Team Zeus:

Andrew Higgins
Stefan Owechko
Gabe Terrasas
Kevin Crisfield

cpthrowingframe@gmail.com

Throwing Frame

For Athletes with Disabilities

Senior Project Final Design Report
California Polytechnic State University, San Luis Obispo
May 31st, 2012

Sponsors:
Fiona Allen, Bridge II Sports Program Coordinator
Dr. Kevin Taylor, Cal Poly Kinesiology Department

Team Advisor:
Sarah Harding, Cal Poly Mechanical Engineering Department

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Team Zeus (Disabled Sports Throwing Frame)
California Polytechnic State University, San Luis Obispo
CPThrowingFrame@gmail.com

Abstract

Team Zeus' senior project was to design, build and test a working throwing frame system for Bridge II Sports, a nonprofit organization in North Carolina. The throwing frame is used to allow physically challenged athletes and individuals with disabilities to throw shot-put, discus, and javelin using a frame to sit against. Team Zeus was specifically tasked to build a frame that is lighter weight and more transportable than products that are currently on the market. This frame also is adjustable to accommodate a wide range of athlete weights, sizes, and abilities. The final result is a 35lb aluminum frame with two different seat configurations and several height and attachment adjustment options.

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Chapter 1: Introduction

Track and field athletes with disabilities that use wheelchairs often compete in throwing events such as javelin, shot-put, and discus through the use of support equipment. The primary device used is a throwing frame, which allows more stability and freedom for the thrower than a wheelchair. Our stakeholder, Bridge II Sports, is a nonprofit organization in North Carolina that empowers people with disabilities to be able to participate in these sports through use of this equipment. Bridge II Sports has identified key areas of improvement with their existing throwing frames, and our team has been tasked with designing a new frame for their organization as a senior project.

Figure 1. *Typical Throwing Frame*. Photograph. *Bridge II Sports*. Web. 19 Oct. 2011. <http://www.bridge2sports.org>

Our team, named Team Zeus, consists of Gabe Terrasas, Andrew Higgins, Stefan Owechko, and Kevin Crisfield. Gabe, Andrew and Stefan are Mechanical Engineering students and Kevin is a Kinesiology student. All are students at California Polytechnic State University, San Luis Obispo. Our advisor is Prof. Sarah Harding of the Mechanical Engineering Department, and our sponsor is Dr. Kevin Taylor of the Kinesiology Department. Our funding will come from a National Science Foundation grant through

the assistance of Dr. Widmann of the Mechanical Engineering Department. Our primary contact at Bridge II Sports is Fiona Allen, who is the Program Coordinator.

Bridge II Sports is in need of improved throwing frames to make the experience safer for users, enable more users to participate in the sport, and eliminate costly repairs of equipment. In addition to Bridge II Sports, many athletes would be able to use the equipment to participate in Paralympic Games.

Objectives

Team Zeus' overall goal is to design and build a working throwing frame system for Bridge II Sports. The throwing frame will be used for individuals with disabilities to throw shot-put, discus, and javelin using a frame that is lighter weight and more transportable than currently implemented frames. This frame also will be adjustable to accommodate a wide range of athlete weights, sizes, and abilities.

From our initial phone interview with Ms. Allen, from Bridge II Sports, and the subsequent communication via e-mail, we have created the following list of requirements and specifications:

- The frame must satisfy Paralympic competition standards.
- The frame must be more easily transported than the current throwing frames used at Bridge II Sports. It is preferred for an individual using a wheelchair to be able to transport the frame independently.
- It must be durable and stable for use by athletes while they sit in it and throw.
- It must be adjustable to fit athletes with a range of weight from 95lb-250lb, both right and left handed throwers, athletes needing arm support bars, and a range of athletes from 13-60 years of age.
- It is also desirable for the frame to be comfortable and capable of holding extra equipment during the competition, such as extra discus' and shot-puts.

These specifications are evident in our Quality Function Deployment (QFD) chart which relates Bridge II Sports' wants and needs with engineering terms and specifications. This has been done to determine the initial objective goals of design. The current QFD can be found in Appendix C. Figure 6, on the next page, depicts these technical engineering requirements. From the QFD we've learned that weight, comfort, and adjustability – which are all of high priority to Bridge II Sports – pose conflicts in that the more adjustable and thus comfortable the solution becomes, the greater the risk of increased weight.

Table 1: Throwing Frame Project Engineering Requirements

Spec. #	Parameter Description	Target [units]	Tolerance	Risk	Compliance
1	Length	1.5 [m]	Max.	M	I
2	Width	1.5 [m]	Max.	M	I
3	Height	75 [cm]	Max.	L	A, I
4	Weight	30 [lb]	Max.	H	A, T, S, I
5	Back Rest Height	6.25 [in]	±1.75in	L	I
6	Base angle of flex	5°	Max.	H	A, T, I
7	Height range	8 [in]	Min.	M	A, T, I
8	Arm support positions	2	Min.	L	T, I
9	Back Rest positions	2	Min.	L	T, I
10	Equipment storage devices	1	Min.	L	I
11	Wheels	1	Min.	L	I
12	Max load	250 [lb]	Min.	M	A, T, I
13	Back Rest Angle	90°	Exact	L	I
14	Frame Tie-Downs	2	Min.	L	I
15	Transportation Attachment	1	Min.	L	I

There are three risk levels – high, medium, and low (H, M, L) – that relate our initially expected risk to the success of accomplishing these goals in design. The two parameters of high risk are the weight and frame base angle of deflection, which correlate with the lightweight and stable design requirements. The weight will also factor into the ease of transportability. These two specific parameters are of high priority to Bridge II Sports. The parameters of medium risk are mostly related to the strength and adjustability of the possible solutions. To minimize weight and maintain strength and stability the team will research alternative composite materials such as carbon fiber. The back rest height and height range targets were produced after analyzing frames that are currently in use and consulting with Bridge2Sports.

The compliance column has four standards – analysis, test, similarity to existing designs, and inspection (A, T, S, I) – which show our intentions of measuring how we meet these targets. Parameters will be inspected by seeing that components are there (such as arm support positions, wheels, and tie-downs) or with measuring devices (such as determining length and height). The necessary conditions for stability and adjustability will be analyzed and tested by modeling components in three-dimensional computer modeling software and using the built in program that applies material conditions and estimates structural responses. Standard engineering structural analysis hand calculations will be done in tandem with the computer modeling to verify the results. Finally, once the prototype is built, these parameters will be confirmed by applying actual loads to the structure and analyzing its response through measurements.

Project Management

Due to the large scope of this project, the various tasks were categorized and delegated to group members to manage:

- Research, Material Acquisition, and Primary Contact: Stefan Owechko
- Prototype Fabrication and Manufacturing Considerations: Andrew Higgins
- Documentation, Analysis, and Frame Testing: Gabe Terrasas
- Athletics and Disabilities Awareness Management: Kevin Crisfield

The task categories listed above did not restrict group members from working on any particular part of the project. These assignments merely reflected who was in charge of specific tasks to establish responsibilities that the other team members assisted with.

In an effort to manage our time wisely, we visually represented our project schedule in a Gantt chart, which can be found in Appendix E. The project lasted three quarters at Cal Poly, from September 2011 through June of 2012. The end result was displayed at the Senior Project Design Expo on May 31, 2012 before being shipped to the customer for use in the field. These milestones and more can be found in the timeline.

Chapter 2: Background

The mission statement of Bridge II Sports is:

> "To create opportunities for children and adults who are physically challenged to play team and individual sports. This is done by providing equipment, developing sports, teams and coaching, thereby helping them to discover tenacity, confidence, self-esteem, and the joy of finding the player within." *Bridge II Sports*. Web. 19 Oct. 2011. <http://www.bridge2sports.org>

To allow for conformity with all levels of throwing events, Bridge II Sports has requested that the throwing frame be built to satisfy the standards of the Paralympic Games. The Paralympics are an international athletic sporting event that enables athletes with disabilities to compete on a global level. The rules and procedures mirror those of the more internationally recognized Olympic Games, however, the Paralympics have not been around nearly as long. The first official Paralympic Games were held in Rome in 1960. By contrast, the first modern Olympic Games were held in 1896, and the history of the Ancient Olympics goes as far back as 776 B.C., which is over 2000 years before the Paralympics were founded. Consequently, the Paralympics are still in the process of overcoming the difficulties associated with maintaining a fair and ethical level of competition while accommodating the vast scope of disabilities and ensuring that all athletes have the ability to participate.

In particular interest for this senior project, the rules governing the throwing frames continue to be a heavily debated topic amongst event judges, athletes, and coaches. As recently as 2008, the International Paralympic Committee published a paper – the "IPC Athletics Summit", found in Appendix A - which addressed the role of the throwing frame in the throwing events and defined the difference between a "secured throw" versus a "seated throw." This paper reaffirmed that the throwing frame was introduced to provide support for persons with disabilities that are unable to stand or are able to stand but have difficulty balancing. The problem with this definition was ambiguity that permitted athletes with the use of their legs and good balance to rise off the seat and stand at the end of the throw, resulting in an advantage to the thrower. This was resolved by decreeing that this was only legal if the athlete maintained contact with the ground with at least one foot during the course of the throw. Conversely, if the athlete is unable to control their legs or otherwise has difficulty touching the ground, they may use the frame without ground contact as long as they do not rise off the seat until after release. As a result, this rule directly affects the height and design of the throwing frame.

Currently, the official Paralympic rules offer significant freedom to frame designs with few limitations. For a complete copy of the section of rules concerning throwing frames, please see Appendix B. In summary, the rules state:

1. Seat height may not exceed 75 cm.
2. All parts must be fixed when the thrower is throwing, including articulating joints.
3. Materials that "store energy" are forbidden, but a "support bar" is allowed.
4. All parts of the chair must fit in the 1.5 meter diameter throwing circle.

Figure 2. *Typical Paralympic Throwing Frame Setup Area*. Photograph. *Athletics*

Figure 3. *Checking the Frame Fits in Circle*. Photograph. *Athletics New Zealand*. Web. 19 Oct. 2011. <http://www.athletics.org.nz>

As more controversies are introduced and new case studies examined, rules will continue to evolve. Consequently, a good frame design will allow for growth of the competition without complete re-engineering of the frame.

A company based out of Georgia, called Eagle Sports Chairs, manufactures a wide variety of support equipment for persons with disabilities, including sport wheelchairs and throwing frames. Two of these frames have seen use at Bridge II Sports, and are shown below in Figures 4 and 5.

Figure 4. *Eagle Sports Chairs, Model "A."* Photograph. *Eagle Sports Chairs*. Web. 19 Oct. 2011. <http://www.eaglesportschairs.com>

Figure 5. *Eagle Sports Chairs, Model "B."* Photograph. *Eagle Sports Chairs*. Web. 19 Oct. 2011. <http://www.eaglesportschairs.com>

Most throwing frames have a seat, backrest, support bar, and footrest. The support bar can be vertical, as in the Model “A” frame, or horizontal, as in the model “B” frame. These chairs offer different levels of accessibility, comfort, and support for the athlete and each has advantages and disadvantages. Model “A” offers more freedom with a smaller backrest and a fold-up footrest, which is better for athletes with less restrictive disabilities to transfer out of the wheelchair. However, it does not offer the armrest support that is available in the Model “B” chair, which may be better for a person that is more unstable in the upper body. Furthermore, both frames are made of heavy steel and have small wheels that make it challenging or impossible for a person in a wheelchair to transport and set up the frame at the event. Since these technologies are intended to empower the athlete, it would be better to have a design that can be utilized by the athlete without reliance on an outside party to help set up the frames. Lastly, the Model “B” frame is asymmetric and favors a right-handed thrower, with the support bar on the left side of the backrest. This is not ideal since the chair would have to be altered or not used at all if the thrower is left-handed or otherwise unable to use the right side of their body.

Equipment for people with disabilities is often custom designed specifically for the unique individual that will be using it, since each person has a different skill set based on their abilities. A challenging aspect of this project will be the attempt to design a universal frame that is accommodating for most types of disabilities.

Chapter 3: Design Development

Concept Generation

After extensive background investigation on the problem, online research of similar or related products, speaking with experts in the field, and gaining awareness of the needs of athletes with disabilities, we began the brainstorming process using a morphological attributes approach. Kevin Crisfield obtained a wheelchair to interact with during the concept generation process. We agreed to follow basic brainstorming guidelines in which all judgment was withheld during the session, regardless of how exotic the ideas were, because these ideas helped inspire new concepts that were feasible. Some ideas developed in this phase included a chair that folds up like standard TV dinner trays do, fabricating a custom wheelchair that mates with an elevating platform, a circular frame that is transported by rolling on its side, and a frame that receives a transfer board into a slot to simplify the process of transferring out of the wheelchair.

After this initial brainstorming session, we started a morphological attributes list using key features of each concept. This list was very extensive and covered the various features present in the new concepts. This was important to the concept generation process because it allowed us to match various pieces of the concepts with each other. One outlandish idea was a pivoting frame that can transform its shape from a circle to a square. This led to an idea to develop a seat top that changes from a square seat to the “L” shape seen on some existing throwing frames, like the Eagle Sports model “B” frame as seen in Figure 5 earlier in this report.

After this morphological attributes session, we finalized a list of twenty distinctly different frame arrangement concepts varying in shape, material, adjustability, transportability, and several other key characteristics. The following is the list of the twenty design concept ideas that were considered:

1. A cylindrical frame that is transported by rolling to the location
2. A sturdy base that elevates the athlete’s personal wheelchair
3. A sturdy base that elevates a custom-built wheelchair
4. A frame that involves a scissor-type lifting mechanism
5. A frame that uses a power screw lifting mechanism, similar to an office chair
6. A frame with fold-out legs, similar to a card table
7. A frame that folds in a similar fashion to a TV tray table
8. A frame that folds up like a speaker stand with a removable top
9. A frame that utilizes hydraulic lifting system, similar to a dentist chair
10. A frame that collapses down to the size of a briefcase for easy storage
11. A static frame with a seat shaped like a bicycle seat
12. A conventional static frame with lightweight material
13. A frame that can be disassembled onsite with simple tools

14. A frame that utilizes exterior folding legs instead of tie-down straps
15. An inflatable frame that can be deflated for transport and storage
16. A conventional frame with one giant wheel on the back to transport
17. A modular frame that can be re-assembled like giant building blocks
18. A tripod frame with a removable top that can be folded for easy transport
19. A frame with a sliding seat to streamline the transfer process
20. A frame with a large, heavy base for extreme stability

With this list finalized, the idea generation phase was complete, and we now moved on to the process of idea selection and sorting through the list.

Idea Selection

At this point in the process, we reviewed our project requirements and the goal that the new design would need to fulfill. As previously mentioned, the top priorities are that the frame satisfies the rules of the sport, is lightweight and easily transported, and strong enough to withstand regular use. It is also desirable for the frame to be adjustable to accommodate athletes with various height and levels of disabilities. Based on these requirements, most of the ideas were rejected as they were too heavy or inconvenient in nature to the athlete. However, several concepts stood out to be real possibilities:

1. The power screw seat, similar to an office chair
2. The “new chair,” a sturdy base that elevates a custom-built wheelchair
3. The frame that folds in a similar fashion to a TV tray table
4. The “multi-top” collapsible frame that folds up with a removable, pivoting top
5. The conventional static frame with lightweight material
6. The folding tripod frame with a removable top

These concepts were agreed upon as having real potential for our project. To help picture these concepts, drawings were mocked up for each, and are attached on the next few pages with notes about each concept. Since the folding frame mechanism of the multi-top design was difficult to picture, a scale model was built by Stefan with functional joints and a similar adjustable top that helped show how the frame would collapse and be able to fit the needs of many different athletes.

Design 1. The Power Screw Chair

Description: Modeled after an office chair, this frame would raise up and down by turning the seat which turns the screw.

Pros: Adjustable height, simple to operate, and incredibly strong. Offers complete upper body freedom to the athlete.

Cons: Extremely heavy, and difficult joints to weld for the legs. No upper body support for persons with disabilities. Will be difficult or impossible to transport with a wheelchair.

Figure 6. *Power Screw Concept.* Rendering. *Team Zeus.* Internal. 8 Nov, 2011.

Design 2. The "New" Chair

Description: This mechanical base would be accompanied by a custom-built wheelchair, allowing the athlete to remain in the chair for the event and not have to transfer to a frame.

Pros: Easy for athlete to use, very strong, stable, and adjustable.

Cons: Extremely heavy, difficult to transport, requires an assistant to set up, requires upper body control to activate lever to raise chair.

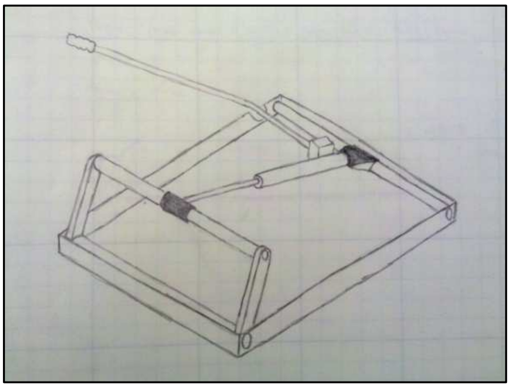

Figure 7. *"New" Chair Base, Chair Not Shown.* Rendering. *Team Zeus.* Internal. 8 Nov, 2011.

Design 3. The Folding TV Tray

Description: This folding frame would have a removable top that isn't shown in the picture. The top part of the frame would disconnect at the red dots via pins, and the legs would fold flat via pivots where they cross the central crossbar. This would allow the entire apparatus to be able to fold flat for transport.

Pros: Lightweight, easy to transport and set up, stores away in small space.

Cons: Likely to be unstable. No room for attachments or other accessories.

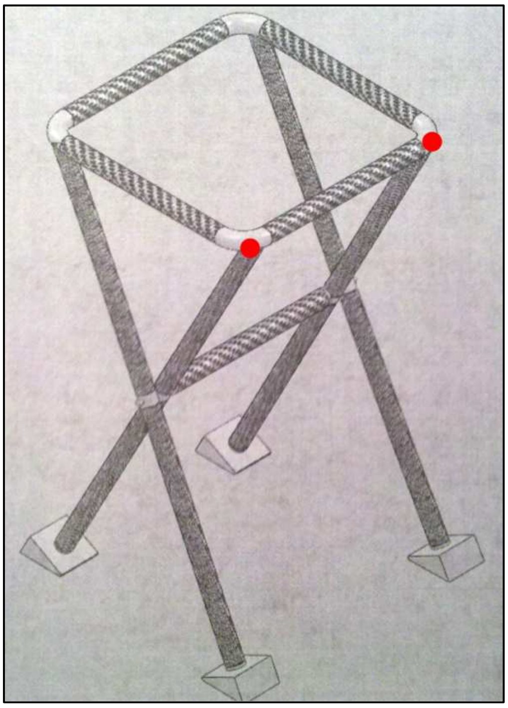

Figure 8. *Folding TV Tray Design.* Rendering. *Team Zeus*. Internal. 8 Nov, 2011.

Design 4. The Folding Tripod

Description: The picture shows the tripod in its folded state. When in use, the three tubes would rotate within the central joint to form a tripod that can be height adjusted via telescoping connectors, shown removed from the tubes. Also, the top would be removable.

Pros: Lightweight, easy for athlete to use, possible for the athlete to set up entirely without assistance. Could work with the multi-top seat (explained in Design 6).

Cons: Likely to be unstable, weak, and uncomfortable. No room for attachments or other accessories.

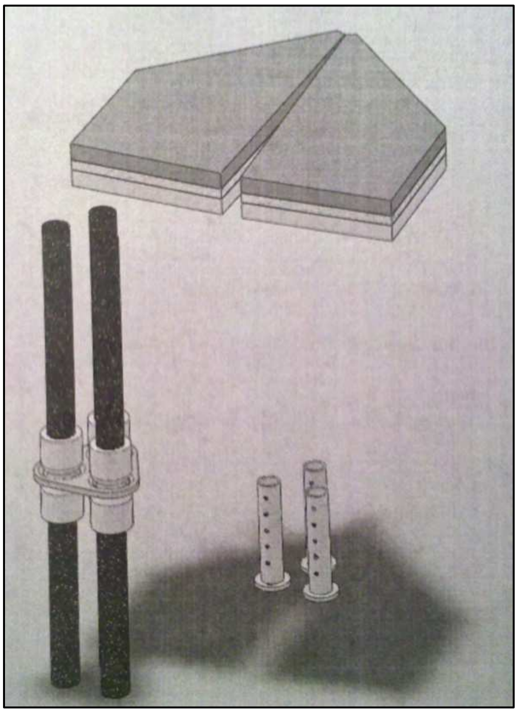

Figure 9. *Folding Tripod with Adjustable Legs and Multi-Top Seat.* Rendering. *Team Zeus.* Internal. 8 Nov, 2011.

Design 5. The Static Frame

Description: This simple design is just a seat with four posts, connected to a square frame at the bottom for rigidity.

Pros: Strong, lightweight, stable, able to connect attachments and other accessories. Offers capability to store equipment in the space underneath the seat.

Cons: Likely to be difficult to transport without wheels or other attachments.

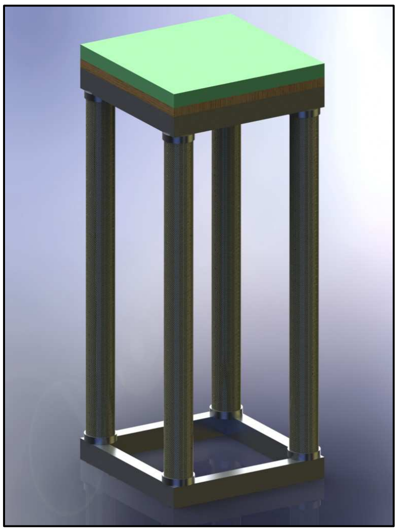

Figure 10. *Static Frame.* Rendering. *Team Zeus*. Internal. 8 Nov, 2011.

Design 6. "Multi-Top" Collapsible Frame

Description: This folding, telescoping, and pivoting frame would be able to collapse down to a very small package. The removable top is shown in its two available configurations, which are achieved by rotating the two halves around the pivot point, seen in the picture on the left.

Pros: Lightweight, easily transported once broken down, and very adjustable.

Cons: Difficult to make stable without some sort of bracing for the legs. The many pivots and joints create many areas of stress concentrations that may result in failure.

Figure 11. *Collapsible Frame* Rendering. *Team Zeus.* Internal. 8 Nov, 2011.

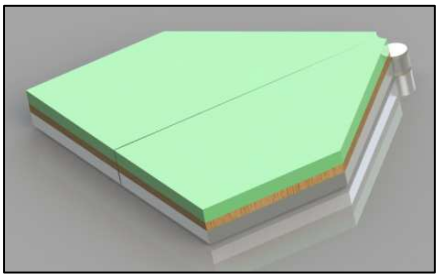

Figure 12. *Multi-Top in Home Plate Orientation.* Rendering. *Team Zeus.* Internal. 8 Nov, 2011.

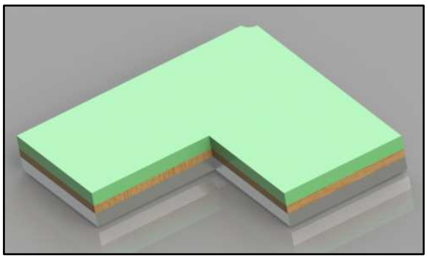

Figure 13. *Multi-Top "L" Shape.* Rendering. *Team Zeus*. Internal. 8 Nov, 2011.

To evaluate these concepts, we created a decision matrix to quantify how each design would satisfy the primary needs. This matrix is attached in Appendix D. The results of the decision matrix were surprising. The tripod and "new chair" ideas were not suitable at all for the application and were thrown out. The next level of proficiency was the power screw and TV tray concepts, but these were also fundamentally flawed and did not perform in some of the most important areas, like stability and weight, so they were also rejected. The top performers were the static and multi-top frames, scoring over twice as high as the next-highest scoring design.

The results for these two frames were so similar that a single winner could not be determined by the matrix alone. To settle the tie, we went back and reconsidered the pros and cons of each, evaluating the concepts from a more rigorous engineering aspect, utilizing three-dimensional CAD software to estimate the weight of each. It turns out the static aluminum frame had the advantage of being simple, sturdy, and ultimately stronger. However, the multi-top was able to adjust to different athletes and applications. It was decided to combine the strong static frame design with the adjustable multi-top seat. This seat is pictured in detail on the next page, shown in both orientations. This arrangement allowed us to maintain the adjustable features of the seat and apply them to the stronger static frame. In an effort to save weight we considered making a carbon fiber frame structure, but the joints must be made out of aluminum and this is where most of the frame's weight is located, so the weight reduction gained from the carbon fiber was negated by the joints. Once we also considered the significant amount of design and manufacturing time that the carbon fiber process would add, this idea was abandoned.

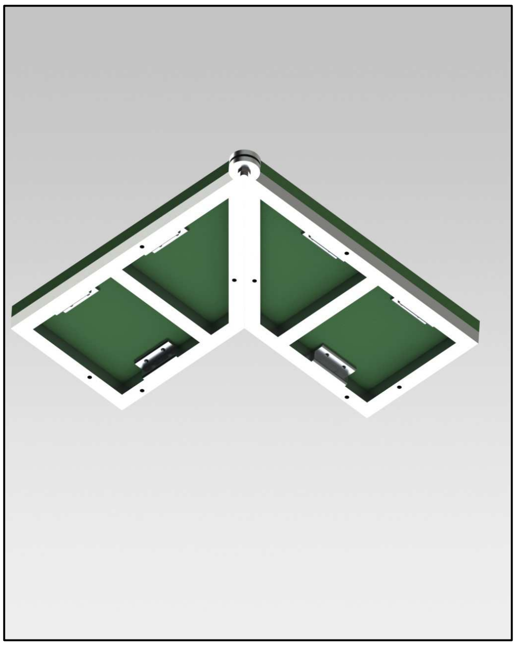

Figure 14. *Multi-Top in "L" Orientation* . Rendering. *Team Zeus.* Internal. 18 Jan, 2012.

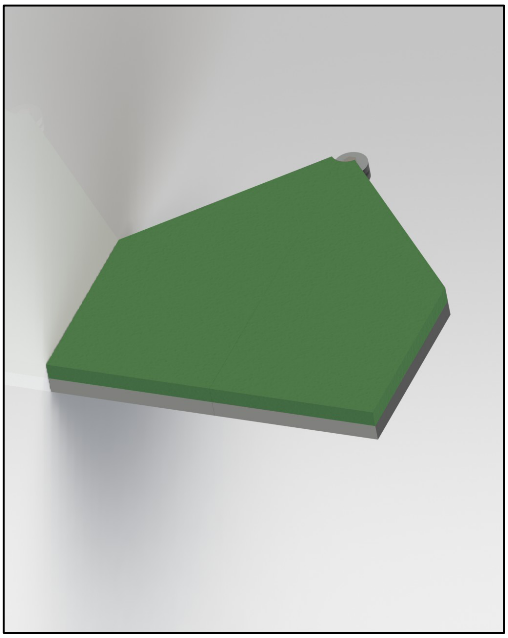

Figure 15. *Multi-Top in "Home Plate" Orientation* Rendering. *Team Zeus.* Internal. 18 Jan, 2012.

Maintenance and Repair Considerations

Another reason for abandoning the carbon fiber frame was that the aluminum frame construction allows the end user to have replacement parts and/or repairs made much more easily. While our design should last a lifetime, in the event that a frame breaks or pieces come loose, the end user would have to make the decision to repair or replace the frame. This decision boils down to the budget available for the repair. If the frame is made of carbon fiber, the cost to fix it would be substantial even with the original mold and designs, and nearly impossible without them. This is due to the labor-intensive process of laying the carbon fiber material and properly curing the adhesive used. On the other hand, aluminum material is much easier to machine, and the tubes can easily be re-welded or replaced with no prior knowledge of the frame design. This provides extra value to the customer and enables them to continue to use the frame without having to scrap it and buy a completely new frame.

Safety Considerations

Overall, the most dangerous part of this frame will be the pinch point of the rotating seat. The hinge is free to rotate, and there is the potential to pinch the fingers of the user. However, the only time this part will be rotating is when the user is changing the orientation of the seat. The rest of the time, the seat is securely attached to the frame with the bolts and will not have the opportunity to rotate unintentionally. Therefore, this hazard is minimized and should not be a problem.

The other safety concern will be verifying that all of the joints are machined properly and do not pose have the opportunity to scrape or cut the user. This is a quality control issue and will be handled by the machining process, so the joints should not pose a safety concern by the time the manufacturing is complete. This will be explicitly verified by hand before moving onto the next phase of manufacturing.

Overall, the final design is a strong, lightweight, and adjustable frame. It will be cost-effective and safe for the end user. Also, it has the potential for more features to be added on by utilizing the attachment mechanisms. Team Zeus is confident that this design will satisfy the customer and provide a superior solution to problems with existing frames.

Chapter 4: Description of Final Design

Overall Layout of Final Design

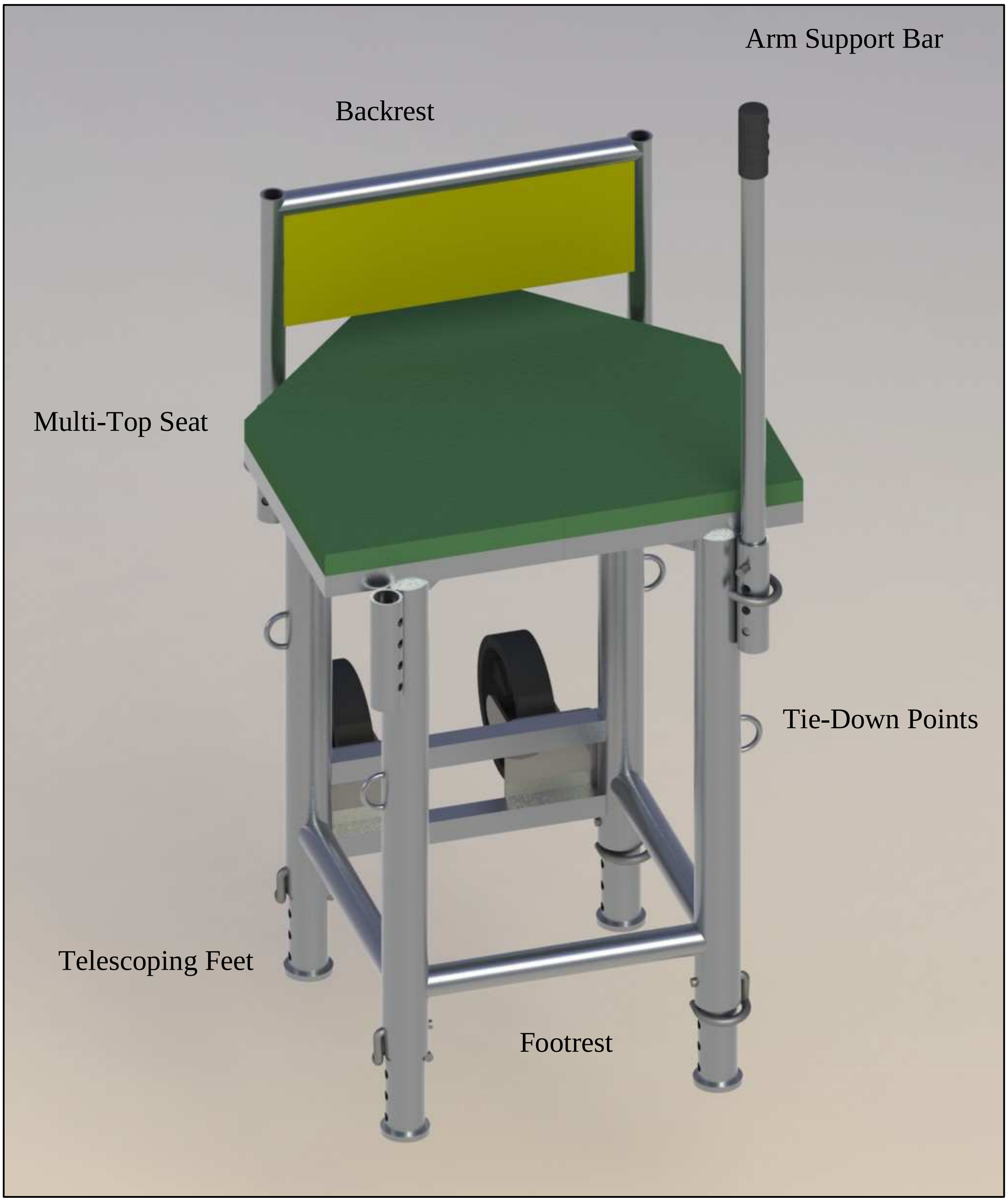

Figure 16. *Combination Frame, Top View* .
Rendering. *Team Zeus*. Internal. 18 Jan, 2012.

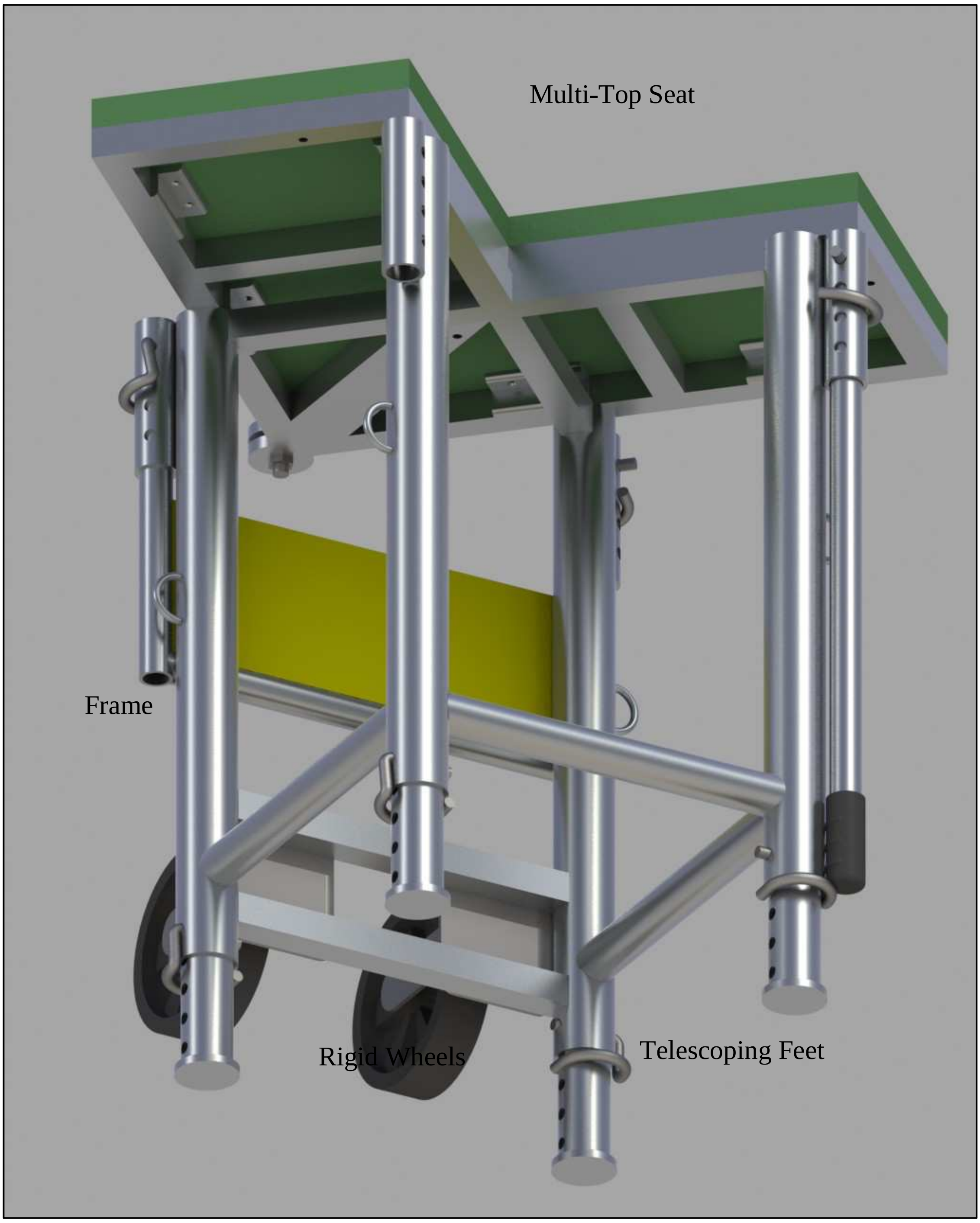

Figure 17. *Combination Frame, Bottom View* .
Rendering. *Team Zeus.* Internal. 18 Jan, 2012.

Engineering Analysis

In order to perform calculations to determine the size of pipe necessary for sufficient strength of the frame, we had to make several assumptions:

1. The welded joints provide rigid, unbending connections.
2. The legs provide a stationary connection with the ground.
3. To estimate forces exerted on the frame, we gathered some rough data:
    a. We performed test throws in a controlled environment to measure the approximate force exerted on the frame while throwing.
    b. The typical ratcheting straps used to secure the frame operate at approximately 200 pounds of force, as measured on a force gauge.

The breakdown of forces exerted on the critical leg of the frame is as follows:

<u>Forces Due to Torque</u>

In some cases, the user will rotate their body in order to accelerate the throwing object. This torque that he or she produces by spinning the torso will create an equal and opposite torque on the throwing frame. We will model this torque as being at the center of the frame, causing forces on the legs perpendicular to the connecting beams. To estimate this force, we threw a discus from a chair that could easily swivel. A spring scale was attached to the chair so that it kept the chair from spinning, while measuring the force required to do so. The highest torque we measured was about 400 pound-inches. As a conservative estimate, we will double this torque to model professional athletes.
Assuming that the final base will be 13 inches square, the counter-moment arm will be:

$$dist = \frac{13in\sqrt{2}}{2}$$

Using this moment arm, and assuming that the load will be distributed evenly among the four legs, the force produced by the angular acceleration of the user's torso will be 21.76 pounds per leg.

<u>Opposing Projectile Force</u>

When the projectile is accelerated and thrown, and equal and opposite force is produced. We will use the record Paralympic throwing distance with a 16 pound shot to determine this force. The record is 32.84 feet. In order to get acceleration time, video recordings of seated throwers have been analyzed. We will use an average time of 0.40 seconds to accelerate the projectile at an ideal launch angle of 45 degrees. This results in a force of 37.6 pounds and, again, we will assume that this will be distributed evenly between the four legs. This means that each leg sees a force of 9.4 pounds in the opposite direction of the throw.

Forces on Arm Bar

Some users may want to use an arm bar to help stabilize them during the throw. We have designed this bar to be adjustable in height and can be completely removed if need be. A pull on this arm bar will affect the frame the most when it is fully extended, which we have designed to be 20 inches above the seat. Data for maximal static hand forces exerted on a vertical handgrip from a seated position can be found in *Creative Design of Products and Systems* (4). The maximum force exerted by someone pulling from a seated position was reported to be 189 pounds.

Support Strap Tension

The final force which we can estimate is the tension in the support straps which secure the frame to stakes pounded into the ground. These straps usually have a maximum working capacity of 400 pounds. However, we were able to acquire such a strap and connect it to a spring scale. We tightened it until we were no longer comfortable tightening it, resulting in a tension of 200 lbf. We will assume that the hooks are located 18 inches above the ground on the frame legs and have the 200 pound force acting at a 45 degree angle.

Modeling the Leg

In order to determine how strong each leg needs to be, we must find reaction forces at the ground as well as at the three welds on the frame. All of these reactions, broken down into components can be seen in the figure below. For initial calculations, see stress analysis in the Appendix. These calculations show that 2 inch nominal Schedule 40 Aluminum tubes can be used for the legs.

Using these assumptions, we found the reaction forces at the ground as well as at the three welds on the frame. These are shown in the figure below. These forces were used to determine that 1.5 inch nominal Schedule 40Aluminum tubes can be used for the legs. The supporting technical calculations can be found in more detail in Appendix F.

Figure 18. *Frame Force Analysis Showing Reaction Forces.* Rendering. *Team Zeus.* Internal. 8 Nov, 2011.

Chapter 5: Product Realization

The complete manufacturing plan is shown in Appendix I. The manufacturing processes that were used can be categorized as material removal, joining, and finishing.

Manufacturing Processes

Material removal involved turning material on a lathe, milling parts, cutting tube stock, drilling holes, and tapping the holes. General cutting on a band saw was used for round tubing that was then faced on a mill to get exact length. Square tubing was cut on a chop saw to achieve miter cuts for the seat pieces. To fabricate the structure of the frame it was necessary to use a machine called the “Tube Shark.” This uses a hole-saw to cut round pipe at angles, which allowed us to cut 90-degree corners. Most drilling processes were done on a drill press using V – blocks and center finders to locate holes in our piping. The only milling necessary for our prototype was to make the seat hinge. A solid square rod was milled into the two hinge halves. The seat hinge also required two tapped holes to bolt to the rest of the seat frame.

Three main joint methods were used: TIG welding, bolting, and pinning. Most rigid connections were TIG welded by Gentry Welding in San Luis Obispo. Gentry was given drawings and pieces prepared for welding. Gentry used their own equipment to fashion jigs and finish welds. The wheels, seat, and hinge used bolts to join parts where welding was either impractical or easier due to dissimilarity in metals. Because of the adjustable nature of the design several parts require removal and replacement; these parts are joined using gravity pins that were ordered. The design of the gravity pins allows for ease of use and is secured by gravity, which holds the curved part against a pipe “locking” it in place.

The finishing processes included deburring, grinding, filing, sanding, buffing, and painting the frame. After most machining processes, burrs form at the edge of a piece that was cut or drilled For these, deburring tools chip off the burr and create a slight bevel or chamfer. Deburring was necessary on all fabricated parts. Hand grinders and sanders were utilized as well as large belt sanders and wire wheels to remove weld beads and sharp edges from the production process. The buffing wheel was used to polish parts to a smooth finish, ie telescoping tubing and attachments. The frame was painted at Full Spectrum Powder Coating in San Luis Obispo.

Figure 19. *Lathe Manufacturing Set-Up.* Photograph. *Team Zeus.* Internal. 28 May, 2011.

Figure 20. *Machine Shop Chop Saw.* Photograph. Team Zeus. Internal. 28 May, 2011.

Figure 21. *Drill Press Set-Up.* Photograph. *Team Zeus.* Internal. 28 May, 2011.

Figure 22. *Machine Shop Mill.* Photograph. *Team Zeus.* Internal. 28 May, 2011.

Figure 23. *Tube Shark Set-Up.* Photograph. *Team Zeus.* Internal. 28 May, 2011.

Figure 24. *Welding Mid-Process*. Photograph. *Team Zeus*. Internal. 28 May, 2011.

Figure 25. *TIG Welding Set-Up*. Photograph. *Team Zeus*. Internal. 28 May, 2011.

Figure 26. *Gravity Pin Close-Up*. Photograph. *Team Zeus*. Internal. 28 May, 2011.

Figure 27. *Tapped Hole with Bolt*. Photograph. *Team Zeus*. Internal. 28 May, 2011.

Figure 28. *Buffing and Grinding Wheel*. Photograph. *Team Zeus*. Internal. 28 May, 2011.

Figure 29. *Ground Down Butt Welds*. Photograph. *Team Zeus*. Internal. 28 May, 2011.

Figure 30. *Deburring Tool Close-Up*. Photograph. *Team Zeus*. Internal. 28 May, 2011.

Deviations from Original Design

During production, changes were made to the prototype that differed from the planned design. The main change was the seat hinge. The original design consisted of rings that were welded to the seat halves and joined with a bolt. After this design was built, however, it failed preliminary testing. The weak bond strength was due to insufficient surface for the weld to attach to, and a redesign was necessary. Consequently, the sturdier milled parts were developed to fit the purpose. A drawing of the new hinge design can be found in Appendix I. This part drawing only represents half of the hinge. There are two of them, one a mirror image of the other, so that they slide over each other about the 0.5" hole. Each piece is then secured to its associated seat half with a bolt.

Another alteration was due to a failed go/no-go test of the backrest fit. It was intended to be able to be used in multiple locations, however after the welding process, the attachment points were slightly off-center and the backrest only fit in one orientation. This resulted in extra time spent resurfacing the backrest attachment bars so that there was more tolerance allowing the other orientations to be used.

The final adjustment to the original design was that the placement and dimensions of the holes for the seat frame pins were altered to ensure a good fit. This was necessary to compensate for slight variances in the design and execution of the seat geometry, specifically due to the deformation of the metal pieces during the welding process.

Suggestions for Future Manufacturing of Frame

The majority of the difficulties with the manufacturing processes are due to the dimensions of the welded frame not matching the original design specifications. Consequently, creating a strong and accurate jig to hold the parts in place during the welding process would greatly improve the accuracy of the final product, thus limiting the necessary post-manufacturing adjustments. The new hinge is also a better design than the original concept and should be used in its place

Chapter 6: Design Verification

During testing, the project design goals were assessed for satisfaction based on the following tests:

1. **Seat stress test:** The frame was designed for a maximum user weight of 250 lbf. This weight will be applied to the seat and the frame will be observed for any measurable deflection or failure.
2. **Weight test:** The design was aimed to weigh 30 lbf or less. The whole frame with all attachments and pins will be weighed. This weight excludes stakes, straps, and extra equipment carried by the system.
3. **Torque test:** The engineering analysis determined that an athlete may exert up to 400 in-lbf of rotational force on the frame when throwing. This will be applied to the frame and the frame will be observed for deflection or failure.
4. **Arm bar test:** During a seated throw, the arm bar may experience up to 190 lbf exerted at the grip. This will be applied and the frame will be observed for any deflection or failure.
5. **Support strap tension test:** The frame will be anchored at the field with ratcheting straps that may produce up to 200 lbf of tension on each leg. These conditions will be recreated and the frame will be observed for any deflection.
6. **Transport test:** For this test, the frame will be transported by a person in a wheelchair to verify that the wheels and tip-to-roll design are appropriate for an athlete with disabilities.
7. **Attachment point test:** The attachments will be installed on the frame in every configuration possible and this test will be rated on a go/no-go fashion. This test aims to check that the gravity pins fit into the appropriate holes and that the fit of each attachment is acceptable.
8. **Hinge and seat compatibility test:** This will also be a go/no-go test. Since the hinge will be fabricated by Team Zeus, it is important to verify that it opens and closes correctly and that the seat fits properly onto the frame.

Table 2: Design Verification Test Results

Test	Goal	Result	Details
1	250 lbf	Pass	Applied over 275 lbf to the seat.
2	30 lbf	Accepted	Final weight 35lbf, still less than half the weight of existing product.
3	400 in-lbf	Pass	Applied over 450 in-lbf of stress with no measurable deflection.
4	190 lbf	Pass	Applied over 250 lbf with minimal elastic deformation.
5	200 lbf	Pass	Zero deformation at the anchor points.
6	Transport	Pass	Transportation by wheelchair is possible with practice.
7	Attachments	Accepted	The backrest is not as mobile as desired, but all other attachments are interchangeable.
8	Good Fit	Pass	Fit is snug and has minimal play in connection.

Chapter 7: Conclusions and Recommendations

Cost Analysis

The pertinent vendor data can be found in Appendix G, with the Bill of Materials in Appendix H. Raw material and parts were purchased on McMaster-Carr's website as well as at McCarthy Steel, a local metal provider. Welding and powder coating services were both done locally in San Luis Obispo, by Gentry Welding and Full Spectrum Powder Coating, respectively. Local services and suppliers were used as much as possible to save on shipping costs.

The total cost of all supplies for prototyping, testing, and services were $1153.85. The parts and materials, including shipping, was 62.1% of this value being $716.35, while welding and powder coating was 37.9%, $412.50 for welding and $25 for powdercoating. The cost of services was a little higher than expected, but due to our student team manufacturing the rest of the parts a lot of money was saved in that field. Also, the quality of work in welding and painting were significantly better than what our team could have accomplished ourselves. Shipping costs constituted 7.4% of our total expenditures and this could have been reduced only slightly if more local suppliers could have been found. However, our initial budget was $1,500 and we were able to stay well within this amount having $346.15 left over in grant funds, meaning we only used 76.9% of the established budget.

Recommendations

The only test that was not able to completely satisfy the initial goals was the weight of the frame. There is, however, the possibility to reduce the weight by trimming the design. For future machinists or developers of throwing frames it is recommended to search for a lighter seat option or a new method of attaching the seat that could reduce materials. Another weight saver could include finding a durable arm bar that isn't solid, unlike our solid aluminum arm bar, to cut down on material cost and weight.

During testing it has been found that steering the frame while transporting it results in a slightly wobbly feel due to a narrow wheel base. If several inches could be placed between the current wheel positions this would greatly improve the ride quality of the frame. Lastly, developing welding jigs as mentioned in the manufacturing section could have reduced the deformation of parts due to precision errors when lining up parts as well as the weld beads cooled which caused some tubes to deform and the tight fit on telescoping parts to change just enough to throw off the tolerance of the snug fit.

Looking Forward

The Throwing Frame has been successfully completed and the plans have been outlined to re-create more frames in the future. The final product will be presented at the Cal Poly Senior Project Design Expo May 31st, 2012. Following this expo, the Throwing Frame will be sent to Bridge II Sports by the Kinesiology Department to be used in the field.

In total, the weight of the frame was 5 lb heavier than what we had aimed for. However, this was acknowledged as an ambitious goal from the start. The Throwing Frame Senior Project was still able to produce a final product that is less than half the weight of the current product being used. This is a tremendous success, especially when coupled with the unprecedented new multi-top seat design. Team Zeus is proud to present Bridge II Sports with this throwing frame and we hope it will enable more individuals with disabilities to participate in throwing events with greater ease and comfort.

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Appendices

A. International Paralympics Committee Paper: "Secured Vs Seated Throwing"
B. Official IPC Rules Governing Throwing Frames
C. Quality Function Deployment (QFD)
D. Concept Design Decision Matrix
E. Project Timeline
F. Engineering Analysis (Strength of Materials)
G. Pertinent Product Literature
H. Cost Analysis
I. Assembly and Part Drawings
J. Manufacturing Plan Diagram

APPENDIX A: IPC COMMITTEE LETTER

F34's & Rule 179
Secured Throwing Vs Seated Throwing

Compiled by Alison O'Riordan & Scott Goodman
Presented by Scott Goodman

Over the last 10 years the IPC Athletics Technical Committee has grappled with the interpretation of Rule 179, particularly in relation to Class F34.

Types of issues that have arisen are to do with differing interpretations of and/or confusion regrding:

1. contact with the upper leg
2. first forward movement of the throw
3. what constitutes a seat and/or a sitting position, and
4. legality of elevated footplates

This has lead to:

- fouling at major meets by officials that are inexperienced and/or misadvised regarding Rule 179 (including the World Championships & Paralympic Games)
- controversy and discontent by athletes, coaches and officials at major meets
- changes in interpretation of Rule 179 close to major meets that dramatically affect athletes hat have been training for many years, and
- interpretations and changes that effect performance and disadvantage athletes in this Class at meets using IPC Pointscore Tables based on flawed data (i.e. Tables formulated from data that contain results that are no longer "legal").

There have been many attempts to address this area by re-writing and/or re-interpreting Rule 179.

The intention of this paper is to challenge what we believe is the crux of the issue. That is to break the perception that all throwers that require the assistance of a throwing frame are "seated throwers".

APPENDIX A CONTINUED

Seated Throwing Vs Secured Throwing

Historically the use of throwing frames was to enable people to "sit and throw". This was particularly the case in the 50's, 60's and 70's when the predominant group involved were spinal cord injured (SCI) athletes. However, over the years many SCI athletes have challenged this perception by exploring techniques/styles that maximise the use of their available function that are on the edge of the boundaries of the Rules.

The reality is that nearly all Class F34 athletes can stand and even walk. Many are initially assessed as Class T/F35, which is an ambulant class. However, they are not able to throw as ambulant throwers due to poor balance and stability. The classification system recognises this and provides them with the option of competing as Class T/F34 athletes where they can use a wheelchair for track events or a throwing frame for throwing events for Occupational Health and Safety purposes.

The purpose of this paper is to encourage IPC Athletics to recognise and accept this and to allow athletes to maximise their potential NOT restrict their potential.

Recommendations

1. That for the next 4 year cycle (i.e. 2009-2012) if an athlete is eligible to compete as a Class F34 athlete then they should be allowed to utilise a throwing frame that enables them to throw with whatever style they prefer as long as:
   - their height is not artificially extenuated (i.e. one foot remains on the ground), and
   - their frame complies with the overall rules for throwing frames, in particular that leverage poles and footplates are within the plane of the circle.
2. That this should also apply to Classes F32 & F33
3. If points 1&2 above are not adopted during this summit, then IPC Athletics "must" comprehensively resolve the ongoing conflicts associated with Rule 179 and its application to Class F34 athletes during this summit so that the affected athletes can prepare unhampered for the 2011 IPC World Athletics Championships and the 2012 London Paralympic Games.
4. That a group of experienced throws coaches should be established to conduct and evidence based review the Classification structure and Rules of all of the "Secured Throwing Classes". Details of the role of this group have been discussed in a separate paper.

Benefits

1. Adopting this approach should minimise the need for interpretation of technique (i.e. other than those required under IAAF Rules in regard to shot-put) and provide a fair environment for Class 34 athletes to prepare for the next 4 year cycle.
2. Eliminates the need for officials to interpret technique re "start of the throw", "sitting position", "first forward movement" and the like. All they have to do is assess that the frame is legal and that at least one foot is in contact with the ground OR height is not artificially enhanced. The Classifiers determine whether the athlete is eligible to compete in the class or not, the rules determine how they can compete NOT interpretations by the officials.
3. Minimises the potential for protest and dispute on the matters outlined above.
4. Allows athletes and coaches to focus on throwing as far as they can rather than constantly being concerned about the scrutiny of their style or technique.
5. Etc, etc, etc

APPENDIX B: IPC RULES

IPC ATHLETICS

RULE 35: Secured Throwing Requirements

(Sport Classes F31-34, F51-58)

[Note to officials; for the purpose of interpreting this rule and other rules regarding the shape, dimensions, construction and other characteristic of competition equipment regard should be had to Regulation 3.3 regarding 'Technology and Equipment' and in particular the 'fundamental principles' set out at regulation 3.3.1.]

1. Throwing Frame Specifications:

   a) The maximum height of the throwing frame including the cushion(s) used as a seat shall not exceed 75 cm;

   b) Footplates if used are for support and stability only;

   c) Footplates to be placed on the ground and to secure the contact foot are allowed, but should not provide height advantage. The height of these footplates must not exceed 1 centimetre;

   d) Side and back rests for safety and stability may be attached to the seat. They must be nonflexible and non-movable;

   e) The frame may have a holding bar. The holding bar material may be of metal, fibreglass or a similar material and must be a single straight piece of material without curves or bends and should not contain springs, joints or articulation. The cross-sectional profile should be circular or square not oval or rectangular. The point where the holding bar is fixed (joined) to the chair must contain no levers or hinges that could assist with propulsion of the implement;

   f) No part of the frame including any holding bar shall be moveable during the throwing action;

   g) A day chair that satisfies these criteria is acceptable.

   Note: Fibreglass can be rigid, flexible and brittle, only rigid fibreglass holding bars will be permitted.

2. Throwing Frame Measurement and Inspection. Throwing Frames will be measured and inspected in the Call Room or at the competition area prior to the commencement of the event. Once it has been measured and inspected an athlete's Throwing Frame must not be taken from the competition area before the start of the event. Throwing Frames can be re-examined by the officials before, during or after the event.

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APPENDIX B CONTINUED

IPC ATHLETICS

Note: Measurement will always take place without the athlete sitting in the frame.

3. Athlete's Responsibility for Throwing Frame Compliance. It is the responsibility of the athlete to ensure that their Throwing Frame conforms to the requirements stipulated above. No event shall be delayed while an athlete makes adjustments to their throwing Frame.
4. Positioning of the Frame (Sport Classes F31-34, F51-58). When positioning and securing the throwing frame inside the competition area all parts of the throwing frame, holding bar and footrests must remain inside the vertical plane of the rim of the circle throughout the trial. The leading edge of the holding bar must be positioned in the line of the vertical plane of the throwing circle
5. Time Allocation for Securing Frames (Sport Classes F31-34 & F51-58). A reasonable time will be permitted for an athletes frame to be placed in the circle before the commencement of their first trial, however the following times should not normally exceed:

   a) 2 minutes for Sports Classes F32-34 and F54-58, or

   b) 3 minutes for classes F31 and F51-53.

   Note: While the responsibility for 'tying down' rests with officials and volunteers, the Technical Delegate will issue specific interpretations at each competition which ensure athletes do not engage in time-wasting tactics.

6. Holding Device Failure (Sport Classes F31-34, F51-58)
   If a holding device should break or fail during the execution of a throw then the overseeing official should:

   a) If the athlete does not foul, offer the athlete the option of re-taking that trial (i.e., if the athlete is happy with the distance and they haven't fouled then the athlete has the option of counting the affected trial), or;

   b) If the athlete fouls then the trial should not be counted and the athlete should be allowed to retake the affected trial.

RULE 36: Secured Throwing Technique, Lifting & Fouling

1. Secured Throwing Technique for F31-34 & F51-58.
   Athletes can use their leg or legs during the throwing action, providing they maintain a sitting position.

   Note: The intended "sitting position" is for at least one buttock to be in contact with the seat of the frame whereby the athlete

APPENDIX B CONTINUED

IPC ATHLETICS

would be able to balance if they were asked to lift their feet off the ground.

2. Athletes also have the option of finishing the throw or put in an upright position providing they:

   a) Maintain a sitting position on their throwing frame until the first forward movement which results in the release of the implement (i.e., any preliminary swings or rocking movements must be done from a sitting position);

   b) Maintain foot contact with the ground or foot plate inside the circle until after the implement has been released;

      Note (i): The intended "foot contact with the ground or footplate" is for at least the ball of the foot to be in contact with the ground or footplate inside the circle. The contact foot can turn as per an "able-bodied" active foot action, but it cannot lift or step until the throw has been released.

      Note (ii): Some athletes can not get in a position with the foot flat on the surface due to their physical impairment and in those cases it will not be deemed a breach of the rule.

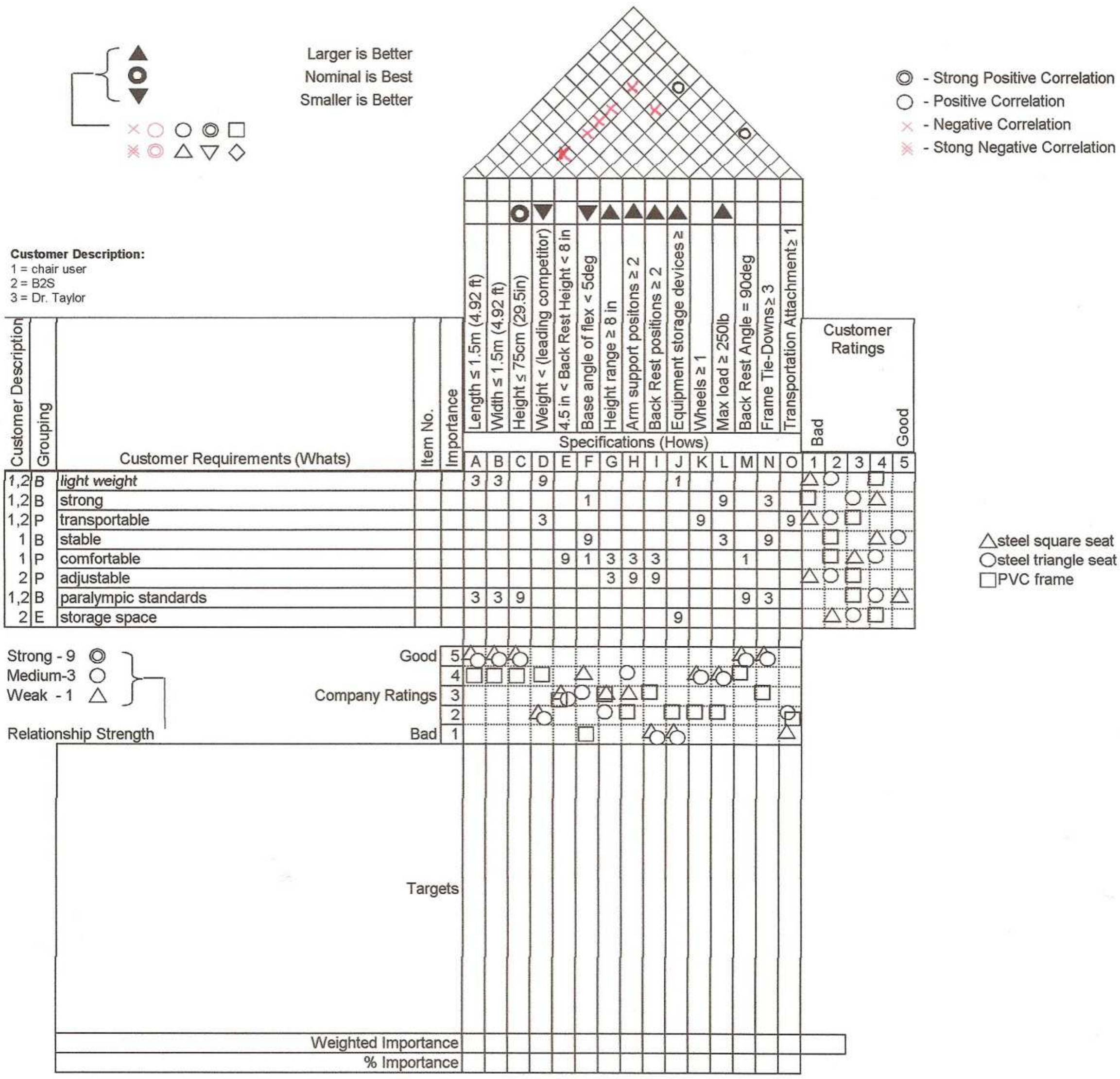
   c) The contact foot may be secured to the ground by strapping or a foot plate, but the thickness of the plate must be ≤1cm, so that it does not provide a height advantage to the athlete. Any foot-securing device must only be at ground level flat to the ground and must not increase the height of release of the implement (e.g., by throwing off raised footplates);

   d) The non-contact foot is free to move within the throwing area as defined by the rules of the event (i.e., the athlete may step into the throw with the non-contact foot).

      Note (i): If an athlete presents with an anatomical limitation that prevents them adhering to the above requirements (e.g., a bilateral amputee), then an assessment will need to be made by the IPC Athletics Technical Delegate in consultation with the Chief Classifier, if a Chief Classifier is available, as to whether or not the athlete is throwing within the spirit of the rules.

      Note (ii): For Sport Classes F32-34, F51-58 from start to finish, the movement of the shot shall be a straight, continuous putting action.

APPENDIX C: QUALITY FUNCTION DEPLOYMENT (QFD)



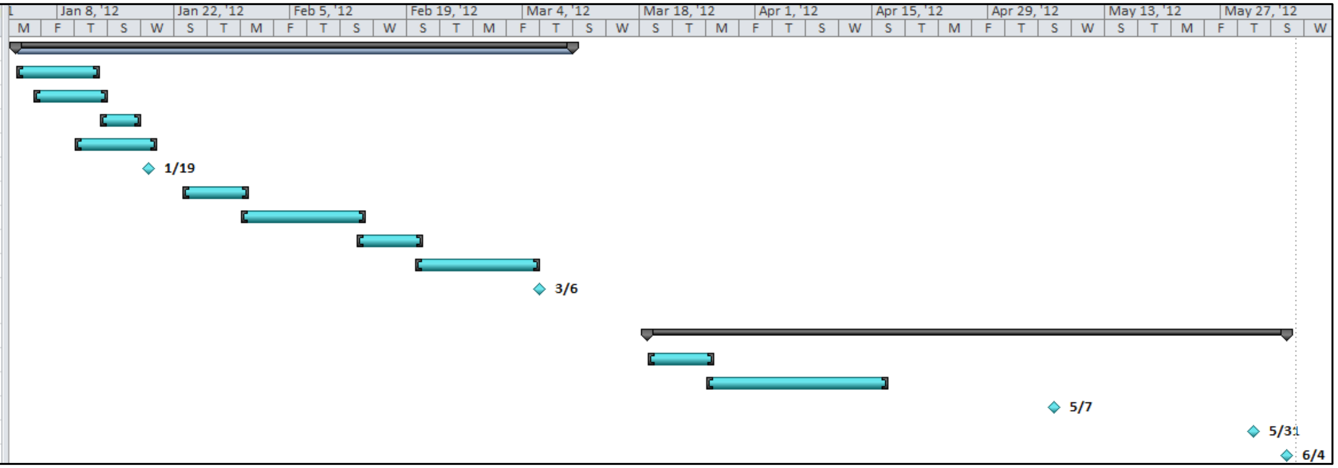
APPENDIX D: DECISION MATRIX

Design Reqs	Weight	New Chair	Power screw	TV Tray	Multi-top	Static	Tripod	Datum	Combination
Light weight (< 40 lbs)	5	-5	-5	5	5	5	5	-5	5
Strong (> 250 lb person)	5	5	5	0	5	5	0	5	5
Transportable	4	3	0	3	3	0	3	0	3
Stable	4	4	4	-4	4	4	-4	4	4
Comfortable	2	2	0	2	2	0	-2	0	2
Adjust: Size	2	0	2	2	2	0	-2	-2	2
Adjust: Left/Right	3	3	3	0	3	3	0	3	3
Adjust: Ability	2	-2	2	2	2	2	0	0	2
Paralympic Standards	5	0	0	0	5	5	0	5	5
Onboard Storage	1	1	1	0	0	1	0	-1	1
Easily Set Up	3	0	3	3	0	3	3	3	3
Manufacturability	3	-3	0	0	3	3	-3	3	3
Cost	2	-2	-2	0	0	2	0	0	0
	Sum	6	13	13	34	33	0	15	38

Note: The “combination” column refers to the final design, which is a combination of the multi-top and static concepts.

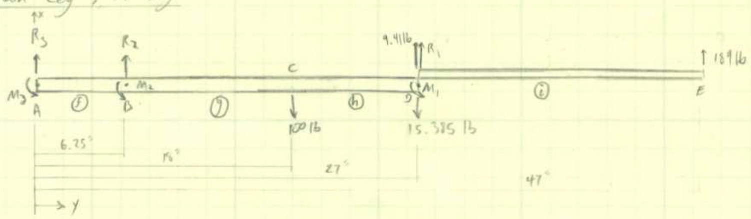
APPENDIX E: GANTT CHART (PROJECT TIMELINE)

Task Name	Duration	Start	Finish
BUILD	**49 days**	**Tue 1/3/12**	**Fri 3/9/12**
Assembly Drawings	8 days	Tue 1/3/12	Thu 1/12/12
BOM Development	7 days	Thu 1/5/12	Fri 1/13/12
Cost Analysis	3 days	Fri 1/13/12	Tue 1/17/12
Design Report	8 days	Tue 1/10/12	Thu 1/19/12
Design Review	0 days	Thu 1/19/12	Thu 1/19/12
Raw Material Orders	6 days	Mon 1/23/12	Mon 1/30/12
Tube Lathe Work	11 days	Mon 1/30/12	Mon 2/13/12
Tube Drill Work	6 days	Mon 2/13/12	Mon 2/20/12
Tube Welding	11 days	Mon 2/20/12	Mon 3/5/12
Manufacturing Review	0 days	Tue 3/6/12	Tue 3/6/12
TEST	**55 days**	**Mon 3/19/12**	**Mon 6/4/12**
Project Update Memo	6 days	Mon 3/19/12	Mon 3/26/12
Testing	16 days	Mon 3/26/12	Mon 4/16/12
Hardware Demo	0 days	Mon 5/7/12	Mon 5/7/12
Project Expo	0 days	Thu 5/31/12	Thu 5/31/12
Final Report	0 days	Mon 6/4/12	Mon 6/4/12



APPENDIX F: ENGINEERING ANALYSIS OF FRAME

Main Leg, x only



statics

$\Sigma F_x = 0$

$0 = R_3 + R_2 - 100\text{ lb} + 9.41\text{ lb} - 15.385\text{ lb} + R_1 + 189\text{ lb}$

$0 = R_1 + R_2 + R_3 + 83{,}025$

$\Sigma M_A = 0$

$0 = M_3 + R_2(6.25\text{in}) + M_2 - 100\text{ lb}(18\text{in}) + 9.41\text{ lb}(27\text{in}) - 15.385\text{ lb}(27\text{in}) + R_1(27\text{in}) + M_1 + 189\text{ lb}(47\text{in})$

$0 = M_3 + M_2 + M_1 + 6.75 R_2 + 27 R_1 + 6921.675\text{ in}\cdot\text{lb}$

Shear, moment, slope, & deflection equations

A-B (section f):

$V_f = R_3$

$M_f = R_3 y + M_3$

$EI\theta_f = R_3 \frac{y^2}{2} + M_3 y + c_1$ * Assume $\theta = 0$ @ $y = 0$ $\therefore c_1 = 0$

$EIx_f = R_3 \frac{y^3}{6} + M_3 \frac{y^2}{2} + c_2$ * Assume $x = 0$ @ $y = 0$ $\therefore c_2 = 0$

B-C (section g):

$V_g = R_3 + R_2$

$M_g = (R_2 + R_3) y + [M_3 + M_2 + 6.25 R_3]$

$EI\theta_g = (R_2 + R_3)\frac{y^2}{2} + [M_3 + M_2 + 6.25 R_3]\, y + c_3$

$EIx_g = (R_2 + R_3)\frac{y^3}{6} + [M_3 + M_2 + 6.25 R_3]\frac{y^2}{2} + c_3 y + c_4$

C-D (section h):

$V_h = R_3 + R_2 - 100$

$M_h = (R_3 + R_2 - 100) y + [M_2 + M_3 + 18 R_3 + 11.75 R_2]$

$EI\theta_h = (R_3 + R_2 - 100)\frac{y^2}{2} + [M_2 + M_3 + 18 R_3 + 11.75 R_2]\, y + c_5$

$EIx_h = (R_3 + R_2 - 100)\frac{y^3}{6} + [M_2 + M_3 + 18.5 R_3 + 11.75 R_2]\frac{y^2}{2} + c_5 y + c_6$

D-E (section i):

$V_i = R_3 + R_2 - 106 + R_1$

$M_i = (R_1 + R_2 + R_3 - 106) y + (M_1 + M_2 + M_3 + 27 R_3 + 20.75 R_2 - 900)$

$EI\theta_i = (R_1 + R_2 + R_3 - 106)\frac{y^2}{2} + [M_1 + M_2 + M_3 + 27 R_3 + 20.75 R_2 - 900]\, y + c_7$

$EIx_i = (R_1 + R_2 + R_3 - 106)\frac{y^3}{6} + [M_1 + M_2 + M_3 + 27 R_3 + 20.75 R_2 - 900]\frac{y^2}{2} + c_7 y + c_8$

APPENDIX F CONTINUED

File:Main_Beam_x.EES 12/2/2011 10:38:48 AM Page 1
EES Ver. 8.889: #552: For use by Mech. Engin. Students and Faculty at Cal Poly

Finding Reactions and Moments on main leg in x

Statics

sum of forces

$$0 = R_1 + R_2 + R_3 + 83.025$$

Moment about bottom

$$0 = M_3 + M_2 + M_1 + 6.25 \cdot R_2 + 27 \cdot R_1 + 6921.675$$

slope and deflection equations

moment at B with section 1 equation

$$M_B = R_3 \cdot 6.25 + M_3$$

angle at B with section 1 equation

$$E \cdot I \cdot t_B = R_3 \cdot \frac{6.25^2}{2} + M_3 \cdot 6.25$$

deflection at B with sec. 1 equation

$$E \cdot I \cdot x_B = R_3 \cdot \frac{6.25^3}{6} + M_3 \cdot \frac{6.25^2}{2}$$

moment at B with section 2 equation

$$M_B = [R_3 + R_2] \cdot 6.25 + 6.25 \cdot R_3 + M_3 + M_2$$

angle at B with section 2 equation

$$E \cdot I \cdot t_B = [R_3 + R_2] \cdot \frac{6.25^2}{2} + [6.25 \cdot R_3 + M_3 + M_2] \cdot 6.25 + C_3$$

deflection at B with sec. 2 equation

$$E \cdot I \cdot x_B = [R_3 + R_2] \cdot \frac{6.25^3}{6} + [6.25 \cdot R_3 + M_3 + M_2] \cdot \frac{6.25^2}{2} + C_3 \cdot 6.25 + C_4$$

moment at C with section 2 equation

$$M_C = [R_3 + R_2] \cdot 18 + 6.25 \cdot R_3 + M_3 + M_2$$

angle at C with section 2 equation

$$E \cdot I \cdot t_C = [R_3 + R_2] \cdot \frac{18^2}{2} + [6.25 \cdot R_3 + M_3 + M_2] \cdot 18 + C_3$$

deflection at C with sec. 2 equation

APPENDIX F CONTINUED

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$$E \cdot I \cdot x_C = [R_3 + R_2] \cdot \frac{18^3}{6} + [6.25 \cdot R_3 + M_3 + M_2] \cdot \frac{18^2}{2} + C_3 \cdot 6.25 + C_4$$

moment at C with section 3 equation

$$M_C = [R_3 + R_2 - 100] \cdot 18 + 11.75 \cdot R_2 + 18 \cdot R_3 + M_3 + M_2$$

angle at C with section 3 equation

$$E \cdot I \cdot t_C = [R_3 + R_2 - 100] \cdot \frac{18^2}{2} + [11.75 \cdot R_2 + 18 \cdot R_3 + M_3 + M_2] \cdot 18 + C_5$$

deflection at C with sec. 3 equation

$$E \cdot I \cdot x_C = [R_3 + R_2 - 100] \cdot \frac{18^3}{6} + [11.75 \cdot R_2 + 18 \cdot R_3 + M_3 + M_2] \cdot \frac{18^2}{2} + C_5 \cdot 18 + C_6$$

moment at D with section 3 equation

$$M_D = [R_3 + R_2 - 100] \cdot 27 + 11.75 \cdot R_2 + 18 \cdot R_3 + M_3 + M_2$$

angle at D with section 3 equation

$$E \cdot I \cdot t_D = [R_3 + R_2 - 100] \cdot \frac{27^2}{2} + [11.75 \cdot R_2 + 18 \cdot R_3 + M_3 + M_2] \cdot 27 + C_5$$

deflection at D with sec. 3 equation

$$E \cdot I \cdot x_D = [R_3 + R_2 - 100] \cdot \frac{27^3}{6} + [11.75 \cdot R_2 + 18 \cdot R_3 + M_3 + M_2] \cdot \frac{27^2}{2} + C_5 \cdot 27 + C_6$$

moment at D with section 4 equation

$$M_D = [R_1 + R_2 + R_3 - 106] \cdot 27 + 27 \cdot R_3 + 20.75 \cdot R_2 - 900 + M_3 + M_2 + M_1$$

angle at D with section 4 equation

$$E \cdot I \cdot t_D = [R_1 + R_2 + R_3 - 106] \cdot \frac{27^2}{2} + [27 \cdot R_3 + 20.75 \cdot R_2 - 900 + M_3 + M_2 + M_1] \cdot 27 + C_7$$

deflection at D with sec. 4 equation

$$E \cdot I \cdot x_D = [R_1 + R_2 + R_3 - 106] \cdot \frac{27^3}{6} + [27 \cdot R_3 + 20.75 \cdot R_2 - 900 + M_3 + M_2 + M_1] \cdot \frac{27^2}{2} + C_7 \cdot 27 + C_8$$

Constants

Mod. of Elasticity of Aluminum

APPENDIX F CONTINUED

File:Main_Beam_x.EES 12/2/2011 10:38:51 AM Page 3
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$$E = 1.04 \times 10^7$$

Moment of Inertia of Schedule 40 2in nominal

$$I = \frac{3.14159}{64} \cdot \left[2.38^4 - 2.07^4 \right]$$

End Condition

moment must be zero at the end of the beam

$$0 = \left[R_1 + R_2 + R_3 - 106 \right] \cdot 47 + 27 \cdot R_3 + 20.75 \cdot R_2 - 900 + M_3 + M_2 + M_1$$

SOLUTION

Unit Settings: SI C kPa kJ mass deg

C_3 = -9675	C_4 = 20156
C_5 = -25875	C_6 = 231034
C_7 = -114163	C_8 = 1.025E+06
E = 1.040E+07	I = 0.6737
M_1 = 6061	M_2 = -957.4
M_3 = -2552	M_B = 1502
M_C = 3302	M_D = 3780
R_1 = -236.2	R_2 = -495.3
R_3 = 648.5	t_B = -0.0004682
t_C = 0.003559	t_D = 0.008108
x_B = -0.003346	x_C = 0.02808
x_D = 0.08013	

No unit problems were detected.

\

APPENDIX F CONTINUED

X-direction

y	force (V)	moment (M)	Normal Stress (σ)	shear stress (τ)
(inches)	(lbs)	(in*lbs)	(psi)	(psi)
0.0	0.0			
0.0	648.5	-2552.0	-4507.6	1197.1
1.0	648.5	-1903.5	-3362.1	1197.1
2.0	648.5	-1255.0	-2216.7	1197.1
3.0	648.5	-606.5	-1071.3	1197.1
4.0	648.5	42.0	74.2	1197.1
5.0	648.5	690.5	1219.6	1197.1
6.0	648.5	1339.0	2365.1	1197.1
6.3	648.5	1501.1	2651.4	1197.1
6.3	153.2	1501.2	2651.6	282.8
7.0	153.2	1616.1	2854.6	282.8
8.0	153.2	1769.3	3125.1	282.8
9.0	153.2	1922.5	3395.7	282.8
10.0	153.2	2075.7	3666.3	282.8
11.0	153.2	2228.9	3936.9	282.8
12.0	153.2	2382.1	4207.5	282.8
13.0	153.2	2535.3	4478.1	282.8
14.0	153.2	2688.5	4748.7	282.8
15.0	153.2	2841.7	5019.3	282.8
16.0	153.2	2994.9	5289.9	282.8
17.0	153.2	3148.1	5560.5	282.8
18.0	153.2	3301.3	5831.1	282.8
18.0	53.2	3301.4	5831.3	98.2
19.0	53.2	3354.6	5925.3	98.2
20.0	53.2	3407.8	6019.2	98.2
21.0	53.2	3461.0	6113.2	98.2
22.0	53.2	3514.2	6207.2	98.2
23.0	53.2	3567.4	6301.1	98.2
24.0	53.2	3620.6	6395.1	98.2
25.0	53.2	3673.8	6489.1	98.2

APPENDIX F CONTINUED

26.0	53.2	3727.0	6583.0	98.2
27.0	53.2	3780.2	6677.0	98.2
27.0	-189.0	3780.6	6677.7	-348.9
28.0	-189.0	3591.6	6343.9	-348.9
29.0	-189.0	3402.6	6010.0	-348.9
30.0	-189.0	3213.6	5676.2	-348.9
31.0	-189.0	3024.6	5342.4	-348.9
32.0	-189.0	2835.6	5008.5	-348.9
33.0	-189.0	2646.6	4674.7	-348.9
34.0	-189.0	2457.6	4340.9	-348.9
35.0	-189.0	2268.6	4007.1	-348.9
36.0	-189.0	2079.6	3673.2	-348.9
37.0	-189.0	1890.6	3339.4	-348.9
38.0	-189.0	1701.6	3005.6	-348.9
39.0	-189.0	1512.6	2671.7	-348.9
40.0	-189.0	1323.6	2337.9	-348.9
41.0	-189.0	1134.6	2004.1	-348.9
42.0	-189.0	945.6	1670.3	-348.9
43.0	-189.0	756.6	1336.4	-348.9
44.0	-189.0	567.6	1002.6	-348.9
45.0	-189.0	378.6	668.8	-348.9
46.0	-189.0	189.6	334.9	-348.9
47.0	-189.0	0.6	1.1	-348.9

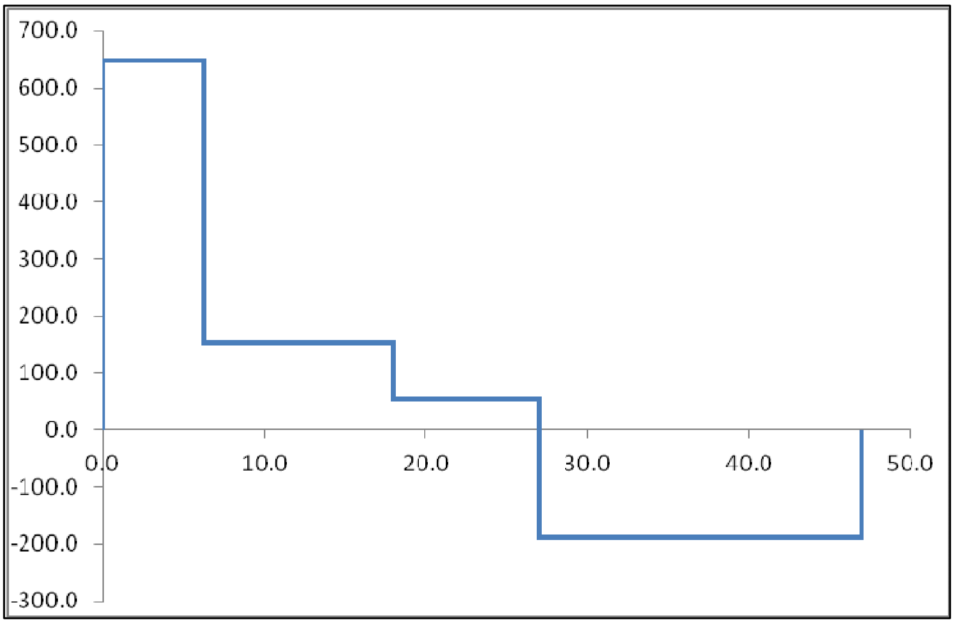
d_i =	2.07
d_o =	2.38
I =	0.67
A =	1.08

R1 =	-236.2	M1 =	6061
R2 =	-495.3	M2 =	-957.4
R3 =	648.5	M3 =	-2552

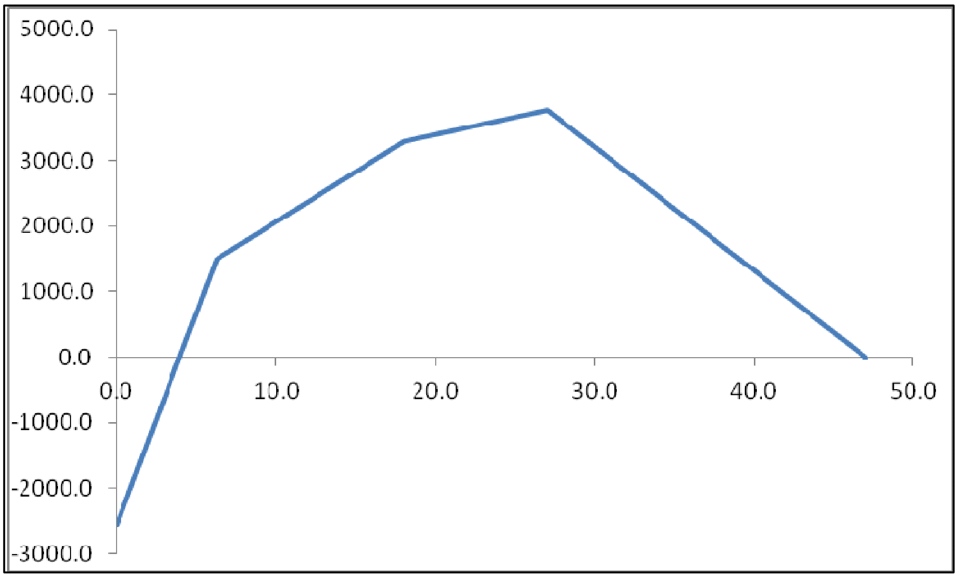
σ_{max} =	6677.70	τ_{max} =	1197.10

APPENDIX F CONTINUED

Shear Diagram of X Direction

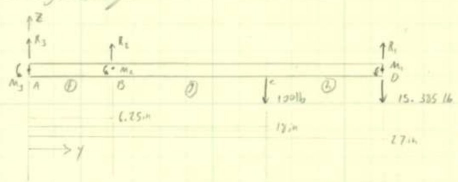


Moment Diagram of X Direction



APPENDIX F CONTINUED

Main leg Z only



Statics

$\Sigma F_z = 0$

$0 = R_3 + R_2 - 100\,lb - 15.385 + R_1$

$0 = R_1 + R_2 + R_3 - 115.385$

$\Sigma M_A = 0$

$0 = M_3 + R_2(6.25in) + M_2 - (100lb)(18in) - (15.385lb)(27in) + R_1(27in) + M_1$

$0 = M_1 + M_2 + M_3 + 27R_1 + 6.25R_2 - 2215.395$

Shear, Moment, slope & deflection equations

A-B (section f):

$V_f = R_3$

$M_f = R_3 y + M_3$

$EI\theta_f = R_3 \frac{y^2}{2} + M_3 y + c_1$ * Assume $\theta = 0$ at $y = 0$ $\therefore c_1 = 0$

$EI z_f = R_3 \frac{y^3}{6} + M_3 \frac{y^2}{2}\ c_2$ * Assume $z = 0$ at $y = 0$ $\therefore c_2 = 0$

B-C (section g):

$V_g = R_3 + R_2$

$M_g = (R_2 + R_3)y + [M_3 + M_2 + 6.25R_3]$

$EI\theta_g = (R_2 + R_3)\frac{y^2}{2} + [M_3 + M_2 + 6.25R_3]y + c_3$

$EI z_g = (R_2 + R_3)\frac{y^3}{6} + [M_3 + M_2 + 6.25R_3]\frac{y^2}{2} + c_3 y + c_4$

C-D (section h):

$V_h = R_3 + R_2 - 100$

$M_h = (R_2 + R_3 - 100)y + [M_3 + M_2 + 18R_3 + 11.75R_2]$

$EI\theta_h = (R_2 + R_3 - 100)\frac{y^2}{2} + [M_2 + M_3 + 11.75R_2 + 18R_3]y + c_5$

$EI z_h = (R_2 + R_3 - 100)\frac{y^3}{6} + [M_2 + M_3 + 11.75R_2 + 18R_3]\frac{y^2}{2} + c_5 y + c_6$

APPENDIX F CONTINUED

File:Main_Beam_z.EES 12/2/2011 10:42:01 AM Page 1
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Finding Reactions and Moments on main leg in z

Statics

sum of forces

$$0 = R_1 + R_2 + R_3 - 115.385$$

Moment about bottom

$$0 = M_3 + M_2 + M_1 + 6.25 \cdot R_2 + 27 \cdot R_1 - 2215.395$$

slope and deflection equations

moment at B with section 1 equation

$$M_B = R_3 \cdot 6.25 + M_3$$

angle at B with section 1 equation

$$E \cdot I \cdot t_B = R_3 \cdot \frac{6.25^2}{2} + M_3 \cdot 6.25$$

deflection at B with sec. 1 equation

$$E \cdot I \cdot z_B = R_3 \cdot \frac{6.25^3}{6} + M_3 \cdot \frac{6.25^2}{2}$$

moment at B with section 2 equation

$$M_B = [R_3 + R_2] \cdot 6.25 + 6.25 \cdot R_3 + M_3 + M_2$$

angle at B with section 2 equation

$$E \cdot I \cdot t_B = [R_3 + R_2] \cdot \frac{6.25^2}{2} + [6.25 \cdot R_3 + M_3 + M_2] \cdot 6.25 + C_3$$

deflection at B with sec. 2 equation

$$E \cdot I \cdot z_B = [R_3 + R_2] \cdot \frac{6.25^3}{6} + [6.25 \cdot R_3 + M_3 + M_2] \cdot \frac{6.25^2}{2} + C_3 \cdot 6.25 + C_4$$

moment at C with section 2 equation

$$M_C = [R_3 + R_2] \cdot 18 + 6.25 \cdot R_3 + M_3 + M_2$$

angle at C with section 2 equation

$$E \cdot I \cdot t_C = [R_3 + R_2] \cdot \frac{18^2}{2} + [6.25 \cdot R_3 + M_3 + M_2] \cdot 18 + C_3$$

deflection at C with sec. 2 equation

APPENDIX F CONTINUED

File:Main_Beam_z.EES 12/2/2011 10:42:03 AM Page 2
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$$E \cdot I \cdot z_C = [R_3 + R_2] \cdot \frac{18^3}{6} + [6.25 \cdot R_3 + M_3 + M_2] \cdot \frac{18^2}{2} + C_3 \cdot 6.25 + C_4$$

moment at C with section 3 equation

$$M_C = [R_3 + R_2 - 100] \cdot 18 + 11.75 \cdot R_2 + 18 \cdot R_3 + M_3 + M_2$$

angle at C with section 3 equation

$$E \cdot I \cdot t_C = [R_3 + R_2 - 100] \cdot \frac{18^2}{2} + [11.75 \cdot R_2 + 18 \cdot R_3 + M_3 + M_2] \cdot 18 + C_5$$

deflection at C with sec. 3 equation

$$E \cdot I \cdot z_C = [R_3 + R_2 - 100] \cdot \frac{18^3}{6} + [11.75 \cdot R_2 + 18 \cdot R_3 + M_3 + M_2] \cdot \frac{18^2}{2} + C_5 \cdot 18 + C_6$$

Constants

Mod. of Elasticity of Aluminum

$$E = 1.04 \times 10^7$$

Moment of Inertia of Schedule 40 2in nominal

$$I = \frac{3.14159}{64} \cdot [2.38^4 - 2.07^4]$$

Assumptions

Slope at B is zero

$$t_B = 0$$

Slope at D is zero

$$0 = [R_3 + R_2 - 100] \cdot \frac{27^2}{2} + [11.75 \cdot R_2 + 18 \cdot R_3 + M_3 + M_2] \cdot 27 + C_5$$

SOLUTION

Unit Settings: SI C kPa kJ mass deg

C_3 = 11706	C_4 = -24387
C_5 = -4494	C_6 = -64728
E = 1.040E+07	I = 0.6737
M_1 = -946.4	M_2 = -957.4
M_3 = 1394	M_B = -1394
M_C = 405.8	R_1 = -37.81
R_2 = 599.3	R_3 = -446.1
t_B = 0	t_C = -0.0008287
z_B = 0.001295	z_C = -0.02616

APPENDIX F CONTINUED

d_i =	2.07
d_o =	2.38
I =	0.67
A =	1.08

R1 =	-37.81	M1 =	-946.4
R2 =	599.3	M2 =	-957.4
R3 =	-446.1	M3 =	1394

σ_{max} =	2462.21	τ_{max} =	282.80

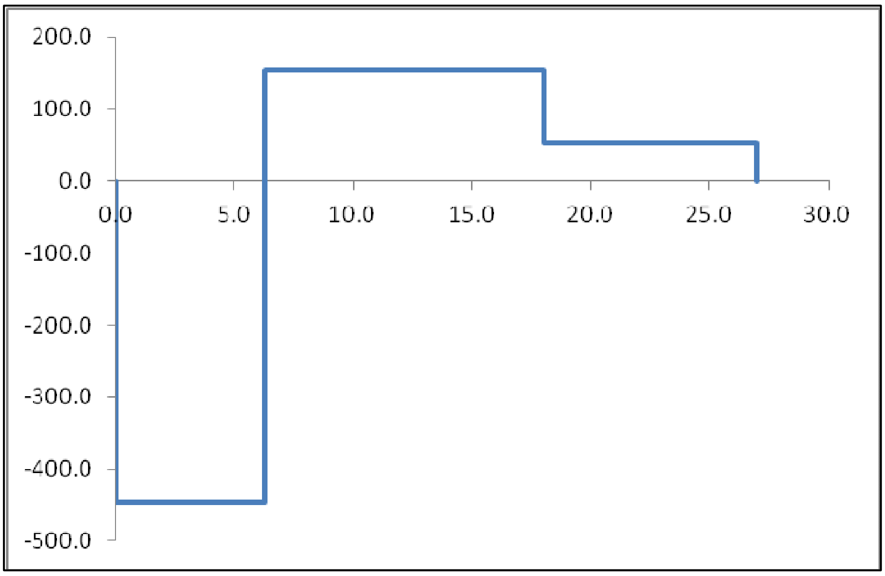
Z-direction

y (inches)	force (V) (lbs)	moment (M) (in*lbs)	Normal Stress (σ) (psi)	shear stress (τ) (psi)
0.0	0.0			
0.0	-446.1	1394.0	2462.2	-823.5
1.0	-446.1	947.9	1674.3	-823.5
2.0	-446.1	501.8	886.3	-823.5
3.0	-446.1	55.7	98.4	-823.5
4.0	-446.1	-390.4	-689.6	-823.5
5.0	-446.1	-836.5	-1477.5	-823.5
6.0	-446.1	-1282.6	-2265.4	-823.5
6.3	-446.1	-1394.1	-2462.4	-823.5
6.3	153.2	-1394.0	-2462.3	282.8
7.0	153.2	-1279.1	-2259.3	282.8
8.0	153.2	-1125.9	-1988.7	282.8
9.0	153.2	-972.7	-1718.1	282.8
10.0	153.2	-819.5	-1447.5	282.8
11.0	153.2	-666.3	-1176.9	282.8
12.0	153.2	-513.1	-906.3	282.8
13.0	153.2	-359.9	-635.7	282.8
14.0	153.2	-206.7	-365.1	282.8
15.0	153.2	-53.5	-94.5	282.8

APPENDIX F CONTINUED

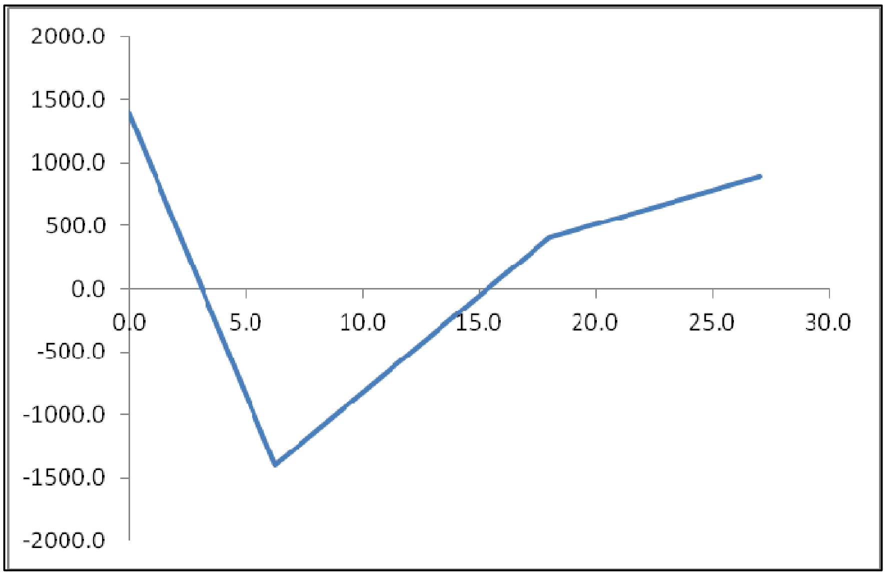
16.0	153.2	99.7	176.1	282.8
17.0	153.2	252.9	446.7	282.8
18.0	153.2	406.1	717.2	282.8
18.0	53.2	406.2	717.4	98.2
19.0	53.2	459.4	811.4	98.2
20.0	53.2	512.6	905.4	98.2
21.0	53.2	565.8	999.3	98.2
22.0	53.2	619.0	1093.3	98.2
23.0	53.2	672.2	1187.3	98.2
24.0	53.2	725.4	1281.2	98.2
25.0	53.2	778.6	1375.2	98.2
26.0	53.2	831.8	1469.2	98.2
27.0	53.2	885.0	1563.1	98.2

Shear Diagram of Z Direction Forces



APPENDIX F CONTINUED

Moment Diagram of Z Direction Forces



APPENDIX F CONTINUED

d_i =	1.61
d_o =	1.90
I =	0.31
A =	0.80

absolutes

σmax =	11983.0
τmax =	5993.0

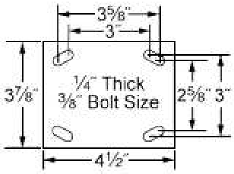
*see DSC_0197 for layout

						j				l				k			
y	Vx	Vz	Mz	Mx	P	σ	τ	σmax	τmax	σ	τ	σmax	τmax	σ	τ	σmax	τmax
(inches)	(lbs)	(lbs)	(in lbs)	(in lbs)	(lbs)	(psi)	(psi)	(psi)	(psi)	(psi)	(psi)	(psi)	(psi)	(psi)	(psi)	(psi)	(psi)
0.00	648.50	-446.10	-2552.00	1394.00	203.62	8078.0	1622.4	8391.7	4352.7	8078.0	1116.0	8229.4	4190.4	9169.1	1969.1	9574.1	4989.5
1.00	648.50	-446.10	-1903.50	947.90	203.62	6090.0	1622.4	6495.2	3450.2	6090.0	1116.0	6288.1	3243.1	6773.5	1969.1	7304.3	3917.6
2.00	648.50	-446.10	-1255.00	501.80	203.62	4102.0	1622.4	4666.1	2615.1	4102.0	1116.0	4385.9	2335.0	4398.1	1969.1	5150.9	2951.8
3.00	648.50	-446.10	-606.50	55.70	203.62	2114.0	1622.4	2993.3	1936.3	2114.0	1116.0	2594.1	1537.1	2121.8	1969.1	3297.6	2236.7
4.00	648.50	-446.10	42.00	-390.40	203.62	383.5	1622.4	1825.4	1633.6	383.5	1116.0	1324.1	1132.4	1458.4	1969.1	2829.0	2099.8
5.00	648.50	-446.10	690.50	-836.50	203.62	2371.5	1622.4	3195.2	2009.5	2371.5	1116.0	2814.1	1628.3	3579.8	1969.1	4451.0	2661.1
6.00	648.50	-446.10	1339.00	-1282.60	203.62	4359.5	1622.4	4897.0	2717.2	4359.5	1116.0	4628.6	2448.8	5938.8	1969.1	6532.4	3563.0
6.25	648.50	-446.10	1501.13	-1394.13	203.62	4856.5	1622.4	5348.6	2920.3	4856.5	1116.0	5100.7	2672.4	6535.0	1969.1	7082.4	3815.0
6.25	153.20	153.20	1501.23	-1394.02	203.62	4856.8	383.3	4886.9	2458.5	4856.8	383.3	4886.9	2458.5	6535.0	542.0	6579.6	3312.1
7.00	153.20	153.20	1616.13	-1279.13	203.62	5209.0	383.3	5237.1	2632.6	5209.0	383.3	5237.1	2632.6	6573.0	542.0	6617.4	3330.9
8.00	153.20	153.20	1769.33	-1125.93	203.62	5678.7	383.3	5704.4	2865.1	5678.7	383.3	5704.4	2865.1	6683.8	542.0	6727.4	3385.6
9.00	153.20	153.20	1922.53	-972.73	203.62	6148.3	383.3	6172.1	3098.0	6148.3	383.3	6172.1	3098.0	6859.8	542.0	6902.3	3472.4
10.00	153.20	153.20	2075.73	-819.53	203.62	6618.0	383.3	6640.1	3331.1	6618.0	383.3	6640.1	3331.1	7096.0	542.0	7137.1	3589.1
11.00	153.20	153.20	2228.93	-666.33	203.62	7087.6	383.3	7108.3	3564.5	7087.6	383.3	7108.3	3564.5	7386.4	542.0	7426.0	3732.8
12.00	153.20	153.20	2382.13	-513.13	203.62	7557.3	383.3	7576.6	3798.0	7557.3	383.3	7576.6	3798.0	7724.7	542.0	7762.6	3900.2
13.00	153.20	153.20	2535.33	-359.93	203.62	8026.9	383.3	8045.2	4031.7	8026.9	383.3	8045.2	4031.7	8104.8	542.0	8140.9	4088.5
14.00	153.20	153.20	2688.53	-206.73	203.62	8496.5	383.3	8513.8	4265.5	8496.5	383.3	8513.8	4265.5	8520.9	542.0	8555.2	4294.8
15.00	153.20	153.20	2841.73	-53.53	203.62	8966.2	383.3	8982.5	4499.4	8966.2	383.3	8982.5	4499.4	8967.7	542.0	9000.4	4516.5
16.00	153.20	153.20	2994.93	99.67	203.62	9435.8	383.3	9451.4	4733.5	9435.8	383.3	9451.4	4733.5	9440.9	542.0	9471.9	4751.5
17.00	153.20	153.20	3148.13	252.87	203.62	9905.5	383.3	9920.3	4967.5	9905.5	383.3	9920.3	4967.5	9936.6	542.0	9966.0	4997.8
18.00	153.20	153.20	3301.33	406.07	203.62	10375.1	383.3	10389.3	5201.7	10375.1	383.3	10389.3	5201.7	10451.4	542.0	10479.4	5253.7
18.00	53.20	53.20	3301.43	406.18	62.50	10198.9	133.1	10200.6	5101.2	10198.9	133.1	10200.6	5101.2	10275.2	188.2	10278.7	5141.1
19.00	53.20	53.20	3354.63	459.37	62.50	10362.0	133.1	10363.7	5182.7	10362.0	133.1	10363.7	5182.7	10458.0	188.2	10461.4	5232.4
20.00	53.20	53.20	3407.83	512.57	62.50	10525.1	133.1	10526.8	5264.2	10525.1	133.1	10526.8	5264.2	10642.6	188.2	10645.9	5324.6
21.00	53.20	53.20	3461.03	565.77	62.50	10688.2	133.1	10689.8	5345.7	10688.2	133.1	10689.8	5345.7	10829.0	188.2	10832.3	5417.8
22.00	53.20	53.20	3514.23	618.97	62.50	10851.3	133.1	10852.9	5427.3	10851.3	133.1	10852.9	5427.3	11017.1	188.2	11020.3	5511.8
23.00	53.20	53.20	3567.43	672.17	62.50	11014.3	133.1	11016.0	5508.8	11014.3	133.1	11016.0	5508.8	11206.8	188.2	11209.9	5606.5
24.00	53.20	53.20	3620.63	725.37	62.50	11177.4	133.1	11179.0	5590.3	11177.4	133.1	11179.0	5590.3	11398.0	188.2	11401.1	5702.1
25.00	53.20	53.20	3673.83	778.57	62.50	11340.5	133.1	11342.1	5671.8	11340.5	133.1	11342.1	5671.8	11590.6	188.2	11593.7	5798.4
26.00	53.20	53.20	3727.03	831.77	62.50	11503.6	133.1	11505.1	5753.3	11503.6	133.1	11505.1	5753.3	11784.7	188.2	11787.7	5895.3
27.00	53.20	53.20	3780.23	884.97	62.50	11666.7	133.1	11668.2	5834.9	11666.7	133.1	11668.2	5834.9	11980.0	188.2	11983.0	5993.0

APPENDIX G: Pertinent Product Literature

Ezy-Roll Casters—300 to 550 lbs.

Swivel Rigid



- Formed steel welded frame with rivet kingpin
- Double ball swivel bearings
- 1/4" leg thickness
- NSF certified

Rubber wheels provide a cushioned ride. Casters are made of corrosion-resistant zinc-plated steel. For casters with the same design, but with higher-capacity wheels, see the Patriot Casters.

Wheel Size Dia.	Wd.	Mount Ht.	Cap. Ea., lbs.	Swivel	Each	Rigid	Each
Wheel with Straight Roller Bearings							
Black Rubber on Polypropylene Wheels—Durometer is 75A							
6"	1 1/2"	7 1/2"	300	2652T51	$27.10	2652T61	$23.23
Optional Side Wheel Brake for Swivel Casters—Field installable.				2531T75	Each		$12.02

The wheels we will be using will be the rigid model of the Ezy-Roll Caster from McMaster-Carr. (http://www.mcmaster.com/#standard-casters/=g2pir7)

Pouches

	Overall Size Wd.	Ht.	No. of Pockets	Max. Belt Wd.	Material		Each
16	6"	8 1/2"	1	2 1/2"	Nylon	7329A21	$11.44
16	7 1/2"	11"	1	2 1/2"	Nylon	7329A22	13.74
16	9"	15 3/4"	1	3"	Nylon	7329A66	15.65
17	12"	8 1/2"	1	4 1/2"	Nylon	7329A26	17.66
18	6 1/4"	9"	4	3 1/2"	Polyester	7337A64	11.38
20	9"	14 1/2"	13	2 3/4"	Polyester	8307T35*•	33.77
20	11 1/4"	14 1/2"	21	2 3/4"	Polyester	8307T36	37.18

* Comes with an 8" × 3" plastic storage box with 12 compartments.
• Includes a belt that fits waist size 26"- 52".

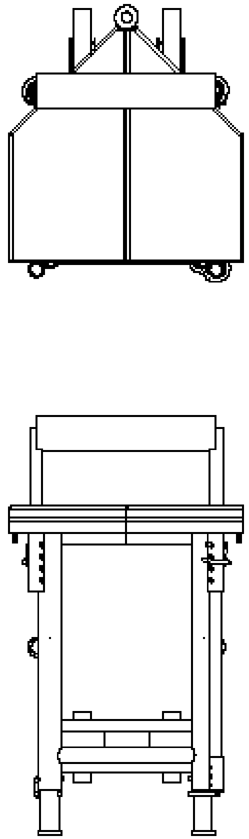
For the storage pouch, we will be attaching a hook to bottom of the top cross of the frame and hanging two of the #17 Fabric Belt Pouches from McMaster-Carr. (http://www.mcmaster.com/#tool-bags/=g2pj3m)

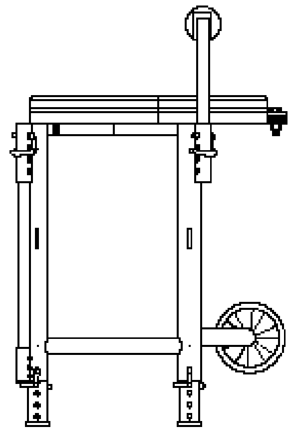
APPENDIX H: Bill of Materials and Cost Analysis

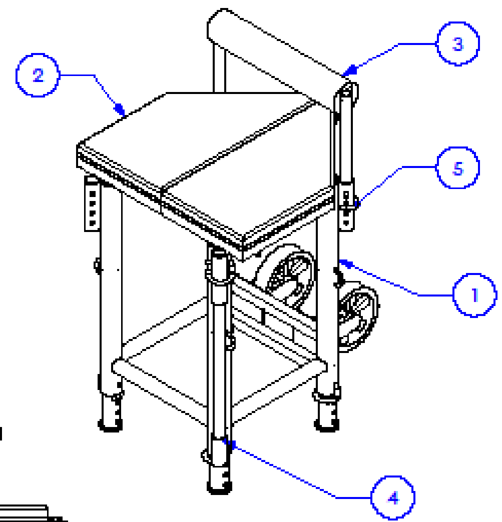
Material / Item	USD/unit	unit type	# of units	cost
6061 Aluminum 1 1/4" schedule 40	3.76	ft	4	15.04
6061 Aluminum 1 1/2" schedule 40	4.42	ft	8	35.36
6061 Aluminum 1" schedule 40	2.78	ft	5	13.9
6061 Aluminum 3/4" schedule 40	1.73	ft	4	6.92
6061 Aluminum 1/4" plate (9246K13)	20.11	12"x12"	1	20.11
6061 Aluminum 1" squre tube (1/8"thick) (6546K11)	27.25	6ft	3	81.75
6061 Aluminum 90° Angle 1"x1" 1/4"thick (8982K194)	19.18	4ft	1	19.18
Ezy-Roll Rigid Caster (2652T62)	29.73	1 wheel	2	59.46
1 1/2" Al. U-Bolt (3035T14)	2.99	1 prt	4	11.96
Gravity Pin (97529A100)	1.89	1 prt	7	13.23
0.19" Aluminum plate (89015K31)	37.41	12"x12"	1	37.41
3/8" MG Plywood (1125T23)	19.8	24x24	1	19.8
Heavy Hex Bolt (91583A121)	8.51	1 prt	1	8.51
Hex Nut (90371A045)	9.56	1 prt	1	9.56
Type 316 Bolt (93190A630)	7.11	1 pkg	2	14.22
6061 Aluminum 1" solid rod (8974K133)	19.34	3 ft	2	38.68
Handle Grip (9282K19)	14.08	1 pkg	1	14.08
Back rest foam (4463K124)	2.84	6 ft	1	2.84
Fabric Pouch (7329A26)	17.66	1 prt	1	17.66
Ratchet Tie-Downs (9116T61)	17.23	1 prt	4	68.92
Polyolefin Heat-Shrink (7852K11)	12.58	1 prt	2	25.16
Ground Anchor, 30" length, 1" eye ID (6300A26)	5.26	1 prt	4	21.04
Low Carbon Rod, 2" diam (8290T311)	29.32	ft	1	29.32
6061 1" square (9008K141)	10.81	ft	1	10.81
2 Flute End Mill, 1/2" diam (8949A55)	25.8	1 prt	1	25.8
Quick Release Button Connector (92988A770)	3.44	1 prt	1	3.44
Steel Locking Pin without Tab lock (98416A130)	2.09	1 prt	1	2.09
Steel Locking Pin for Pipe (90978A400)	2.68	1 prt	1	2.68
Steel Locking Pin (98416A215)	2.09	1 prt	1	2.09
Shipping	85.33	N/A	1	85.33
Welding (Gentry)	75	hr	5.5	412.5
Powder Coating (Full Spectrum)	25	frames	1	25
TOTAL				**1153.85**

NOTE: Materials available on McMaster-Carr's website have the product numbers included in the descriptions above. Non-numbered items and materials were purchased at McCarthy Steel, a local metal provider. Welding and powder coating services were both done locally in San Luis Obispo, company names are parenthetically referenced.

APPENDIX I: Assembly and Part Drawings





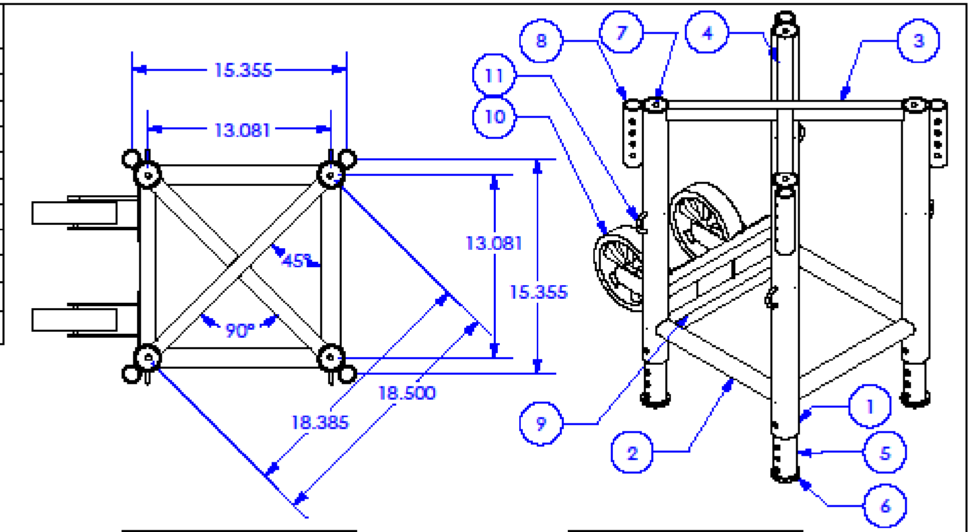


NO.	PART NUMBER	DESCRIPTION	QTY.
1	Z_100	FRAME	1
2	Z_200	MULTI-TOP SEAT	1
3	Z_300a	BACKREST	1
4	Z_300b	ARM BAR	1
5	97529A100	GRAVITY PIN	7

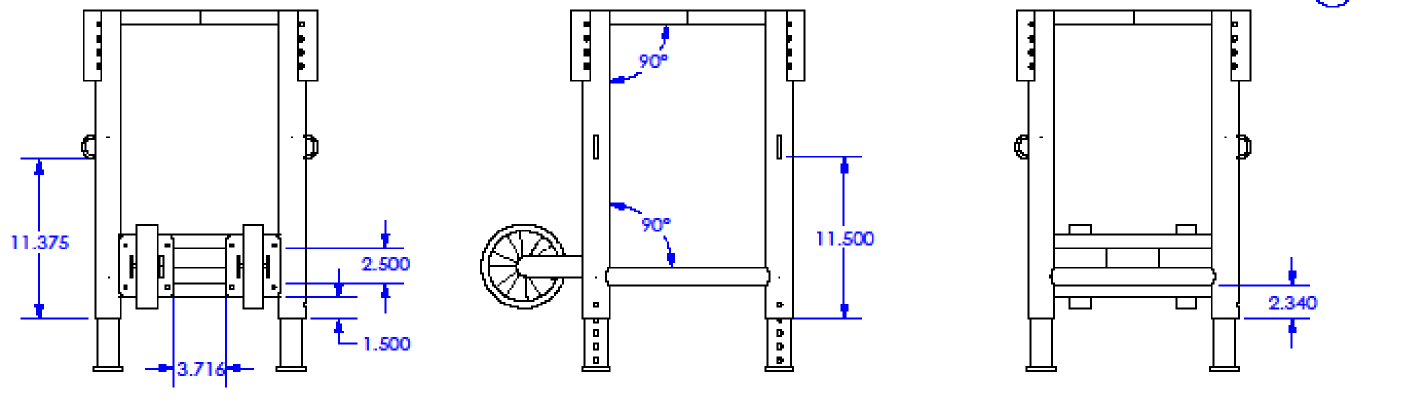
TEAM ZEUS Dissabled Sports Throwing Frame Mechanical Engineering CAL POLY	DATE: 2/2/12	UNITS: INCHES	MATERIAL: SEE PART SHEETS
	TOLERANCE:	SCALE: 1:12	TITLE: ZEUS THROWING FRAME
		NEXT ASSY: N/A	NAME: ANDREW HIGGINS
		DRAWING #: A-000	SIGNATURE:

APPENDIX I: Assembly and Part Drawings

NO.	PART NUMBER	DESCRIPTION	QTY.
1	Z_101	LEG	4
2	Z_102	FOOT BAR	3
3	Z_103	CROSS LONG	1
4	Z_104	CROSS SHORT	2
5	Z_105	TEL. FOOT	4
6	Z_106	FOOT	4
7	Z_107	RECEIVER	4
8	Z_108	ATTACH. REC.	4
9	Z_109	WHEEL MOUNT	2
10	Z_110	WHEELS	2
11	Z_111	TIE DOWN HOOK	4

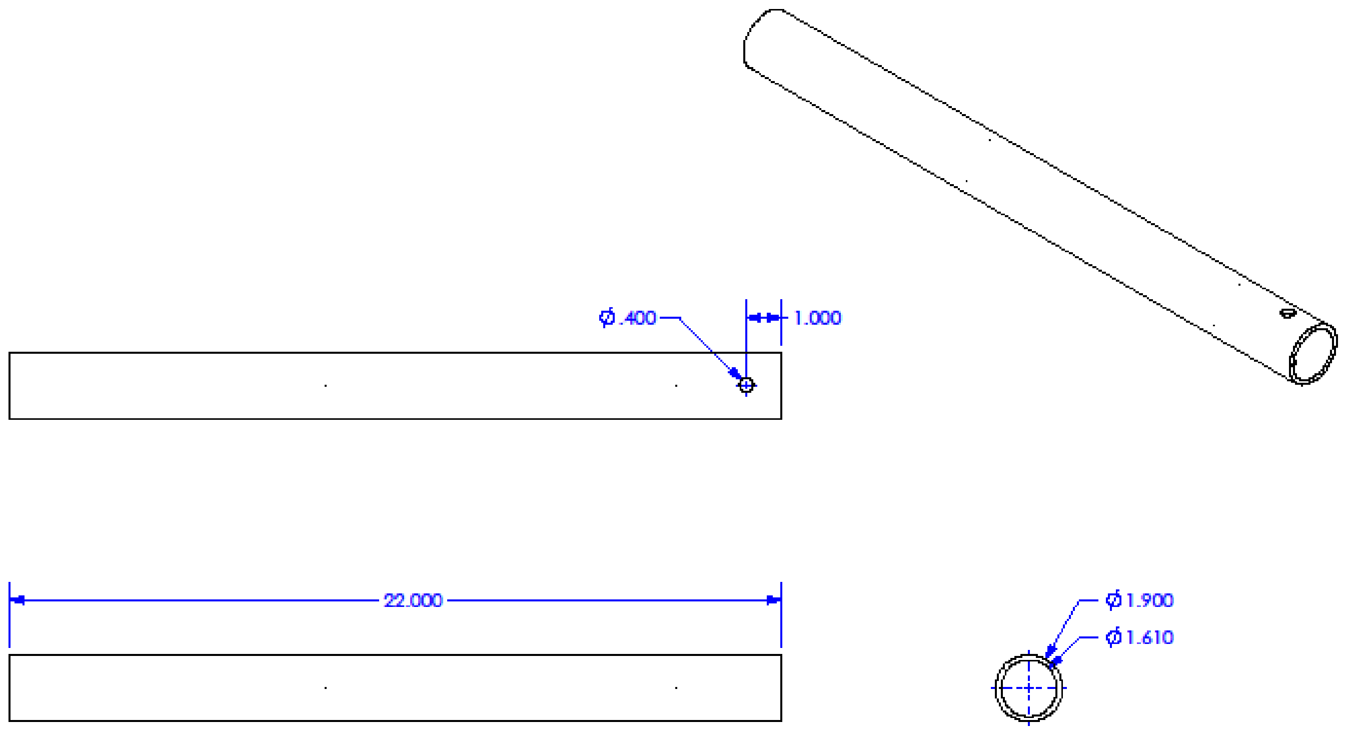


WELD NOTE: ALL WELDS ARE
0.125" GTAW, ALL AROUND, FLAT



TEAM ZEUS Dissabled Sports Throwing Frame Mechanical Engineering CAL POLY	DATE: 1/31/12	UNITS: INCHES	MATERIAL: SEE PART DRAWINGS
	TOLERANCE:	SCALE: 1:10	TITLE: FRAME ASSEMBLY
		NEXT ASSY: A-000	NAME: ANDREW HIGGINS
		DRAWING #: 100	SIGNATURE:

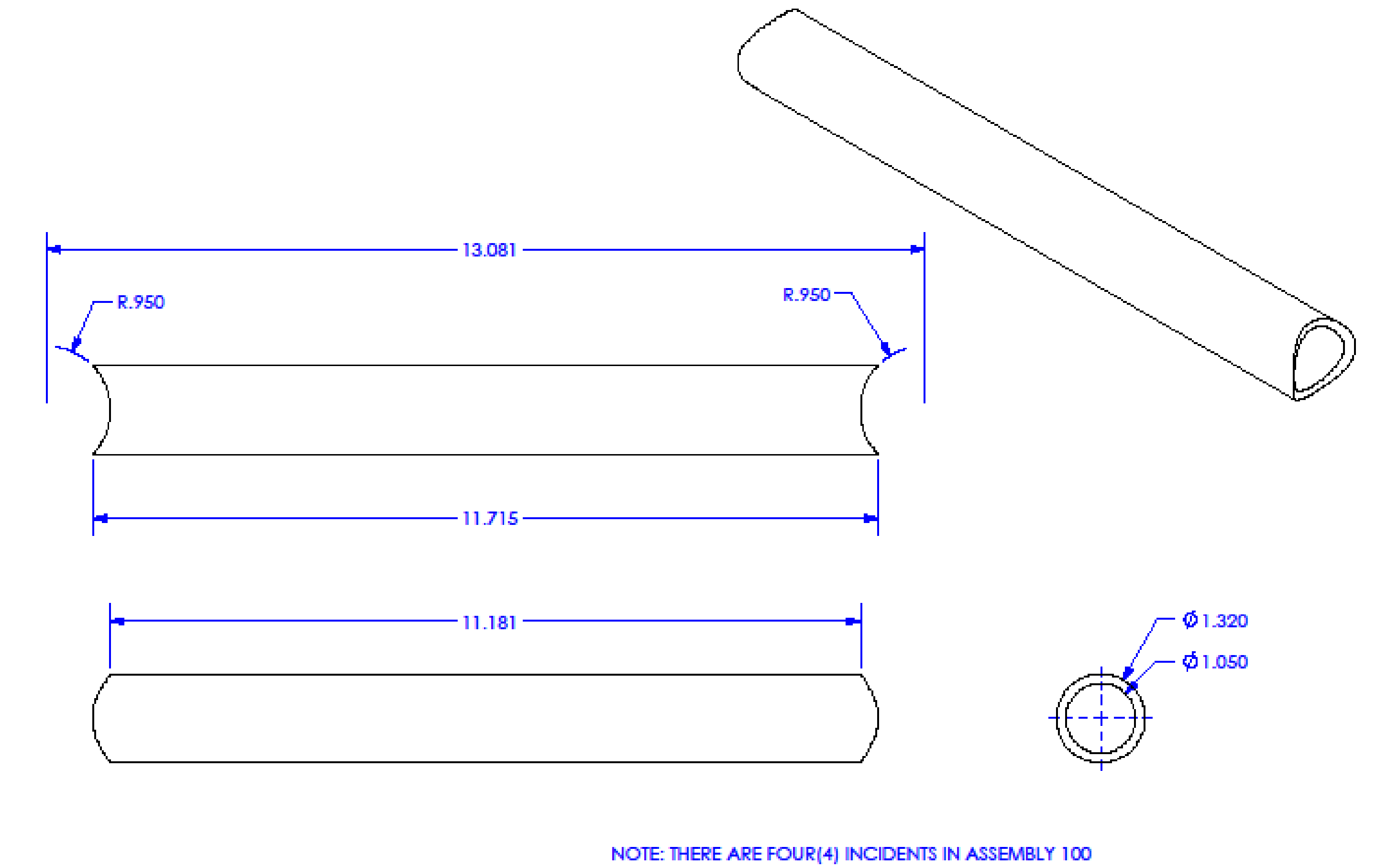
APPENDIX I: Assembly and Part Drawings



NOTE: THERE ARE FOUR(4) OCCURANCES IN ASSEMBLY 100

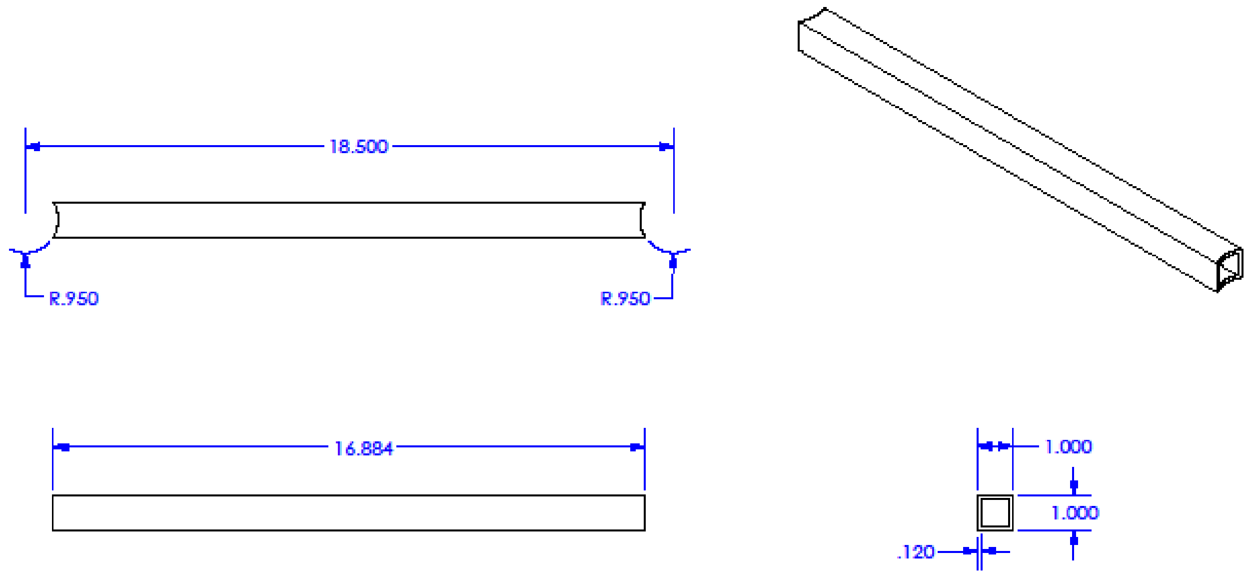
TEAM ZEUS Dissabled Sports Throwing Frame Mechanical Engineering CAL POLY	DATE: 1/27/12	UNITS: INCHES	MATERIAL: ALUMINUM
	TOLERANCE:	SCALE: 1:4	TITLE: LEG
		NEXT ASSY: 100	NAME: ANDREW HIGGINS
		DRAWING #: 101	SIGNATURE:

APPENDIX I: Assembly and Part Drawings



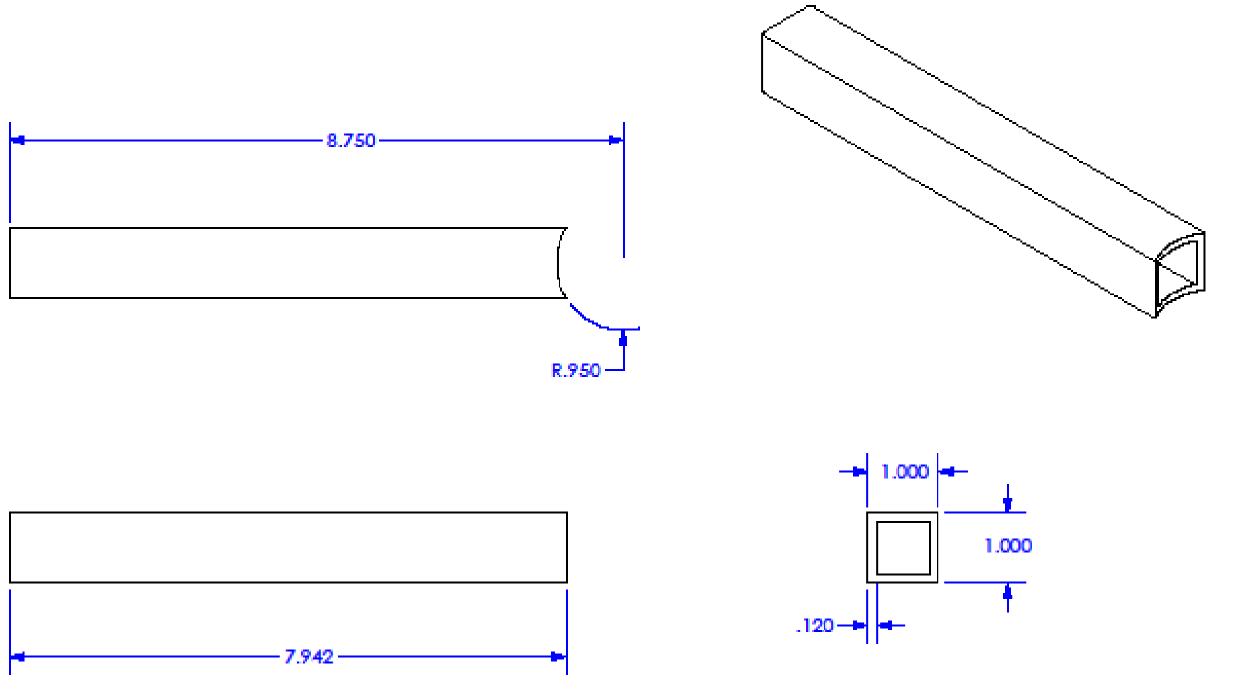
TEAM ZEUS Dissabled Sports Throwing Frame Mechanical Engineering CAL POLY	DATE: 1/27/12	UNITS: INCHES	MATERIAL: ALUMINUM
	TOLERANCE:	SCALE: 1:2	TITLE: FOOT BARS
		NEXT ASSY: 100	NAME: ANDREW HIGGINS
		DRAWING #: 102	SIGNATURE:

APPENDIX I: Assembly and Part Drawings



TEAM ZEUS Dissabled Sports Throwing Frame / Mechanical Engineering CAL POLY	DATE: 1/27/12	UNITS: INCHES	MATERIAL: ALUMINUM
	TOLERANCE:	SCALE: 1:4	TITLE: TOP CROSS - LONG
		NEXT ASSY: 100	NAME: ANDREW HIGGINS
		DRAWING #: 103	SIGNATURE:

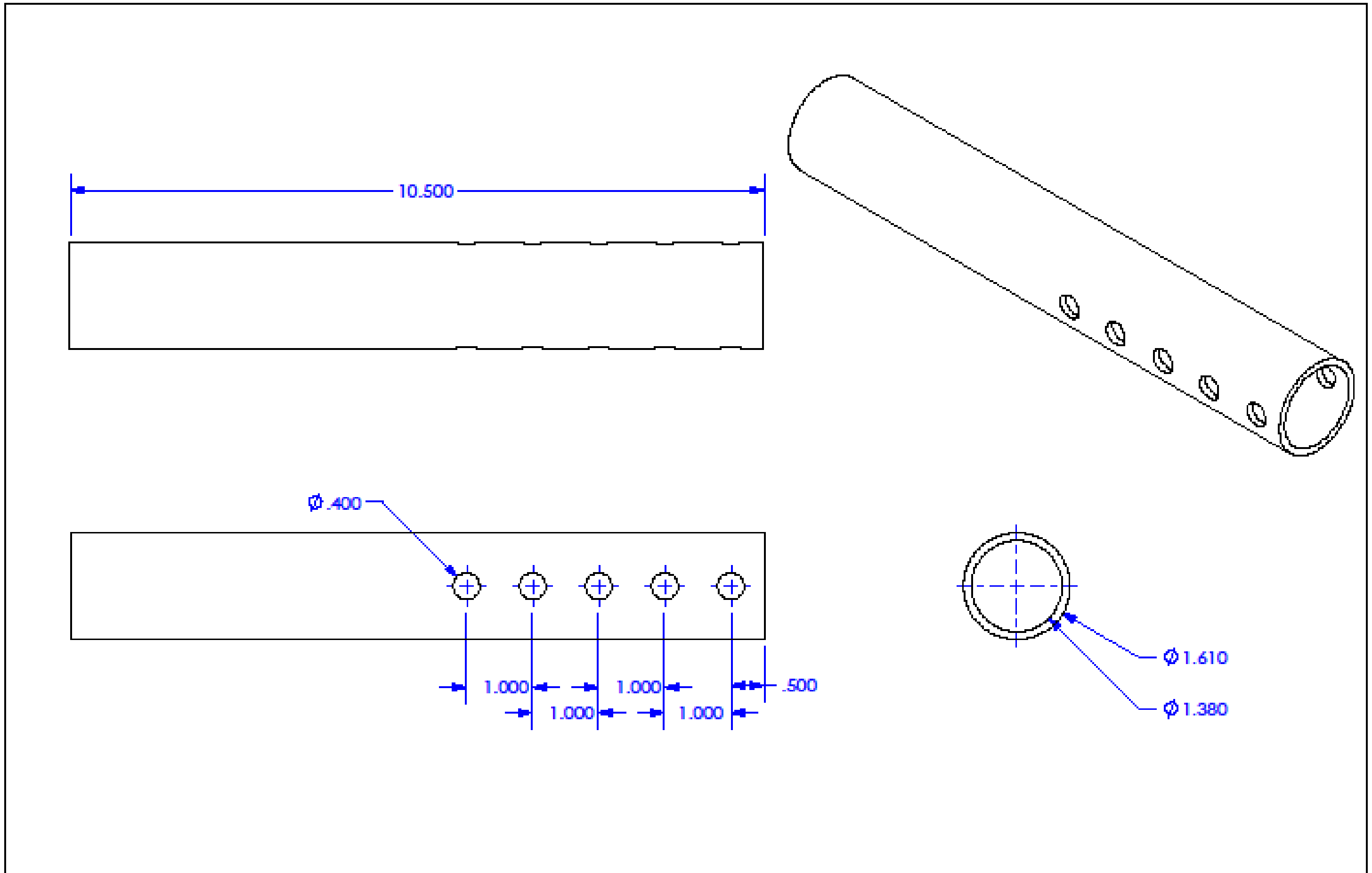
APPENDIX I: Assembly and Part Drawings



NOTE: THERE ARE TWO(2) INCIDENTS IN ASSEMBLY 100

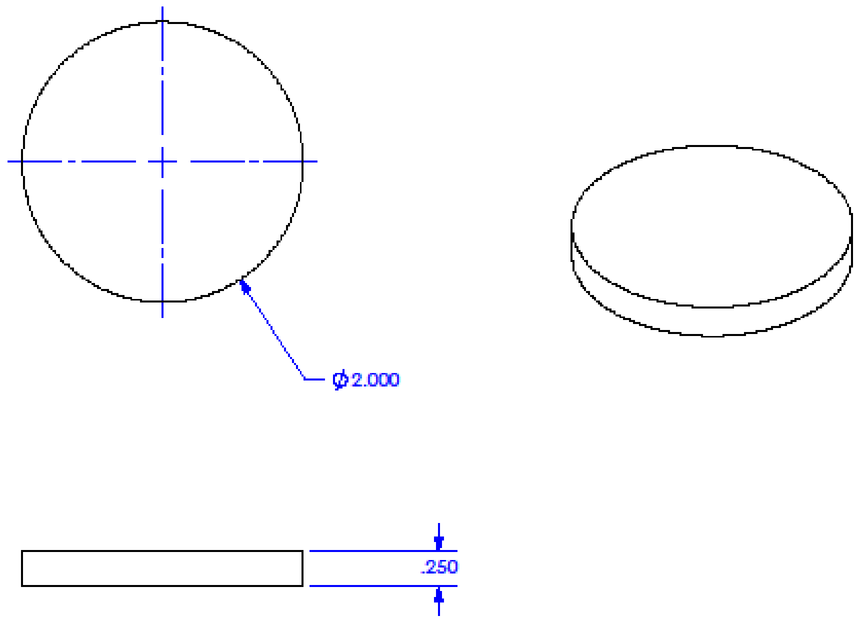
TEAM ZEUS Dissabled Sports Throwing Frame Mechanical Engineering CAL POLY	DATE: 1/27/12	UNITS: INCHES	MATERIAL: ALUMINUM
	TOLERANCE:	SCALE: 1:2	TITLE: FRAME TOP CROSS - SHORT
		NEXT ASSY: 100	NAME: ANDREW HIGGINS
		DRAWING #: 104	SIGNATURE:

APPENDIX I: Assembly and Part Drawings



TEAM ZEUS Dissabled Sports Throwing Frame Mechanical Engineering CAL POLY	DATE: 1/27/12	UNITS: INCHES	MATERIAL: ALUMINUM
	TOLERANCE:	SCALE: 1:2	TITLE: TELESCOPING FOOT
		NEXT ASSY: 100	NAME: ANDREW HIGGINS
		DRAWING #: 105	SIGNATURE:

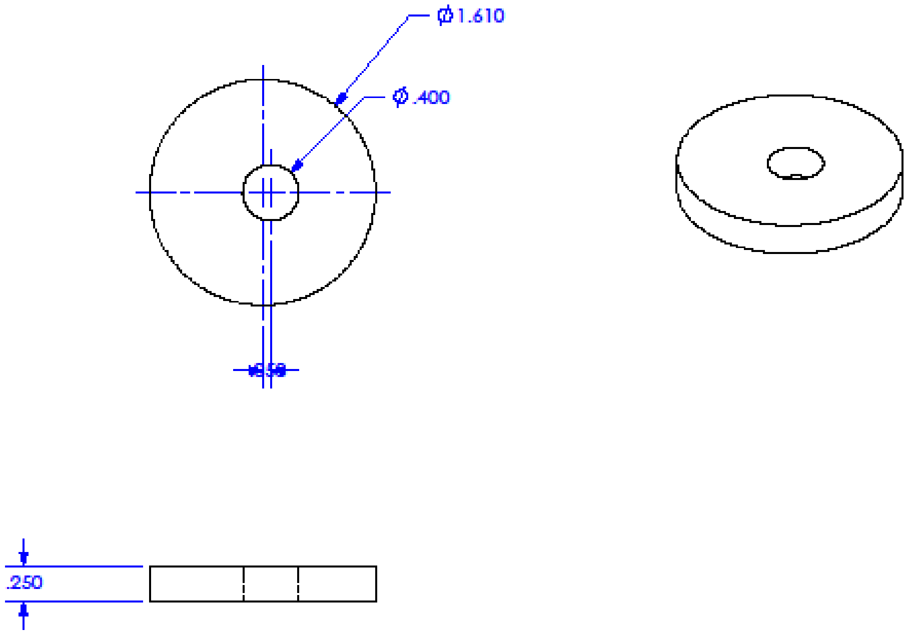
APPENDIX I: Assembly and Part Drawings



TEAM ZEUS Dissabled Sports Throwing Frame	DATE: 1/27/12	UNITS: INCHES	MATERIAL: ALUMINUM
Mechanical Engineering CAL POLY	TOLERANCE:	SCALE: 1:1	TITLE: FOOT
		NEXT ASSY: 100	NAME: ANDREW HIGGINS
		DRAWING #: 106	SIGNATURE:

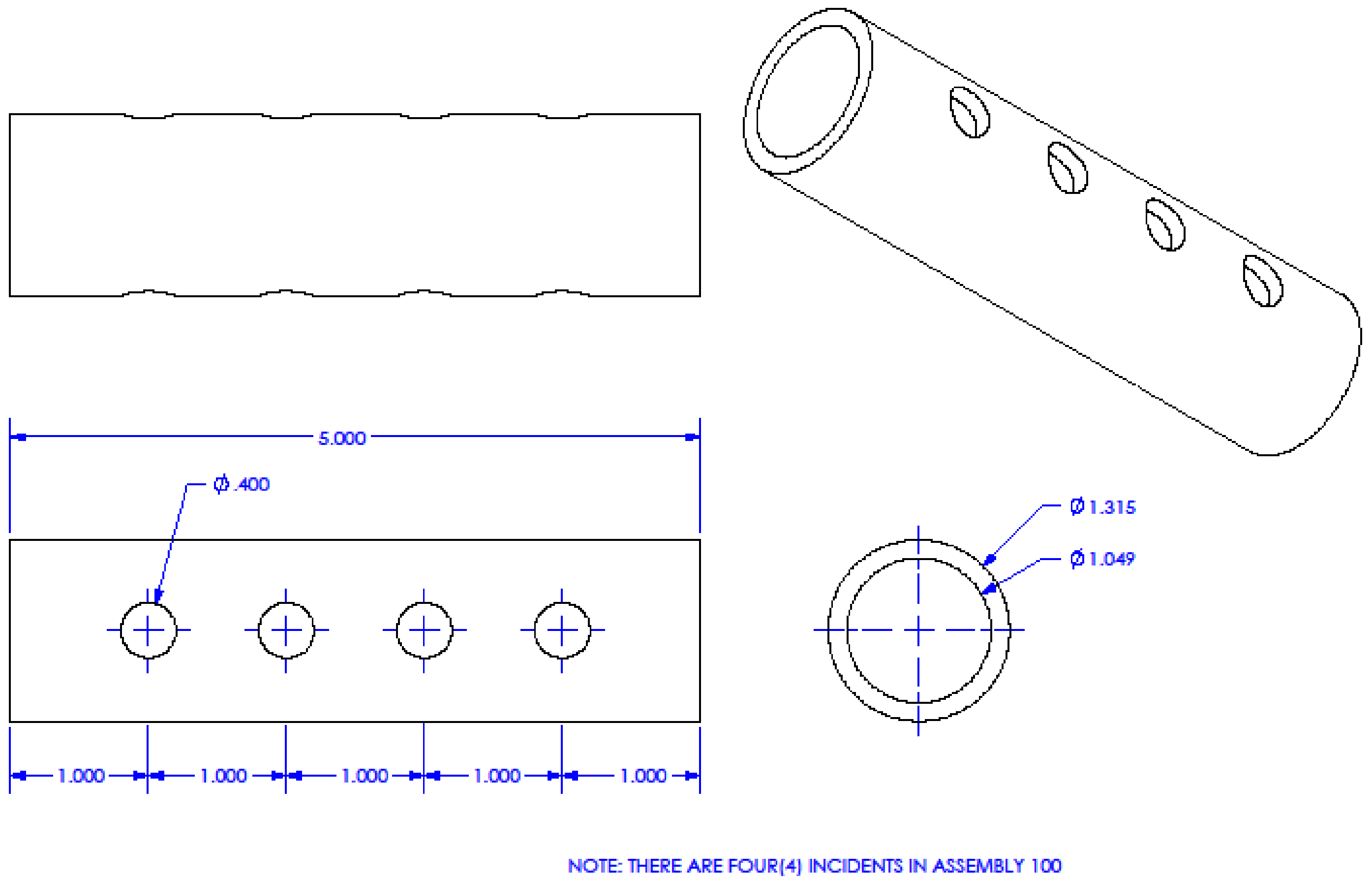
Team Zeus (Disabled Sports Throwing Frame)
California Polytechnic State University, San Luis Obispo
CPThrowingFrame@gmail.com

APPENDIX I: Assembly and Part Drawings



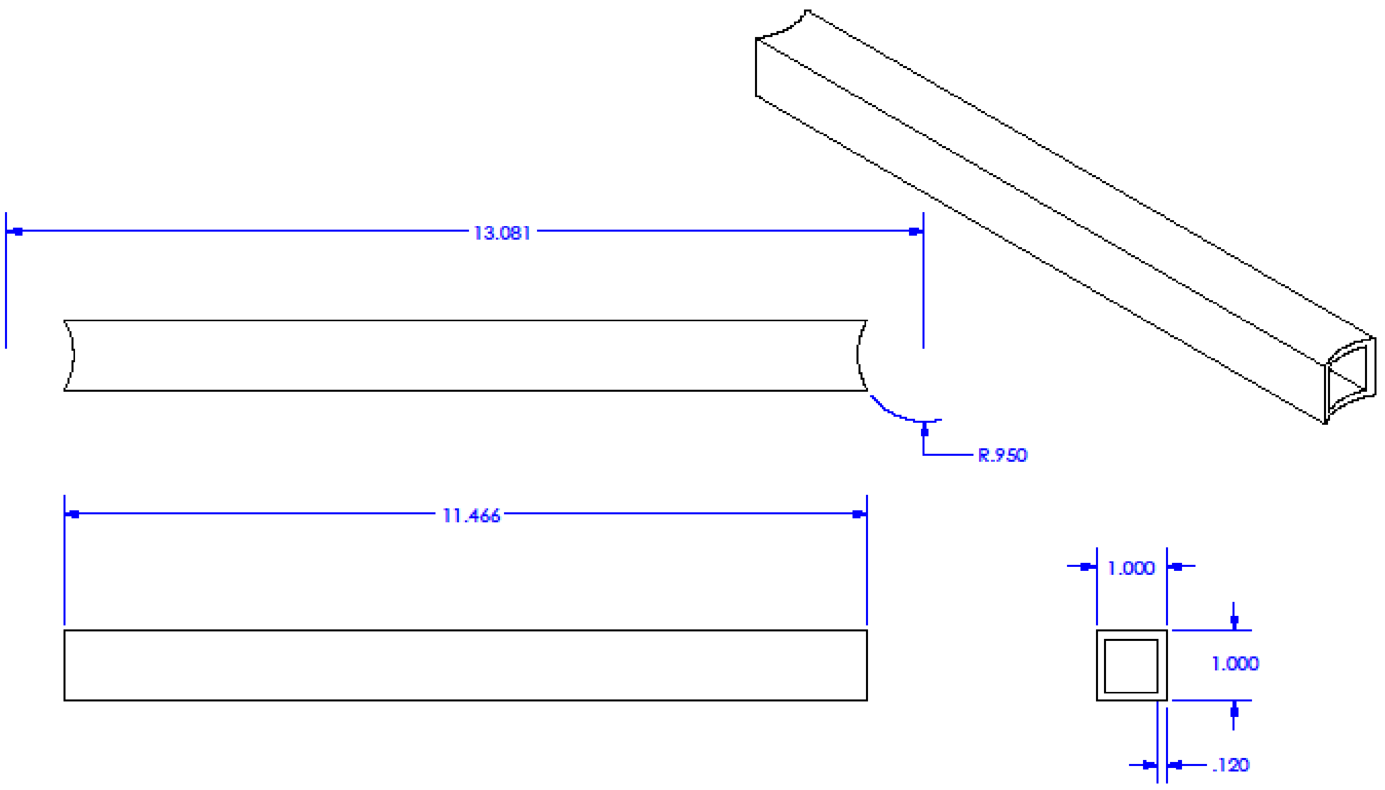
TEAM ZEUS Dissabled Sports Throwing Frame Mechanical Engineering	DATE: 1/27/12	UNITS: INCHES	MATERIAL: ALUMINUM
	TOLERANCE:	SCALE: 1:1	TITLE: SEAT RECEIVER
		NEXT ASSY: 100	NAME: ANDREW HIGGINS
		DRAWING #: 107	SIGNATURE:

APPENDIX I: Assembly and Part Drawings



TEAM ZEUS Dissabled Sports Throwing Frame Mechanical Engineering CAL POLY	DATE: 1/27/12	UNITS: INCHES	MATERIAL: ALUMINUM
	TOLERANCE:	SCALE: 1:2	TITLE: ATTACHMENT RECEIVER
		NEXT ASSY: 100	NAME: ANDREW HIGGINS
		DRAWING #: 108	SIGNATURE:

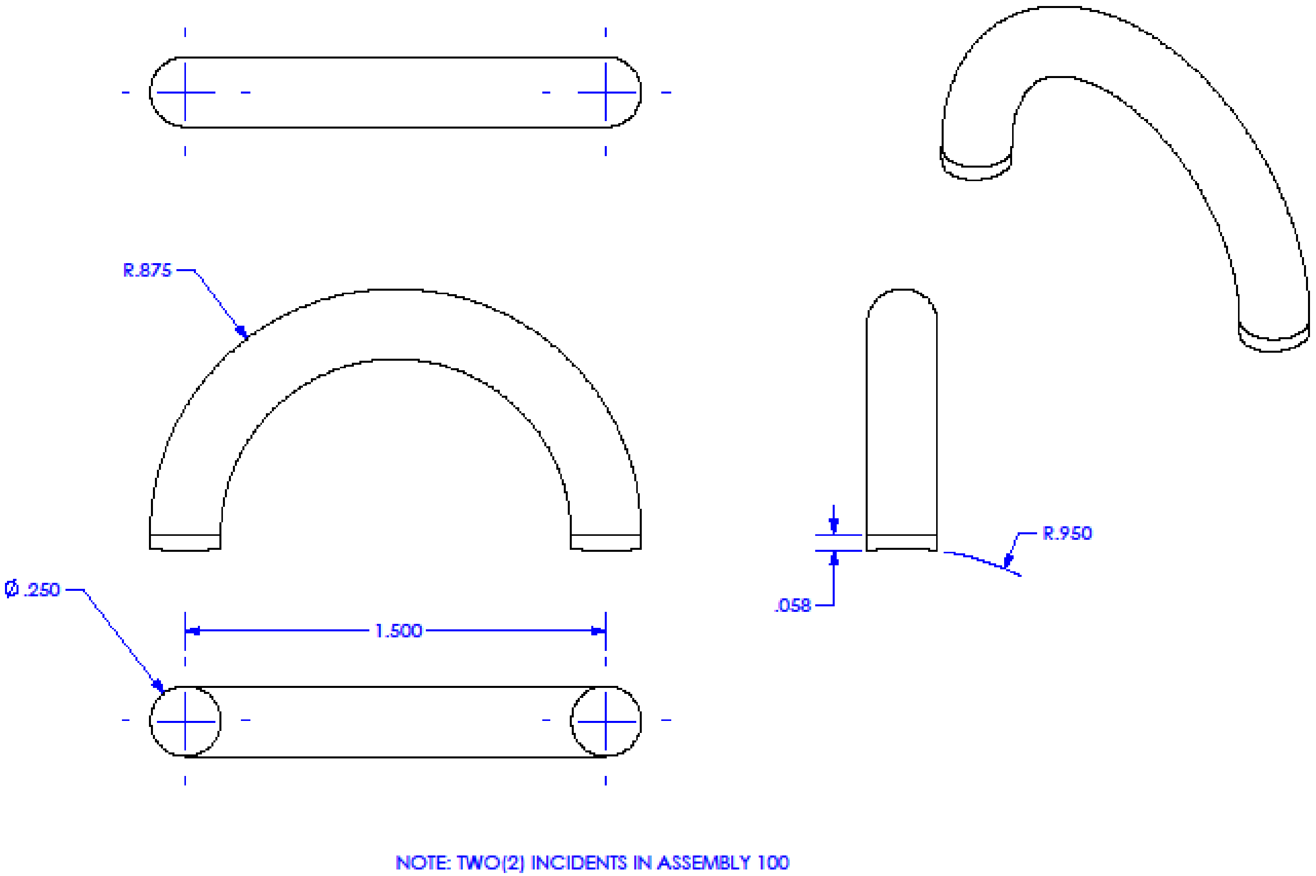
APPENDIX I: Assembly and Part Drawings



NOTE: TWO(2) INCIDENTS IN ASSEMBLY 100

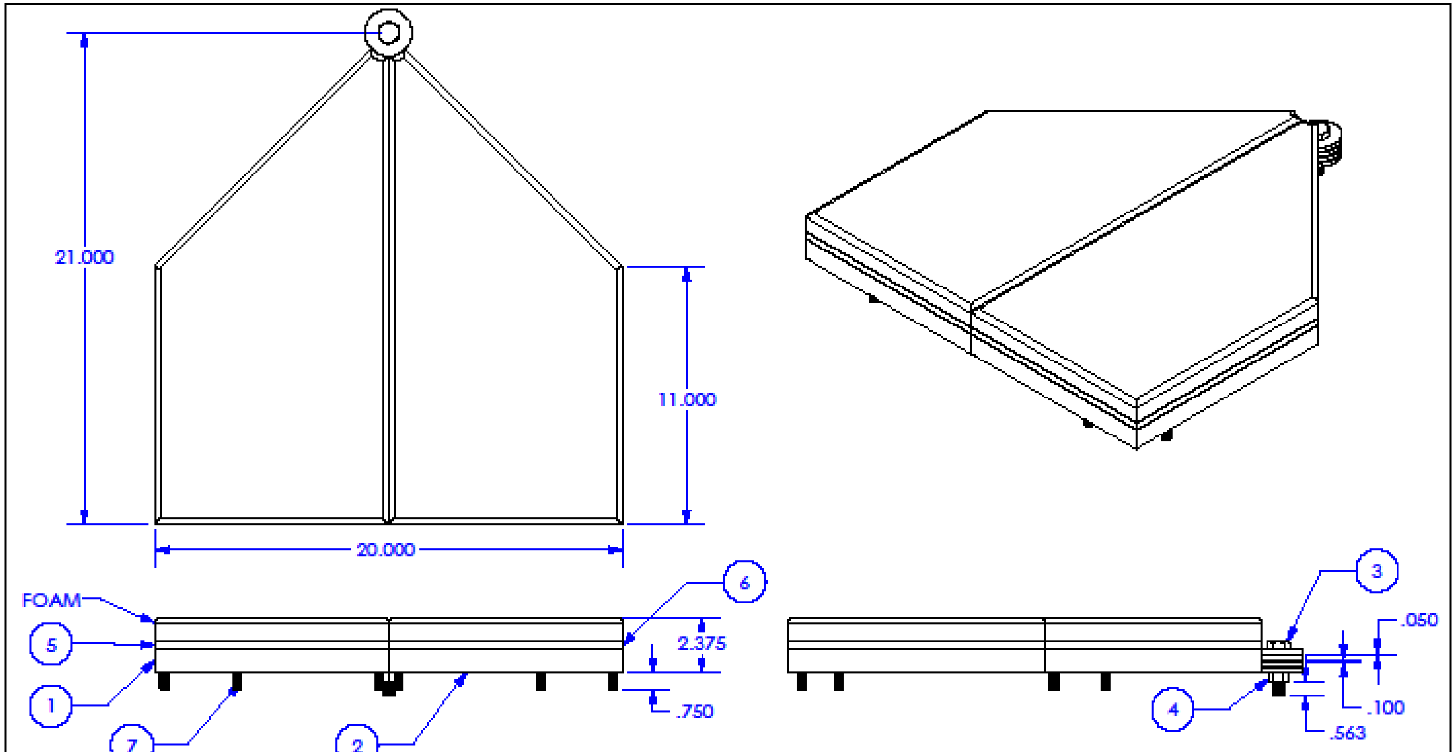
TEAM ZEUS Dissabled Sports Throwing Frame	DATE: 1/27/12	UNITS: INCHES	MATERIAL: ALUMINUM
Mechanical Engineering CAL POLY	TOLERANCE:	SCALE: 1:2	TITLE: WHEEL MOUNT BARS
		NEXT ASSY: 100	NAME: ANDREW HIGGINS
		DRAWING #: 109	SIGNATURE:

APPENDIX I: Assembly and Part Drawings



TEAM ZEUS Dissabled Sports Throwing Frame Mechanical Engineering CAL POLY	DATE: 2/2/12	UNITS: INCHES	MATERIAL: ALUMINUM
	TOLERANCE:	SCALE: 2:1	TITLE: TIE DOWN HOOKS
		NEXT ASSY: 100	NAME: ANDREW HIGGINS
		DRAWING #: 111	SIGNATURE:

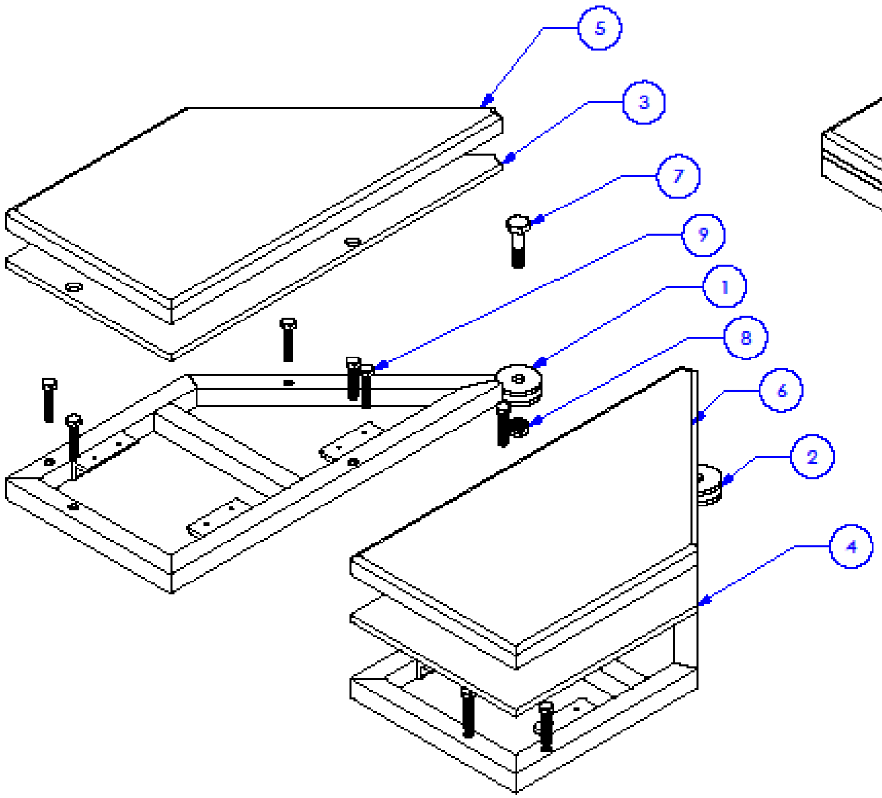
APPENDIX I: Assembly and Part Drawings

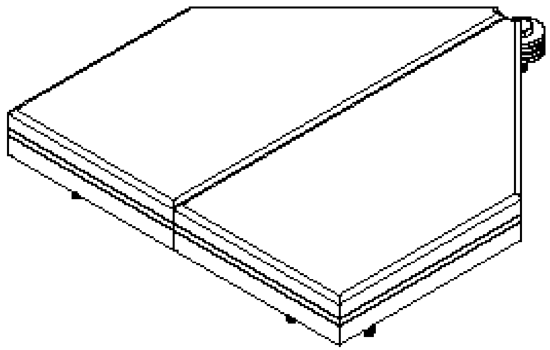


#	PART #	DESCRIPTION	QUANTITY
1	200L	FRAME - L	1
2	200R	FRAME - R	1
3	91583A121	HINGE BOLT	1
4	90371A045	HINGE NUT	1
5	210L	SEAT - L	1
6	210R	SEAT - R	1
7	93190A630	SEAT BOLT	8

TEAM ZEUS DISSABLED SPORTS THROWING FRAME Mechanical Engineering CAL POLY	DATE: 2/2/12	UNITS: INCHES	MATERIAL: SEE PART DRAWINGS
	TOLERANCE:	SCALE: 1:6	TITLE: MULTI-TOP SEAT ASSEMBLY
		NEXT ASSY: A-000	NAME: ANDREW HIGGINS
		DRAWING #: 200	SIGNATURE:

APPENDIX I: Assembly and Part Drawings

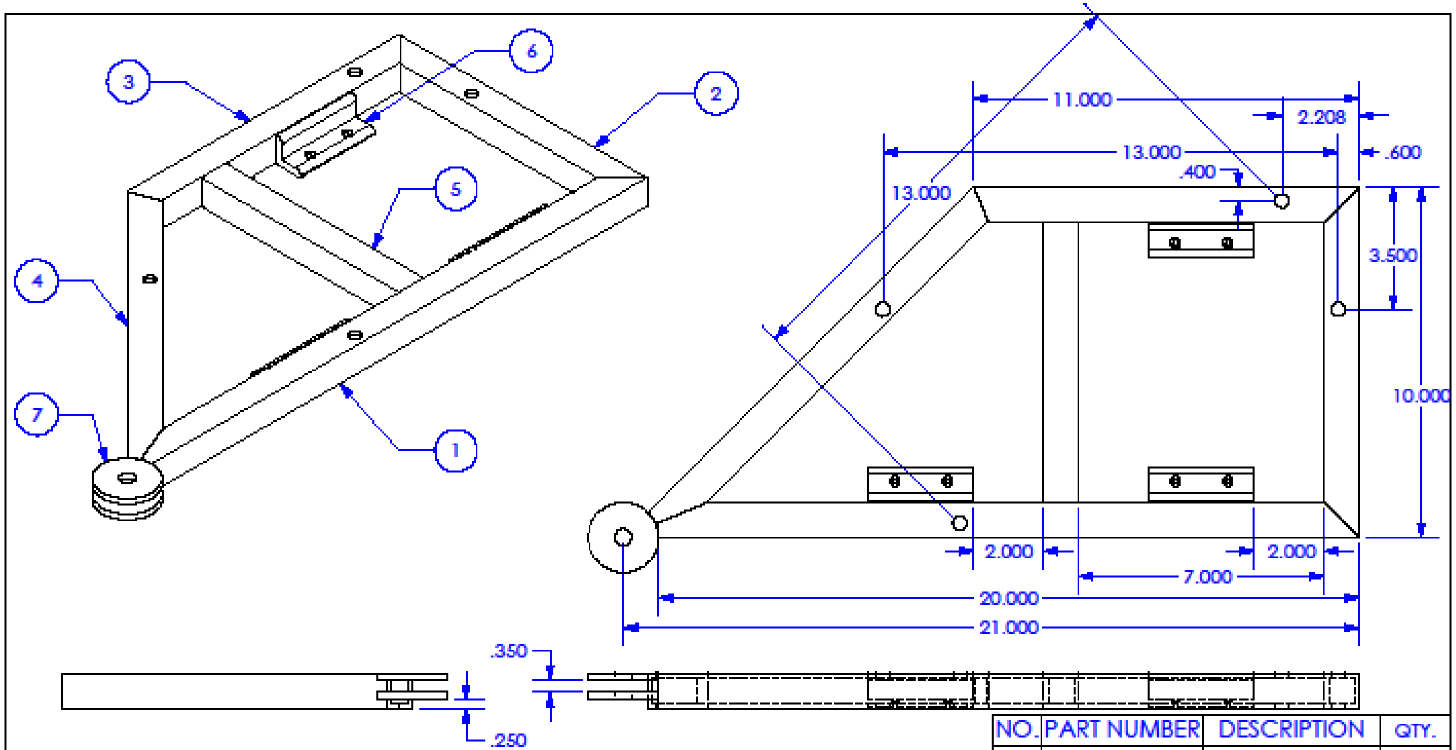




NO.	PART NUMBER	DESCRIPTION	QTY.
1	Z_200L	LEFT FRAME	1
2	Z_200R	RIGHT FRAME	1
3	Z_211	LEFT PLANK	1
4	Z_211	RIGHT PLANK	1
5	Z_210R	LEFT CUSHION	1
6	Z_210L	RIGHT CUSHION	1
7	90371A045	HINGE BOLT	1
8	91583A121	HINGE NUT	1
9	93190A630	FRAME BOLT	8

TEAM ZEUS DISSABLED SPORTS THROWING FRAME Mechanical Engineering CAL POLY	DATE: 2/2/12	UNITS: INCHES	MATERIAL: SEE PART DRAWINGS
	TOLERANCE:	SCALE: 1:6	TITLE: MULTI-TOP SEAT EXPLODED
		NEXT ASSY: A-000	NAME: ANDREW HIGGINS
		DRAWING #: 200E	SIGNATURE:

APPENDIX I: Assembly and Part Drawings

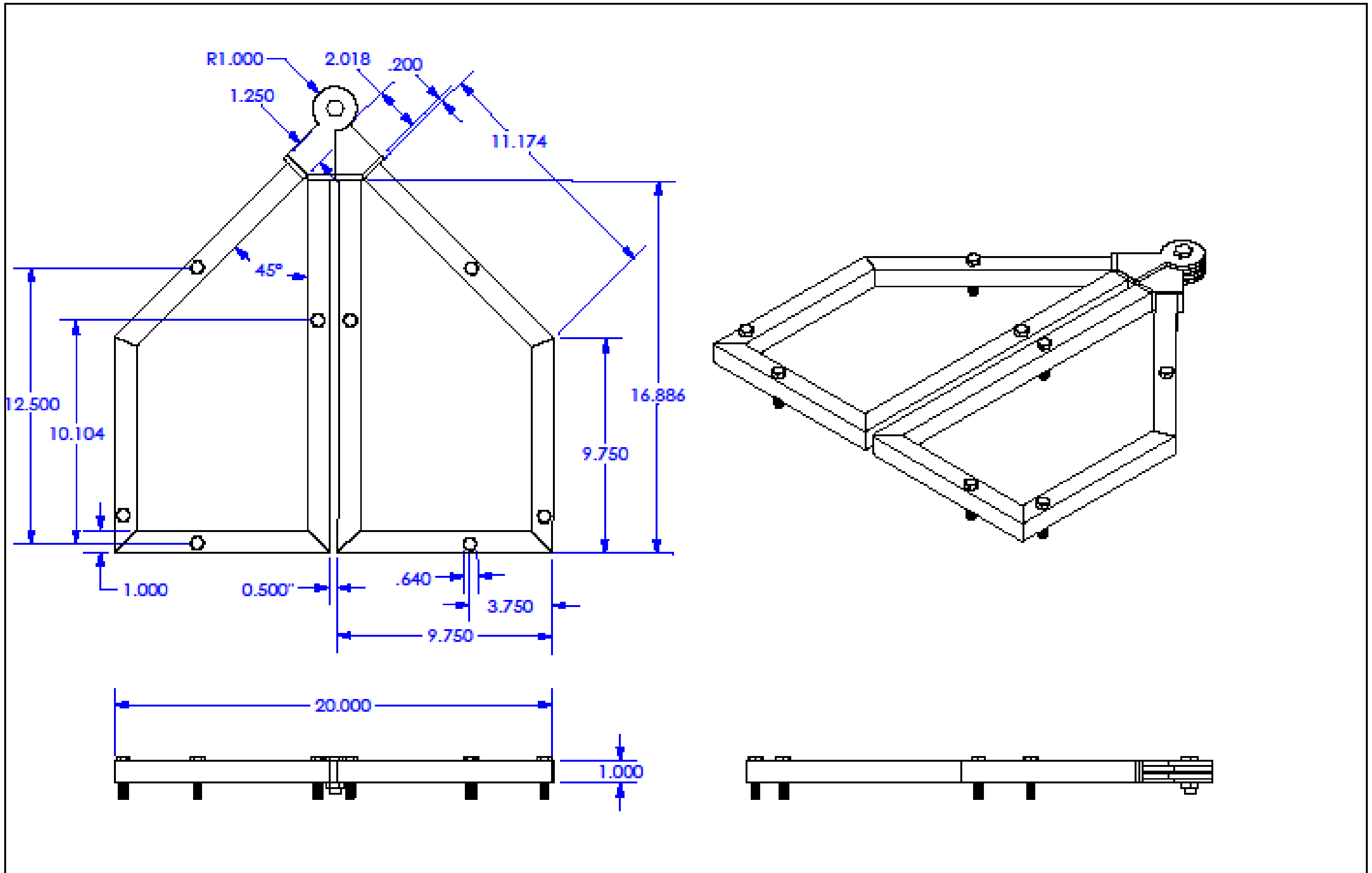


NOTE: 200R IS MIRROR IMAGE ABOUT EDGE OF PIECE (1)
WELDERS NOTE: ALL JOINTS TO BE 0.125" GTAW, ALL AROUND, FLUSH

NO.	PART NUMBER	DESCRIPTION	QTY.
1	Z_201	SQR. PIPE	1
2	Z_202	SQR. PIPE	1
3	Z_203	SQR. PIPE	1
4	Z_204	SQR. PIPE	1
5	Z_205	SQR. PIPE	1
6	Z_206	L_BRACKET	3
7	Z_207	HINGE	2

TEAM ZEUS DISSABLED SPORTS THROWING FRAME Mechanical Engineering CAL POLY	DATE: 2/2/12	UNITS: INCHES	MATERIAL: ALUMINUM
	TOLERANCE:	SCALE: 1:4	TITLE: SEAT FRAME ASSEMBLY - LEFT
		NEXT ASSY: 200	NAME: ANDREW HIGGINS
		DRAWING #: 200L	SIGNATURE:

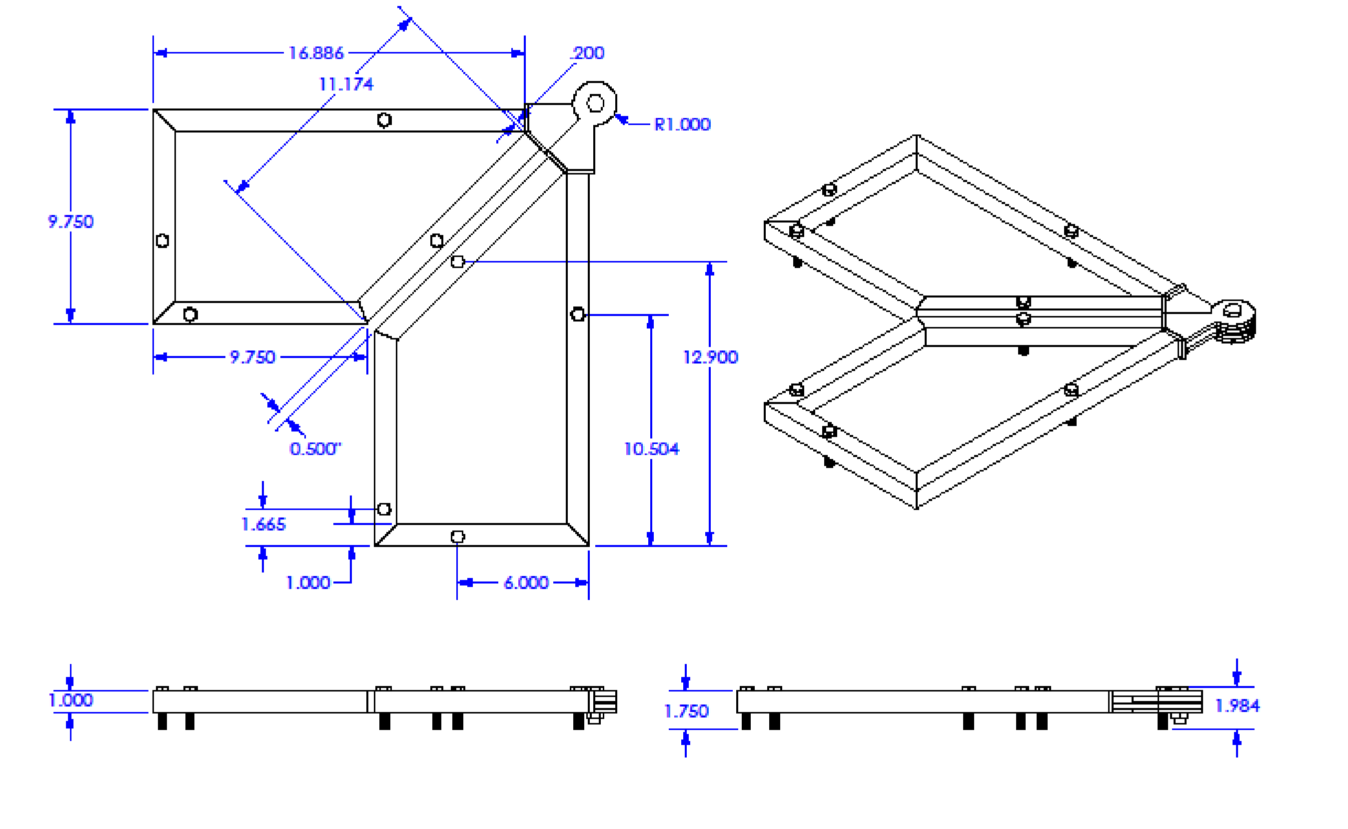
APPENDIX I: Assembly and Part Drawings



Team Zeus Dissabled Sports Throwing Frame Mechanical Engineering CAL POLY	DATE: 1/26/12	UNITS: inches	MATERIAL: ALUMINUM
	TOLERANCE:	SCALE: 1:6	TITLE: Seat Assembly - 200
		NEXT ASSY:	NAME:
		DRAWING #: 200H	SIGNATURE:

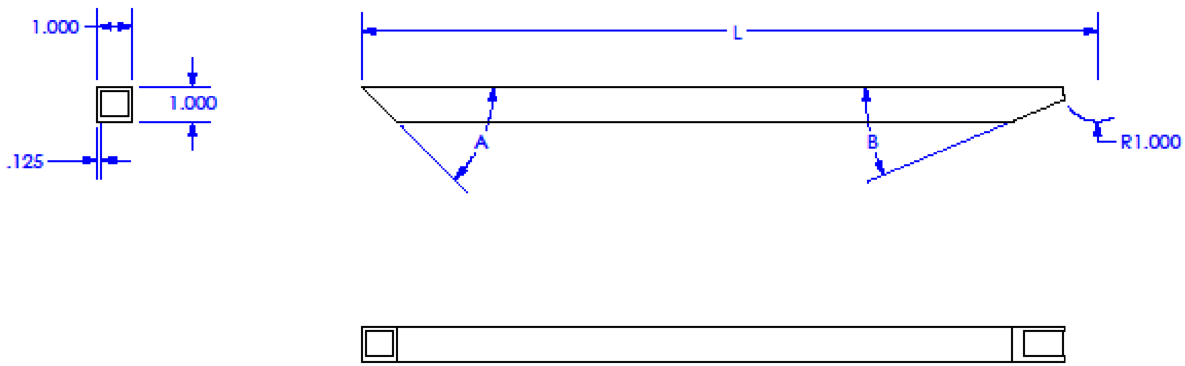
APPENDIX I: Assembly and Part Drawings

SSS



Team Zeus Dissabled Sports Throwing Frame Mechanical Engineering CAL POLY	DATE: 1/26/12	UNITS: inches	MATERIAL: ALUMINUM
	TOLERANCE:	SCALE: 1:6	TITLE: Seat Assembly - 200
		NEXT ASSY:	NAME:
		DRAWING #: 200L	SIGNATURE:

APPENDIX I: Assembly and Part Drawings



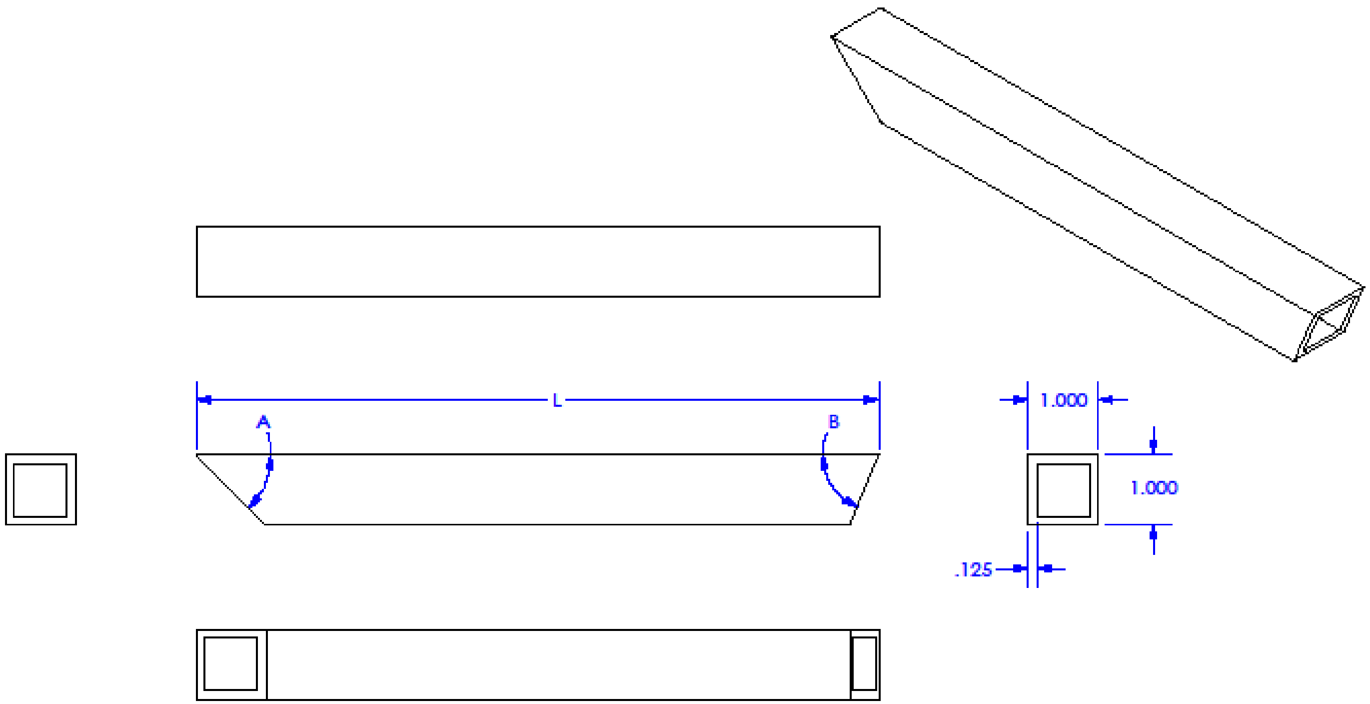
NOTE: PART 201 SHOWN

Part #	L [in]	A [deg]	B [deg]	Units
201	21.00	45°	23°	2
204	14.142135	67.5	23°	2

TEAM ZEUS DISSABLED SPORTS THROWING FRAME Mechanical Engineering CAL POLY	DATE: 2/2/12	UNITS: INCHES	MATERIAL: ALUMINUM
	TOLERANCE:	SCALE: 1:4	TITLE: SEAT FRAME COMPONENTS 1 & 4
		NEXT ASSY: 200	NAME: ANDREW HIGGINS
		DRAWING #: 201 & 204	SIGNATURE:

Team Zeus (Disabled Sports Throwing Frame)
California Polytechnic State University, San Luis Obispo
CPThrowingFrame@gmail.com

APPENDIX I: Assembly and Part Drawings

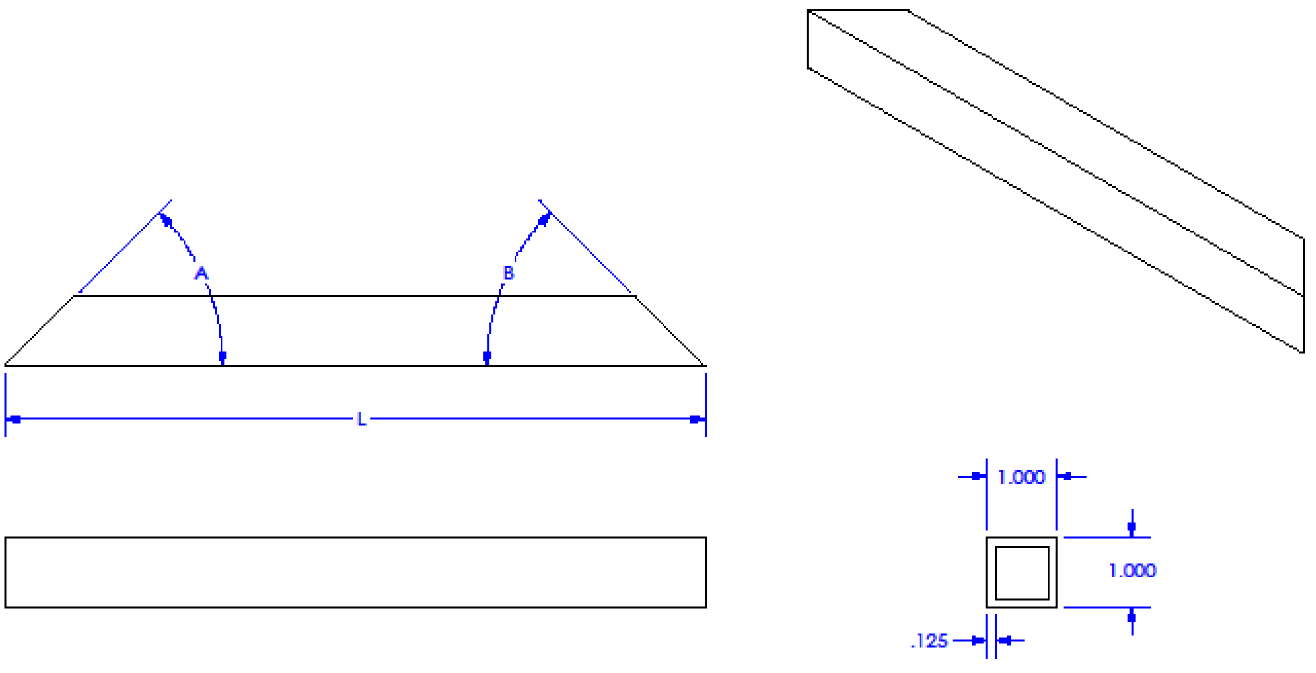


NOTE: PART 203 SHOWN

Part #	L [in]	A [deg]	B [deg]	Units
201	16.886	45	90	2
202	9.750	45	45	2
203	9.750	45	67.5	2
204	11.174	67.5	90	2

TEAM ZEUS DISSABLED SPORTS THROWING FRAME Mechanical Engineering CAL POLY	DATE: 1/26/12	UNITS: INCHES	MATERIAL: ALUMINUM
	TOLERANCE:	SCALE: 1:2	TITLE: SEAT FRAME COMPONENTS
		NEXT ASSY: 200	NAME: ANDREW HIGGINS
		DRAWING #: 201-204	SIGNATURE:

APPENDIX I: Assembly and Part Drawings

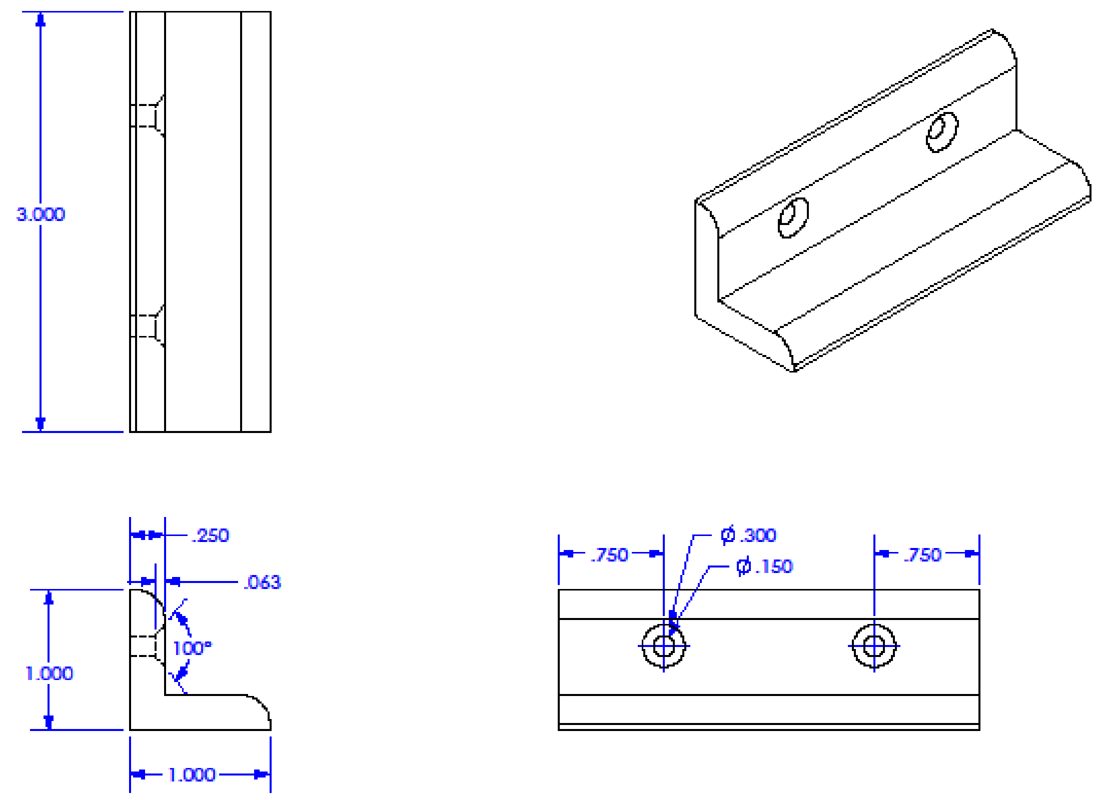


NOTE: PART 202 SHOWN

Part #	L [in]	A [deg]	B [deg]	Units
202	10.000	45	45	2
203	11.000	45	67.5	2
205	8.000	90	90	2

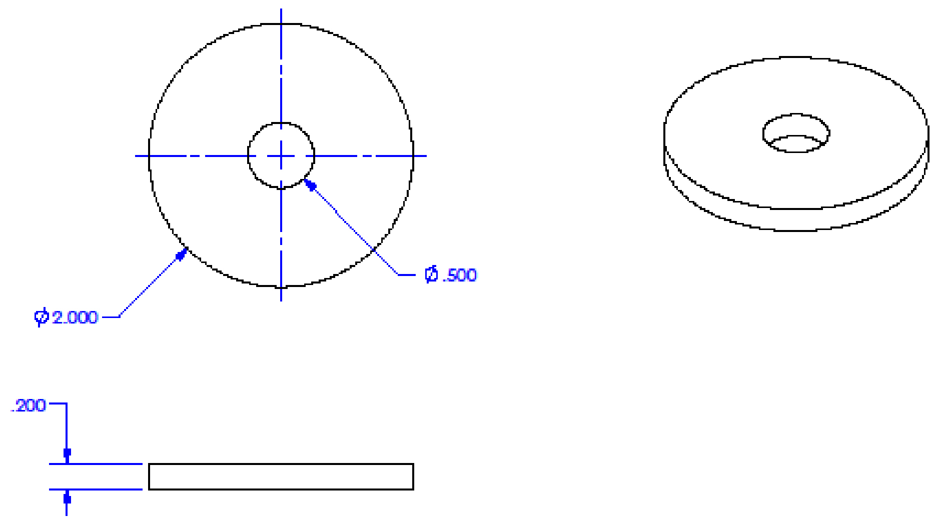
TEAM ZEUS DISSABLED SPORTS THROWING FRAME Mechanical Engineering CAL POLY	DATE: 2/2/12	UNITS: INCHES	MATERIAL: ALUMINUM
	TOLERANCE:	SCALE: 1:2	TITLE: SEAT FRAME COMPONENTS 2, 3, & 5
		NEXT ASSY: 200	NAME: ANDREW HIGGINS
		DRAWING #: 202, 203, 205	SIGNATURE:

APPENDIX I: Assembly and Part Drawings



TEAM ZEUS DISSABLED SPORTS THROWING FRAME Mechanical Engineering CAL POLY	DATE: 2/2/12	UNITS: INCHES	MATERIAL: ALUMINUM
	TOLERANCE:	SCALE: 1:2	TITLE: SEAT ATTACHMENT BRACKET
		NEXT ASSY: 200	NAME: ANDREW HIGGINS
		DRAWING #: 206	SIGNATURE:

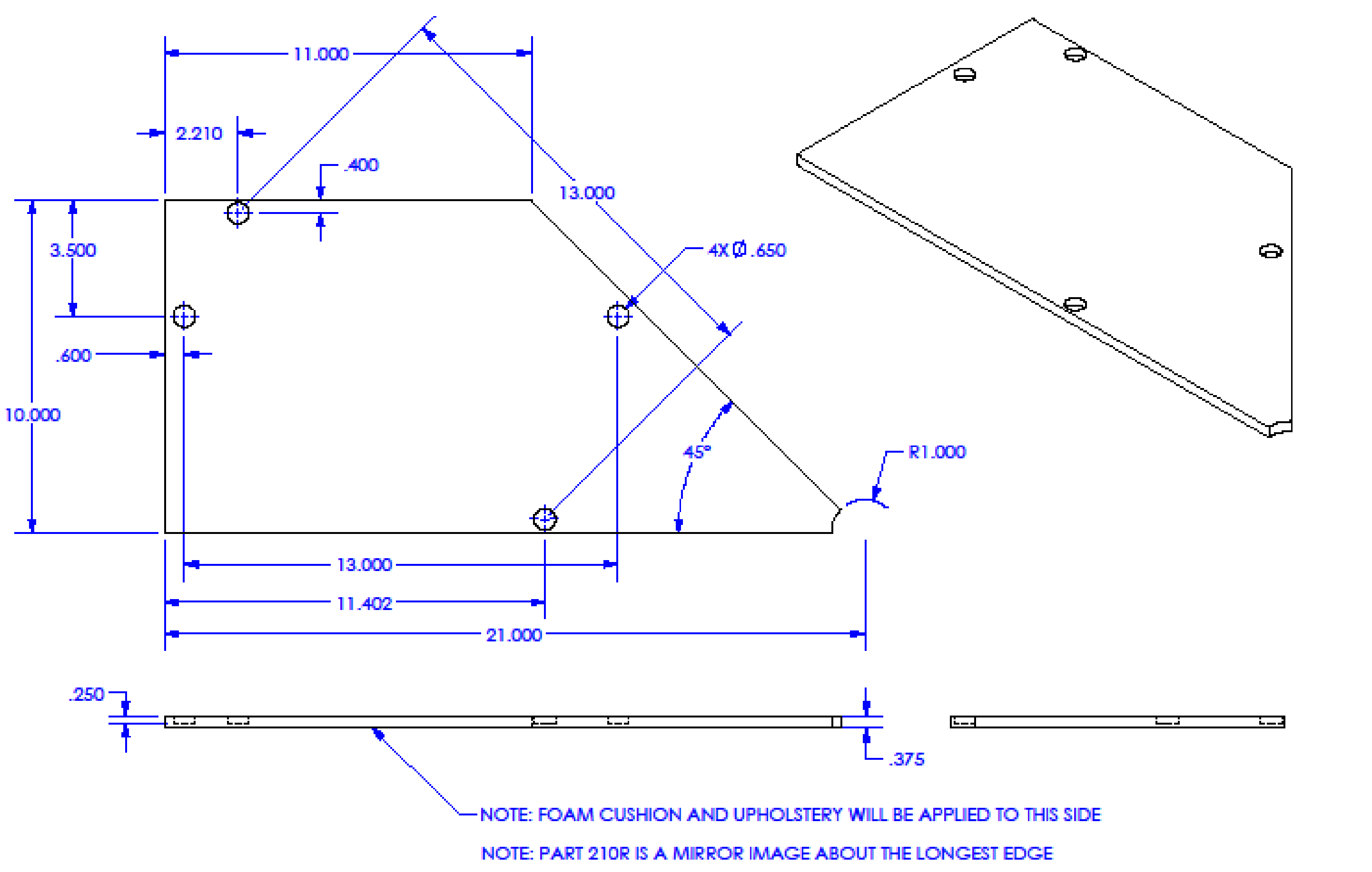
APPENDIX I: Assembly and Part Drawings



NOTE: THERE ARE FOUR (4) INCIDENTS IN ASSEMBLY 200

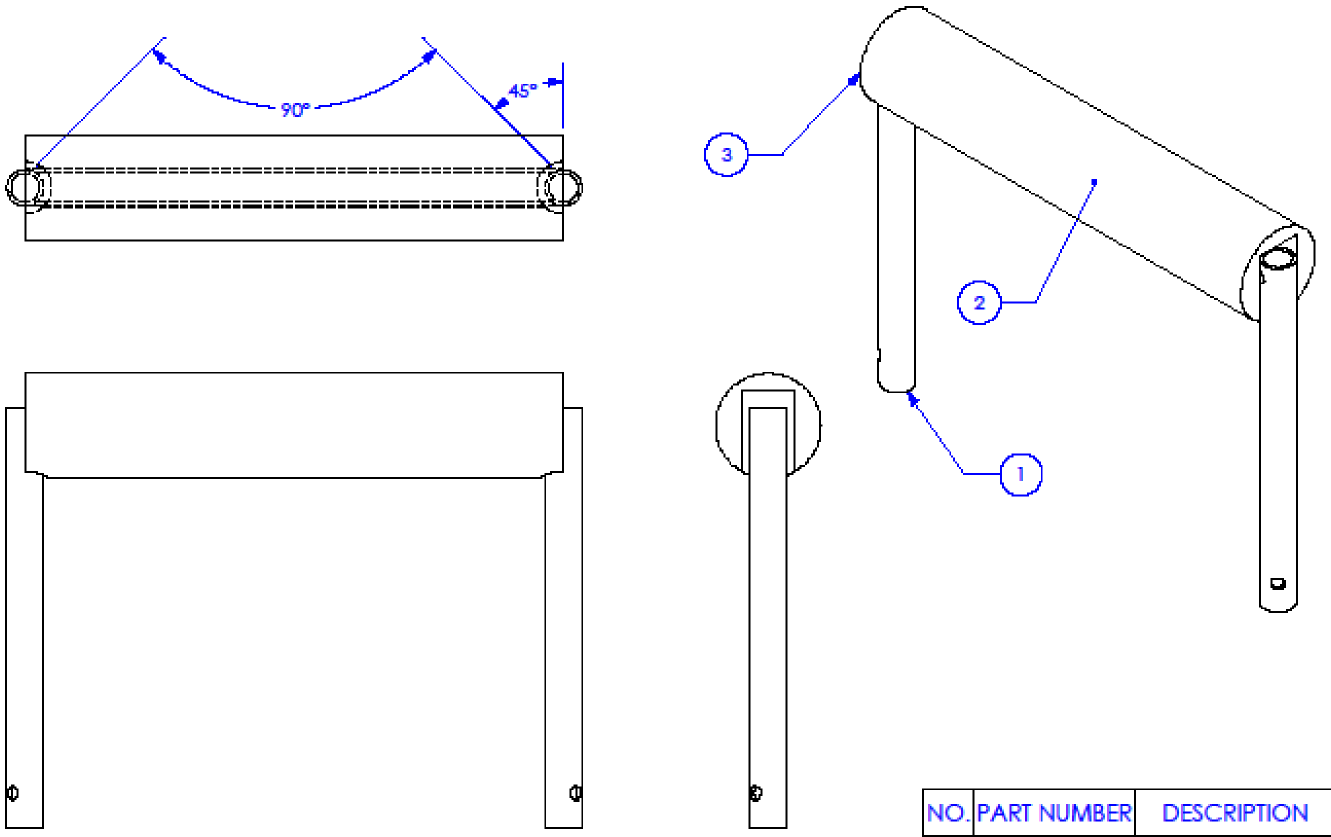
TEAM ZEUS DISSABLED SPORTS THROWING FRAME Mechanical Engineering CAL POLY	DATE: 2/2/12	UNITS: INCHES	MATERIAL: ALUMINUM
	TOLERANCE:	SCALE: 1:1	TITLE: HINGE
		NEXT ASSY: 200	NAME: ANDREW HIGGINS
		DRAWING #: 207	SIGNATURE:

APPENDIX I: Assembly and Part Drawings



TEAM ZEUS DISSABLED SPORTS THROWING FRAME Mechanical Engineering CAL POLY	DATE: 2/2/12	UNITS: INCHES	MATERIAL: 3/8" MARINE GRADE PLYWOOD
	TOLERANCE:	SCALE: 1:4	TITLE: SEAT PLANK
		NEXT ASSY: 200L	NAME: ANDREW HIGGINS
		DRAWING #: 210L	SIGNATURE:

APPENDIX I: Assembly and Part Drawings



WELD NOTE: BOTH WELDED JOINTS ARE 0.125" GTAW, ALL AROUND, FLAT

NO.	PART NUMBER	DESCRIPTION	QTY.
1	Z_303	VERT. BAR	2
2	Z_304	HORIZ. BAR	1
3	Z_305	FOAM	1

TEAM ZEUS Dissabled Sports Throwing Frame	DATE: 2/2/12	UNITS: INCHES	MATERIAL: SEE PART SHEETS
	TOLERANCE:	SCALE: 1:4	TITLE: BACKREST
Mechanical Engineering CAL POLY		NEXT ASSY: A-000	NAME: ANDREW HIGGINS
		DRAWING #: 300A	SIGNATURE:

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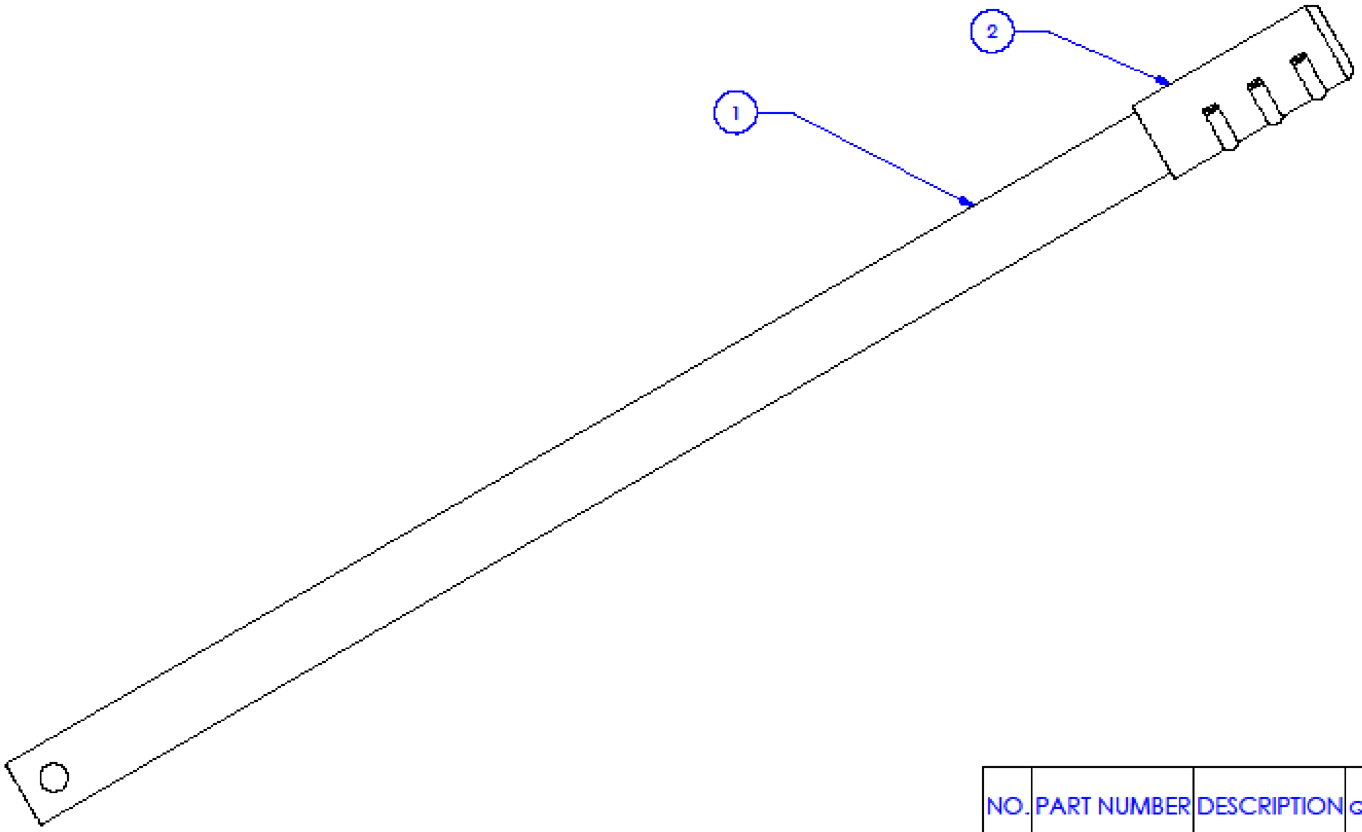
California Polytechnic State University, San Luis Obispo
CPThrowingFrame@gmail.com

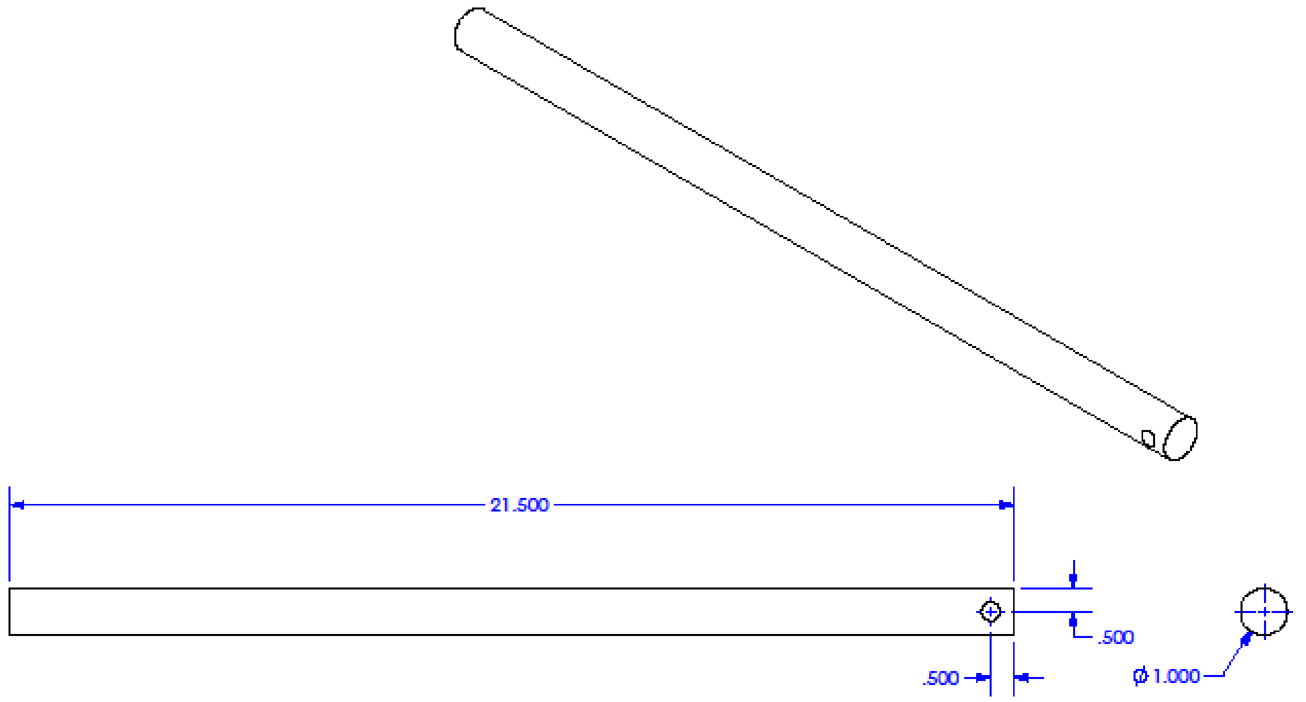
APPENDIX I: Assembly and Part Drawings



NO.	PART NUMBER	DESCRIPTION	QTY.
1	Z_301	BAR	1
2	Z_302	GRIP	1

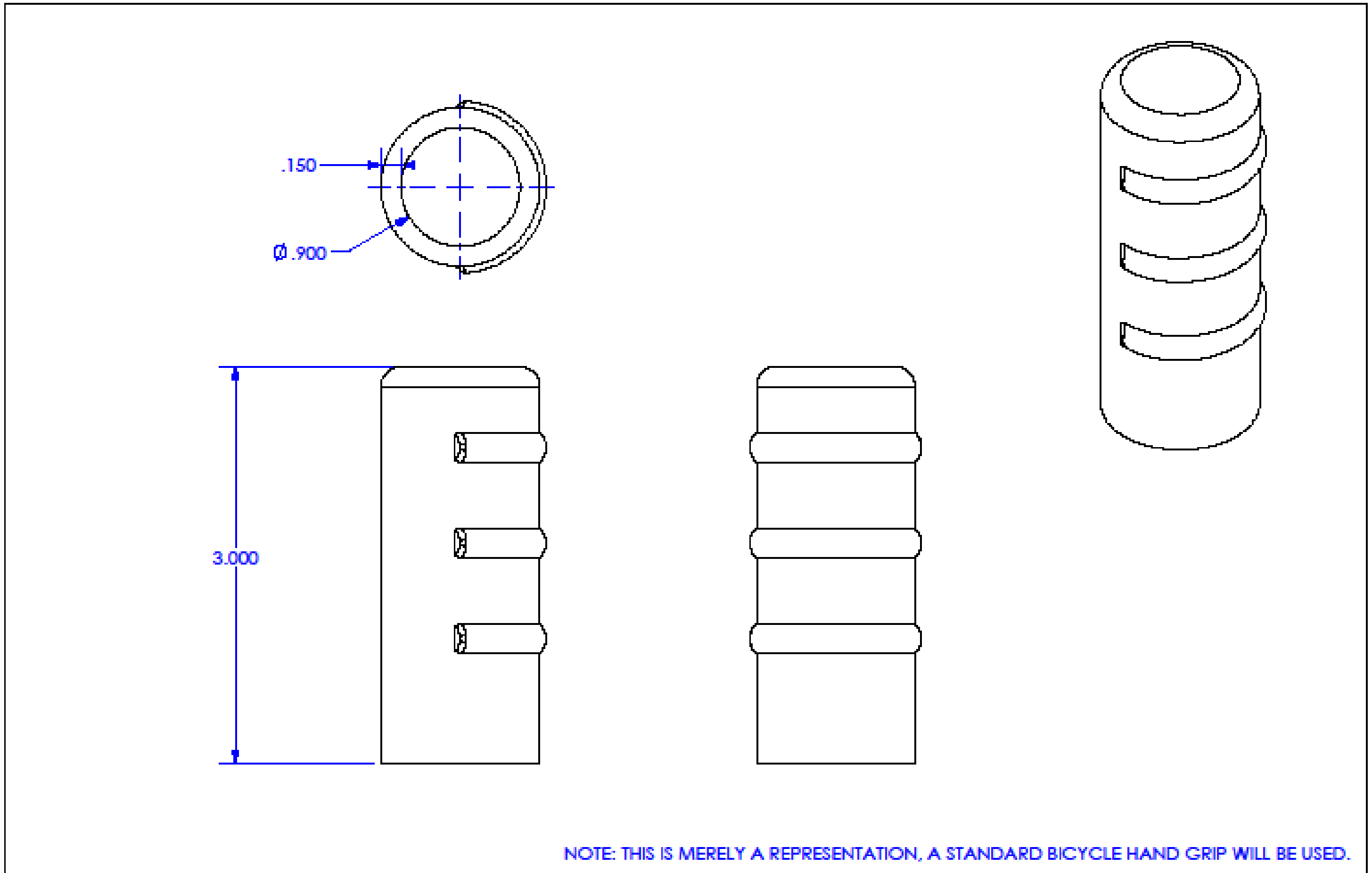
TEAM ZEUS Dissabled Sports Throwing Frame Mechanical Engineering CAL POLY	DATE: 2/2/12	UNITS: INCHES	MATERIAL: SEE PART SHEETS
	TOLERANCE:	SCALE: 1:2	TITLE: ARM BAR ASSEMBLY
		NEXT ASSY: A-000	NAME: ANDREW HIGGINS
		DRAWING #: 300B	SIGNATURE:

APPENDIX I: Assembly and Part Drawings



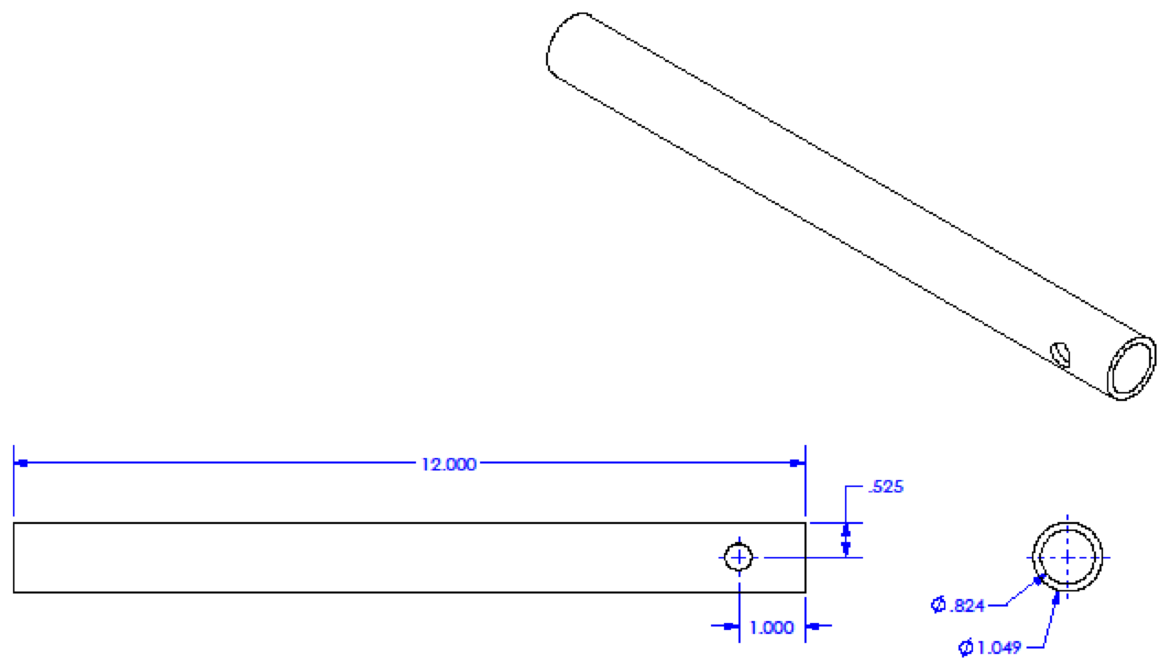
TEAM ZEUS Dissabled Sports Throwing Frame Mechanical Engineering CAL POLY	DATE: 2/2/12	UNITS: INCHES	MATERIAL: ALUMINUM
	TOLERANCE:	SCALE: 1:3	TITLE: ARM BAR
		NEXT ASSY: 300B	NAME: ANDREW HIGGINS
		DRAWING #: 301	SIGNATURE:

APPENDIX I: Assembly and Part Drawings



TEAM ZEUS Dissabled Sports Throwing Frame Mechanical Engineering CAL POLY	DATE: 2/2/12	UNITS: INCHES	MATERIAL: RUBBER
	TOLERANCE:	SCALE: 1:1	TITLE: HAND GRIP
		NEXT ASSY: 300B	NAME: ANDREW HIGGINS
		DRAWING #: 302	SIGNATURE:

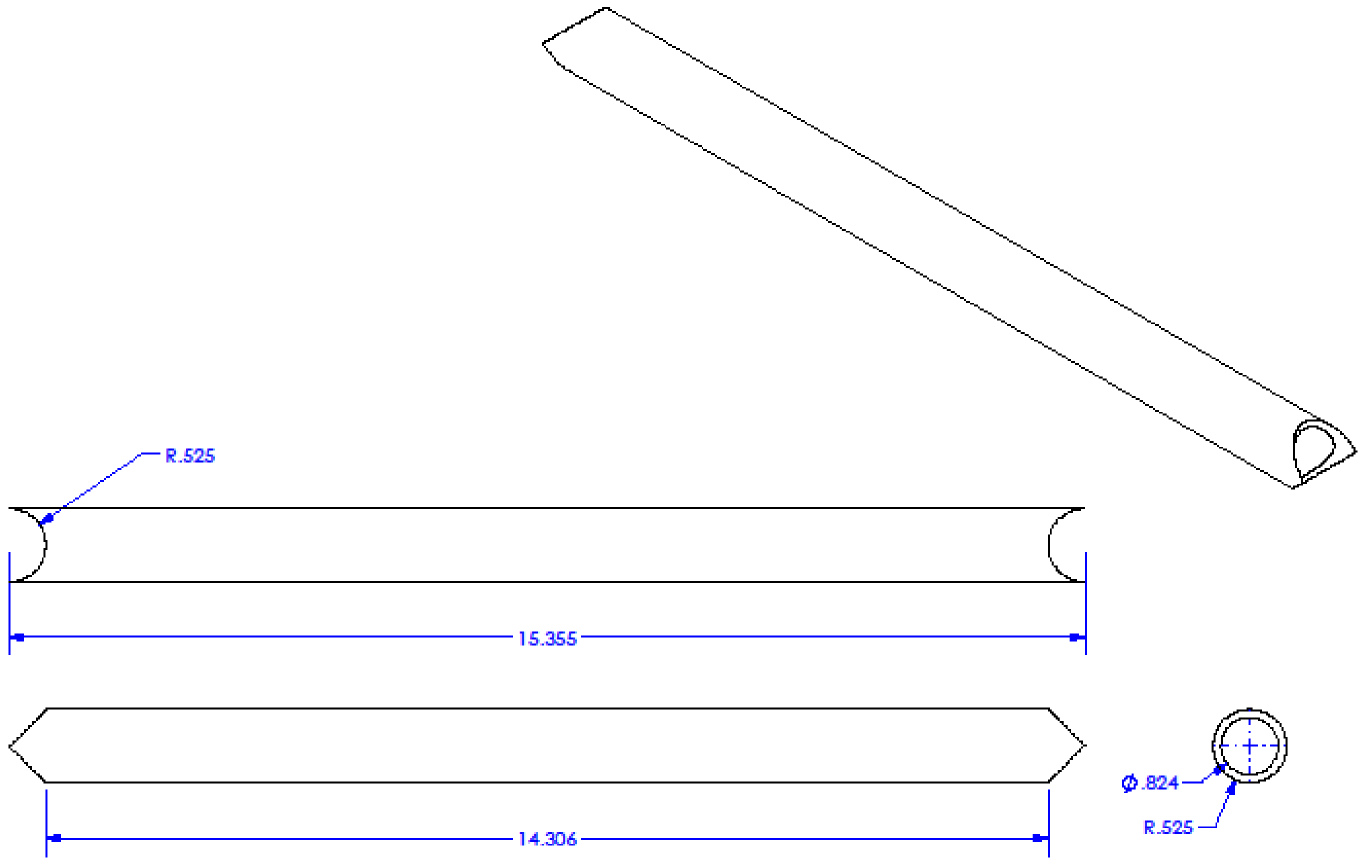
APPENDIX I: Assembly and Part Drawings



NOTE: THERE ARE TWO (2) OCCURANCES IN ASSEMBLY 300A

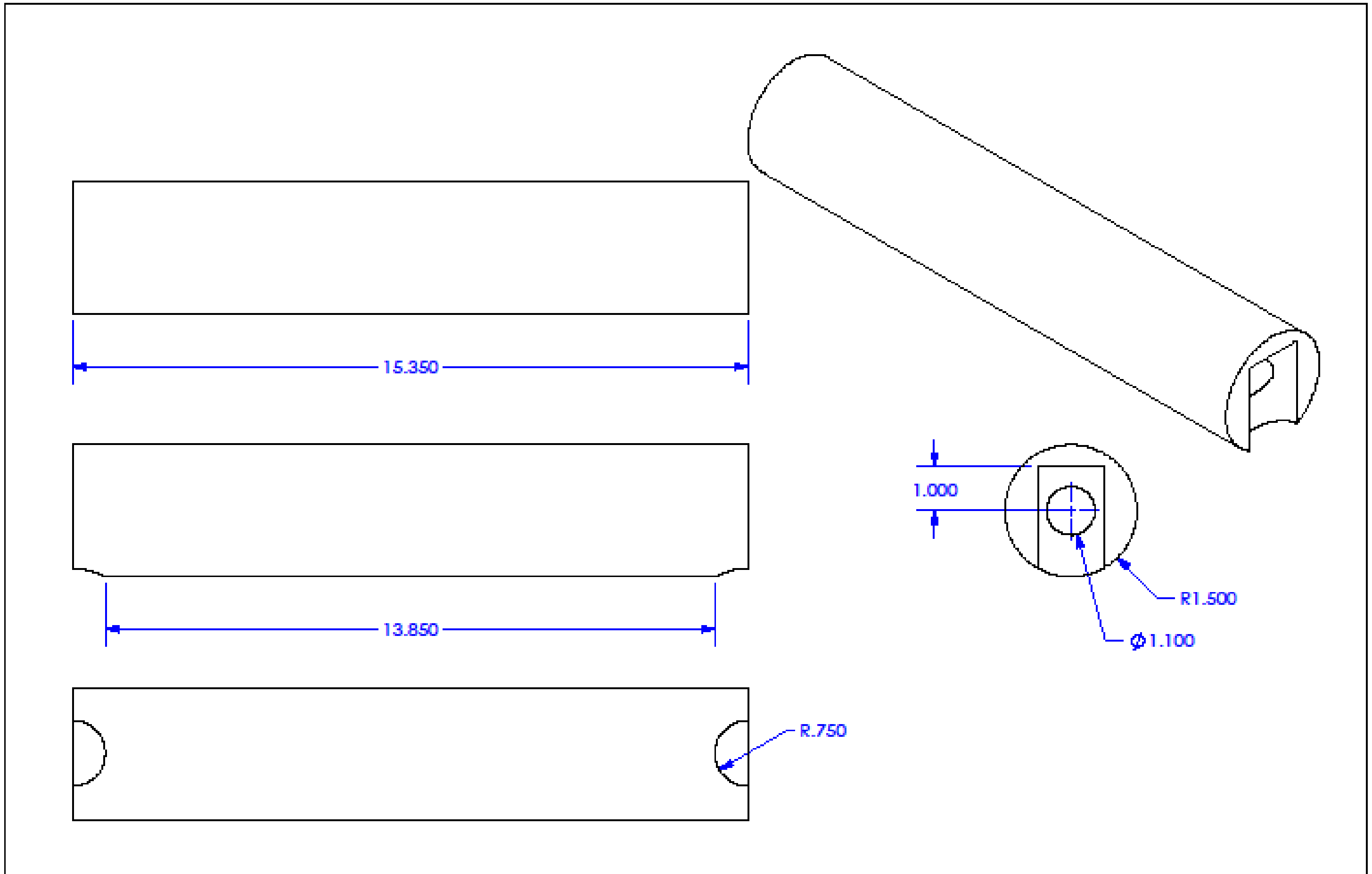
TEAM ZEUS Dissabled Sports Throwing Frame Mechanical Engineering	DATE: 2/2/12	UNITS: INCHES	MATERIAL: ALUMINUM
	TOLERANCE:	SCALE: 1:2	TITLE: BACK VERTICAL BARS
		NEXT ASSY: 300A	NAME: ANDREW HIGGINS
		DRAWING #: 303	SIGNATURE:

APPENDIX I: Assembly and Part Drawings



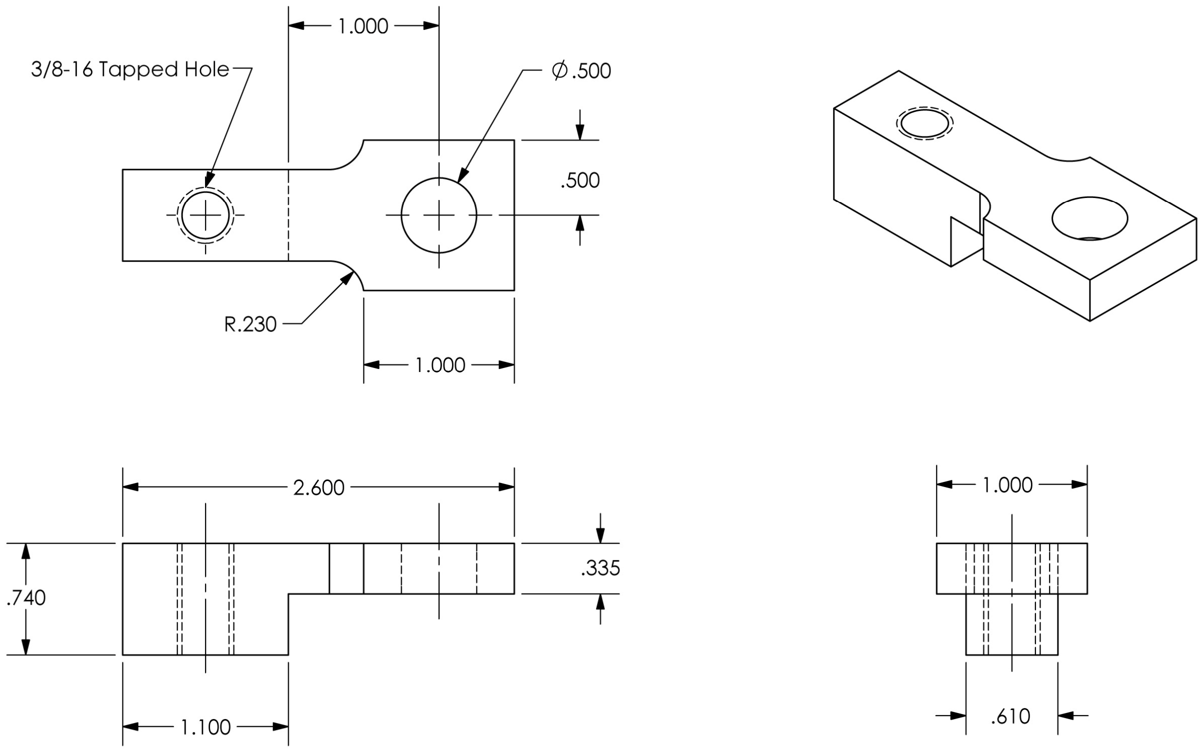
TEAM ZEUS Dissabled Sports Throwing Frame Mechanical Engineering CAL POLY	DATE: 2/2/12	UNITS: INCHES	MATERIAL: ALUMINUM
	TOLERANCE:	SCALE: 1:2	TITLE: BACK HORIZONTAL BAR
		NEXT ASSY: 300A	NAME: ANDREW HIGGINS
		DRAWING #: 304	SIGNATURE:

APPENDIX I: Assembly and Part Drawings



TEAM ZEUS Dissabled Sports Throwing Frame	DATE: 2/2/12	UNITS: INCHES	MATERIAL: LOW DENSITY FOAM
Mechanical Engineering CAL POLY	TOLERANCE:	SCALE: 1:3	TITLE: BACKREST FOAM
		NEXT ASSY: 300A	NAME: ANDREW HIGGINS
		DRAWING #: 305	SIGNATURE:

APPENDIX I: Assembly and Part Drawings



NOTE: The 0.5" OD through hole is to be drilled after both hinge pieces are secured to seat frames and aligned.

TEAM ZEUS DISSABLED SPORTS THROWING FRAME Mechanical Engineering CAL POLY	DATE: 5/2/12	UNITS: INCHES	MATERIAL: ALUMINUM
	TOLERANCE:	SCALE: 1:1	TITLE: New Hinge
		NEXT ASSY: 200	NAME: GABRIEL TERRASAS
		DRAWING #: 212	SIGNATURE:

APPENDIX J: Manufacturing Timeline