Date: Wed 3/7/12

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

Page 2

ID	Task Name	Duration	Start
33	Critical Design Review	0 days	Thu 2/2/12
34	**Build**	**56 days**	**Mon 2/13/12**
35	**Prototype**	**56 days**	**Mon 2/13/12**
36	Order Parts	1.6 wks	Mon 2/13/12
37	**Fabricate**	**49 days**	**Wed 2/22/12**
38	Cut Material to Length	11 days	Wed 2/22/12
39	Machine Axle	2 wks	Tue 3/13/12
40	Machine Bearing Seat	2 wks	Tue 3/13/12
41	Weld Frame	2 wks	Tue 3/20/12
42	Weld Steering System	2 wks	Tue 4/3/12
43	Final Welding	10 days	Tue 4/17/12
44	Manufacturing and Test Review	1 day	Tue 3/6/12
45	**Test**	**13 days**	**Tue 5/1/12**
46	**Performance Tests**	**4 days**	**Tue 5/1/12**
47	Test Size	1 day	Tue 5/1/12

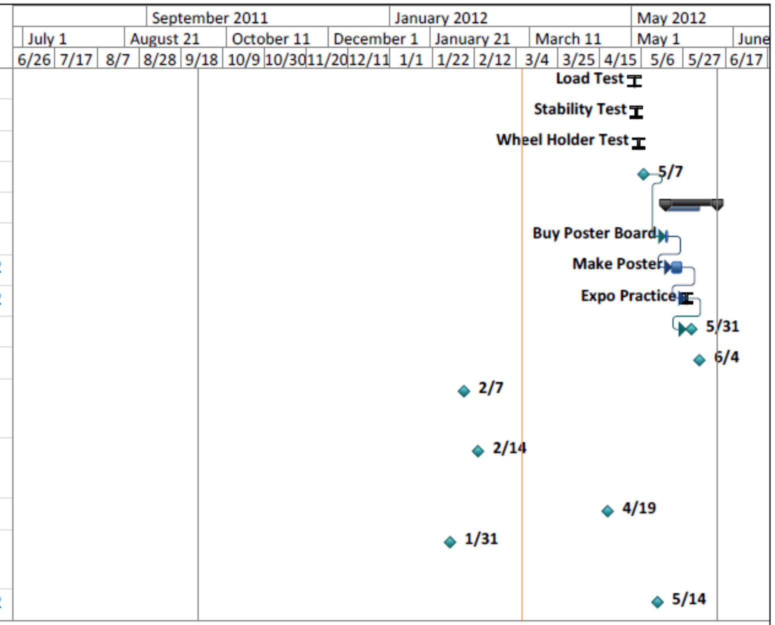


Project: !PolyCartTimeline11-03-1
Date: Wed 3/7/12

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

Page 3

ID	Task Name	Duration	Start
48	Load Test	1 day	Wed 5/2/12
49	Stability Test	1 day	Thu 5/3/12
50	Wheel Holder Test	1 day	Fri 5/4/12
51	Hardware Demo	0 days	Mon 5/7/12
52	**Expo**	**18 days**	**Fri 5/18/12**
53	Buy Poster Board	1 day	Fri 5/18/12
54	Make Poster	1 wk	Mon 5/21/12
55	Expo Practice	1 day	Mon 5/28/12
56	Expo Date	0 days	Thu 5/31/12
57	Final Report Due	0 days	Mon 6/4/12
58	Individual Ethics Memo Due	0 days	Tue 2/7/12
59	Team Ethics Presentation	0 days	Tue 2/14/12
60	Senior Exit Exam	0 days	Thu 4/19/12
61	Individual Ethics Memo Topic Due	0 days	Tue 1/31/12
62	Complete Senior Survey	0 days	Mon 5/14/12



Project: !PolyCartTimeline11-03-1
Date: Wed 3/7/12

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

Page 4

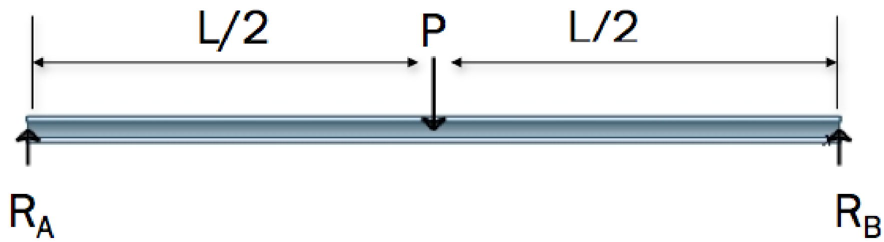
Appendix C

Normal stress and deflection calculation

Assumptions:

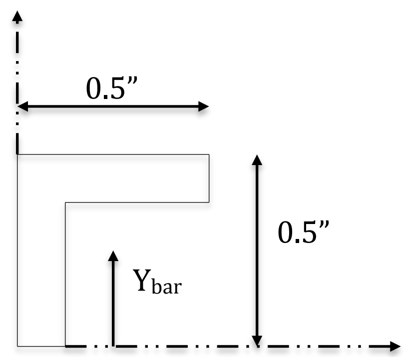
- The load acts on the center of the beam
- Pure and symmetrical bending

Statics:



From statics and by symmetry: $R_A = R_B = \frac{1}{2}P$

Beam Cross-Section



$$Y_{bar} = \frac{(0.5)(0.0625)\left(\frac{0.5}{2}\right) + (0.5)(0.0625)\left(0.5 - \frac{0.0625}{2}\right)}{2(0.5)(0.0625)} = 0.359 \text{ in}$$

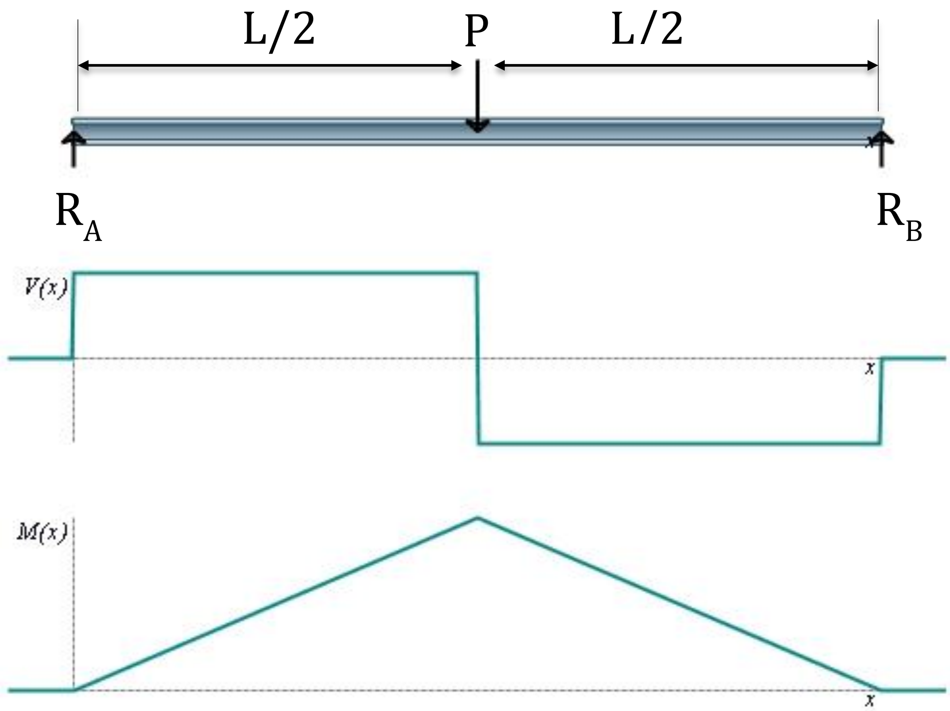
$$I_{x,1} = \frac{1}{12}(0.0625)(0.5)^3 + (0.0625)(0.5)\left(0.359 - \frac{0.5}{2}\right)^2$$

$$I_{x,2} = \frac{1}{12}(0.5)(0.625)^3 + (0.0625)(0.5)\left(0.5 - \frac{0.0625}{2}\right)^2$$

$$I_x = I_{x,1} + I_{x,2} = 0.00789\ in^4$$

Stress Analysis:

Let L = 36 in,



$$\sigma = \frac{My}{I}$$

$$\sigma = \frac{(9P)(0.359in)}{0.00789in^4}$$

$$\sigma = 409P$$

Assuming a load of 50 lbs

$$\sigma = 20452\ psi$$

Maximum deflection;

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

Where E = 10Mpsi for aluminum

$$Y_{max} = 0.615\ in$$

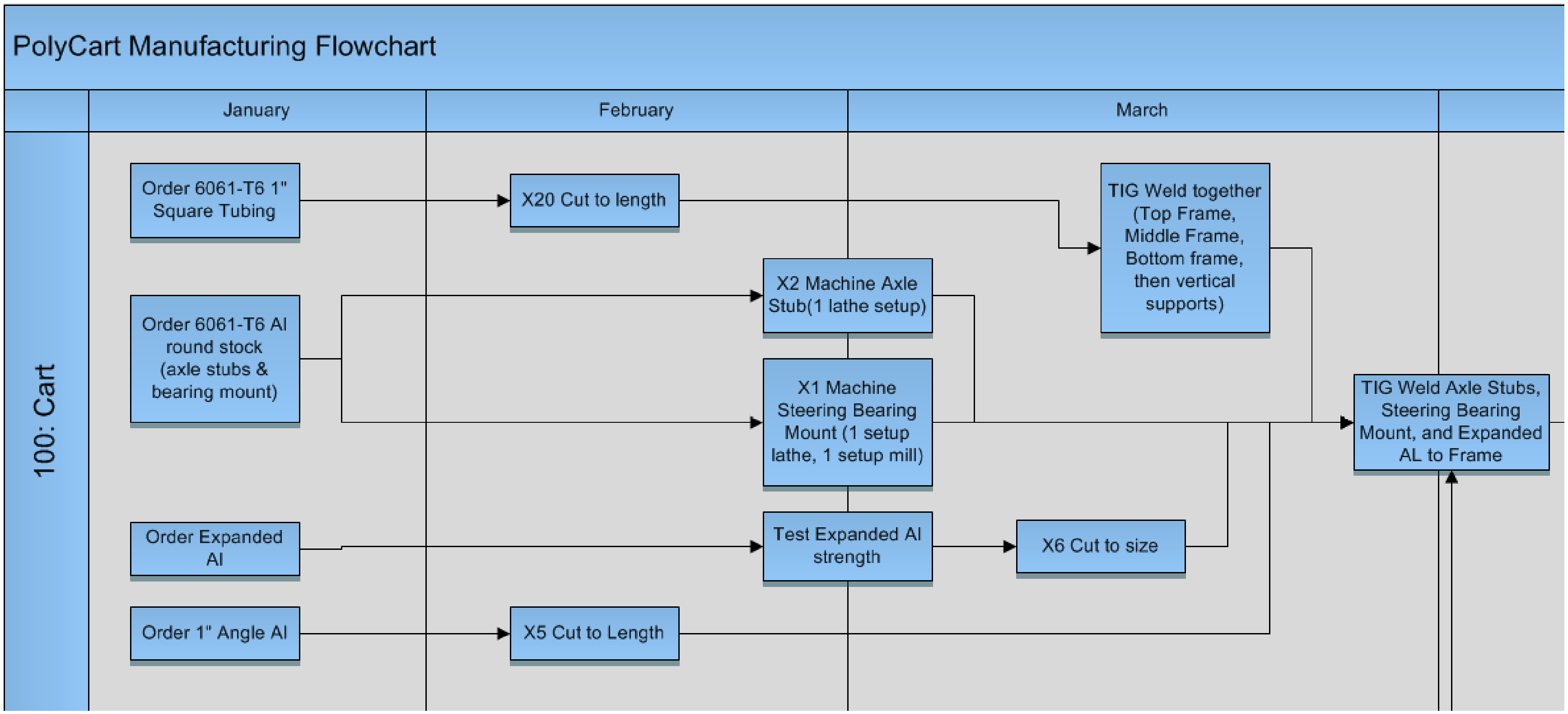
Appendix D

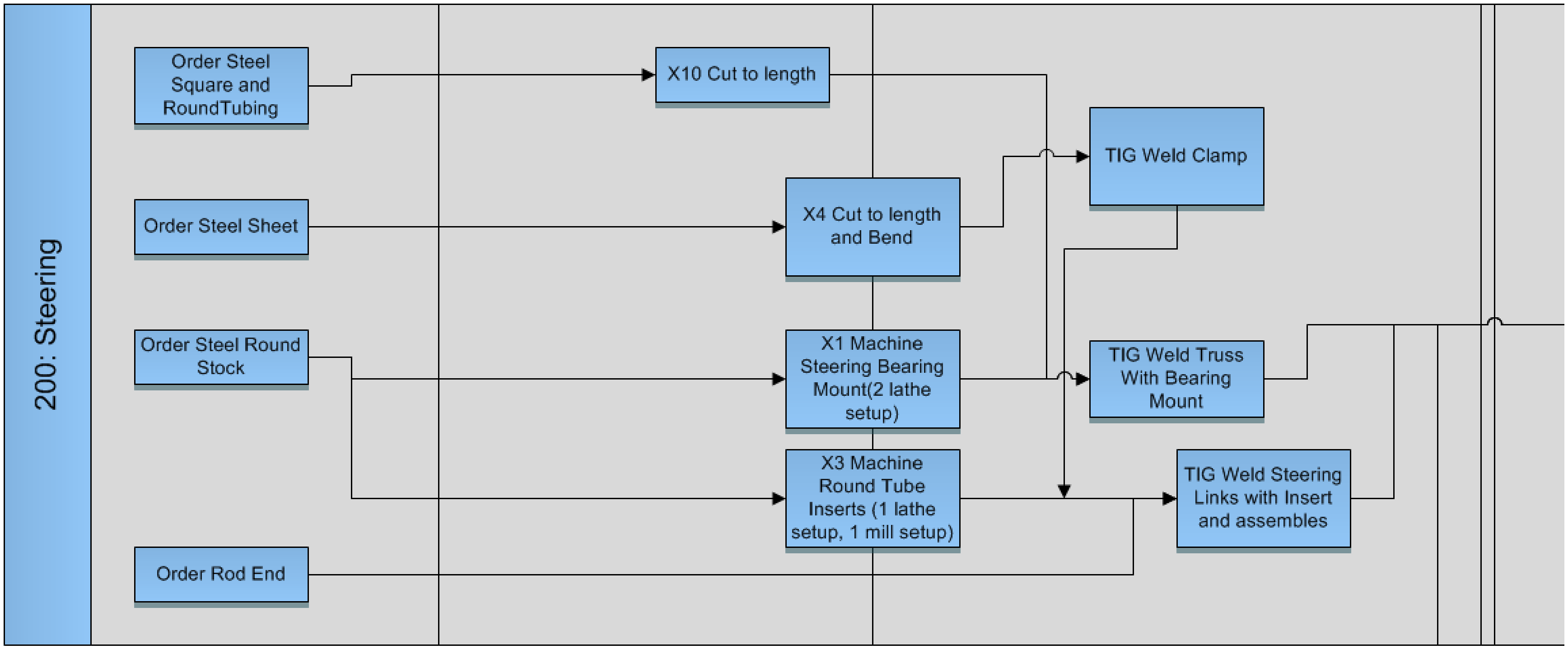
Engineering Equation Solver Code

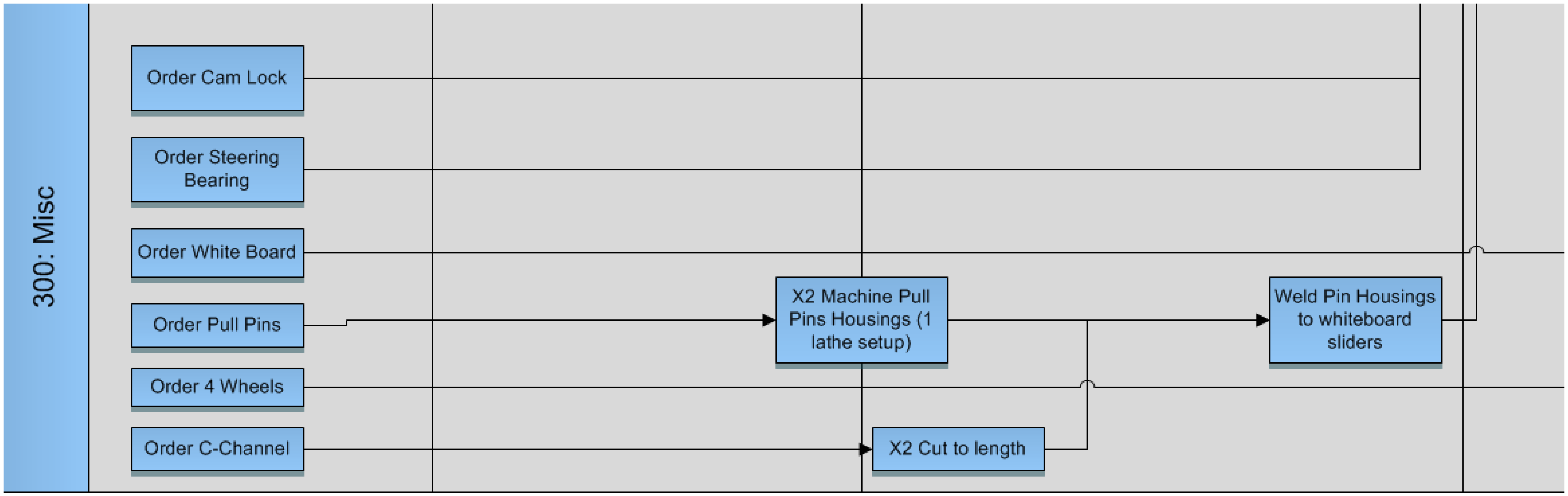
```
"==========================Point load Calculation====================="
"assumptions"
"1. The load acts on the center of the beam"
"2. Pure and symmetrical bending"

"=====================Reaction forces==============================="

P = 200                                          "Load (lbs)"
L = 3*12                                         "Lenght (in)"
"assuming the point load is at the center of the menber"
F_A = 1/2*P
F_B= F_A

"====================Inertia for a square=============================="
h_o =1                                           "outer height (in)
t =1/16                                          "thickness (in)"
h_i =h_o-t*2                                     "inner height (in)"

I = 1/12*h_o^4 - 1/12*h_i^4

"========================Normal Stress============================="
y= h_o/2
M = L/2*F_A
sigma_max = M*y/I
"======================Maximum deflection========================="
E = 10e6                                         "Modulous of eslastisity for Al (psi)"
y_max = P*L^3/(48*E*I)                           "Maximum deflection"

"=========================Safety Factor============================="
YieldStrength = 36000                            " psi"
 SF = YieldStrength/sigma_max

"===========================weight================================="
density = 0.0975137                              "lb/in^3"
volume= L*(h_o^2-h_i^2)                          "in^3"
mass = density*volume                            "lbs"

"=========================Buckling=================================="

K =0.5                                           "column effective length factor"
F_critical = (pi)^2*E*I/(K*L)^2                  "Critical Buckling Force"
SF_B=F_critical /P
```

