Adapted Pool Cue

by

Cole Clark (cclark07@calpoly.edu)
Daniel Patterson (drpatter@calpoly.edu)
Michelle Cheung (mlcheung@calpoly.edu)
Dylan Sauer (dgsauer@calpoly.edu)

Advised by Dr. James Widmann and Dr. Kevin Taylor

Mechanical Engineering Department

California Polytechnic State University

San Luis Obispo

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Statement of Disclaimer

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Executive Summary

Our primary goal was to develop an adaptive device to allow a user with limited upper body mobility to more effectively play a game of pool. Within this goal it was important to design around the concept of a least restrictive environment, in order to provide the user with as close to a standard pool playing experience as possible. The device was designed to specifically meet the needs of John Lee, an Assistive Technology Specialist at Cal Poly's Disability Resource Center. Mr. Lee has muscular dystrophy, which limits his upper and lower body mobility and currently requires his use of a wheelchair.

Research into the specific needs of our customer, current products, and pool game elements was performed to better understanding of the project goals. From this research and discussion with John Lee, customer requirements and engineering specifications were developed. These were then used to guide the design development process. Several ideation techniques were used, and concepts for a bridge mechanism and supporting bases were created. A rough prototype was developed to test the concepts before our final design direction was decided.

Our final design acts as a robust bridge device with a self-supporting base that constrains the path of the pool cue to a set path, allowing the user to focus their effort on providing power to the shot. The base can be rolled around the table, and stabilizing posts are lowered through a cable system when the shot is being made to prevent the base from sliding. The shooting mechanism features horizontal and vertical angle adjustment to allow for proper positioning of the cue, as well as a small cue stop to adjust the allowable travel of the pool cue. A vertical height adjustment is also present to allow the mechanism to reach over the edge of the pool table and for special high angle shots. The shooting mechanism itself features fixed and sliding rollers that act as a modified pool bridge, limiting travel of the pool cue to one axis of motion. The top part of the device can be separated from the base and clamped to the upright post for easier transport. These design choices allow the device to be compatible with any size regulation pool cue.

Engineering analysis was performed to select materials and size components for the final device. Parts were specified and costs recorded to keep within the program budget. The device was then manufactured to the specifications shown in the included technical drawings, and testing was performed to verify that the final product met the design requirements.

The overall experience was successful, and the final product received strong approval from John Lee. Recommendations for potential future improvement of both manufacturing and design of the device are included, as are as tips for device operation.

Chapter 1 – Introduction

Sponsor Background and Needs

The Adapted Pool Cue project aimed to create a device that makes the game of pool accessible to people with disabilities who would otherwise be unable to play the game effectively or at all. This project's main sponsor was the NSF (National Science Foundation) grant through the RAPD (Research to Aid People with Disabilities) program. This grant was being applied via the Activity4All program under Dr. Kevin Taylor, and our project group was advised by Dr. James Widmann. The goal of this project was to design and manufacture a working product for our customer, John Lee, with the hope that our design will someday reach other potential players.

Regular pool play requires simultaneous control of the pool cue in both aim and stroke execution, which may be difficult or impossible for people with physical limitations. This may cause them to give up the game, suffer disadvantages against other players, or resort to using non-regulation compliant equipment. Our device allows the user the use a regulation pool cue and play pool with much fewer physical limitations to overcome. The user should be able to play without experiencing physical discomfort, and also be able to use the pool cue in a method as similar to that without device assistance as possible. For this initial project run, the device was also created for a wheelchair user, but the general device concept can be adapted in the future for seated or standing users.

User's Abilities

John Lee has a form of muscular dystrophy (MD). Muscular dystrophy is a genetic disease in which muscle fibers are unusually susceptible to damage. These damaged muscles become progressively weaker. This explains why people with MD typically eventually need to use a wheelchair.

John's condition is at the point where he must use a wheelchair, cannot comfortably carry things that weigh more than about 5 pounds for long periods of time, and is unable to produce much force on his own. His range of motion at the shoulder joint is adequate, allowing him to raise his arms to just above shoulder height. This enables him to hold a pool cue at the positions and angles to execute pool shots; however, his muscular weakness compromises his ability to aim a pool cue steadily. Therefore, our design adapts for aim by controlling the path of the pool cue. This way, John will be able to lock in his shot, and then be able to exert enough force on his own to execute every other shot.

Customer Requirements

The goal of the adapted pool cue project was to design, manufacture, and present to the user a device that will enhance their pool playing ability. From the initial project presentation introducing the project, we learned that the project was supposed to be an aid for people who were limited in physical mobility and/or strength. The given requirements were that the project had to incorporate a regular pool cue, cost less than $1500, and provide a Least Restrictive Environment (LRE). We defined LRE to specifically mean that the user would be able to execute most, if not all, of the actions regularly performed in pool, and to do so in a natural manner.

We also met with our customer, John Lee, to determine what he required from this project. From his description of his own abilities and our observations of them, we developed the requirements for the device to hold the cue in position after aiming, require relatively low forces to operate, be lightweight, let the cue be moved only in one direction, be compatible with wheelchair users, and not let the cue wobble.

After our meeting with the customer, we developed a list of specifications (as shown in Table 1 at the end of the Engineering Specifications section) that guided our design. The following paragraphs detail the requirements and their corresponding specifications. A Quality Function Deployment chart is located in the Appendix A, Figure 22. This chart helped us to determine the strength of correlations between our customer requirements and engineering requirements, and thus the relative importance of each engineering specification to our design goals.

The customer requirements for this device are as follows:

- It must use a regulation pool cue.
- It must be safe for the user and any surrounding players.
- It must hold the cue in position after the user has finished aiming in order to allow the user to focus on pushing the cue with sufficient force.
- It must be operable with only a small amount of force.
- It should restrain the path of the cue to one direction.
- It must be a sturdy design that allows only a little wobble of the cue during operation.
- It must be useable for people with lower upper body mobility and/or strength.
- It must not force the user to raise his/her elbow above the shoulder.
- It must be usable while sitting and be compatible with a wheelchair user.
- It must allow the use of natural pool movements
- It must allow the user to attempt most of the moves required for a successful game.
- It must support the cue away from the table surface.
- It must be lightweight.
- It must not take a long time to set up.

- It must be portable while using a wheelchair.
- It should cost less than $1500 to develop.

Engineering Specifications

Using the customer requirements determined from John and Dr. Taylor, we created the engineering specifications summarized in Table 1. The most important requirement of this device is that it must use a regulation pool cue. The device can attach to the cue in any way but it must use a standard pool cue, which measures 46 to 57 inches in length. This is crucial in creating the LRE, as the pool cue is one of the only pool devices that the player can own and bring to any pool hall. The device will be able to accommodate the tapering shape of a cue and allow the cue to be attached and removed with relative ease.

Just as important is the requirement that the device be safe. The user should be able to operate the device without posing any danger to his or herself, or others around them. While we do not expect our device to be particularly dangerous, we still must be careful in our design so as to avoid pinch points. Since our device will have moveable parts, we need to be sure that careless operation of the device could not result in pinched or torn skin due to either pinch points or exposed, moving pieces.

Another very important requirement is the ability of the device to restrict cue movement to one axis (direction). The goal of the device is to make it easier for the user to play, by accounting for either force or control, which is at the user's discretion. If the device is able to hold the cue in one position, the user can focus on putting power behind the shot and can thus make much more effective shots.

Related to restricting the cue's movement to one axis is the specification of not allowing the cue tip to deflect more than 15 degrees in extreme cases. If the cue deflects too much, it is possible for the cue to miss the ball or graze the side, ruining the shot. Therefore, the device should be sturdy enough to hold the cue in the line of travel established when the shot was set up.

The portability and usability of the design is another key component. The design must be both lightweight and operable from a seated position. We are aiming for any part of the device that needs to be lifted to be less than 15 pounds, so that the user will be able to lift it temporarily if necessary for transport or operation.

Two other crucial considerations are that the device should not require a great amount of force or time to operate, especially when moving the device around the table. It should not require more than 5 pounds of force to move around the table, as this will occur frequently throughout the game. Since the device must be constantly moved around the table to make various shots, it needs to be easy to set up and move, with a target set-up time of 1 to 2 minutes, otherwise he/she would be spending too much time and energy moving the device around, and not enough time actually playing pool.

Positioning and movement of the tip of the cue is very important to the game of pool, as cue travel is necessary in order to build up the momentum to send the cue ball forward with enough energy. Most pool players draw their cue back about 6 inches before striking. Our device will be able to do the same. In addition, it will be able to hold the cue at least half an inch off the table. Holding the cue tip near the table will enable the user to pull off tricky shots by imparting backspin on the ball.

Overall position and range of motion is a very important element of pool. Not only does the user need to be able to move the cue forward and backward, but in all other directions as well. The cue must be able to be angled to make a wide variety of shots that may be required during a game of pool. For example, the cue ball may be against a wall, and the user wants to shoot it along the wall. In order to enable the user to hit the cue ball in whatever direction he/she wants, the device must grant the cue a range of motion of at least 180 degrees horizontally and at least 20 degrees vertically. In addition, the ball must be able to reach at least 2.5 feet across the table. These values were chosen so that, from each side of the table, the cue ball could be hit in any direction outward. Also, being able to reach 2.5 feet across will allow the device to reach any ball on the table regardless of table size.

Money is another consideration for this project. We have been given a budget of $1500, which we can use on research, development, and construction of prototypes and the final product.

Finally, the device will be able to produce some additional energy on its own. This feature would be used in "breaking," which is the act of scattering the original triangular formation of balls. The user will be able to decide between using the feature or not, depending on need. The device will provide enough additional energy so that the cue ball can be propelled up to 15 mph (the minimum speed needed to break).

Table 1 - Summary of Engineering Specifications

Spec #	Parameter Description	Target	Tolerance	Risk	Compliance
1	Cue Length Compatibility	57 in.	- 21	L	T, I
2	Cost	$1,500	Max	L	A
3	# of Pinch Points	0	Max	M	A, T
4	Movement	Free	Min	M	T
5	Force to Move / Position Device	5 lbs	± 1	H	A, T
6	Vertical Reach	32 in.	± 5	L	T, I
7	Vertical Angle Range	5-20 deg.	± 2	M	A, T, I
8	Horizontal Angle Range	0-180 deg.	± 10	M	A, T, I
9	Cue Movement Limit	1 Axis	Min	L	T, I
10	Weight	15 lbs	± 1	M	A, T
11	Horizontal Reach	36 in.	± 1	H	A, T, I
12	Operation	Seated		M	T, I
13	Table to Cue Tip Distance	0.5 in.	Min	L	A, T, I
14	Elbow Movement Limit	Below Shoulder	Max	L	T
15	Cue Travel	1-6 in.	± 0.5	L	A, T, I
16	Max Cue Deflection	15 deg.	± 1	M	T, I
18	Exposed Moving Parts	0	Max	M	T, I
19	Set-Up Time	1-2 min.	± 30 sec	M	T

L = Low, M = Medium, H = High / T = Test, I = Inspection, A = Analysis

After compiling all of the customer requirements and engineering specifications, we compared them to each other using a Quality Function Deployment (QFD, also known as a House of Quality) chart to search for relationships between them. The QFD chart also ranks how three of the existing products (the wooden ramp, the spring-loaded cue, and the standard bridge) meet the user's requirements. The QFD chart works by comparing the user's needs to the engineering specifications created by the engineers. By comparing them, we can find out if each of the customer's requirements is satisfied by one or more of our specifications. By the end of our QFD analysis, we determined that our specifications addressed all of the requirements. A copy of our QFD chart is included in Appendix A, Figure 22.

In the central part of the chart, if you look at the intersections of the rows and columns for each requirement / specification pair, you will see either a blank or a symbol. The symbol determines how related the requirement and specification are. For example, if there is a black dot between a pair, then that means that the specification is strongly related to the requirement, and meeting the specification is crucial to meeting the corresponding requirement. Hollow circles indicate a medium correlation, while triangles indicate that the requirement and specification are only somewhat related. A blank space means that there is no connection between the requirement and specification. The section at the bottom of the chart lists the target values of the specifications that we will be meeting. The right-most section of the chart lists the three benchmarks that we have chosen to compare with the requirements. A chart value of 1 means that the requirement was not met, while a chart value of 5 means that the requirement was completely met, with values in-between indicating in-between stages of fulfilling the requirement. At the bottom of the QFD lie the benchmark sections where we compare our goals to the specifications of devices available on the market. However, since there were very few devices on the market related to our project, let alone any sort of specification or details about them, this section is left blank as no comparison can be made.

Management Plan

The entire project is a collaborative effort between team members. As such, all subsystems and areas of responsibility had contributions from each individual member, and no subset of the project was pinned solely on one individual. However general areas of responsibility were delegated according to individual skills and interests. Functionally, this meant that if a problem or question appeared that was covered under one of these categories, the member responsible was be the go-to person, and their opinion was given the most weight. Team member responsibilities are as follows:

Michelle - Information gathering: This involved gathering any important background research, safety information, and vendor information for parts our outsourced production methods.

- Documentation of project progress: This covered documenting overall progress, including weekly status reports as well as detailed documentation of manufacturing updates and time spent on various tasks.

- Management of deadlines: Included in this was making sure that group members were aware of upcoming milestones, as well as tracking changes in important dates and gathering necessary information for deadlines.

Daniel

- Testing plans: This involved creation, execution, and documentation of testing plans for the thorough testing of the device after manufacturing.

- Documentation of product feedback: This involved documentation of recommendations for changes to the design of the product, both during design reviews and after manufacturing.

- Public presentations: This covered preparation of presentation slides and delegation of content for design presentations and other public aspects of the project, such as the Design Expo.

Cole

- Manufacturing considerations: This involved research of manufacturing methods and determination of the ideal methods to use for our project. This also covered determination of ideal material selection.

- Fabrication of prototypes: This covered responsibilities for development of any prototypes or designs that were not a part of the final product.

- Gameplay considerations: This position acted as the resource for questions regarding shots, rules, and other gameplay related information specific to pool.

Dylan

- Kinesiology expert: This position was in charge of matters related to the physical capabilities of the user and any physical considerations for the effectiveness of the design.

- Communications: This position involved communication with the Kinesiology department and Dr. Kevin Taylor for any of his concerns or questions about the progress and design of the project.

An in depth plan was followed throughout the year that detailed time allowed for completion of various tasks as well as important milestones. This Gantt chart can be found in Appendix E.

Chapter 2 – Background

The Game and Necessary Equipment

Pool, also known as billiards, is a game where players use a cue stick to hit a white cue ball into a target billiard ball, knocking it into a target pocket on a specialized pool table. Equipment for the different pool games generally includes the aforementioned pool cue (stick), white cue ball, up to fifteen solid colored or striped balls, cue chalk, and pool table.

The pool cue is a stick, generally wooden, with a taper that narrows toward the impact end (tip). It can be anywhere between 36 and 60 inches long [1], with most cues being about 58 inches long [2], and weighs between 18 and 21 ounces. During the game, chalk can be applied to the tip to increase friction (so that the tip does not slide off the ball during the shot and cause a "miscue").

The cue ball and pool balls are made of a plastic compound (composition dependent on individual brand) and manufactured to be smooth and hard [3]. The cue ball is white and may sometimes be larger or heavier than the other pool balls. The pool balls are numbered and either solid or stripe- painted in different colors. According to the WPA, both types of balls are to be 2.25 (+0.005) inches in diameter and weigh 5.5 to 6 ounces.

Figure 1 - Standard Pool Table Design[4]

The pool table, an example of which is shown in Figure 1, can be manufactured out of various kinds of materials, but their sizing and features must be consistent. All tables have a depression in the middle covered in felt which is the playing surface. The flatness of the playing surface must be maintained, and under the felt is usually a large single slab of slate. Six pockets line the perimeter of the depression for players to shoot pool balls into. Finally, while the horizontal dimensions of the table can vary from 6 to 9 feet long and 3.5 to 4.5 feet wide [5], the height of the playing surface off the ground should only be between 29 and 31 inches (2.4 to 2.6 feet) [6].

Regulations

The rules for pool are determined by the World Pool-Billiard Association (WPA), and the rules for each specific type of game can be found in the included resources [7]. The tournament regulations that apply to our device are detailed in Section 7 of the official rules, titled "Wheelchair Competition." In summary, the player is supposed to be seated, with his/her feet not touching the floor, and cannot be helped by another person while executing the shot. Therefore, in accordance to these regulations, our device must allow the player to be self-sufficient and to make the shot from a completely seated position.

An important thing to note is that tournament regulations forbid the user from using "novel equipment" in standard play, but specifically allow wheelchair users to use any help aids such as "cue extensions, special bridges, etc.". Our device should clearly fall in the category of "special bridges" however it would be best for users to consult with the referee or tournament organizer before using this device for competitive play.

Existing Products

Upon beginning the project, we researched existing products that solved the same problem or related problems. Through both Google and online patent searches, we found information on five products related to the problem.

Figure 2 - Various Designs of Weighted Bridges [8]

The first product that we found was a weighted bridge, with various designs shown in Figure 2. When placed on the table, it allows the user to rest the cue on it, thus alleviating the user from having to lean over the table or manipulate a bulky standard bridge. This product solves part of the problem by eliminating the need for the user to stretch his or her body over the table.

Figure 3 - Spring Loaded Pool Cue by Hot Shot Cues [9]

The second product we found was a spring loaded cue, which replaces a regular cue. It features a cue-sized tube around a smaller, spring-loaded rod that can be released with the press of a button, as shown in Figure 3. This allows the user to hit the cue ball without needing to exert the large amount of force required when pushing a standard pool cue. This also allows the user to hit the cue ball without using a typical pool shooting stance, which could cause upper body strain. This product does not relate as much to our project goal, because it does not alleviate the user from needing to lean over the table to aim, nor does it use a regulation pool cue.

The third product that we found was a ramp device (no photo available) that was specially created for a child with cerebral palsy. Instead of using a cue of any sort to hit the cue ball, the device is a smooth wooden ramp is to be placed on the playing surface and moved around. The child plays the game by rolling the cue ball down the ramp, increasing cue ball velocity using the ramp rather than the impact of the cue. The product does not have much bearing on our project, either, since not only does it fail to use a regulation pool cue, but it is not operable by the user alone and creates a more restrictive environment for the user and for any other players.

Figure 4 - Pool Cue Cuff Model 9462 from Access to Recreation [10]

The fourth product, shown in Figure 4, was the Pool Cue Cuff Model 9462. It is a simple strap made of leather, Dycern, and Velcro, that makes it easier for the user to hold onto the pool cue without slipping. While this item is to be used with a regular pool cue, it does not solve any other problems other than that of a weak grip.

The fifth and final product, called the Snooker Cue Adaptation Model 6SNKC-R from TFH Special Needs Toys (no photo available), seemed the most appropriate design to use as inspiration. It was a device that would fit on a regular pool cue and allow the user to manipulate the cue with only one hand. However, the product was discontinued, and there are no accessible records or additional information for it

The Physical Experience of Playing Pool

We also spent time researching and experimenting with the range of motion and forces needed to effectively play pool, and learned why pool would be difficult for someone with limited body articulation. During the week prior to meeting with the customer, we went to the Mustang Lanes bowling alley and arcade and played a few games of pool. During one of these games, we deliberately maneuvered a chair around the table and sat for all of our shots. In addition, we tried to avoid holding the cue in such a way that would cause our elbows to lift above our shoulders, in order to simulate limited upper body mobility. We found that it was incredibly difficult to move the cue in a straight line while sitting, especially while trying to not raise our elbows above our shoulders, and we could not consistently hit the cue ball in the direction we intended it to go. Also, we found it very difficult to reach the cue ball in some situations, as we were not able to lean across the table and had to regularly use the standard bridge that was available. Finally, we were not able to see from high enough to aim the ball correctly. Overall, we found it difficult to make shots that would otherwise be simple.

Chapter 3 – Design Development

Design Development

After determining the specifications that needed to be met, we started developing concepts. To make it easier to pick and combine ideas, we split our project into two main parts: the base of the device, and the actual mechanism to interact with the pool cue.

Initial Ideation

To begin, we listed all the functions that our device was supposed to have, such as holding the cue, transferring force to the cue, aiming the cue, etc. Then, for each main function, we wrote and illustrated methods on Post-it Notes, with one method per note. When we had finished going through all of our primary functions, we laid them out in rows according to function. The end result was a table, resembling a morphological matrix, that listed out different methods we could put together for our device to accomplish all its functions.

In addition, we spent one day in lab creating concept models using foam board, hot glue, Popsicle sticks, and other simple materials. The results of our modeling can be found in Figure 5. This process was useful as it allowed us to easily visualize and share our ideas and possible solutions. It also helped show how some of our ideas were not as simple or useful as we had hoped.

Figure 5 - Initial Concept Models

Developing the Shooting Mechanism

Our method for developing a concept for this part of the device was fairly simple; we developed concepts, analyzed all of them, and then developed one final concept that got rid of the flaws in the previous concepts.

The three main initial concepts involved a spring tube, a pendulum, and a slide track (modeled below in Figure 6). The spring tube was discarded because the tube would have to be large enough to accommodate all sizes of pool cue, be long enough to reach the butt of the cue, and be rigid enough to allow the user to compress the spring with the cue. The pendulum concept was discarded because the pendulum would need to be overly large, and the hanging mass heavy, for it to impart enough momentum to the cue for shots. It would also be extremely cumbersome to have a device that held up the cue (likely from the middle of the cue) and need to hang a pendulum over the end of the cue. The last idea, the slide track, originally seemed promising, but we worried that there would be too much friction along the track to overcome without much force.

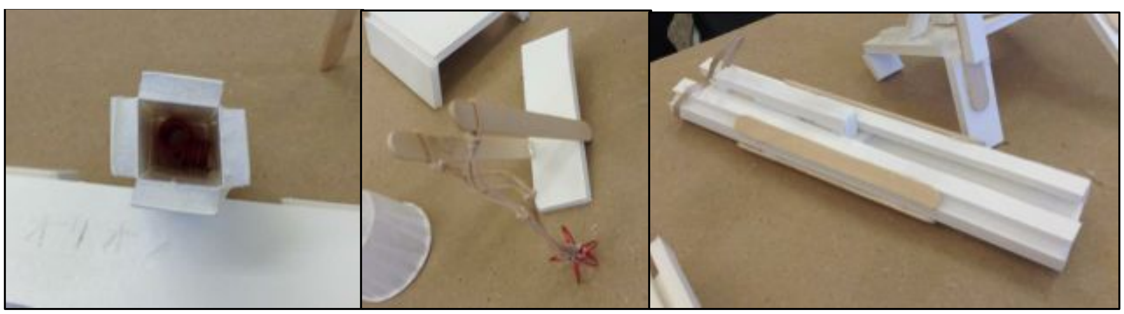

Figure 6 - Our Shooter Mechanism Concepts From Left to Right: Spring Tube, Pendulum, and Slide Track

Top Shooting Mechanism Concept

After discarding the previous shooter mechanism concepts, we came up with a design that improved functionality and fewer flaws, shown in Figure 7.

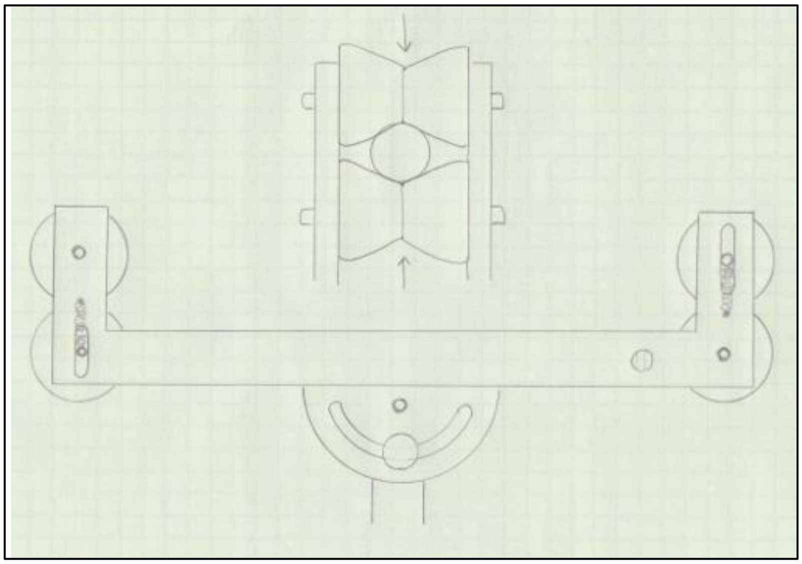

Figure 7 - Layout Sketch of the Roller Concept

The main structure of this concept is a machined aluminum bar with four rollers attached to it, two on each end. The pool cue would be inserted in between the two pairs of rollers. To adjust for the taper of the pool cue, one roller in each pair would be allowed to move, being connected to its corresponding roller by a spring attachment. When shooting, the force of the push would most likely not be perfectly parallel to the device, instead pointing down to apply a moment to flip the tip of the cue up. Therefore, the bottom roller on the butt side of the cue, and top roller on the tip side of the cue are to be fixed to provide reaction forces to counteract this moment. This design is very stable since as long as the center of gravity or point of force application is behind the wheels; the two fixed wheels provide all the support needed to constrain the cue to one direction of movement. If the forces were to move to a location where this stability would be disrupted, the spring-loaded rollers will impart forces to the cue to keep it from straying wildly from its desired position. Visual aid for these supporting forces is found in Appendix A, Figure 27.

One major consideration for this design is that the taper of the pool cue will cause the tip of the cue to follow a nonlinear path. However, this is not an issue since the tip will follow the same path every time. When making a shot, the user would position the cue in the rollers so that it was at the farthest point in its “travel”. Then, the user would aim the tip of the cue at the ball, and move the tip to right next to the ball. After locking in the position, the user would pull the cue back, and then push to hit the cue ball with it. The position of the tip will change as the cue is pulled back, but because of the fixed geometry the tip will return to the chosen striking position. Although the motion is nonlinear, it is easily predicted and still allows for accurate shooting. A simple drawn explanation of this path is found in Appendix A, Figure 28.

This roller system would be mounted onto an aiming system similar to a tripod's camera mount. It will be able to rotate around the vertical axis as well as around a horizontal axis, allowing rotational aim and vertical angling. This is important so that the user can hit the cue ball even if it is in front of another ball, where a high angle of attack is needed. The position and angle of the system will be tightened and fixed before each shot so as to remove any chance of movement or wobble.

This concept satisfies our project specifications much better than our previous concepts. First and foremost, it is able to both constrain the movement of the cue to one direction (relatively - see earlier in this section) and minimize the amount of friction. In addition, it is easily able to use any size regulation pool cue, since the rollers can expand to allow any amount of taper and there is no limit to how far into the device the cue can travel. Since it is fully adjustable as far as rotation and inclination is concerned, it satisfies the requirements of range of motion/aim. In addition, the bar that the "tripod" system is attached to was intended to be telescoping, allowing the user to extend the device over the table, enabling him to reach the cue ball no matter where it is on the table.

Developing the Base

Initially, we came up with ten different designs for the base of the device to connect to the shooting mechanism. Since the benefits and drawbacks of these ten systems were not as easy to compare and choose as the shooting mechanism, we created a weighted decision matrix to help with the decision-making process.

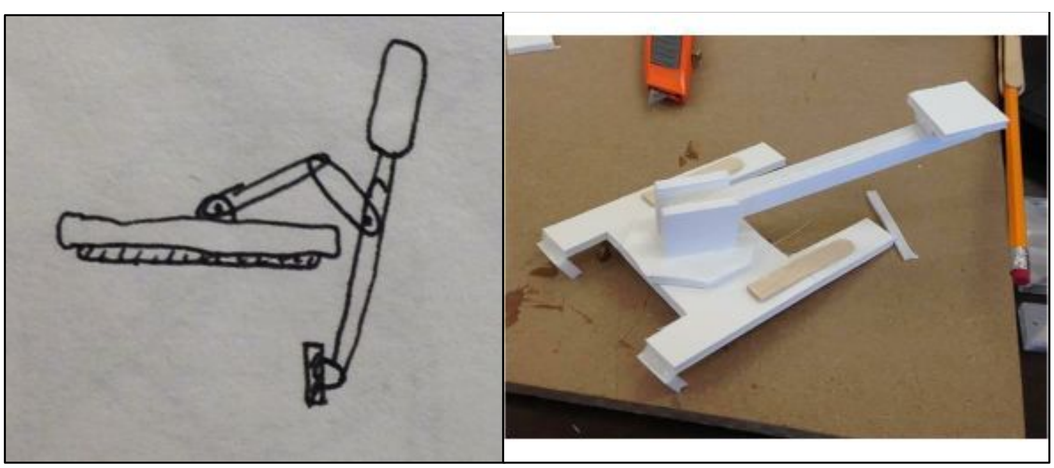

Figure 8 - Sketch and Concept Model of the Over-Center Lever Clamp Concept

Of our ten designs that we compared using the weighting and decision matrices, some of them were a bit stronger than the others and received more consideration. Out of these designs, the most deliberated-over was the design featuring arms that would reach over the bumper, with an over-center lever clamping the device to the edge of the table, as shown in Figure 8. When we first began coming up with concepts, this was the first idea that we really put more consideration and design into. Since it rigidly clamps to the side of the table, the design lends well to the shooting device being very sturdy. However, the main reason that we did not end up pursuing this concept was because we realized that most pool hall owners would not want anything “clamping” to or even touching the felt of their pool tables. The felt on a pool table is somewhat delicate and is expensive to replace, so at that point we decided that our design couldn’t pose any threat to the pool table itself.

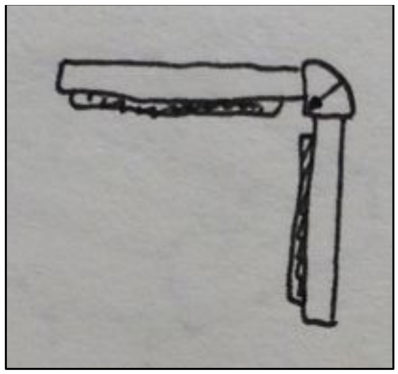

Figure 9 - Sketch of Frictional Clam Concept

Another design we consider that builds off of the previous concept was a device that would use a frictional clamp to attach to the side of the table without actually touching the felt, shown in Figure 9. This design, however, still touches the table and also relies on certain conditions, such as the table being able to maintain a high coefficient of friction with the clamp. While it would solve one of the problems posed by the bumper clamp, it could still be seen as unacceptable by pool hall owners, so we decided it would not be a reliable solution.

Many of our other ideas were simply modifications of our bumper clamp design, such as using weights to hold it down instead of a clamp, or a handle that the user would hold while using their other hand to operate the device. We also considered attaching a wheel post to the bumper system, so that the device would rest on the ground and lean on the table, as shown in Figure 10. However, we decided that most of these designs would be too inconvenient or unwieldy to move about the table.

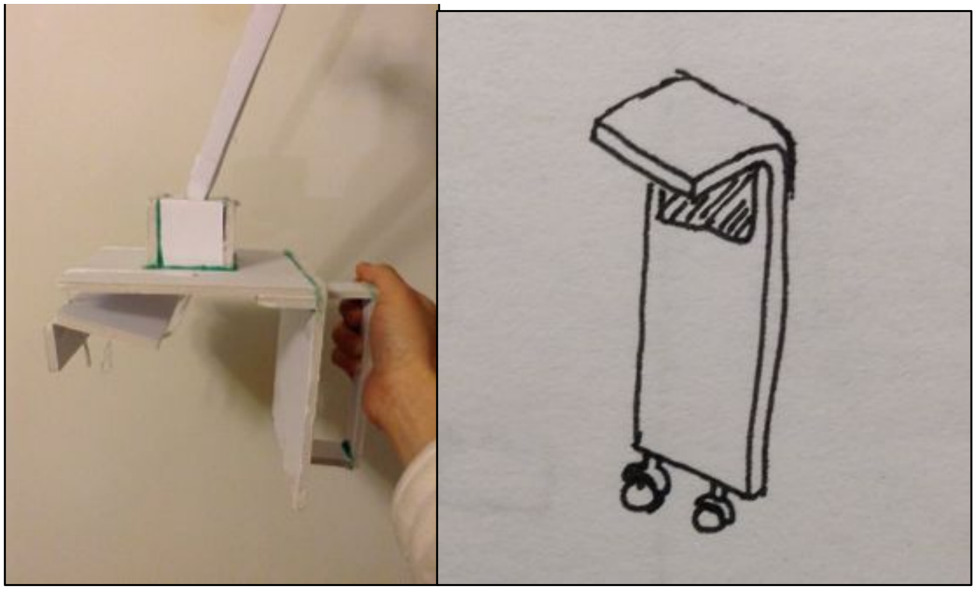

Figure 10 - Model of the Handled Base (Hook Over the Bumper), and Sketch of the Wheeled Base That Would Lean on the Side of the Table

Two designs that stood out to us as being the best potential solutions were a design with a free-rolling base and a design that attached to the user's wheelchair (sketches in Figure 11 on the next page). Both these designs featured the same "upper" system, with an arm that extends over the table with the roller and tripod mount system. These designs seemed promising since they not only provided a sturdy base from which to use the shooting mechanism, but they also avoided touching the table entirely. However, we found that comparing these two potential designs was difficult as they both had benefits and drawbacks that seemed roughly equal, making it nearly impossible to declare one to be better than the other. At this point, we went through with the weighted decision matrix to see if our analysis and thoughts matched with the actual analytical results from the matrix.

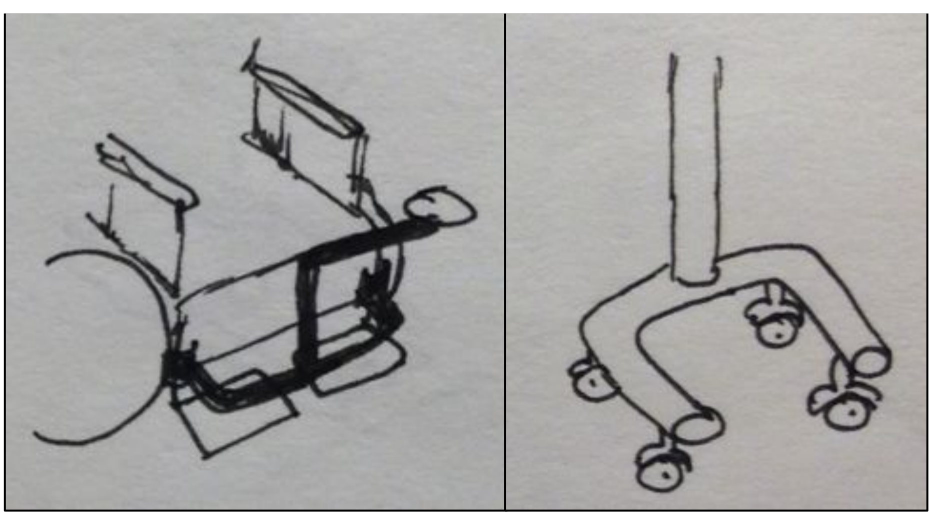

Figure 11 - Sketches of the Attachment Onto the Wheelchair Concept and the Free-Rolling Base

First, we created a weighting table found in Figure 12 in order to get weighting values for use in our decision matrix. The table compares each customer requirement, and at each point of comparisons, decides which requirement is more important. Summing these data points, we were able to calculate the appropriate weighting for each of the customer requirements.

	Transportable	Mobility	LRE	Guide in 1-D	Carry Weight < 5lbs	Force Production	Quick Set Up	Quick Usage	Does Not Damage Table	Sturdy	Low Strength Requirement
Transportable		1	1	1	1	0	0	1	1	1	1
Mobility	0		0	1	1	0	0	1	1	1	0
LRE	0	1		0.5	0	0	0	1	1	0	1
Guide in 1-D	0	0	0.5		0	0	0	0	1	0	0
Carry Weight < 5lbs	0	0	1	1		0	0	0	1	0	0.5
Force Production	1	1	1	1	1		0	1	1	1	0.5
Quick Set up	1	1	1	1	1	1		1	1	1	1
Quick Usage	0	0	0	1	1	0	0		1	0	0
Does Not Damage Table	0	0	0	0	0	0	0	0		0	0
Sturdy	0	0	1	1	1	0	0	1	1		0.5
Low Strength Requirement	0	1	0	1	0.5	0.5	0	1	1	0.5	
Sum	2	5	5.5	8.5	6.5	1.5	0	7	10	4.5	4.5
Rank	9	6	5	2	4	10	11	3	1	7	7

Figure 12 - Table to Determine the Weighting for Each Customer Requirement

With our weighting values (the highlighted values in Figure 12), we moved on to creating the weighted decision matrix (Figure 13). By placing the project requirements on the left and the potential designs on the top, we are able to assign a performance value to each design with respect to each requirement. For example, if a design satisfies a particular requirement excellently, then we would place a 5 in that cell. However, if that same design utterly failed at satisfying a different requirement, that cell would get a 1. Once we went through the entire matrix and assigned all the performance values to each design, we applied our weighting values to them.

In order to get our "total performance" for each design, we multiplied each performance value by the weight for each particular requirement, and summed them for each design. This results in a value that can be compared to all other designs, allowing a direct comparison of how well each design meets the project requirements overall.

	weighting	bumper slider with wheels on ground		clamp to bumper of table		frictional clamp to table		bendable tripod with bridge		rolling frame with arms over table		standing tripod		weight hanging over side of table		bumper hooks with handle		bridge with cue path on top		arms attached to wheelchair	
		U	W	U	W	U	W	U	W	U	W	U	W	U	W	U	W	U	W	U	W
Transportable	2	3	6	4	8	4	8	5	10	3	6	3	6	4	8	4	8	3	6	4	8
Mobility	5	4	20	3	15	3	15	4	20	5	25	1	5	3	15	4	20	4	20	3	15
LRE	5.5	3	16.5	3	16.5	3	16.5	4	22	4	22	2	11	3	16.5	2	11	4	22	3	16.5
Carry Weight < 5lbs	6.5	2	13	4	26	4	26	4	26	4	26	2	13	2	13	4	26	4	26	5	32.5
Force Production	1.5	2	3	4	6	4	6	1	1.5	4	6	1	1.5	4	6	2	3	2	3	4	6
Quick Set up	0	4	0	3	0	3	0	5	0	2	0	4	0	2	0	5	0	4	0	2	0
Quick Usage	7	3	21	4	28	4	28	3	21	4	28	3	21	4	28	4	28	3	21	4	28
Does Not Damage Table	10	3	30	2	20	2	20	2	20	5	50	4	40	2	20	2	20	4	40	3	30
Sturdy	4.5	2	9	5	22.5	4	18	1	4.5	4	18	1	4.5	3	13.5	2	9	1	4.5	4	18
Low Strength Requirement	4.5	3	13.5	3	13.5	3	13.5	2	9	3	13.5	2	9	3	13.5	2	9	2	9	3	13.5
Sum			132		155.5		151		134		194.5		111		133.5		134		152		188

Figure 13 - Weighted Decision Matrix for Comparing the 10 Concepts
U = Unweighted, W = Weighted

From our weighted decision matrix above in Figure 13, we got results that agree with our discussions and analysis of the possible designs. The sums of the performances suggested that the free rolling base and the wheelchair-mounted arm were the strongest concepts, with very near performance. Some of the other higher concepts were the other ones we considered, such as the clamping designs.

At this point, we decided to go through with both base designs. Since the difference in usability between the two is not easily discernible without prototyping and testing the designs, we will carry both through into next quarter so that we can properly prototype them both. Once we have them prototyped, we, as well as John, will try using them to see which is more convenient and effective. At that point, we will choose which one to fully design and produce.

Top Base Concepts

The two main concepts that we will moving to the prototyping stage next quarter are the "rolling frame with arms over table" and "arms attached to wheelchair" concepts, as described in the weighted decision matrix.

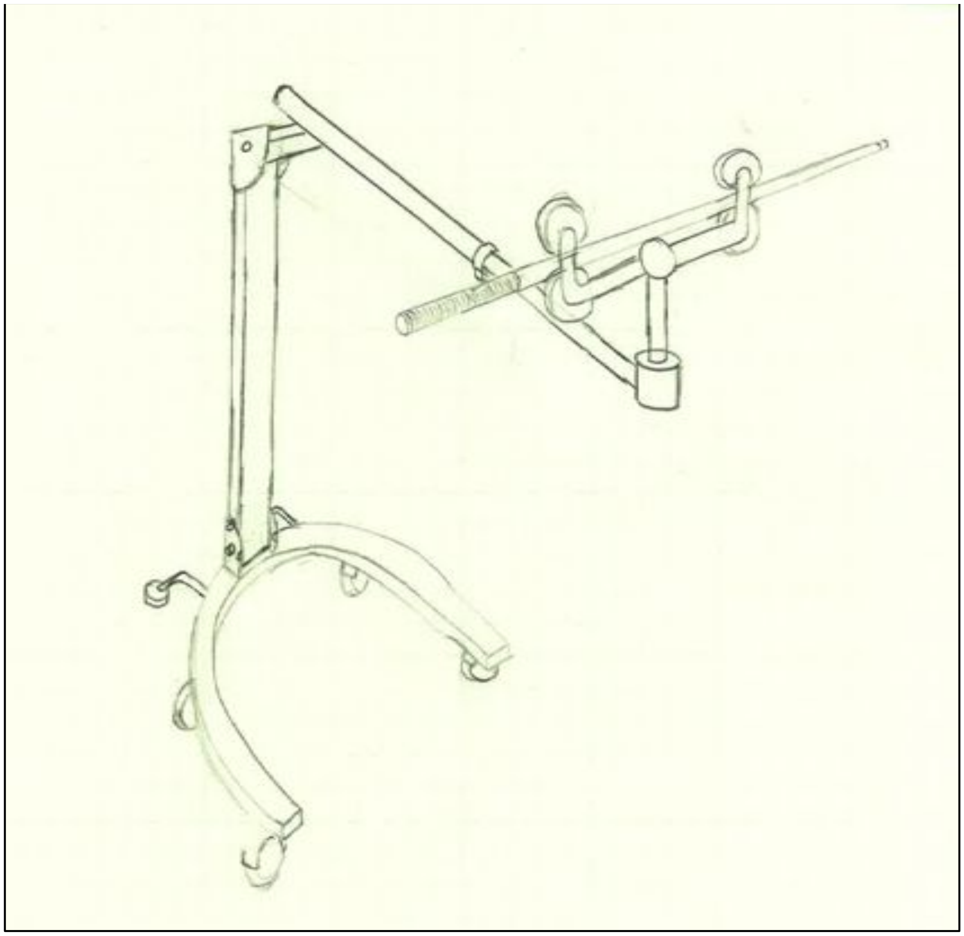

Figure 14 - Free-Rolling Base Concept

The first concept, with a decision matrix score of 194.5, was the rolling frame. This design involves a U-shaped base, with four caster wheels, two smaller wheels near its center on the side (Figure 14 not accurate for this feature), an extendable riser post, and a tube with a collar fastener at the top. The U-shaped base is designed so that the device can be positioned around the leg of the pool table, allowing the arm to reach in diagonally from the corner. Everything from the base up was inspired by the design of a scooter. The center post can fold parallel to the U-shaped base by a having a pin on the post slide between two slots, one slot in the position where the post would be standing, and one pin in the position where the post would be folded. The horizontal tube would be connected to the center post in a similar manner. Then, the user would insert the shooting mechanism, attached to a fitted tube, into the horizontal tube and tighten the collar with a lever.

The shooting mechanism would remain the same as described earlier in the report, featuring four rollers connected with a bar. One of the benefits of this design is that it can collapse and fold to a relatively small size. Once folded, the device can either be rolled on the ground or it can be picked up. Another possible feature that we plan to implement that is not depicted in the drawing is the addition of stabilizer legs. When the user is ready to shoot, he will pull a lever which causes four small posts to lower into the ground, very slightly lifting the casters off the ground. Thus, the device would essentially be a firm stand or table without the option of movement provided by the casters. A free-body diagram of the free-rolling base is shown in Appendix A, Figure 29.

This solution satisfies the specification of the project in that it is completely free to maneuver. Since it is independent of the table, it can be moved anywhere around the table, allowing the user the most freedom for positioning. The device also satisfies the weight requirement. Since the user is not actually carrying the device, the weight he is carrying is very little. Also, the device is quick to set up, as it is simply a matter of unfolding the arms and sticking a pin into a hole in the side of the arms. This design allows the user to attempt most shots because of the fact that it is very mobile. Since it can reach over the table and can be freely moved around, there are no points on the table where the user could not position the shooting mechanism. It is also vertically adjustable, allowing it to be adapted to potential differences in pool table height.

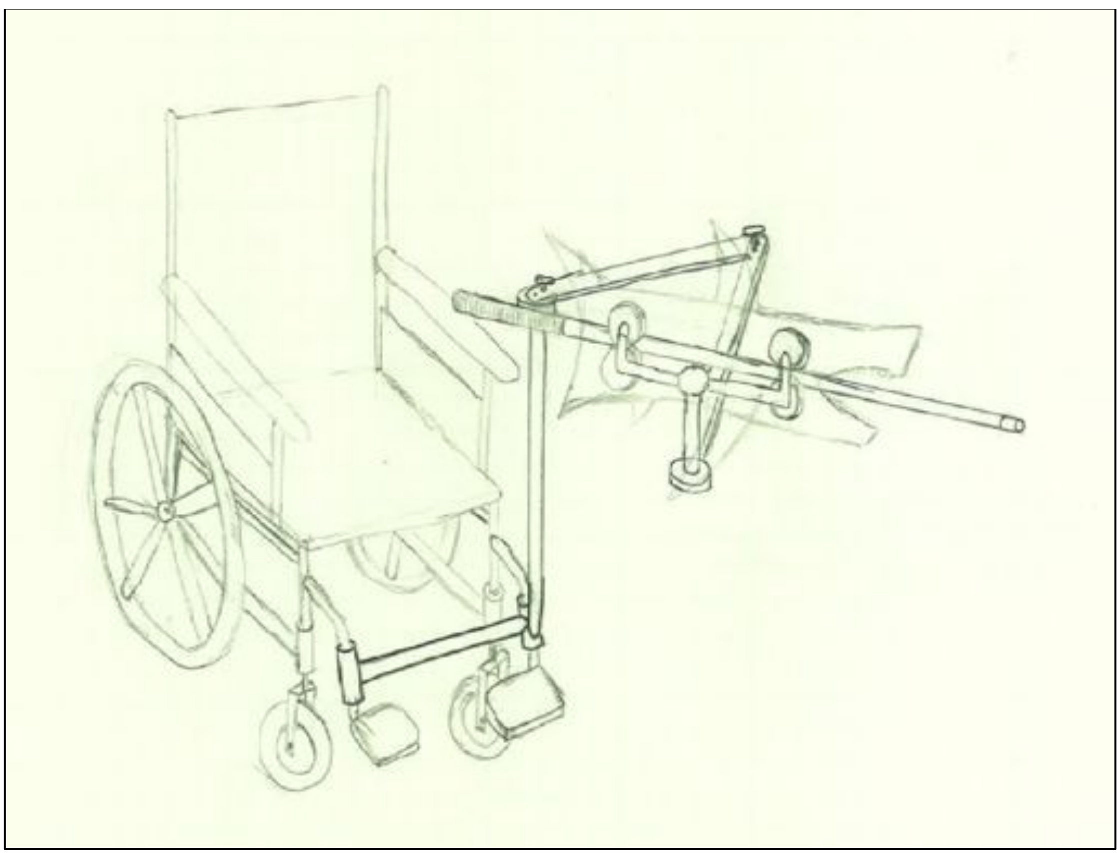

Figure 15 - Arms Attached to Wheelchair Concept.

Our second top concept, with a decision matrix score of 188, is the "arms attached to wheelchair" design shown in Figure 15. This design features a mount that rigidly attaches to the front two support posts of the user's wheelchair. While the design does not differ from the free rolling base above the mount, it does have a whole different set of potential features. With the wheelchair system, the user does not have to carry the device in and out of the pool hall as it would already be attached to the wheelchair and thus would move with the user. It also eliminates the need for the user to push around or carry anything. However, it also poses some problems such as the forces on the wheelchair potentially being an issue. The free-body diagrams of the design are shown in Appendix A, Figure 30. In order to alleviate the forces on the wheelchair supports, a sort of monopod leg could be attached to the arm so that some of the forces are resolved into the ground. In addition, if the user were to get a new wheelchair, they would no longer be able to use the device, as the mount would be designed for a specific wheelchair.

Concept Testing

Based on additional feedback from Dr. Taylor and others, as well as additional analysis of current wheelchair designs, we were able to eliminate the "arms attached to wheelchair" design. With a non-universal mounting design, the device would be unusable whenever John gets a new wheelchair. A non-universal wheelchair mount would also preclude people with different upper body mobility limitations from being able to effectively use the device. Further engineering analysis of a universal mounting design also revealed some significant flaws. First, to create a universal design, you need to find a method of attachment that is structurally secure. To achieve this, you must use the only universal support structure on modern wheelchairs, which is the seat itself. Attaching to this in a way that works for multiple wheelchair models would involve the use of straps across the seat base and backrest. While this kind of design is possible, to keep the attachment structurally sturdy the straps would have to be taut, creating an uncomfortable sitting position for John and negating any ergonomic considerations inherent in the wheelchair seat's original design. While it could be argued that such a system would be acceptable for the short amount of time involved in playing a game of pool, attaching to the seat also means that attaching and removing the device is at best inconvenient, and at worst involves the assistance of another person which would violate the Least Restrictive Environment goal of the project.

With this new insight we focused on creating a prototype of the rolling frame design. We fashioned a rough model of the frame out of wood to get a better physical understanding of the size of the device. We also attached a wooden mockup of the shooting mechanism, with two 'v' shaped supports to prove that our cue-restraint system worked as we expected. Finally, we attached easily removable casters to the base to allow movement around the table. Removing the casters allowed us to simulate the locked system that would be used when actually making a shot.

Figure 16 - Wooden Concept Testing Prototype

We met with John at Mustang Lanes to get feedback on our concept prototype, shown in Figure 16, and analyze any concerns that may exist when at an actual pool hall. John had no problems or complaints with moving the base around the table. When our device was acting as a fixed base, John was able to interface with it easily to make shots. We noted that when John positioned himself and the prototype to make a shot, he automatically grabbed the upright bar to brace the device, and moved the pool cue with his other hand. This helped to prevent the device against tipping and sliding. The new insight as to the drawbacks of the “arms attached to wheelchair” design combined with the positive feedback on our prototype confirmed our decision to proceed with the rolling base concept.

Chapter 4 – Final Design Description

Overall Description / Layout

Our final design consists of a free-rolling base attached to the shooting mechanism by a telescoping upright tube and an L-shaped tube, as shown in Figure 17. For each shot, the base is to be moved around the table to the desired location, where the user then makes adjustments to the position of the cue. The height of the shot is adjusted at the upright telescoping tube, while the vertical and horizontal angle adjustments are made at the shooting mechanism itself. When the shot is lined up properly, a friction lever is engaged that raises the base off of the casters and onto four posts, preventing the base from rolling. After the shot is made, the friction lever is disengaged and the user rolls the base to the next shot location. For transportation to and from the pool hall, the device can be partially disassembled and reoriented for a less obtrusive rolling configuration, and can store in the user's van in two separate parts.

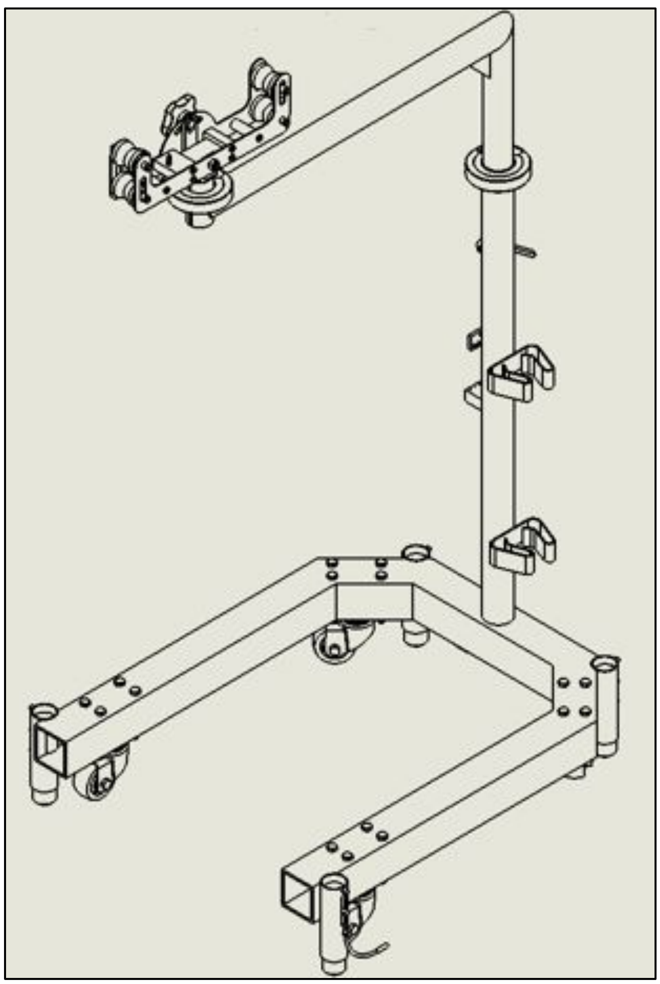

Figure 17 - Layout Drawing of the Final Rolling Base Design.

Detailed Design Description

The rolling base consists of 2”x2”x.125” hollow square aluminum tubing, welded into a U-shape. The distance between the legs of the base is 14”, allowing for the base to straddle objects on the ground such as the legs of a pool table. The base is 22” long, which increases the stability of the system by keeping the forces exerted on the shooting mechanism inside of the wheelbase. Rotating casters are bolted onto the base at the corners to allow the device to moved around without difficulty. The casters will allow the device to be rolled between John’s van and the pool hall, as well as around the pool table during the game.

Attached to the outside of the rolling base are four aluminum post sleeves surrounding nylon posts, as shown on the left of Figure 18. These posts descend to the ground and lift the base a small distance off the floor to prevent the device from rolling when a shot is being attempted. Each post has an aluminum pin embedded in its side that fits into a slot drilled into the supporting sleeve. Each pin is connected to an individual cable that runs through a routing system to the cable splitter located on upright tube. This custom-designed cable splitter connects the four individual post cables to a single cable that runs into the stabilizing lever, as shown on the right of Figure 18. This friction-based lever is then operated by the user and holds the system in place. When the lever is released, springs connected from the pin in the post to the protrusion on the post sleeve help to pull the posts off the ground to prevent the posts from dragging.

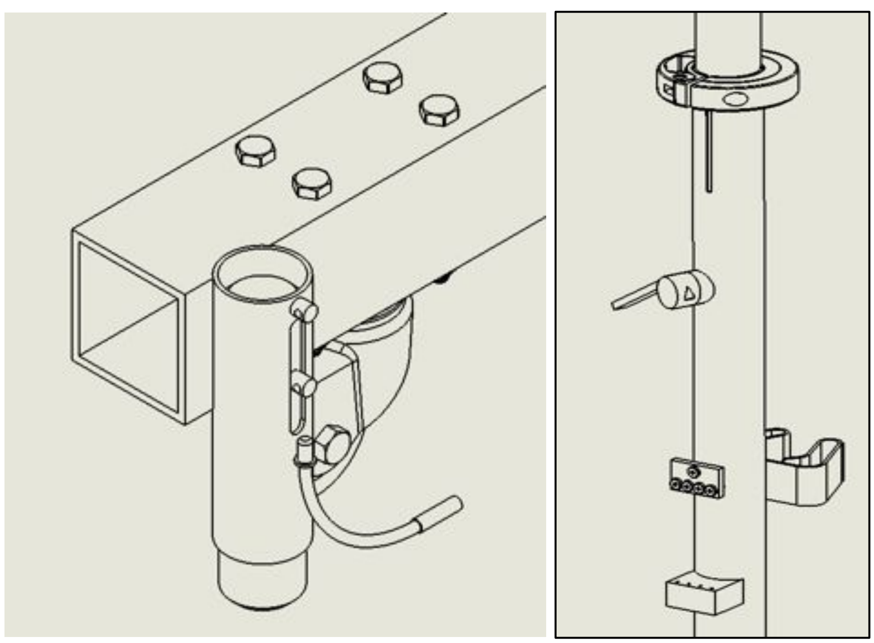

Figure 18 - Layout Drawings of the Stabilizing Post System, with the Post on the Left and the Cable Activation System on the Right

The upright telescoping tube is welded to the back of the base, and allows for vertical height adjustment of the system. Adjustment works through a tube collar clamp that can be released when the tubes need to be moved, and then easily clamped tight when the desired height is reached. Markings on the inner telescoping tube locate pre-determined shot heights so that the user does not have to be looking at the cue while adjusting the telescoping tubes. The upright tube has the stabilizing lever and cable splitter attached on one side, while on the opposite side, there are two flexible clamps. This allows the inner tube to be removed, rotated 90 degrees, and then snapped into place for less obtrusive transport, as shown in Figure 19.

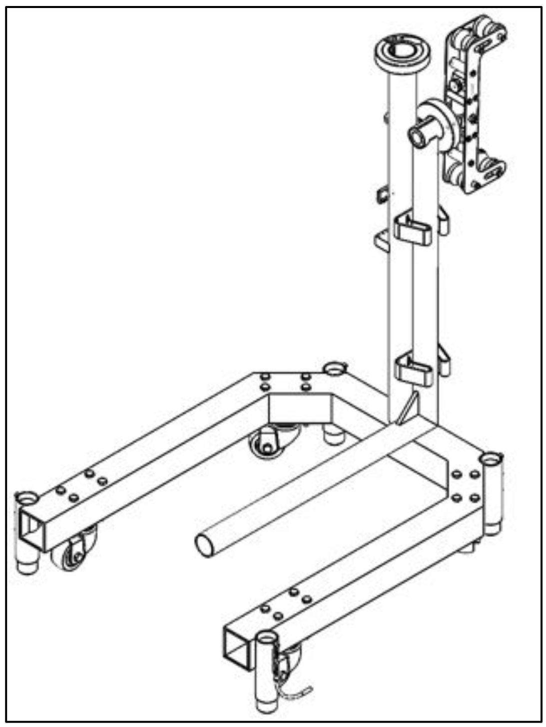

Figure 19 - Layout Drawing of the Device when Disassembled for Ease of Transport

The inner tube extends vertically into a 90 degree bend, and then horizontally 20” over the base. At the end of the horizontal portion, there is a slotted sleeve with a tube collar clamp, where the shooting mechanism attaches as shown in Figure 20 on the following page. This clamp allows for very small levels of vertical adjustment (if necessary) and for 360 degrees of horizontal angle adjustment.

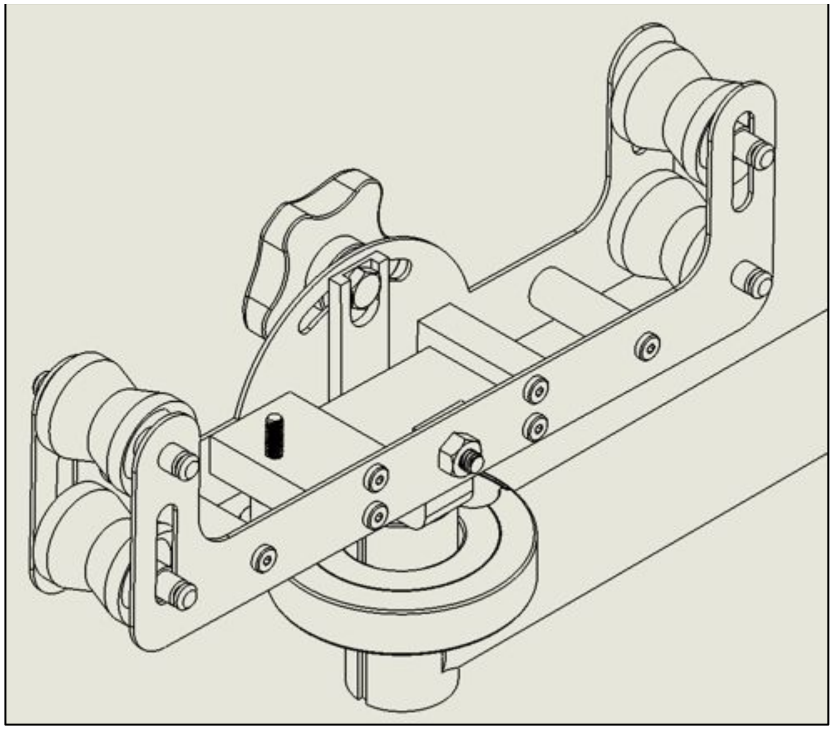

Figure 20 - Layout Drawing of the Shooting Mechanism

A post fits inside the sleeve at the end of the horizontal tube, and is welded to an aluminum fork. This fork has a short arm on one side that connects to the shooting mechanism's base block. The other side has a longer arm that is bolted to a curved slot in one of the shooter's side plates. This bolt for this slot has a large knob on the outside of the assembly that allows for vertical angular adjustment of the shooting mechanism by loosening the bolt. A rubber tipped screw is located at the front half of the base block with a knob on the underside of the block. This screw acts as a stop for the cue's travel, and can be adjusted depending on the type of shot being made in order to protect the pool table from contact with the tip of the cue. Between the side plates are two standoffs to contribute to the structural stability of the mechanism. At both ends of the shooting mechanism are two polyurethane rollers with 'v'-shaped grooves cut into them. These grooves provide contact with the cue as it tapers while minimizing motion transverse to the intended shot path. The lower back and upper front rollers are fixed in place, while the other rollers in each pair are able to translate vertically. The fixed rollers allow for the pool cue to be fully self-supported while the resultant force on the cue is downward and aft of the rear roller pair. The roller shafts extend outside of the side plates, where each pair is then connected by two springs. These springs allow for a force to be applied to the rollers that resists vertical forces exerted in ways not covered in the self-supported case, while accounting for the taper of the cue.

Analysis Results

Analysis for our design was heavily concerned with the structural strength of the frame due to our desire to minimize weight. Secondary to this was stability analyses to determine the risk of tipping and sliding when in position to make a shot. Throughout the analysis, care was taken to not only consider the effects of forces on our design, but also the likelihood of these forces occurring. The results of this analysis are shown in Table 2.

Table 2 - Summary of Analysis Results

Parameter	Value
$F_{vertical}$ for beam yielding	189.6 lb_f
$F_{vertical}$ for tipping	586 lb_f
$F_{forward}$ for tipping	12.7 lb_f
$F_{sideways}$ for tipping	7.9 lb_f
$F_{xy,max}$ for device to slide	~ 0.7-1.0 * W_{device} (18.4 – 26.3 lb_f)
$F_{xyz,max}$ for cable to snap	~ 150 – 250 lb_f
$K_{elastic}$ for roller springs	2.80 lb_f/in
$K_{elastic}$ for riser springs	1.70 lb_f/in

The most significant parameter to analyze was the amount of force required to cause yielding of the aluminum structure. Using ProE's Structure as shown in Appendix D, Figure 31, it was determined that yielding would first occur at the 90-degree joint of the horizontal bar when sufficient vertical force was exerted on the shooting mechanism. While the initial vertical force required was determined to be high enough to not be likely, the loss of strength of welded aluminum brought the value low enough to be much more concerning. As such, it was determined that post-weld heat treatment or additional bracing of the joint was required. As a precaution, enough material is being purchased to create multiple copies of this part with various levels of structural support, to assure that in the final product, yielding will not be expected. Analysis of beam deflection done in Excel, as shown in Appendix D, Figure 32, shows that deflection is small enough to be considered negligible, and not effect the operation of the device.

For non-vertical applied forces, the system's reaction was found through force and moment calculations done in Excel, as shown in Appendix D Figure 33. As is clearly shown, even relatively low magnitude, horizontally applied loads will easily tip or slide the device. This behavior was determined to be beneficial as the structure will effectively move away from the applied force far before the magnitude reaches a point where yielding is likely.

This force analysis also pointed towards the risk of the device tipping or sliding while a shot is being attempted. However John's natural reaction of grabbing the upright tube of the prototype when making a shot easily cancels out any horizontal forces imparted into the shooting mechanism. While adding weights to the base was proposed as an extra fail-safe solution to this behavior, the analysis showed that the amount of weight required would far exceed the weight requirements of our engineering specifications. It was thus decided that the user reaction was an acceptable solution.

The cable system was analyzed to determine the likelihood of failure in general operating conditions. Conservative estimates place the load that a standard bike brake cable can withstand before breaking at between 150 and 250 pounds, which could be conceivably achieved with someone standing on the rolling base. However, this load would first be transferred through the system to the friction-based lever. As the amount of friction that this lever generates can be adjusted easily with a screw on the side, the lever can be tuned to release the posts at a force significantly less than 150 pounds, but greater than the standard vertical load on the device. This tuning is easily done, and as such, none of the cables should break in any normal operation of the device.

The spring constants were pulled from the technical data of parts that can be found in Appendix B, Table 5. These constants were then compared to their desired function within the device. For the rise springs, their only function is to lift up the posts when the cable system is released. With the low weight of each individual post, the spring should be able to generate more than enough restoring force to lift the post, even with relatively small amounts of deflection. For the riser springs, their restoring force needs to be enough to support the cue when it is far enough into the shooting mechanism that its center of gravity is between the rollers. They do not have to counteract a completely misapplied force on the part of the user. As such, their combined spring constant far exceeds the expected load, and they should be acceptable for their specific application.

Cost Analysis

We purchased as many parts as possible for our design from readily available online and local resources. Our primary online resource was McMaster-Carr, where we purchased the majority of our raw materials as well as pieces such as fasteners and casters. We also purchased other parts on Amazon.com, such as our skateboard wheels and theirs components, our gripper clips, our bike cables, etc. A moderate portion of our cost came from the custom waterjet-cut steel plates from Central Coast Creative Cutting. A summary of our vendor information is found in Appendix C.

Table 5 in Appendix C shows our bill of materials. The table is organized similar to how this section of the report is organized, so that you can follow the sources of the project costs efficiently. Our bill of materials accounts for all of our purchases through the completion of the final device.

Our purchases from McMaster included the majority of our raw materials, such as various sizes of aluminum rod and bar stock as well as our thick aluminum tubing for the base. In many cases, we bought much more material than we required for the parts it was used for, as many of the parts to which this applies were somewhat small and delicate, and it is good to have plenty of extra material in case any mistakes happened. In addition to our raw material purchases, we also bought the majority of our fasteners from McMaster. Again, the purchases sizes often included 50 or 100 of the part when we actually only needed a few. Lastly, a few special parts were bought from McMaster such as the casters, the springs, and the plastic tube plugs for the base. All in all, the cost of our McMaster purchases totaled $393.34.

One of the most important pieces of material for our project was the aluminum telescoping tubing that was used for the vertical and horizontal posts to hold the shooting mechanism. We ordered this tubing in 6-foot lengths from texastowers.com. They offer a number of stepping sizes of telescoping tubing that all fit within one another, and are sold in 6-foot and 12-foot lengths. We purchased two 6-foot lengths of each size so that we had enough extra material in case our welds went bad, and had enough to allow us to do some material testing on the tubing since it has a relatively thin wall thickness. The total cost for the telescoping tubing was $42.99.

We ordered a number of parts off of Amazon.com. Some of these parts include the skateboard wheels and bearings, the bike cable and its tubing, the gripper clips which will be used to fasten the disassembled device, and the quick release clamps. By ordering the clamps on Amazon and through careful sizing of our telescoping tubing, we were able to use standard bike post clamps to save money and time ordering. The total cost of our parts from Amazon was $109.29.

We ended up paying $86.00 for the custom waterjet-cut steel plates. Central Coast Creative Cutting was local and provided a good option for outsourcing.

We spent $72.40 on practice, prototyping, and testing materials. These materials included the wood bought to create our first prototype, the extra telescoping tubing for practicing welds on and testing the strength of the material, and the aluminum stock to polish our welding skills on.

Finally, we spent $70 on incidentals, which in this case was aluminum to steel solder. We also purchased a pool cue for John so that he has his own cue when he goes to play. We spent $75.58 on a high-end cue and carrying case. Adding other local purchases for fasteners, poster materials, and tooling, the cost from local venders was approximately $232.42.

After totaling all of our purchases from the individual vendors, our cost for the device came to a grand total of $886.03. This only accounts for a little over half of our budget of $1500. If you exclude the "external" costs such as the cue and the practice / prototyping material, the cost to manufacture just the device itself is $720.79. Overall, money was not an issue and we had plenty of leftover budget.

Material Selection

In choosing the materials from which to build our device, we had to consider a number of factors. Weight was one the most driving factors in our decision, as John is not exceedingly strong due to his disability. Since he has to be able to lift the device in and out of his van, it was incredibly important that the device by light enough for him to pick up on his own without straining himself. Stiffness was also a very important factor, as the goal of the device is to restrain the movement of the cue to one direction. Were we to choose a material that was able to deflect and bend significantly, the whole point of the device would be moot as the pool cue could move left and right due to the flex of the material. Lastly, strength was important since the device will be undergoing forces, albeit small ones. In regular play, the device will be loaded by the weight of the cue, the forces of repositioning, and even the occasional bump or somebody leaning on the device. For these reasons, it was important to pick materials that would not easily yield and permanently deform the device, potentially ruining its function.

For the majority of the device, we ended up going with aluminum for many reasons. For one, it is an exceedingly light metal, while still retaining respectable stiffness and strength. Although steel is stronger and stiffer, it is also much heavier and the device would be too much of a strain on John to lift in and out of his van. In addition, aluminum has excellent corrosion resistance. Since John plans on having and using the device for a potentially long time, it is important that regular use will not cause the device to begin to corrode or deteriorate.

For the side plates on the shooting mechanism, we chose steel for its strength. Since the side plates are the largest piece of the shooting mechanism, we did not want them to be very thick, as that would add a significant amount of bulk to the device. In lieu of a thicker piece of aluminum, we chose to go with a thin piece of steel. Steel is a good choice because it is easily water cut into the exact geometries that are necessary for our side plate. It is also even more readily available and cheap than aluminum. The biggest factor, though, was keeping the shooting mechanism slim so that it has the least interference with the shooter's aim.

We chose some materials to be plastics / polymers because their low friction and their flexibility. The bearing spacers in our shooting mechanism were made of polymers because they will be in contact with moving parts such as bearings. A plastic to metal contact has a much lower coefficient of friction than a metal-to-metal contact, allowing the wheels to spin more freely and allowing the shafts to slide up and down in their slots without grinding on the side plates. The plastic used for the support posts is actually self-lubricating nylon, which helps it feel even less friction and wear less from repeated sliding up and down in the sleeve. Since the support posts will be moved up and down in their sleeves every time the user sets up a shot, it is important that they are able to slide freely without resistance so that the user does not have to apply extra force to compensate for stuck posts.

All of our material choices were made with function in mind. Weight is an incredibly important factor in our design, as is the structural integrity of the shooting mechanism and the longevity of the moving parts within the device. For these reasons, aluminum, steel, and polymers make excellent materials choices.

Safety Considerations

Our final design has a few safety considerations that the user should be aware of. Chief amongst these is the danger that the cue itself can pose to others. If the cue is being held in the shooting mechanism while the device is being moved, lack of attention could cause it to swing into or poke either the user or a bystander. The device itself has a few hard corners, and while they will be sanded down, the user should be aware of their presence. Despite its relatively low weight, if the device were to tip, it could cause an impact that could cause minor injuries to someone around it. Finally, if someone were to assume that they could lean their weight on it, the device may tip, which could cause injuries due to an unexpected loss of balance.

Maintenance and Repair Considerations

The most likely aspect of the device to require maintenance is the cable system. As all of the individual components apart from the custom cable splitter are readily available bike parts, replacements should be easy to come by. Also anyone with experience routing and adjusting bike cables should be able to easily perform the maintenance. If one of the soldered / epoxied components breaks off, the replacement part should be able to be fixed by someone with relatively small amounts of shop experience.

In general, the device should not be stored for long periods of time in areas exposed to the elements, particularly salt water. However due to the aluminum, plastic, and stainless steel design, no significant material degradation or corrosion is expected.

Chapter 5 – Design Realization

Manufacturing Overview

Manufacturing of the device was completed on campus at the Student Projects Hangar. The design necessitated a significant amount of machining in order to create custom parts for the various systems, and to achieve the intended frame shape and functionality. A TIG welder, hand-operated gas torch, manual mill, manual lathe, aluminum chop saw, and drill press were the main tools used in the creation of the device.

Side Plates: The side plates for the shooting mechanism were outsourced to a local water jet cutting company, Creative Cutting. This choice allowed us to bypass the complications involved in creating CNC-machined parts on campus, and resulted in a final product that was accurate to the design drawings for minimal cost. The longer lead-time associated with the outsourcing was acceptable due to not needing the side plates until final assembly.

Skate Wheel Roller: The v-shaped rollers used to guide the pool cue in the shooting mechanism were manufactured from readily available polyurethane skateboard wheels. In order to machine the wheels on a lathe, an arbor was required. To create the arbor, a piece of 1" diameter aluminum stock was turned down on a manual lathe. One side of the arbor was turned down to feature a chamfered edge so that the rollers would center themselves on the arbor, and the smaller diameter extension was threaded with a die. The other side of the arbor had a hole drilled in it, and this hole was then tapped to create a matching set of threads.

A polyurethane wheel was then centered and clamped on the completed arbor, and the arbor was inserted into the manual lathe chuck. The wheel was turned down to create the 'v' shape, and skateboard bearings were then inserted in the finished roller. A before and after image of the rollers is shown in Figure 21.

Figure 21 - Skate Wheel Roller, Before and After

Roller Shafts: The roller shafts were cut to size from small aluminum bar stock, and then turned down to size on a manual lathe. The chamfered edges and the grooves for attaching springs were also machined on the lathe.

U-Shaped Base: The U-shaped base had pieces of 2” x 2” x 0.125” square aluminum tubing cut to size using an aluminum chop saw. Four notches were cut into the sides of the tubing using a drill press to provide attachment points for the post sleeves. A hole was cut into the middle piece of tubing where the base attaches to the base center post. This tubing was then TIG-welded together to form the overall shape of the base. After the ‘u’ shape was welded, holes were drilled in the top of the tubing for the bolts needed to attach the caster wheels.

Brake Post: The brake post was machined on the manual lathe out of self-lubricating nylon. The stock material was turned down to size, and a chamfer was added on both ends. The hole for the post pin was created using a drill press. The post pin was cut to size and the cable hole was made using the drill press.

Brake Post Sleeve: The brake post sleeve was cut to size from the hollow aluminum tube stock. The slot was created using an end mill, which was also used to create the spring attachment point. The spring attachment hole was created using a drill press, and the nub was attached to the sleeve using a specialty aluminum solder and a hand torch after the sleeve was attached to the base.

Horizontal Bar and Base Center Post: The horizontal bar and base center post were cut to size with the necessary 45° angle where needed. For the outer base center post, the slot was cut using and end mill. For the horizontal bar, the notch for attaching the post was machined using the drill press.

Fork: The fork was created by cutting a 3/16” thick aluminum bar to size and welding the three parts together in a ‘u’-shape. This was then welded to an aluminum post that was turned down on a lathe to be the necessary1 1/8”-OD. The slot and holes in the top of the fork were then machined on a manual mill after welding was complete. The fork sleeve was cut to size from 1 1/4”-OD hollow aluminum tubing, and the slot was machined on the end mill.

Shooter Block: The main shape of the shooter block, as shown in Figure 22, was machined entirely on a manual mill. Once the holes were drilled in the block, they were tapped to create the necessary threads. Creation of this part was particularly time consuming.

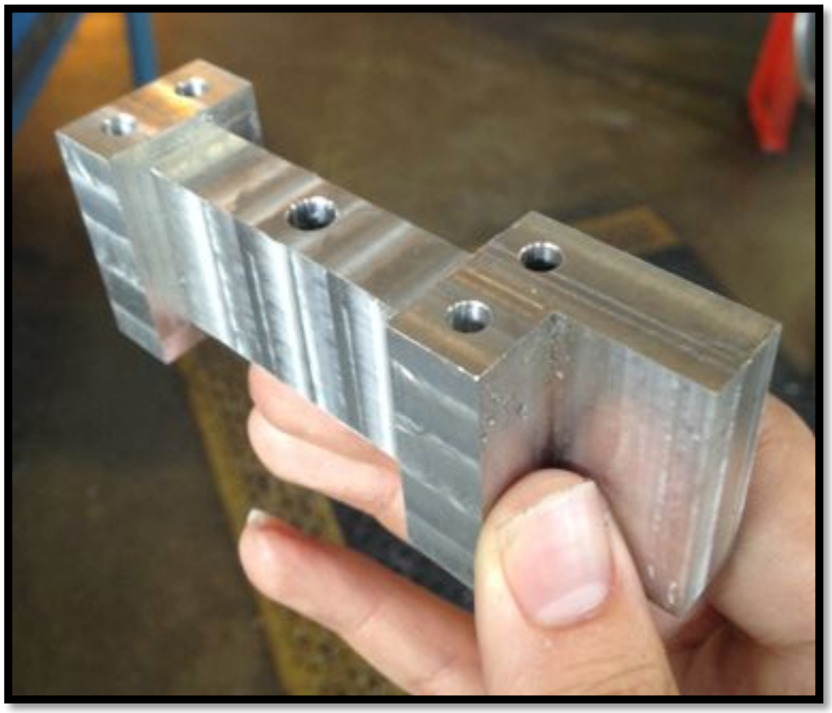

Figure 22 - Machined Shooter Block

Cable Aligner and Retainer: Both the cable aligner and the cable retainer were machined on a manual mill from aluminum stock. Holes in the aligner were drilled initially for the smaller section, and then larger holes were drilled partway through from the other side. Holes in the retainer were drilled and then tapped to create necessary threads.

Assembly: Additional welding was required to attach the horizontal bar to the inner base center post, and to attach the outer base center post to the U-shaped base. The brake post sleeves were also welded to the base for additional strength. The cable aligner, clips on the side of the center post, brake lever, and small guides for the cable system were all attached with specialty aluminum solder. This allowed for low temperature attachment of steel to aluminum, and for attachment of pieces that welding would significantly warp. Epoxy was used for some of the small cable guides where the solder was ineffective. The shooting mechanism and casters were assembled using fasteners, and collar-clamps were set in place on the notched tubes. Finally, the cable system was routed through cable housing to attach the brake lever to the brake posts, and springs were added to the brake posts and roller shafts.

All drawings required for fabrication of our design are located in Appendix B, where appropriate dimensions and tolerances are specified.

Differences From Planned Design

Manufacturing led to some unforeseen changes to our design. Most of these changes were purely aesthetic and did not affect the overall cost. These changes, and the reasoning behind them, are important for understanding the final state of the delivered product.

On the aesthetic front, the final colors of the device were did not end up as initially designed. For the rollers, they were initially intended to be entirely black, to contribute to the sleek look of the device. However upon machining them, it became apparent that the wheels purchased were not uniformly black throughout the polyurethane, and were instead only black on the surface. After consultation with John Lee, it was decided to keep the rollers as black on the outside edges and white on the contact surface, rather than replacing them. Additionally, manufacturing delays and available machine shop resources prevented the overall frame from receiving the intended powder-coating layer. Instead, painting was limited to the steel side plates, which were the only components of the frame at risk of significant corrosion if left untreated.

For attaching the casters at the back of the device, only three holes were drilled into the base. This was due to proximity to the welds and concern over structural integrity of the welds if holes were drilled through them. The secure attachment of the casters was not affected by this change.

The initial design called for a press fit of the brake post pin into the nylon brake post. However this proved problematic in manufacturing due to the material properties of the nylon. When drilling into the nylon, heat from the drill bit caused the nylon to expand around the hole. Upon cessation of drilling, the nylon then shrunk to a smaller size than the nominal measurement of the drill bit in use. This made drilling a hole accurate to the design drawings impractical. Also, with the nylon, any actual press fit proved difficult to achieve, as the pin would have to be press fit only after the post is placed in the sleeve. This caused problems not only for assembly, but also for any future disassembly if repairs were to be made. As such, it was decided that creating a clearance fit for the pin was a better option, as horizontal deflection of the pin in the hole was minimal and due to the geometry of the post/pin/cable/sleeve system, the pin was at no risk of falling out.

We originally intended to create the fork by bending a piece of aluminum bar to the desired ‘u’-shape. However upon creating the part in this way, we discovered that the bend radii were causing undesired interference with the shooting mechanism’s adjustment feature. To remedy this, the fork design was changed so that three separate pieces of the aluminum bar would be welded together, making sharp corners that would not cause interference. After fine adjustment through sanding and filing, this solution proved acceptable.

Our original manufacturing plan called for significant amounts of brazing of steel and aluminum parts to the main aluminum structure. Our initial research and purchased product descriptions led us to believe that this would be a relatively easy solution. However upon actual attempts at using the specialty brazing filler rod, it became apparent that the skill required to get the aluminum-silica filler rod to flow properly without burning the flux or the base metals was far beyond our skill level, and that the time needed to improve our skills was impractical for the project timeline. As a result, we made the decision to replace many of the intended brazed connections with a specialty aluminum solder.

The aluminum solder came with it's own set of drawbacks. Due to the low melting temperature of the solder, any direct heat would burn the flux, and reapplication of heat after a joint was made would destroy the joint. Additionally, the lower strength of the joints when compared to the initially intended brazing combined with the difficulty in determining by inspection whether or not the joint was good created doubt about some of the joints. These complications led to two main adjustments. First, the joints attaching the brake post sleeves to the base were changed to welded joints, to insure adequate strength and guarantee a good joint quality. Second, we decided that anywhere that the soldering proved problematic, we would replace the solder with epoxy. This ended up necessary for the small cable guides, as well as the upper clamp on the center post.

Recommendations for Future Manufacturing

Through lessons learned in our manufacturing of this device, any future manufacturing of this design can be improved in a variety of ways. Chief amongst these would be to have all welds done by a professional welder. Though we incorporated the assistance of our welding instructor, Kevin Williams, for many of our more difficult welds, the overall quality could be improved by having all welds done by the same accomplished welder. The welds could also be improved through small design changes to make access to the welds more convenient. Similarly, someone accomplished with aluminum brazing would be able to improve the appearance, quality, and strength of the joints that we had to solder. Another manufacturing improvement involves the alignment of lathes for fabrication of many of the parts. Due to difficulty in getting the parts properly and consistently centered, all lathe work on the same part should be done at once, or should be done in a high quality and properly calibrated lathe in order to save time.

Chapter 6 – Design Verification Plan

To validate our design, we created a Design Verification Plan (DVP) that outlined what tests we performed and our acceptance criteria for each test. The primary function of these tests was to verify that our final manufactured design met our engineering specifications, and to assure that the final product works as we intended. The full test plan can be found in Appendix F, Table 3. An overview of the final testing results is as follows:

1. **Cue Length Compatibility:** This test involved observing cues placed in the shooting mechanism, to determine when the mechanism was no longer able to support them without user assistance. The key measurement was how much length of the pool cue needed to be in front of the front rollers before the cue fell out of the device. The final test result was that with any part of the cue between the front rollers, no matter how small, the device was able to freely support the cue without outside involvement.

2. **Pinch Points:** Design of the device to be user friendly and safe required that there be no significant pinch points located on the device. Visual inspection confirmed that no area of the device posed a pinching hazard, while the roller clamping force was confirmed to not cause physical pain.

3. **Free Movement:** The device was designed to be freely moved around the table so that various shots could be made, as shown in Figure 23. Testing on floor surfaces including wood, carpet, and concrete confirmed that the casters operated as intended and that movement of the device in a pool hall environment is reasonable.

Figure 23 - Device Moved Around Table to Make a Shot

4. **Vertical Reach:** The engineering specifications required that the device be at least at the height of 32” to reach over the edge of a standard pool table. Testing confirmed that the

vertical adjustability of our device is between 32” and over 40”, conclusively meeting this requirement.

5. **Horizontal Reach:** The device needed a horizontal reach of at least 36” in order to be able to make pool shots. Measurements indicate that the reach of the device allows the tip of the pool cue to extend at least 48” over the edge of a pool table, satisfying this requirement.

6. **Vertical Angle Range:** In order to make the majority of pool shots, vertical angle adjustment needed to incorporate between 5° and 20° of vertical positioning. The mechanism can travel between -30° and +30°, greatly exceeding the engineering specification.

7. **Horizontal Angle Range:** With an effective horizontal angle adjustment of 360°, the device exceeds the 0° to 180° engineering requirement initially specified.

8. **Cue Movement Limit:** Observation of the device in action confirmed that the shooting mechanism constrains the travel of the pool cue to a single axis of movement, greatly improving user control over their shots. Figure 24 shows the pool cue aligned with the shooting mechanism, demonstrating the direction that the cue is restrained during the shot.

Figure 24 - Device Lined Up for Shot, Shadow Showing Axis of Travel on Table Surface

9. **Seated Operation:** Through user testing in a pool hall environment, we were able to confirm that the device allows for full adjustment and for shots to be made while the user is seated, confirming compatibility for seated and wheelchair use.

10. **Elbow Movement Limit:** User testing confirmed that the device allows for pool shots to be made with the user's elbow below their shoulder. This meets the related engineering specification to improve usability for those with more limited upper body mobility.

11. **Cue Travel:** Due to the mechanism's ability to support the pool cue with any length of the pool cue in front of the front rollers, the available cue travel for a shot greatly exceeds the 6" required.

12. **Max Cue Deflection:** By manually rotating the pool cue in the shooting mechanism at its furthest travel, deflection of the cue tip approaches 15° from the centerline of the mechanism. This allows for slight variations in the outcome of shots consistent with providing a authentic pool experience, while still allowing the shots to be constrained to improve accuracy and effective functionality.

13. **Exposed Moving Parts:** Safety of the device called for no moving parts to be exposed on the outside of the device. With the rollers located between the shooting mechanism plates, and no hazardous sliding or rotating elements accessible in normal operation of the device, visual inspection verifies compliance with this test.

14. **Set-up Time:** In order to be useable in a standard game of pool without causing prohibitive delays, the time to set up a shot needed to be less than two minutes long. Multiple trials confirmed that the device is able to be moved and adjusted fully to make a shot in less than two minutes, and depending on the shot, can be made in less than a minute.

15. **Forward Tipping Force:** In order to ensure stability of the device and prevent damage to the pool table, it is preferred that the entire device slide on the ground before it tips into the pool table. Pushing forward on the device in various ways confirmed that the device behaves as intended.

16. **Sideways Tipping Force:** Overall stability of the device necessitated that the device slides when subjected to a sideways force, rather than tip and have to be righted by the user. Through movement about the table, and purposeful pushing of this device, the intended sliding behavior was observed.

17. **Pin Lever Release:** For safety and reparability reasons, desired behavior of the brake and

cabling system involved the brakes receding when significant downward force is applied to the device, preventing the cables from snapping. This behavior was observed repeatedly and was well within the 75lb requirement.

18. **Cue Stop:** In order to protect the surface of the pool table and allow for shots at extreme angles to have the right amount of cue travel, the adjustable cue stop had to effectively stop the cue during a shooting motion. Observation of cue travel with various cue stop adjustments confirmed that the cue stop worked as intended.

19. **Sliding Force:** In order for the device to allow shots to be aimed and made as the user intends, the device should not slide when a shot is being made. Through observation at the pool hall and use of the device by multiple users, it was confirmed that the device remains stationary when a shot is attempted.

In addition to the testing plan we followed, the device held up without problems during the Senior Project Expo. It was able to be used by a wide variety of people, and all adjustability and mechanism functionality worked as intended. Though not formal testing, it helped confirm that the durability and user-friendly design aspects were accomplished.

Chapter 7 – Use, Conclusions, and Recommendations

How to Use Device

The use of our device involves a generally straightforward series of steps, as listed and as shown in Figure 25.

1. (blue) Adjust height and angles of the shot using collar clamps and knob.
2. (red) Push down lever to lower the stabilizing posts.
3. (green) Take the shot.

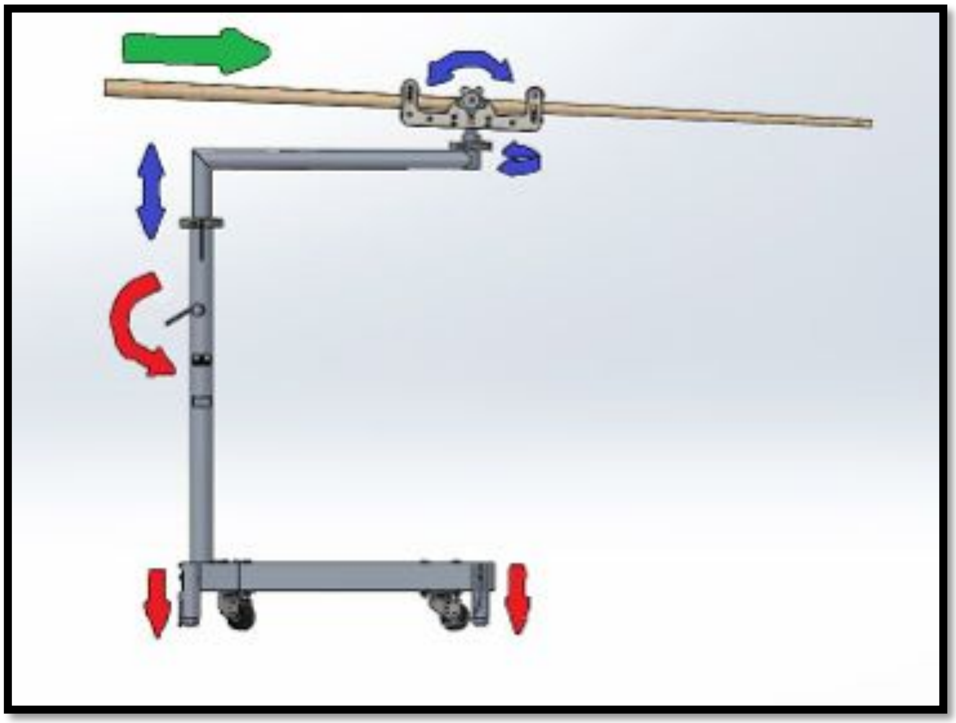

Figure 25 - Details for Operation of Device

However even with these steps, there is a noticeable learning curve involved before shots can be made in a comfortable manner. To assist in minimizing this learning curve, the following tips for the use of the device are provided.

- If the device is properly set up for general shots, raise the cue in the shooting mechanism to get the cue tip over the edge of the table. Adjusting the shooting mechanism angle to get the cue tip over the edge takes more time, and requires readjustment for the next shot.
- To avoid contact with the table, push the cue in the shooting mechanism as far as possible, and adjust the device until the cue tip is no longer in contact with the table. Then pull the cue out of the device slightly to set up the shot.
- When setting up the shot, let the cue rest in the shooting mechanism wherever you feel a

slight initial resistance. If the cue tip at this point is right next to the cue ball, the mechanism will have enough travel to follow through with the shot.

- Avoid pushing on the cue when adjusting the shooting mechanism, as this risks prematurely hitting the cue ball before the actual shot is attempted.
- Have the stabilizing posts lowered when adjusting the angle of the shot. Once the angle is set, it is okay to raise the posts to more easily line up the shot. Do not forget to re-lower the posts when you attempt the shot.
- When making all adjustments, try to adjust by holding and rotating the shooting mechanism, not the cue. This will minimize time required to perfectly align the shot.

Conclusions

This project called for a device that would allow people with limited upper body mobility to more effectively play a game of pool in a real pool hall environment. After thorough background research, a comprehensive design development process, and weeks of manufacturing, we are confident that our final product satisfies this need.

The device can be freely moved around the table and adjusted in the horizontal and vertical planes, all while restraining the path of the cue in a way that improves the accuracy of shots. The construction is lightweight, able to be disassembled, and designed in such a way that reparability of the more complicated mechanisms is straightforward. Careful selection of materials ensures that the device will resist environmental degradation and continue to perform as expected for many years to come. The adjustment interfaces that were chosen allow for the device to be utilized fully, whether the user is standing or seated in a wheelchair.

Feedback from our client, John Lee, was very positive. In his view, the playability of the device, maneuverability between shots, and ease of transport exceeded his expectations. With this feedback and our own experience, we feel this design will effectively improve his ability to play pool, and will be a valuable asset to anyone with limited upper body mobility in the future.

Recommendations

Though our device serves as a good solution to the engineering problem we were presented, there are some aspects of our design that can be improved in future iterations. One such improvement that could be made involves a redesign of the cable system. Though the cables provide a simple and easily repairable solution, their aesthetics could be improved by rerouting their path or redesigning the connection between the lever and the posts. For the lever itself, adding a mechanism to lock it in place when the posts are down could improve stability of the system and resistance to sliding. The posts could potentially be redesigned to be more flush with the base, to improve both the aesthetics and the footprint of the device.

For the shooting mechanism, the main improvement that can be made is redesigning the roller shafts so that the free roller is unable to rotate in the slot. This would help reduce cue tip deflection for shots that are made with significant sideways forces. From an aesthetic standpoint, the shooting mechanism could be enclosed, however this may add unnecessary weight.

On a broad project level, our device was designed primarily to meet the needs of our customer, with a secondary emphasis on making a device that could be used by people with general upper body mobility limitations. Many of our design decisions reflect this choice of priorities. If the goal in the future is to create a device that is more general in nature, a complete redesign may be necessary, though smaller changes in the earlier design phases may accomplish this as well.

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Appendices

Appendix A: QFD Chart and Concept Design Documentation

Appendix B: Design and Manufacturing Drawings

Appendix C: List of Vendors, Contact Information, and Pricing

Appendix D: Detailed Supporting Analysis

Appendix E: Gantt Chart with Time Summaries

Appendix F: Design Verification Plan

Appendix A: QFD Chart and Concept Design Documentation

Project: Adapted Pool Cue

Engineering Requirements (HOWS)

Customer (Step #1) Requirements (Whats)	Weighting (Total 100)	cost less than $1500	cue movement limited to 1 axis	hold cue off table	weigh around 3-5 lbf	elbows should not rise above shoulder level while operating	no pinch points	have cue travel of	use regulation pool cue	prevent cue tip from deflecting more than allowed by elastic impact	move freely to all sides of the tables including corners	[opt.] provide force to cue without direct user force input (for breaking)	be attached/detached by user with less than 5 lbf of effort	be operable/removable while seated	reach over a 32 inch pool table	reach across the pool table	vertical angle range	horizontal angle range	no exposed moving parts	take little time to set	Benchmarks: ramp	spring loaded cue	bridge
use regulation pool cue	8	Δ		Δ	○			Δ	●	○	Δ		Δ		○	○	Δ	Δ			1	1	6
cost less than $1500	1	●			○				Δ												5	5	6
be carry-able using a wheelchair	2	Δ		Δ	●				Δ		●		Δ	●	○						2	5	5
allow use of natural pool movements	4		Δ	Δ		Δ		○	●	●	○			●			○	○			1	4	5
hold cue in position after aiming to allow focus on force production	6		●	●		Δ		Δ	Δ	○		Δ		○	○		●	●			1	2	6
should be light	2	○			●				○	○	○		●	●							3	5	6
be configured to produce force on its own	4								●			●	○	●						○	5	5	1
be safe	7	Δ					●					○	○						●		5	4	5
support the cue off the table	3		○	●	Δ					Δ	Δ	○			○		○				1	1	5
not force the user to hold elbow over shoulder level	5					●										○					5	4	4
be usable for people with low upper body mobility and/or strength	5			Δ	●	○					Δ	●	●	○						○	5	4	4
require little force for operation	6											●	●	○						○	5	5	5
be a sturdy design with little wobble or play	6	Δ	○	Δ	○					●		○			○		Δ	Δ			5	2	6
useable while sitting/compatible with a wheelchair user	5			Δ		Δ					○		○	●		●				○	5	5	6
guide the cue in a sliding motion in one direction	6		●	○				Δ									Δ	Δ			1	2	5
allow the user to attempt most shots	4								○		●	○				○	●	●			4	5	5
be operable quickly	2								Δ		●		●	○						●			
Units		$	axis	inch	lbf			inch	inch	deg			lbf		inch		deg	deg	part	min			
Targets		<1500	1	</=0.5	3 to 5			1 to 6	57	3			< 5		32		5 to 20	</= 180	0	1 to 2			
Benchmark #1																							
Benchmark #2																							

Customer Requirements (Step #2)

● = 9 Strong Correlation
○ = 3 Medium Correlation
Δ = 1 Small Correlation
Blank No Correlation

Figure 26 - Quality Function Deployment Chart

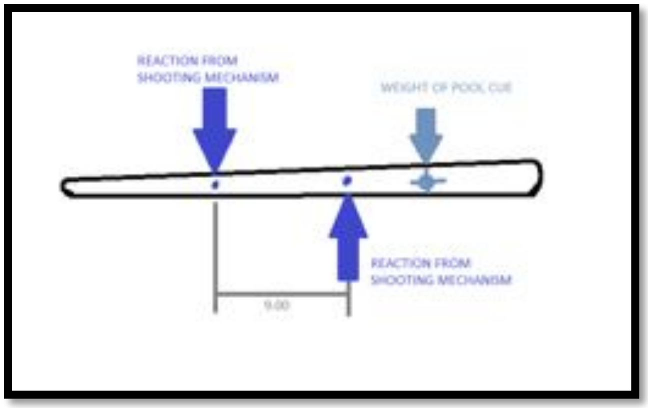


Figure 27 - General Free-Body Diagram of the Forces on the Pool Cue from the Shooting Mechanism

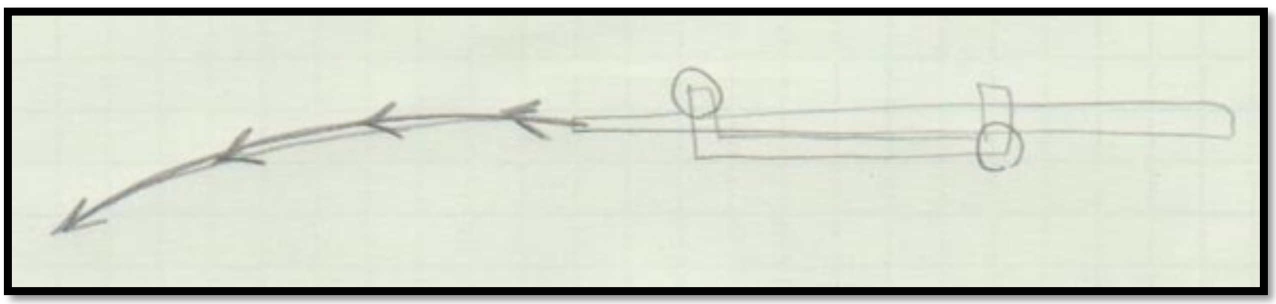


Figure 28 - Sketch of the Motion of the Pool Cue Through the Shooting Mechanism

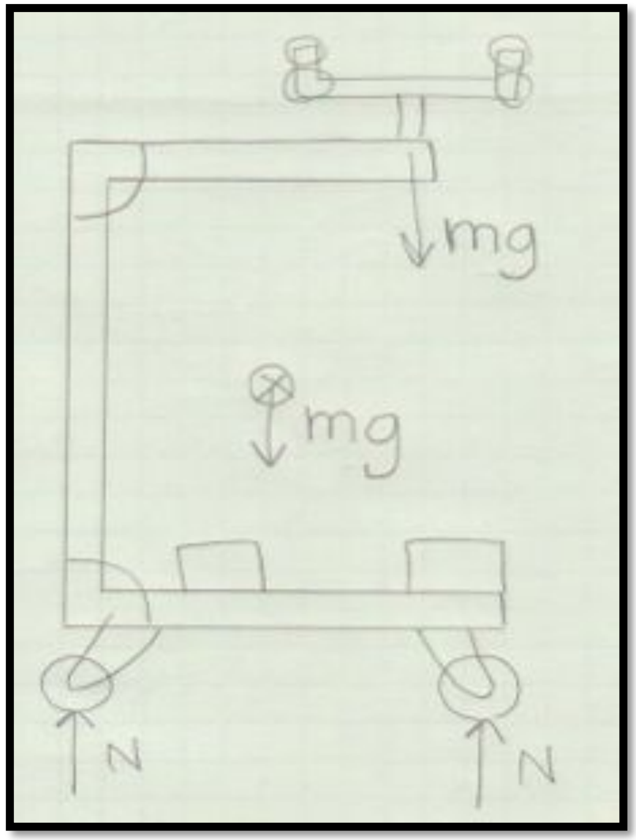


Figure 29 - General Free-Body Diagram of the Forces Involved in the Roller Base Concept

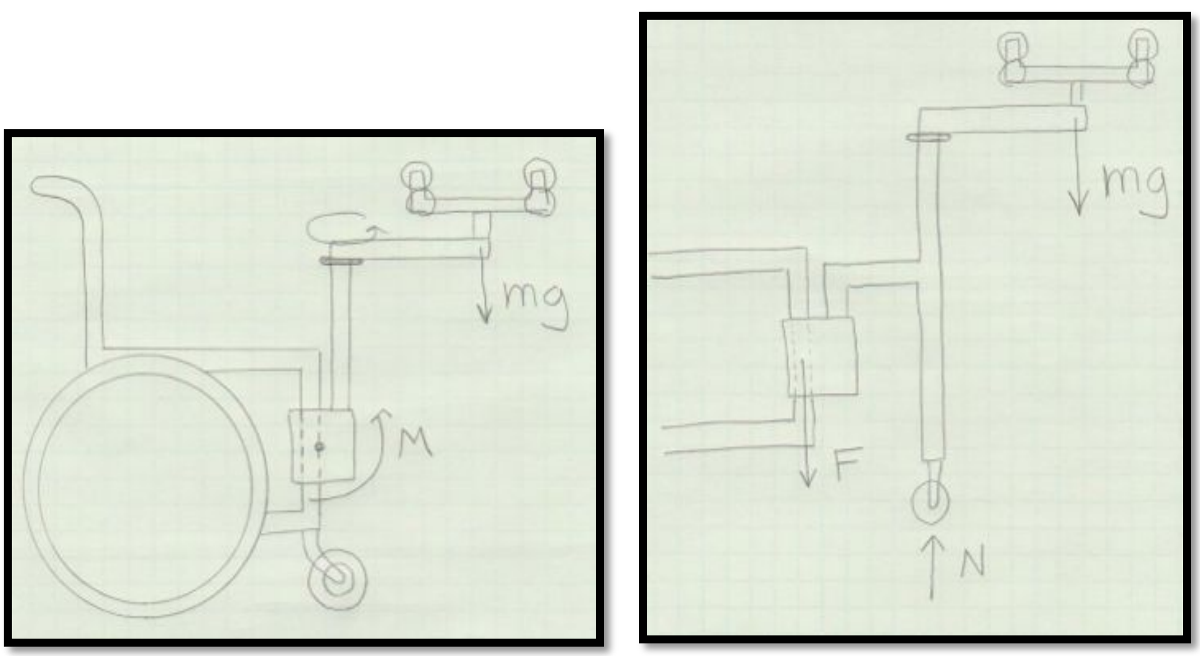
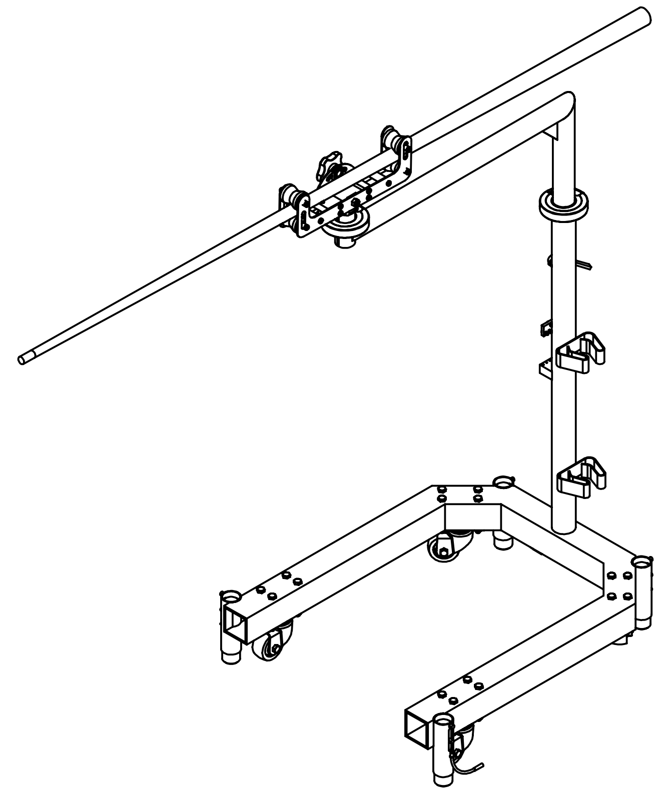


Figure 30 - General Free-Body Diagrams of the Forces Involved in the Wheelchair Attachment Concept

Appendix B: Design and Manufacturing Drawings

ITEM NO.	PART NAME	STOCK PART NUMBER (IF APPLICABLE)	DRAWING NUMBER	QTY.
1	U-SHAPED BASE		CMD102	1
2	BASE CENTER POST		CMD109	1
3	POST HOLDER		CMD104	4
4	BASE CENTER POST INNER		CMD110	1
5	HORIZONTAL BAR		CMD105	1
6	CASTER	2406T28		4
7	FORK HOLDER		CMD106	1
8	CABLE STOP		CMD107	1
9	BRAKE BOSS			1
10	SHIFTER HANDLE			1
11	CABLE RETAINER		CMD108	1
12	SOCKET HEAD CAP SCREW 8-32 UNC, 3/8" LENGTH	92220A152		5
13	POST		CMD103	4
14	POST PIN		CMD111	4
15	SHOOTER ASSEMBLY		CMD201	1
16	STEEL CAP SCREW GRADE 5, 1/4"-20 UNC, 2-1/2" LENGTH	91247A552		16
17	STEEL HEX NUT GRADE 8, 1/4"-20 UNC, 7/16" WIDTH, 7/32" HEIGHT	90499A029		16
18	BRAKE NOODLE			4
19	SEAT POST CLAMP, 1-1/2" DIAMETER	(1511K33)		1
20	SEAT POST CLAMP, 1-3/8" DIAMETER	(1511K32)		1
21	GRIP CLIP			2



NOTE: PART NUMBERS IN PARATHESES ARE CURRENTLY PLACEHOLDER MODEL PARTS FROM MCMASTER CARR.

	NAME	DATE
DRAWN	MC	2/6/14
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

WEIGHT: 11.517 LBF

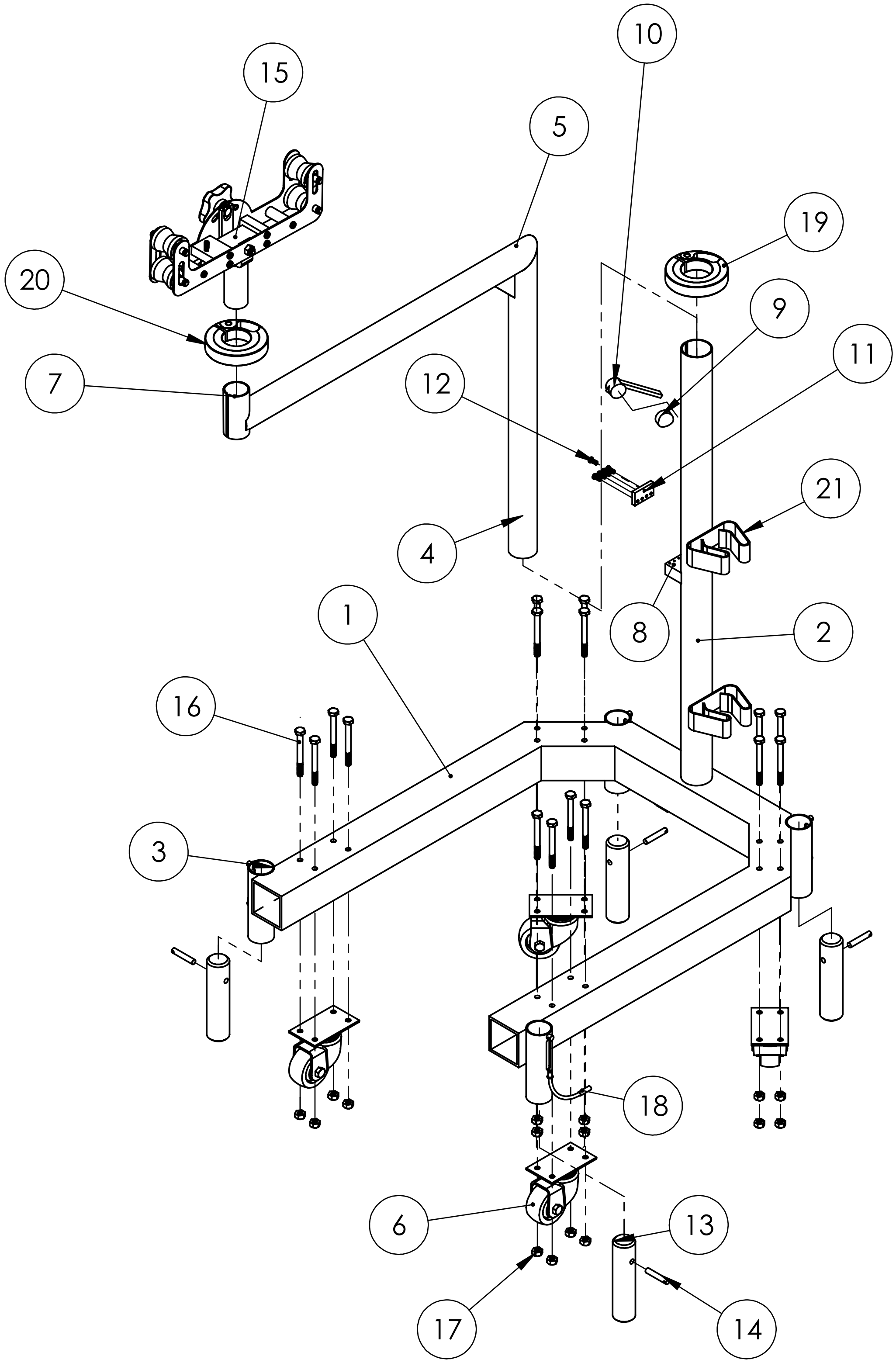
TITLE:

BASE ASSEMBLY

SIZE	DWG. NO.	REV
A	CMD101	

NEXT ASSY: N/A | SCALE: 1:12 | SHEET 1 OF 2

5 4 3 2 1



	NAME	DATE
DRAWN	MC	2/5/14
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

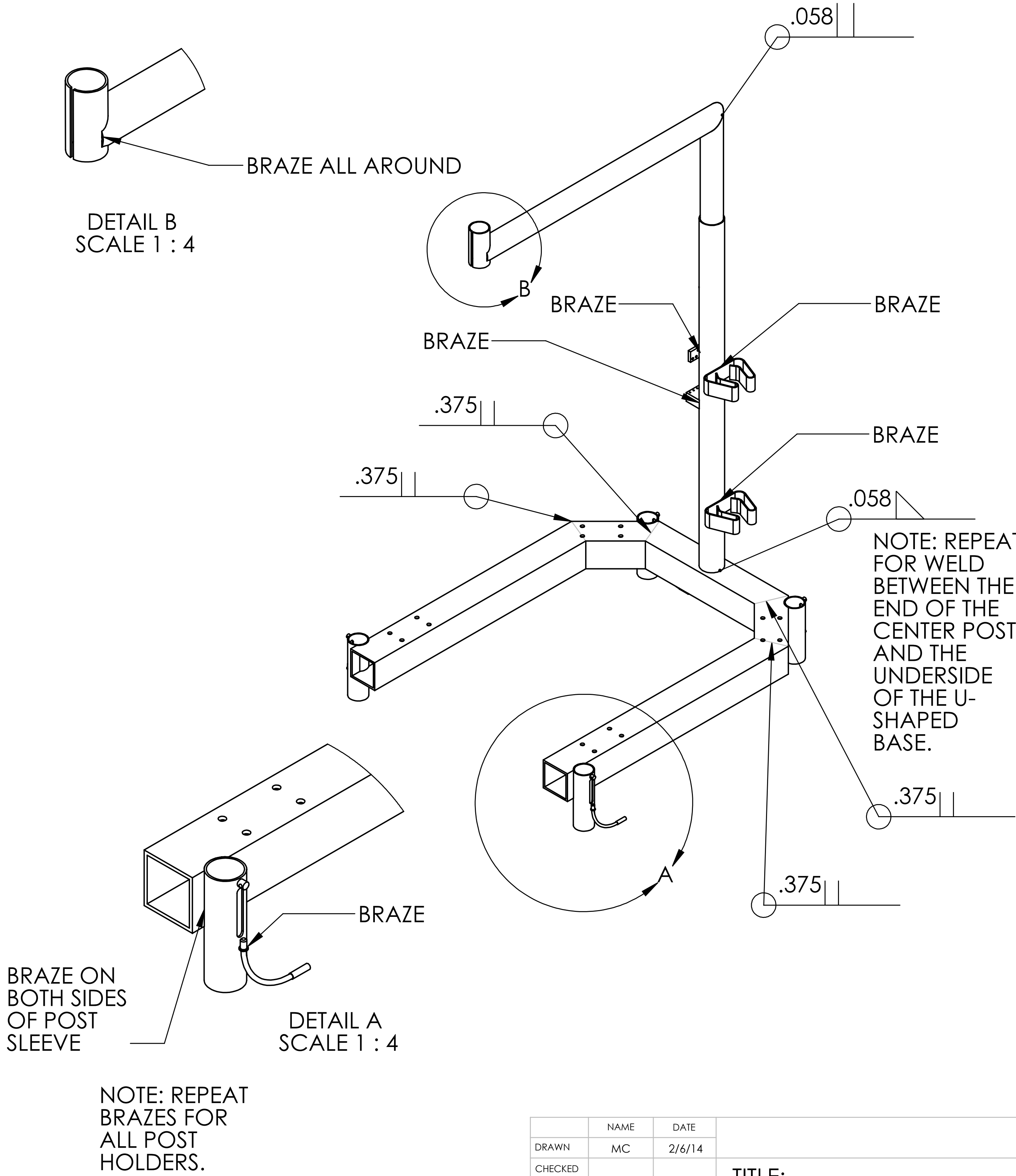
TITLE:

BASE ASSEMBLY

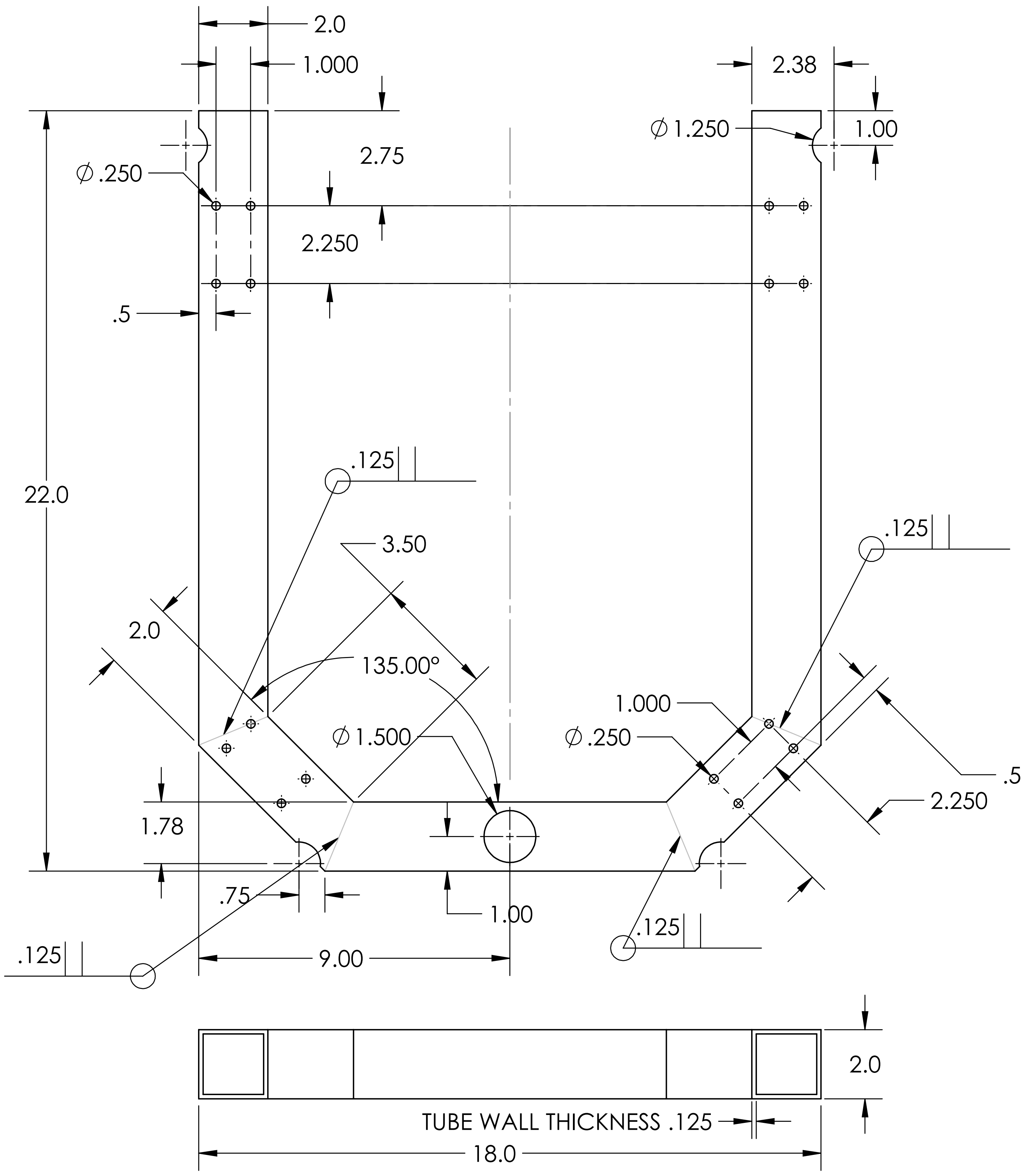
SIZE A | DWG. NO. CMD101 | REV.

SCALE: 1:8 | WEIGHT: 11.517 LBF | SHEET: 2 OF 2

NEXT ASSY: N/A



	NAME	DATE	
DRAWN	MC	2/6/14	
CHECKED			TITLE:
ENG APPR.			WELD AND BRAZING LOCATIONS
MFG APPR.			
Q.A.			
COMMENTS:			SIZE A DWG. NO. CMD001 REV.
			SCALE: 1:8 SHEET 1 OF 1



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

MATERIAL: Al 6061-T6

FINISH: 30 - 250 MICRO-INCHES

NEXT ASSY: CMD101

	NAME	DATE
DRAWN	MC	2/6/14
CHECKED	CC	2/6/14
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

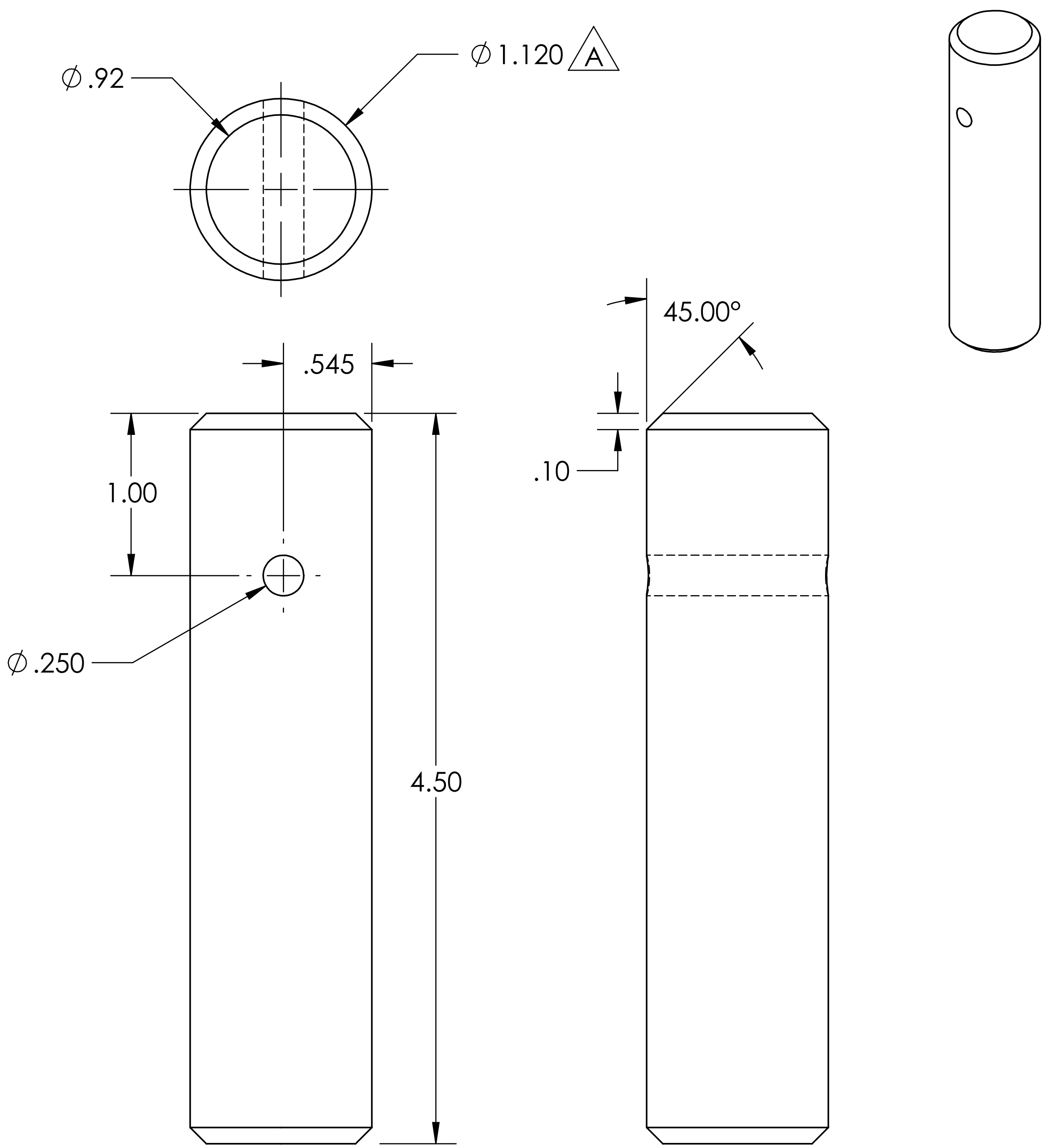
MADE OUT OF 2" x 2" x .125" SQUARE TUBING.

TITLE:

U-SHAPED BASE

SIZE	DWG. NO.	REV.
A	CMD102	

SCALE: 2:1 | WEIGHT: .061 LBF | SHEET 1 OF 1



REVISIONS			
REV.	DESCRIPTION	DATE	APPROVED
A	FIXED O.D. FROM 1.090 TO 1.120	6/6/2014	M.C.

DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005

	NAME	DATE
DRAWN	MC	2/6/14
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

MATERIAL: NYLON MDS-FILLED

FINISH: 30 - 250 MICRO-INCHES

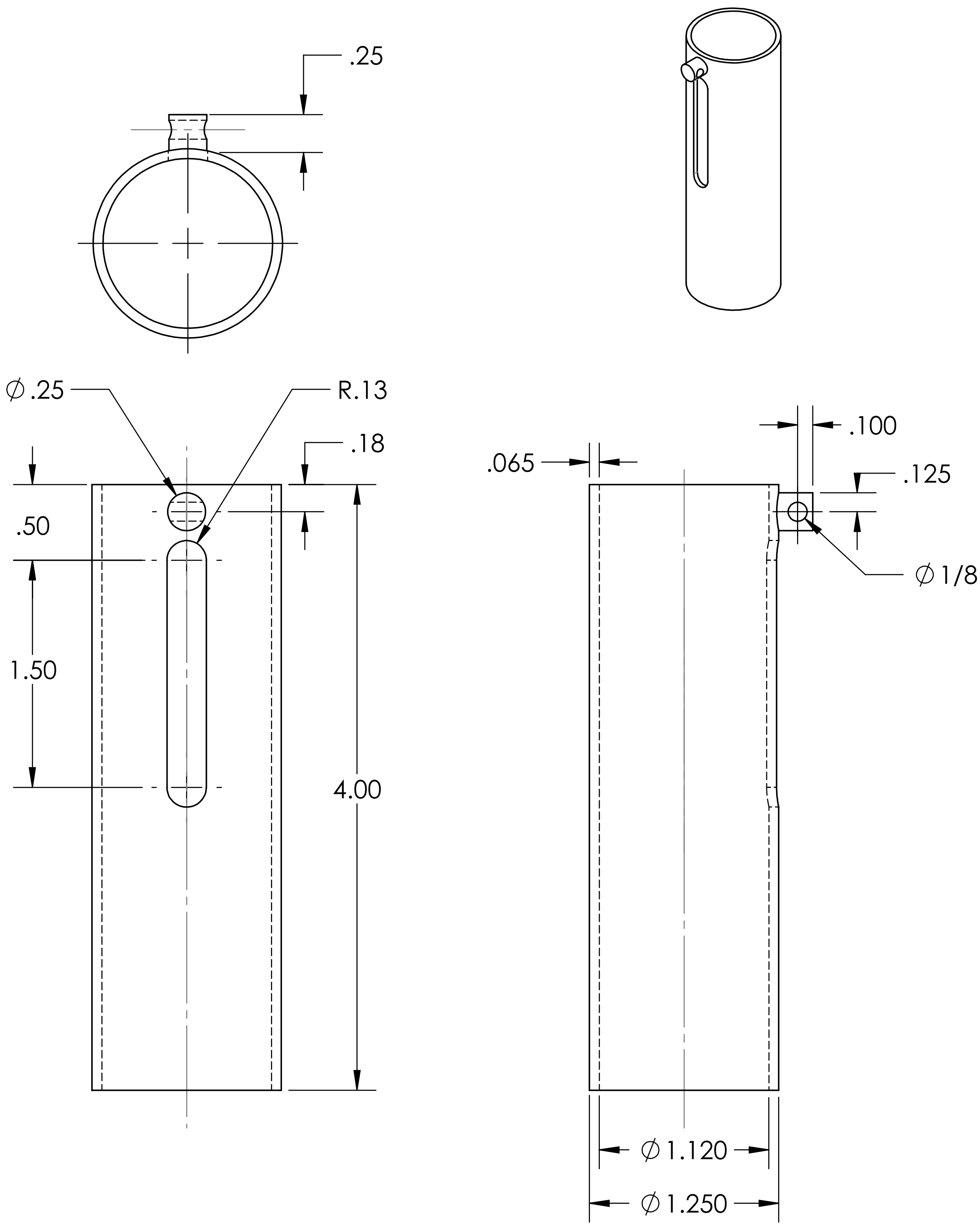
NEXT ASSY: CMD101

TITLE:

POST

SIZE A DWG. NO. CMD103 REV. A

SCALE: 1:1 WEIGHT: .171 LBF SHEET 1 OF 1



DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/32
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005

MATERIAL: Al 6061-T6

FINISH: 30 - 250 MICRO-INCHES

NEXT ASSY: CMD101

	NAME	DATE
DRAWN	MC	2/5/14
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

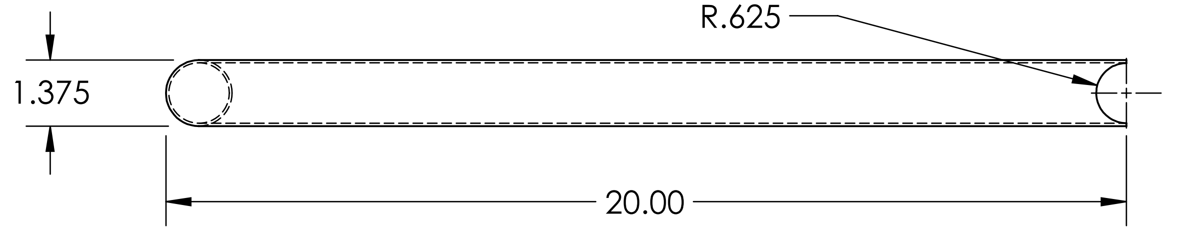
COMMENTS: PEG WITH 1/8 HOLE TO BE MACHINED SEPARATELY AND THEN ATTACHED BY SOLDERING/BRAZING.

TITLE:

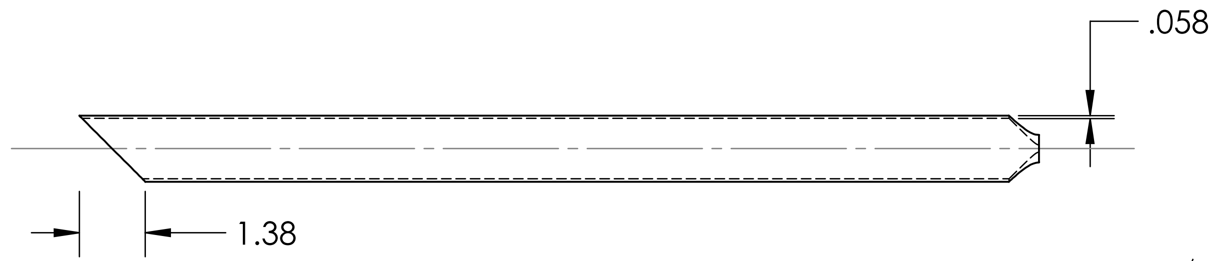
POST HOLDER

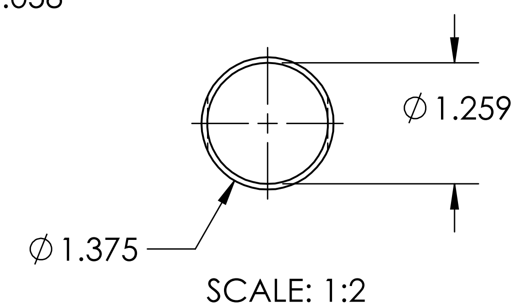
SIZE	DWG. NO.	REV.
A	CMD104	

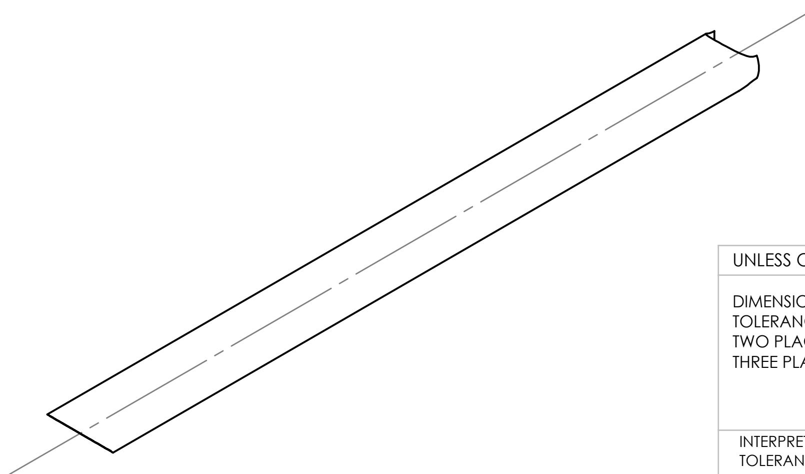
SCALE: 1:1 | WEIGHT: .092 LBF | SHEET 1 OF 1



NOTE: I.D., O.D., AND THICKNESS DIMENSIONS ARE AS SPECIFIED FOR STOCK. DO NOT MACHINE THESE DIMENSIONS.

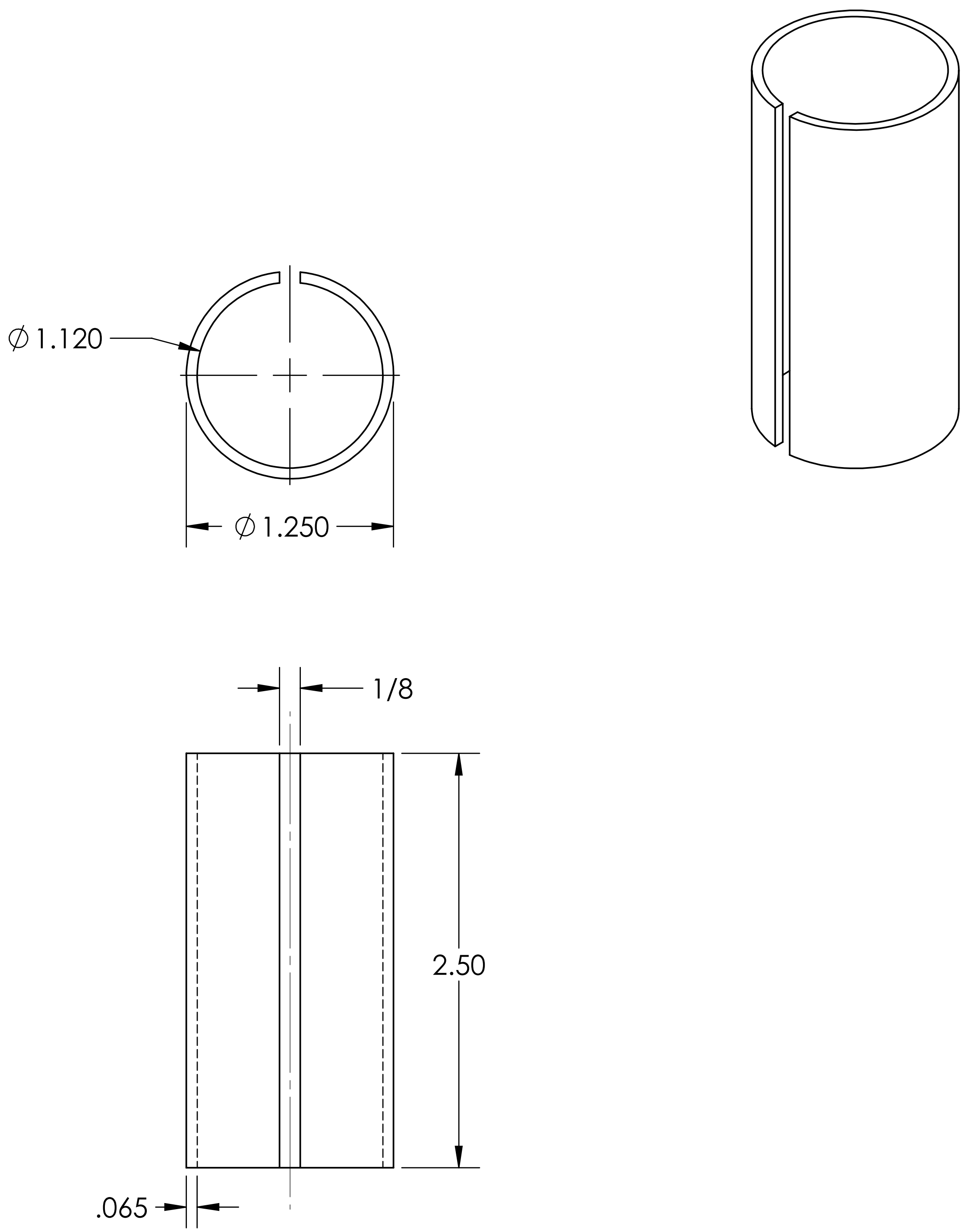






UNLESS OTHERWISE SPECIFIED:		NAME	DATE	WEIGHT: .44 LBF
DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005	DRAWN	MC	2/5/14	TITLE:
	CHECKED			HORIZONTAL BAR
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL: AL 6063-T832	COMMENTS: LEFT TRIANGULAR CUT SURFACE TO BE PREPPED FOR GTAW.			SIZE A · DWG. NO. CMD105 · REV
FINISH: 30 - 250 MICRO-INCHES				
NEXT ASSY: CMD101				SCALE: 1:4 · SHEET 1 OF 1

5 4 3 2 1

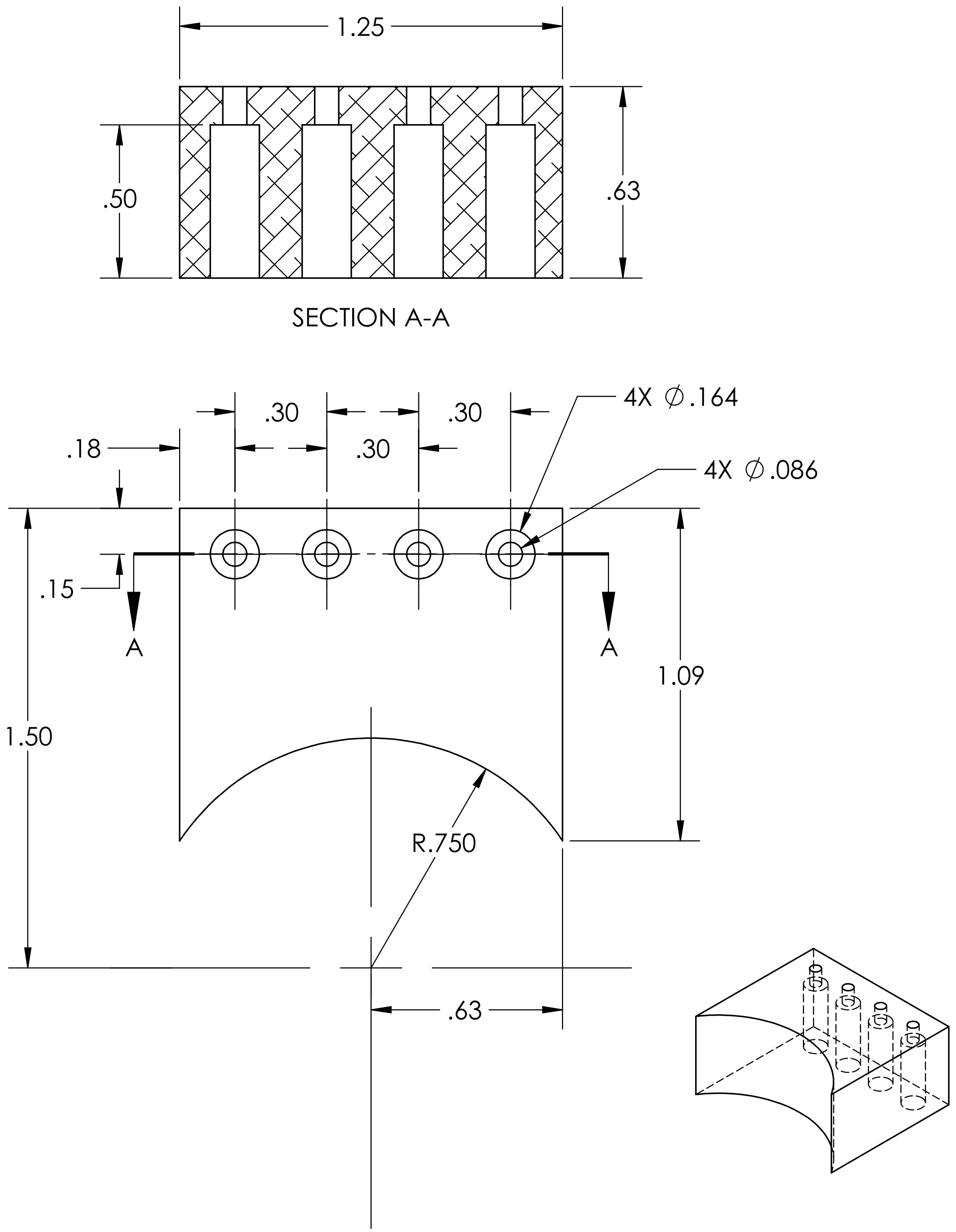


DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005		NAME	DATE
	DRAWN	MC	2/5/14
	CHECKED		
	ENG APPR.		
	MFG APPR.		
MATERIAL: Al 6061-T6	Q.A.		
FINISH: 30 - 250 MICRO-INCHES	COMMENTS: I.D., O.D., AND THICKNESS DIMENSIONS ARE SPECIFIED FOR TUBING STOCK PURCHASE. DO NOT MACHINE THESE DIMENSIONS.		
NEXT ASSY: CMD101			

TITLE:

FORK HOLDER

SIZE	DWG. NO.		REV.
A	CMD106		
SCALE: 1:1	WEIGHT: .06 LBF	SHEET 1 OF 1	



DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005

MATERIAL: Al 6061-T6

FINISH: 30 - 250 MICRO-INCHES

NEXT ASSY: CMD101

	NAME	DATE
DRAWN	MC	2/5/14
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

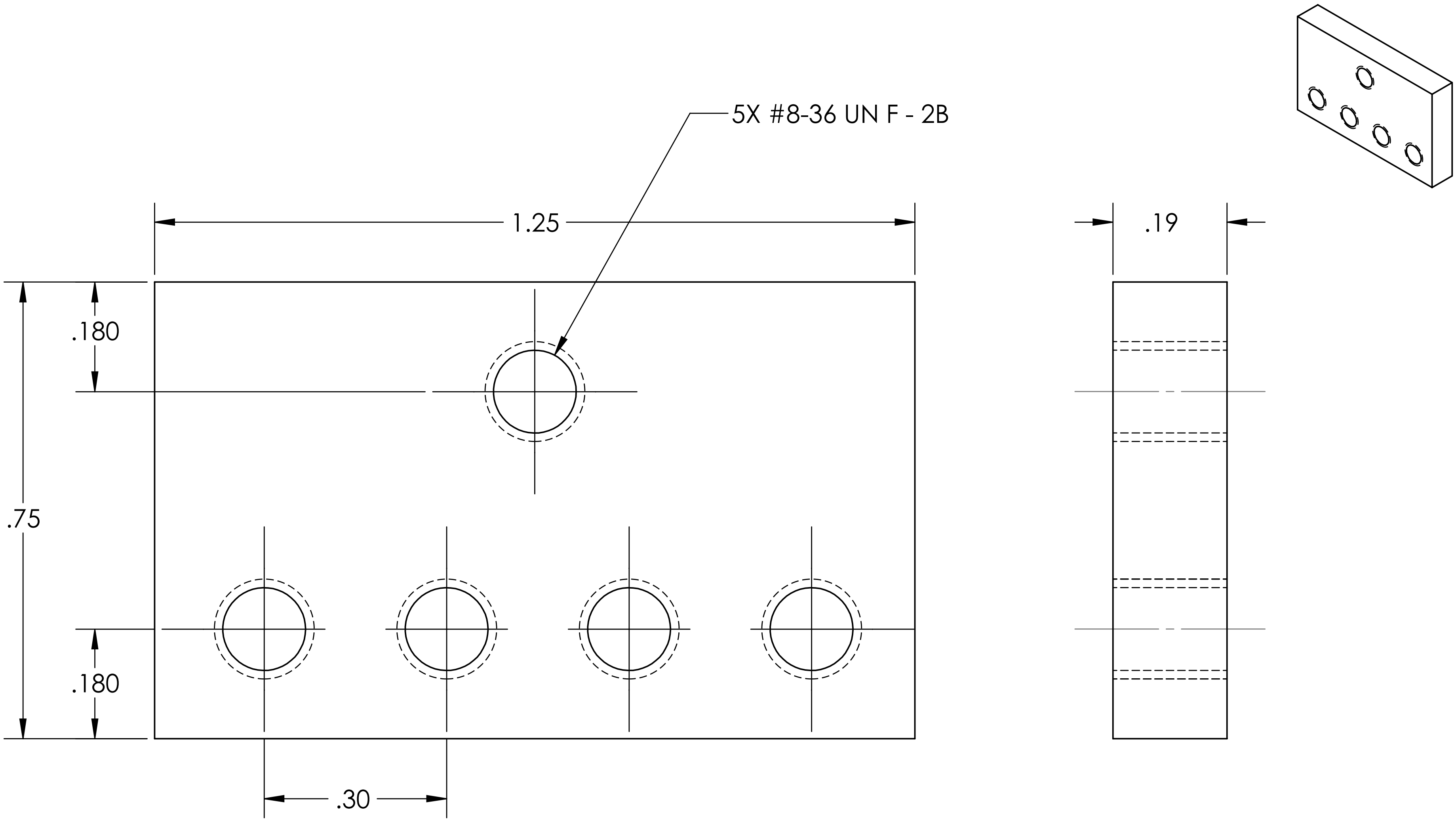
COMMENTS:

TITLE:

CABLE STOP

SIZE A | DWG. NO. CMD107 | REV.

SCALE: 2:1 | WEIGHT: .061 LBF | SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005

INTERPRET GEOMETRIC
TOLERANCING PER:

MATERIAL: Al 6061-T6

FINISH: 30 - 250 MICRO-INCHES

NEXT ASSY: CMD101

	NAME	DATE
DRAWN	MC	2/5/14
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

WEIGHT: .016 LBF

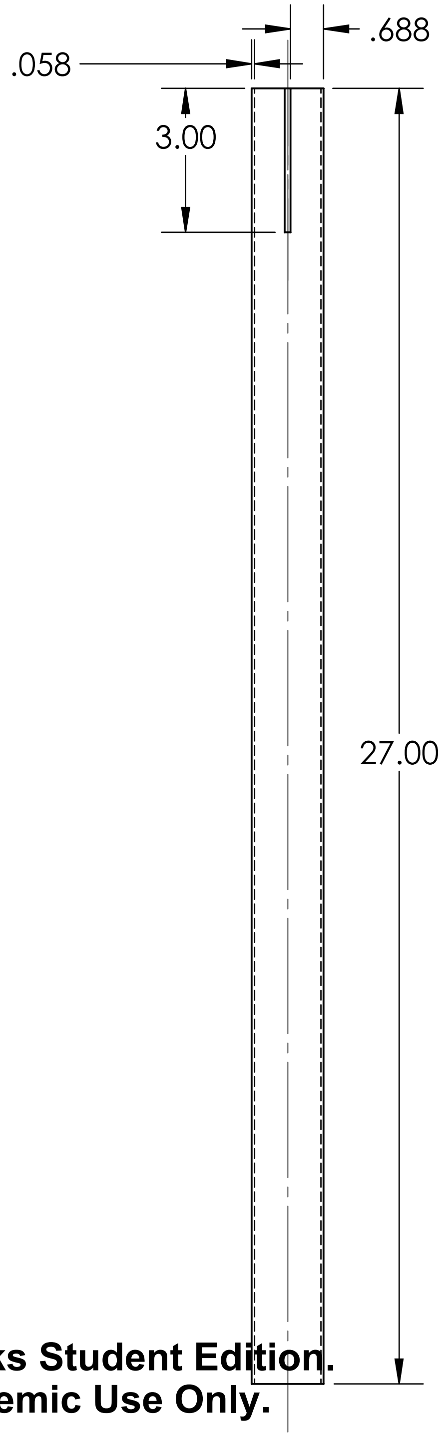
TITLE:

CABLE RETAINER

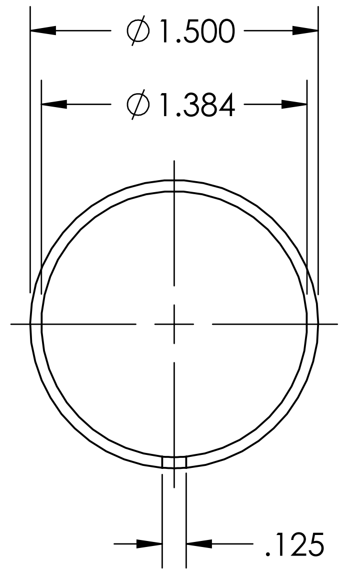
SIZE: A
DWG. NO. CMD108
REV

SCALE: 4:1
SHEET 1 OF 1

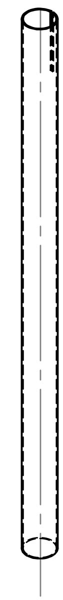
5 4 3 2 1



NOTE: DIMENSIONS FOR I.D., O.D., AND THICKNESS ARE AS SPECIFIED FOR STOCK. DO NOT MACHINE.

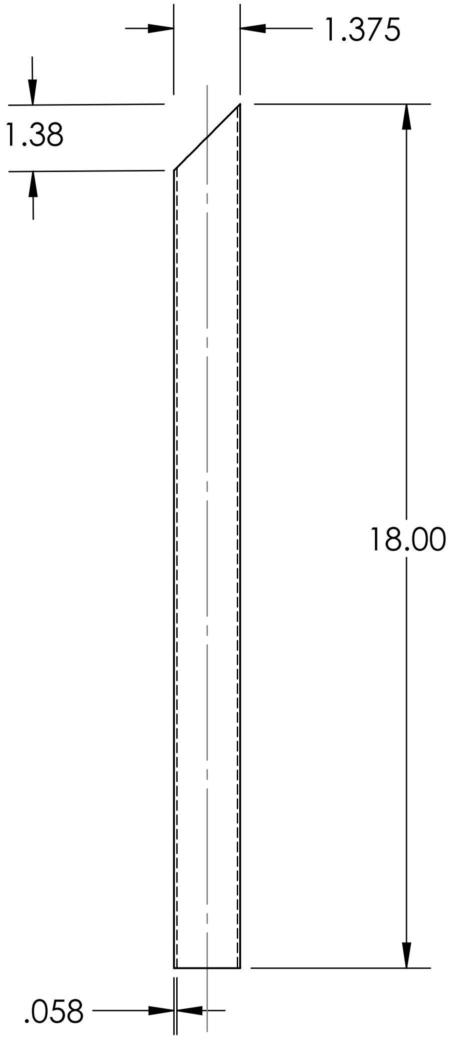


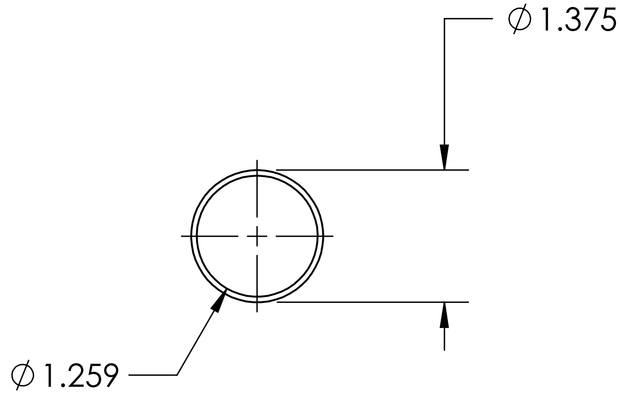
SCALE: 1:1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE		WEIGHT: .639 LBF
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005	DRAWN	MC	2/5/14	TITLE: BASE CENTER POST	
	CHECKED				
	ENG APPR.				
	MFG APPR.				
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.				
MATERIAL: Al 6063-T832	COMMENTS: OUTSIDE TELESCOPING TUBE. BOTTOM EDGE WILL NEED TO BE PREPPED FOR GTAW.			SIZE A	DWG. NO. CMD109 / REV
FINISH: 30 - 250 MICRO-INCHES					
NEXT ASSY: CMD101				SCALE: 1:4	SHEET 1 OF 1

5 4 3 2 1



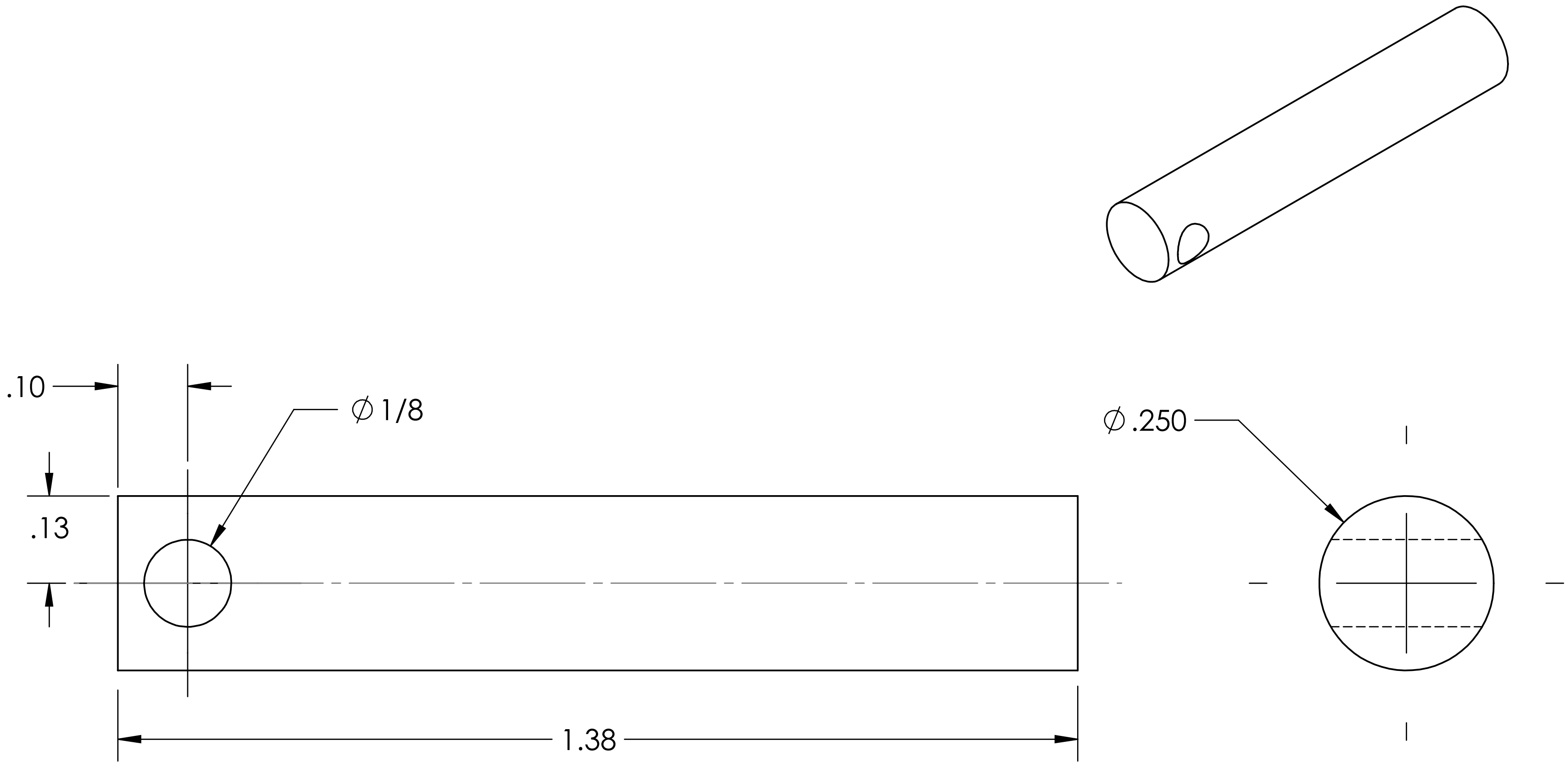


SCALE: 1:2

NOTE: DIMENSIONS FOR I.D., O.D., AND THICKNESS ARE AS SPECIFIED FOR STOCK. DO NOT MACHINE.

UNLESS OTHERWISE SPECIFIED:		NAME	DATE	WEIGHT: .41 LBF
DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005	DRAWN	MC	2/5/14	TITLE:
	CHECKED			BASE CENTER POST INNER
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL : Al 6063-T832	COMMENTS: SLANTED EDGE MUST BE CLEANED AND PREPARED FOR GTAW .			SIZE A — DWG. NO. CMD110 — REV
FINISH: 30 - 250 MICRO-INCHES				
NEXT ASSY: CMD101				SCALE: 1:4 — SHEET 1 OF 1

5 4 3 2 1



UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/32
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005

INTERPRET GEOMETRIC
TOLERANCING PER:

MATERIAL: AL 6061-T6

FINISH: 30 - 250 MICRO-INCHES

NEXT ASSY: CMD101

	NAME	DATE
DRAWN	MC	2/6/14
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

WEIGHT: .006 LBF

TITLE:

POST PIN

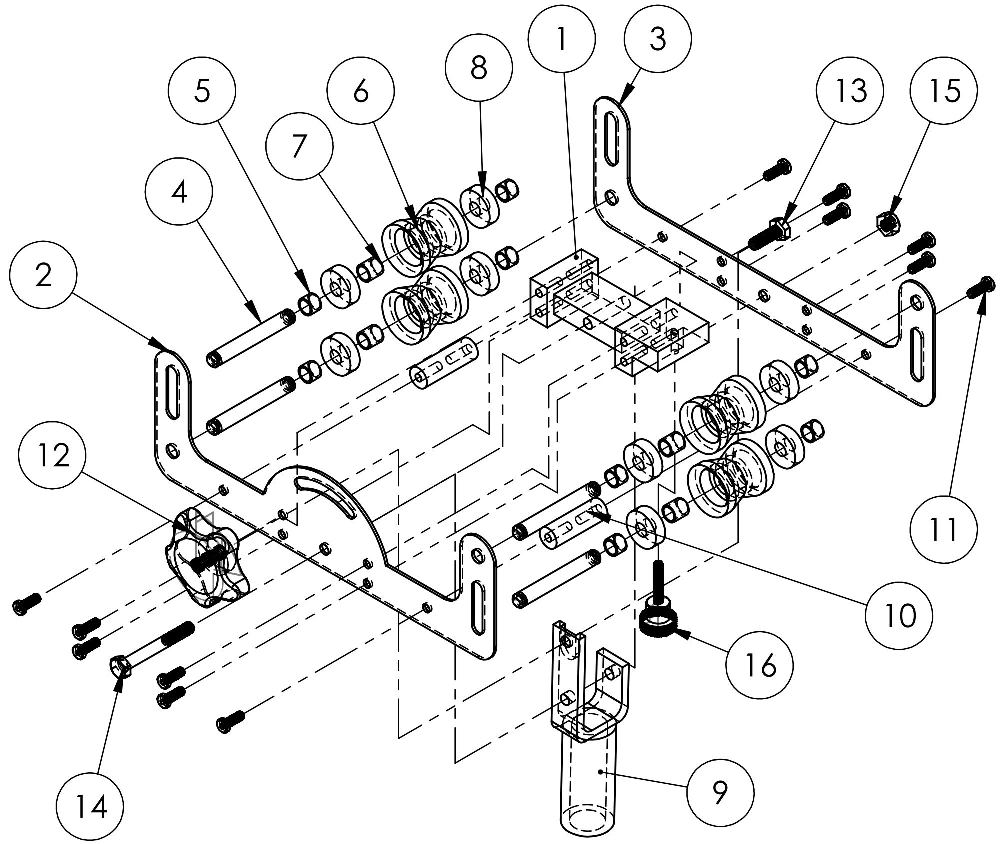
SIZE	DWG. NO.	REV
A	CMD111	

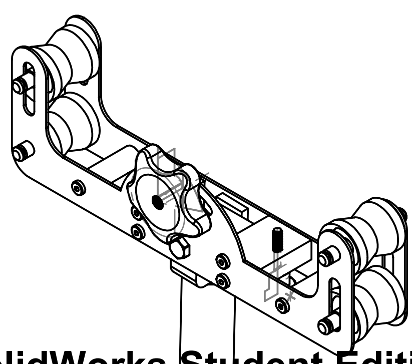
SCALE: 4:1

SHEET 1 OF 1

5 4 3 2 1

ITEM NO.	PART NAME (STOCK PART NUMBER)	STOCK PART NUMBER (IF APPLICABLEI SEE MASTER BOM)	DRAWING NUMBER	QTY.
1	SHOOTER BLOCK		CMD106	1
2	SIDE PLATE SLIDE		CMD202	1
3	SIDE PLATE		CMD205	1
4	FREE SHAFT		CMD208	4
5	WHEEL STANDOFF			8
6	SKATE WHEEL ROLLER		CMD204	4
7	BEARING SPACER			4
8	WHEEL BEARING			8
9	FORK		CMD203	1
10	PLATE STANDOFF		CMD207	2
11	SOCKET HEAD CAP SCREW, 10-32 UNF 1/2" LENGTH	92220A173		12
12	FIVE-ARM KNOB 1/4"-20 UNC 2-1/4" DIAMETER	59625K74		1
13	CAP SCREW GRADE 5, 1/4"-20 UNC, 3/4" LENGTH	92865A540		1
14	CAP SCREW GRADE 5, 1/4"-20 UNC, 2" LENGTH	91247A550		1
15	STEEL HEX NUT GRADE 8, 1/4"-20 UNC, 7/16" WIDTH, 7/32" HEIGHT	90499A029		1
16	STEEL KNURLED-RIM KNOB, 10-24 UNC, 1" LENGTH, 3/4" DIAMETER	6079K12		1





	NAME	DATE
DRAWN	MC	2/6/14
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

NEXT ASSY: CMD101

WEIGHT: 1.651 LBF

TITLE:

SHOOTER ASSEMBLY

SIZE A

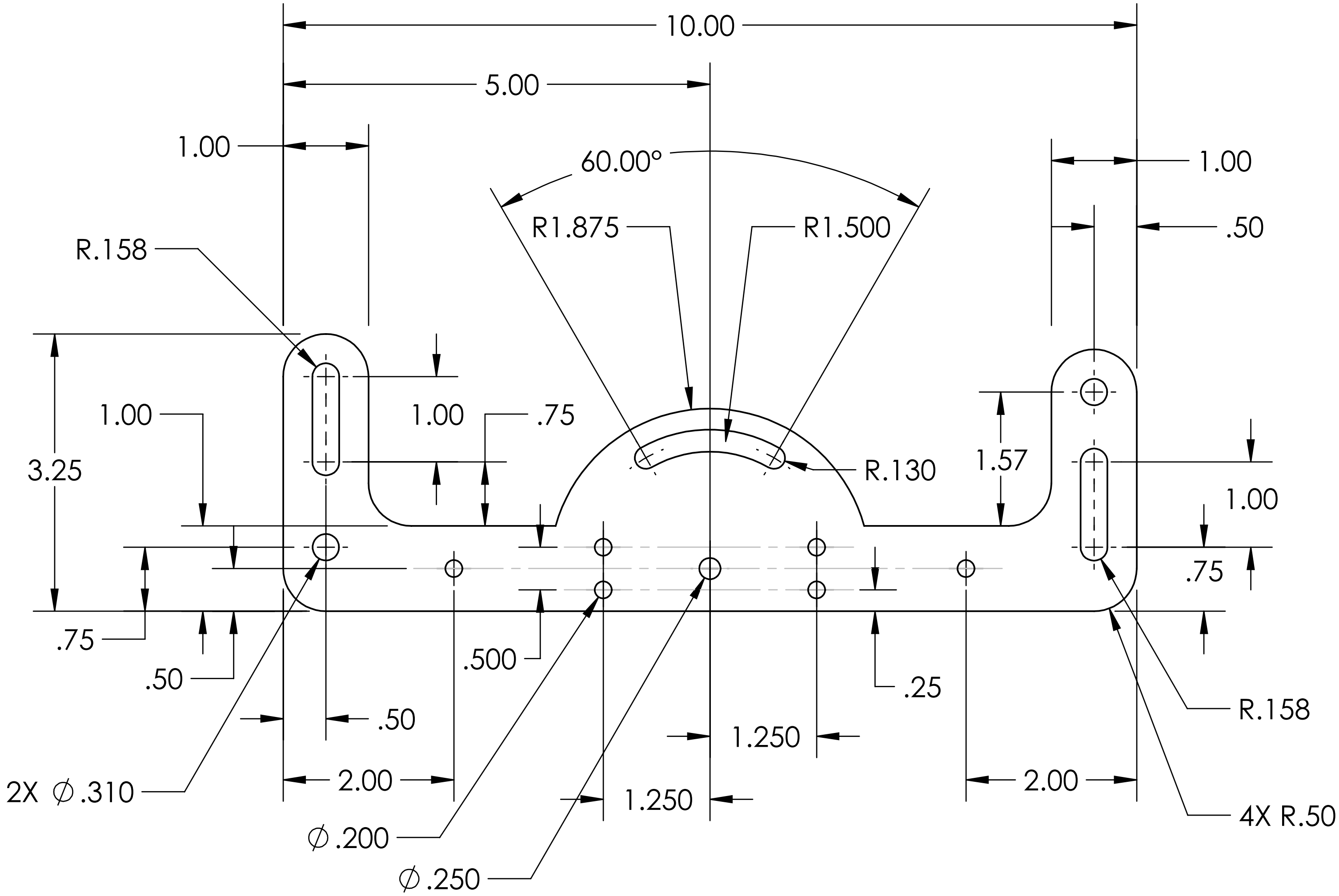
DWG. NO. CMD201

REV

SCALE: 1:4

SHEET 1 OF 1

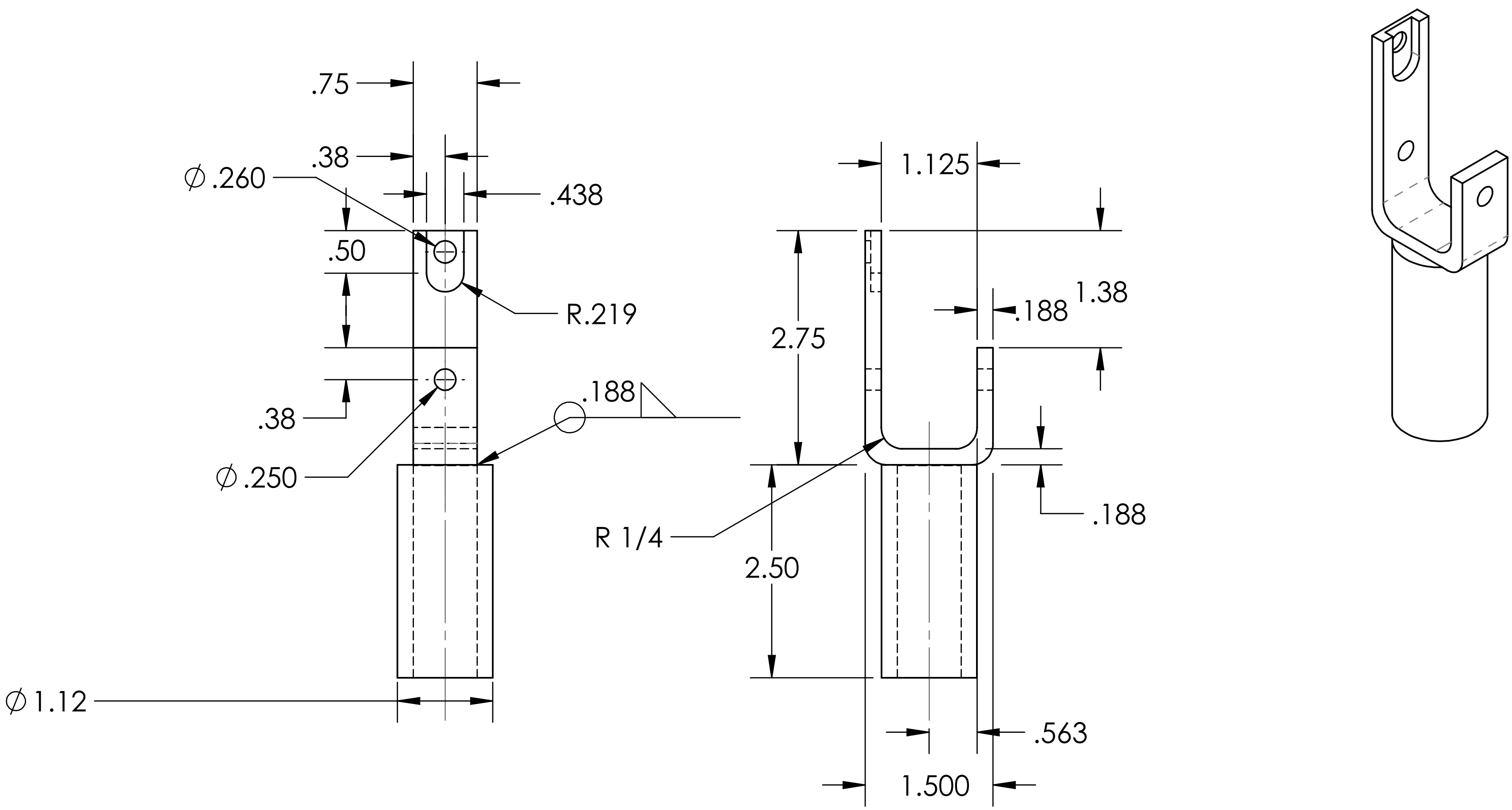
5 4 3 2 1



NOTE:
THICKNESS OF THE SHEET IS .0747 INCHES (14 ga).

UNLESS OTHERWISE SPECIFIED:		NAME	DATE	WEIGHT: .329 LBF
DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.005	DRAWN	MC	2/6/14	TITLE:
	CHECKED			SIDE PLATE SLIDE
	ENG APPR.			
	MFG APPR.			
	Q.A.			
MATERIAL MILD STEEL	COMMENTS:			SIZE A DWG. NO. CMD202 REV
FINISH: 30 - 250 MICRO-INCHES				SCALE: 1:2 SHEET 1 OF 1
NEXT ASSY: CMD201				

5 4 3 2 1



UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/32
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Al 6061-T6

FINISH: 30 - 250 MICRO-INCHES

NEXT ASSY: CMD101

	NAME	DATE
DRAWN	MC	1/28/14
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:
.438 INCH SLOT TO BE MADE WITH 7/16 INCH DIAMETER END MILL.

TITLE:
FORK

SIZE A | DWG. NO. CMD203 | REV

SCALE: 1:2 | WEIGHT: .199 LBF | SHEET 1 OF 1

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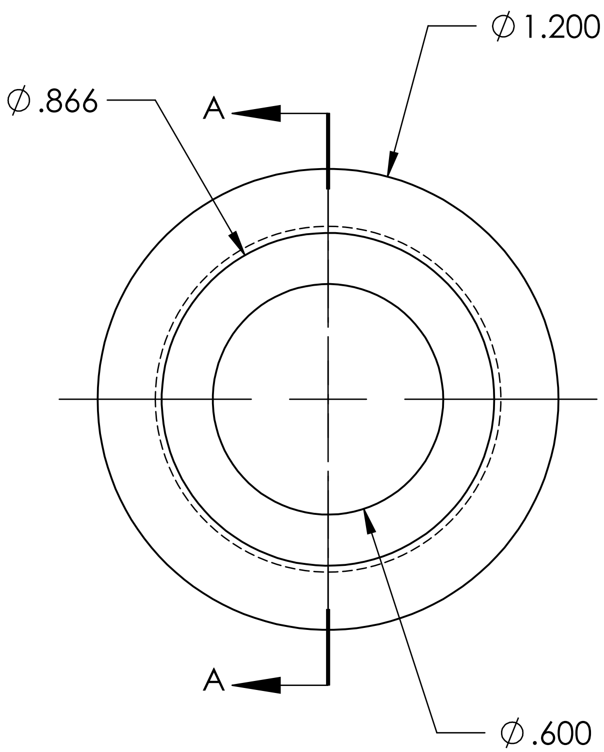
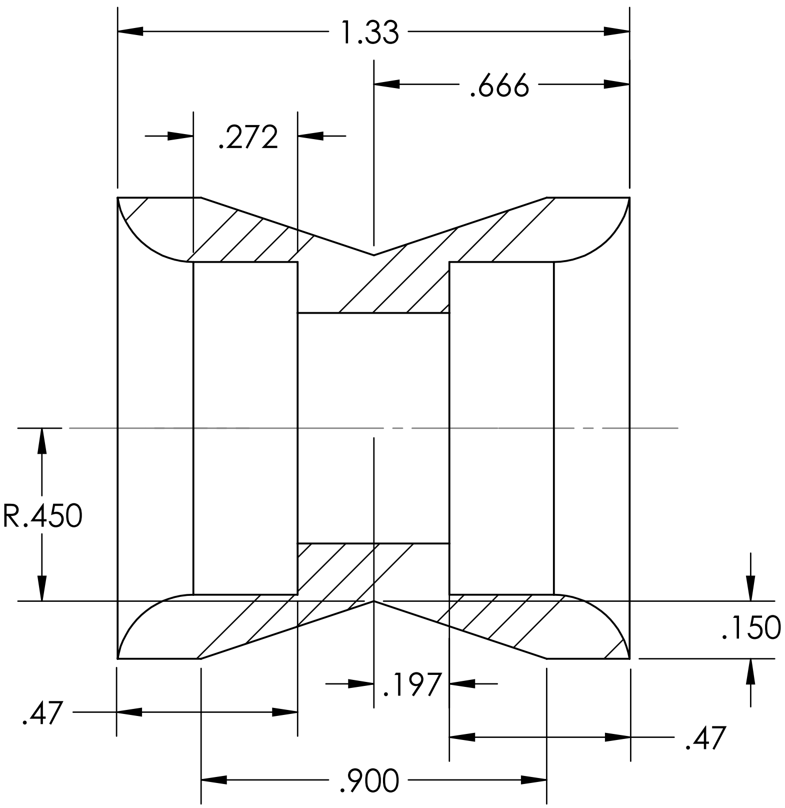
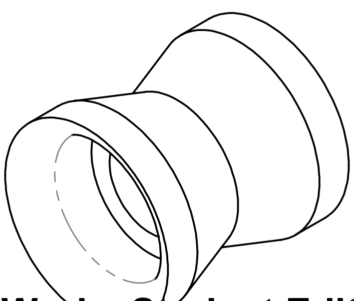
5 4 3 2 1





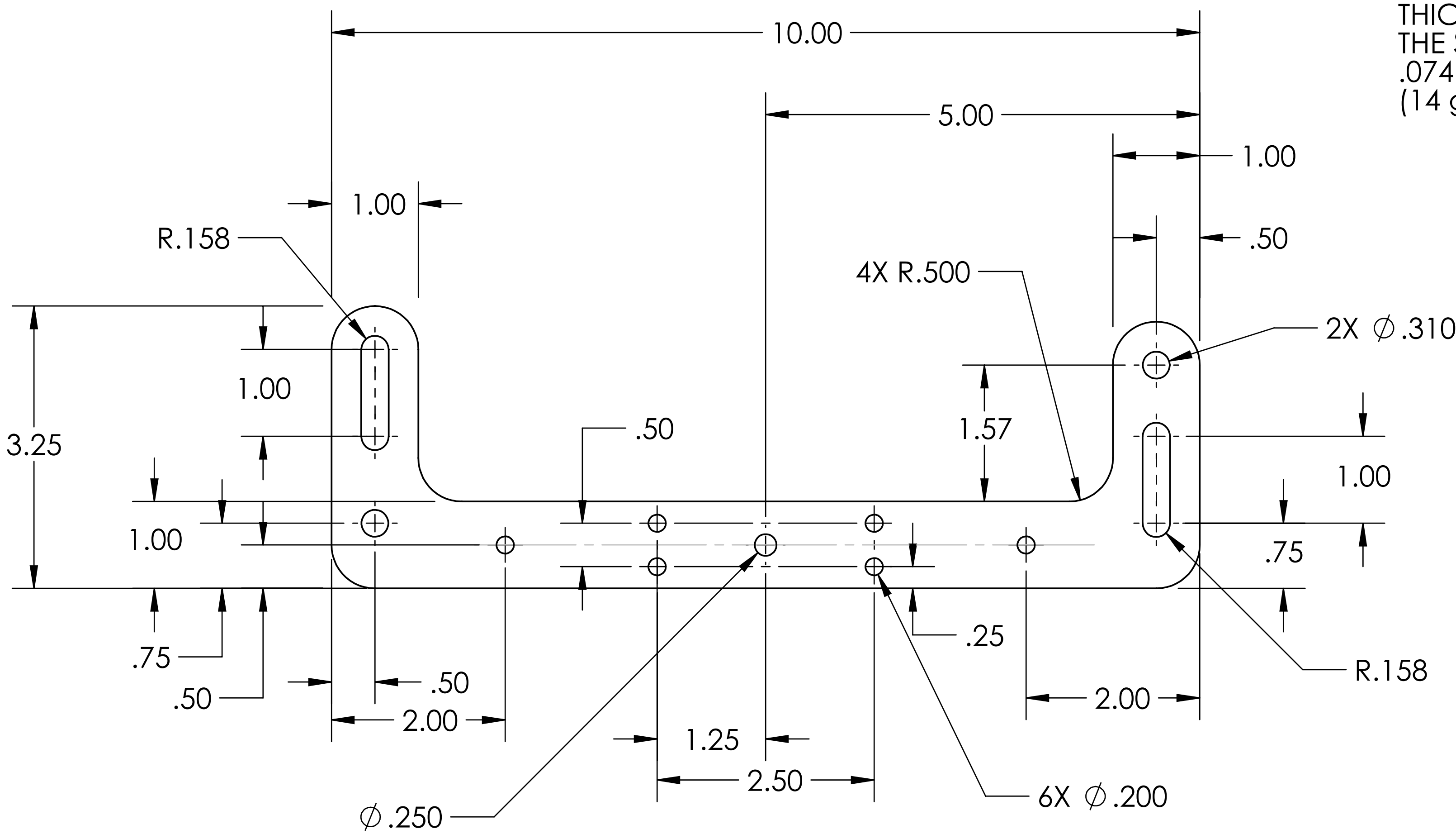
SECTION A-A
SCALE 2 : 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	WEIGHT: .025 LBF
DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005	DRAWN	MC	2/6/14	TITLE:
	CHECKED			SKATE WHEEL ROLLER
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL: POLYURETHANE	COMMENTS:			SIZE A · DWG. NO. CMD204 · REV
FINISH: 30 - 250 MICRO-INCHES				
NEXT ASSY: CMD201				SCALE: 2:1 · SHEET 1 OF 1

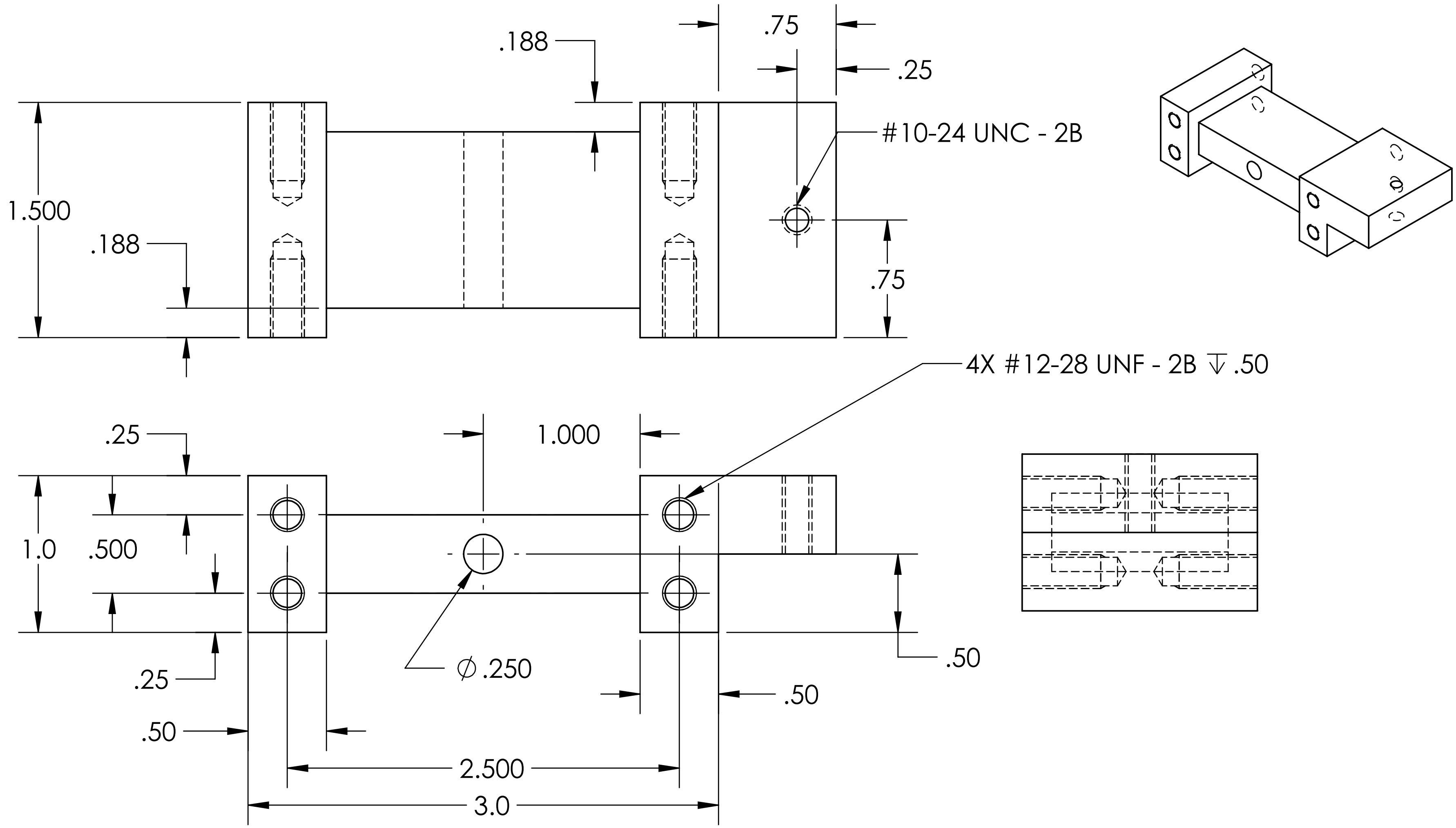
5 4 3 2 1

NOTE:
THICKNESS OF THE SHEET IS .0747 INCHES (14 ga).



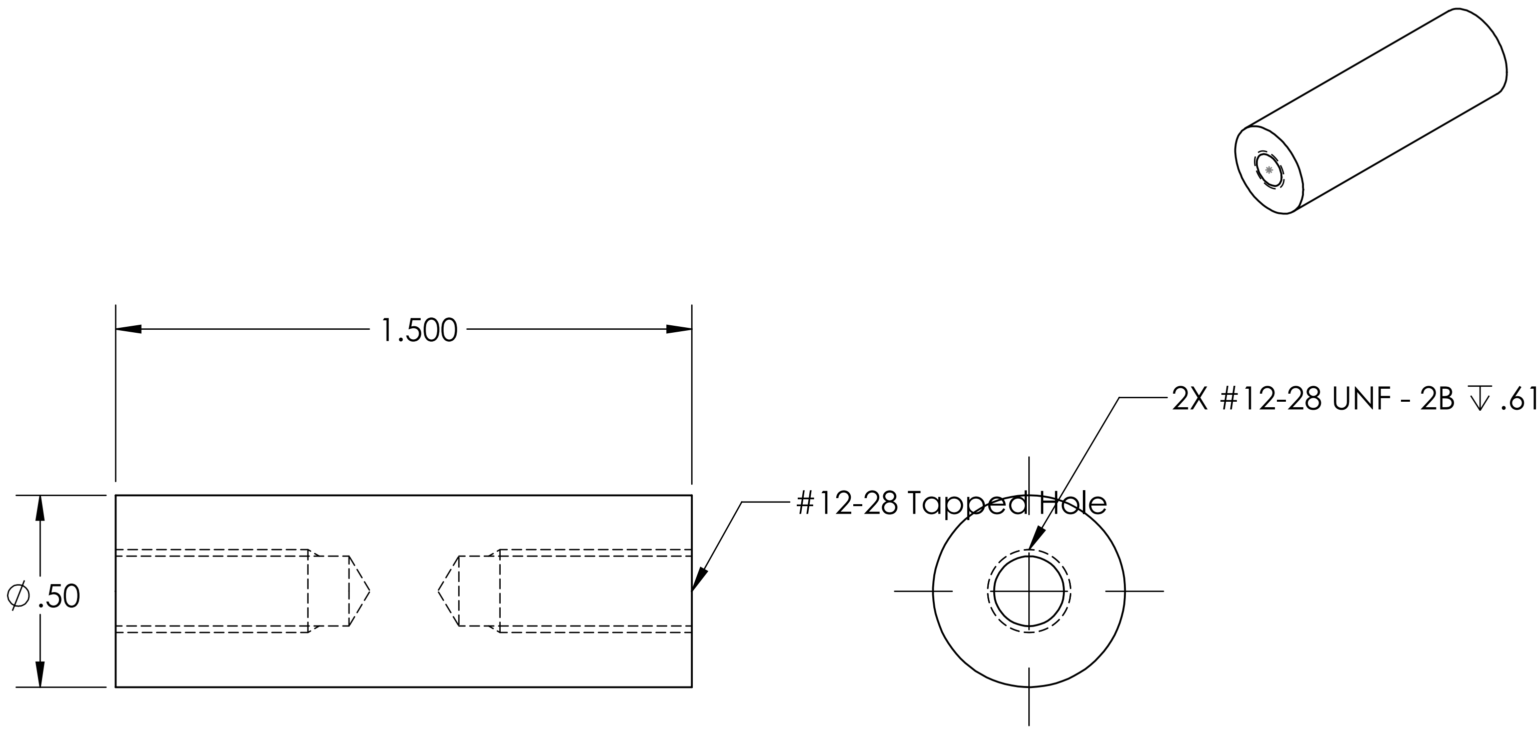
UNLESS OTHERWISE SPECIFIED:		NAME	DATE		WEIGHT: .272 LBF
DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005	DRAWN	MC	2/6/14	TITLE:	
	CHECKED				
	ENG APPR.			SIDE PLATE	
	MFG APPR.				
	Q.A.				
MATERIAL: MILD STEEL	COMMENTS:			SIZE A	DWG. NO. CMD205 REV
FINISH: 30 - 250 MICRO-INCHES					
NEXT ASSY: CMD201				SCALE: 1:2	SHEET 1 OF 1

5 4 3 2 1



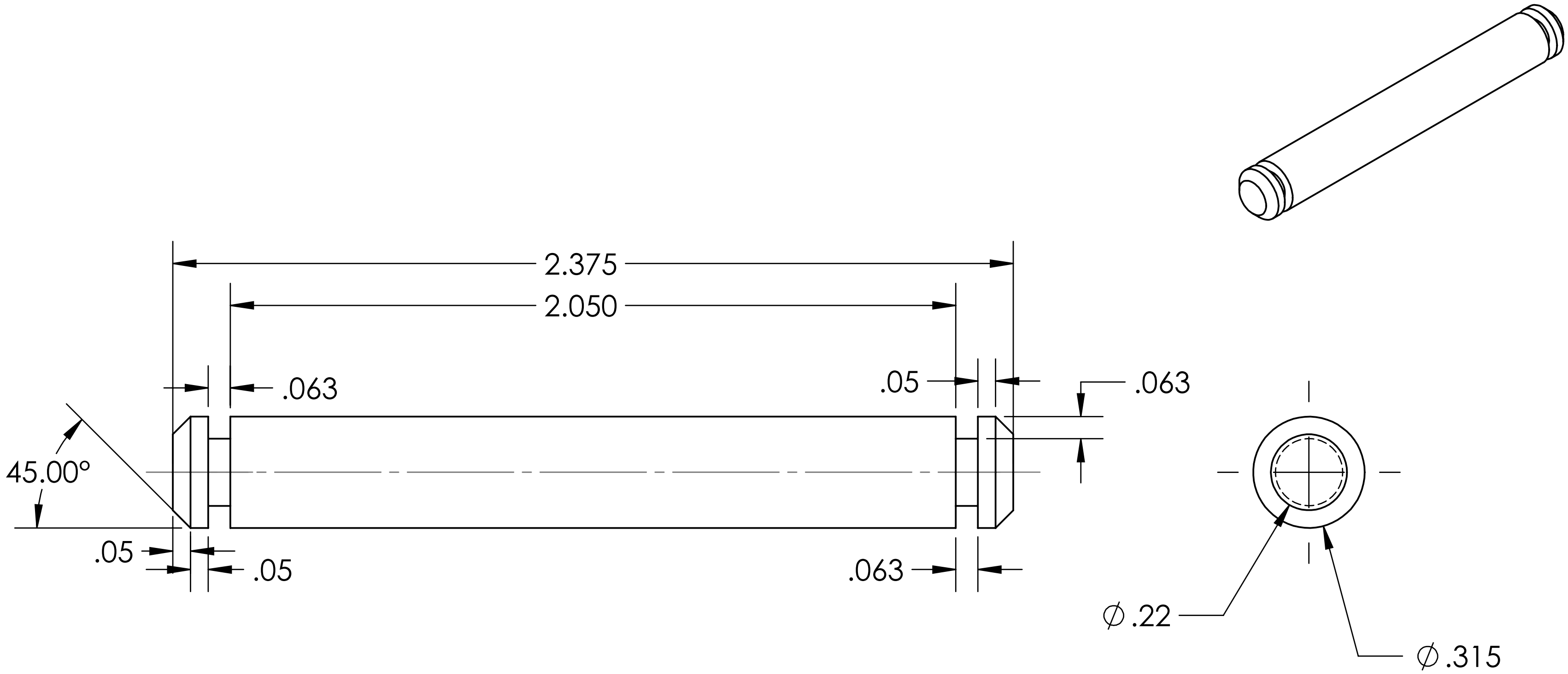
UNLESS OTHERWISE SPECIFIED:		NAME	DATE		WEIGHT: .292 LBF
DIMENSIONS ARE IN INCHES TOLERANCES: ONE PLACE DECIMAL ± .05 TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005	DRAWN	MC	2/6/14	TITLE:	
	CHECKED	CC	2/6/14	SHOOTER BLOCK	
	ENG APPR.				
	MFG APPR.				
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.				
MATERIAL: AL 6061-T6	COMMENTS:			SIZE A	DWG. NO. CMD206 — REV
FINISH: 30 - 250 MICRO-INCHEs					
NEXT ASSY: CMD201				SCALE: 1:1	SHEET 1 OF 1

5 4 3 2 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	WEIGHT: .026 LBF
DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005	DRAWN	MC	2/6/14	TITLE:
	CHECKED			PLATE STANDOFF
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL: AL 6061-T6	COMMENTS:			SIZE A / DWG. NO. CMD207 / REV
FINISH: 30 - 250 MICRO-INCHEs				
NEXT ASSY: CMD201				SCALE: 2:1 / SHEET 1 OF 1

5 4 3 2 1



UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL: AL 6061-T6

FINISH: 30 - 250 MICRO-INCHES

NEXT ASSY: CMD201

	NAME	DATE
DRAWN	MC	2/6/14
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

WEIGHT: .017 LBF

TITLE:

FREE SHAFT

SIZE A | DWG. NO. CMD208 | REV

SCALE: 2:1 | SHEET 1 OF 1

5 4 3 2 1

Appendix C: List of Vendors, Contact Information, and Pricing

Vendor Information:

Central Coast Creative Cutting

4149 #3 Santa Fe Road
San Luis Obispo, CA 93401
Phone: (805) 235-4619
ian@creative-cutting.com
creative-cutting.com

Mc-MASTER-CARR

9630 Norwalk Blvd.
Santa Fe Springs, CA 90670-2932
Phone: (562) 692-5911
la.sales@mcmaster.com
mcmaster.com

Texas Towers

1108 Summit Avenue, #4
Plano, TX 75074
texastowers.com

Appendix C. List of Vendors and Pricing

McMaster Carr Device Parts

Part that Stock is for	Stock Part	McMaster Part Number	#Units	per Unit ($)	Price ($)
	Mighty-Lite Caster, Swivel, 2" x 7/8" Black Rubber Wheel, 150 lbf Capacity	2406T28	4	6.66	26.64
U-shaped base	Multipurpose 6061 Aluminum Rectangular Tube, 1/8" Wall Thickness, 2" x 2", 6' Length	6546K13	1	53.02	53.02
	Multipurpose 6061 Aluminum Rectangular Tube, 1/8" Wall Thickness, 2" x 2", 3' Length	6546K233	1	30.75	30.75
Fork and Cable Retainer	Multipurpose 6061 Aluminum, 3/16" Thick x 3/4" Width x 6' Length	8975K21	1	6.96	6.96
Shooter Block and Cable Stop	Multipurpose 6061 Aluminum, 1-1/2" Thick x 2" Width x 1' Length	8975K311	1	22.16	22.16
Post Pins	Multipurpose 6061 Aluminum Rod, 1/4" Diameter x 6' Length	8974K31	1	6.08	6.08
Plate Standoff	Multipurpose 6061 Aluminum Rod, 1/2" Diameter x 6' Length	8974K33	1	14.5	14.5
Roller Shafts	Multipurpose 6061 Aluminum Rod, 3/8" Diameter x 6' Length	8974K32	1	11.85	11.85
Fork Post	Multipurpose 6061 Aluminum Tube, 1-1/4" OD, 3/4" ID, .25" Wall Thickness, 1 ft Length	9056K291	1	11.62	11.62
Fork Holder	Multipurpose 6061 Aluminum Tube, 1-1/4" OD, 1.120" ID, 0.065" Wall Thickness, 3' L	9056K762	1	25.07	25.07
Side Plates (Slide and not)	Multipurpose 304 Stainless Steel Sheet, 0.075" Thick, 12" x 12"	8983K13	1	28.33	28.33
Posts	Self-Lubricating MDS-FILLED Nylon Rod, 1-1/8" Diameter, Black	8554K29	2	6.33	12.66
	Five-Arm Knob, 1/4"-20 Threaded Through, 2-1/4" Diameter, Vibration Absorbing	59625K740	1	1.05	1.05
Gloves	TIG Welding Glove, with 2" Open Cuff, Cowhide, Large	5346T9	1	10.53	16.78
Brazing	Brazing Kit for Aluminum, 0.3 oz Coile Aluminum Brazing Wire & .25 FL oz. Flux	7797A11	2	10.4	20.8
	Precision Music Wire Extension Spring, 1.375" L, 0.250" OD, 0.026" Wire Diameter, Zinc-Plated Steel	9432K29	1	11.08	11.08
	Precision Music Wire Extension Spring, 1.0" L, 0.250" OD, 0.026" Wire Diameter, Zinc-Plated Steel	9432K28	1	10	10
Stop Adjustment	Steel Knurled-Rim Knob, 10-24 x 1" Threaded Stud, 3/4" Diameter	6079K12	1	4.1	4.1
Arbor	Multipurpose 6061 Aluminum Rod, 1" Diameter, 1" Long	8974K13	1	7.74	14.29
	Multipurpose 6061 Aluminum Rod, 2" Diameter x 1' Length	8974K71	1	23.99	23.99
Tax and Shipping					41.61
			Total so far		393.34

Texas Towers Device Parts

Center Post Outer	Telescoping Aluminum Tubing, 6' Length, 1.500" OD, 0.058" Thick		1	9	9
Center Post Inner	Telescoping Aluminum Tubing, 6' Length, 1.375" OD, 0.058" Thick		1	8.4	8.4
Tax and Shipping					25.59
			Shopping Cart		42.99
			Total so far		436.33

Appendix C. List of Vendors and Pricing

Muggy Weld					
Al Soldering Kit					70
Amazon Device Parts					
Gripper Clip			2	1.52	3.04
Skateboard Bearing Spacers			1	6.99	6.99
Brake Noodle			1	16.66	16.66
Quick Release Seat Clamp			1	10.39	10.39
Seat Post Clamp			1	11	11
Skate Bearings			1	14.52	14.52
Brake Cable			2	12.85	25.7
Skateboard Wheels			1	3	3
Elastic Band	Surgical Tubing		1	17.99	17.99
Bike Shifter					22.54
			Shopping Cart		179.29
			Total so far		615.62
Bought Online					
Ebay	Square Plastic Tubing Plug/End Cap 2 inch each		2	1.98	5.16
Fastenal	#8-36 x 3/8" Black Oxide Finish Button Socket Cap Screw		10	3.63	14.42
			Shopping Cart		19.58
			Total so far		635.2
Project Costs					
Prototyping and Practice Materials					55
	Telescoping Aluminum Tubing, 6' Length, 1.500" OD, 0.058" Thick		1	9	9
	Telescoping Aluminum Tubing, 6' Length, 1.375" OD, 0.058" Thick		1	8.4	8.4
			Shopping Cart		72.4
			Total so far		707.6

Appendix C. List of Vendors and Pricing

Locally Bought						
	Miner's	5/16" Rod, Rubber Bumpers				8.79
	Home Depot	Sandpaper, Paint, Epoxy				25.13
	Miner's	Fasteners				13.38
	Home Depot	Hole Saws				22.29
	Michael's	Poster Supplies				17.26
	Pool Cue and Case					75.58
	Waterjet Cut Part					86
				Shopping Cart		248.43
				FINISH TOTAL		956.03

Appendix D: Detailed Supporting Analysis

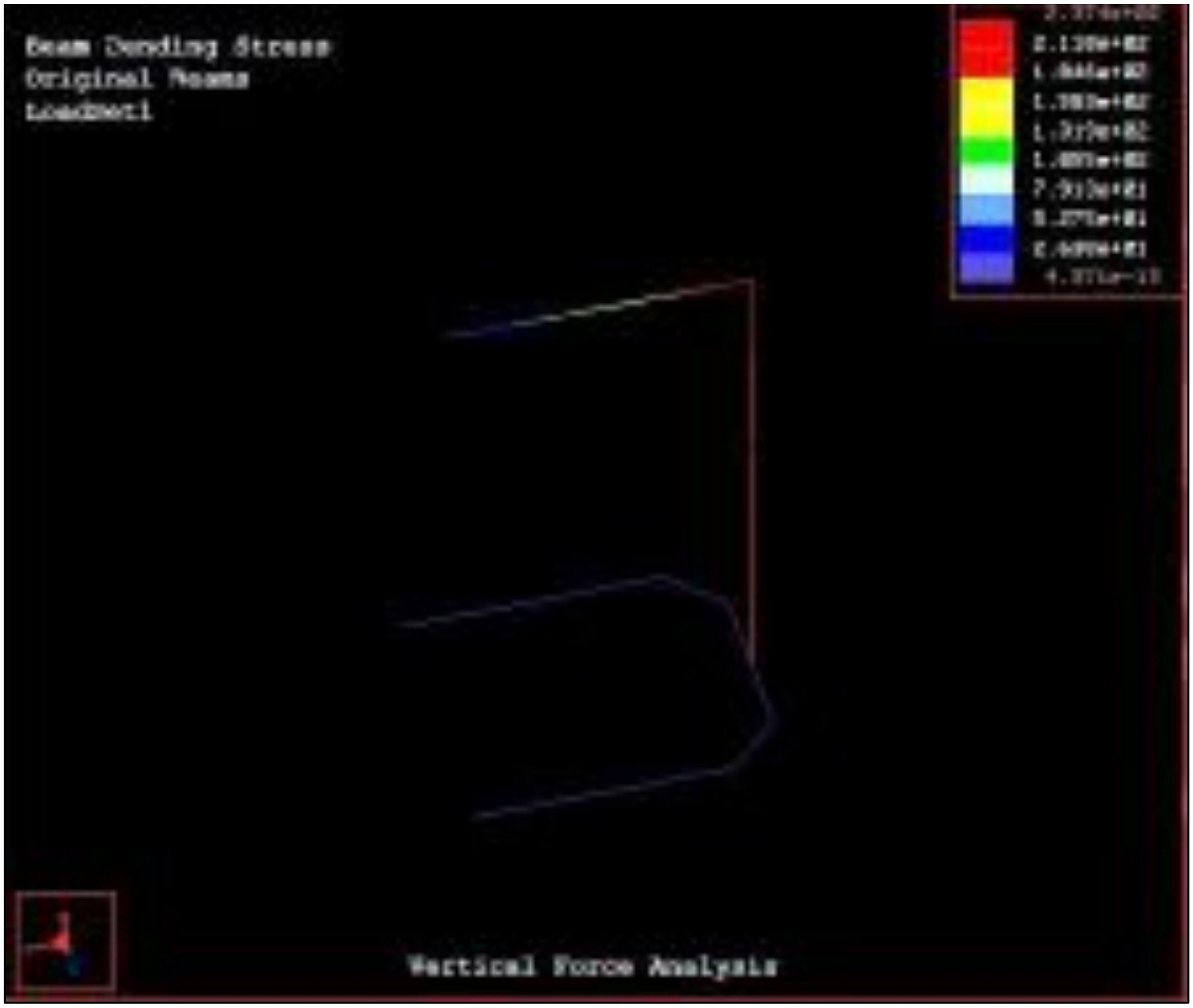


Figure 31 - FEA Stress Distributions from ProE Structures

Horizontal Tube Properties						
Length, l	in	20				
Weight, w	lbf	0.44				
OD	in	1.375		Router	in	0.6875
ID	in	1.259		Rinner	in	0.6295
I	in^4	0.052129876				

Vertical Top Tube Properties						
Length, l	in	20				
Weight, w	lbf					
OD	in	1.375		Router	in	0.6875
ID	in	1.259		Rinner	in	0.6295
I	in^4	0.05213				
Extended	in	9				

Horizontal Bar deflections

Deflection from weight alone		
dist. from left, a	in	10
ymax at pt	in	-0.00224717
slope at pt	rad	0.000224717

Deflection from weight of shooter mech + additional downward force from pushing		
weight of shooter mech	lbf	1.78
downward force at end	lbf	20
ymax at end	in	-0.11838

Vertical Post Properties						
Length, l	in	25				
Weight, w	lbf					
OD	in	1.5	Router	in	0.75	
ID	in	1.384	Rinner	in	0.692	
I	in^4	0.068405				

Deflection from weight at end		
y from bar	in	-0.00489616
total ymax	in	-0.12083101

assumes fixed left end

ONLY CHANGE YELLOW VALUES

Vertical Top Tube deflections

Deflection from forces named above		
Moment of bar weight, M1	lbf in	4.4
Moment of shooter+forces	lbf in	455.6
Total Moment	lbf in	460
xmax at top	in	0.035680187
new vertical extension, f	in	8.999929273
horizontal bar deflection down, g	in	7.07267E-05
total shooter dip	in	-0.12090712

assumes fixed at telescoping clamp

Vertical post deflections			
	total height	in	34
	xmax at horizontal tube	in	0.388061835
	new vertical height	in	33.99778534
	horizontal bar deflection down	in	0.00221466
	total shooter dip	in	-0.12305105

assumes telescoping clamp is rigid and that combines both vertical tubes into one tube with the larger tube properties

Figure 32 - Summary of Deflection Analysis from Excel

Transferred properties						
Weight	lbf	10.705		Weight (with 15 lbf of extra weight)	lbf	26.266
COG x coordinate	in	10.804		COG x coordinate	in	5.343
COG y coordinate	in	13.375		COG y coordinate	in	8.074
COG z coordinate	in	0		COG z coordinate	in	0
Height of horizontal bar off ground	in					

Front to Back Loading		
Distance between front to back posts	in	20.78
Percentage of weight on rear posts	N/A	0.480077
Percentage of weight on front posts	N/A	0.519923
Weight on back posts	lbf	5.139224
Weight on one back post	lbf	2.569612
Weight on front posts	lbf	5.565776
Weight on one front post	lbf	2.782888

Max external downward force (weighted)		
Force	lbf	585.9368

Max external downward force (when rear posts don't support any weight)		
Force	lbf	75.98258

Max horizontal forward force (when horizontal bar is 35 in up from ground)		
Force	lbf	2.439517

Max horizontal forward force (at y = 32 in, AND with 3.5lbf weights attached (integrated))		
Height off ground	in	32
Force	lbf	12.67088

Max horizontal sideways force		
Height off ground	in	32
Force	lbf	7.878158

Figure 33 - Summary of Stability Analysis from Excel

Appendix E: Gantt Chart with Time Summaries

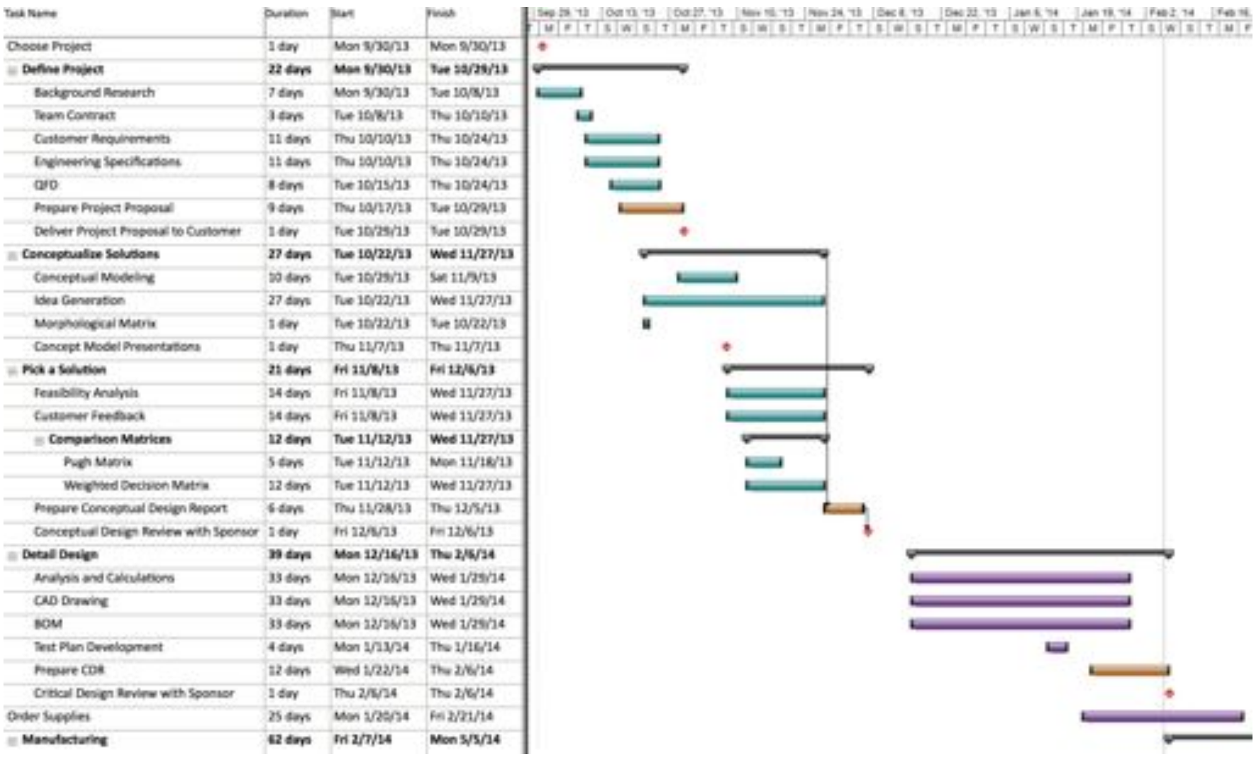


Figure 34 - Gantt Chart Summary of Fall to Mid-Winter Quarters

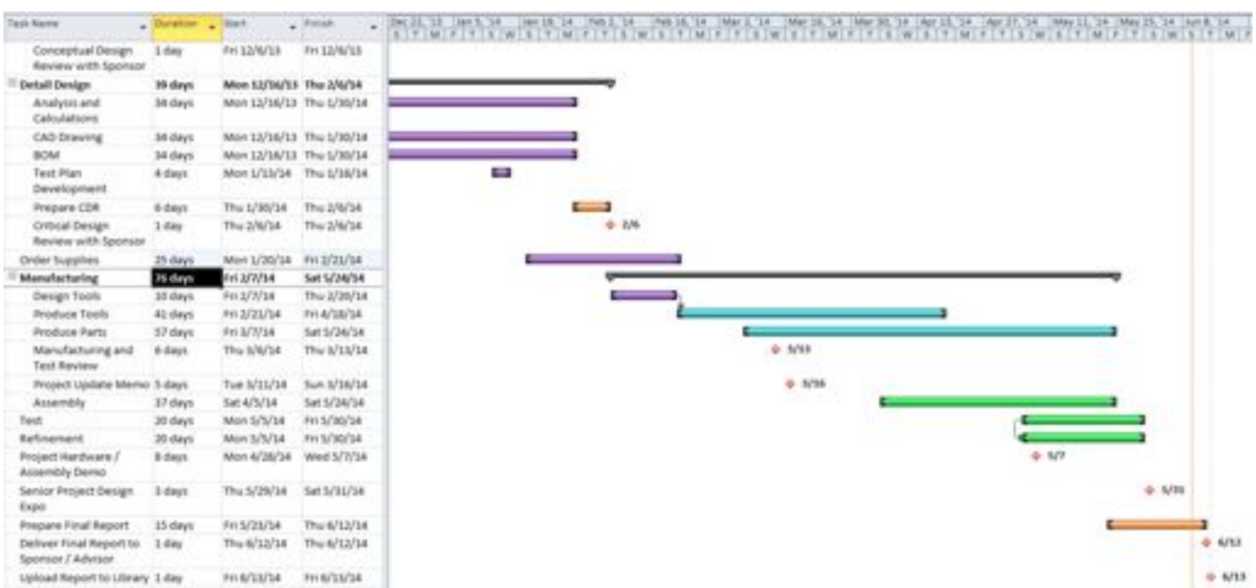


Figure 35 - Gantt Chart Summary of Mid-Winter to Spring Quarters

Appendix F: Design Verification Plan

Table 3 - Design Verification Test Plan and Results

Adapted Pool Cue DVP&R										
TEST PLAN							TEST REPORT			
Item No	Specification	Test Description	Acceptance Criteria	Test Stage	SAMPLES #	SAMPLES Type	Result	# Pass	# Fail	NOTES
1	Cue Length Compatibility	Observe length at which device no longer supports pool cue	4" - 24" past front roller with no failures	DV	3	B	Pass	3	0	Can support with tip at front roller (0")
2	Pinch Points	Observation and tactile feedback inspection	0 pinch points	DV	1	B	Pass	1	0	
3	Free Movement	Observation of translation on multiple surfaces	no failures	DV	3	B	Pass	3	0	Carpet, wood, concrete
4	Vertical Reach	Standard distance measurement	32" - 37"	CV, DV	1	A, B	Pass	1	0	
5	Horizontal Reach	Standard distance measurement	36" ± 12"	CV, DV	1	A, B	Pass	1	0	48"
6	Vertical Angle Range	Angle measurement of device range of motion	5° - 20° ± 2°	DV	1	B	Pass	1	0	
7	Horizontal Angle Range	Angle measurement of device range of motion	0° - 180° ± 10°	DV	1	B	Pass	1	0	
8	Cue Movement Limit	Observation of device behavior during action	1 axis, no failures	DV	5	B	Pass	5	0	
9	Seated Operation	Observation of user ergonomics	no failures	DV	1	B	Pass	1	0	
10	Elbow Movement Limit	Observation of user ergonomics	elbow below shoulder > 75% of shots	DV	20	B	Pass	20	0	
11	Cue Travel	Measurement of marks from inked roller	1" - 6" ± 0.5"	DV	5	B	Pass	5	0	Far exceeds 6" due to ability to support @ 0"
12	Max Cue Deflection	Manual cue rotation with protractor	15° ± 5° with no contact on board	DV	3	B	Pass	3	0	
13	Exposed Moving Parts	Observation and tactile feedback inspection	0 exposed moving parts	DV	1	B	Pass	1	0	
14	Set-up Time	Post-training customer time trial	< 2 minutes	DV	3	B	Pass	3	0	
15	Forward Tipping Force	Observation of device as pushed forward on shooting mechanism	slide before tip	DV	3	B	Pass	3	0	
16	Sideways Tipping Force	Observation of device as pushed sideways on shooting mechanism	slide before tip	DV	3	B	Pass	3	0	
17	Pin Lever Release	Weights on base till posts recede	< 75 lbf	DV	3	B	Pass	3	0	
18	Cue Stop	Observe effectiveness of adjustable brake stopping cue movement	no contact with table, shorter cue travel	DV	10	B	Pass	10	0	Adjustability works
19	Sliding Force	Observation of device behavior during action	no sliding during shots	DV	20	B	Pass	20	0	