Boccia Ball Ramp for Boccia International Sports Federation Classification 3 (BC3) Athletes

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Final Design Report

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Statement of Disclaimer

Table of Contents

List of Figures

List of Tables

Executive Summary

In this report, the design process in creating an assistive device for Boccia Classification 3 (BC3) players is outlined. The initial research steps, including research into the rules of the game, capabilities of the players, and existing products is documented to show where ideas for the product stemmed from. This transitions into requirements that the sponsor requested, and preliminary designs and ideas for the product. Finally, this report explains the details of the final design, which has been analyzed for safety, ease of use, and ability to function under different conditions. The processes of manufacturing and testing will also be discussed. The overall goal of this report is to condense the findings from the research, design process, and manufacturing process in order to advance the playing capability of BC3 athletes, and to continue making progress in this field of assistive technology.

Introduction

Boccia is an established, adaptable sport that has been played for several decades by wheelchair athletes. USA Boccia is the nonprofit organization that has made competing in the sport of boccia possible for many people with disabilities in the United States. Many athletes compete in the sport with the help of an assistive device which enables them to aim and propel balls onto the field of play. When the game was originally created, it was designed for athletes who have cerebral palsy. However, as time has passed, the game has evolved, and players with different levels of injury have come to compete in the sport, including people living with quadriplegia. Players with high level quadriplegia have a limited range of motion from the neck down, while players living with cerebral palsy will generally be able to move their arms and their torso. As of now, there are no ramps on the market, produced in the United States, that cater to the specific needs of athletes living with quadriplegia.

It is important to note that this report and all subsequent reports will use "people first" language. People first language refers to emphasizing the person, rather than the disability that they live with. For example, rather than referring to someone as "a disabled person," (defining them by their condition), they would be referred to as "a person living with a disability" (defining them as a person who has the condition). Language is important, and we hope to maintain respect and understanding for the clients of this product.

USA Boccia has sponsored a team of three undergraduate students at California Polytechnic State University, San Luis Obispo, to create an assistive device for this specific group of players. In order to effectively complete this project, each student managed an aspect of the project: Alissa Koukourikos was in charge of communication, reports, and analysis; Matthew Lee was in charge of Solidworks designs and testing; Nathan Bernards was the head of manufacturing. There were multiple milestones included in our Gantt Chart that required sponsor participation. We met with our sponsors at these times to review our ideas and designs, and receive and feedback to give. These meetings were essential to ensure that we understood the scope and the final goals of the project.

This Final Design Report reviews the complete process utilized to create this product, and enable players with high level quadriplegia to play the game at the highest level possible.

Background

To begin this project, the group conducted research on several topics that we believed would be helpful in developing ideas for our final design. The first topic that we looked into was the rules that govern the sport of Boccia. In this section, there is a summary of the Boccia International Society Federation (BISFED) rules that were found to be pertinent to the design process, and will later impact the design specifications for our product.

Boccia is a game played by two teams. One team plays with six red balls, the other plays with six blue balls. The game begins with the first player (red) rolling a white ball (Jack) onto the field of play. They then throw a red ball onto the court. After these two balls have been thrown out, it is the second player's (blue) turn. The person whose balls on the court are furthest from the Jack continues to play until they throw one of their balls closer than their opponent's. Once all balls are thrown, the round (end) is over, and points are awarded to the player whose balls are closest to the Jack. For each ball that the player has closer to the Jack than their opponent, one point is awarded. Four ends are played, and the team with the highest score at this point wins the match.

There are four different Boccia Classifications (BC) of athletes. The first of these is BC1, players who can move the ball with either their hand or their foot. They are allowed a sport assistant, but only to help stabilize their chair. BC2 class players can throw the ball with their hand, and are not eligible for assistance. BC3 class players do not have the ability to propel the Boccia ball onto the court using their hand or foot. A BC3 athlete is allowed to have a sport assistant to help set up their assistive device, but at no point is the assistant allowed to view the field of play. Each BC3 athlete is given 6 minutes in order to set up during each end. The final class of athlete is BC4, players who have "severe locomotor dysfunction" but are capable of throwing the ball on the court. The athlete is required to be the person who releases the ball via direct physical contact. The product will be designed for athletes classified as BC3.

The court for Boccia is 41.0 ft x 19.7 ft (12.5 m x 6 m), with six boxes at the front of the court, measuring 8.2 ft x 3.3 ft (2.5 m x 1 m). The full layout of the court can be seen in Figure 1. The sport assistant, athlete, athlete's wheelchair, and the base of the assistive device must be able to fit in one of the boxes at the front of the court. The ramp may overhang the edges of the box, but it cannot touch the ground outside of the box. The device, when laid on its side, must be able to fit into a 3.3 ft x 8.2 ft (1 m x 2.5 m) box at the front of the court. At the beginning of each end, the ramp is to be "visibly" moved at least 0.7 ft (0.2 m) to the left and to the right. The ramp is not allowed to have any additions to it that would aid in propulsion, affect the velocity of the ball, or change the orientation of the ramp. Specific examples of banned devices include lasers, levels, brakes, sighting devices, and scopes. The ramp is allowed to have different colors of paint on it, so a center stripe may be painted on the inside.

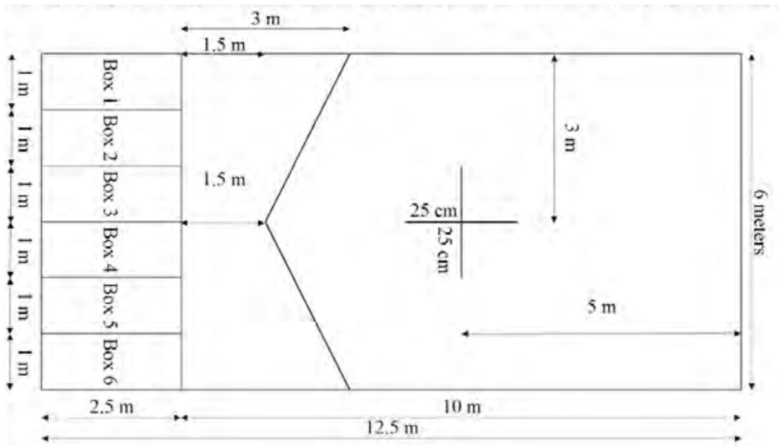


Figure 1. Dimensions and setup of a Boccia court

Along with the ramp, classification BC3 players are allowed to use a device to help them propel the ball onto the court, referred to as a pointer. Generally, the pointer is a "stick" that can either be attached to their head or held in their mouth. The player is required to have the final, direct physical contact with the ball when it is propelled onto the court. There is no limit on the length of the pointer, and the angle of the device can be moved in anyway.

Boccia balls are made in a variety of hardness. In terms of weight, they are to be between 0.58 lbs and 0.61 lbs (263 g, and 287 g, respectively). Players generally prefer the softer balls due to the fact that these balls move less on the court. This keeps the balls from being able to be moved into a different position by an opponent's balls. In terms of circumference, the balls are to be between 0.86 ft and 0.91 ft (262 mm and 278 mm, respectively). There is a new device that will be used to test these balls that requires the ball to roll a certain distance, and fit between a specifically sized set of bars. Boccia can be played on several different surfaces including wooden gym/basketball floors, sport court, or a material called "TerraFlex." Terraflex has a coefficient of friction of 0.6, which is the highest out of all other floor materials.

Current Products

During our preliminary research into designing a new product, we looked into some of the ramps that are currently being used by Boccia players. These ramps range in complexity from a handmade, handheld ramp, to a ramp with a base and adjustable height and angle. Our search on patented designs in the United States did not yield any results. Most of the current ramps are light enough for the assistant to lift and fit the standard dimensions of carry-on luggage when disassembled. Many ramps are manufactured and distributed from other countries, which increases the already high cost of the ramp (about $1000 to $1500), due to the costs associated with international shipping. It also increases the difficulty of contacting the manufacturers. Most ramps on the market are designed for Boccia ball players with cerebral palsy. Players with cerebral palsy generally have a different range of motion than players with spinal cord injuries. Current ramps do not take this into account, which can make it difficult for quadriplegic players to see the field and the point at which the ball is being released on the ramp.

One of the lower quality ramps used in competition is a simple polycarbonate ramp made by Handi Life, as seen in Figure 2. This ramp does not have a base or adjustable height, which limits the distance that the player would be able to propel the ball. The material this ramp is made of obstructs the player's view. This is a perfect example of a ramp that is not designed for a Boccia ball player with limited neck movement. The player would not be able to see the Jack while aiming, and due to the limited range of motion and force, the ball would be propelled at relatively the same velocity every time.

Figure 2. Simple Boccia ramp created by Handi Life

Two of the highest quality Boccia ball ramps on the market are the Boccia NOVA ramp, made by DEMAND, and the Acrylic-Phenolic ramp made by a company in South America called Boccas. The Boccas ramp is unable to reach the height that players require to help propel the ball. Thus, athletes are limited in terms of how far the ball will roll. Both of these ramps meet all of the minimum requirements to solve the current problem. However, the main problem with these ramps is the price because they both cost over $1000. As mentioned above, one of our main focuses of this project is to bring down the total price of the ramp.

Figure 3. The Boccia NOVA ramp, made by DEMAND

Figure 4. Current Boccia ball ramp created by Boccas, based in Portugal

In conjunction with the ramp, we also researched existing head pointers. Figures 5-7 are examples of pointers that are currently on the market. The pointers seem to only move in a few directions, which can potentially make it difficult for users with quadriplegia to reach every part of the ramp. They also seemed slightly bulkier and not very aesthetic. Another example of a head pointer is seen in Figure 8. This pointer is fully flexible, and is used by Canadian player Eric Bussiere. However, this seems to be a custom made piece, and is not available for purchase elsewhere.

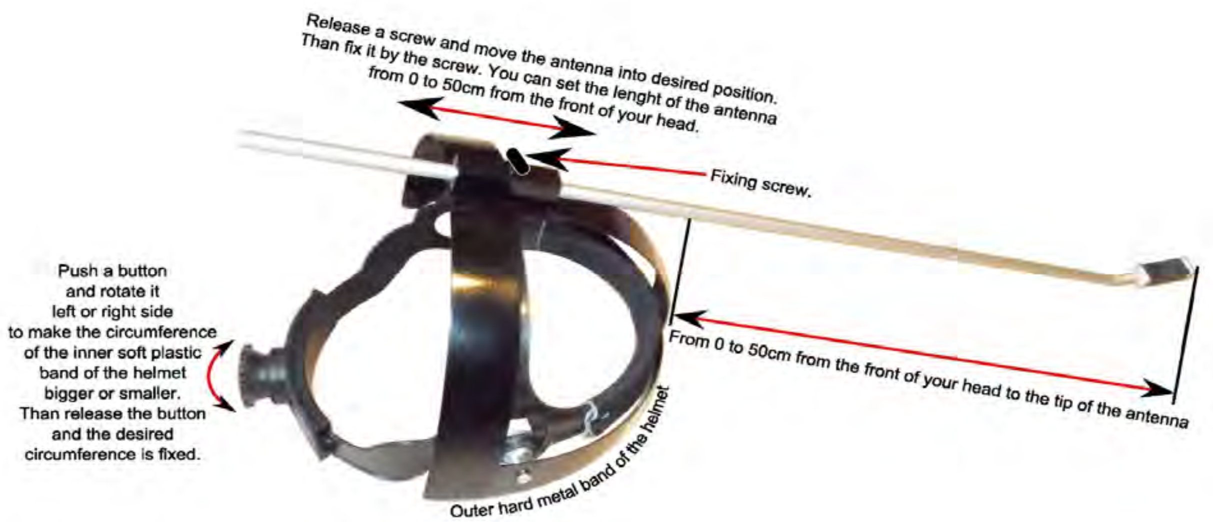


Figure 5. Head Pointer sold by eshop-parahry.sk, a Slovakian company.

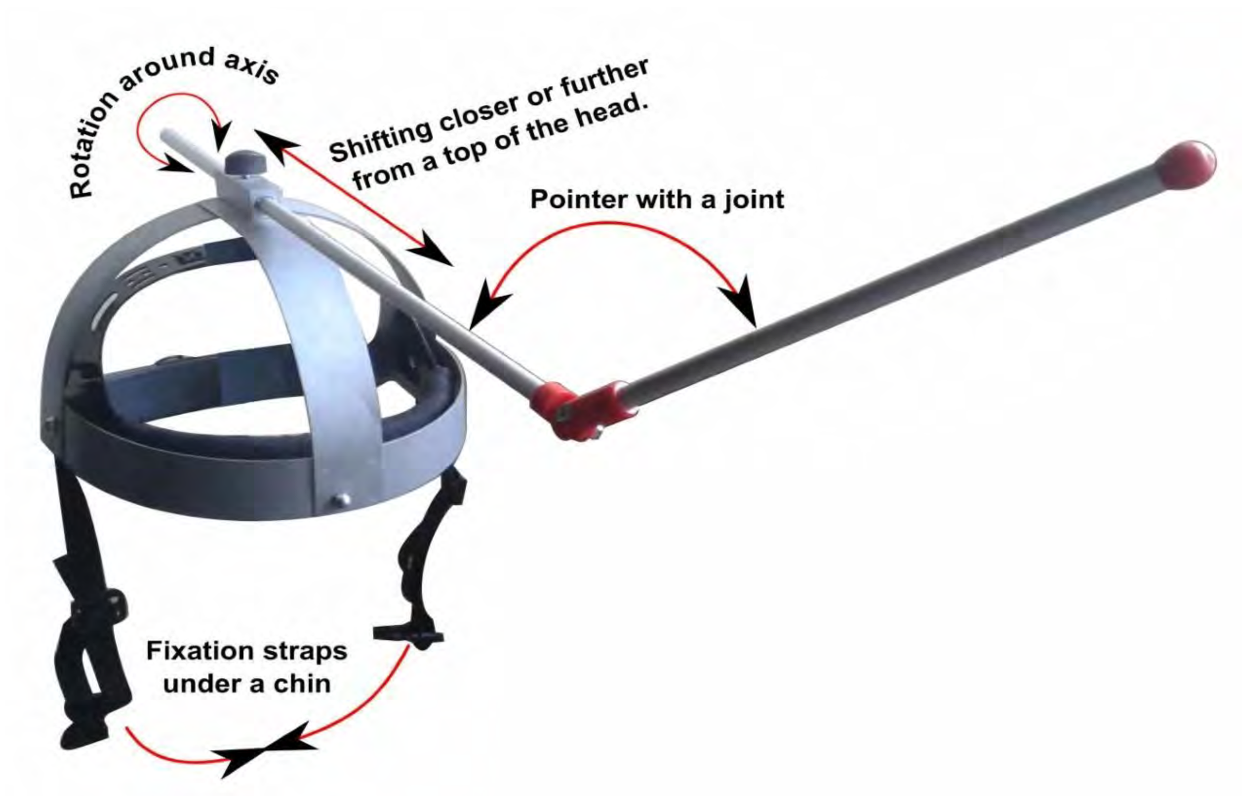


Figure 6. Iteration of Head Pointer found on parahry.sk

Figure 7. Head Pointer sold by Demand

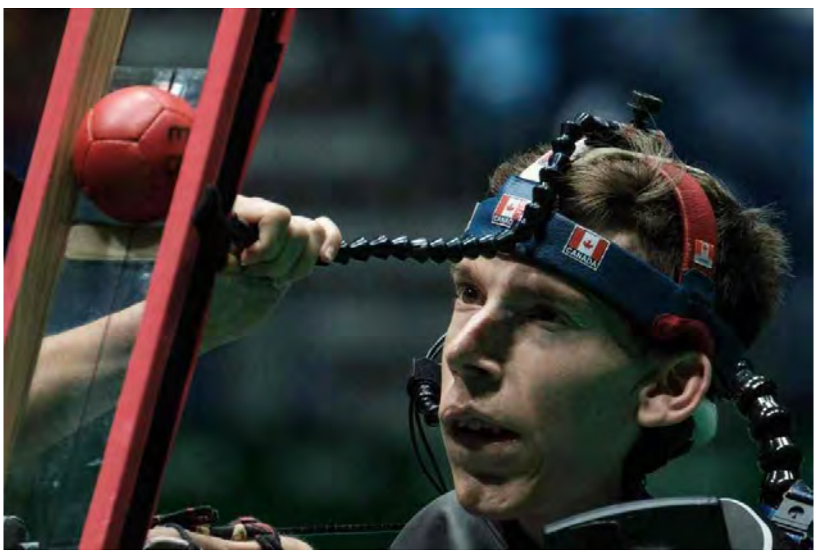


Figure 8. Eric Bussiere using his head pointer.

We spoke with several members of the Cal Poly faculty, and conducted our own research in order to try and understand the amount of force that a person living with a spinal cord injury may be able to exert on a system like what we plan to create. Due to the fact that spinal cord injuries vary greatly from person to person, the information that we found was sparse, and are usually based on a single case study. In general, it has been assumed that players will be able to exert about 3 lbs (13.34 N) of force to propel the ball. We have also been able to assume that the players will be able to have some type of control over their wheelchair in order to move it.

Design Requirements and Specifications

There are several goals that this project will accomplish, compiled from what we understand the customer's needs to be. We will be creating a new design that fulfills all of the following criteria. First, it will be able to be used by athletes with various levels of disability, specifically athletes with high level spinal cord injuries competing in the BC3 division. The device will allow the user to accurately propel the ball onto any part of the court. The height, position, forward angle, and upward angle of the device will be able to be adjusted. The ramp should have the capability of being used with Boccia balls of varying hardness and diameter. Because Boccia is played on several different surfaces, the device will be able to be used on all of the potential playing fields. The ramp is to be portable, allowing the user to easily travel with the apparatus and all of its components to competitions. The ramp will be designed to allow the ball to be released from any position on the ramp. An external device that can be attached to the player's body will be designed in conjunction with the ramp. The Boccia International Sports Federation competition rules will be explicitly followed in the creation of the design. Ideally, the final product will be able to be manufactured in the United States for a lower price than existing products.

Due to the engineering nature of this project, several design constraints were created using the initial parameters given to us by the sponsor. Combining these ideas, we created a Quality Function Deployment (QFD) matrix, which can be seen in Appendix C. The QFD, which looks complicated at first glance, is helpful in the design process, and is based on the diagram (also known as the "House of Quality") in Figure 9. In our matrix, the "Who" is our customer, the sponsor. Underneath the "Who," we have listed the design requirements from the customer. To the left of these, the values are ranked in weighted importance, based on the customer's needs. The "Now" section looks into products that already exist in the market. We intend to compare the design that we formulate to these existing products. The "Now vs. What" section compares how the current products fulfill the customer's needs. These are rated on a scale from 0-5, with 0 being the lowest. In the "How" section, we have listed design constraints. In the "What vs. How" section, the design constraints are compared to the customer's design requirements. They are compared in terms of relationship (high, moderate, or low). Below the "What vs. How" section, you can find the "How Much" section. This section is made to add tolerances to the design specifications, in either quantitative, or qualitative terms (i.e. pass or fail). The existing designs are compared to the design specifications, using a scale from 0-5. At the top of the matrix, in the "How vs. How" section, the design specifications are compared to each other, using a negative or positive correlation scale.

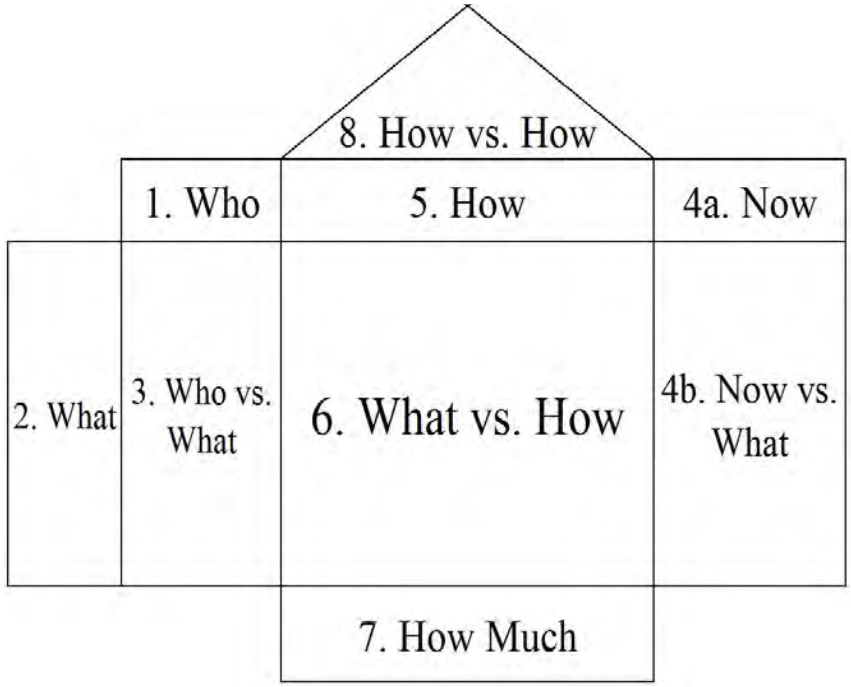


Figure 9. An example QFD, also called a House of Quality

In order to create the best product, we developed several engineering specifications to guide our design process. To begin with, the ramp is to be portable. Because of the amount of equipment that each player requires, the sport assistant has quite a few things to hold and travel with. In light of this, the ramp and case are to collectively weigh less than 20 lbs (9.07 kg).. The case will have maximum dimensions of 0.75 ft x 1.17 ft x 1.83 ft (0.23 m x 0.36 m x 0.56 m), the size of a standard carry-on, and the ramp must be able to fit into the case when disassembled. When the ramp is fully assembled, it will fit into a space that measures 8.2 ft x 3.3 ft (2.5 m x 1 m).

Since Boccia is played on a variety of surfaces, the ramp will need to be able to accurately propel the ball on each surface to any point of the court. The minimum distance that the ball is required to move is 4.9 ft (1.5 m), and the maximum distance required is 49.5 ft (14 m). The bottom of the ramp will be able to be set to a range of angles from 0∘ to 135∘, with 0∘ facing one sideline of the court. We are considering mechanizing the ramp in order to allow the player to have control of the yaw angle, height and position of the ramp. If we choose to pursue this idea, the design specifications will remain the same in terms of distance the ball will be propelled, angle of the ramp, and the range of height.

We plan to design this product to be used by people with a minimum range of motion of 15 degrees to the left and right, 15 degrees of motion up and down. An example of this range of motion can be found in Figure 10. Because there is a time constraint on the amount of time an athlete has to play their part of the end, easy assembly of the device is necessary. The device will be able to be assembled and prepared for play by the sport assistant within two minutes. It will be able to be adjusted for a new ball (moving the ramp 20 cm to the left and right, and set-up) within 20 seconds. To allow athletes to know what point the ball is being released from, the design will allow the athlete to see the ball that is being put into play. It will also allow for the athlete to see the Jack and the surrounding balls in play, as well as at least 90% of the playing field when the ramp is assembled and prepared to propel a new ball onto the playing field . Because Boccia balls can fluctuate in size, the ramp should be able to accommodate the standard size of the ball, within the tolerances described in the BISFed regulations. In our research, we have found that most ramps cost between $1000 to $1500. We aim to deliver a product that will be less than $1000 in total, which includes the price of manufacturing, and transportation.

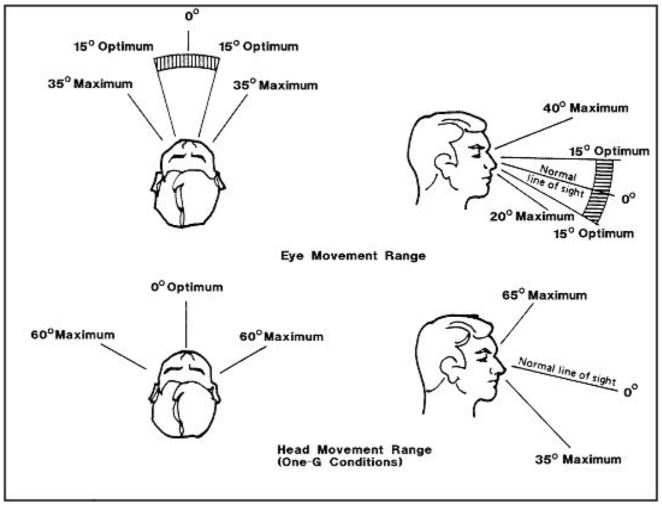


Figure 10. Depiction of neck range of movement in terms of angle.

Table 1 is a formalized version of the current design specifications. The design specifications have been quantified, as described above, and set to a tolerance value. The risk involved with each parameter was rated as “Low,” and was therefore not included in the table. The compliance of each engineering specification will be measured in several ways, either through Analysis (A), Testing (T), or Inspection (I).

The external device mentioned above is to add to the propulsion of the ball from the ramp onto the playing field. It will not cause any discomfort to the player. In order to achieve this, the product will be adjustable, and according to common practice, be designed to be used by the 5th percentile of women up to the 95th percentile of men. In addition, it will not weigh more than 1 lb. It will also be able to fit into the case that has been made to hold the ramp. Therefore, at its longest length for storage it will only be 1.83 ft (0.56 m) long. When extended, the maximum length may exceed this length.

Table 1. Boccia Ramp Project Engineering/Design Specifications

Specification #	Parameter Description	Requirement or Target (Units)	Tolerance	Compliance
1	Complies with BISFed Rules	Y/N	-	A, I
2	Portable	0.75 ft x 1.17 ft x 1.83 ft (0.23 m x 0.36 m x 0.56 m)	Nominal	A, T, I
3	Works with any playing surface	Y/N	-	T, I
4	Adjustable Forward Angle	0° to 135°	Maximum	T
5	Adjustable Court Position	65 ft (.20 m)	Minimum	T
6	Mechanized	Y/N	-	T
7	Lightweight	Weighs less than 20 lbs (9.1 kg)	Maximum	A, I
8	Accurate	Distance from Ball < 0.001 ft (.001 m)	Minimum	A, I, T
9	Powerful	4.9 ft (1.5 m) < Distance Ball is Propelled < 49.5 ft (14 m)	Minimum	A, T
10	Inexpensive	Overall Design costs less than $1000	Maximum	A
11	Durable	Lasts 5 years with regular use	Minimum	T
12	Works with High level injuries	±15° of motion in every direction (see NASA diagram)	Minimum	A, T, I
13	Interchangeable parts	Y/N	-	A, I

14	Released from any point	Between 1.3 ft to 6 ft (0.4 m to 1.8 m)	Minimum	A, I
15	Adjustable Angle (Up and Down)	From 51° to 66°	Minimum	A, I

Design Development

Rather than creating one single design, the group decided that the best way to approach the problem would be to break the product into the pieces that were the most important. We chose to examine designs for the base of the ramp, the ramp itself, how the ball is released from the ramp, and the athlete's headpiece. We created a Pugh Matrix that included multiple smaller matrices, analyzing our ideas for each of these components.

To analyze our designs using a Pugh Matrix, we put our design ideas for each component on the x-axis of the matrix, and our design specifications on the y-axis. We chose existing products to use as a datum to compare our design ideas to for each component. We then rated each of our designs in terms of how they met each specifications compared to the datum. Using a '+' meant the design was better than the datum, an 'S' was given to designs the same as the datum, and a '-' meant the design was worse. A '+' counted as one point, 'S' counted as zero points, and '-' counted as negative one point. After rating each design we counted up its total points, and the design with the most points was determined to be the best design.

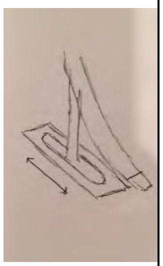
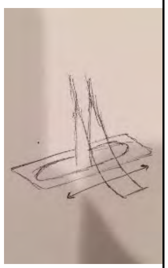
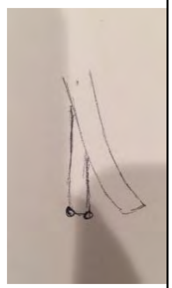
In order to make sure that our chosen design was actually the best one, we placed a "weight" on all of our design specifications, creating a weighted Decision Matrix. Each design specification was given a percentage out of 100 based on how important that specification was to our sponsors. For example, being able to accurately rotate the ramp from side to side was given a percentage of 7% importance, while being able to mechanize the ramp only had 2% importance. By applying this percentage to each rating given to our different designs, we were able to accurately determine the design that would best satisfy our customer for each component. The Decision Matrices are included in the Appendices.

A brief description of each part of the ramp, the designs that were created for each part, which of the designs was selected, and why these designs were selected is as follows.

Ramp Base

The ramp base is the way that the ramp is supported, as well as how the ramp is eventually aimed. Therefore, it is essential that the base allows for the ramp to be effectively rotated and transitioned from side to side. We included many different designs for the base of the ramp in our Pugh Matrix.

Table 2. Ramp Base Designs

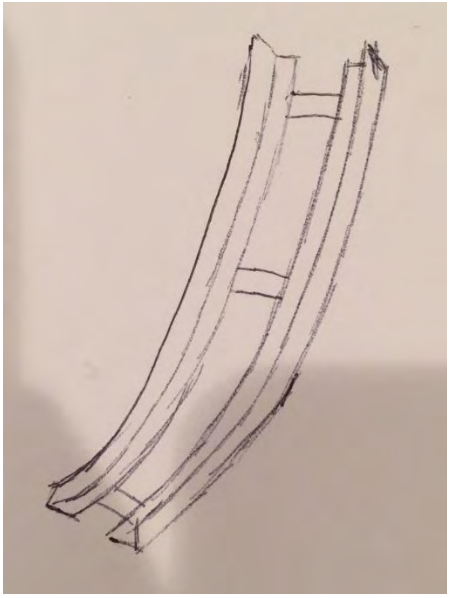
Design 1	Design 2	Design 3	Design 4	Design 5	Design 6	Design 7
						
The base is stationary with a vertical slot to slide the ramp back and forth.	The base is stationary with a horizontal slot to slide the ramp side to side.	The ramp is supported by two bars, both with wheels on the bottom.	The ramp is supported by a single bar with wheels on the bottom.	Cylindrical base with wheels on the bottom, with two rods attaching the ramp.	The base is a tripod style with wheels on the bottom.	The ramp is attached to the back of the wheelchair.

The datum for this piece of the design was a basic stationary, high-friction surface, single bar seen as the base on many current Boccia ramps being used today. Some of the important design specifications we used were that the design would comply with BISFed rules, have an accurate adjustable forward angle and court position, and would work with high level injuries. We found that having the ramp attach to the wheelchair as a base would be the best option, after it scored a total of 20 points. This design has many advantages, including being accurate, lightweight, and adjustable. One of the biggest benefits of this design is that it efficiently uses the space provided. It also allows for the player to have some control of the ramp, with the help of their wheelchair. Furthermore, this design allows for the ramp's forward angle to be mechanized as an added benefit. The ramp will most likely attach to the back of the wheelchair and come around the front, being supported by adjustable arms. A support beam in the back will insure that the ramp is level to the ground.

Ramp

The ramp piece of the assistive device is mostly self-explanatory, i.e., the part of the device that the ball is placed on and then rolled on in order to reach the specific part of the playing field.

Table 3. Ramp Designs

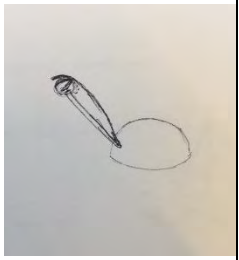
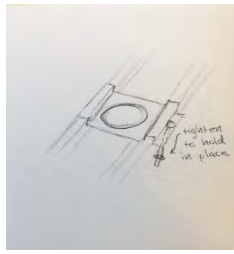
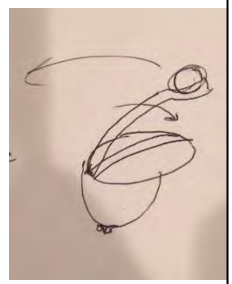
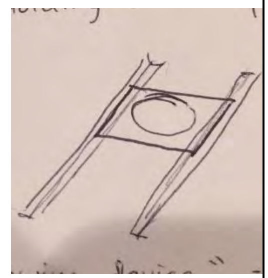
Design 1	Design 2
	
The ramp is composed of two separate rails that are attached at multiple points.	The ramp is composed of two separate rails that are connected by minimal material in the middle.

There were two main designs we considered for the structure of the ramp itself: having the ramp consist of two rails on the side, with an opening in the middle, or having two side pieces with minimal material in the middle. Both of these designs would allow for a player with quadriplegia or another serious neck injury to easily see where they are aiming the ball through the ramp. We compared both of these designs to a ramp of full material, with clear material on the bottom. Using the same design specifications as the ramp base, we found that having a ramp with minimal material in the middle would be the best option. With this design, the athlete will still be able to see through the rails to properly aim, and the ramp will be more sturdy because of the added connection.

Ball Release

The ball release is some type of device or attachment that allows the player to keep the ball in place until they are ready to propel the ball onto the playing floor. Several design options were considered for this mechanism.

Table 4. Ball Release Designs

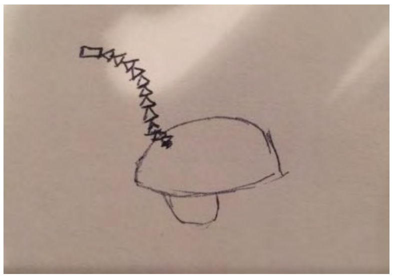
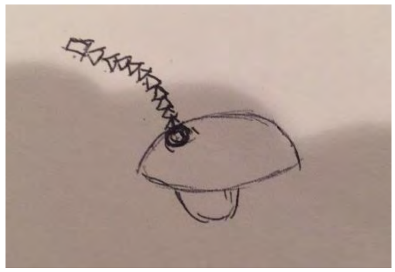
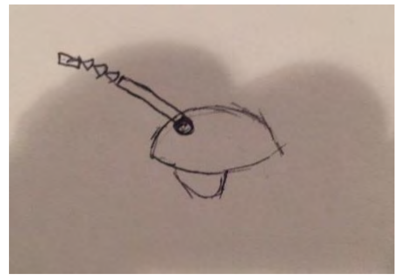
Design 1	Design 2	Design 3	Design 4	Design 5
				
A rubber band is attached to the ramp, and uses friction to keep the ball in place.	An attachment is used in conjunction with the head pointer to hold the ball in place. The ball is released when the player moves their head.	A piece of material with a ball shaped cut-out in it is attached to the ramp. The "pocket" is able to move to any point on the ramp.	An attachment that allows the player to launch the ball onto the ramp.	Similar to Design 3, however, the cut-out is only in one place.

These designs were compared qualitatively and quantitatively. Using the weighted design matrix, we were unable to rule out the ideas that were the least feasible for what the end product should be. Each idea was compared to the sport assistant holding the ball in place before the player propels the ball. In the design matrix, Design 2 and 3 have the same amount of "points" in both the normalized category and in the weighted section. In terms of price and manufacturing, both devices are similar. We have decided to pursue both options for our preliminary design, and further discuss feasibility as time progresses.

Pointer

The pointer device is an additional piece of equipment that the player will use to propel the ball forward, in accordance with the BISFed rules. There are two classifications of pointers, those held in the mouth of the player, and those supported by the head of the player. All of the mouth pointers were eliminated. Mouth pointers are not as stable as head pointers, and could result in a less accurate shot. They also require a different range of motion for players, that BC3 players may not have. There were also concerns in terms of hygiene (i.e., this device will be shared by several people). This left the group with three designs to consider.

Table 5. Pointer Designs

Design 1	Design 2	Design 3
		
A fully flexible arm that is controlled by the head of the player	A fully flexible arm attached to a rotating base	A fully flexible arm attached to a metal extrusion attached to a rotating base.

The designs were compared to an existing design similar to the idea seen in Figure 5. All of the designs utilize the idea of a fully flexible arm. This allows the player to be able to easily add force to the ball at any point on the ramp. In each device, at least one part of the the arm is fully flexible, and can therefore be changed to any angle. Because of this, it was decided that there was no need for the base to move as well. As a result, Design 1 was chosen to keep the cost low, and make manufacturing easier.

<u>Preliminary Design</u>
Taking all of these ideas in conjunction, a completed preliminary design was developed.

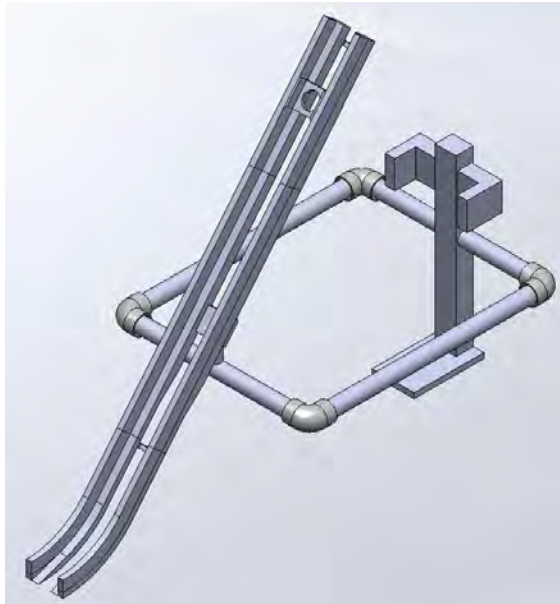


Figure 11. Front View of CAD Model of Preliminary Design

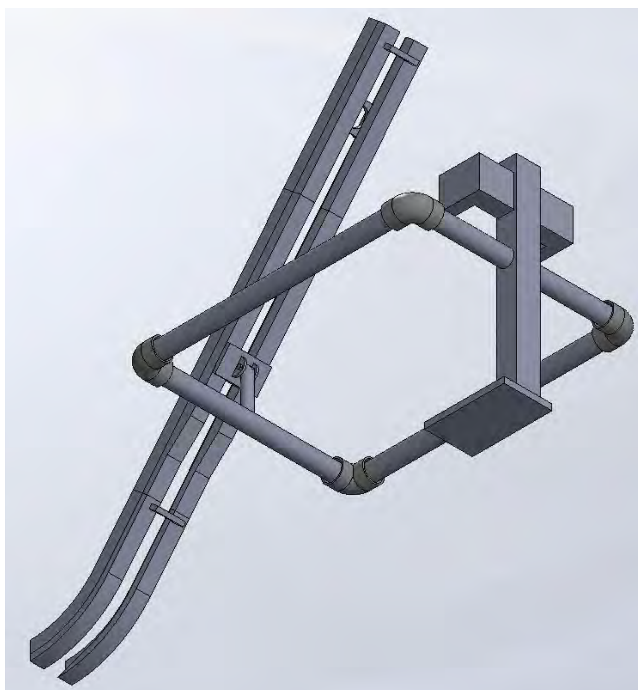


Figure 12. Bottom View of CAD Model Preliminary Design

This design implements the base being an attachment to the wheelchair, as well as the idea of the ramp with two sides and a small amount of material in the middle. The base will be able to attach to the back of the wheelchair on the sides, using adjustable clamps, in order to fit onto any type of wheelchair. There may also be an attachment that grounds the entire unit, adding stability to the device. It will be designed in order to allow the athlete to still have use of their arms, and also allow them to remove the frame from the wheelchair in the event that the player needs to view the field of play. The front part of the frame has an extrusion that the ramp will attach to. This will also allow the sport assistant to adjust the angle of the ramp so that it does not touch the ground outside of the player's box at the front of the field. Ideally it will be made from some type of plastic or lightweight material that can be easily taken apart and put together, as well as making the full device easy to transport. Additional analysis will be conducted to ensure that the ramp attachment does not cause too much stress in the base and cause excess deflection.

As seen in Figure 12 the ramp will be attached to the base described above. The ramp will also be created using a lightweight material, such as plastic or carbon fiber, to keep the device portable. The space between the middle of the ramp and the sides of the ramp will be carefully analyzed in order to make sure that the ball does not fall through the middle. The ramp will be made from three (3) separate pieces, which allows the device to be stored easily. Preliminary ideas as to how the pieces will be attached to each other include magnetizing the ends, adding hinges to the ends, and making the bottom of one piece be able to slide into the top of the other piece. There will be added material on each of the pieces between the two sides to keep them in line with each other. The bottom piece of the ramp will be angled so that the ball can smoothly transition from the ramp to the floor.

The piece that holds the ball, which we will refer to from here on as the "everywhere pocket" will be attached to the ramp with clips that allow it to be placed anywhere on the ramp. It will be made from a low friction material, most likely the same type as the what the ramp is created from. The center of the everywhere pocket will be in the same position as the center of the two sides of the ramp. This will ensure that the ball can be propelled accurately onto the field. The sides and bottom of the everywhere pocket will be padded to keep the ramp from being damaged when adjusting the everywhere pocket.

The pointer attachment will allow the player to propel the ball forward at any point. The material chosen will be fully flexible, but also strong enough to hold the shape that the sport assistant creates. Figure 13 is an example of the type of material we would consider working with. We would like it to attach to either a helmet or headband that keeps the player comfortable and supports the pointer.

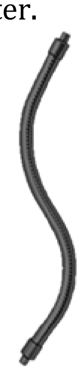


Figure 13. Screw-on Any-Which-Way Positioning Arm from McMaster-Carr

Final Design

From the preliminary design, some changes were made in order to create a better final product. The ramp is separated into four pieces that easily connect, and it still includes a gap down the middle for aiming. An "everywhere pocket" that fits into the ramp is used to hold the ball before it is released, and stays in place at any point on the ramp due to friction. The ramp has a support in the front of the frame that can easily be adjusted to change the vertical height of the ramp. The ramp is connected to the base on a hinge so that the ramp's pitch can also change easily. There are casters on the bottom of the support to allow the ramp to rotate with the frame and the wheelchair. The frame attached to the ramp also attaches to the wheelchair with the aid of sliding clamps. The clamps and length of the frame's arms can be adjusted to properly fit the player. As the wheelchair moves, the ramp moves with it, so players will be able to have more autonomy of their ramp placement. An annotated layout drawing of the final ramp design can be seen in Appendix J.

Figure 14. The final built design being tested by a volunteer student.

There are many components and features of the ramp design that come together to make the complete model. The ramp itself is made of 8 layers of prempregnated (prepreg) fiberglass composite. The ramp consists of three 2 feet pieces, and a fourth curved piece for the bottom of the ramp. A 1" gap runs down the middle of the ramp to allow a player with quadriplegia to easily aim through the ramp. Therefore, each piece consists of two corner brackets, connected on both ends by fiberglass bracket that is epoxied to both pieces. To connect the ramp together, each piece of the ramp attaches to the other with a connecting clip. This ensures that the ramp will stay together, and makes assembly of the ramp easy.

The height of the ramp can easily be adjusted on its front support using 80-20 T-slots connected by a linear bearing, that has a brake to hold the slots in place. The ramp is also attached to the frame on a hinge system, so the ramp's pitch can be adjusted.

The aforementioned everywhere pocket slides within the guards of the ramp, which allows the player to hit the ball from any point on the ramp. The pocket is 3D printed and is made to have very tight tolerances with the ramp, so it will stay in place at any point on the ramp. The pocket does not slide as easily as we hoped, but can be removed and placed on another point on the ramp with little effort.

The final frame was built using different lengths of 1 square inch aluminum 80/20 t-slots. The t-slots allow for a lightweight frame that can be easily assembled, and the parts can be re-ordered if they need to be replaced. The pieces of the ramp connect to each other with slide-in T-nuts and bolts. Each corner is connected by a gusseted corner bracket to ensure sturdiness of the frame. The distance away from the ramp can be adjusted for preference using a bar that slides along the side bars. The wheelchair clamps are also attached to this bar. The bar backs up against the back of the wheelchair, and the clamps can slide along the bar to match the width and thickness of the backrest of the wheelchair. The clamp plates can also swivel to adjust for any angle of the backrest. The support that was initially placed at the back of the chair is now positioned directly under the ramp. Because the ramp is the heaviest part of the design, it made the most sense to limit the moment that this would create on the back pipe, as well as adding stability to the ramp. The support consists of two 80/20 t-slotted bars, one 18 in. and one 10 in., that are connected by a linear bearing with a braking handle. The vertical height of the ramp on the support can easily be adjusted by sliding the support through the bearing and locking it with the brake.

The pointer attachment did not change from the preliminary design, as shown above in Figure 13. However, we found that the part we ordered for the pointer was much too heavy for a player to support with their head. Due to time constraints, we decided that the best pointer options for players are pointers that are already on the market.

Analysis

To analyze the mechanics of our design, we began by solving for the acceleration of the ball as it rolls down the ramp at a given angle. We specified this angle to be 51°, which we assumed to be the average angle of a ramp as it is in play. Based on the weight of the Boccia ball, 287 g or 0.633 lb, we determined the acceleration of the ball to be 1.2 m/s^2. We will use these values to complete testing with our everywhere pocket and the angle range of the ramp in the future.

We continued our analysis by completing a static analysis of the ramp, including the weight of the ball. The purpose of this analysis was to determine the effect the front support has on the ramp, and what moment the ramp would create about the frame arms and clamps. We began by assuming that ramp will be made out of fiberglass. We plan on manufacturing the ramp out of different types of composites, and fiberglass would most likely be the heaviest material we would test. Using a density of fiberglass of 0.055 lb/in^3, we found the mass of the ramp to be about 14.98 lb, or 6.8 kg. Also assuming an average arm length of 4.5 feet, or 1.37 m, we determined the moment on the frame to be 1.98 N-m. This value indicates a very small moment about the arms of the frame, which is one of the goals of our design.

We then used this calculated moment to determine the critical stresses of points on the arm where there is a change in diameter. Once these bending stresses were determined, we used them to determine a factor of safety to make sure our design will meet specifications and not fail. To complete this analysis we placed reaction forces at the points in the extendable frame arm where the diameter changes, to account for any extra force placed on these discontinuities. We found that the total bending stress on the arm, considering the moment and reaction forces, turned out to be 6400 psi. To find the factor of safety, we then divided the yield strength of PVC pipe by the bending stress we calculated. Research provided us with values of 12,800 psi for PVC's flexural yield strength and 7,500 psi for tensile yield strength. Because we are focused on the effect of the moment on the arms, we used the flexural yield strength in our calculations. Using this value resulted in a safety factor of 2, indicating that our design will successfully support the ramp. A more detailed account of this analysis can be found in Appendix F.

Once we determined our final design, we completed a Finite Element Analysis (FEA) using our final Solidworks model. This analysis helped us to determine the critical stress points of our design, and to make sure that the maximum stresses on our design did not exceed the yield stresses. First, we tested for the amount of deflection caused by the clamps that attach to the back of the wheelchair. The results of this test are shown in Figure 15. This test showed the greatest deflection is near the center of the side bars of the frame, which is expected because that is the area of the frame that is least supported.

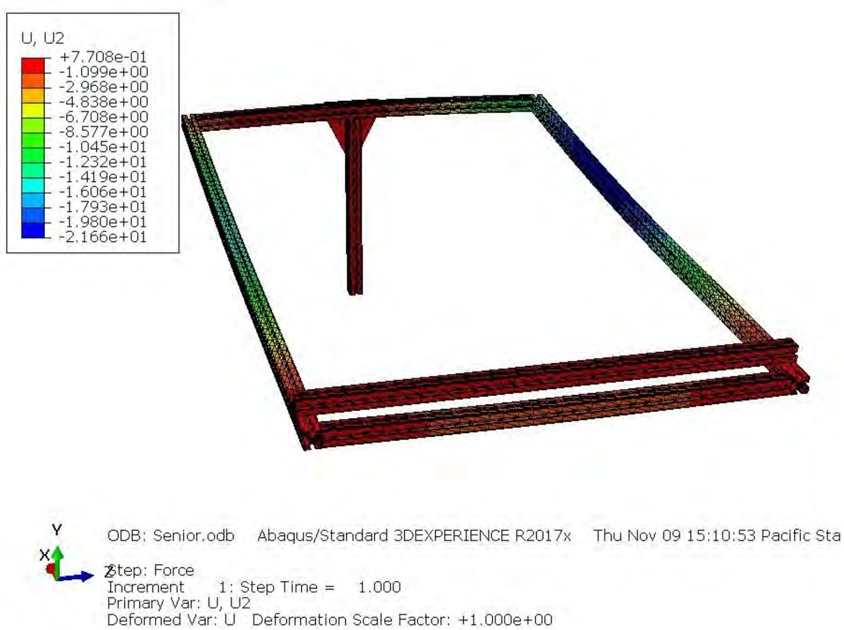


Figure 15. FEA analysis of the deflection caused by the clamps.

We then analyzed the strength of the arms of the frame, to ensure that they will support the ramp without risk of breaking. Internal stresses along the x-axis were measured, shown in Figure 16. This results showed a maximum stress of about 25.2 ksi. However, this analysis tested for the clamps supporting 15 lbs of the frame's weight without any support coming from the wheelchair. Furthermore, our final frame weighed about 9 lbs, so the actual stress on the frame will be less than the test predicts. Compared to the yield stress of aluminum, 38 ksi, the maximum stress on the arms is much less, and failure will not occur.

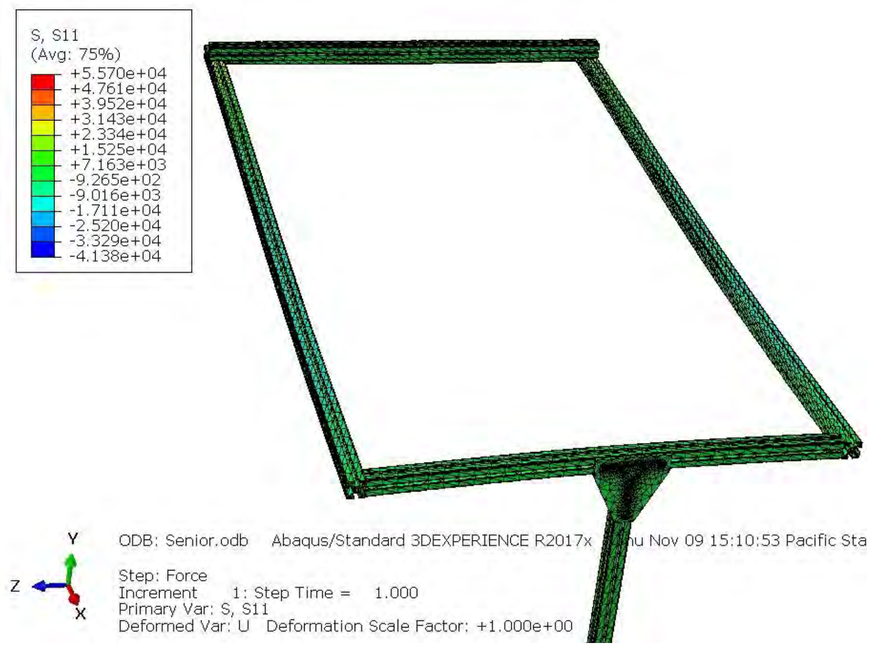


Figure 16. FEA analysis of the arms of the frame along the x-axis.

Cost Breakdown

Although our team had multiple costs for both the prototype and the final design, the majority of the cost came from the components of our final design. Our prototype purchases included PVC pipes for the arm frames, a steel rectangular tube for composite construction, fiberglass U-channels for the ramp, and acrylic material for various uses, such as the everywhere pocket. Steel scrap from the Cal Poly Mustang 60 machine shop was used for brackets and castors as well. The total cost of our prototype materials was $57.91.

Our final design costs came mostly from the 80/20 t-slot purchases. This order included multiple t-slot bars, nuts and bolts, corner brackets, linear bearing brakes, and plates used for the clamps. We also purchased two castors for the front support, and a flexible positioning arm. The total cost for our final design was $553.85. We were fortunate to have many resources available to us for free, such as the prepreg fiberglass composite material, as well as all of the other materials needed to make the composite, like foam molds and vacuum bags. With these added costs, the price of our final design would come out to about $853.85. See Appendix E and F for a total cost history.

Materials
Several different materials were chosen for the different sections of the device, for both the prototype and the final product. In order to keep the design both lightweight and inexpensive, the prototype developed was made from PVC pipe. PVC pipe comes in several standard sizes, and is easily procurable, making this the best choice at the time. The final product uses aluminum T-slots for the frame, which fit together with better tolerances, are stronger, and are more sturdy. The ramp is made from a prepreg fiberglass composite, which will keep the ramp strong, light, and inexpensive. All of the fixtures that attach the ramp sections together are small aluminum clips, and the brackets that hold each section together are also made of fiberglass. The clamps, corner brackets, linear bearing brake, and hinge design are made of aluminum. The everywhere pocket was 3D printed, but could be made of acrylic or another plastic.

Safety Considerations
Safety for the user, and those around the device was a prime concern of the team during the design development. In order to prevent injuries to players, and sport assistants, several considerations were taken into account. Each part of the device was broken down in order to fully analyze the failure, eliminate injury to the player, sport assistant, or bystander, and prevent damage to the device, in the event of device failure. Each potential effect of failure was ranked on a scale from 1-10 for severity, with 10 being the most severe. Each potential cause of failure was ranked on a scale from 1-10 for the likelihood in which it would occur, with 10 being the most likely to occur. The product of these two numbers became the criticality of the failure. All potential effects of failure that would injure a person, or damage the ramp were place at the highest severity. Each of these failures was given a recommended action to prevent the effects of failure. A full account of this can be seen in the Design Failure Modes and Effects Analysis (DFMEA) in Appendix A.

The first section of the device that was analyzed was the clamps that attach the support to the back of the wheelchair. Two potential failure modes that could stem from this are that the clamps do not attach to the back of the wheelchair, and the clamps could become a pinch point. As a result of these failures, the ramp could fall off the wheelchair, be set up incorrectly, or break, the player could become injured, and the wheelchair could be damaged. The potential causes of the failure were deemed to be the clamps becoming loose, the clamps breaking, the clamps not fitting onto the specific chair, or the sport assistant installing the clamps incorrectly. In order to prevent these failures from occurring, the recommended action was to make sure that the clamps were easily adjustable, to keep the sport assistant safe, as well as ensuring the clamps would fit on any type of wheelchair, and adding a support to the ramp, so in the event that the clamps failed, it would not immediately fall onto the floor and become damaged. The current clamps now back up against the back of the wheelchair, keeping it locked in place against the back bar of the frame and greatly reducing their risk of failing. The clamps will be rigorously tested once the final product is assembled.

The next section that was analyzed was the extendable arms of the product. These had several potential failure modes, including the case when the arms got stuck in place, the arms became too loose, and the potential for pinch points when the arms moved. A result of the failure in the arms not extending is the potential for the ramp not being set up in the correct position, the arms could break, or as a worst case scenario, the player could be injured. These were all considered high severity effects. Potential causes of this failure mode included interference within the poles, impact either from other people, or during transportation of the device, improper handling of the device, or deformations within the poles themselves. Generally speaking, the relative likelihood for each of these happening was rather low. In order to prevent these causes, the team chose to make the frame using aluminum T-slot bars instead of round telescoping poles. The fixtures attaching the T-slots together allow them to easily slide and adjust to change the reach of the ramp. The T-slots also fit into the fixtures with little clearance, keeping the frame sturdy and intact. In the case of the pinch points, the potential effects were potentially injuring the player, or the sport assistant, and the ramp cannot be adjusted to the correct position. Both of these were potentially caused by moving parts. In order to keep this from happening, plastic coverings will be placed over the slots in the bars that could cause any injury. Furthermore, there will no longer be telescoping parts, only a single bar that can slide back a forth across the arms of the frame.

After this section, the rotation feature of the ramp was discussed. The two potential failure modes that were considered were if the ramp did not rotate, or if the ramp did not stay in place. A result of the ramp not rotating would be that the ramp would not be able to be aimed. If the ramp rotation was unable to lock, this could cause undesired rotation, the player or others around could be injured, and the aim of the ramp could be inaccurate. Potential causes of these could be incorrect tolerances, outside material causing incorrect tolerances, and the locking mechanism could fail. In order to make sure the ramp is able to rotate, casters were attached to the base of the ramp via aluminum fixtures that fit into the T-slots.

The ramp pitch was next analyzed in terms of safety. Several potential failure modes included the ramp not being able to rotate up and down, the ramp rotating too far up and down, and the potential for a pinch point. If the ramp did not rotate up and down, this could result in inaccurate aiming. If the ramp were to rotate too far, the player could potentially be injured and the aim of the player could be inaccurate. As stated before, the pinch points could potentially harm the sport assistant. Causes of these failures include interference from outside objects, deformations from overuse, failure within the hinge, incorrect tolerances, a failure from the locking mechanism, and moving parts within the design. In order to eliminate these potential failure modes, the design has been made to ensure correct tolerances, and to disallow foreign objects from entering the hinge mechanism.

Another part that was to be analyzed was the base of the ramp that would be supporting the ramp. If the base were to fail, the ramp could fall off, and could also injure the player. Two potential causes of this failure could be either that the base is assembled incorrectly, or the analysis conducted by the team was incorrect. In order to combat this, the group has conducted analysis with the ball rolling down the ramp, and has conducted testing to make sure that the analysis matches up with real life user experience.

The detachable ramp pieces were also examined in the project for failure modes. The ones that were considered were the pieces unintentionally detaching, the potential for sharp corners, and once again, the potential for pinch points. Each of these failure modes had potential to injure the player, or cause the ramp itself to fail. Because of this, the team spent some extra time ensuring that design of these pieces was safe, but still functional. In order to keep this safe, the edges of the ramp pieces were sanded and rounded down, and the device was to be designed in order to limit contact with the pinch points. The pieces will be able to be assembled with the person's hands at the top of the part, rather than at the bottom, where the potential pinch point is.

Because the ramp is now controlled by the wheelchair, there are some potential failures in this function. As the ramp extends beyond the player's wheelchair, they may potentially injure someone while they are moving to the throwing box. This could be caused either by an obstruction of view, or an inability to remove the ramp from the support. In order to make sure no one is injured from this, the team has conducted testing to make sure that the ramp does not block the player's view, and make it abundantly clear to those using the system that the player should not move while the ramp is still attached to the support.

Another item that was considered was the "everywhere pocket." Potential failure modes for this include the pocket not being able to slide up and down the ramp, and the potential for pinch points. If these were to occur, this could result in inaccurate aim for the player, or injury to the sport assistant. Underlying causes from these could be incorrect tolerances, an excess amount of friction, and moving parts. To keep this feature safe and working in the best way possible, the materials that were selected for the everywhere pocket and the ramp will be low friction, and placement of the pocket would not require contact with the pinch points. However, our tolerances for the everywhere pocket were slightly too small, so the pocket must be removed and placed back into the ramp, increasing the risk of a pinch point. We recommend the manufacturing of a slightly smaller everywhere pocket, and advise the assistant to be careful when removing and placing the current pocket.

The final item that was considered was the head pointer. This could potentially detach from the head piece, or it could also hit or poke other people around the player. As a result of these failures, people could be injured, or the pointer could be broken. The causes of these failures could be in the connection from the head piece to the pointer, overuse, a pointer that is too long. The pointer we planned on manufacturing ended up being too heavy, and due to time constraints we recommend that the player use a head pointer that is already on the market.

While every product design does have potential for failure, the team has done its best to minimize both the failures, and the effects of these failures throughout the process of creating this design.

Assembly and Maintenance

Our team's goal was to make the final product as easy to assemble as possible, so that the player and assistant can work quickly and effectively. However, due to the nature of our design there is some extensive assembly necessary before the player enters the area of play. The frame is assembled using 4-hole straight flat plates lined with the t-nuts and bolts. The nuts slide into the slots and are tightened with the bolts to ensure the frame pieces stay in place. Inside corner brackets slide into each corner to maintain the integrity of the frame's structure. Casters are screwed to the bottom of the front support using L brackets. Each component can be loosened and adjusted by loosening and tightening bolts. Each ramp section is connected using metal clasps. A list of detailed instructions that describe how to assemble the entire ramp and frame design will be sent to our sponsors along with the final product.

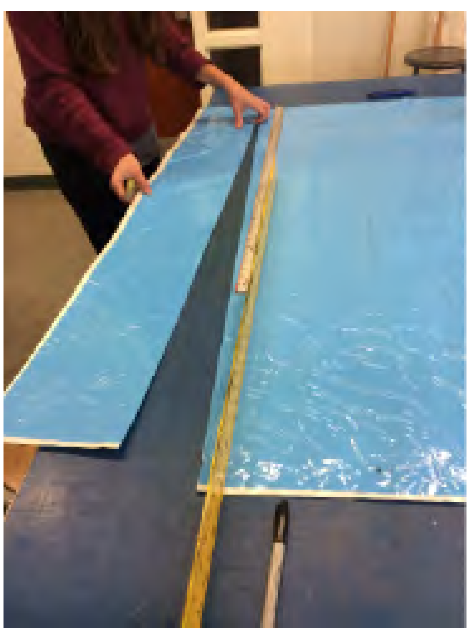
The product has been designed to ensure easy maintenance and repair of the product. The pieces of the ramp will be made from fiberglass, which is a relatively sturdy and inexpensive material. The top three pieces will be interchangeable, in order to replace each part. The locking mechanisms are made from aluminum metal and can easily be machined, which will make it easy to replace as well. All of the screws throughout the product have been chosen for ease of replacement, and will be a nominal size. Furthermore, the T-slot bars and fixtures are pre-made in the United States, and can easily be replaced. According to the rules of Boccia, if a ramp is broken during play, the team has exactly ten minutes to fix this before forfeiting the match. To keep the repair time on the plastic parts low, the team will be recommending an adhesive that will cure quickly, and hold until the end of the match, at which point the broken piece can be fully replaced, or fixed.

Product Realization:
Manufacturing Processes

Fiberglass Ramp Components

Each section of the ramp was made using layers of prepreg fiberglass wrapped around high density polyurethane foam molds. The dimensions of the molds can be found in Appendix I, pages, 66-68. The molds for the three straight ramp sections and the joints that the halves of each section together were cut from the foam and shaped by hand using sand paper. The mold for the curved section of the ramp was made from the same foam, but cut and shaped using a vertical band saw, a belt sander, and by hand with sand paper. Each mold was smoothed using increasingly fine sand paper from 240 grit to 1200 grit. This was done to ensure that the final interior surfaces of the ramp and ramp joints were smooth. The mold for the joints that hold the ramp sections together was made using the same mold shape as the straight ramp sections, but with a 1" inner diameter PVC pipe cut in half and laid along the top. The outer diameter of the pipe is about 1.3", creating a mold negative with that diameter curve.

The fiberglass sections were prepared in Cal Poly's Composites Lab with the assistance of Dr. Elghandour and Joshua DiMaggio. Each the straight and curved ramp sections use 8 layers of prepreg fiberglass with a cross section of 7" x 28", which were laid out carefully prior to wrapping the around the molds. The joints holding the ramp sections together were made of 8 layers of 9" x 28" fiberglass. Each layer was laid down on top of the previous layer before being smoothed out using a plastic tool.



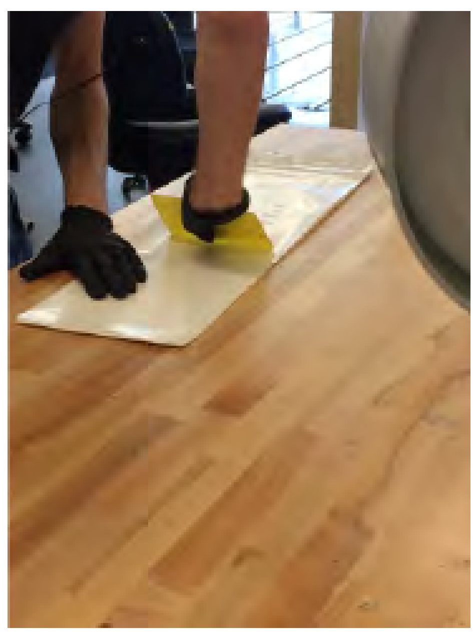


Figure 17. Fiberglass strips being layered together before wrapping around mold

Once the strips were laid together, the molds were prepared for curing by wrapping them in a specialized plastic that keeps the fiberglass from becoming stuck to the mold during the cure process. After this step, the prepared fiberglass sections were bent around each mold by hand and covered with the same specialized plastic. The fiberglass sheet used for the curved section of the ramp had to be cut in several places so that it could be wrapped around the curve.

Figure 18. Wrapping of the fiberglass around the molds

The next step was to prepare the oven for the cure process, by lining the perimeter of the steel gantries that parts are placed on with gum tape. This creates an airtight seal between the vacuum bag and the gantries when the bags are placed around the parts. The completed molds were then placed on the gantries and the vacuum bags placed around them. To prevent the vacuum bags from being over stressed during the cure cycle, "rabbit ear" sections were created along the gum tape/vacuum bag seals, spaced between each part. Then holes were cut in the vacuum bag so that the fixtures that connect to the vacuum pump hoses could be fitted.

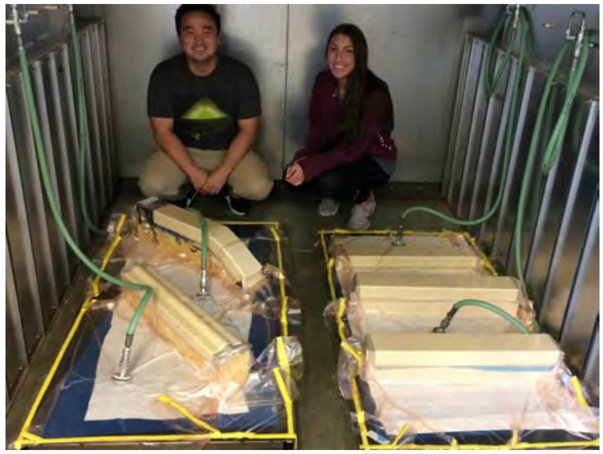


Figure 19. Completed cure setup for fiberglass molds

Once the setup was complete, the oven was programmed to complete the fiberglass' specific cure cycle, characterized by heating at 250°F for 2 hours, with the pumps holding the hose pressure at 30 psi. The fiberglass was allowed to cool for 12 hours to ensure a complete cure process, after which the ramp sections were removed from the molds.

Each ramp section was then cut using a tablesaw in the Mustang 60 Machine Shop, and deburred using a file and sandpaper. The L shaped ramp sections were cut so that when they were fitted to the joints, the space between the rails would be 1.3". The joints were cut from the single long piece of fiberglass cured with the PVC pipe placed on the mold. The joints were then glued to each ramp section using structural adhesive provided by Dr. Elghandour. Each new L shaped ramp section was aligned with its twin on its original mold, and then the individual sections were aligned with each other. This required the molds to be lined up with each other, and the ramp sections bridged across the molds, aligned with each other. Then the ramp joints were glued onto the ramp sections in the appropriate spots, and clamped together on the mold using wood clamps and C clamps. This setup was allowed to cure for 24 hours before the latches were attached with the structural adhesive. The latches were aligned and left latched open so that when they were latched closed they would hold the ramp sections together. This new setup was then allowed to cure for another 24 hours.

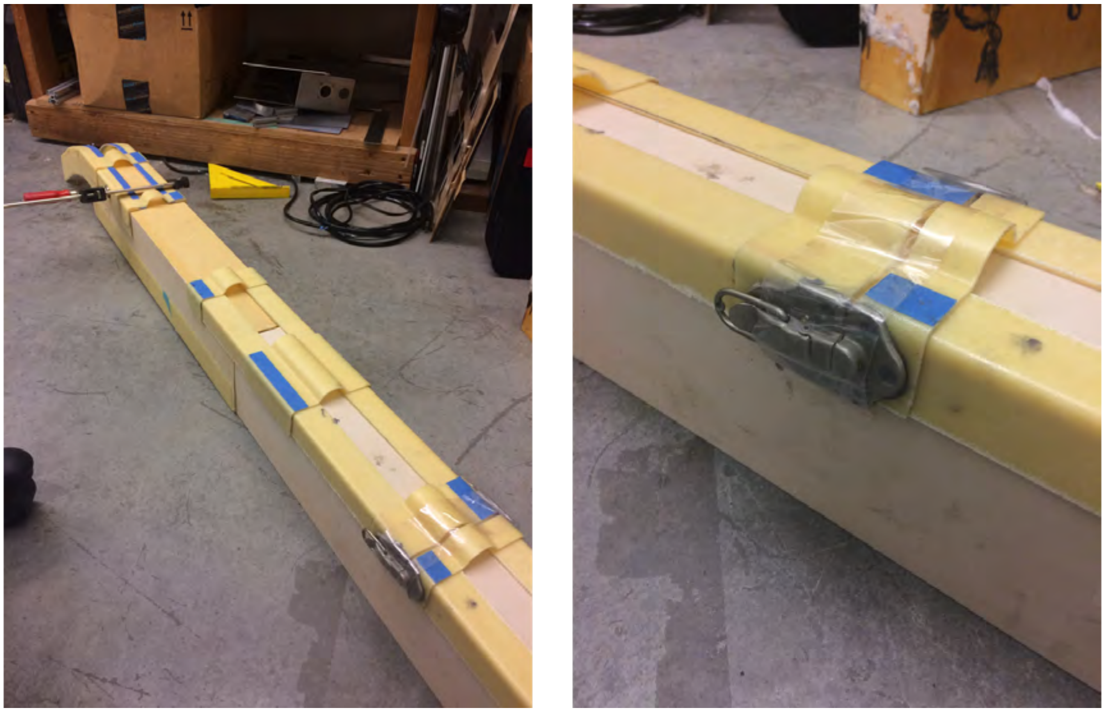


Figure 20. Ramp joint and latch gluing setup

Aluminum Frame

The functioning prototype of the frame was originally made out of PVC pipe, but it was decided to move forward with aluminum T-slotted extrusions from 80/20 Inc. for the final construction. The main body of the frame is a rectangle made from the extrusions, which connect to each other with brackets and gussets that slide on and off by use of the slots. Rather than use two single bars for the two long sections of the frame, each long section was made of three smaller extrusions. This design is less strong and less stable, but allows for the frame to be broken down to a packable size. The connection between the floor and the ground is made using a single extrusion, two plate braces and two casters mounted to the bottom of the extrusion. The casters allow the frame to rotate with the motion of the player's wheelchair. The ramp is connected to the frame using a long extrusion connected to a custom ramp holder also made from 80/20 extrusions. Drawings of the ramp holder can be found in Appendix I. The extrusion that holds the ramp up is attached to the frame using a linear bearing with a brake, so that the height of the ramp can be adjusted by players. Additionally, the ramp holder has a pivot attached to it so that the angle of the ramp adjusts itself when the height is changed.

The custom ramp connector was made from 2 types of aluminum extrusion. The base of the connector was made from 7" of double wide 1" 80/20 extrusion, and the bars that hold the ramp in place were made from 1" 80/20. The connector base was milled and filed so that the cross section of the ramp joint can rest within the base. The bars were modified using a mill to create threaded holes that screws could be inserted into, to hold the bars to the base and to hold the ramp in place.

Figure 21. Aluminum T-slots.

Figure 22. Complete assembled frame in Solidworks.

The clamps are also made using the T-slotted extrusions, joined by hinges and joints acquired from 80/20. A 27 inch extrusion lays parallel to the short side of the frame and has an adjustable distance from the front of the frame. The 8 inch T-slot extrusions can be adjusted in two dimensions (length and width) with respect to the 27-inch extrusion. Dynamic hinges attached to the short extrusions allow the plates to freely rotate and adjust to any chair angle when tightening the clamps. The plan for clamp manufacturing can be seen in Figure 22.

The everywhere pocket was printed out of PLA using the 3D printers in the Innovation Sandbox, and is press fit into the ramp section. It can be moved, although not without effort.

Figure 23. Complete final model.

Final Design vs. Prototype

There were many changes made to our prototype in order to transform our design into a final product. Our original design featured a frame with telescoping arms, so the ramp could be moved closer or farther away from the player. We envisioned these arms as round tubes that fit inside each other, and could be adjusted by sliding a tube in or out and fixing it in place with a pin. We used PVC pipe for our prototype, with multiple evenly spaced holes for pin placement, shown in Figure 24. For final manufacturing, we decided to use aluminum t-slots for the frame. The t-slots were more expensive than the PVC pipe, but also lighter, sturdier, easy to assemble, and more aesthetic. Furthermore, if a part is broken or missing, it can easily be replaced by ordering it through the 80/20 website. The final frame design can be seen in Figure 25. We also altered the design of our front support. The original support had a flat acrylic piece at the bottom to allow the frame to slide easily along the ground as it is rotated. Instead, we placed castors on the bottom of the support to allow the ramp to roll with wheelchair rotation.

Figure 24: Prototype design with a PVC pipe frame.

Figure 25: Model of final design, with a frame made of 80/20 aluminum t-slots.

Our original clamp design was complicated, shown in Figure 26, and we had not yet decided on the best way to manufacture them. The clamps featured plates made out of aluminum or acrylic that would attach to the back bar of the frame, and could adjust to the width of a wheelchair using a long screw. Instead, we placed the clamps on the bar that slides across the arms of the frame, and replaced the telescoping arms. The new were also made out of 80/20 materials so that they can easily be adjusted and assembled to the frame. The aluminum plates used for the clamps can slide to adjust for both the width and depth of the wheelchair backrest.

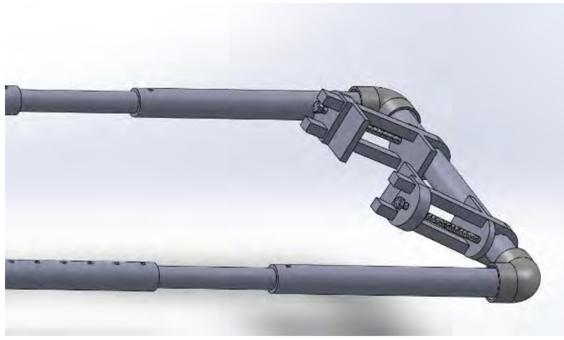


Figure 26. Model of original clamp design.

The final ramp was made out of fiberglass as we planned, but instead of using the slot design we attached each ramp section to the other with metal clips. The slots proved too difficult to manufacture using composites, and the clips prevent the ramp sections from being loose in any direction. We also intended to originally design a new pointer for the players as well, but due to time constraints we recommend that players use current pointers on the market.

Future Recommendations

We were happy with how our final design turned out, although given more time we would like to work out the kinks in our final product. The 80/20 aluminum t-slots work well for our design, but there could be alternative frame designs that would require less assembly time. We recommend researching possible ways to design a frame from fiberglass or another composite material. A composite frame would eliminate the need screw in nuts and bolts, and would result in a lighter frame. We also recommend manufacturing each straight section of the ramp with the curved bump down the center, rather than just one. This will allow for only three ramp sections to be made instead of six, reducing time and cost. For more support and ease of rotation, we also recommend using three castors on the bottom of the front support that are more spread out. Using more castors would steady the ramp, and increasing the distance of each from the other would prevent interference, allowing for a smoother rotation.

Design Verification: Testing

We performed many tests to verify the multiple functions of our design, all of which can be seen in the Design Verification Plan and Results (DVP&R) in Appendix H. Cal Poly student Evan Lalanne graciously volunteered to test our design with his wheelchair, seen in Figure 27. With Evan, we tested the clamps, pitch function of the ramp, adjustability of the frame, and the ability of the ramp to rotate with the chair. The clamps were able to adjust to fit the width and depth of Evan's wheelchair, and could be tightened enough to remain on the wheelchair as the entire fixture rotated. Therefore, we determined our clamps passed. The frame also passed, because the sliding bar across the arms allowed Evan to adjust his distance from the ramp, and stayed in place with the help of t-slot bolts. Although the ramp's front support was slightly less stable than we would like, due to the castors, it effectively rotated with the wheelchair's rotation and passed. Furthermore, the ramp could easily change its pitch as the height of the ramp was adjusted, and the pitch never caused the ramp to rotate far enough back to hit Evan in the head. Therefore, the ramp's pitch function passed.

Figure 27. Cal Poly student Evan Lalanne testing our final product.

We also performed tests to verify the accuracy and distance of the balls that our ramp produced. First, we practiced releasing the ball using the "everywhere pocket". The pocket can easily be removed a replaced anywhere on the ramp, allowing the ball to be released from any point. However, at steeper angles the ball does not stay in the everywhere pocket before it is released, and failed the test of being released from any angle. We then tested for distance the ball can travel, and speed the ball travels with. We made sure to perform these tests with both the hard and soft boccia balls. Both balls prove to travel farther than 4.9 feet, and could roll up to 50 feet, confirming that our distance test passed. Next, we tested the power and speed that the balls rolled with at shallow and steep angles. We released the balls from a two different angles, aimed at a cluster of boccia balls about 10 feet away, seen in Figure 28. In all cases, the balls broke the cluster, confirming that our ramp provided them with enough power and speed to effectively play the game. Photos of this test are shown in Figures 29 and 30.

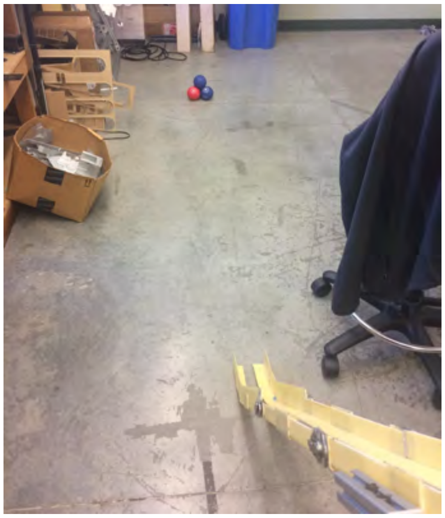


Figure 28. Setup for testing the power and speed of the boccia balls rolled down our ramp.

Figure 29. Ball cluster before the test.

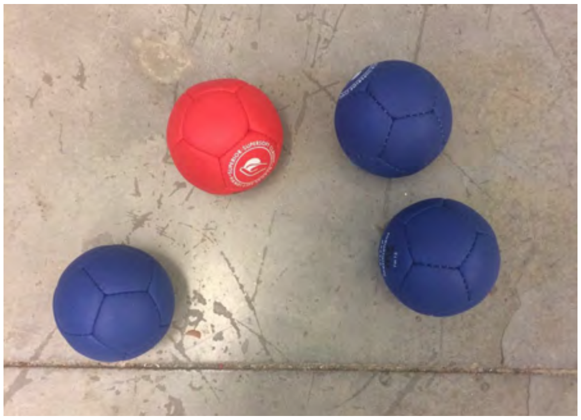


Figure 30. Ball cluster after the test.

Conclusion

After many design iterations, Team Ramp It Up completed senior design project with a final design that fit the design requirements of the sponsor as best as possible. We created a ramp mechanism that allows players with quadriplegia to accurately aim and release balls with the proper distance, speed, and power. Our design grants the players some autonomy by allowing the player to rotate the ramp with their wheelchair, due to a frame design that attaches the two together. We quantitatively and qualitatively analyzed our final design and its components to verify its functions, and produced a lightweight, durable, adjustable design that also complies with USA Boccia BISFed rules. Given more time we would have liked to perfect our design and perform more testing. However, we hope that our design will serve as a solid basis for future ramp designs like it, and will help boccia players with quadriplegia have a better playing experience. We have had a wonderful time working for USA Boccia, and thank them for their input and support.

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Appendices

A. **Nomenclature**
B. **Gantt Chart**
C. **QFD: House of Quality**
D. **Pugh Matrices**
Note: Due to the amount of information in each of these spreadsheets, the resolution was reduced in order to keep the formatting of the document. An Excel Documents with each matrix is available at request, and can also be found in the "Sponsor Documents" folder in the CP Boccia Senior Project Google Drive
D.1. Base
D.2. Ramp
D.3.Holding Ball in Place
D.4. Pointer
E. **Prototype Cost Analysis**
F. **Final Design Cost Analysis**
G. **Hand Calculations**
H. **Failure Mode Effects Analysis**
I. **DVPR (Design Verification Plan and Results)**
J. **Final Design Drawings**

Appendix A: Nomenclature

Most of the nomenclature in this section is from the BISFed International Boccia Rules – 2017 (v.2), along with some interpretation from the project team. If you are interested in looking into further rules or definitions, please visit https://usaboccia.org/official-rules/.

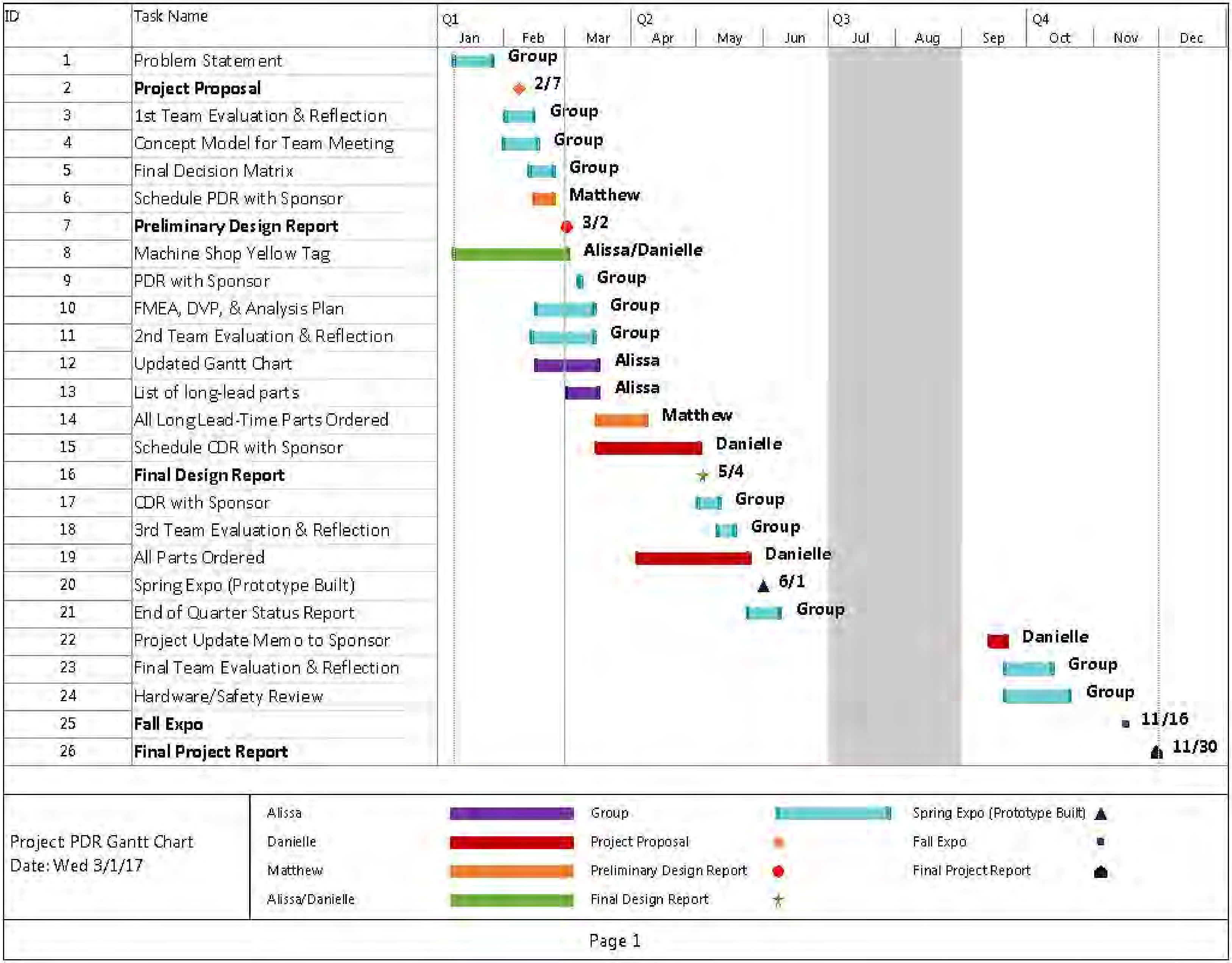
Jack: "The white target ball" used at the beginning of the match. Players will attempt to get their ball as close to the Jack as possible.

Match: "A competition between two sides."

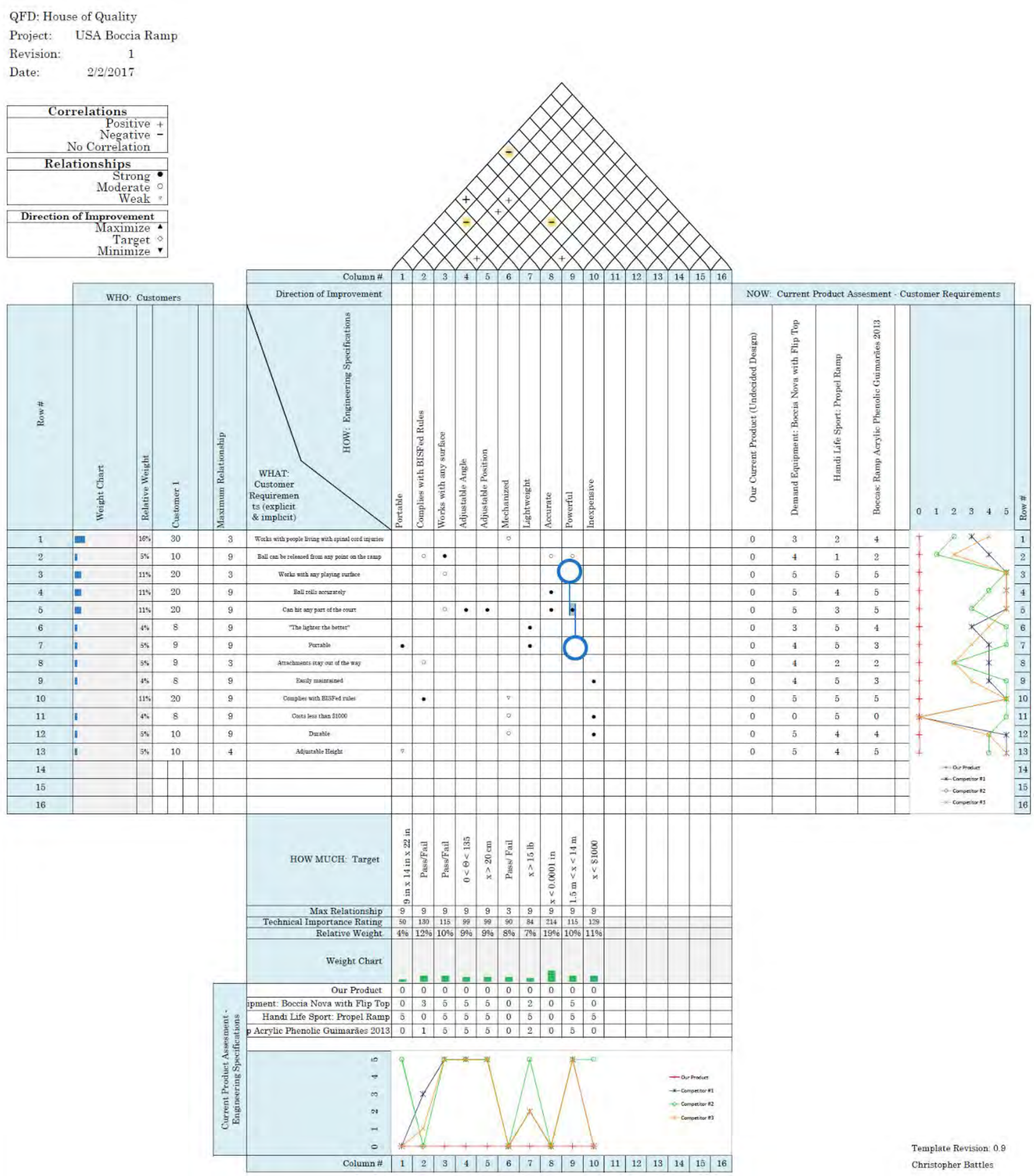
End: "One section of a match when all balls have been played by two Sides."

Sport Assistant: "An individual who assists athletes in accordance with the Sports Assistant Rules." In this case, they will generally be the person assembling, and maintaining the ramp.

<u>Appendix B: Gantt Chart</u>


ID
Task Name
Q1
Jan
Feb
Mar
Q2
Apr
May
Jun
Q3
Jul
Aug
Sep
Q4
Oct
Nov
Dec
1
Problem Statement
Group
2
Project Proposal
2/7
3
1st Team Evaluation & Reflection
Group
4
Concept Model for Team Meeting
Group
5
Final Decision Matrix
Group
6
Schedule PDR with Sponsor
Matthew
7
Preliminary Design Report
3/2
8
Machine Shop Yellow Tag
Alissa/Danielle
9
PDR with Sponsor
Group
10
FMEA, DVP, & Analysis Plan
Group
11
2nd Team Evaluation & Reflection
Group
12
Updated Gantt Chart
Alissa
13
List of long-lead parts
Alissa
14
All Long Lead-Time Parts Ordered
Matthew
15
Schedule CDR with Sponsor
Danielle
16
Final Design Report
5/4
17
CDR with Sponsor
Group
18
3rd Team Evaluation & Reflection
Group
19
All Parts Ordered
Danielle
20
Spring Expo (Prototype Built)
6/1
21
End of Quarter Status Report
Group
22
Project Update Memo to Sponsor
Danielle
23
Final Team Evaluation & Reflection
Group
24
Hardware/Safety Review
Group
25
Fall Expo
11/16
26
Final Project Report
11/30
Project PDR Gantt Chart
Date: Wed 3/1/17
Alissa
Danielle
Matthew
Alissa/Danielle
Group
Project Proposal
Preliminary Design Report
Final Design Report
Spring Expo (Prototype Built)
Fall Expo
Final Project Report
Page 1

Appendix C. QFD: House of Quality



QFD: House of Quality
Project: USA Boccia Ramp
Revision: 1
Date: 2/2/2017

Correlations	
Positive	+
Negative	−
No Correlation	

Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼

Row #	Relative Weight	Customer 1	Maximum Relationship	WHAT: Customer Requirements (explicit & implicit) / HOW: Engineering Specifications	1 Portable	2 Complies with BISFed Rules	3 Works with any surface	4 Adjustable Angle	5 Adjustable Position	6 Mechanized	7 Lightweight	8 Accurate	9 Powerful	10 Inexpensive	11	12	13	14	15	16	Our Current Product (Undecided Design)	Demand Equipment: Boccia Nova with Flip Top	Handi Life Sport: Propel Ramp	Boccas: Ramp Acrylic Phenolic Guimarães 2013	Row #
1	16%	30	3	Works with people living with spinal cord injuries						○											0	3	2	4	1
2	5%	10	9	Ball can be released from any point on the ramp		○	●					○	○								0	4	1	2	2
3	11%	20	3	Works with any playing surface			○														0	5	5	5	3
4	11%	20	9	Ball rolls accurately								●									0	5	4	5	4
5	11%	20	9	Can hit any part of the court			○	●	●			●	●								0	5	3	5	5
6	4%	8	9	"The lighter the better"							●										0	3	5	4	6
7	5%	9	9	Portable	●						●										0	4	5	3	7
8	5%	9	3	Attachments stay out of the way		○															0	4	2	2	8
9	4%	8	9	Easily maintained										●							0	4	5	3	9
10	11%	20	9	Complies with BISFed rules		●				▽											0	5	5	5	10
11	4%	8	9	Costs less than $1000						○				●							0	0	5	0	11
12	5%	10	9	Durable						○				●							0	5	4	4	12
13	5%	10	4	Adjustable Height	▽																0	5	4	5	13
14																									14
15																									15
16																									16

Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
HOW MUCH: Target	9 in x 14 in x 22 in	Pass/Fail	Pass/Fail	0 < Θ < 135	x > 20 cm	Pass/ Fail	x > 15 lb	x < 0.0001 in	1.5 m < x < 14 m	x < $1000						
Max Relationship	9	9	9	9	9	3	9	9	9	9						
Technical Importance Rating	50	130	115	99	99	90	84	214	115	129						
Relative Weight	4%	12%	10%	9%	9%	8%	7%	19%	10%	11%						
Our Product	0	0	0	0	0	0	0	0	0	0						
ipment: Boccia Nova with Flip Top	0	3	5	5	5	0	2	0	5	0						
Handi Life Sport: Propel Ramp	5	0	5	5	5	0	5	0	5	5						
p Acrylic Phenolic Guimarães 2013	0	1	5	5	5	0	2	0	5	0						

Current Product Assesment - Engineering Specifications

NOW: Current Product Assesment - Customer Requirements

Template Revision: 0.9
Christopher Battles

Appendix D: Pugh Matrices

D.1. Base Matrix

	Criteria \ Concept	Weight	Single Bar with High Friction Surface at the Bottom	Slotted base (Back and Forth/Rotating)	Slotted Base (Side to Side/Rotating)	Two Bars with Wheels at the Bottom	Single Bar with Wheel at Bottom	Cylindrical Base with Rods Attached	Tripod Style with Wheels at Bottom	Attached to Wheelchair
			Base							
1	Portable	4		-	-	+	S	-	+	+
2	Complies with BISFed Rules	7		S	S	S	S	S	S	S
3	Works with any playing surface	7		S	S	S	S	S	S	S
4	Adjustable Forward Angle	7		S	S	S	S	S	S	S
5	Adjustable Court Position	7		-	S	+	+	+	+	+
6	Adjustable Upward and Downward Angle	7		N/A	N/A	N/A	N/A	N/A	N/A	N/A
7	Mechanized	2		S	S	S	S	S	S	+
8	Lightweight	4		-	-	S	S	-	S	+
9	Accurate	7		S	S	S	S	S	S	+
10	Powerful	6		N/A	N/A	N/A	N/A	N/A	N/A	N/A
11	Consistent	4		+	+	+	+	+	+	+
12	Inexpensive	5		-	-	S	S	-	S	-
13	Durable	4		-	-	+	+	-	-	-
14	Works with High level injuries	7		S	S	S	S	S	S	+
15	Interchangeable parts	5		-	-	-	-	-	-	-
16	Released from any point	6		N/A	N/A	N/A	N/A	N/A	N/A	N/A
17	Manufacturability	6		-	-	-	-	-	-	-
18	Autonomy of Player	5		S	S	S	S	S	S	+
	Σ	100								
				Normalized	Normalized	Normalized	Normalized	Normalized	Normalized	Normalized
	Σ+			1	1	4	3	2	3	8
	Σ-			7	6	2	2	6	3	4
	ΣS			7	8	9	10	7	9	3
	Total Score			-6	-5	2	1	-4	0	4
				Weighted	Weighted	Weighted	Weighted	Weighted	Weighted	Weighted
	Σ+			4	4	19	15	11	15	40
	Σ-			35	28	11	11	28	15	20
	ΣS			42	49	51	55	42	51	21
	Total Score			-31	-24	8	4	-17	0	20

D.2. Ramp Matrix

	Criteria \ Concept	Weight	Ramp		
			Clear Material on the Bottom	Rails on the side	Two side pieces with minimal material in the middle
1	Portable	4		+	+
2	Complies with BISFed Rules	7		S	S
3	Works with any playing surface	7		S	S
4	Adjustable Forward Angle	7		S	S
5	Adjustable Court	7		S	S
6	Adjustable Upward and Downward Angle	7		S	S
7	Mechanized	2			
8	Lightweight	4		+	+
9	Accurate	7		-	+
10	Powerful	6		+	+
11	Consistent	4		+	+
12	Inexpensive	5		+	-
13	Durable	4		-	S
14	Works with High level injuries	7		+	+
15	Interchangeable parts	5		S	S
16	Released from any point	6		+	+
17	Manufacturability	6		+	-
18	Autonomy of Player	5		-	+
	Σ	100			
				Normalized	Normalized
	Σ+			8	8
	Σ-			3	2
	ΣS			6	7
	Total Score			5	6
				Weighted	Weighted
	Σ+			42	43
	Σ-			16	11
	ΣS			40	44
	Total Score			26	32

D.3. Ball Release Matrix

	Criteria \ Concept	Weight	Ball Release: Sports Assistant	Rubber Bands	Pointer Attachment Release	"Everywhere Pocket"	Slingshot Ball Release	Stationary Pocket
1	Portable	4		-	-	-	-	-
2	Complies with BISFed Rules	7		S	S	S	S	S
3	Works with any playing surface	7		N/A	N/A	N/A	N/A	N/A
4	Adjustable Forward Angle	7		N/A	N/A	N/A	N/A	N/A
5	Adjustable Court	7		N/A	N/A	N/A	N/A	N/A
6	Adjustable Upward and Downward Angle	7		S	S	S	S	-
7	Mechanized	2		N/A	N/A	N/A	N/A	N/A
8	Lightweight	4		N/A	N/A	N/A	N/A	N/A
9	Accurate	7		-	+	+	-	-
10	Powerful	6		N/A	N/A	N/A	N/A	N/A
11	Consistent	4		+	+	+	-	+
12	Inexpensive	5		-	-	-	-	-
13	Durable	4		-	S	S	-	S
14	Works with High level injuries	7		S	S	S	-	-
15	Interchangeable parts	5		N/A	N/A	N/A	N/A	N/A
16	Released from any point	6		S	S	S	-	-
17	Manufacturability	6		+	+	+	-	+
18	Autonomy of Player	5		+	+	+	+	+
	Σ	100						
				Normalized	Normalized	Normalized	Normalized	Normalized
	Σ+			3	4	4	1	3
	Σ-			4	2	2	8	6
	ΣS			4	5	5	2	2
	Total Score			-1	2	2	-7	-3
				Weighted	Weighted	Weighted	Weighted	Weighted
	Σ+			15	22	22	5	15
	Σ-			20	9	9	43	36
	ΣS			27	31	31	14	11
	Total Score			-5	13	13	-38	-21

D.4. Pointer Matrix

	Concept / Criteria	Weight	Pointer			
			Telescoping arm	Fully flexible arm	Flexible arm attached to rotating base	Flexible Arm attached to "stick" attached to rotating base
1	Portable	4		+	+	+
2	Complies with BISFed Rules	7		S	S	S
3	Works with any playing surface	7		N/A	N/A	N/A
4	Adjustable Forward Angle	7		N/A	N/A	N/A
5	Adjustable Court	7		N/A	N/A	N/A
6	Adjustable Upward and Downward Angle	7		+	+	+
7	Mechanized	2		N/A	N/A	N/A
8	Lightweight	4		+	+	+
9	Accurate	7		+	+	+
10	Powerful	6		N/A	N/A	N/A
11	Consistent	4		-	-	-
12	Inexpensive	5		+	-	-
13	Durable	4		+	+	+
14	Works with High level injuries	7		S	S	S
15	Interchangeable parts	5		N/A	N/A	N/A
16	Released from any point	6		+	+	+
17	Manufacturability	6		S	-	-
18	Autonomy of Player	5		+	+	+
	Σ	100				
				Normalized	Normalized	Normalized
	Σ+			8	7	7
	Σ-			1	3	3
	ΣS			3	2	2
	Total Score			7	4	4
				Weighted	Weighted	Weighted
	Σ+			42	37	37
	Σ-			4	15	15
	ΣS			20	14	14
	Total Score			38	22	22

Appendix E: Prototype Cost Analysis

Item	Amount	Price/Unit	Total Cost of Material	Purpose
HandyPanel	1	$9.92	$9.92	Plastic for base/Other Parts
CA Lumber Fee	1	$0.09	$0.09	Added on to price of wood
Lexan Sheet	1	$4.18	$4.18	Support the frame on the wheelchair
Cotter Pins	4	$0.70	$2.80	Assemble frame
Steel Downspout	1	$3.27	$3.27	Hold frame in place on wheelchair
1-1/4” X 2’ PVC Pipe	7	$2.74	$19.18	Create the frame
1/2” X 2’ PVC Pipe	1	$1.28	$1.28	Create the frame
1” X 2’ PVC Pipe	3	$2.13	$6.39	Create the frame
1-1/4” PVC Elbow	4	$1.28	$5.12	Assemble frame
1-1/4” PVC Coupling	2	$0.76	$1.52	Assemble frame
3/4“-1” X 4’ Telescoping PVC Pipe	1	$19.45	19.45	Support the frame on floor
Subtotal			$53.75	
Tax			$4.16	
Total Cost Winter Quarter 2017-Spring Quarter CDR (5/4/2017):			$57.91	

Appendix F: Final Design Cost Analysis

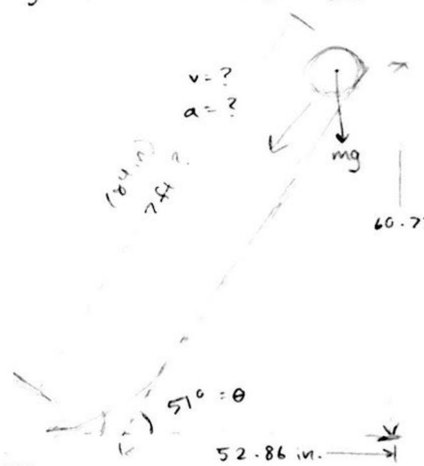
Item	Amount	Price/Unit	Total Cost of Material	Purpose
Metal clasps	5 sets	3.5	17.5	Connecting each ramp section
4 open T-slot 22"	2	5.37	10.74	Frame
4 Hole Tall Gusseted Inside Corner Bracket	4	5.65	22.6	Frame corners
1/4-20 x .500" Slide-In Economy T-Nut	69	0.4	27.6	Frame assembly
1"x 2" 6 open T-slot 7"	1	4.68	4.68	Frame hinge
10 Series Standard T-slot Cover	2	3.45	6.9	Covering extra slots in frame
10 Series End Cap	6	1.05	6.3	Covering ends of T-slots
10 Series 5 Hole - "L" Flat Plate	4	6.55	26.2	Frame
1" x 1" 4 open T-slot 27"	1	8.16	8.16	Frame
1" x 1" 4 open T-slot 8"	2	3.79	7.58	Frame
1" x 1" 4 open T-slot 18"	1	6.09	6.09	Frame
1" x 1" 4 open T-slot 25"	2	7.7	15.4	Frame
1" x 1" 4 open T-slot 18"	4	6.09	24.36	Frame
1" x 1" 4 open T-slot 10"	1	4.25	4.25	Frame
1" x 1" 4 open T-slot 14"	3	5.17	15.51	Frame
10 Series 3 Hole - Slotted Inside Corner Bracket	4	4.5	18	Castor attachment
1/4-20 x .500" Slide-In Economy T-Nut	8	0.37	2.96	Clamp assembly
1/4-20 x .750" Socket Head Cap Screw	1	0.21	0.21	Frame assembly
90 Degree Dynamic Pivot Assembly	2	18.15	36.3	Clamp rotation
5 Hole - Tee Flat Plate	2	6.8	13.6	Front support attachment
"L" Handle Linear Bearing Brake Kit	1	9.55	9.55	Front support adjustment

2 Hole Gusseted Inside Corner Bracket	6	3.95	23.7	Clamps
7 Hole - Tee Flat Plate	2	8.15	16.3	Front support attachment
6 Hole - Tee Flat Plate	1	7.3	7.3	Frame
2 Hole Pivot Joint	1	17.75	17.75	Ramp to frame attachment
Single Mount Unibearing Assembly	1	34.15	34.15	Front support adjustment
4 Hole Straight Flat Plate	8	4.8	38.4	Frame assembly
Subtotal			422.09	
Tax			36.63	
Shipping and Handling (may vary)			95.13	
TOTAL			553.85	

Appendix G: Hand Calculations

SP ANALYSIS

Velocity & Acceleration of Ball



(Heaviest)
Weight of ball = 287 g
= 0.633 lb

Composite $\mu \approx 0.65$
(Science Direct)
$\rho \approx 0.055$ lb/in³
(Fiberglass)

60.77 in = 1.54 m
- Max height of ramp

Volume of ramp = 272.52 in³
(approximation based on Solidworks model)

Court extends 10 m

$\rho = \frac{m}{V}$

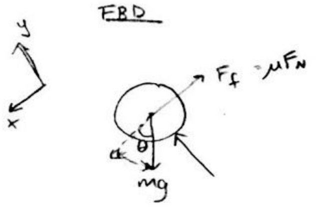
$m = \rho V$

$= (.055 \frac{lb}{in^3})(272.52\ in^3)$

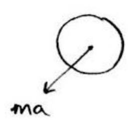
$m = 14.98$ lb

$= 6.8$ kg

FBD



MAD



$\Sigma F_y = 0: \quad F_N = mg \sin\theta$

$= (.287\ kg)(9.81\ m/s^2)\sin(51)$

$F_N = 2.2\ N$

$\Sigma F_x = ma: \quad mg\cos\theta - F_f = ma$

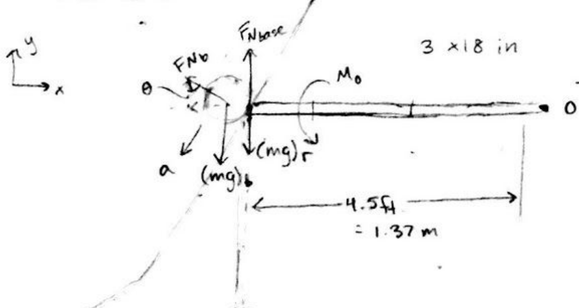
$(.287\ kg)(9.81\ m/s^2)\cos(51) - 0.65(2.2N) = .287a$

$a = \frac{0.34}{0.287} = \boxed{1.2\ m/s^2}$

$F_{Nr} = m_r g \sin\theta$

$= 8.15\ kg(9.81)\sin 51$

$= 62.13\ N$



$\Sigma M_o = 0:$

$(m_b + m_r)g(1.37m) - F_{Nb}\cos\theta(1.37m)$

$- F_{N\,base}(1.37m) + M_o = 0$

$\rightarrow (.287 + 6.8)(9.81)(1.37) - (2.2)\cos 51(1.37)$

$-(66.7)(1.37) + M_o = 0$

$95.25 - 1.89 - 91.38 + M_o = 0$

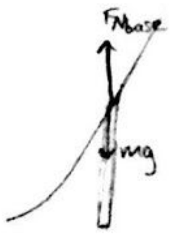
$\boxed{M_o = 1.98\ Nm}$

$= 1.46$ lbft

Appendix G (cont.)

Ramp Analysis

FBD



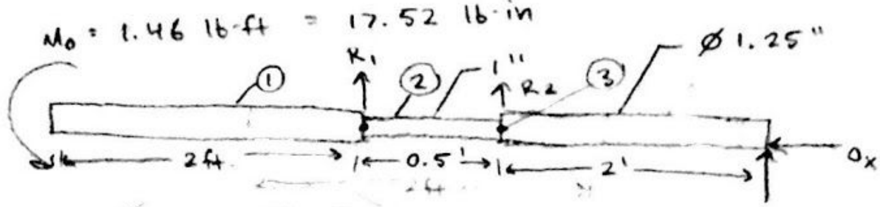
$\Sigma F_y = 0 \quad F_{Nbase} = mg$

$= (6.8\ kg)(9.81\ m/s^2)$

$F_{Nbase} = 66.71\ N$

FACTOR OF SAFETY

$M_o = 1.46\ lb\cdot ft = 17.52\ lb\cdot in$



Hollow PVC

Flexural Yield Strength: 12,800 psi

$\rho = 1.42\ \frac{g}{cm^3}$

$= .051\ lb/in^3$

$\sigma = \frac{Mc}{I} \quad I = \frac{\pi}{64} d^4 \quad c = r \quad \sigma = \frac{S_y}{n}$

$m_{1,3} = \rho V_{1,3} = \rho \pi (.625^2 - .5^2) 24'' = 0.54\ lb$

$m_2 = \rho V_2 = \rho \pi (.5^2 - .375^2) = 0.105\ lb$

$I_{1,3} = \frac{\pi}{64}(1.25 - 1)^4 = 1.92 \times 10^{-4}\ in^4$

$I_2 = \frac{\pi}{64}(1 - .75)^4 = 1.92 \times 10^{-4}\ in^4$

$\sigma_1 = \frac{Mc}{I} = \frac{17.52\ lb\text{-}in\ (0.625\ in)}{1.92 \times 10^{-4}\ in^4} = 5.7 \times 10^4\ psi$

$\sigma_2 = \frac{Mc}{I} = \frac{9.73\ (0.5)}{1.92 \times 10^{-4}\ in^4} = 2.53 \times 10^4\ psi$

$\sigma = 5.7 \times 10^4\ psi - 2.53 \times 10^4 - 2.53 \times 10^4 = 6400\ psi$

$\sigma = \frac{S_y}{n}$

Assume $R_1 = R_2 = R$

$\Sigma M_o = 0$

$17.52\ lb\text{-}in - R(30'') - R(24'') = 0$

$R = 0.324\ lb.$

$M_2 = 9.73\ lb\text{-}in$

$M_3 = 7.78\ lb\text{-}in.$

$\sigma_3 = \frac{M_3 c}{I}$

$= \frac{7.78(0.625)}{1.92 \times 10^{-4}}$

$\sigma_3 = 2.53 \times 10^4\ psi$

Flexural $\rightarrow n = \frac{S_y}{\sigma} = \frac{12,800\ psi}{6400\ psi} = \boxed{2}$

Tensile $\rightarrow n = \frac{7500\ psi}{6400\ psi} = \boxed{1.2}$

Appendix H: Failure Mode Effects Analysis

Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s) / Mechanism(s) of Failure	Occurence	Criticality	Recommended Action(s)	Responsibility & Target Completion Date
Clamps attach to back of wheelchair	Clamps don't attach to back of wheelchair	Ramp falls off of the wheelchair	7	Clamps come loose	5	35	Make clamps adjustable and add support on ramp	Alissa Koukourikos 5/30/17
				Clamps break	3	21		
				Clamps don't fit	1	7		
				Sports assistant	4	28		
		Ramp is crooked	4	Clamps come loose	5	20	Make clamps adjustable and add support on ramp	Alissa Koukourikos 5/30/17
				Clamps break	3	12		
				Clamps don't fit	1	4		
				Sports assistant	4	16		
		Ramp mechanism breaks	8	Clamps come loose	5	40	Make clamps adjustable and add support on ramp	Alissa Koukourikos 5/30/17
				Clamps break	3	24		
				Clamps don't fit	1	8		
				Sports assistant	4	32		
		Injure player	9	Clamps come loose	5	45	Make clamps adjustable and add support on ramp	Alissa Koukourikos 5/30/17
				Clamps break	3	27		
				Clamps don't fit	1	9		
				Sports assistant	4	36		
		Damage wheelchair	6	Clamps come loose	5	30	Make clamps adjustable and add support on ramp	Alissa Koukourikos 5/30/17
				Clamps break	3	18		
				Clamps don't fit	1	6		
				Sports assistant	4	24		

Appendix H: Failure Mode Effects Analysis (cont.)

Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s) / Mechanism(s) of Failure	Occurence	Criticality	Recommended Action(s)	Responsibility & Target Completion Date
Extendable Arms	Arms get stuck/don't extend	Ramp will be too far/too close to player	8	Interference	6	48	Measure correct tolerances, design easy telescoping mechanism, protect in case	Danielle Purdy 5/4/17
				Impact	4	32		
				User interaction	5	40		
				Deformations on pole	3	24		
		Arms break	8	Interference	6	48	Measure correct tolerances, design easy telescoping mechanism, protect in case	Danielle Purdy 5/4/17
				Impact	4	32		
				User interaction	5	40		
				Deformations on pole	3	24		
		Injure player	9	Interference	6	54	Measure correct tolerances, design easy telescoping mechanism, protect in case	Danielle Purdy 5/4/17
				Impact	4	36		
				User interaction	5	45		
				Deformations on pole	3	27		
	Arms are too loose	Arms fall off	7	Incorrect tolerances	6	42	Make arms screw on to ensure their attachment to wheelchair	Danielle Purdy 5/4/17
				Impact	4	28		
				User interaction	5	35		
				Deformations on pole	3	21		
		Arms break	8	Incorrect tolerances	6	48	Make arms screw on to ensure their attachment to wheelchair	Danielle Purdy 5/4/17
				Impact	4	32		
				User interaction	5	40		
				Deformations on pole	3	24		
		Injure player	9	Incorrect tolerances	6	54	Make arms screw on to ensure their attachment to wheelchair	Danielle Purdy 5/4/17
				Impact	4	36		
				User interaction	5	45		
				Deformations on pole	3	27		
	Pinch points	Injure player/assistant	9	Moving parts	7	63	Design mechanism to easily extend arms without making contact with pinch points	Danielle Purdy 5/4/17
		Object prevents movement	4	Moving parts	7	28		

Appendix H: Failure Mode Effects Analysis (cont.)

Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s) / Mechanism(s) of Failure	Occurence	Criticality	Recommended Action(s)	Responsibility & Target Completion Date
Ramp Rotation	Ramp does not rotate	Cannot aim ramp	7	Incorrect tolerances	6	42	Low friction surface on base, measure correct tolerances	Matthew Lee 5/4/17
			7	Base of support gets stuck	7	49		
			7	Object prevents movement	3	21		
	Ramp rotation does not lock	Undesired rotation	4	Locking mechanism fails	5	20	Design set screw mechanism to lock ramp in place	Matthew Lee 5/4/17
		Injure player/others	9	Locking mechanism fails	5	45		
		Inaccurate aim	6	Locking mechanism fails	5	30		

Appendix H: Failure Mode Effects Analysis (cont.)

Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s) / Mechanism(s) of Failure	Occurence	Criticality	Recommended Action(s)	Responsibility & Target Completion Date
Ramp Pitch	Ramp does not rotate up/down	Ramp gets stuck	4	Interference	6	24	Measure correct tolerances, create composite hinge mechanism that does not allow room for foreign objects	Matthew Lee 5/4/17
			4	Object prevents movement	3	12		
			4	Deformations	3	12		
			4	Hinge failure	4	16		
		Inaccurate aim	6	Interference	4	24	Measure correct tolerances, create composite hinge mechanism that does not allow room for foreign objects	Matthew Lee 5/4/17
			6	Object prevents movement	6	36		
			6	Deformations	4	24		
			6	Hinge failure	5	30		
	Ramp rotates too far	Injures player	9	Incorrect tolerances	4	36	Measure correct tolerances, create composite hinge mechanism that does not allow room for foreign objects	Matthew Lee 5/4/17
			9	Locking mechanism fails	6	54		
		Inaccurate aim	6	Incorrect tolerances	3	18	Measure correct tolerances, create composite hinge mechanism that does not allow room for foreign objects	Matthew Lee 5/4/17
			6	Locking mechanism fails	5	30		
	Pinch Point	Injures player/others	9	Moving parts	8	72	Measure correct tolerances, create composite hinge mechanism that does not allow room for foreign objects	Matthew Lee 5/4/17
Ramp Base	Base fails	Ramp falls off of the wheelchair	7	Support is assembled incorrectly	7	49	Analyze loading while rolling ball down ramp, design sturdy, flat support	Alissa Koukourikos 5/4/17
			7	Incorrect support analysis	3	21		
		Injures player	9	Support is assembled incorrectly	7	63	Analyze loading while rolling ball down ramp, design sturdy, flat support	Alissa Koukourikos 5/4/17

			9	Incorrect support analysis	3	27		

Appendix H: Failure Mode Effects Analysis (cont.)

Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s) / Mechanism(s) of Failure	Occurence	Criticality	Recommended Action(s)	Responsibility & Target Completion Date
Detachable Ramp Pieces	Pieces unintentionally detach	Injure player	9	Incorrect tolerances	3	27	Use magnet/mechanism to hold pieces in place	Matthew Lee 5/4/17
		Ramp breaks	5	Incorrect tolerances	3	15		
	Potentially sharp corners	Injure player/assistant	9	Sharp corners	3	27	Incorporate rounded edges into design/Coat pieces to lessen sharp edges	Matthew Lee 5/4/17
	Pinch points	Injure player/assistant	9	Moving parts	8	72	Design so that assembly does not require contact with pinch points	Matthew Lee 5/4/17
Ramp Moves with Wheelchair	Ramp obstructs player's view	Injure player/others	9	Ramp is unable to detach from frame	6	54	Ensure with testing that the ramp does not obstruct the player's view/Include in instructions that the players should not move with the ramp attached to the assembly	Danielle Purdy 10/2/17
				Ramp obstructs view	4	36		
Everywhere Pocket	Does not slide up and down ramp	Inaccurate aim	6	Incorrect tolerances	8	48	Keep friction between ramp and pocket low	Alissa Koukourikos 5/4/17
				Too much friction	4	24		
	Pinch point	Injures player/assistant	9	Moving parts	6	54	Design so that assembly does not require contact with pinch points	Alissa Koukourikos 5/4/17
Head Pointer	Detaches from helmet	Injures player	9	Bad base connection	7	63	Keep edges rounded/Test weight of head pointer	Danielle Purdy 10/2/17
		Pointer breaks	6	Overuse/Misuse	7	42		
	Hits/pokes others	Injures assistant/others	9	Pointer too long	3	27	Ensure that the length of the pointer does not extend past the wheelchair	Danielle Purdy 5/4/17
				Pointer comes loose	7	63		

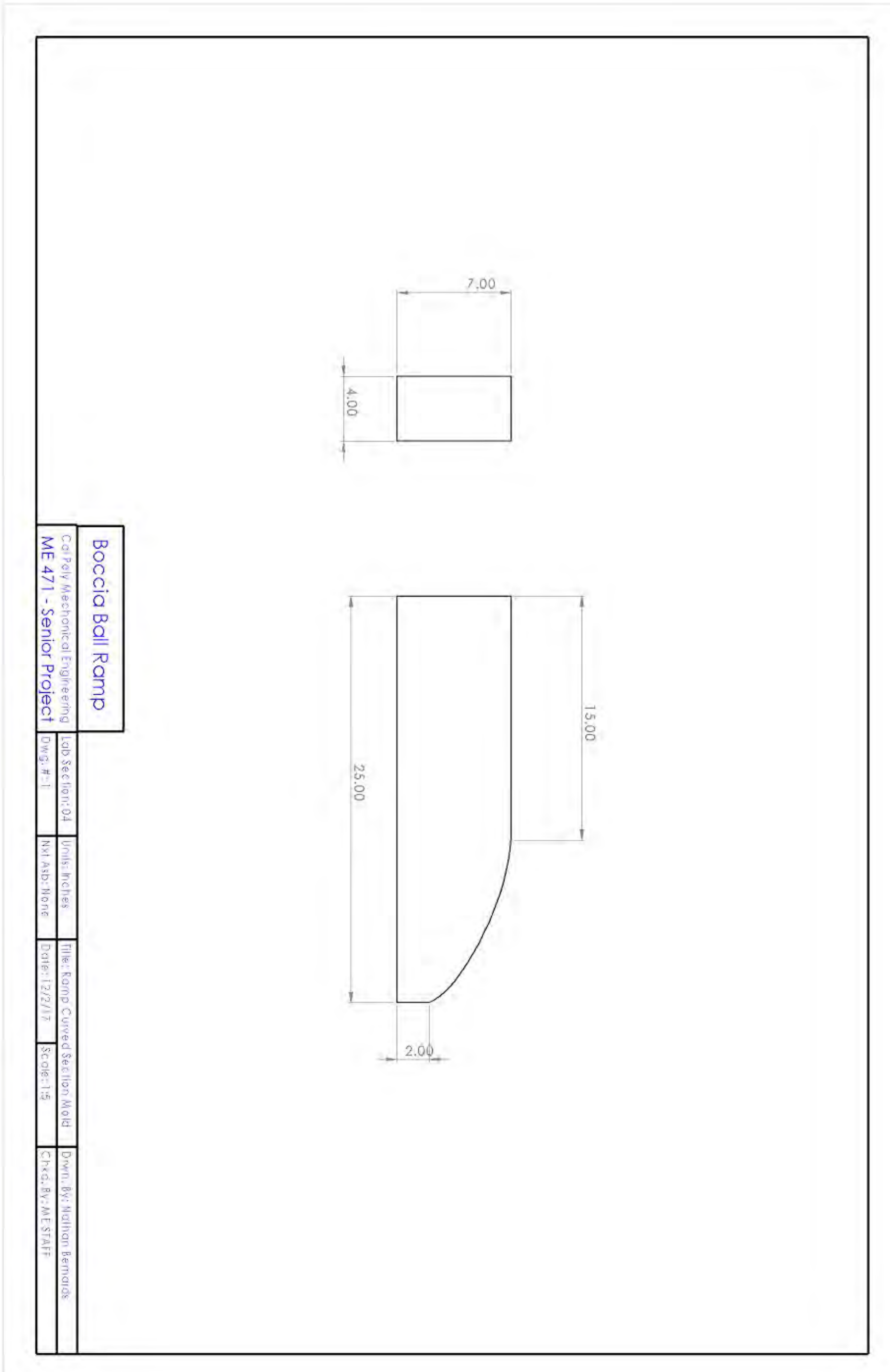
Appendix I: DVP&R (Design Verification Plan and Report)

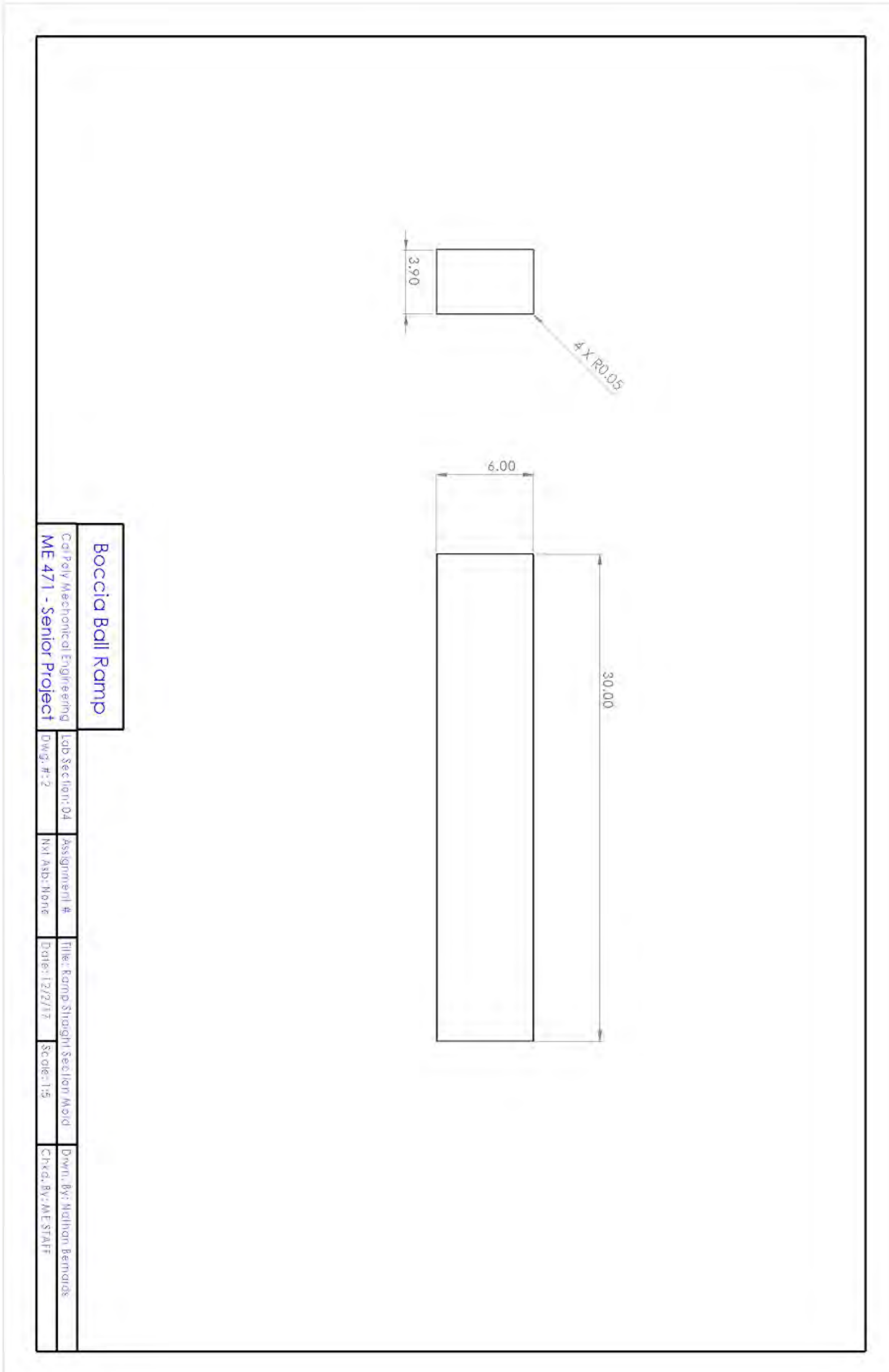
ME 429 DVP&R											
Report Date		12/3/17	Sponsor	USA Boccia					Boccia Ramp Assembly		
TEST PLAN									TEST REPORT		
						SAMPLE TESTED	TIMING		TEST RESULTS		
Item No	Specification or Clause Reference	Test Description	Acceptance Criteria	Test Responsibility	Test Stage	Quantity	Start date	Finish date	Test Result	Quantity Pass	Quantity Fail
1	Pitch angle of the ramp	Make sure the ramp can change angle, but does not hit the player in the head.	Ramp can change angle from 51 degrees to 66 degrees	Team	DV	1	5/15	11/14	Ramp does not hit player head	Pass	
2	Attachment to the wheelchair	Ensure the support is able to attach to a variety of different wheelchairs	Ramp support attaches to wheelchair, and can rotate with wheelchair	Team	DV	1	4/24	11/14	Frame effectively attaches to wheelchair, with a sturdy connection. Front support was a little unstable.	Pass	
4	Tolerance of support arms	Make sure arms slide appropriately	Pass/Fail (Arms are in tolerance/ Arms are not in tolerance)	Team	DV	1	4/24	11/13	Arms can be properly adjusted by sliding a bar along the arms. The arms themselves no longer need to slide in and out.	Pass	

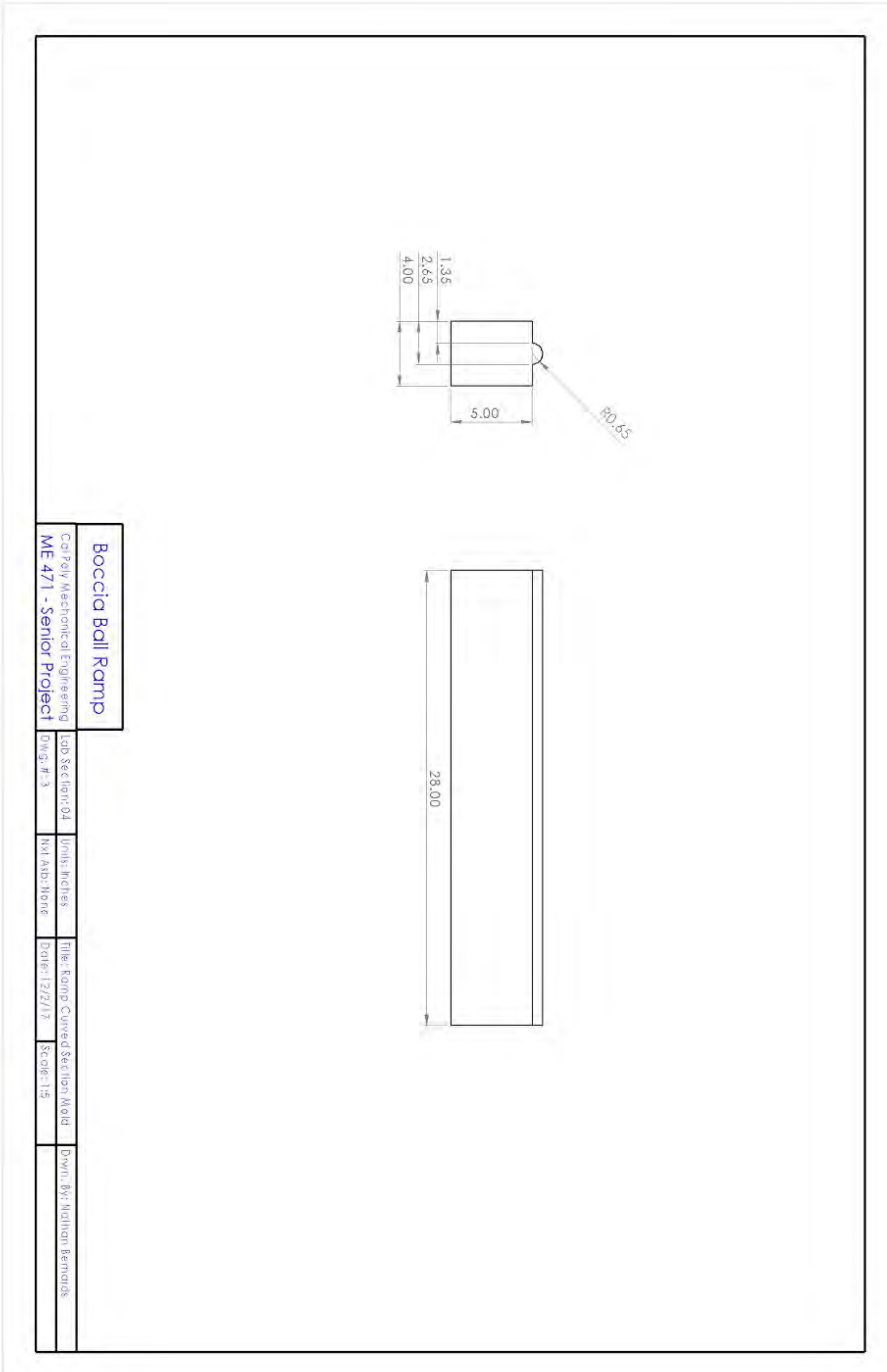
5	Weight of total assembly	Use scale to measure	Weighs less than 20 lbs altogether	Team	DV	1	5/15	11/14	Total ramp and frame assembly weighs approximately 15 lbs.	Pass	
6	Fits in box	Lay on side and measure	Pass/Fail (Fits in box, or is too large)	Team	DV	1	5/15	11/14	Parts of ramp are slightly larger than carry on size case.		Fail
7	Distance Ball travels	Measurement of how far the ball rolls when released from several different heights	Travels at least 4.9 ft, can travel 49.5 ft	Team	DV	1	5/15	11/14	Ball travels at least 4.9 ft.	Pass	
8	Ball Can be released from any point	Everywhere pocket test	Pocket can move with little difficulty on ramp, and player can release ball easily	Team	DV	1	5/15	11/14	"Everywhere pocket" stays in place at any point on ramp, ball is easily released from it.	Pass	
9	Ball Can be released from any angle	Everywhere pocket test	Ball will stay in everywhere pocket at any angle.	Team	DV	1	5/15	11/14	Ball falls out of everywhere pocket at steeper angles		Fail
10	Ball Speed	Roll the ball down the ramp at different angles into a cluster of balls, to make sure it rolls fast	Ball rolls fast enough to break into or on top of clusters.	Team	DV	1	5/15	11/14	Both soft and hard balls roll fast enough down the ramp at multiple angles to break	Pass	

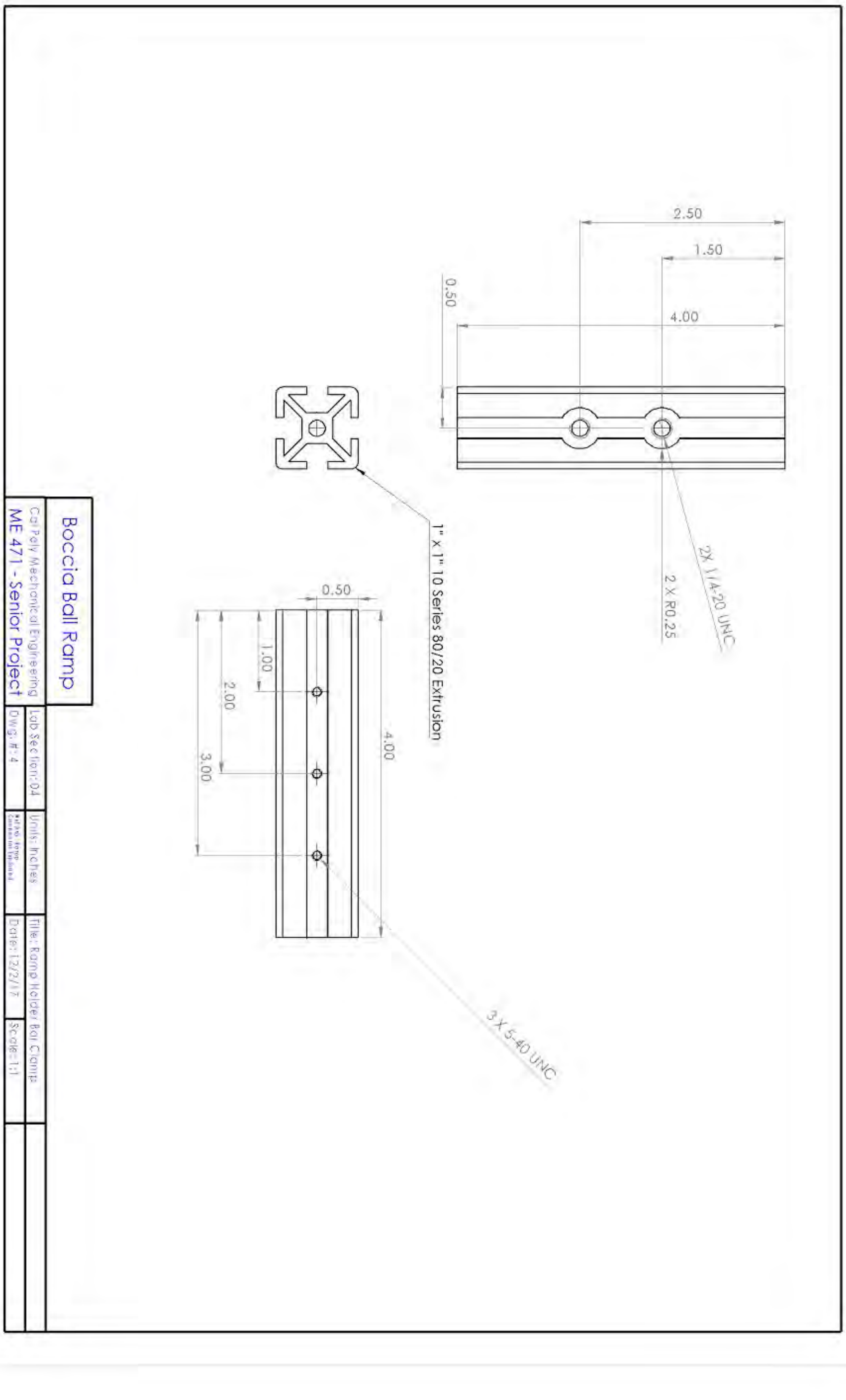
		enough							clusters.		

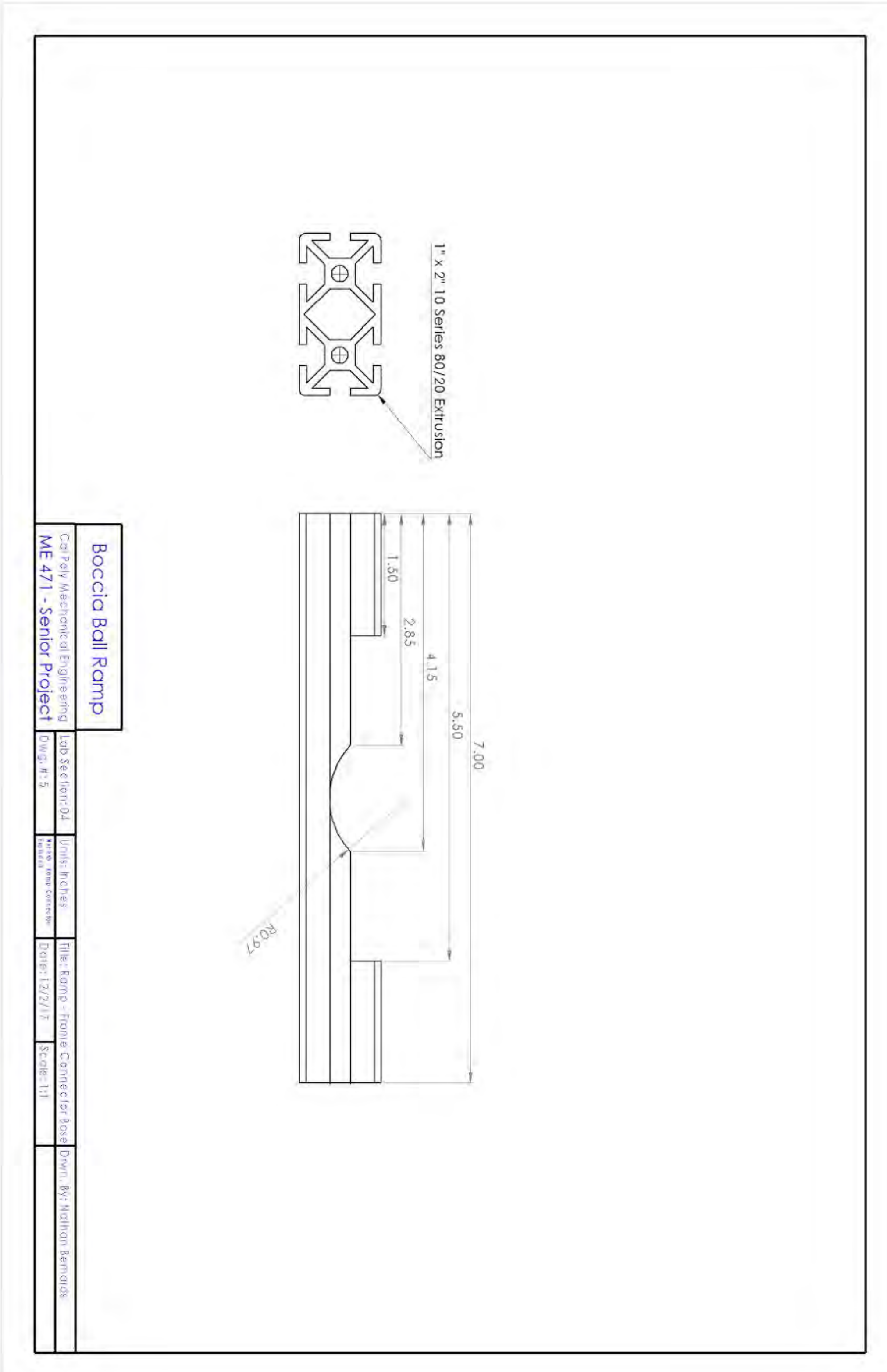
Appendix J: Final Design Drawings

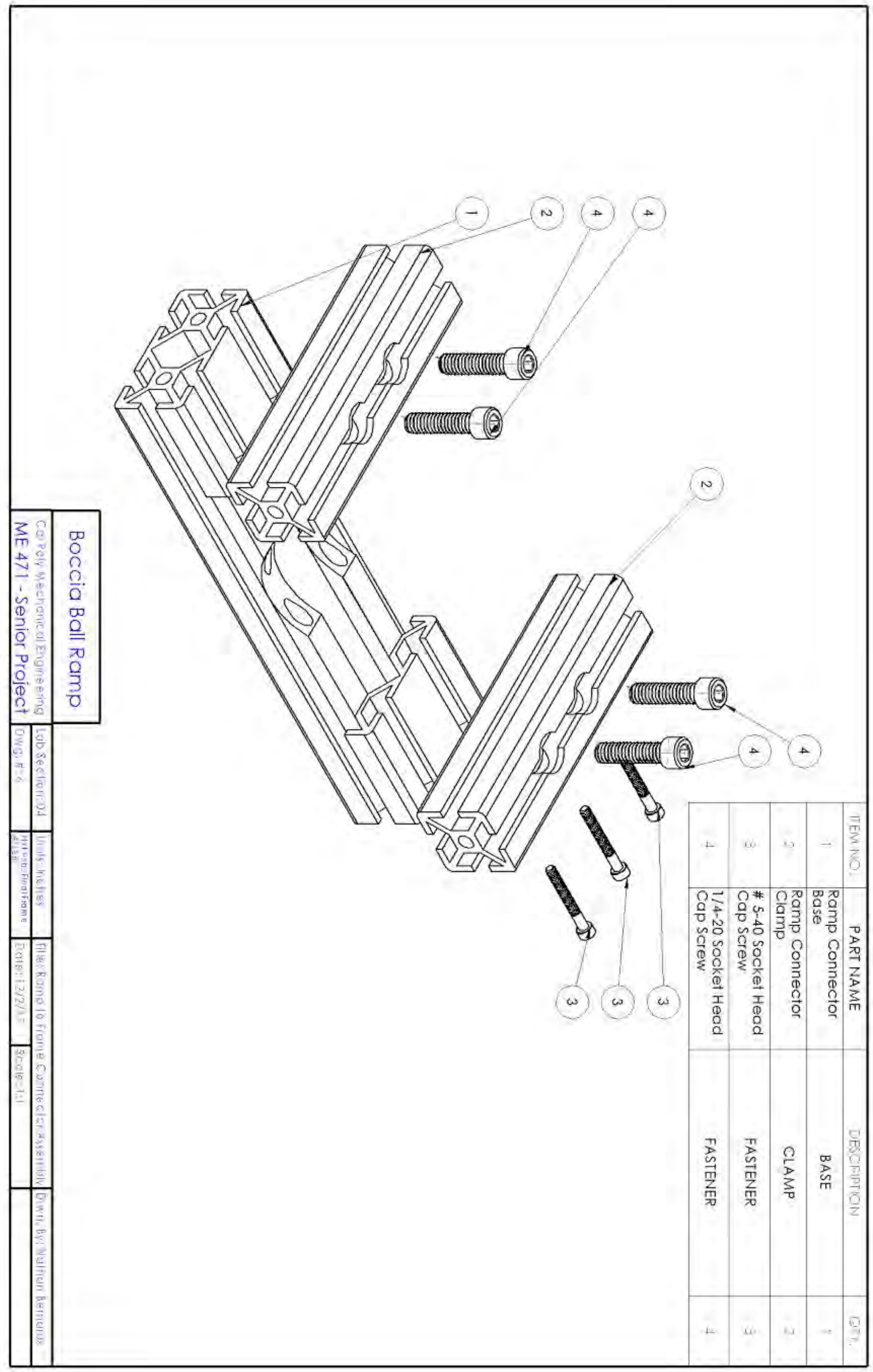



3.90
4 X R0.05
6.00
30.00
Boccia Ball Ramp
Cal Poly Mechanical Engineering
ME 471 - Senior Project
Lab Section: 04
Dwg. #: 2
Assignment #
Nxt Asb: None
File: Ramp Straight Section Mold
Date: 12/2/17
Scale: 1:5
Drwn. By: Nathan Bernards
Chkd. By: ME STAFF

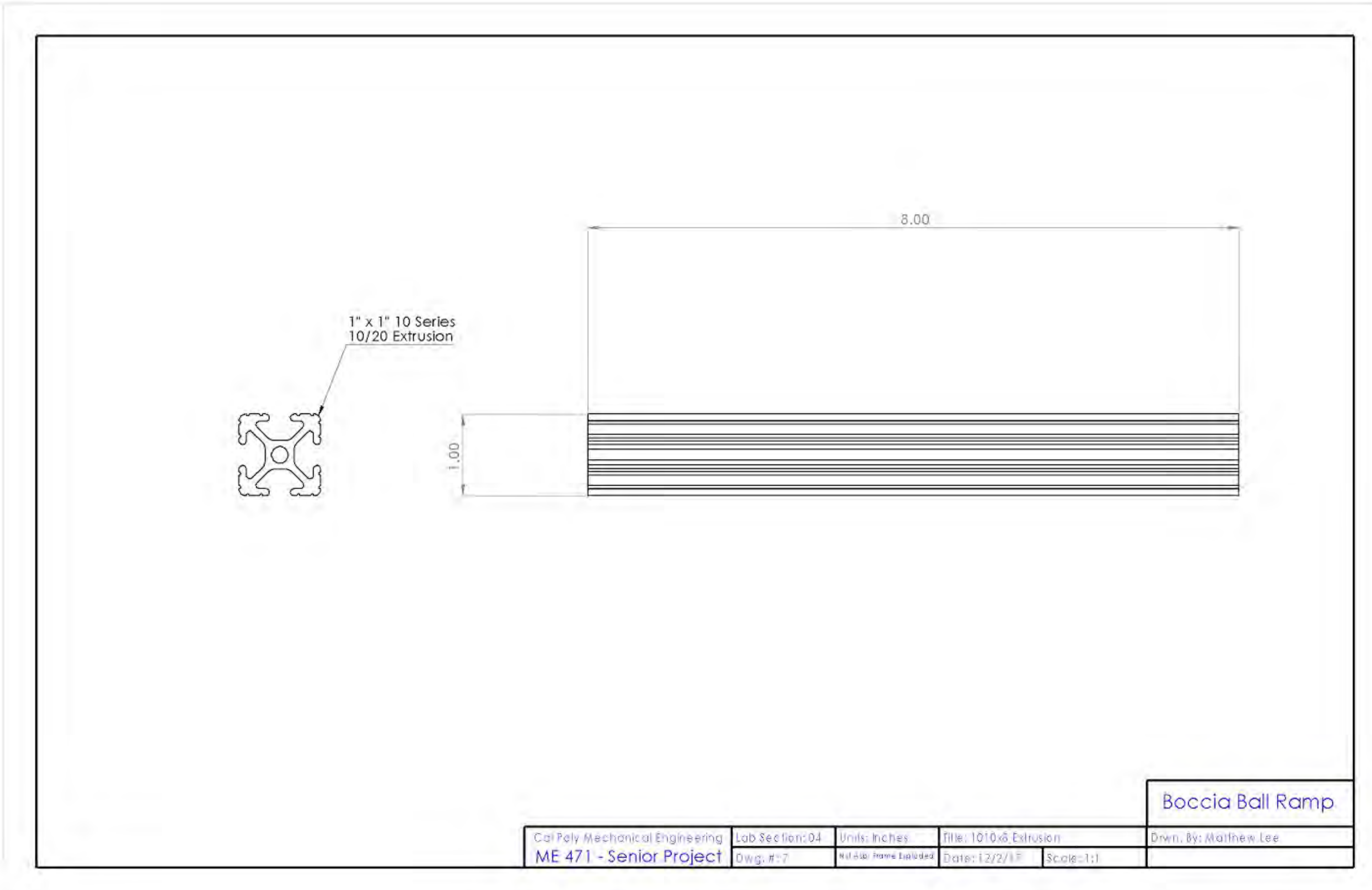

Boccia Ball Ramp
Cal Poly Mechanical Engineering
ME 471 - Senior Project
Lab Section: 04
Dwg. #: 3
Units: Inches
Nxt Asb: None
Title: Ramp Curved Section Mold
Date: 12/2/17
Scale: 1:5
Drwn. By: Nathan Bernards
1.35
2.65
4.00
5.00
R0.65
28.00

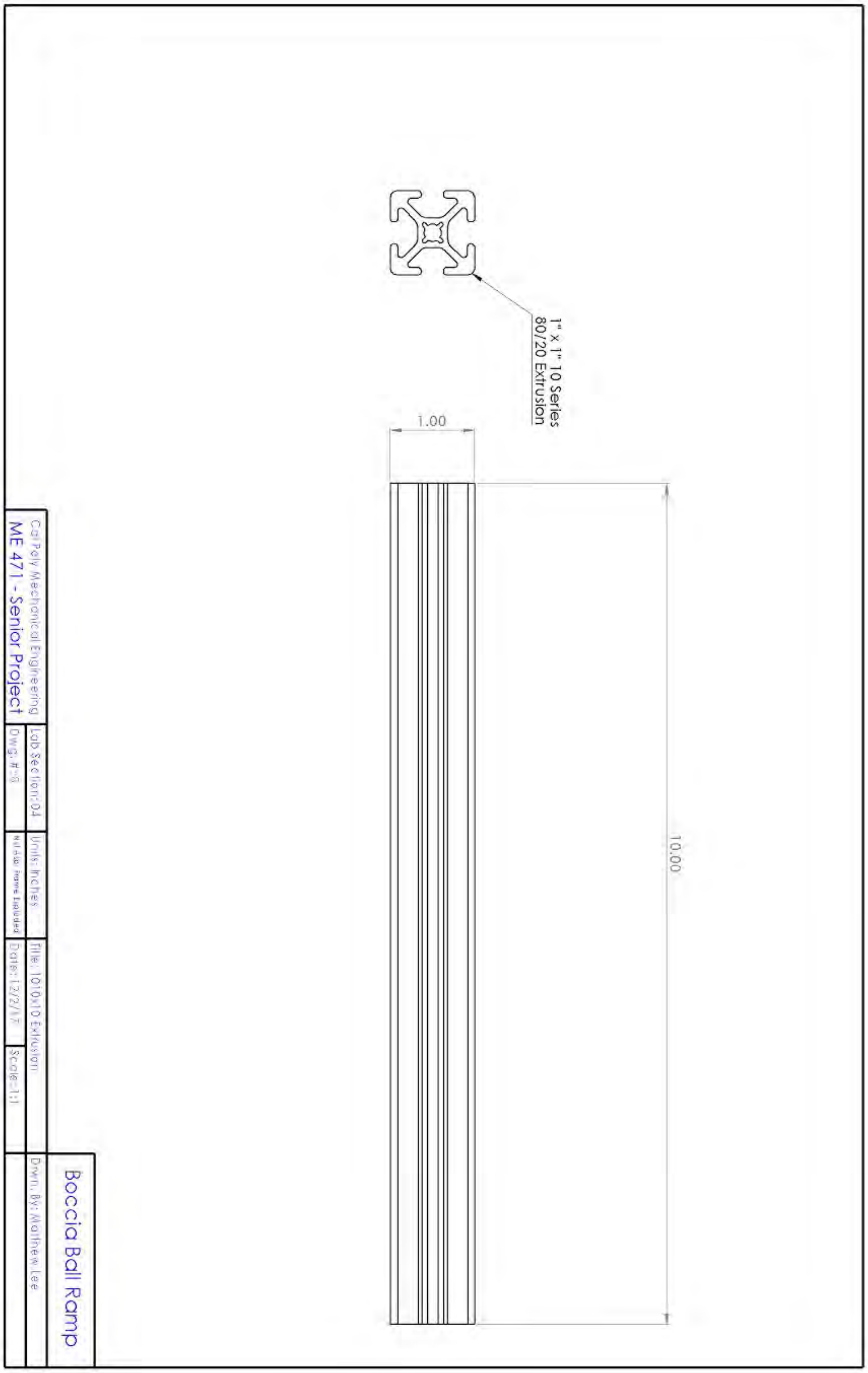

Boccia Ball Ramp
Cal Poly Mechanical Engineering
ME 471 - Senior Project
Lab Section: 04
Dwg. #: 4
Units: Inches
File: Ramp Holder Bar Clamp
Date: 12/2/17
Scale: 1:1
2.50
1.50
0.50
4.00
2X 1/4-20 UNC
2 X R0.25
1" x 1" 10 Series 80/20 Extrusion
0.50
1.00
2.00
3.00
4.00
3 X 5-40 UNC

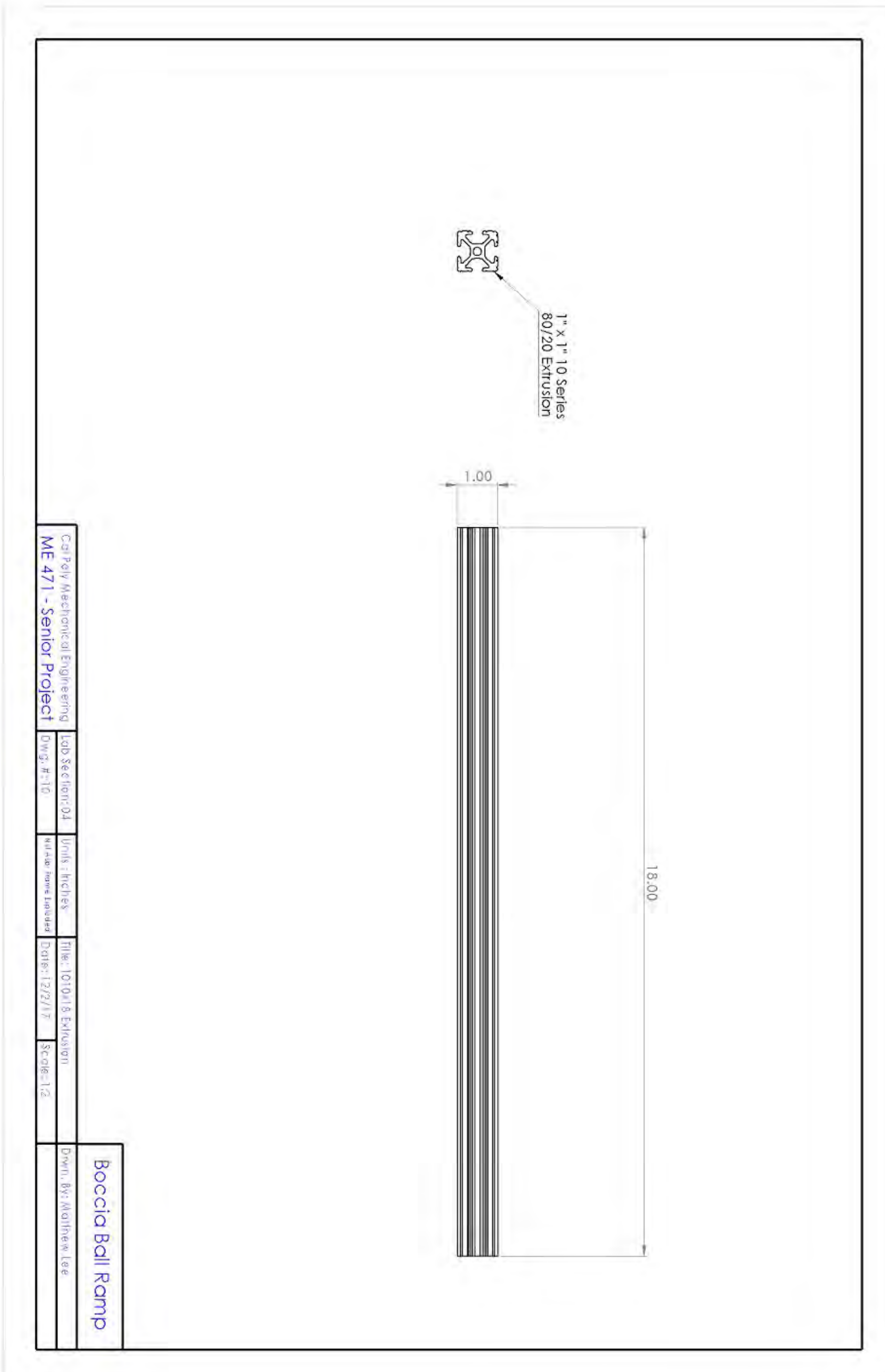

1" x 2" 10 Series 80/20 Extrusion
1.50
2.85
4.15
5.50
7.00
R0.97
Boccia Ball Ramp
Cal Poly Mechanical Engineering
ME 471 - Senior Project
Lab Section:04
Dwg. #:5
Units: Inches
Title: Ramp - Frame Connector Base
Date: 12/2/17
Scale: 1:1
Drwn. By: Nathan Bernards



1
2
4
4
2
4
4
3
3
3
ITEM NO. | PART NAME | DESCRIPTION | QTY.
1 | Ramp Connector Base | BASE | 1
2 | Ramp Connector Clamp | CLAMP | 2
3 | # 5-40 Socket Head Cap Screw | FASTENER | 3
4 | 1/4-20 Socket Head Cap Screw | FASTENER | 4
Boccia Ball Ramp
Cal Poly Mechanical Engineering
ME 471 - Senior Project
Lab Section: 04
Dwg. #: 6
Units: Inches
File: Ramp to Frame Connector Assembly
Date: 12/2/17
Scale: 1:1


8.00
1.00
1" x 1" 10 Series
10/20 Extrusion
Boccia Ball Ramp
Cal Poly Mechanical Engineering
ME 471 - Senior Project
Lab Section:04
Dwg. #:7
Units: Inches
Title: 1010x8 Extrusion
Date: 12/2/17
Scale: 1:1
Drwn. By: Matthew Lee


1" x 1" 10 Series
80/20 Extrusion
1.00
10.00
Cal Poly Mechanical Engineering
ME 471 - Senior Project
Lab Section: 04
Units: Inches
File: 1010x10 Extrusion
Date: 12/2/17
Scale=1:1
Drwn. By: Mathew Lee
Boccia Ball Ramp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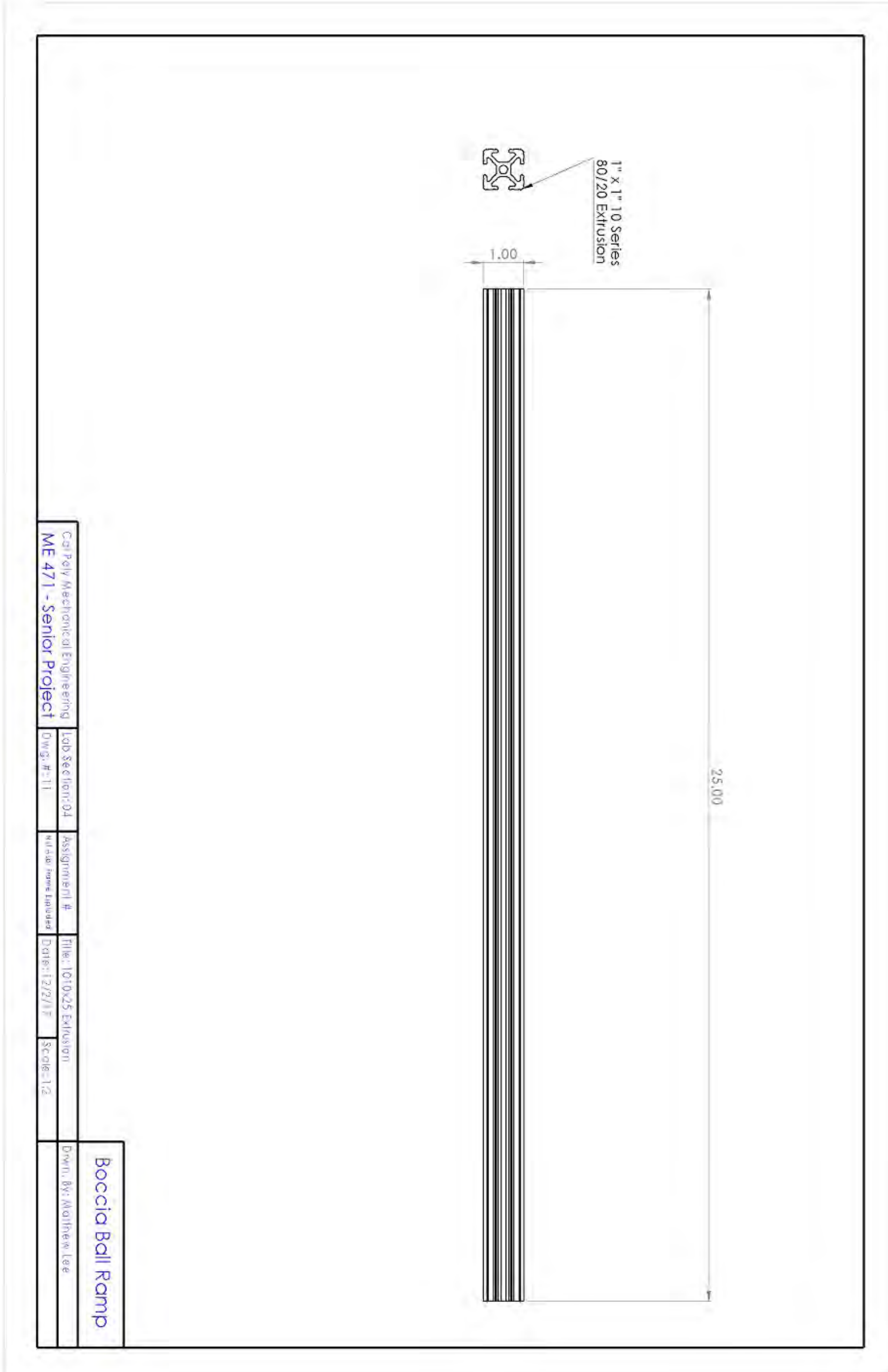
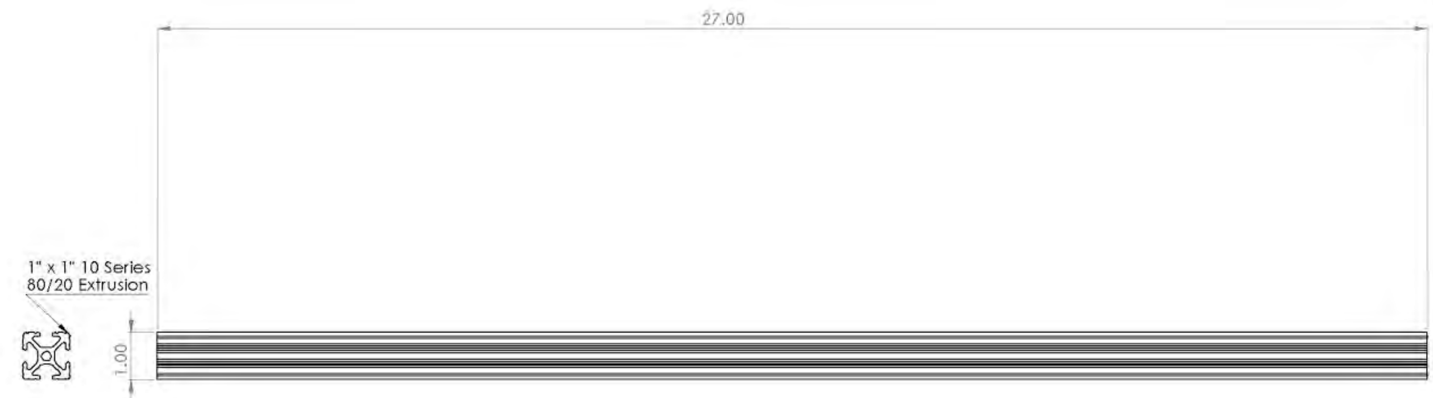
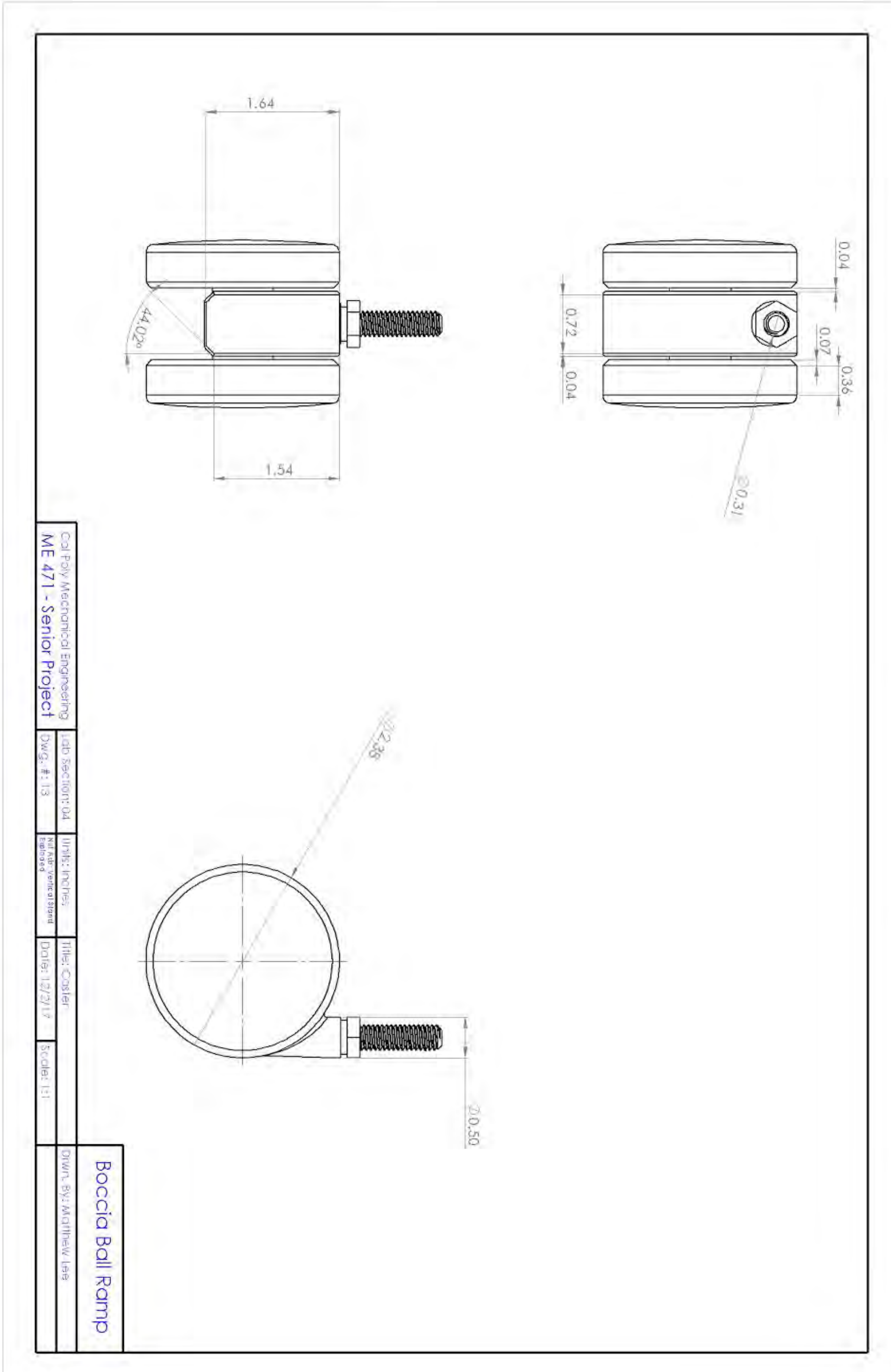
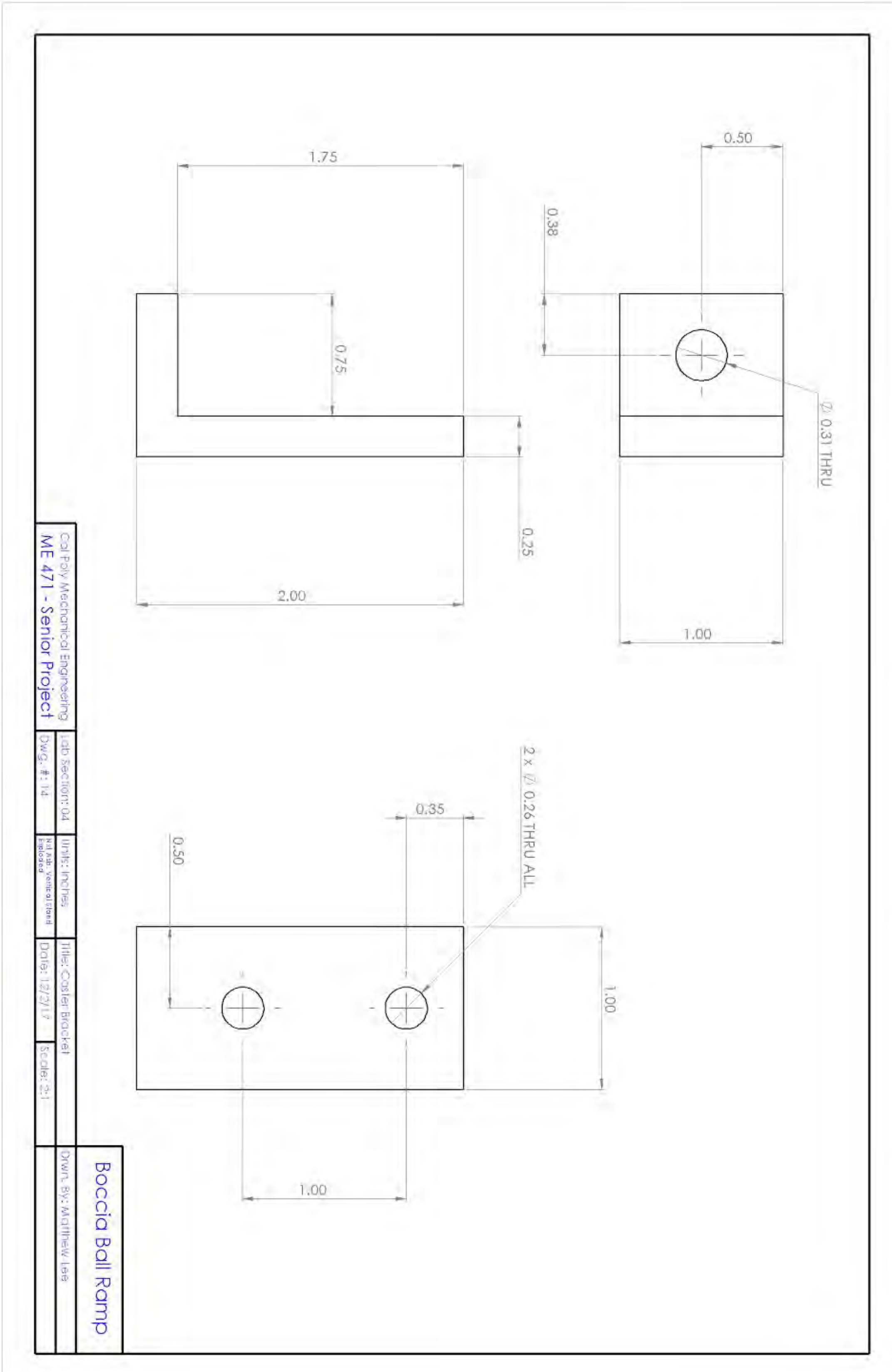
80/20 Extrusion
1.00
18.00
Cal Poly Mechanical Engineering
ME 471 - Senior Project
Lab Section: 04
Dwg. #: 10
Units: Inches
File: 1010x18 Extrusion
Date: 12/2/17
Scale: 1:2
Dwn. By: Matthew Lee
Boccia Ball Ramp

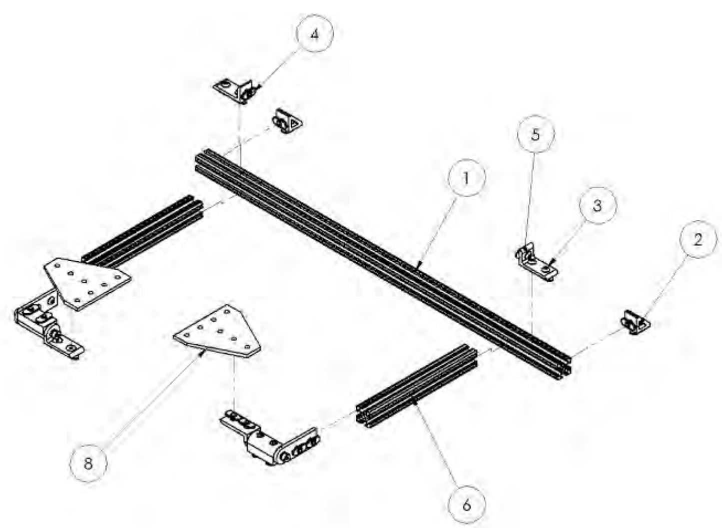

1" x 1" 10 Series
80/20 Extrusion
1.00
25.00
Cal Poly Mechanical Engineering
ME 471 - Senior Project
Lab Section:04
Dwg. #: 11
Assignment #
File: 1010x25 Extrusion
Date: 12/2/17
Scale: 1:2
Boccia Ball Ramp
Drwn. By: Matthew Lee



					Boccia Ball Ramp
Cal Poly Mechanical Engineering	Lab Section: 04	Units: Inches	Title: 1010x27 Extrusion		Drwn. By: Matthew Lee
ME 471 - Senior Project	Dwg. #: 12	Nxt Asb: Frame Exploded	Date: 12/2/17	Scale: 1:2	


1.64
44.02°
1.54
0.04
0.72
0.07
0.36
0.04
Ø0.31
Ø2.35
Ø0.50
Cal Poly Mechanical Engineering
ME 471 - Senior Project
Lab Section: 04
Dwg. #: 13
Units: Inches
Title: Caster
Date: 12/2/17
Scale: 1:1
Boccia Ball Ramp
Drwn. By: Matthew Lee

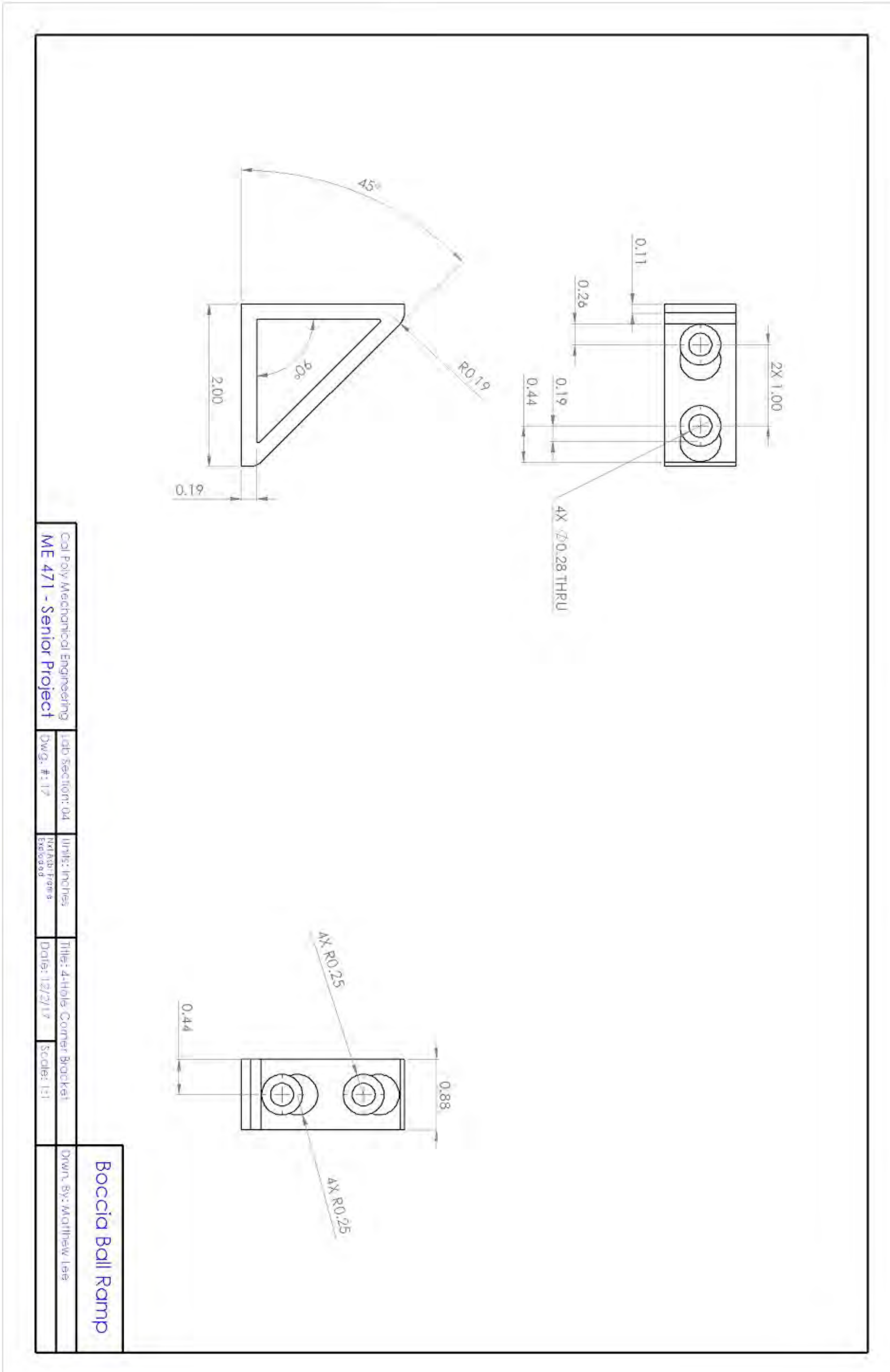

Cal Poly Mechanical Engineering
ME 471 - Senior Project
Lab Section: 04
Dwg. #: 14
Units: Inches
Nxt Asb: Vertical Stand Exploded
Title: Caster Bracket
Date: 12/2/17
Scale: 2:1
Drwn. By: Matthew Lee
Boccia Ball Ramp
1.75
0.75
0.25
2.00
0.50
0.38
Ø 0.31 THRU
1.00
2 x Ø 0.26 THRU ALL
0.35
0.50
1.00
1.00

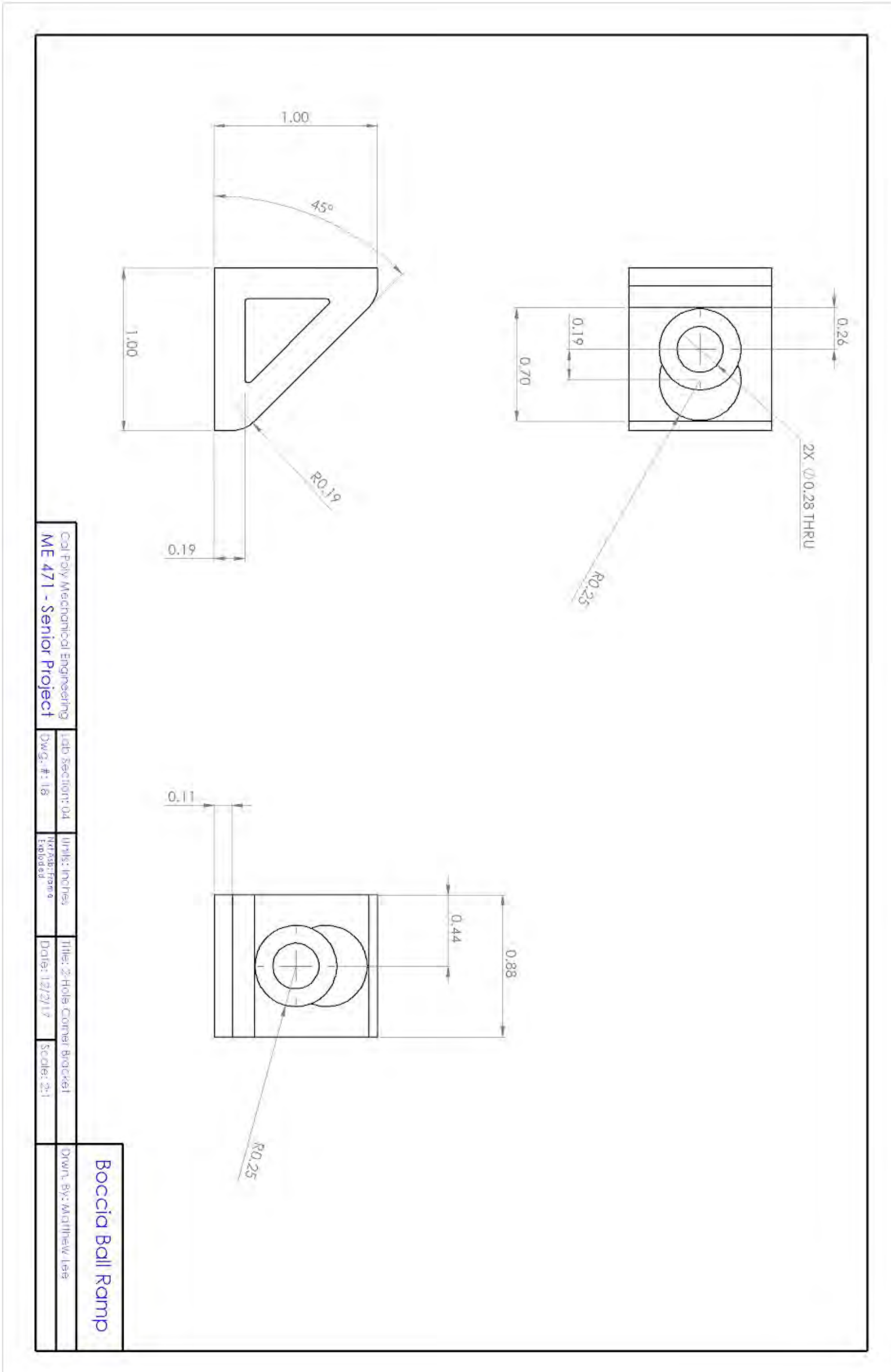


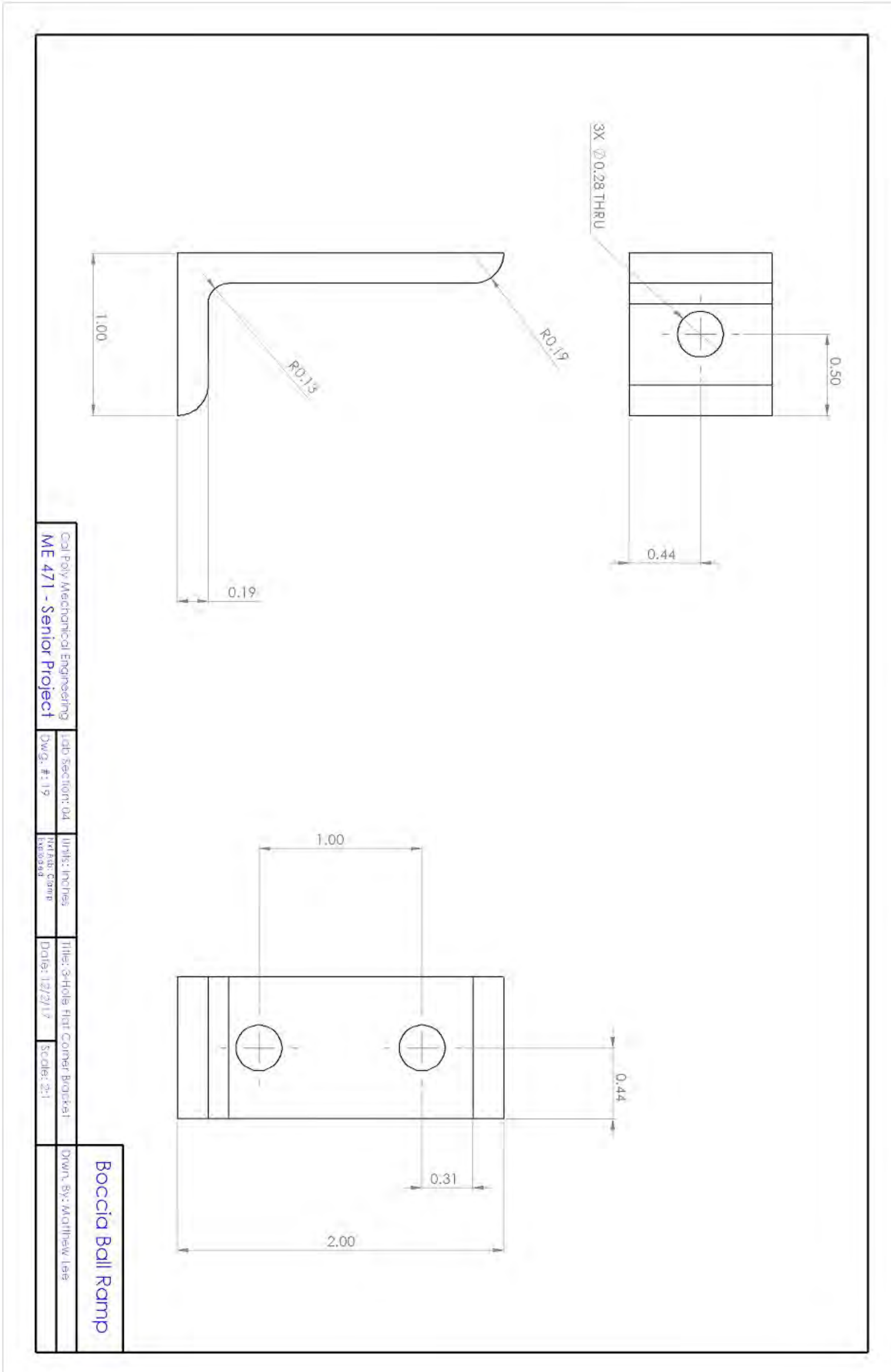
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	1010 x 27	27 inch Tslot extrusion	1
2	2-Hole Gusseted Corner Bracket	2-Hole inside corner bracket	2
3	SBHCSCREW 0.25-20x0.5-HX-C	1/4x20x0.5 hex head screw	14
4	651163 Economy T-Nut	1/4x20 T-nut	18
5	3-Hole Flat Corner Bracket	3-Hole inside corner bracket	2
6	1010 x 8	8 inch Tslot extrusion	2
8	7-Hole Tee Flat Plate	7-hole flat plate fastener	2
9	_SB_5_16x14_2_4		4
10	_4172_a_6		2
11	_3400_8		4
12	_SB_5_16x1_4_3_14		4
13	_SB_5_16x1_4_1_16		4
14	Dynamic Hinge	90 ° Dynamic Hinge	2
15	_3071_28		4
16	_3382_10		4

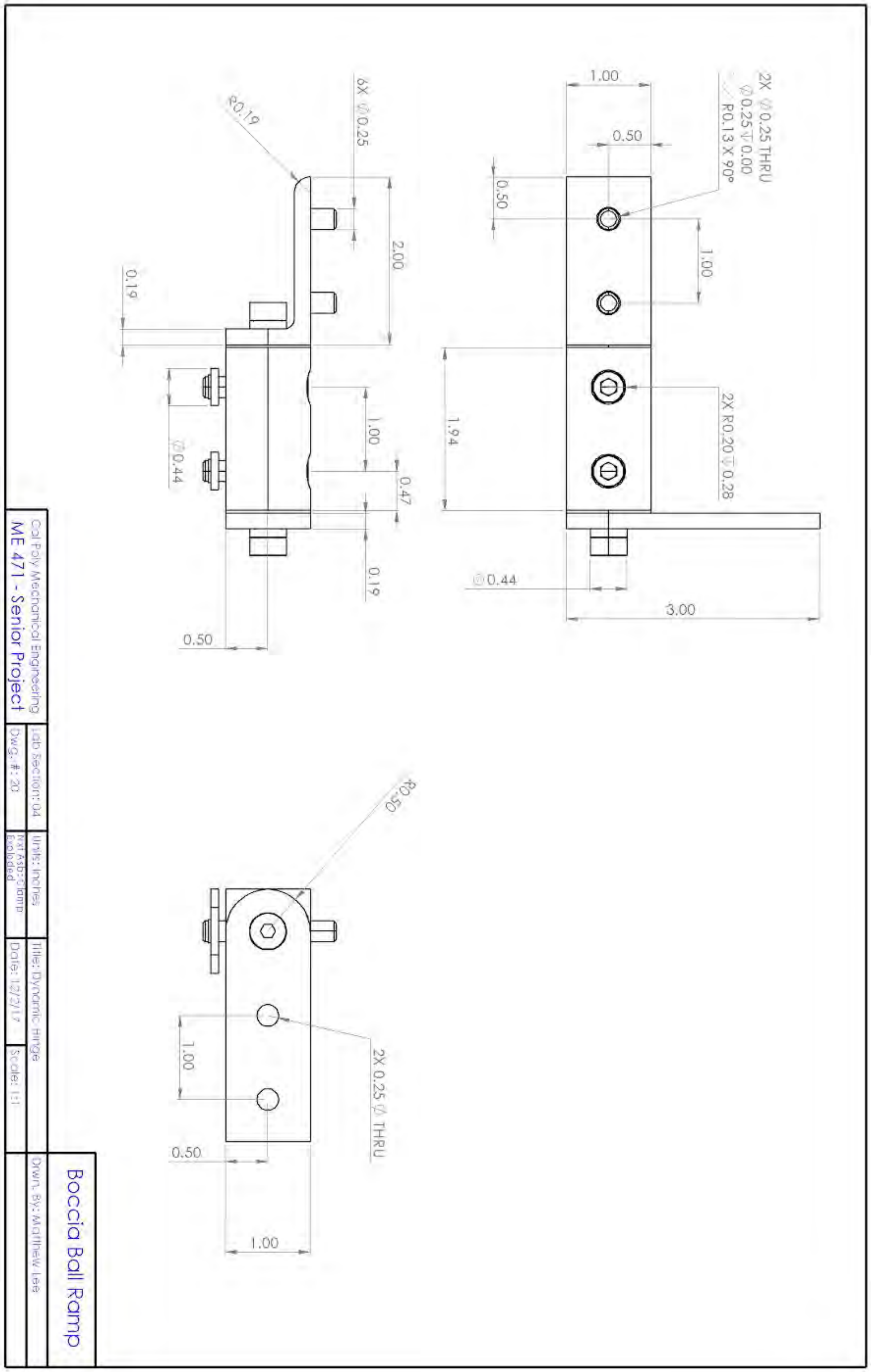
Boccia Ball Ramp

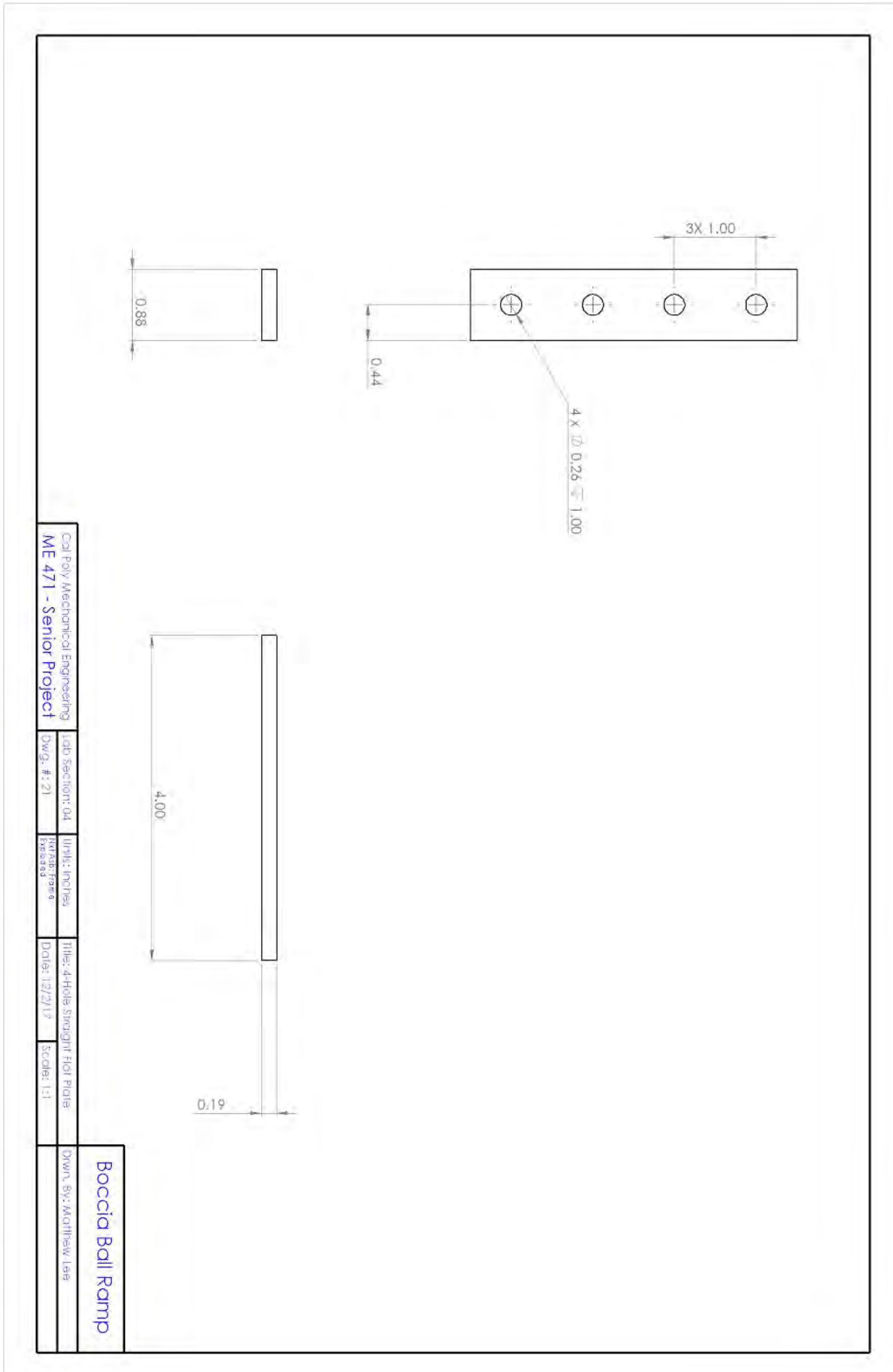
Cal Poly Mechanical Engineering	Lab Section: 04	Units: Inches	Title: Clamp Exploded View	Drwn. By: Matthew Lee
ME 471 - Senior Project	Dwg. #: 15	Nxt Asb: Full Render	Date: 12/1/2017 Scale: 1:5	

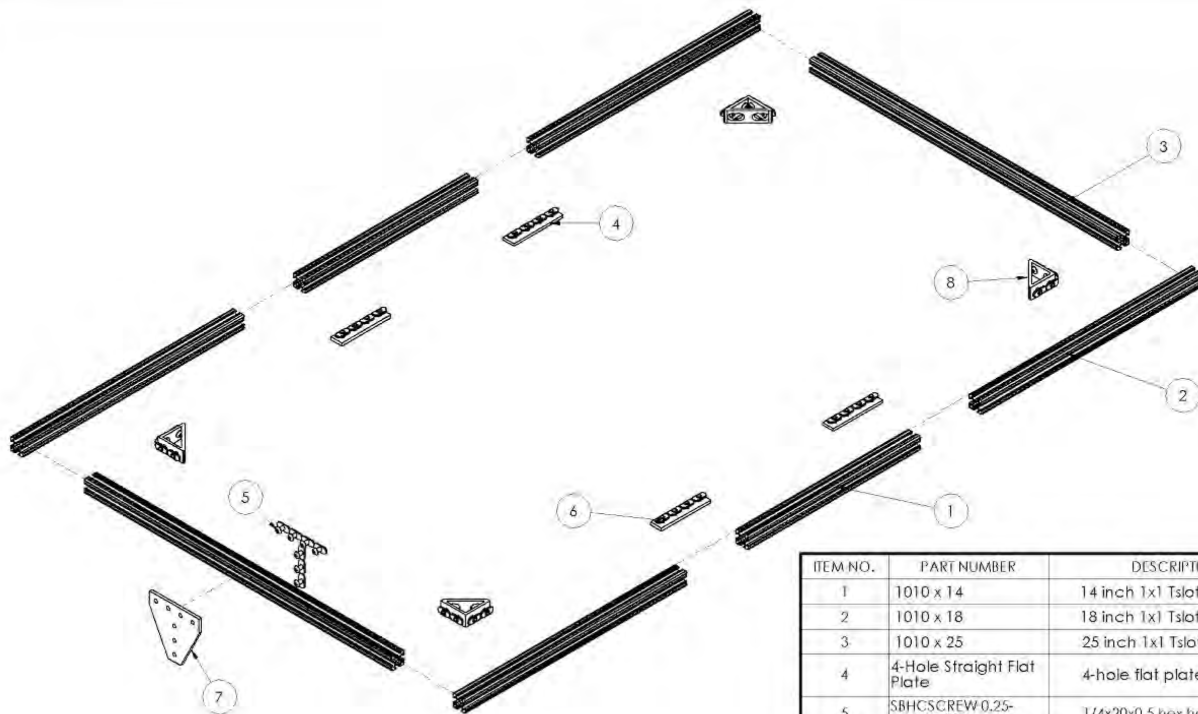

45°
0.11
0.26
2X 1.00
R0.19
90°
2.00
0.19
0.44
0.19
4X ⌀0.28 THRU
4X R0.25
0.44
0.88
4X R0.25
Cal Poly Mechanical Engineering
ME 471 - Senior Project
Lab Section: 04
Dwg. #: 17
Units: Inches
Title: 4-Hole Corner Bracket
Date: 12/2/17
Scale: 1:1
Boccia Ball Ramp
Drwn. By: Matthew Lee


1.00
45°
1.00
R0.19
0.19
0.19
0.70
0.26
2X ⌀0.28 THRU
R0.25
0.11
0.44
0.88
R0.25
Cal Poly Mechanical Engineering
ME 471 - Senior Project
Lab Section: 04
Dwg. #: 18
Units: Inches
Nxt Asb: Frame Exploded
Title: 2-Hole Corner Bracket
Date: 12/2/17
Scale: 2:1
Drwn. By: Matthew Lee
Boccia Ball Ramp


3X ∅0.28 THRU
1.00
R0.13
R0.19
0.50
0.44
0.19
1.00
0.44
0.31
2.00
Cal Poly Mechanical Engineering
ME 471 - Senior Project
Lab Section: 04
Dwg. #: 19
Units: Inches
Nxt Asb: Clamp Exploded
Title: 3-Hole Flat Corner Bracket
Date: 12/2/17
Scale: 2:1
Drwn. By: Matthew Lee
Boccia Ball Ramp


Boccia Ball Ramp
Drwn. By: Matthew Lee
Title: Dynamic Hinge
Scale: 1:1
Date: 12/2/17
Units: Inches
Nxt Asb: Clamp Exploded
Lab Section: 04
Dwg. #: 20
Cal Poly Mechanical Engineering
ME 471 - Senior Project
2X Ø0.25 THRU
Ø0.25 ⌵ 0.00
R0.13 X 90°
2X R0.20 ⌵ 0.28
6X Ø0.25
R0.19
R0.50
2X 0.25 Ø THRU
Ø0.44
1.00
0.50
2.00
1.94
0.47
0.19
3.00


3X 1.00
0.88
0.44
4 X ⌀ 0.26 ↧ 1.00
4.00
0.19
Cal Poly Mechanical Engineering
ME 471 - Senior Project
Lab Section: 04
Dwg. #: 21
Units: inches
Nxt Asb: Frame Exploded
Title: 4-Hole Straight Flat Plate
Date: 12/2/17
Scale: 1:1
Drwn. By: Matthew Lee
Boccia Ball Ramp

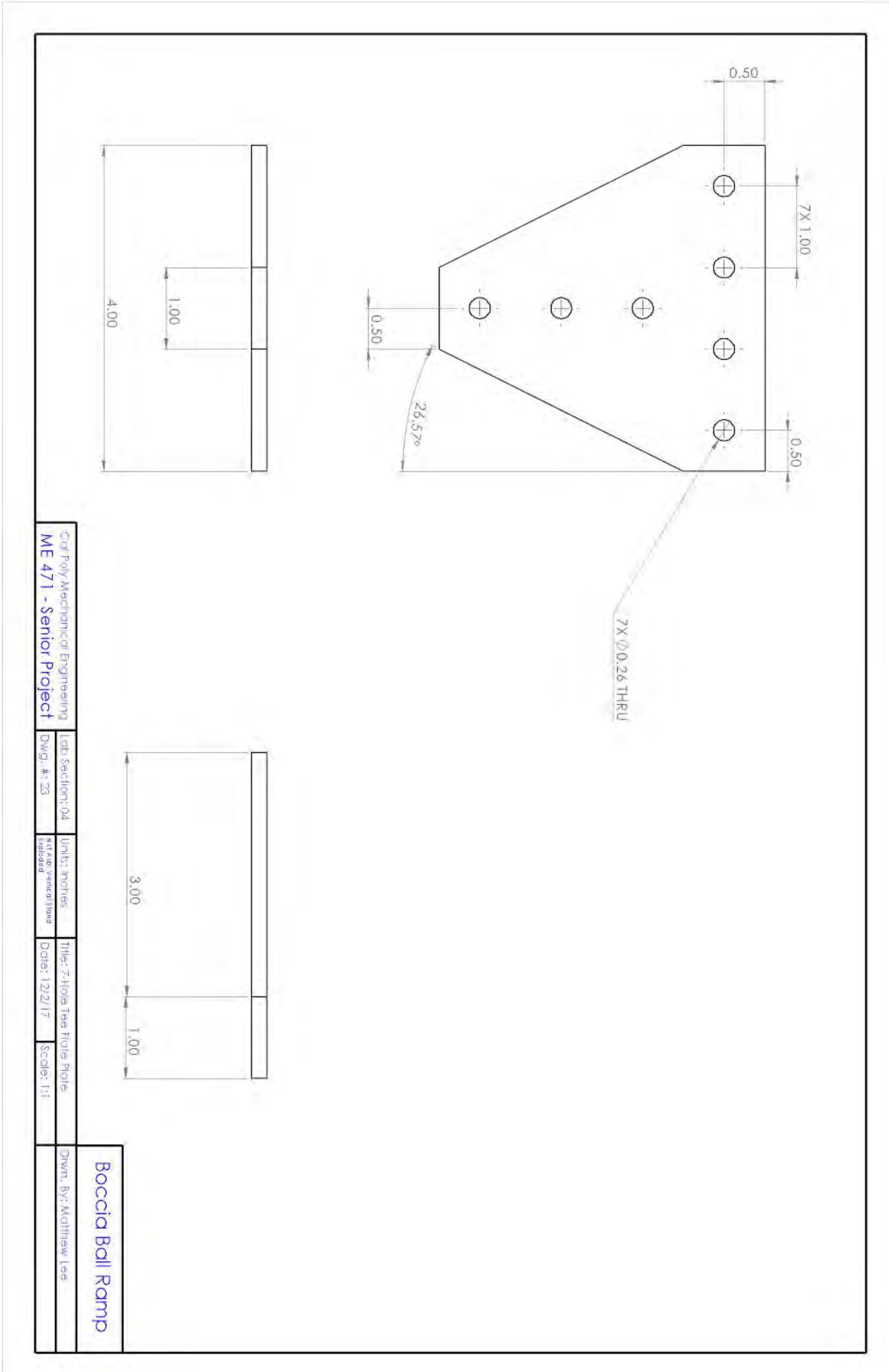


ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	1010 x 14	14 inch 1x1 Tslot extrusion	2
2	1010 x 18	18 inch 1x1 Tslot extrusion	4
3	1010 x 25	25 inch 1x1 Tslot extrusion	2
4	4-Hole Straight Flat Plate	4-hole flat plate fastener	4
5	SBHCSCREW 0.25-20x0.5-HX-C	1/4x20x0.5 hex head screw	39
6	651163 Economy T-Nut	1/4x20 T-nut	39
7	7-Hole Tee Flat Plate	7-hole flat plate fastener	1
8	4-Hole Gussted Corner Bracket	4-hole inside corner bracket	4

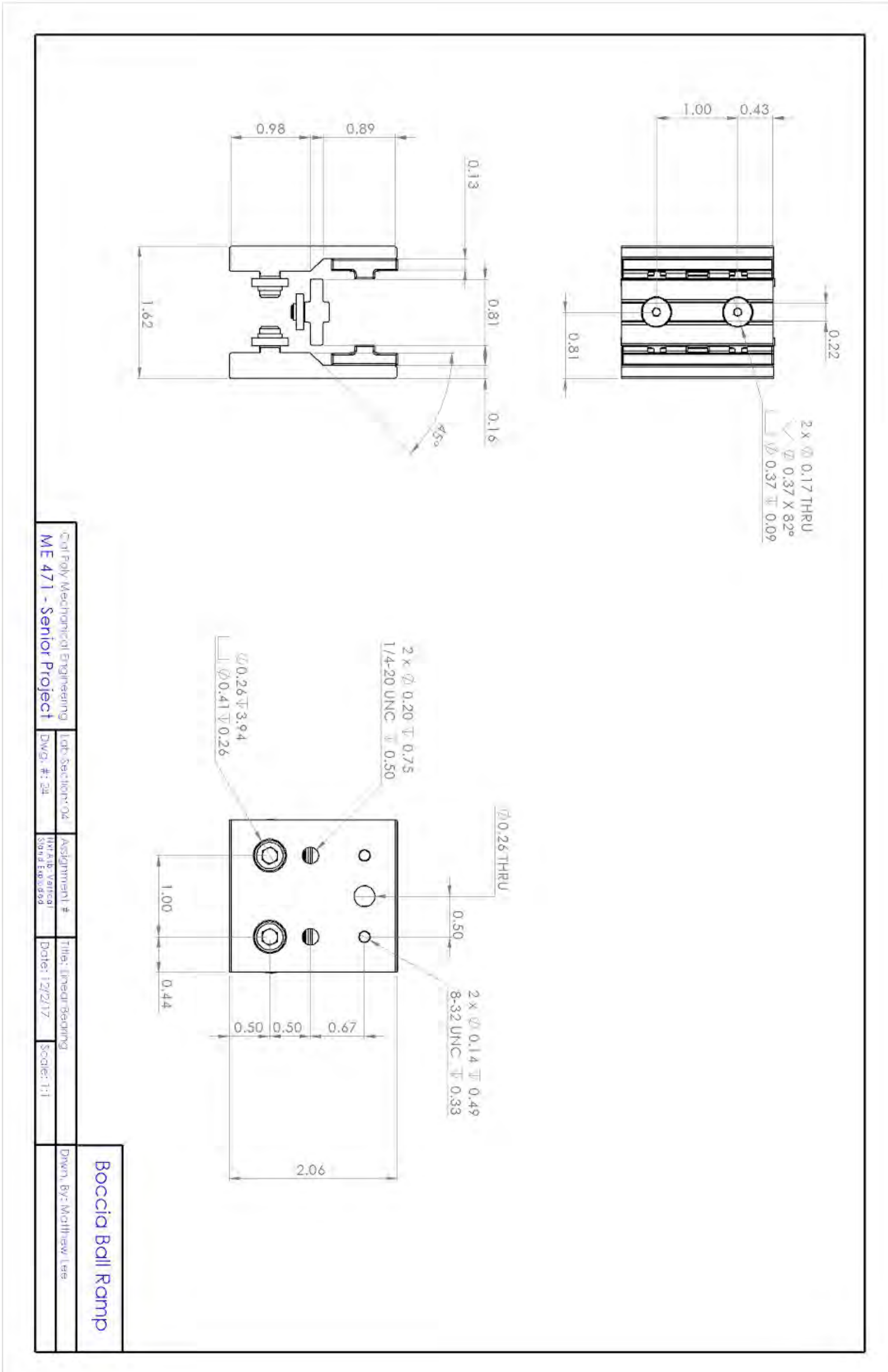
Boccia Ball Ramp

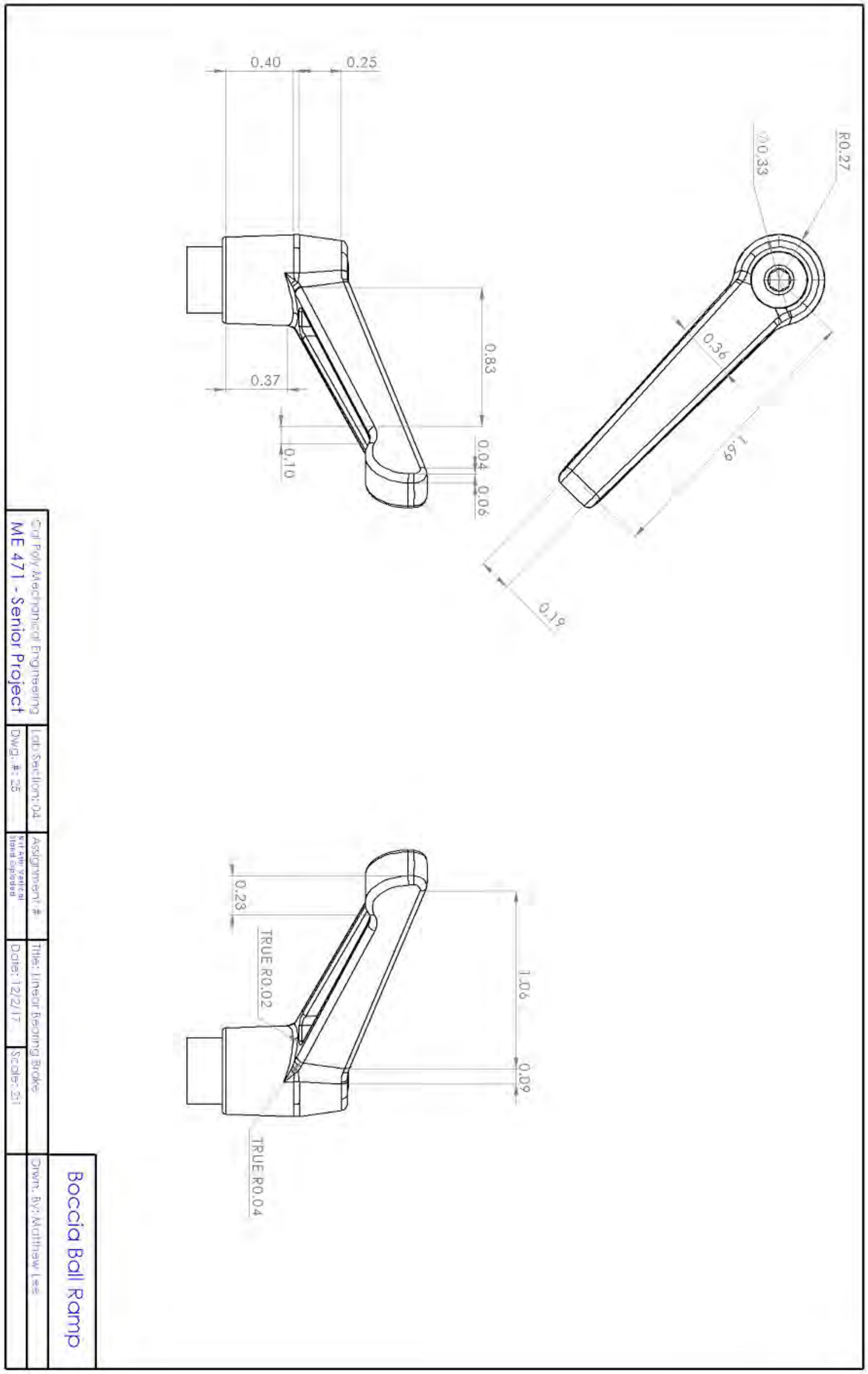
Cal Poly Mechanical Engineering
ME 471 - Senior Project

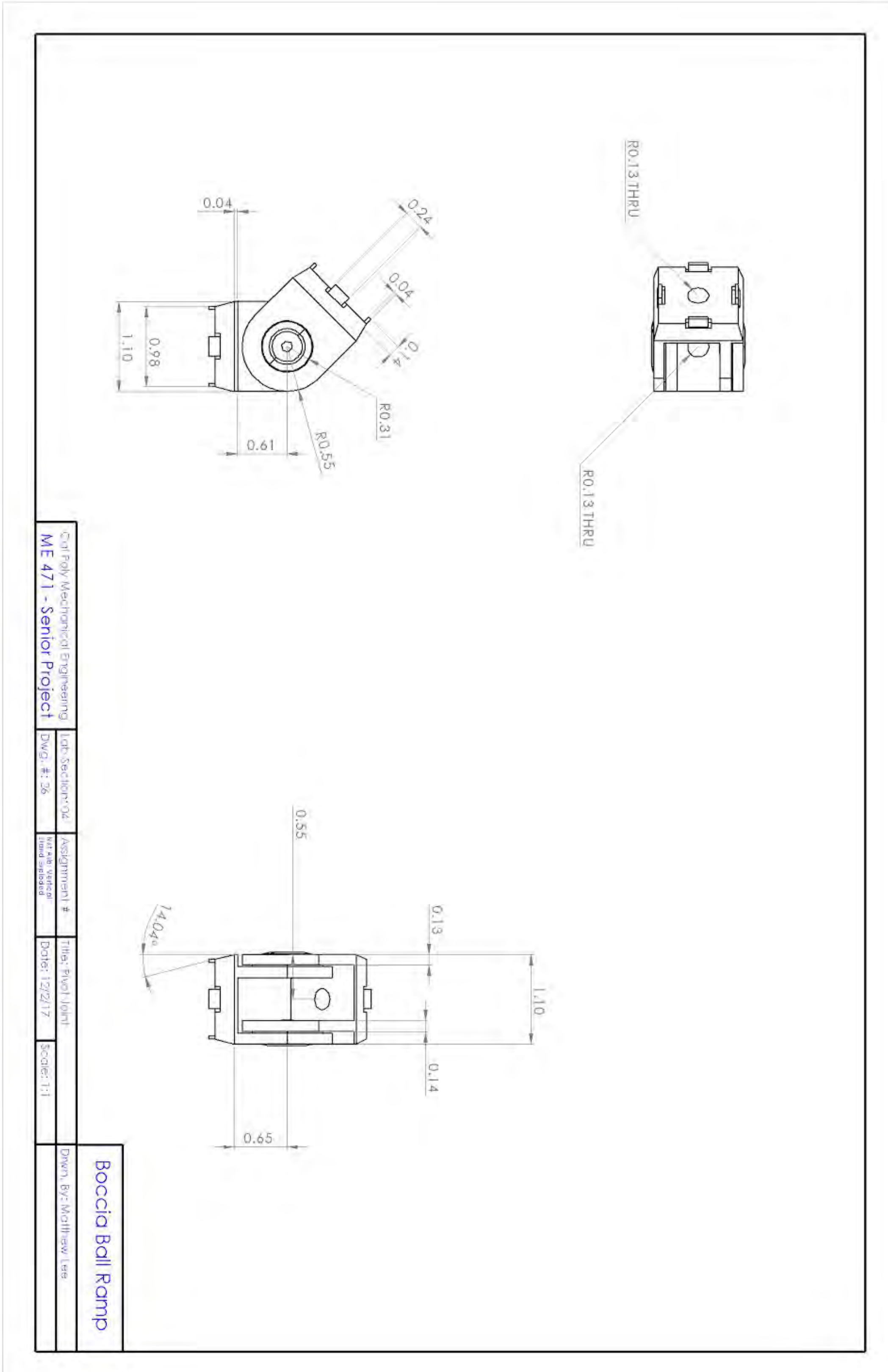
Lab Section: 04	Units: Inches	Title: Frame Exploded View		Drwn. By: Matthew Lee
Dwg. #: 22	Nxt Asb: Full Render	Date: 12/1/2017	Scale: 1:20	

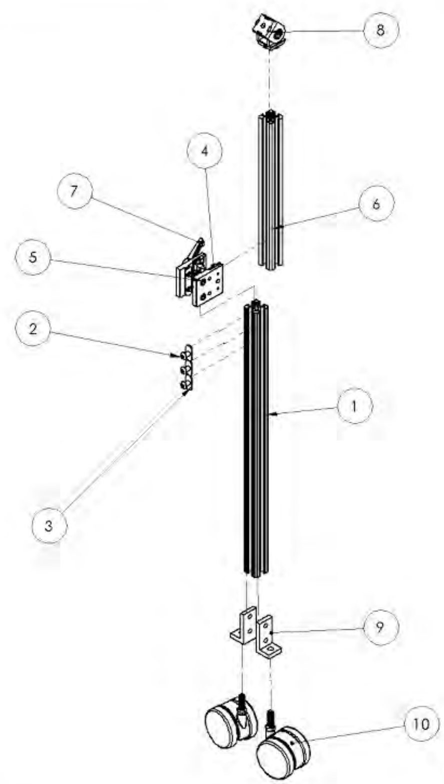


0.50
7X 1.00
0.50
26.57°
0.50
4.00
1.00
7X ∅0.26 THRU
3.00
1.00
Cal Poly Mechanical Engineering
ME 471 - Senior Project
Lab Section: 04
Dwg. #: 23
Units: inches
Nxt Asb: Vertical Stand Exploded
Title: 7-Hole Tee Flate Plate
Date: 12/2/17
Scale: 1:1
Drwn. By: Matthew Lee
Boccia Ball Ramp


0.98
0.89
0.13
1.62
0.81
0.16
45°
1.00
0.43
0.81
0.22
2 x ⌀ 0.17 THRU
⌵ ⌀ 0.37 X 82°
⌴ ⌀ 0.37 ↧ 0.09
2 x ⌀ 0.20 ↧ 0.75
1/4-20 UNC ↧ 0.50
⌀0.26 ↧3.94
⌴ ⌀0.41 ↧ 0.26
⌀0.26 THRU
1.00
0.50
0.44
0.50
0.50
0.67
2 x ⌀ 0.14 ↧ 0.49
8-32 UNC ↧ 0.33
2.06
Cal Poly Mechanical Engineering
ME 471 - Senior Project
Lab Section: 04
Dwg. #: 24
Assignment #
Title: Linear Bearing
Date: 12/2/17
Scale: 1:1
Drwn. By: Matthew Lee
Boccia Ball Ramp


0.40
0.25
R0.27
Ø0.33
0.83
0.36
0.37
0.10
0.04
0.06
1.69
0.19
0.23
TRUE R0.02
1.06
0.09
TRUE R0.04
Cal Poly Mechanical Engineering
ME 471 - Senior Project
Lab Section: 04
Dwg. #: 25
Assignment #
Date: 12/2/17
Title: Linear Bearing Brake
Scale: 2:1
Drwn. By: Matthew Lee
Boccia Ball Ramp

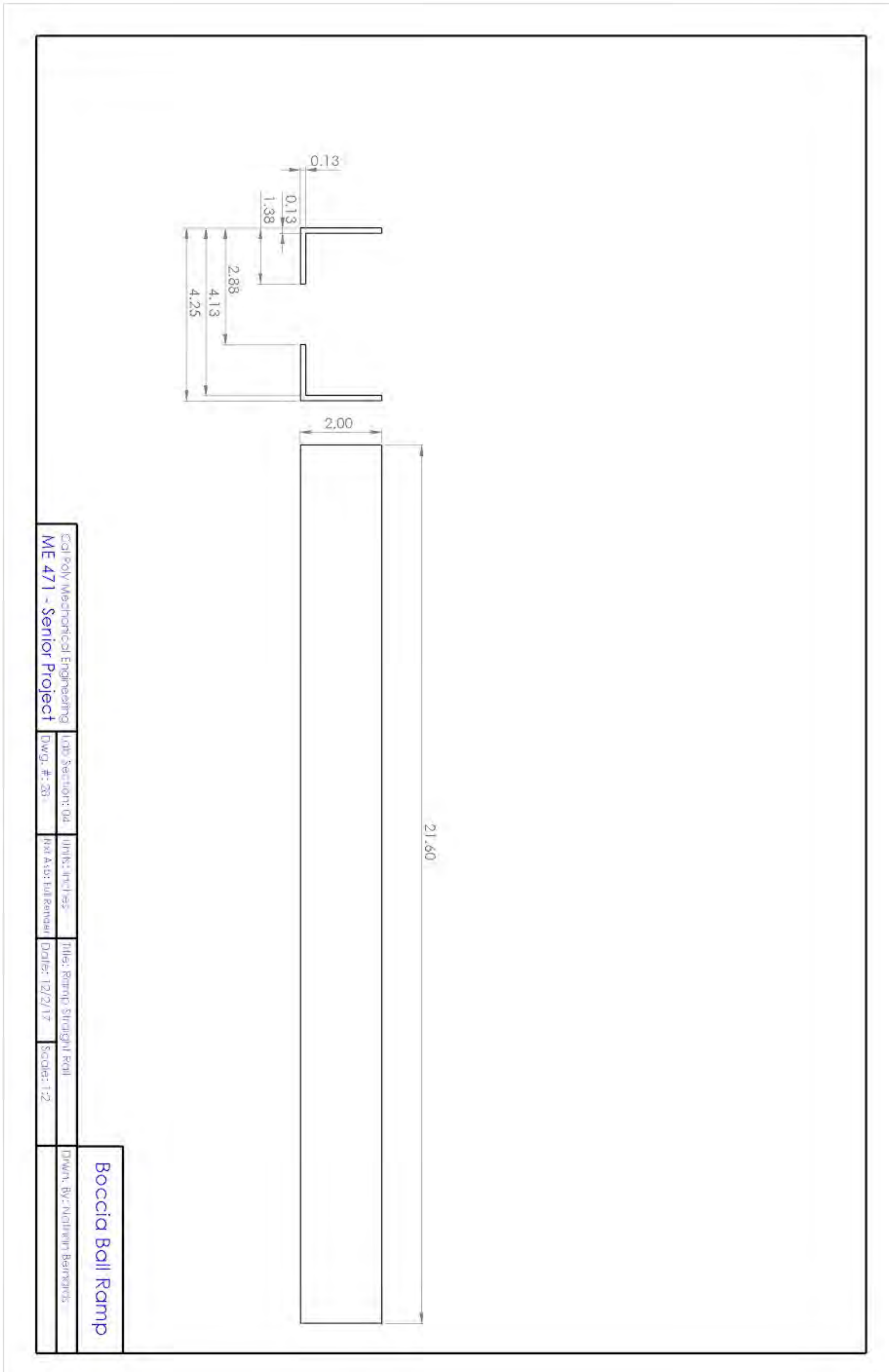

R0.13 THRU
0.04
0.24
0.04
0.14
1.10
0.98
R0.31
0.61
R0.55
R0.13 THRU
0.55
0.13
14.04°
1.10
0.14
0.65
Cal Poly Mechanical Engineering
ME 471 - Senior Project
Lab Section: 04
Dwg. #: 26
Assignment #
Title: Pivot Joint
Date: 12/2/17
Scale: 1:1
Drwn. By: Matthew Lee
Boccia Ball Ramp

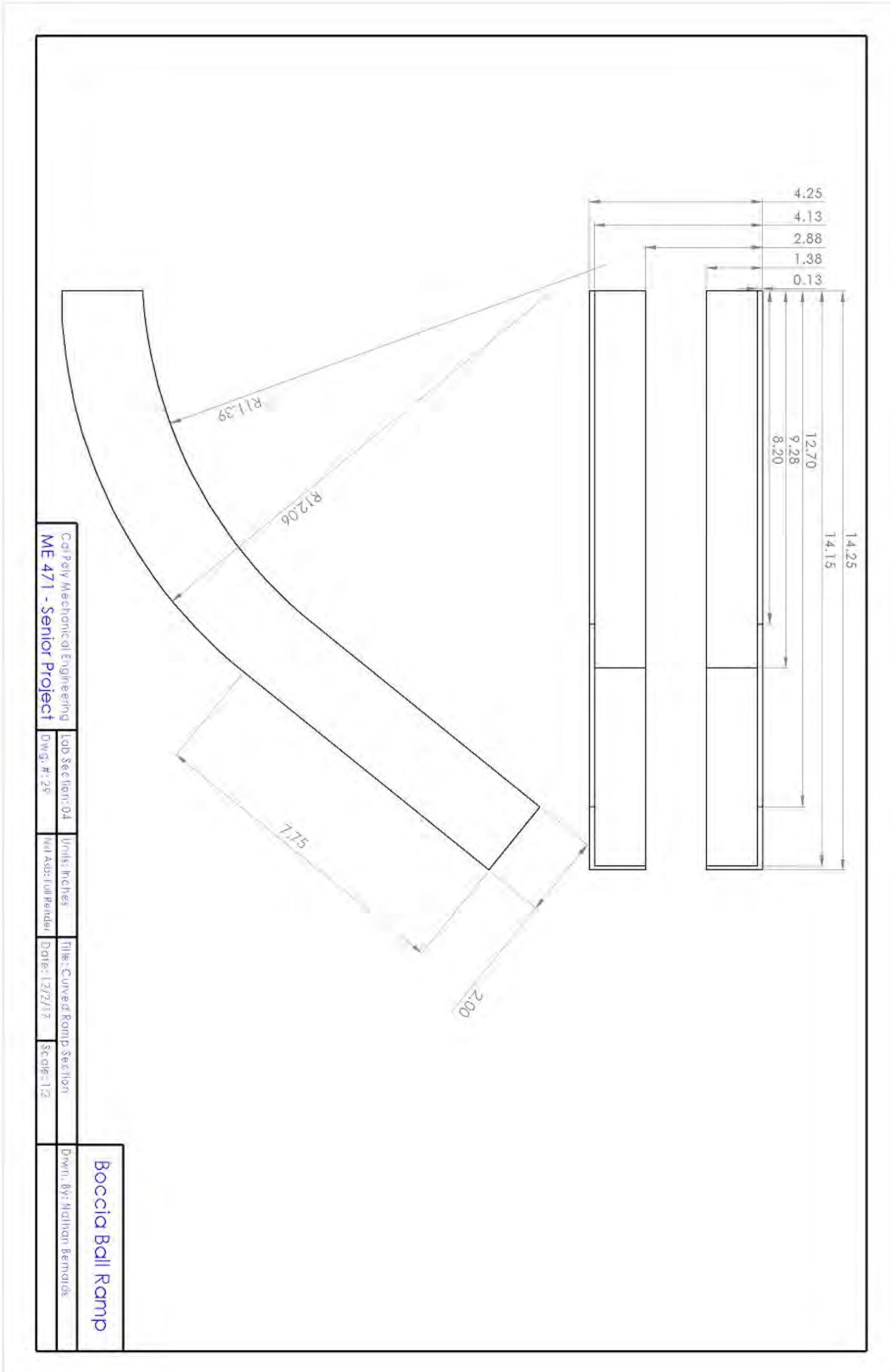


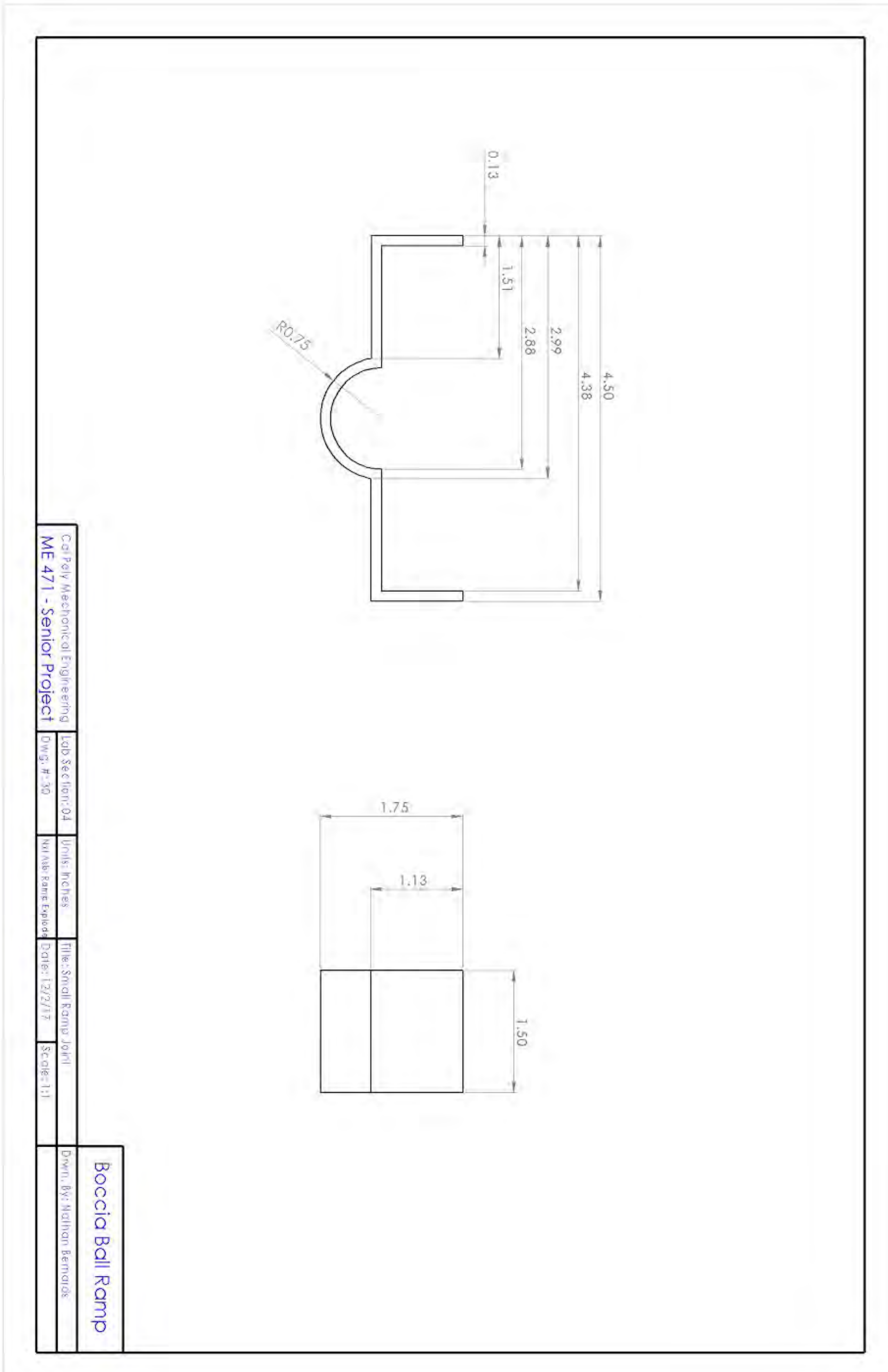
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	1010 x 18	18 inch 1x1 Tslot extrusion	1
2	SBHCSCREW 0.25-20x0.5-HX-C	1/4x20x0.5 hex head screw	3
3	651163 Economy T-Nut	1/4x20 T-nut	3
4	670509		2
5	Socket Countersunk Screw 0.25x20x0.5	1/4x20x0.5 hex head countersunk screw	2
6	1010 x 10	10 inch 1x1 Tslot extrusion	1
7	Linear Bearing Brake	Linear Bearing Brake	1
8	Pivot Joint	Pivot Joint	2
9	Caster Bracket	Caster Bracket	2
10	Caster	Caster w/ 2.38 inch wheel	2

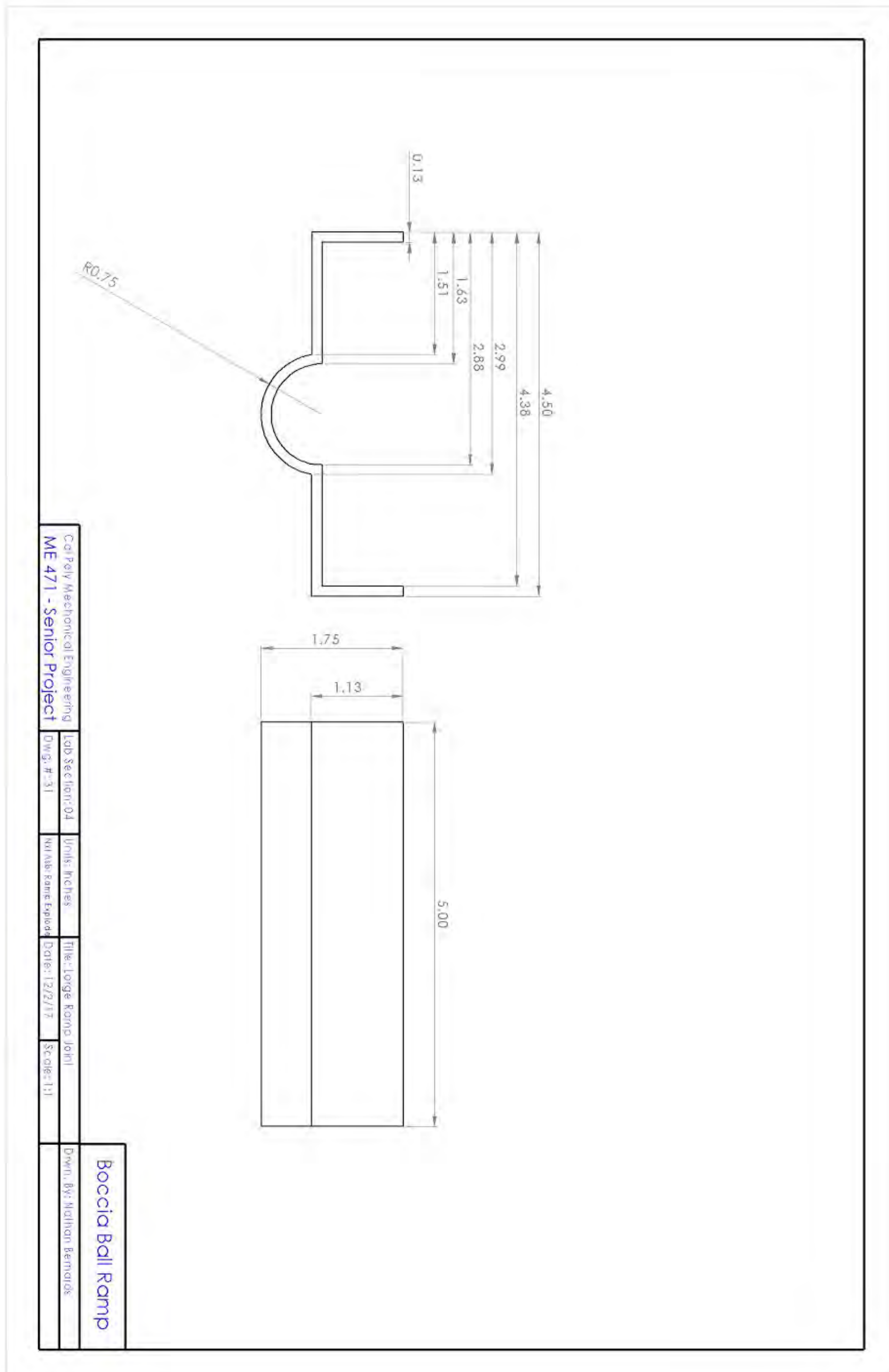
Boccia Ball Ramp

Cal Poly Mechanical Engineering	Lab Section: 04	Units: Inches	Title: Vertical Stand Exploded View	Drwn. By: Matthew Lee
ME 471 - Senior Project	Dwg. #: 27	Nxt Asb: Full Render	Date: 12/1/2017 Scale: 1:5	Chkd. By:


0.13
0.13
1.38
2.88
4.13
4.25
2.00
21.60
Cal Poly Mechanical Engineering
ME 471 - Senior Project
Lab Section: 04
Dwg. #: 28
Units: inches
Nxt Asb: Full Render
Title: Ramp Straight Rail
Date: 12/2/17
Scale: 1:2
Drwn. By: Nathan Bernards
Boccia Ball Ramp

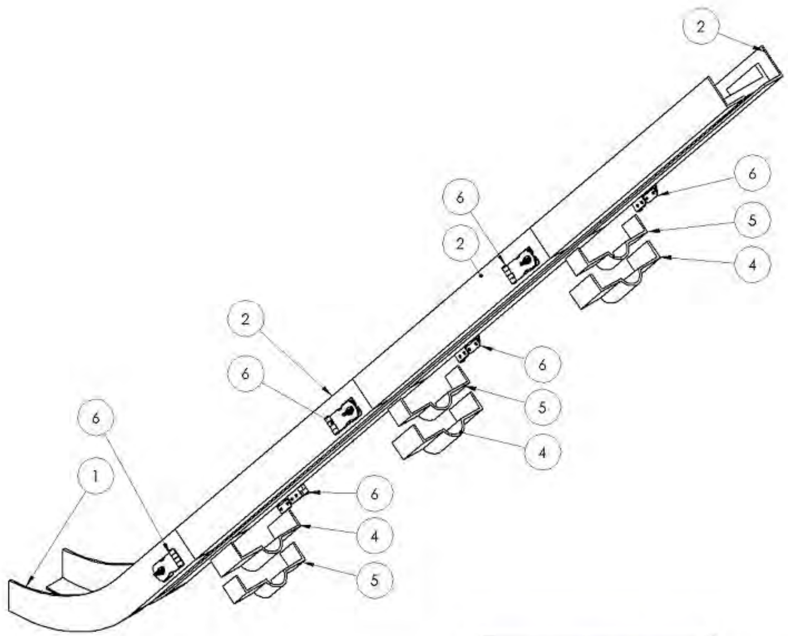

Boccia Ball Ramp
Drwn. By: Nathan Bernards
Cal Poly Mechanical Engineering
ME 471 - Senior Project
Lab Section: 04
Dwg. #: 29
Units: Inches
Title: Curved Ramp Section
Date: 12/2/17
Scale: 1:2
R11.39
R12.06
7.75
2.00
4.25
4.13
2.88
1.38
0.13
12.70
9.28
8.20
14.25
14.15


0.13
1.51
2.88
2.99
4.38
4.50
R0.75
1.75
1.13
1.50
Cal Poly Mechanical Engineering
ME 471 - Senior Project
Lab Section: 04
Dwg. #: 30
Units: Inches
Nxt Asb: Ramp Explode
Title: Small Ramp Joint
Date: 12/2/17
Scale: 1:1
Drwn. By: Nathan Bernards
Boccia Ball Ramp



0.13
R0.75
1.51
1.63
2.88
2.99
4.38
4.50
1.75
1.13
5.00
Cal Poly Mechanical Engineering
ME 471 - Senior Project
Lab Section: 04
Dwg.#: 31
Units: Inches
Nxt Asb: Ramp Explode
File: Large Ramp Joint
Date: 12/2/17
Scale: 1:1
Dwn. By: Nathan Bernards
Boccia Ball Ramp

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Bottom Rail 2		1
2	Middle Rail 2		3
3	Ball Pocket		[illegible]
4	Ramp Bracket		3
5	Ramp Bracket Small		3
6	Lock Hasp		6



Boccia Ball Ramp

Cal Poly Mechanical Engineering	Lab Section: 04	Units: Inches	Title: Ramp Exploded View		Drwn. By: Nathan Bemarde
ME 471 - Senior Project	Dwg. #: 32	Nxt Asb: Full Render	Date: 12/2/[illegible]	Scale: 1:5	