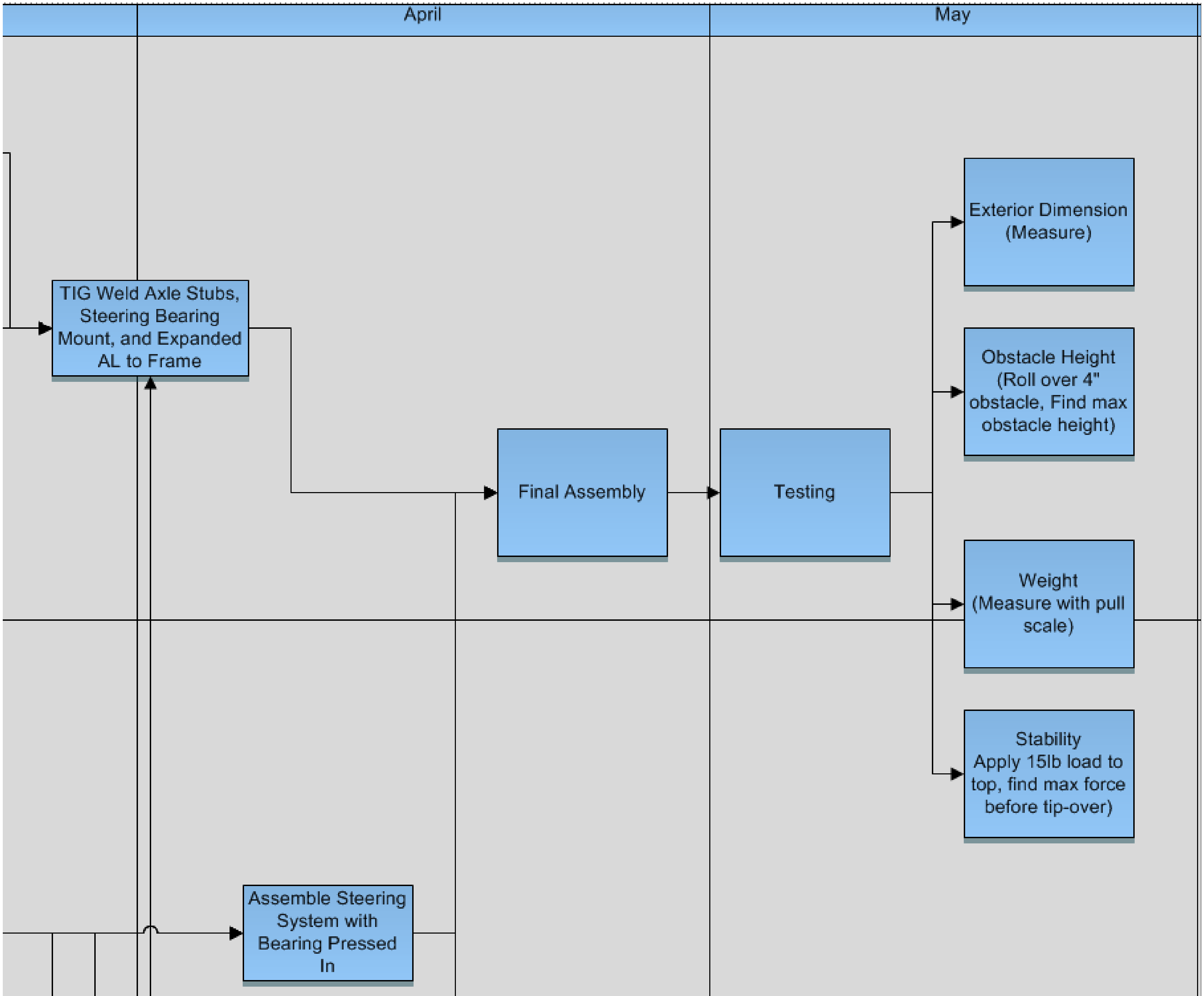
Appendix E

Manufacturing Flow Chart




200: Steering
Order Steel Square and RoundTubing
Order Steel Sheet
Order Steel Round Stock
Order Rod End
X10 Cut to length
X4 Cut to length and Bend
X1 Machine Steering Bearing Mount(2 lathe setup)
X3 Machine Round Tube Inserts (1 lathe setup, 1 mill setup)
TIG Weld Clamp
TIG Weld Truss With Bearing Mount
TIG Weld Steering Links with Insert and assembles


300: Misc
Order Cam Lock
Order Steering Bearing
Order White Board
Order Pull Pins
Order 4 Wheels
Order C-Channel
X2 Machine Pull Pins Housings (1 lathe setup)
X2 Cut to length
Weld Pin Housings to whiteboard sliders


April
May
TIG Weld Axle Stubs, Steering Bearing Mount, and Expanded AL to Frame
Final Assembly
Testing
Exterior Dimension (Measure)
Obstacle Height (Roll over 4" obstacle, Find max obstacle height)
Weight (Measure with pull scale)
Stability Apply 15lb load to top, find max force before tip-over)
Assemble Steering System with Bearing Pressed In

Appendix F

Parts list

Part	Company	Part #	Unit Cost ($)	Quantity	Cost ($)	Tax ($)	Shipping ($)	Total ($)
6'-1"x1"x.065" AluminumSquare Tube	Texas Towers		9.90	8	79.20	0.00	25.05	104.25
8'-1"x1"x.065" Aluminum Angle Bars	McMaster	8982K392	7.99	2	15.98	17.71	0.00	33.69
4'x4' Expanded Aluminum	McMaster	9305T43	55.96	1	55.96	0.00	0.00	55.96
4'x8' Expanded Aluminum	McMaster	9305T13	97.21	1	97.21	0.00	0.00	97.21
Swivel Ball Joint	McMaster	6960T11	20.36	1	20.36	0.00	0.00	20.36
T Handle Pull Pin	McMaster	90222A503	13.22	2	26.44	0.00	0.00	26.44
4'-13/16" Strut Channel	McMaster	3230T311	14.84	1	14.84	0.00	0.00	14.84
5/16" Cam Lever	McMaster	5720K17	13.19	1	13.19	0.00	0.00	13.19
Steel Tapered-Roller Bearing	McMaster	5709K13	10.78	1	10.78	9.76	52.48	73.02
Bearing Outter Ring	McMaster	5709K53	5.80	1	5.80	0.00	0.00	5.80
6'-7/8"x.049" Aluminum Tubing	McMaster	89965K65	18.38	1	18.38	0.00	0.00	18.38
4'x4' Expanded Aluminum	McMaster	9305T44	80.41	1	80.41	0.00	0.00	80.41
Quick-Release Button Connectors	McMaster	92988A660	10.63	1	10.63	0.00	0.00	10.63
6'-3/4"x.065" Round Steel Tube	Metals Depot	T234065	25.62	1	25.62	0.00	35.57	61.19
2'-1-1/4" Round Steel Bar	Metals Depot	R1114	12.50	1	12.50	0.00	0.00	12.50
8'-1/2"x1/2"x.065" Steel Square Tube	Metals Depot	T11216	10.64	1	10.64	0.00	0.00	10.64
2'-3/4"x3/4"x.065" Steel Square Tube	Metals Depot	T13416	3.62	1	3.62	0.00	0.00	3.62
2'-7/8" Round Steel Bar	Metals Depot	R178	9.20	1	9.20	0.00	0.00	9.20
1'x2'x.060" Steel Sheet	Metals Depot	S116	12.80	1	12.80	0.00	0.00	12.80
Wheels	Strider Sports	1NWU5	17.00	4	68.00	0.00	24.14	92.14
White Board	Amazon	1824MBMGA	18.99	1	18.99	0.00	0.00	18.99
Welding	Siro Works		25.00	10.5	262.50	0.00	0.00	262.50

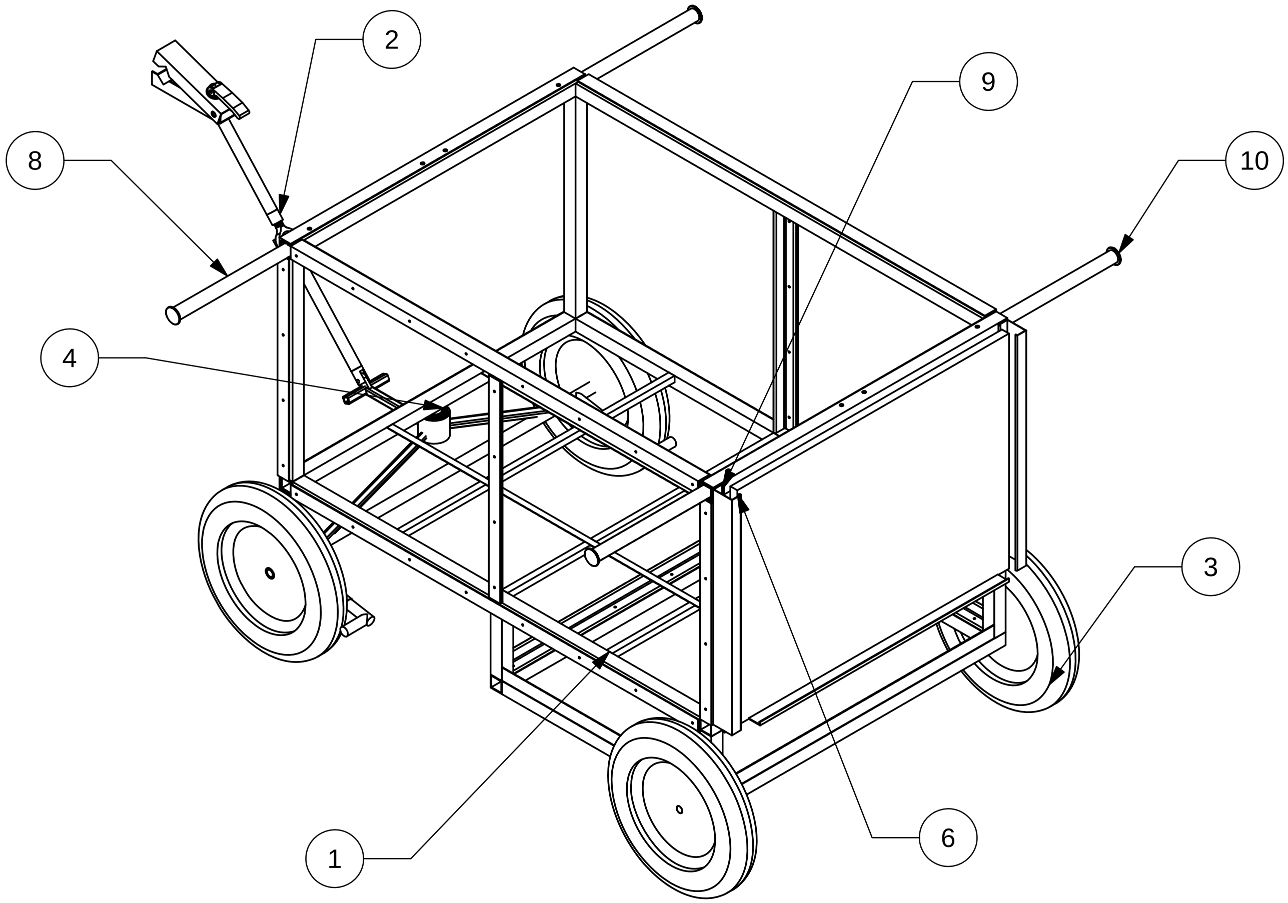
Powder Coating	Full Spectrum Powder Coating		75.00	1	75.00	0.00	0.00	75.00
Misc. Hardware	Miners Ace Hardware		5.42	1	5.42	0.00	0.00	5.42
Misc. Hardware	Miners Ace Hardware		13.72	1	13.72	0.00	0.00	13.72
6'-1"x1"x.065" Aluminum Angle Bars	Miners Ace Hardware		12.92	5	64.60	0.00	0.00	64.60
Misc. Materials	Miners Ace Hardware		29.98	1	29.98	0.00	0.00	29.98
Krylon Spraypaint	Miners Ace Hardware	17104	4.49	1	4.49	0.76	0.00	5.25
Fastener	Miners Ace Hardware	56	1.39	2	2.78	0.00	0.00	2.78
Fastener	Miners Ace Hardware	56	1.29	2	2.58	0.00	0.00	2.58
Drawer	WalMart	9046	13.97	1	13.97	1.08	0.00	15.05
Brake Cable	Foothill Cyclery	BRA315373940	3.99	2	7.98	1.32	0.00	9.30
Cable Housing	Foothill Cyclery	CAB19706849T	1.50	6	9.00	0.00	0.00	9.00
				Total	948.05	30.63	137.24	1270.44

Appendix G

Drawings & Bill of Materials

PART NUMBER	DESCRIPTION	QTY.
0000	EQUIPMENT CART	1
1000	CAGE	1
1010	BOTTOM FRAME	1
1011	SQUARE TUBE (36")	4
1012	SQUARE BAR (26")	4
1013	ANGLE BAR (7.83")	9
1014	ANGLE BAR (36")	2
1020	TOP FRAME	1
1021	SQUARE TUBE WITH HOLES	2
1030	TRAY FRAME	1
1031	SQUARE TUBE (17.5")	2
1032	AXLE STUB	2
1040	SQUARE TUBE (17")	4
1050	SQUARE TUBE (5")	4
1060	EXPANDED ALUMINUM SIDING (26”X38”)	1
1070	EXPANDED ALUMINUM SIDING (19”X26”)	3
1080	EXPANDED ALUMINUM SIDING (19”X38”)	2
1100	STEERING SYSTEM STUB	1
1110	RIVETED SUPPORTS TOP SIDES	2
1120	RIVETED SUPPORTS TOP FRONT AND BACK	2
1130	RIVETED SUPPORTS VERTICALS CORNERS	4
1140	RIVETED SUPPORTS VERTICAL MIDDLE	2
1150	RIVETED SUPPORTS BOTTOM SIDES	2
1160	RIVETED SUPPORTS BOTTOM BACK, FRONT AND BACK TRAY	3
1170	RIVETED SUPPORTS BOTTOM FRONT	1

1180	RIVETED SUPPORTS SIDES TRAY	2
1190	RIVETED SUPPORTS VERTICAL MIDDLE (FLAT ALUMINUM)	2
2000	STEERING SYSTEM ASSEMBLY	1
2010	STEERING TRUSS	1
2011	BEARING	1
2012	BEARING HOUSING	1
2013	FRONT WHEEL AXLE	1
2014	AXLE TO BEARING HOUSING BAR	2
2016	SQUARE BAR FROM BEARING HOUSING TO SQUARE BAR	1
2017	SQUARE BAR CONNECTING HORIZONTAL AND ANGLE SQUARE BARS	1
2018	Linkage Hitch	1
2019	Braking Lever	2
2020	LOWER STEERING LINK	1
2021	Outer Brake Tube	2
2030	UPPER STEERING LINK	1
2050	ROD END THREADED INSERT	1
2060	ROD END COUPLER	1
2070	HINGE INSERT	1
2080	BEARING RETAINER	1
2090	BOTTOM CLAMP	1
2100	TOP CLAMP	1
2110	BALL JOINT	1
2120	CAM LEVER	1
3020	WHEEL HOOKS	4
3030	WHEELCHAIR WHEELS HOLDER	4
3040	SNAP PIN	4
3050	STRUT CHANNEL	2
3051	WHITEBOARD	1
3052	WHITEBOARD PINS	2
3060	WHEELS	4



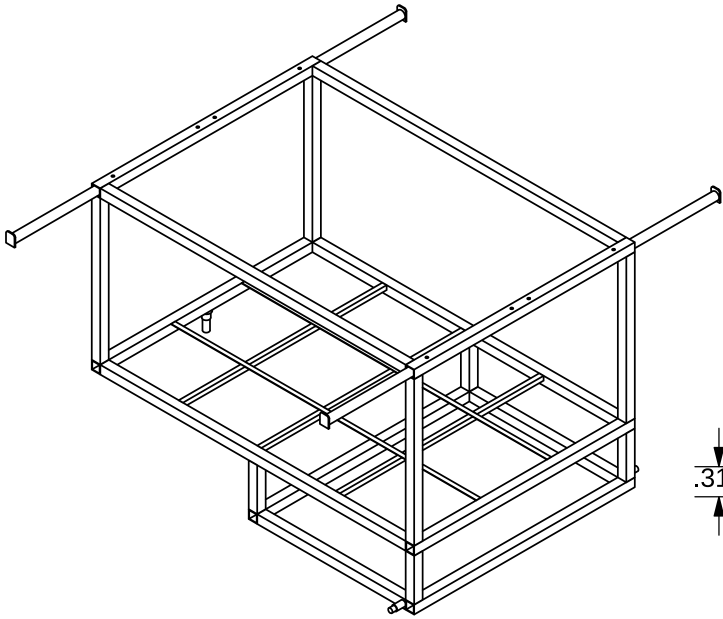
NOTE: FOR CLARITY THE EXPANDED ALUMINUM IS NOT SHOWN

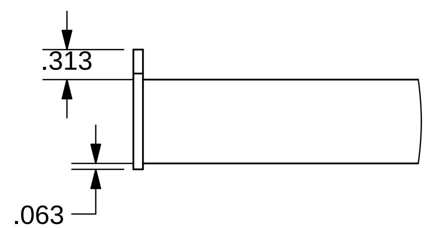
ITEM NO.	PART NUMBER	QTY.
1	1000	1
2	2000	1
3	3010	4
4	3030	1
5	2080	1
6	3040	1
8	3020	4
9	3050	2
10	3030	1

POLY CART

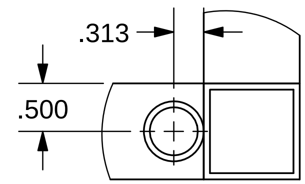
DATE: 2/2/12	UNITS: INCHES	MATERIAL:
TOLERANCE: +/- 0.05	SCALE: 1:12	TITLE: EQUIPMENT CART
	NEXT ASSY:	NAME: RYAN BOLTON
	DRAWING #: 0000	SIGNATURE:

ITEM NO.	PART NO.	DESCRIPTION	QTY.
1	1020	TOP FRAME	1
2	3040	SNAP PIN	4
3	3020	WHEEL HOOKS	4
4	1040	VERTICAL BAR	4
5	1010	BOTTOM FRAME	1
6	1050	VERTICAL TRAY BAR	4
7	1030	TRAY FRAME	1
8	1032	REAR WHEEL AXLE	2
9	1100	BEARING SEAT	1
10	3030	WHEELCHAIR WHEELS HOLDER	4

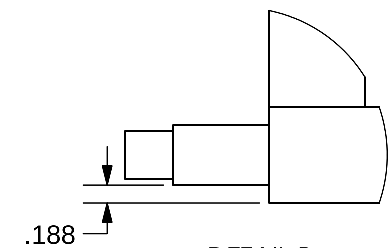




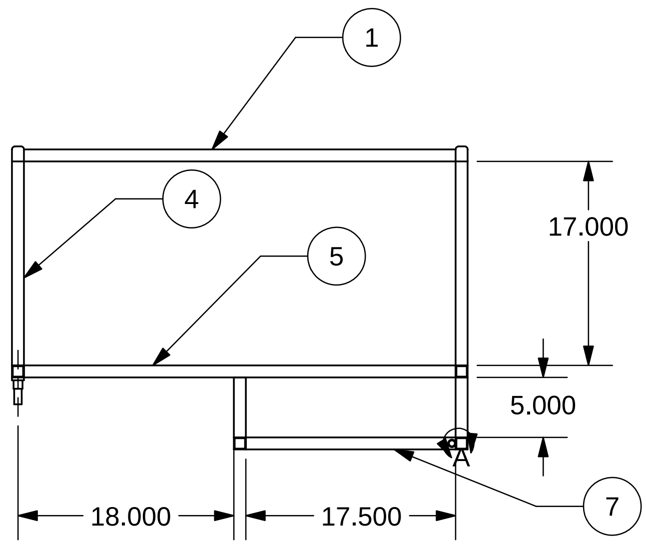
DETAIL C
SCALE 1 : 2

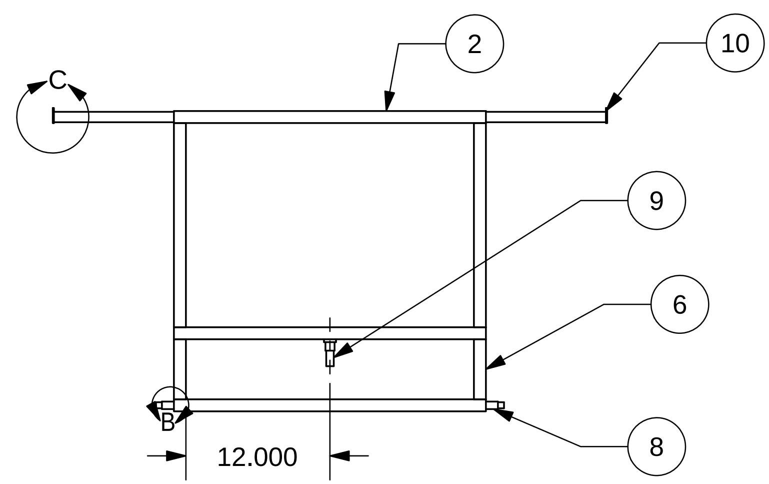


DETAIL A
SCALE 1 : 2



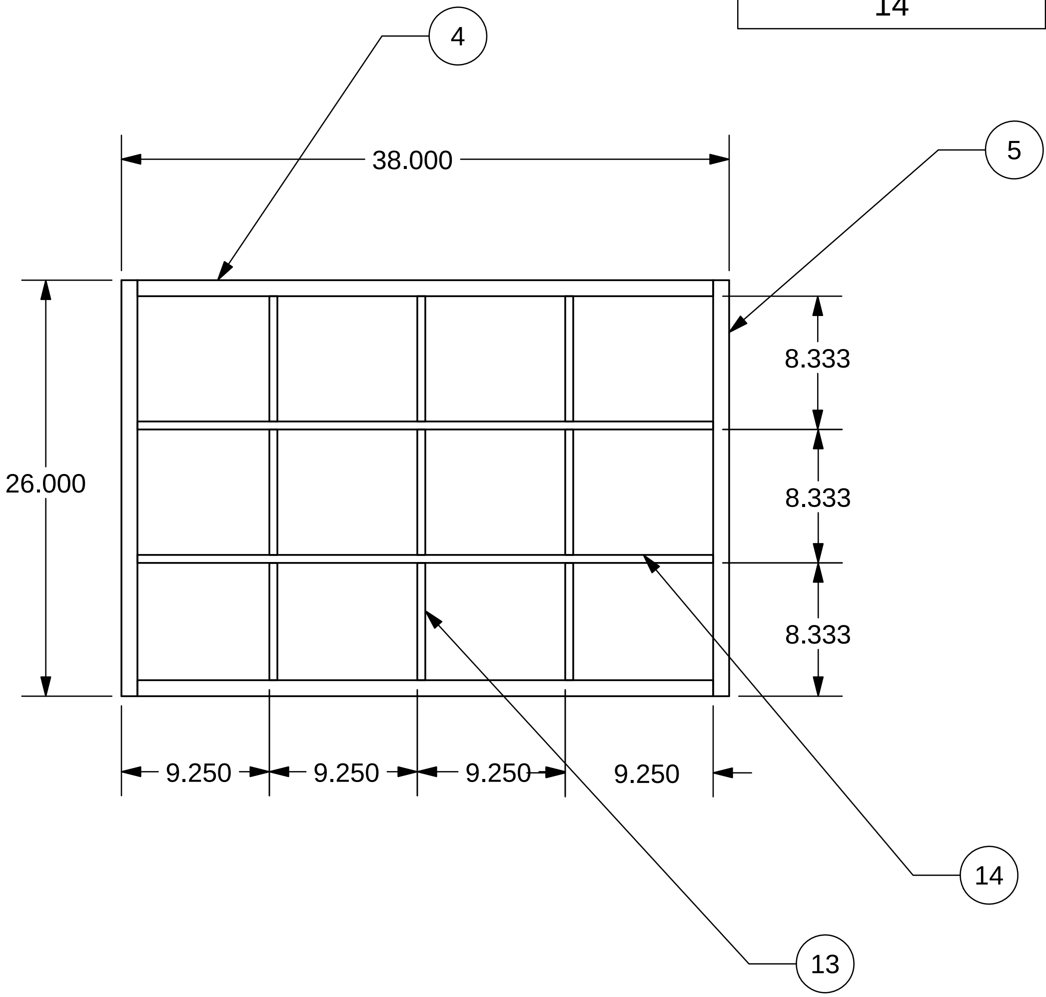
DETAIL B
SCALE 1 : 2

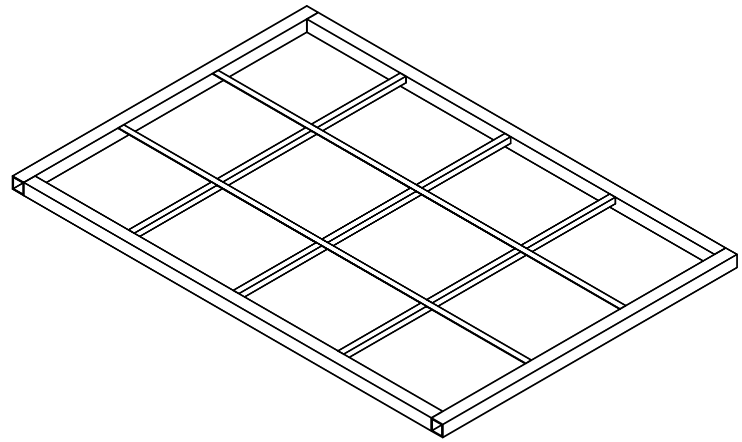




DATE: 2/2/12	UNITS: INCHES	MATERIAL:
TOLERANCE: +/- 0.05	SCALE: 1:16	TITLE: CAGE
	NEXT ASSY: 0000	NAME: RODRIGO SANCHEZ
	DRAWING #: 1000	SIGNATURE:

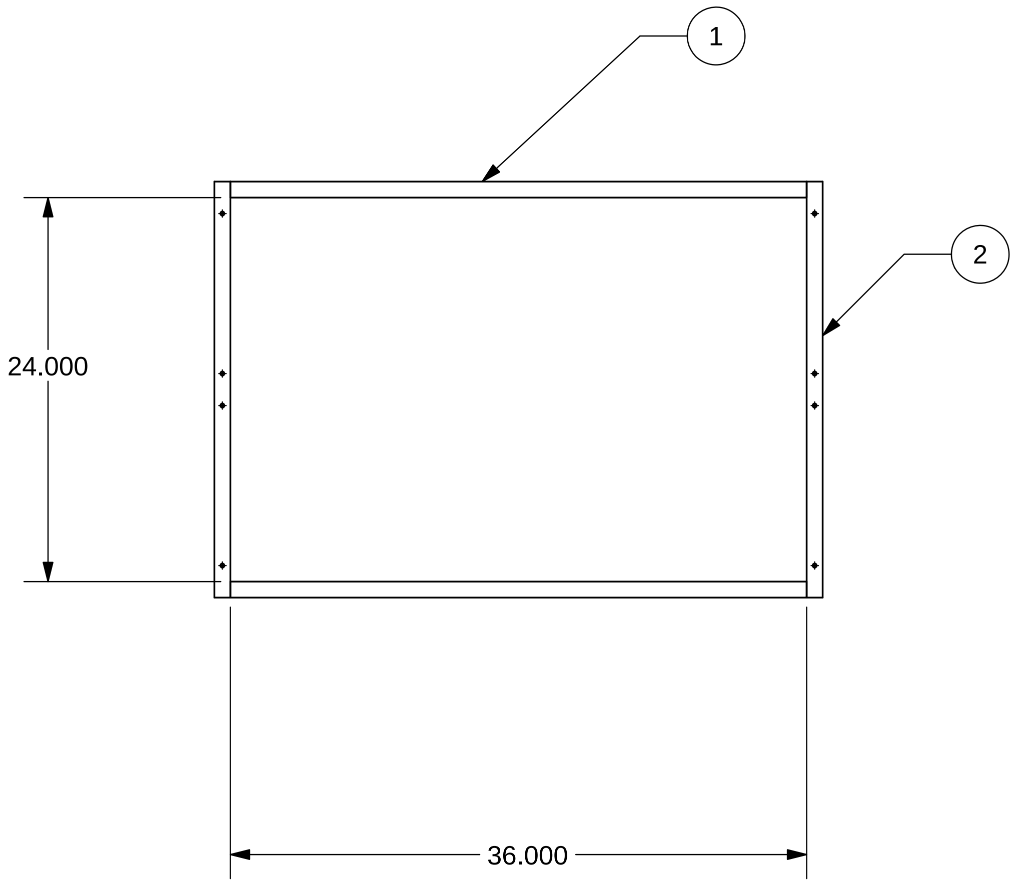
ITEM NO.	PART NO.	DESCRIPTION	QTY.
4	1011	LATERAL BAR	2
5	1012	SQUARE BAR NO HOLES	2
13	1013	ANGLE BAR (7.83")	9
14	1014	ANGLE BAR (36")	2

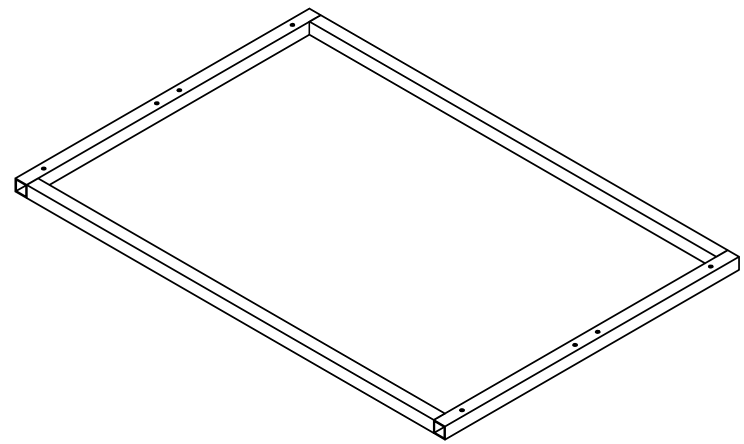




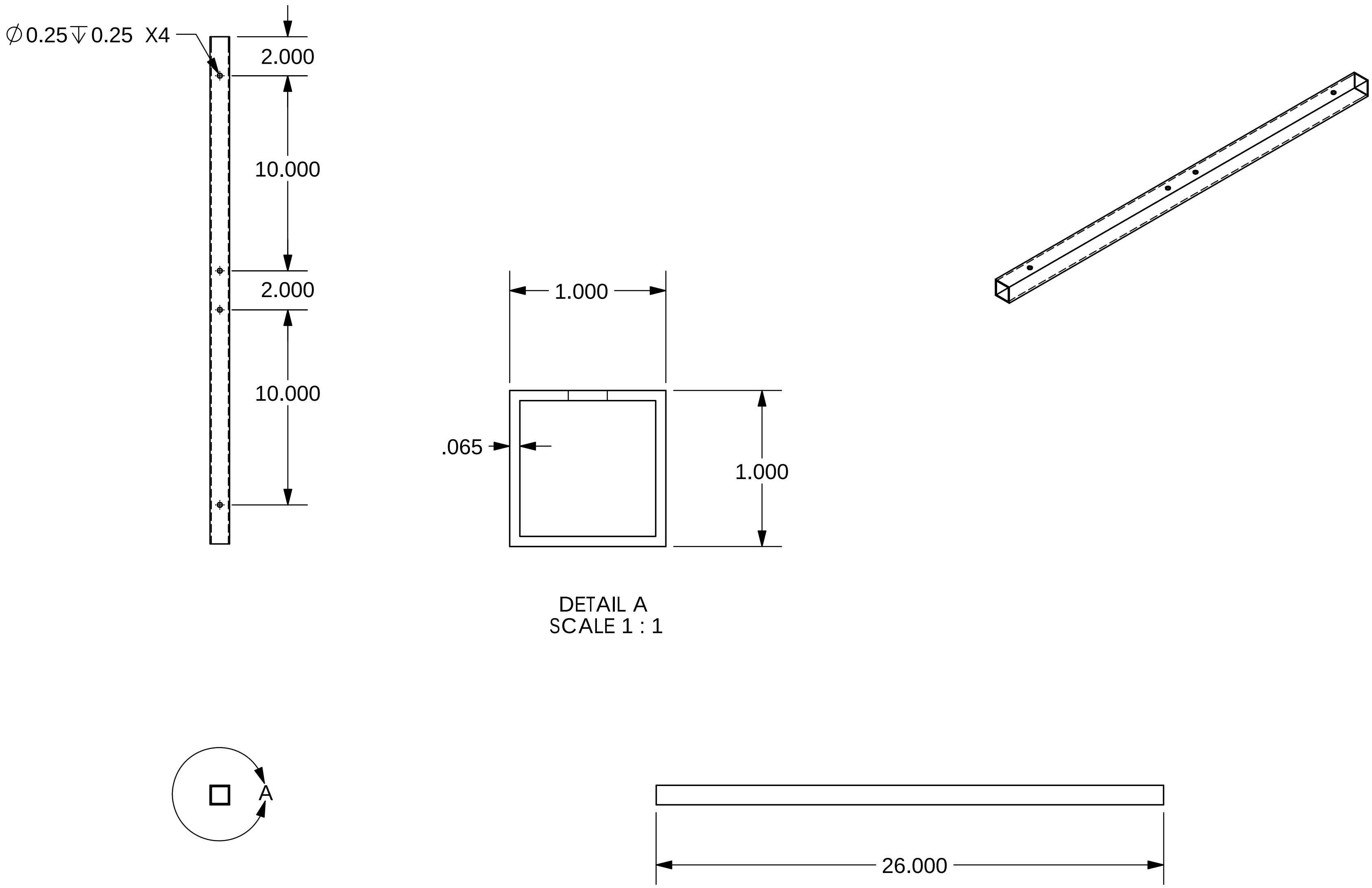
DATE: 2/2/12	UNITS: INCHES	MATERIAL: 6061 ALUMINUM
TOLERANCE: +/- 0.05	SCALE: 1:12	TITLE: BOTTOM FRAME
	NEXT ASSY: 1000	NAME: RYAN BOLTON
	DRAWING #: 1010	SIGNATURE:

ITEM NO.	PART NO.	DESCRIPTION	QTY.
1	1011	LATERAL BAR	2
2	1021	BAR WITH HOLES	2



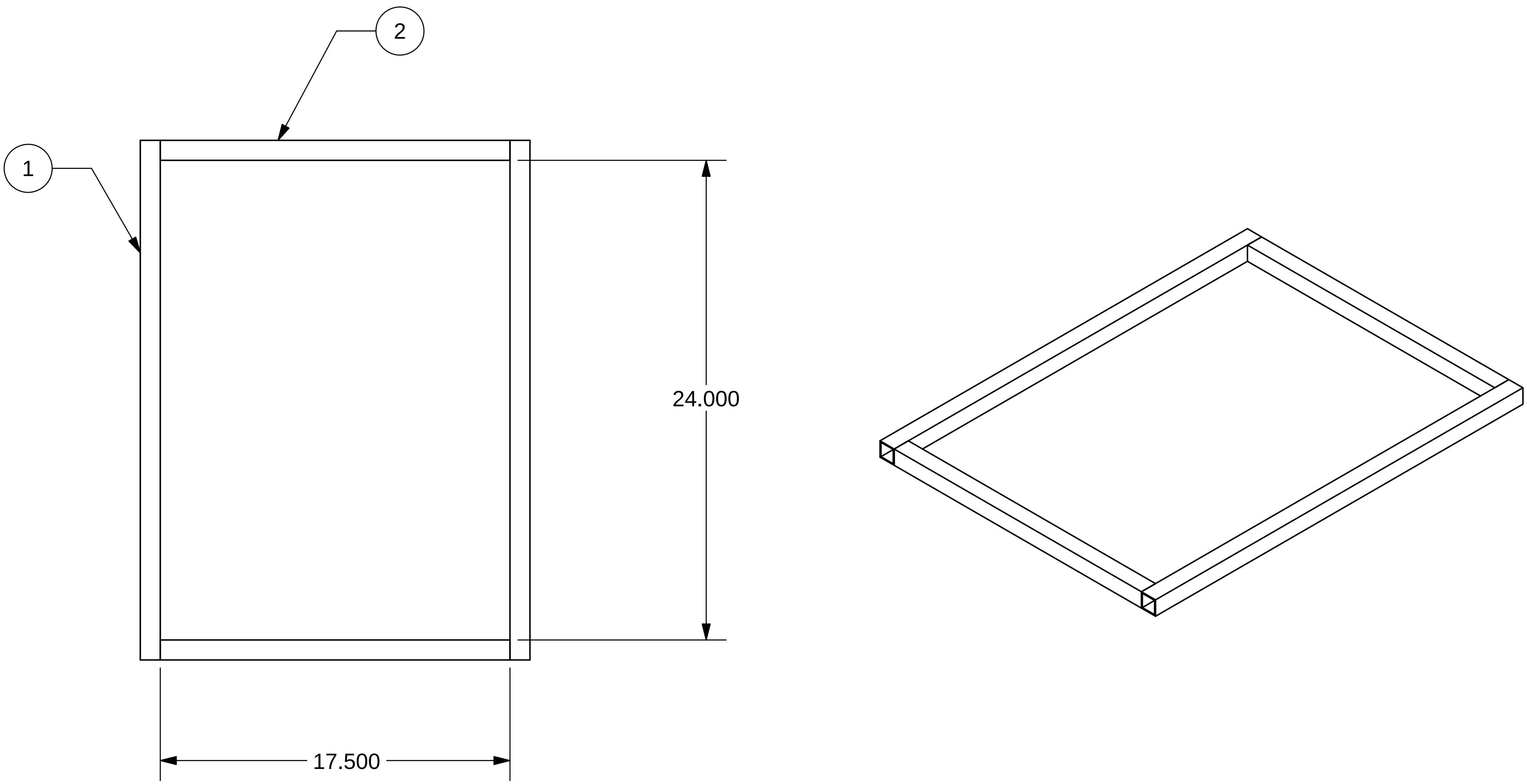


	DATE: 2/2/12	UNITS: INCHES	MATERIAL: 6061 ALUMINUM
	TOLERANCE: +/- 0.05	SCALE: 1:12	TITLE: TOP FRAME
		NEXT ASSY: 1000	NAME: RODRIGO SANCHEZ
		DRAWING #: 1020	SIGNATURE:

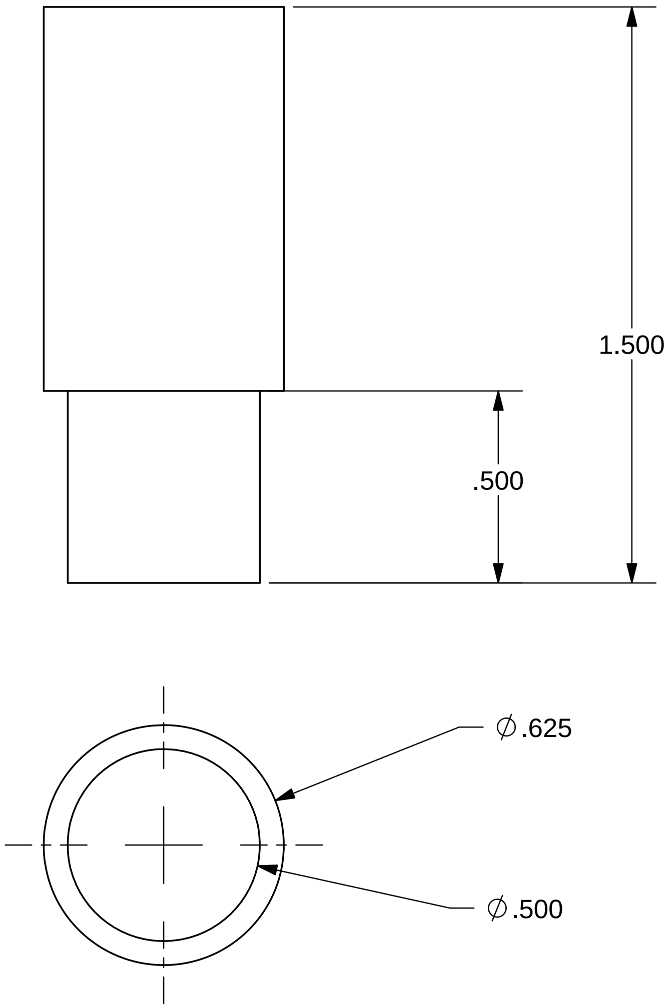


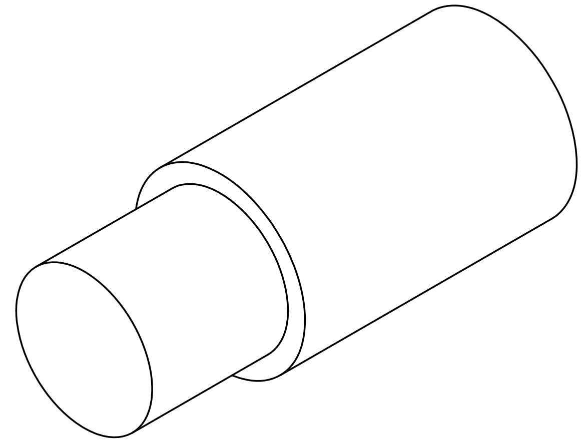
DATE: 2/2/12	UNITS: INCHES	MATERIAL: 6061 ALUMINUM
TOLERANCE: +/- 0.05	SCALE: 1:8	TITLE: SQUARE TUBE WITH HOLES
	NEXT ASSY: 1020	NAME: RODRIGO SANCHEZ
	DRAWING #: 1021	SIGNATURE:

ITEM NO.	PART NO.	DESCRIPTION	QTY.
1	1012	FRONT AND BACK SQUARE BAR (NO HOLES)	2
2	1031	TRAY SQUARE BAR (17.5")	2



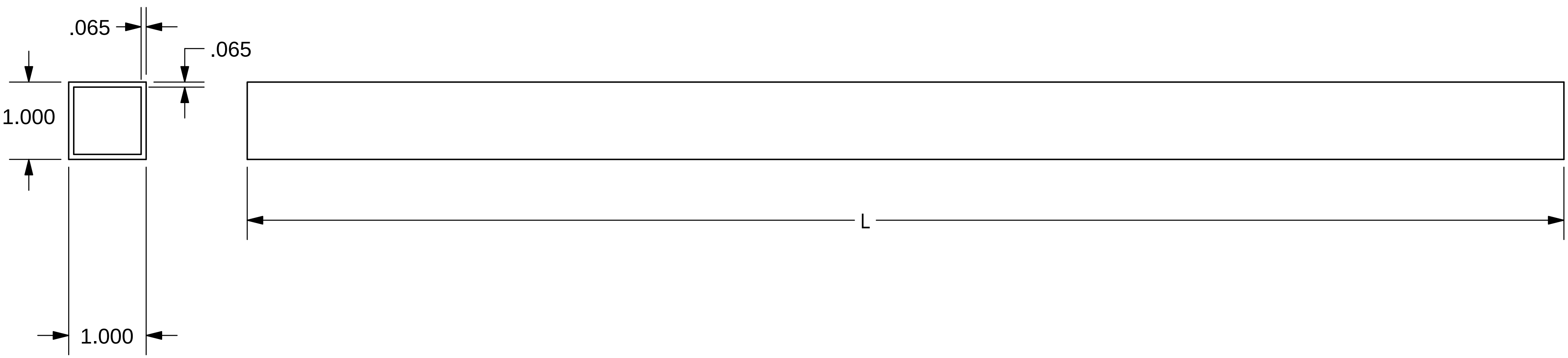
DATE: 2/2/12	UNITS: INCHES	MATERIAL: 6061 ALUMINUM
TOLERANCE: +/- 0.05	SCALE: 1:8	TITLE: TRAY FRAME
	NEXT ASSY: 1000	NAME: RODRIGO SANCHEZ
	DRAWING #: 1030	SIGNATURE:





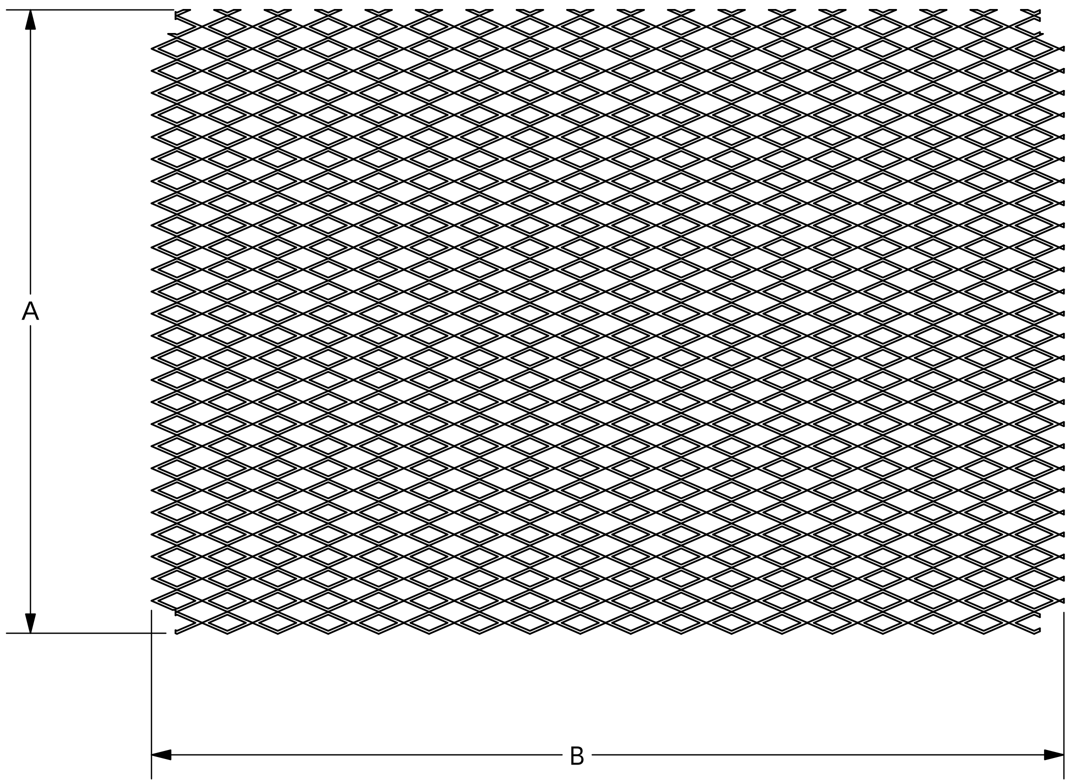
DATE: 2/2/12	UNITS: INCHES	MATERIAL: 6061 ALUMINUM
TOLERANCE: +/- 0.05	SCALE: 2:1	TITLE: AXLE STUB
	NEXT ASSY: 1030	NAME: RODRIGO SANCHEZ
	DRAWING #: 1032	SIGNATURE:

Part Number	L	Quantity	NEXT ASSY
1011	36	4	1010
1012	26	4	1010
1031	17.5	2	1030
1040	17	4	1000
1050	5	4	1000

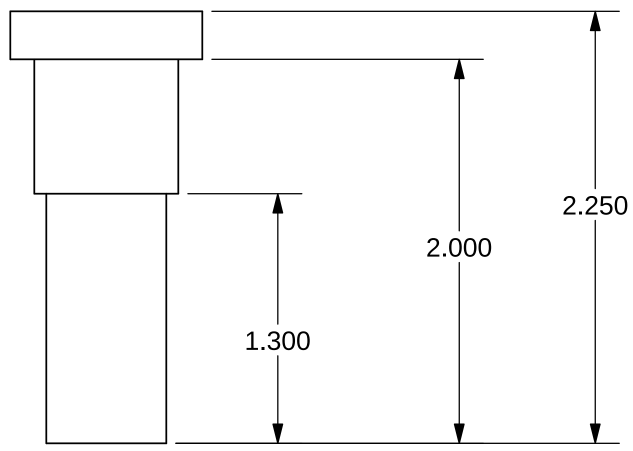


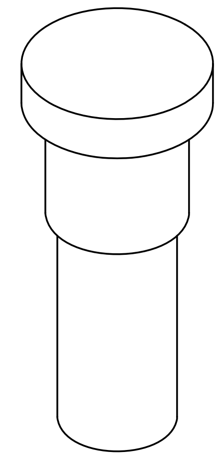
	DATE: 2/2/12	UNITS: INCHES	MATERIAL: 6061 ALUMINUM
	TOLERANCE: +/- 0.05	SCALE: 1:2	TITLE: SQUARE TUBE
		NEXT ASSY:	NAME: RODRIGO SANCHEZ
		DRAWING #: 1040	SIGNATURE:

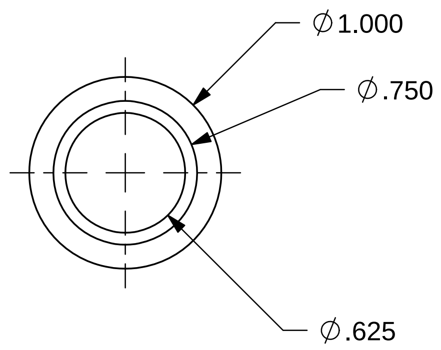
Part Number	A	B	Quanity
1060	26	38	1
1070	19	26	3
1080	19	38	2



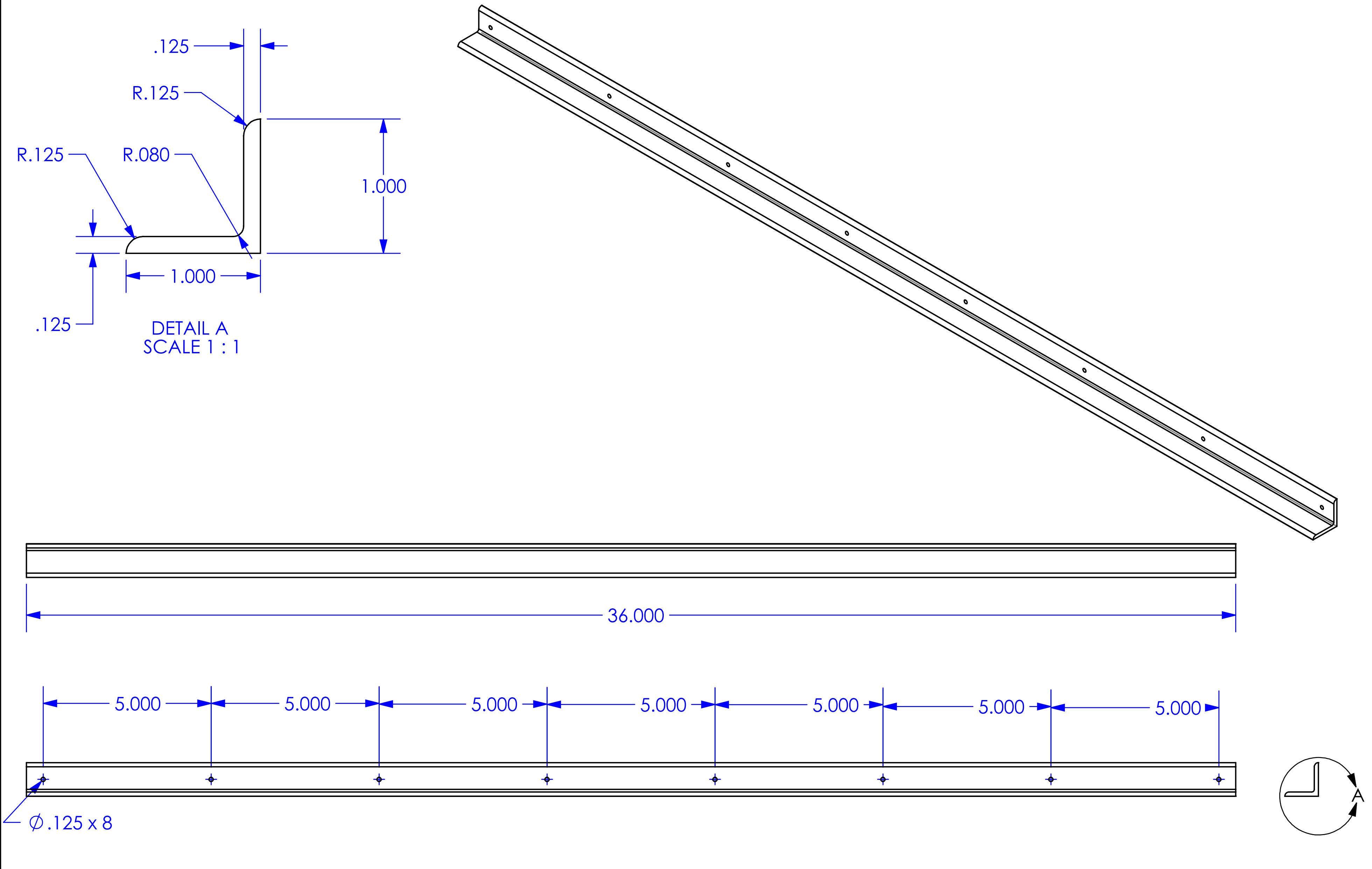
DATE: 2/2/12	UNITS: INCHES	MATERIAL: 6063 ALUMINUM
TOLERANCE: +/- 0.05	SCALE: 1: 8	TITLE: EXPANDED ALUMINUM SIDING
	NEXT ASSY: 1000	NAME: RODRIGO SANCHEZ
	DRAWING #: 1060	SIGNATURE:



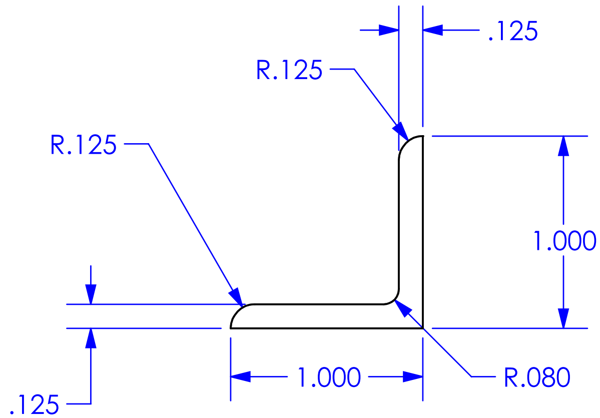




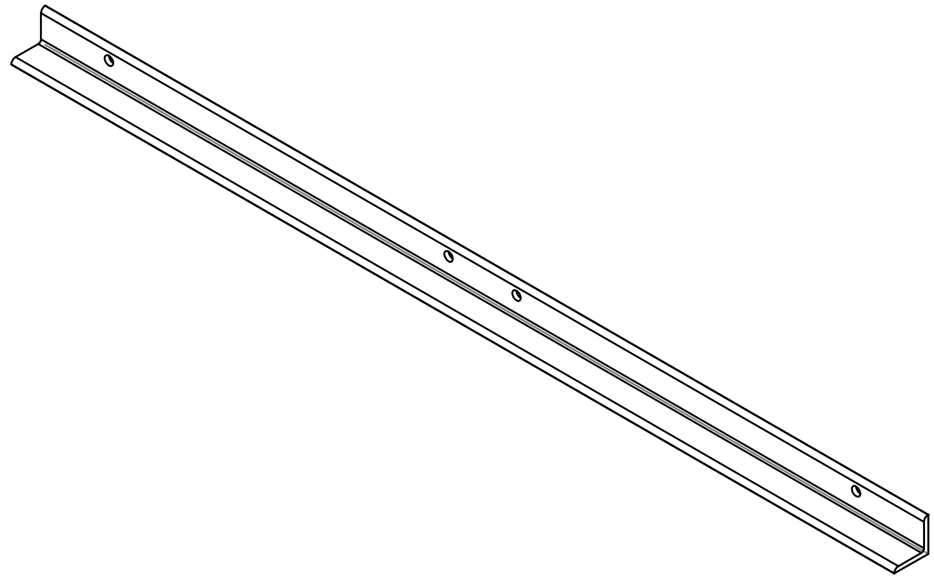
DATE: 2/2/12	UNITS: INCHES	MATERIAL: 6061 ALUMINUM
TOLERANCE: +/- 0.05	SCALE: 1:1	TITLE: STEERING SYSTEM STUB
	NEXT ASSY: 1000	NAME: RODRIGO SANCHEZ
	DRAWING #: 1100	SIGNATURE:

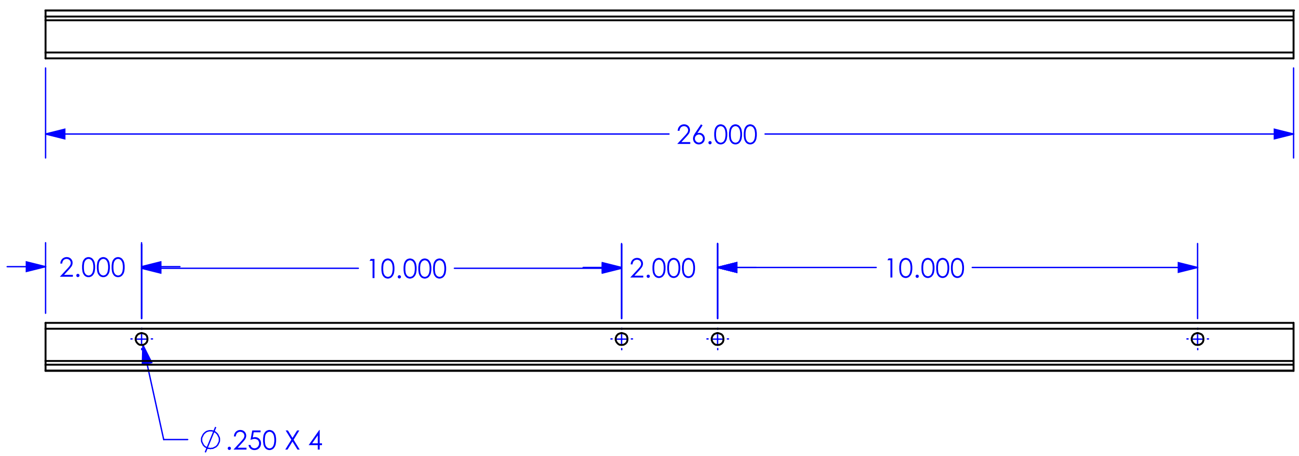


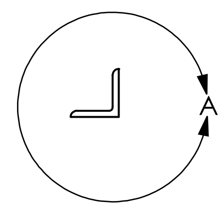
DATE: 5/28/2012	UNITS: INCHES	MATERIAL: 6061 ALUMINUM
TOLERANCE: +/- 0.05	SCALE: 1:4	TITLE: RIVETED SUPPORT TOP SIDES
	NEXT ASSY: 1000	NAME: RODRIGO SANCHEZ
	DRAWING #: 1110	SIGNATURE:



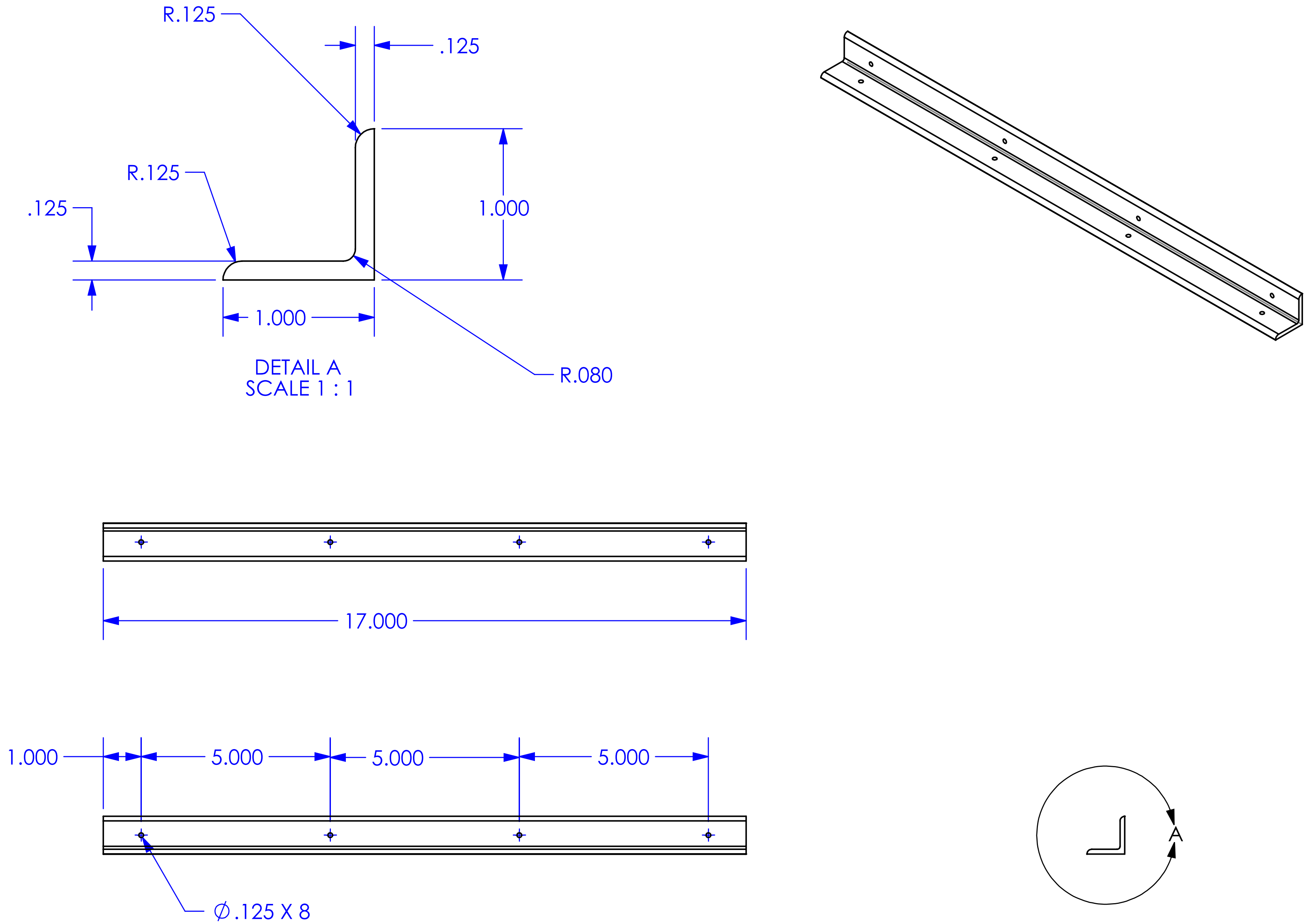
DETAIL A
SCALE 1 : 1



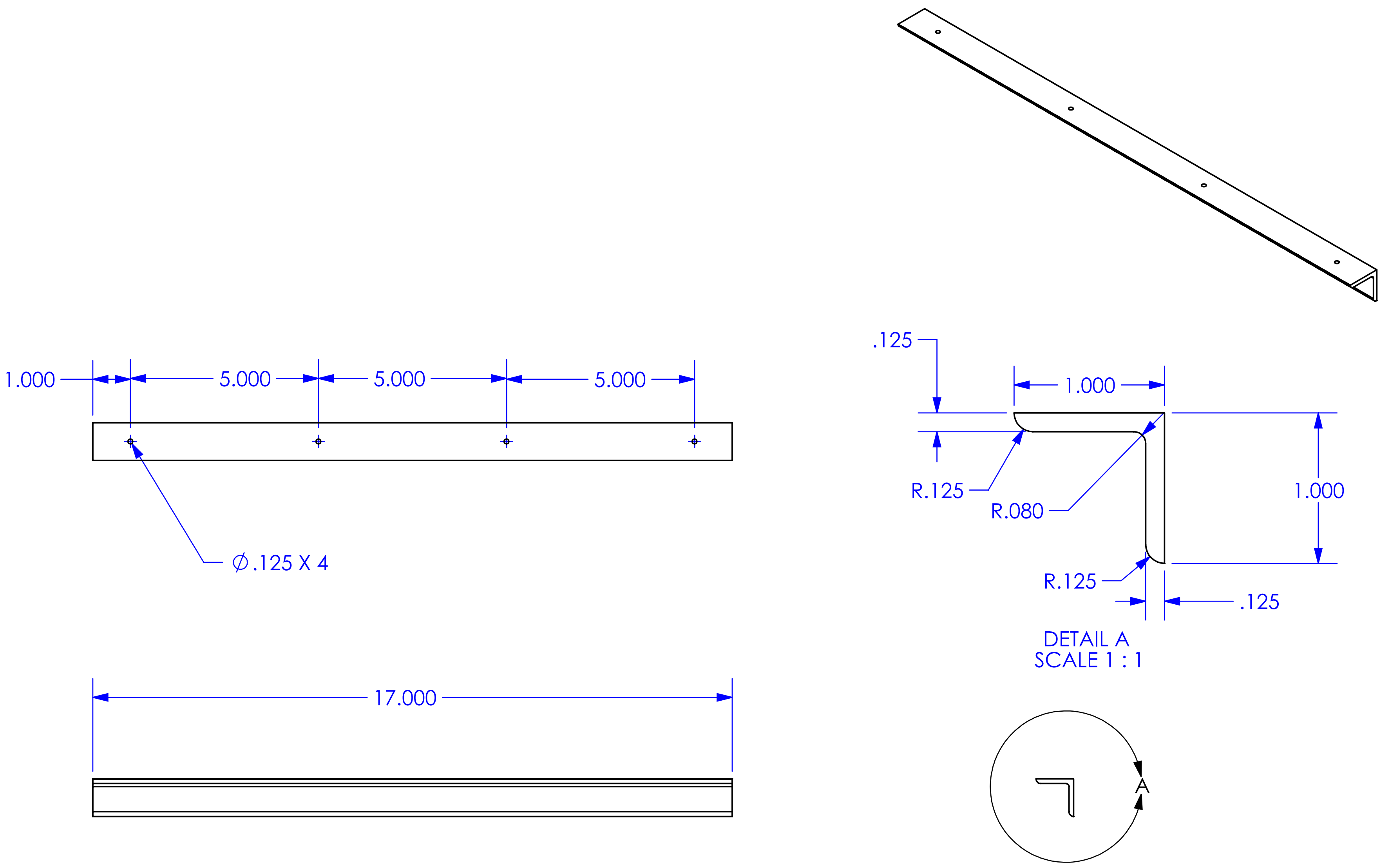




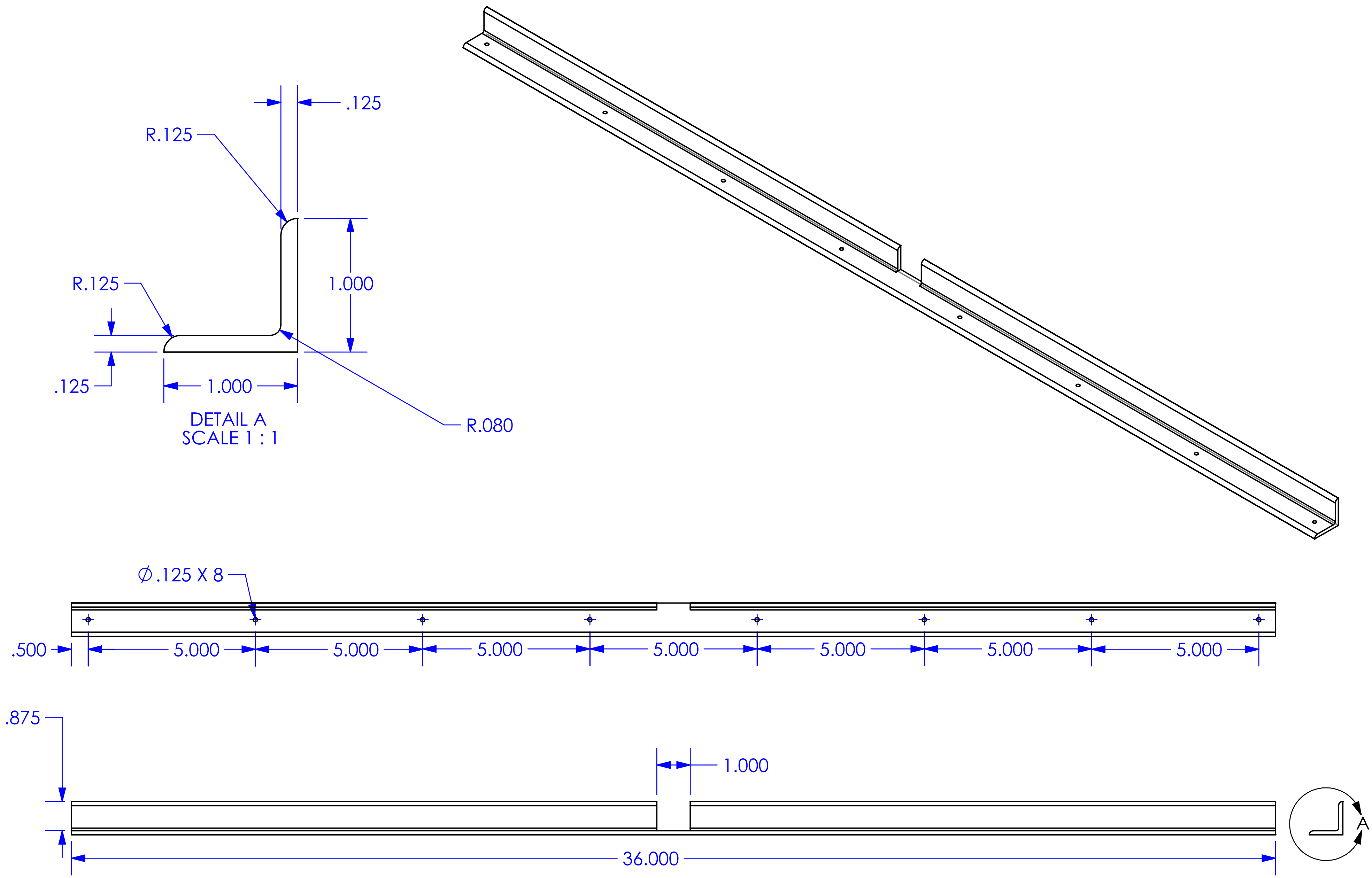
POLY CART	DATE: 2/2/12	UNITS: INCHES	MATERIAL: 6061 ALUMINUM
	TOLERANCE: +/- 0.05	SCALE: 1:4	TITLE: RIVETED SUPPORT FRONT & BACK TOP
		NEXT ASSY: 1000	NAME: RODRIGO SANCHEZ
		DRAWING #: 1120	SIGNATURE:



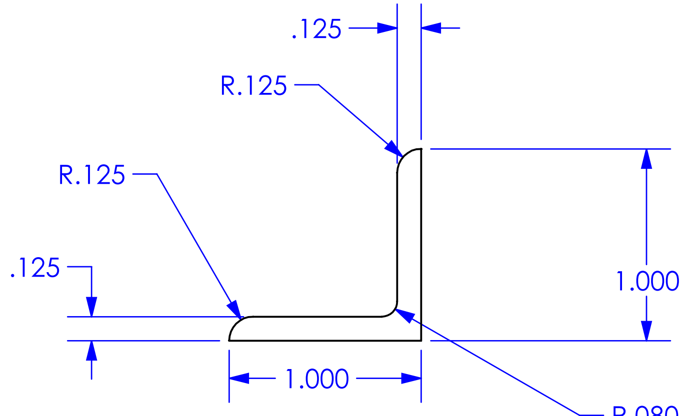
DATE: 5/28/2012	UNITS: INCHES	MATERIAL: 6061 ALUMINUM
TOLERANCE: +/- 0.05	SCALE: 1:4	TITLE: RIVETED SUPPORT VERTICAL
	NEXT ASSY: 1000	NAME: RODRIGO SANCHEZ
	DRAWING #: 1130	SIGNATURE:



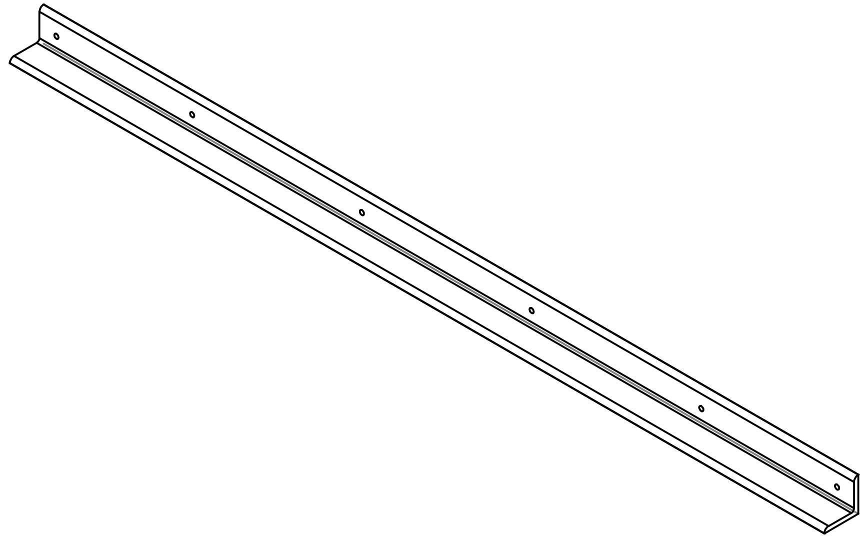
DATE: 5/28/2012	UNITS: INCHES	MATERIAL: 6061 ALUMINUM
TOLERANCE: +/- 0.05	SCALE: 1:4	TITLE: RIVETED SUPPORT VERTICAL MIDDLE
	NEXT ASSY: 1000	NAME: RODRIGO SANCHEZ
	DRAWING #: 1140	SIGNATURE:

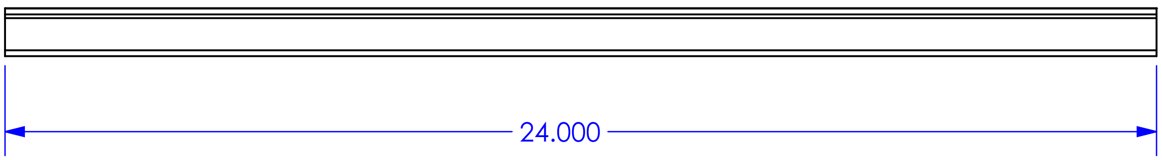


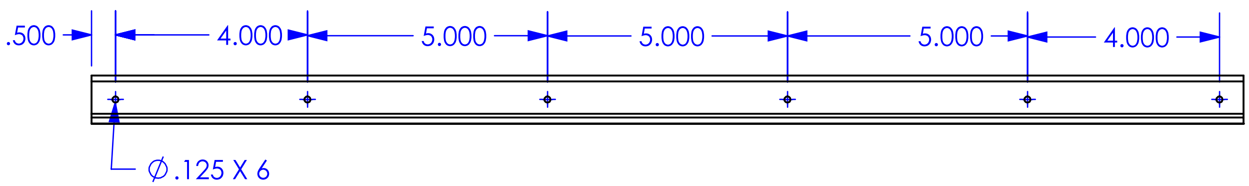
POLY CART	DATE: 5/28/2012	UNITS: INCHES	MATERIAL: 6061 ALUMINUM
	TOLERANCE: +/- 0.05	SCALE: 1:4	TITLE: RIVETED SUPPORT BOTTOM SIDES
		NEXT ASSY: 1000	NAME: RODRIGO SANCHEZ
		DRAWING #: 1150	SIGNATURE:

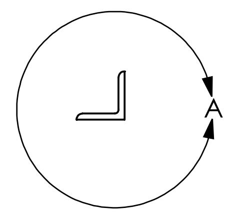


DETAIL A
SCALE 1 : 1

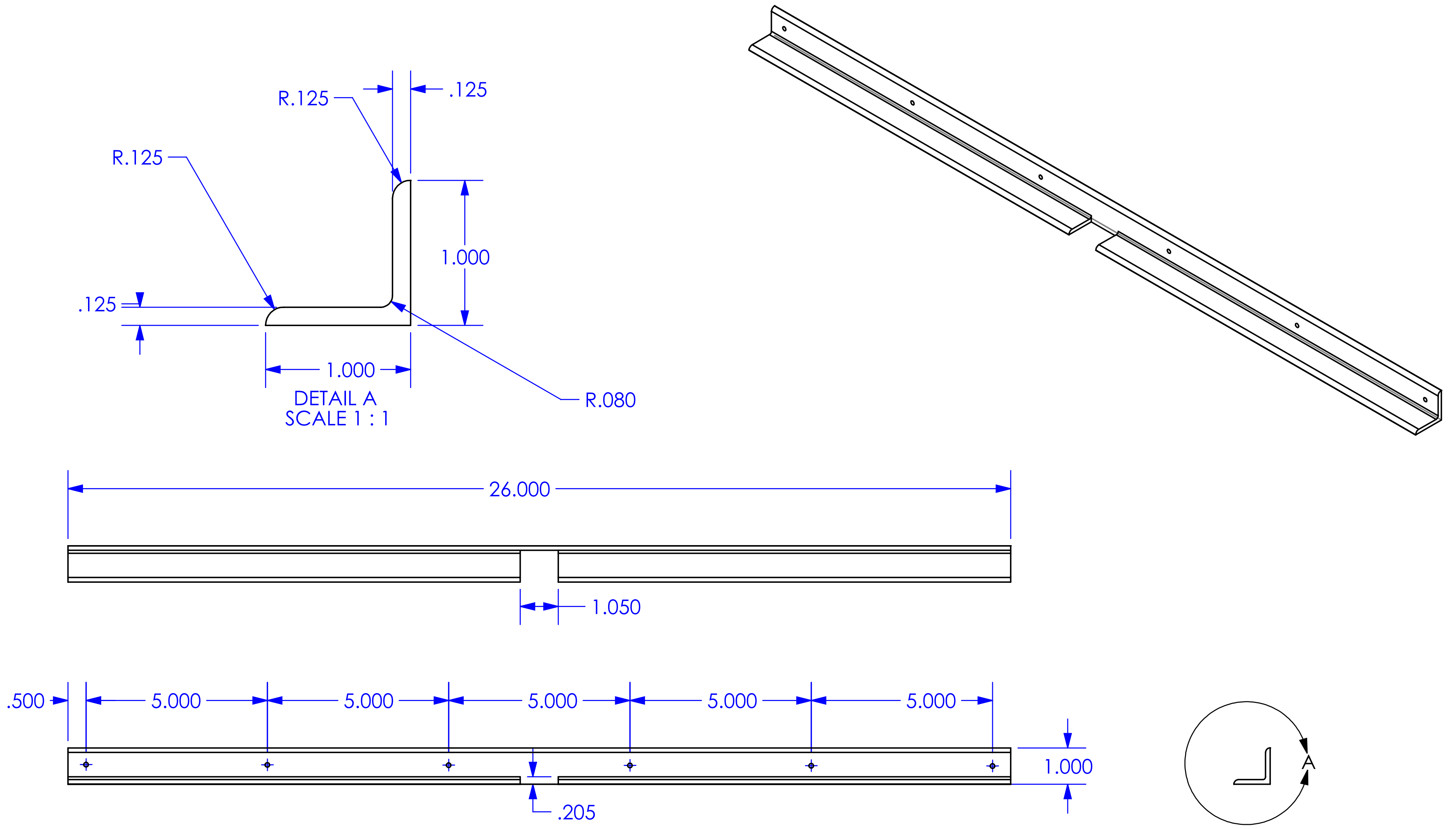




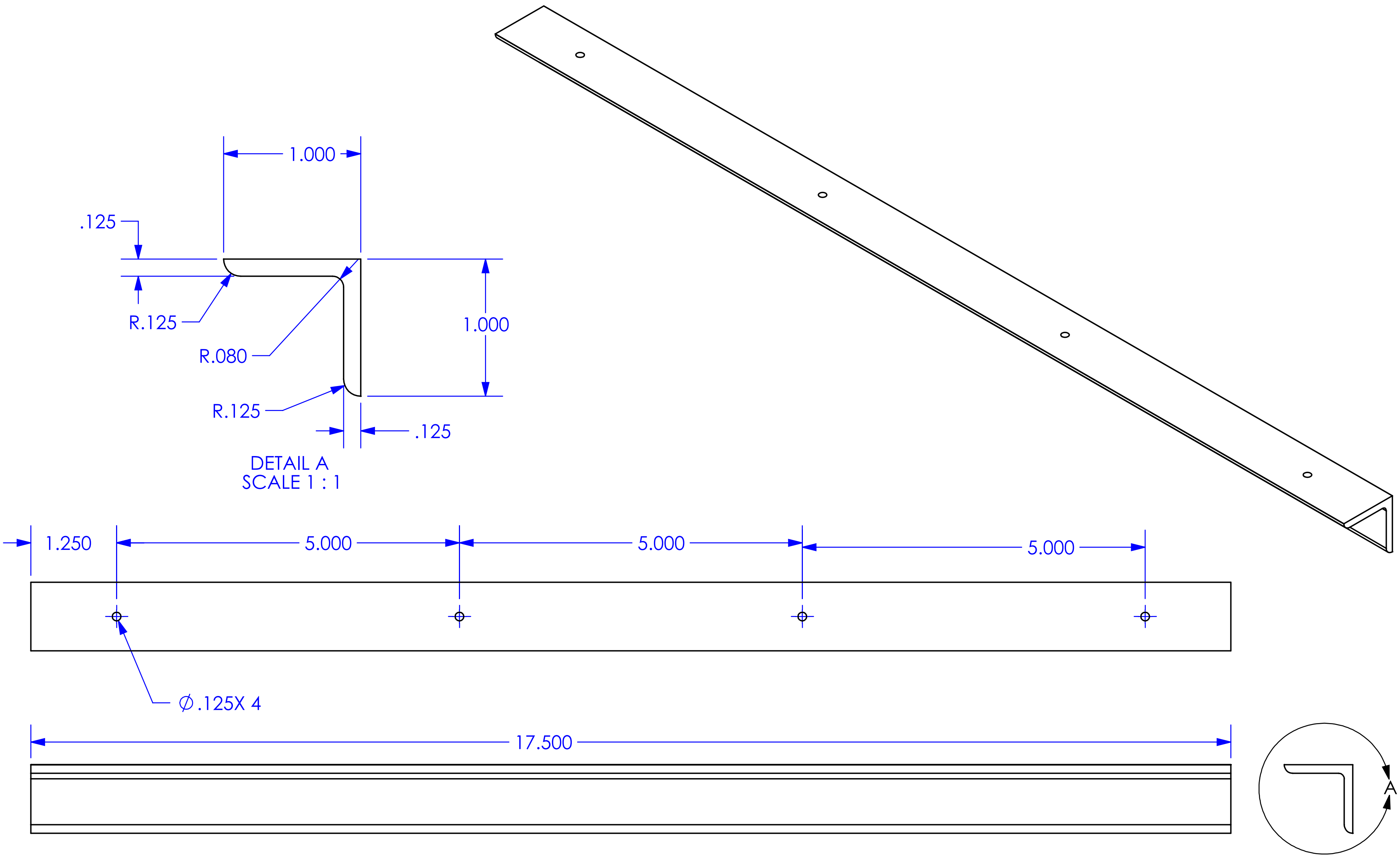




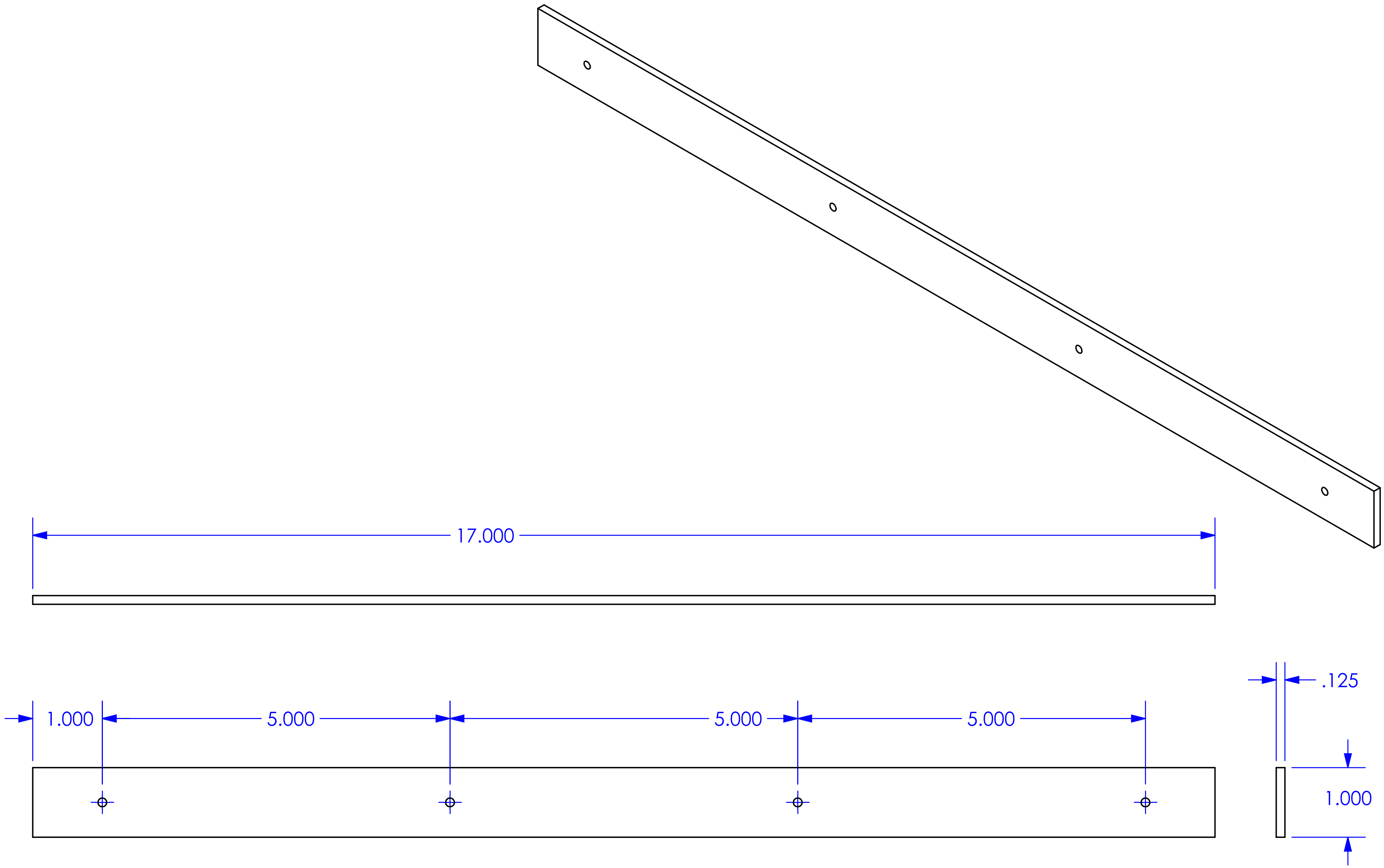
DATE: 5/28/2012	UNITS: INCHES	MATERIAL: 6061 ALUMINUM
TOLERANCE: +/- 0.05	SCALE: 1:4	TITLE: RIVETED SUPPORT BACK BOTTOM, FRONT &BACK TRAY
	NEXT ASSY: 1000	NAME: RODRIGO SANCHEZ
	DRAWING #: 1160	SIGNATURE:



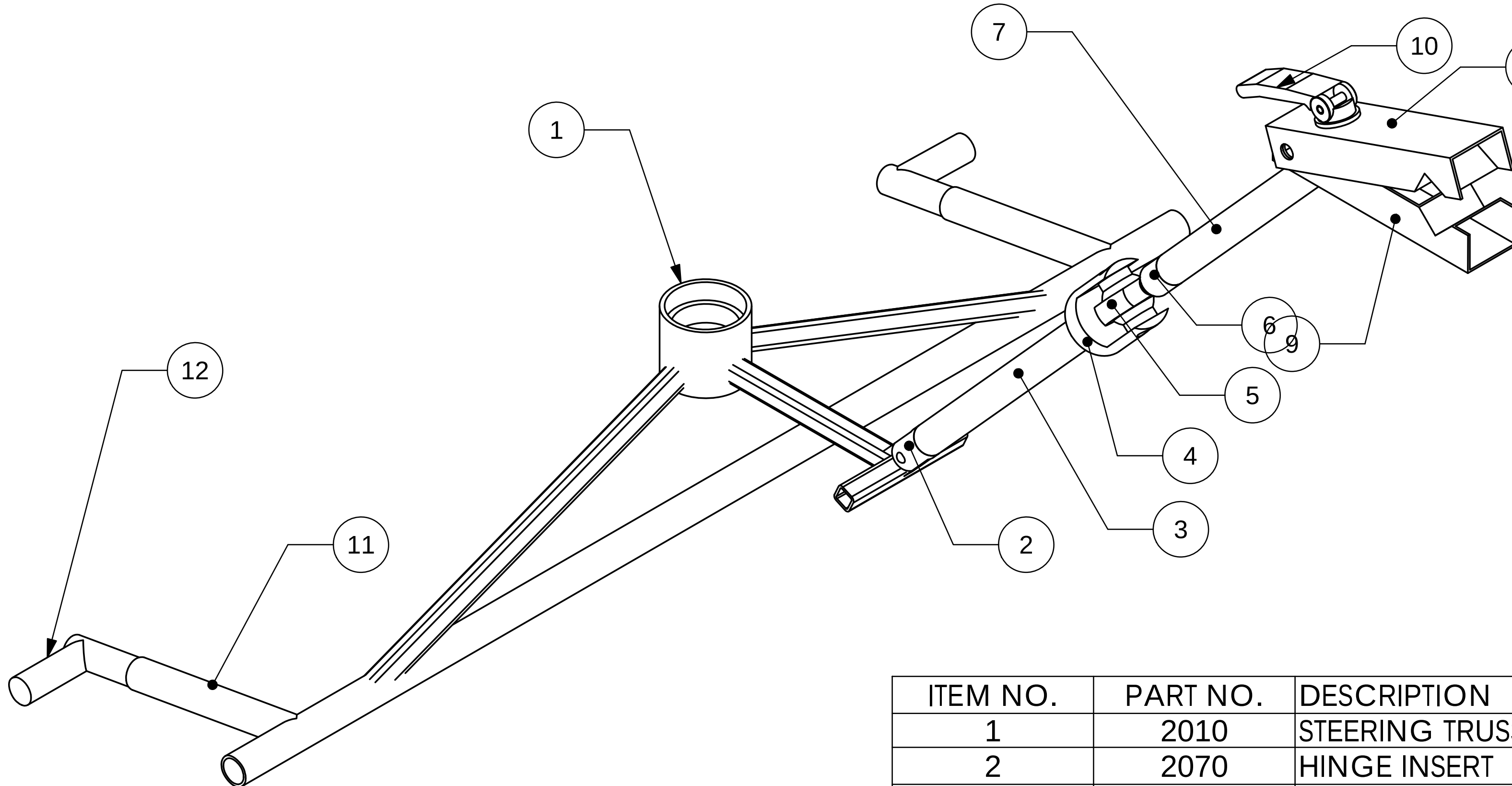
DATE: 5/28/2012	UNITS: INCHES	MATERIAL: 6061 ALUMINUM
TOLERANCE: +/- 0.05	SCALE: 1:4	TITLE: RIVETED SUPPORT FRONT BOTTOM
	NEXT ASSY: 1000	NAME: RODRIGO SANCHEZ
	DRAWING #: 1170	SIGNATURE:



POLY CART	DATE: 5/28/2012	UNITS: INCHES	MATERIAL: 6061 ALUMINUM
	TOLERANCE: +/- 0.05	SCALE: 1:2	TITLE: RIVETED SUPPORT SIDES TRAY
		NEXT ASSY: 1000	NAME: RODRIGO SANCHEZ
		DRAWING #: 1180	SIGNATURE:



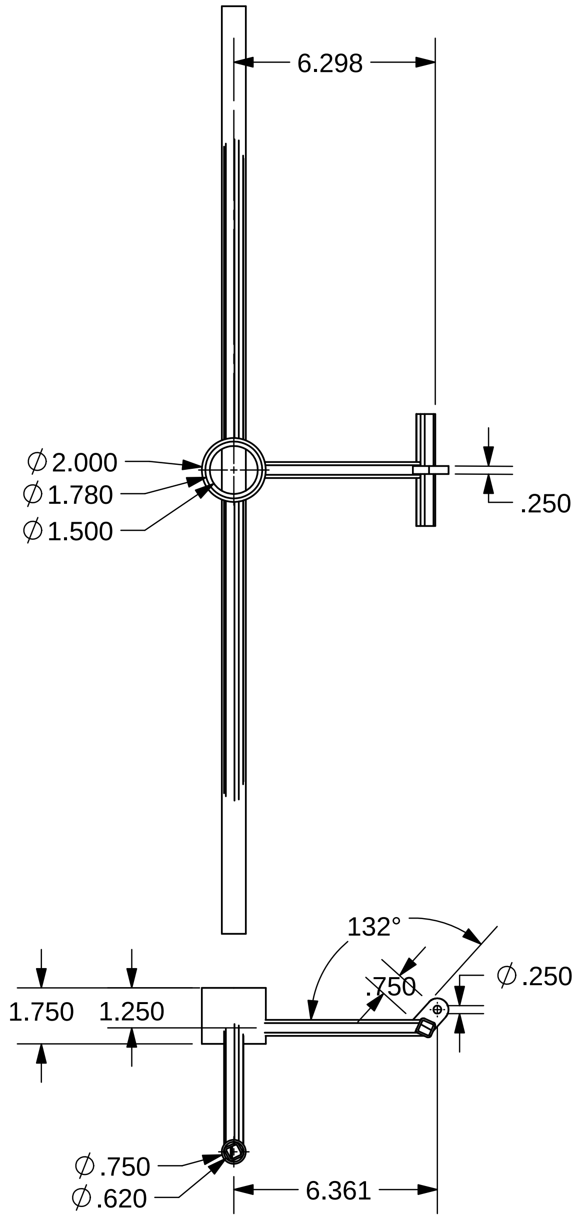
POLY CART	DATE: 5/28/2012	UNITS: INCHES	MATERIAL: 6061 ALUMINUM
	TOLERANCE: +/- 0.05	SCALE: 1:2	TITLE: RIVETED SUPPORT VERTICAL MIDDLE
		NEXT ASSY: 1000	NAME: RODRIGO SANCHEZ
		DRAWING #: 1190	SIGNATURE:

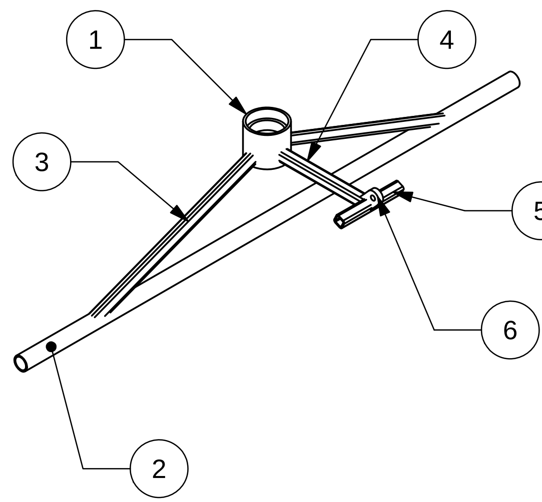


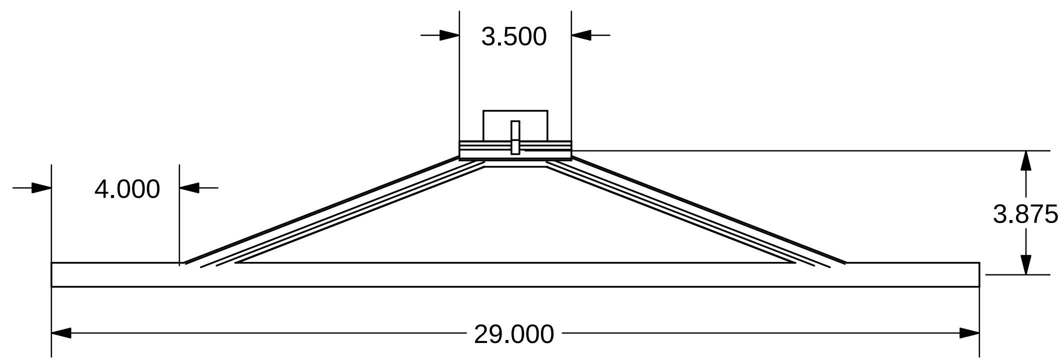
ITEM NO.	PART NO.	DESCRIPTION	QTY.
1	2010	STEERING TRUSS	1
2	2070	HINGE INSERT	1
3	2020	LOWER STEERING LINK	1
4	2060	ROD END COUPLER	1
5	2110	BALL JOINT	1
6	2050	ROD END THREADED INSERT	1
7	2030	UPPER STEERING LINK	1
8	2100	TOP CLAMP	1
9	2090	BOTTOM CLAMP	1
10	2120	CAM LEVER	1
11	2018	OUTTER BRAKE TUBE	1
12	2019	BRAKING LEVER	1

DATE: 2/2/12	UNITS:	MATERIAL:
TOLERANCE: +/-	SCALE: 1:4	TITLE: STEERING ASSEMBLY
	NEXT ASSY: 0000	NAME: VINCENT CONTRERAS
	DRAWING #: 2000	SIGNATURE:

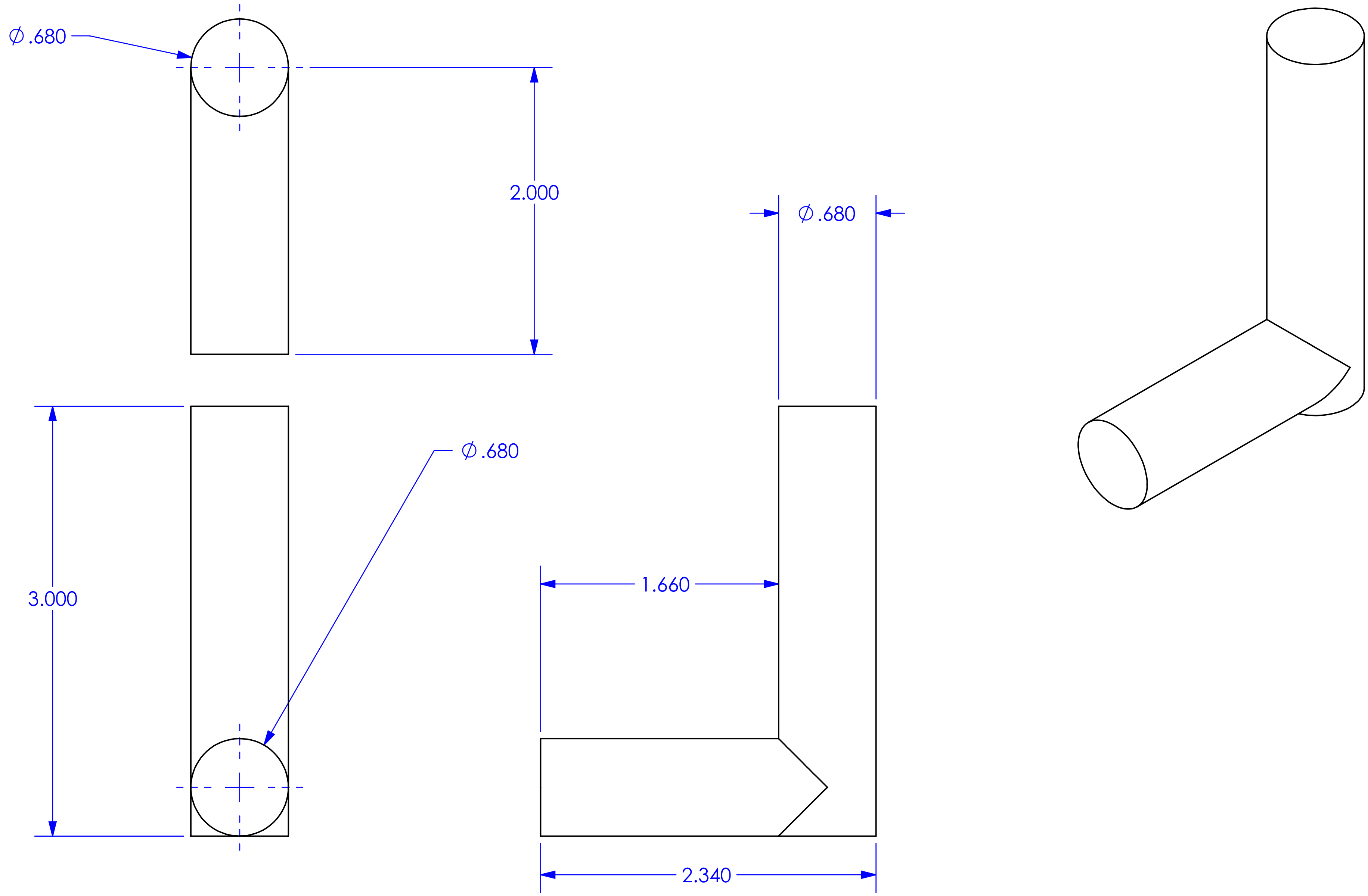
ITEM NO.	PART NO.	DESCRIPTION	QTY.
1	2012	BEARING HOUSING	1
2	2013	FRONT WHEEL AXLE	1
3	2014	AXLE TO BEARING HOUSING BAR	2
4	2016	SQUARE BAR(FROM BEARING HOUSING TO SQUARE BAR	1
5	2017	SQUARE BAR(CONNECTING HORIZONTAL AND ANGLE SQUARE BARS)	1
6	2018	LINKAGE HITCH	1



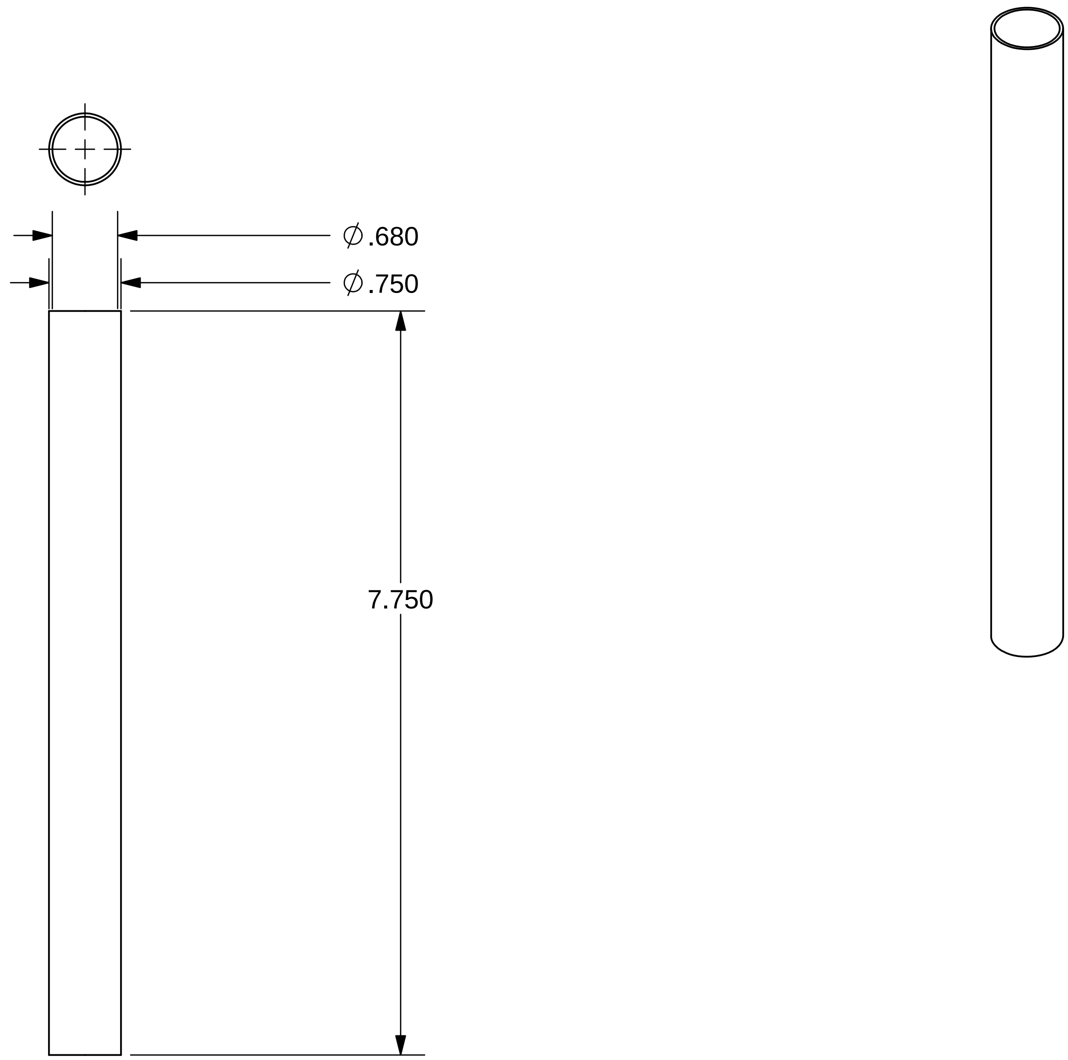




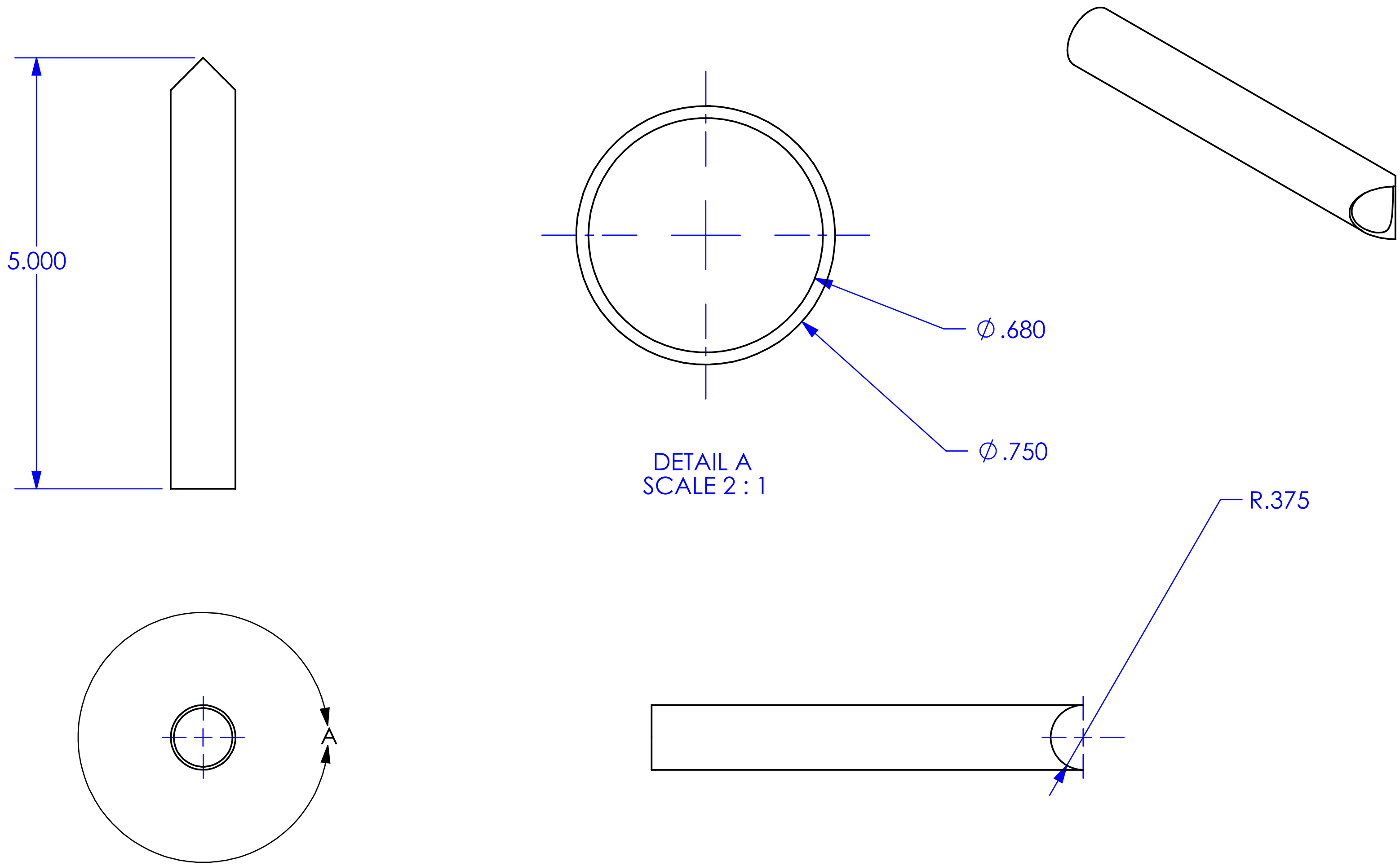
POLY CART	DATE: 1/30/2012	UNITS: INCHES	MATERIAL:1018 STEEL
	TOLERANCE: +/- .25	SCALE: 1:6	TITLE:: STEERING TRUSS
		NEXT ASSY: 2000	NAME: VINCENT CONTRERAS
		DRAWING #: 2010	SIGNATURE:



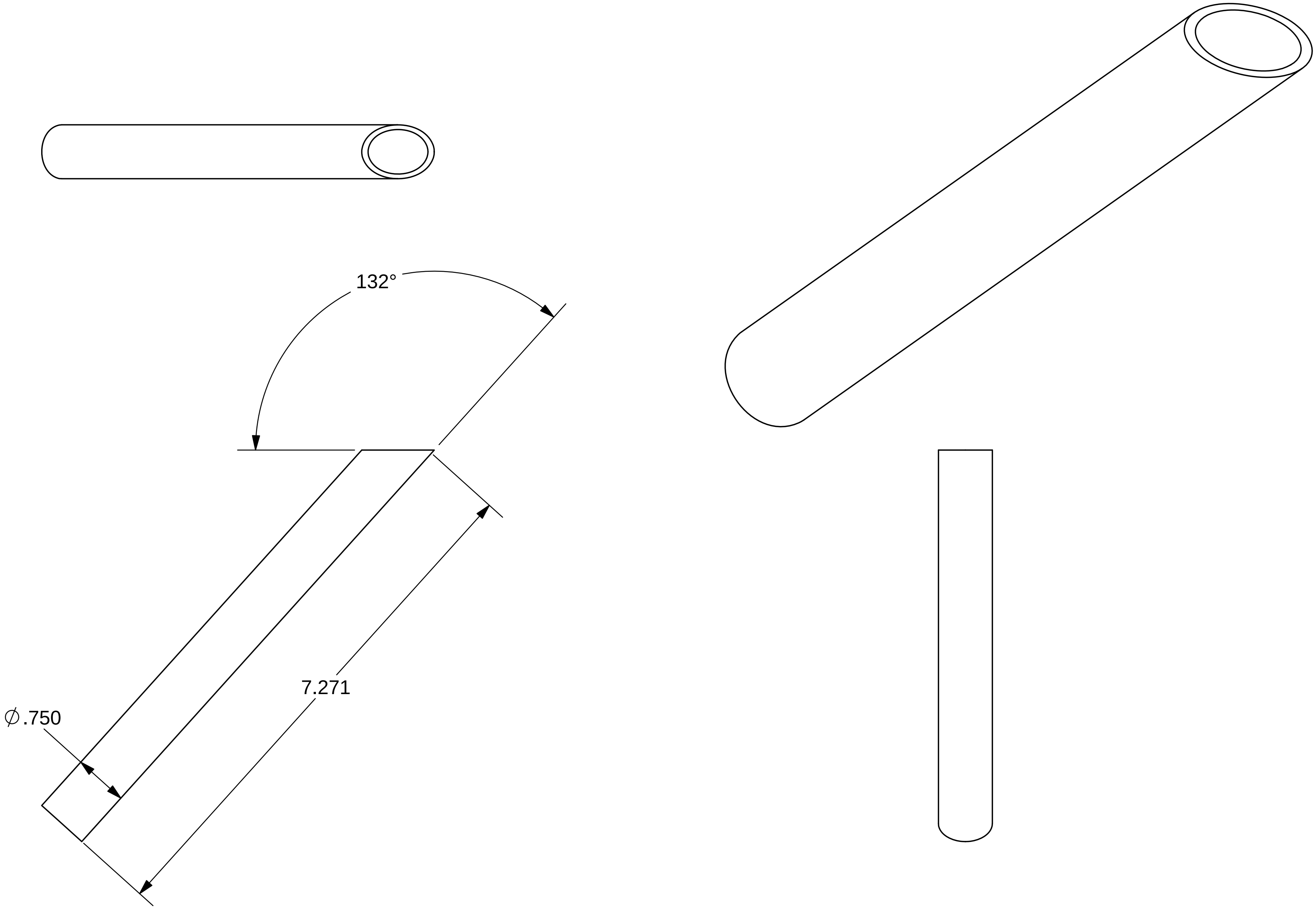
POLY CART	DATE: 2/2/12	UNITS: INCHES	MATERIAL: STEEL
	TOLERANCE: +/- 0.05	SCALE: 1:1	TITLE: BRAKING LEVER
		NEXT ASSY: 2000	NAME: RODRIGO SANCHEZ
		DRAWING #: 2019	SIGNATURE:



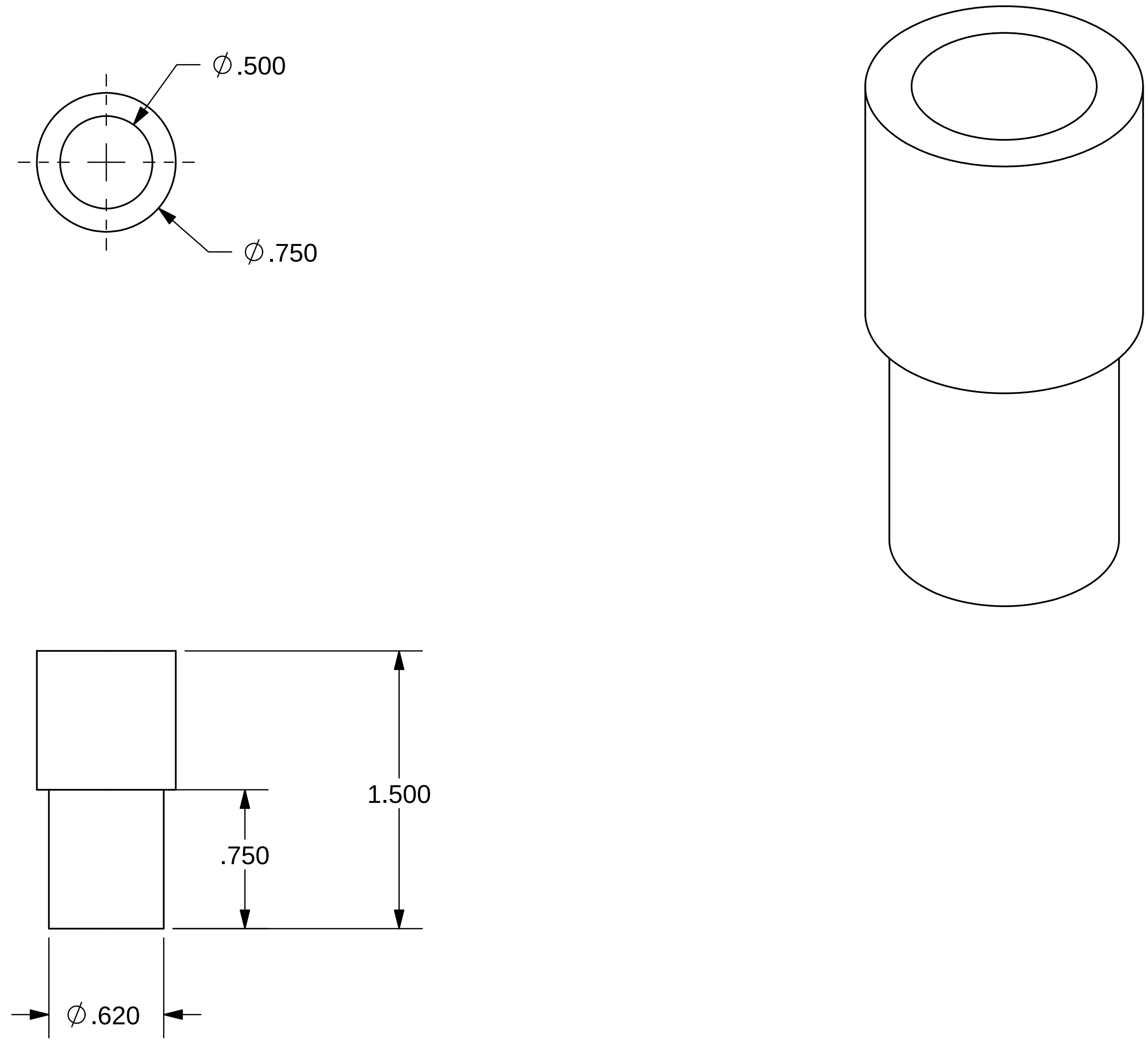
DATE: 1/30/2012	UNITS: Inches	MATERIAL: 1018 STEEL
TOLERANCE: +/- .125	SCALE: 1:2	TITLE: LOWER STEERING LINK
	NEXT ASSY: 2000	NAME: VINCENT CONTRERAS
	DRAWING #: 2020	SIGNATURE:



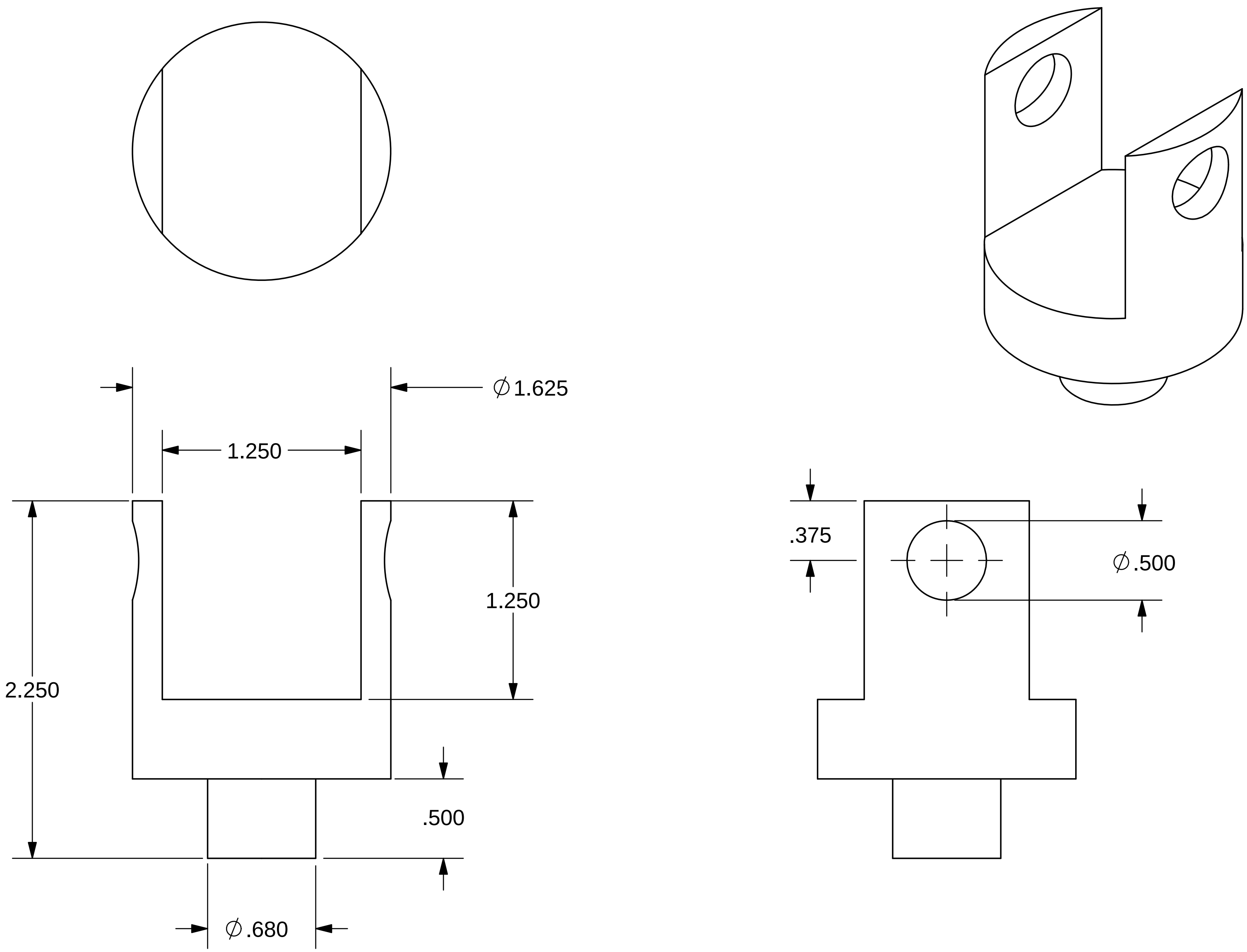
POLY CART	DATE: 2/2/12	UNITS: INCHES	MATERIAL: STEEL
	TOLERANCE: +/- 0.05	SCALE: 1:2	TITLE: OUTTER BRAKE TUBE
		NEXT ASSY: 2000	NAME: RODRIGO SANCHEZ
		DRAWING #: 2021	SIGNATURE:



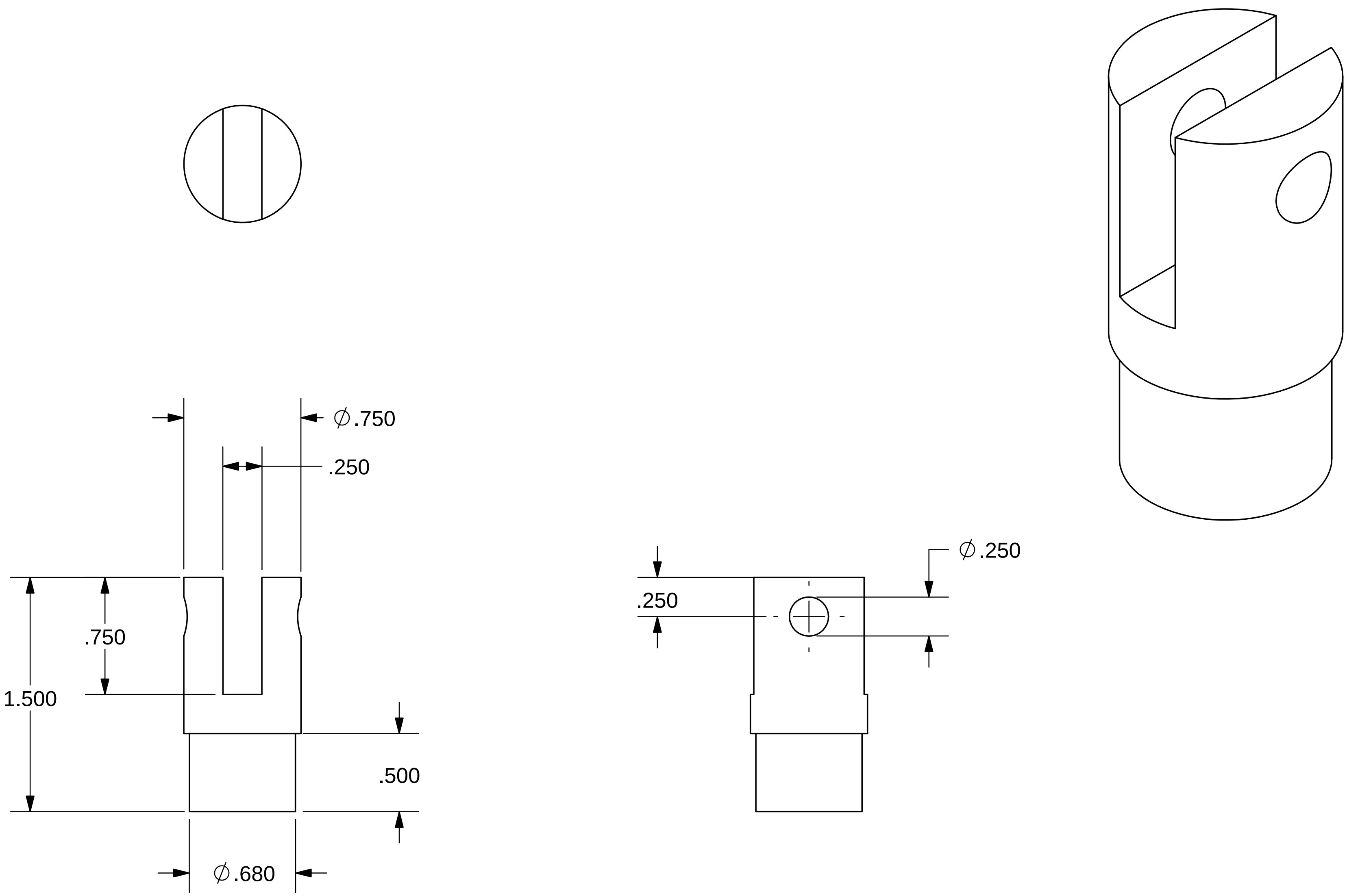
POLY CART	DATE: 1/30/2012	UNITS: INCHES	MATERIAL: 1018 STEEL
	TOLERANCE: +/- .125	SCALE: 1:2	TITLE: UPPER STEERING LINK
		NEXT ASSY: 2000	NAME: VINCENT CONTRERAS
		DRAWING #: 2030	SIGNATURE:



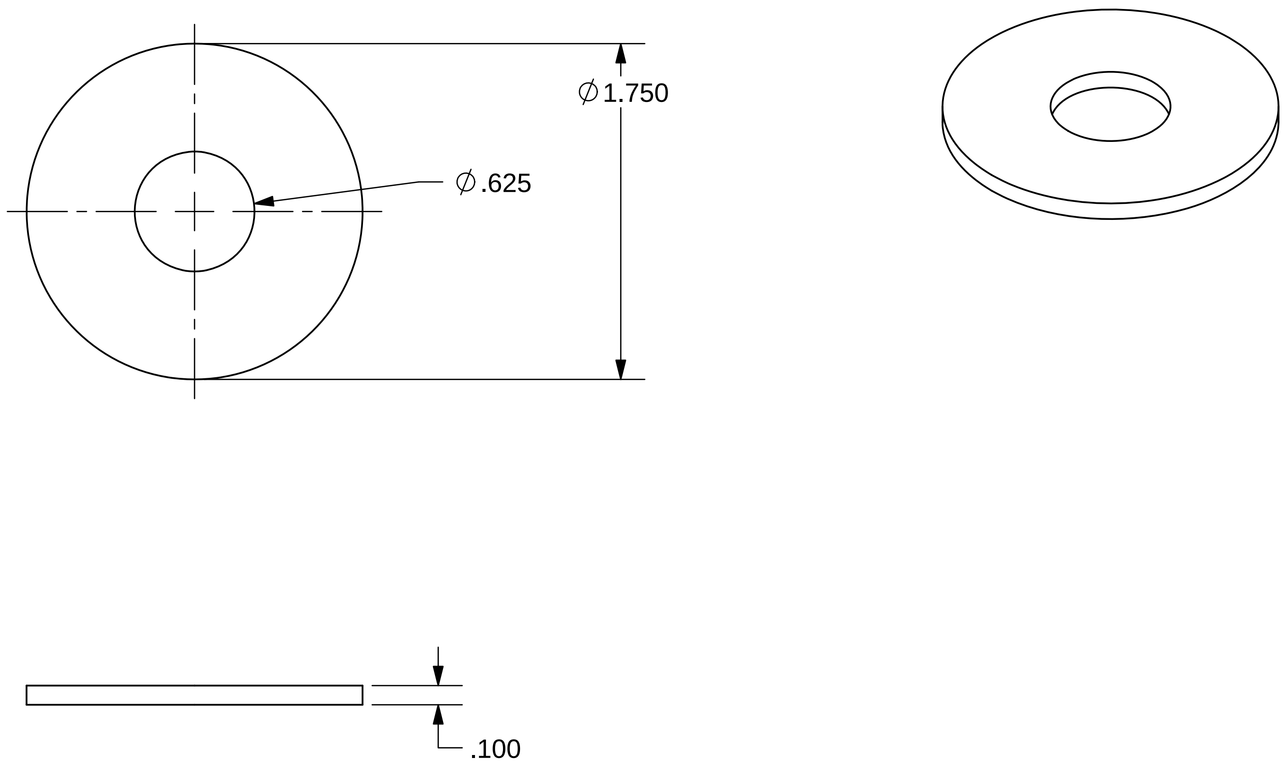
DATE: 1/31/2012	UNITS: INCHES	MATERIAL: 1018 STEEL
TOLERANCE: +/- .005	SCALE: 1:1	TITLE: ROD END THREADED INSERT
	NEXT ASSY: 2000	NAME: VINCENT CONTRERAS
	DRAWING #: 2050	SIGNATURE:



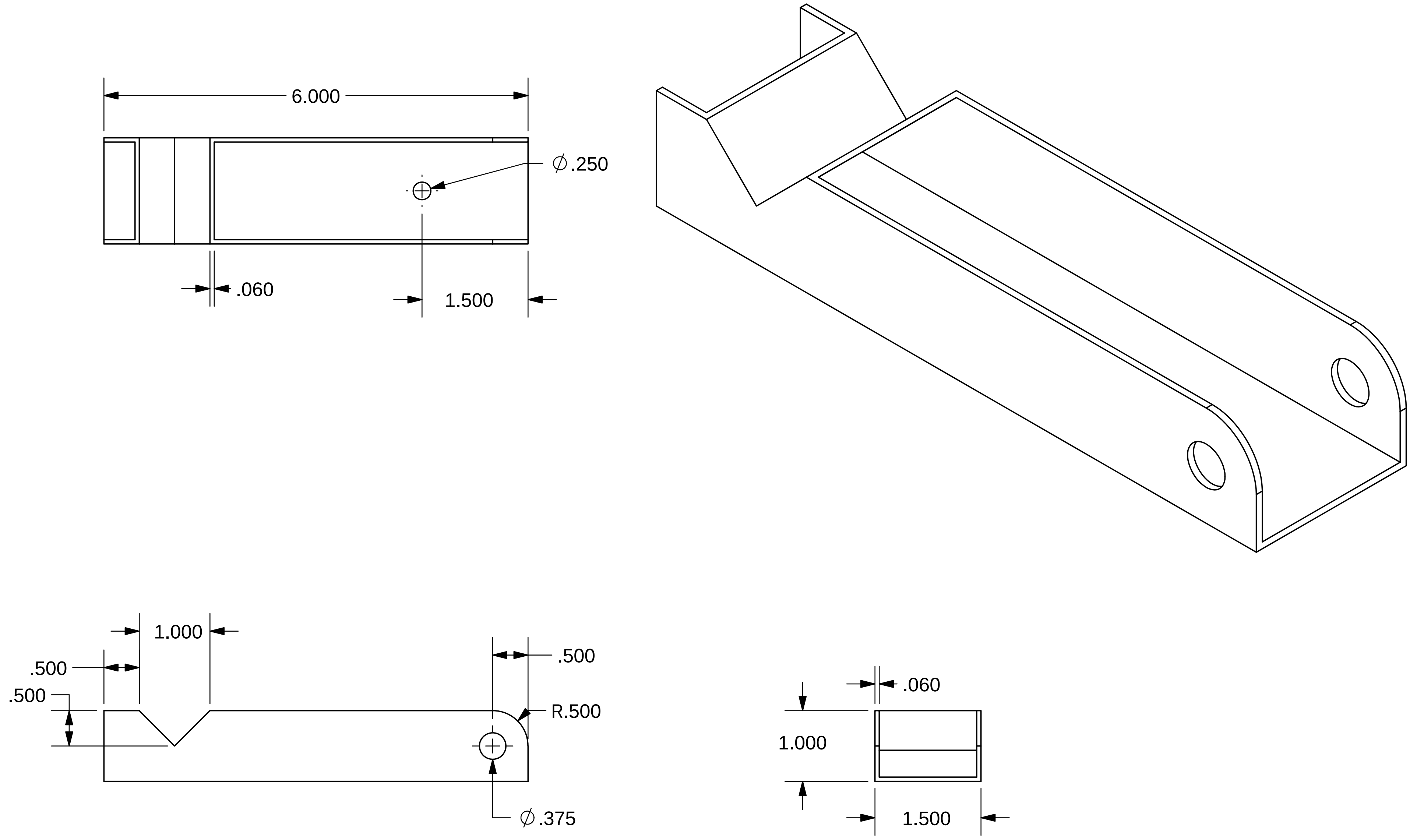
POLY CART	DATE: 1/31/12	UNITS: INCHES	MATERIAL: 1018 STEEL
	TOLERANCE: +/- .005	SCALE: 1:1	TITLE: ROD END COUPLER
		NEXT ASSY: 2000	NAME: VINCENT CONTRERAS
		DRAWING #: 2060	SIGNATURE:



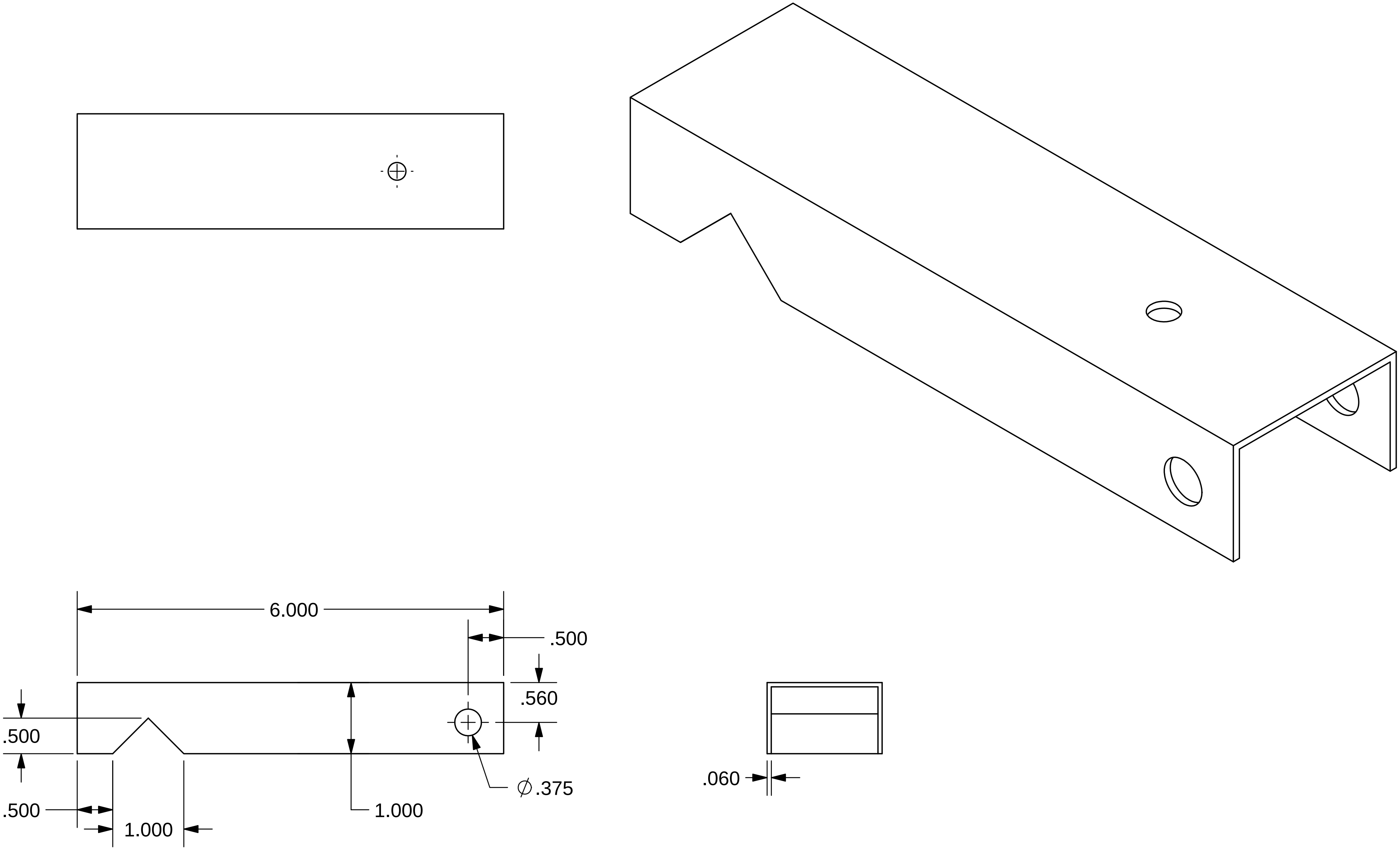
	DATE: 1/31/12	UNITS: INCHES	MATERIAL: 1018 STEEL
	TOLERANCE: +/- .005	SCALE: 1:1	TITLE: HINGE INSERT
		NEXT ASSY: 2000	NAME: VINCENT CONTRERAS
		DRAWING #: 2070	SIGNATURE:



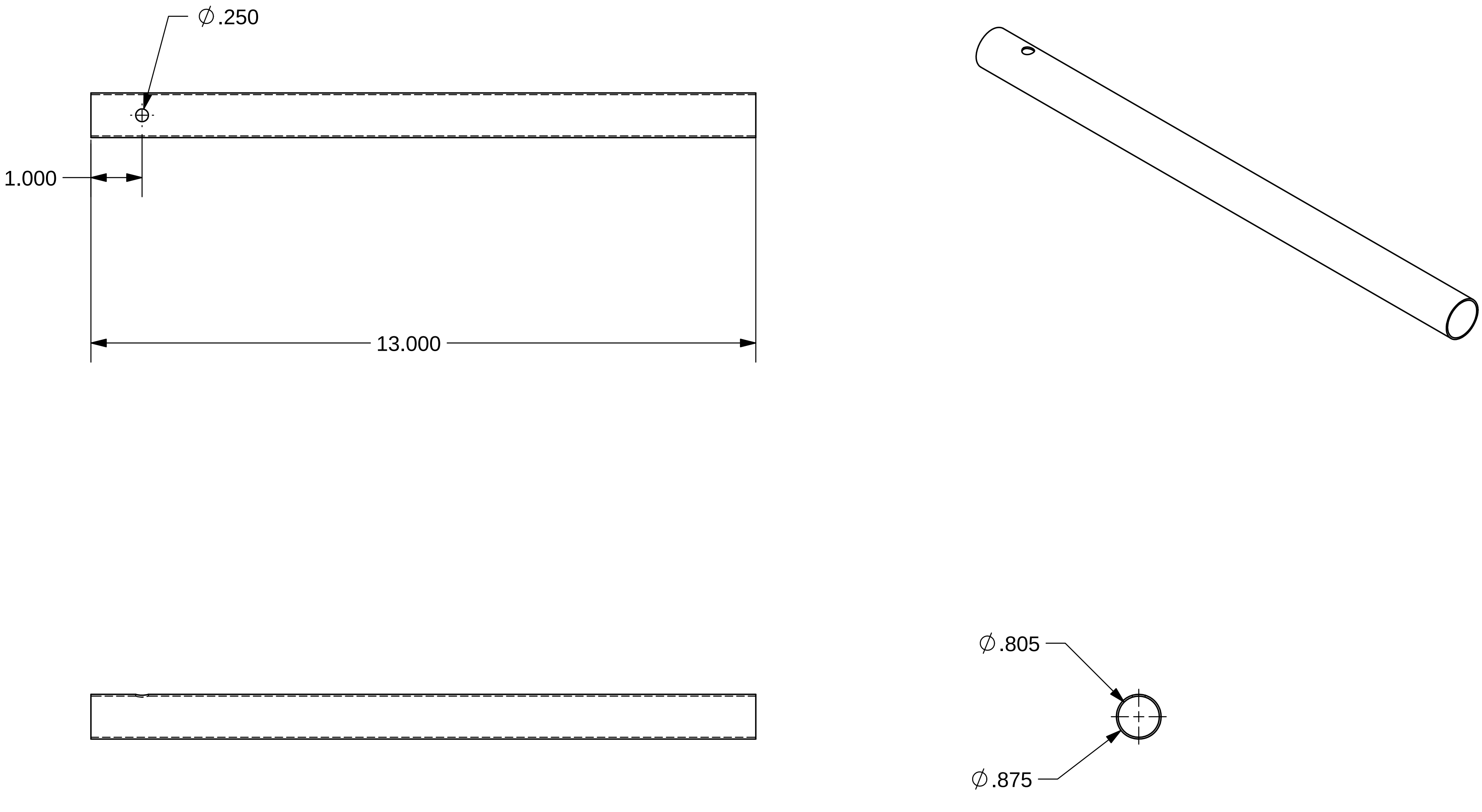
DATE: 1/31/12	UNITS: INCHES	MATERIAL: 1018 STEEL
TOLERANCE: +/- .005	SCALE: 1:1	TITLE: BEARING RETAINER
	NEXT ASSY: 1000	NAME: VINCENT CONTRERAS
	DRAWING #: 2080	SIGNATURE:



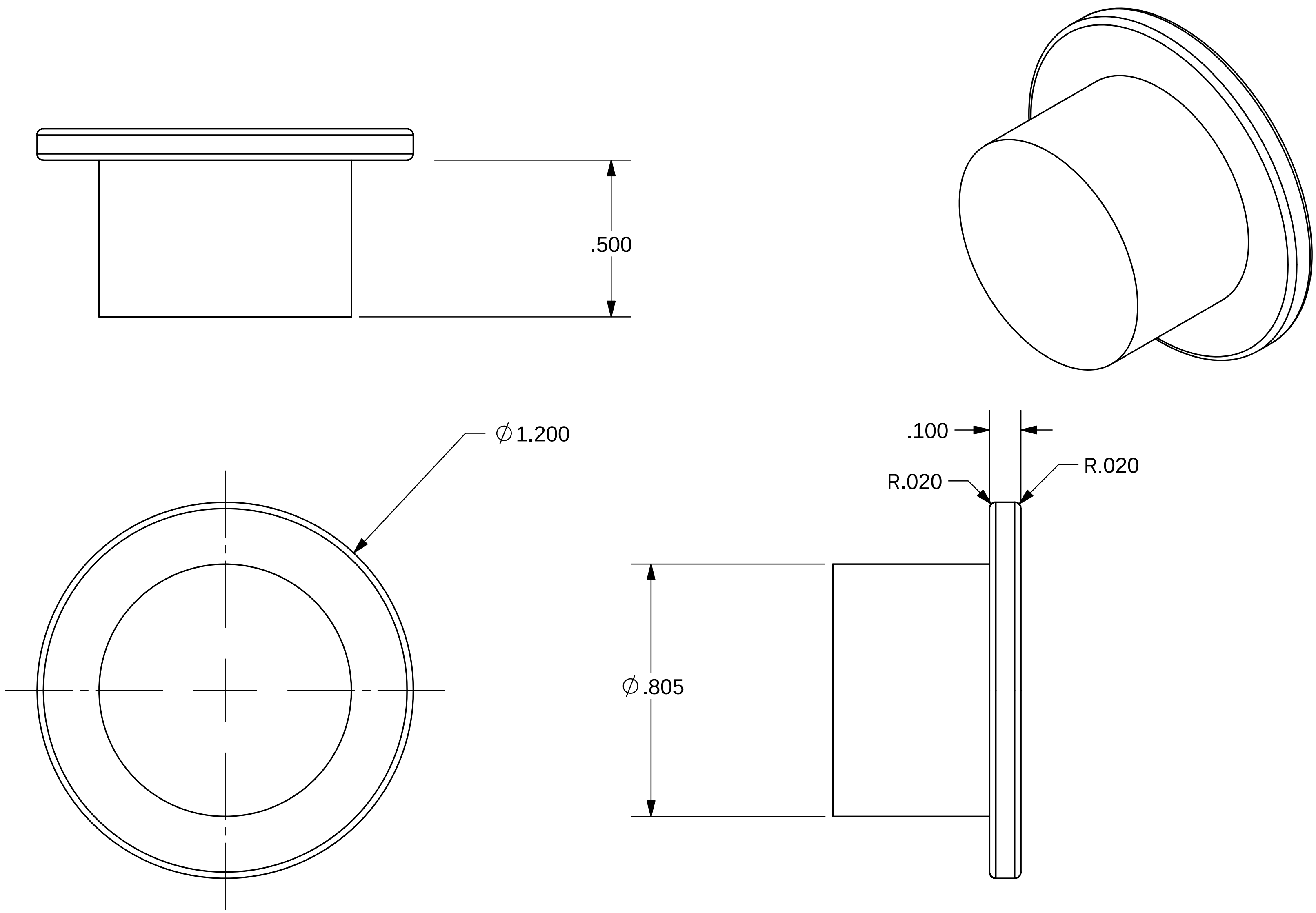
DATE: 2/2/12	UNITS: INCHES	MATERIAL: 1018 STEEL
TOLERANCE: +/- 0.05	SCALE: 1:2	TITLE: BOTTOM CLAMP
	NEXT ASSY: 2000	NAME: VINCENT CONTRERAS
	DRAWING #: 2090	SIGNATURE:



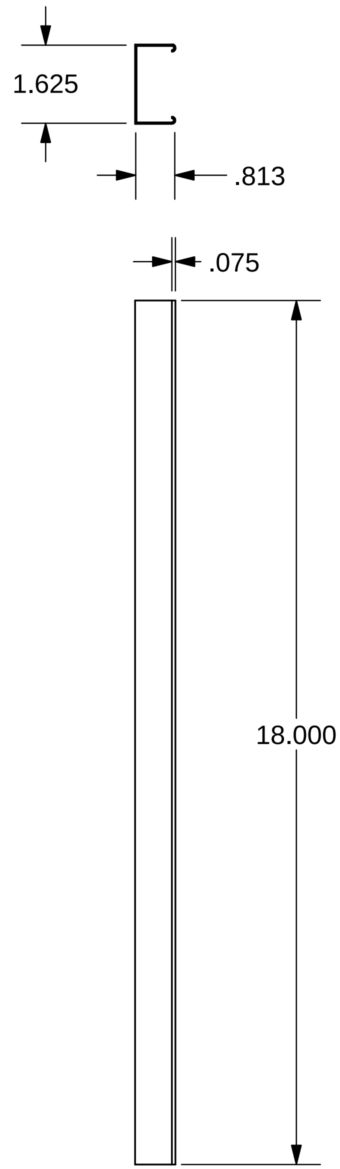
DATE: 2/2/12	UNITS: INCHES	MATERIAL: 1018 STEEL
TOLERANCE: +/- 0.05	SCALE: 1:2	TITLE: TOP CLAMP
	NEXT ASSY: 2000	NAME: VINCENT CONTRERAS
	DRAWING #: 2100	SIGNATURE:

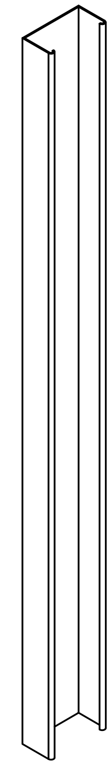


	DATE: 2/2/12	UNITS: INCHES	MATERIAL: 6061-T6 ALUMINUM
	TOLERANCE: +/- .050	SCALE: 1:3	TITLE: WHEEL HOOKS
		NEXT ASSY: 0000	NAME: VINCENT CONTRERAS
		DRAWING #: 3020	SIGNATURE:



	DATE: 3/7/12	UNITS: INCHES	MATERIAL: ALUMINUM
	TOLERANCE: +/- 0.05	SCALE: 1:1	TITLE: WHEELCHAIR WHEELS HOLDER
		NEXT ASSY: 1000	NAME: RODRIGO SANCHEZ
		DRAWING #: 3030	SIGNATURE:





DATE: 2/2/12	UNITS: INCHES	MATERIAL: 6061-T6 ALUMINUM
TOLERANCE: +/- .05	SCALE: 1:4	TITLE: STRUT CHANNEL
	NEXT ASSY: 0000	NAME: VINCENT CONTRERAS
	DRAWING #: 3050	SIGNATURE: