# Foam Wars II

**Sponsored by Dr. Kevin Taylor**

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# Contents

# Tables and Figures

## Executive Summary

The team producing Foam Wars II consists of three Mechanical Engineering students and five Kinesiology students (three the first two quarters and two the last quarter) at California Polytechnic State University, San Luis Obispo. The project is the second iteration of Foam Wars as a senior project at Cal Poly, sponsored by Dr. Kevin Taylor under the National Science Foundation grant. Persons with disabilities often feel limited when it comes to recreational activities and Foam Wars would provide them with an outlet to interact and engage themselves in a group setting. The game consists of various wheelchair attachments that would pit two teams of five players against each other, where the objective is to score points by launching foam balls into stationary targets placed around a typical regulation basketball court. The goal of the project is not only to improve upon the previous hardware, but to redesign and refresh the whole game to be more engaging and inclusive for its participants. This document will detail the rules of the game and follow the development of the necessary hardware to implement them.

# Chapter 1: Introduction

## Sponsor Background/Needs

The sponsor for this project is Dr. Kevin Taylor and the Kinesiology Department at California Polytechnic State University. Dr. Taylor has a deep interest in increasing the physical activity of people with disabilities, and has proposed several projects that pair kinesiology and engineering students to design and create equipment that is universally accessible. For example, a kayak was outfitted with a sip/puff system that allows quadriplegics to operate the kayak using only their mouth. Other projects involved a universal playframe that allows various attachments for many different sports. The success of these projects has impacted everyone involved in an extraordinary way, and has expanded the realm of what is possible.

## Formal Problem Definition

The desire to participate in engaging physical activities is universal, regardless of age, culture or physical ability. Unfortunately, there are a limited number of activities that are universally accessible that would make it possible for everyone to fulfill this desire. In 2009, a senior project group composed of six engineering students at Cal Poly attempted to tackle this problem by creating a game accessible to everyone. The result was Foam Wars I (FWI), a game in which carts fixed with foam-ball launching devices can be attached to a wheelchair with the objective of firing balls into goals mounted on the top of the carts. There were aspects of FWI that were successful, but ultimately the system as a whole had many shortcomings. For example, balls that missed their target would have to be collected by a bystander, the equipment could not be easily transported, and several other issues arose making it impractical for widespread use as was originally intended. Thus, our objective is to improve on the work done by the FWI team, and design sturdy, efficient equipment for a highly entertaining and exciting game that can be played by anyone. Our team is comprised of three senior Mechanical Engineering students and five Kinesiology students (three the first two quarters, and two the final quarter), and our final goal is to see Foam Wars played in Special Olympics and Physical Education classes across the country.

## Objectives/Specification Development

In order for us to be successful with this project, there are certain design requirements that we must adhere to. In terms of drafting these requirements, FWI provided useful information as to what works, and what does not. General concepts that can be utilized from the previous project are the ball launcher and the bungee attachment system; however the rest of the equipment and game rules will be

original. For this project, Dr. Kevin Taylor has given us defined objectives for what he wants to see at the end of this project. They are as follows:

**Ball retrieval system**: Explore the feasibility of mounting a ball retrieval device on the cart so that the user can move around the court and pick up balls on his/her own. This would force the user to move around the court (a problem in FWI, where a standoff between players was common), as well as remove the necessity for helpers to constantly chase balls around the court.

**Portability:** FWI featured two carts that were cumbersome. They did not collapse, did not fit through many doorways, and had to be transported off-site to Wheelchair Summer Camp in a flatbed trailer. Ideally, our design will be able to collapse and fit in a set of bags much like a tent, and all components for each team should be able to fit in the back of a minivan.

**Standard parts:** In case any of the equipment needs to be replaced in the future, all parts will be available locally or easy to manufacture. Replacing those broken parts quickly so that the product will function again is of the utmost importance. FWI featured parts that were not common, so it was difficult to find replacements when a part failed and cost a substantial sum of money to fix.

**Simple, yet engaging game play:** For a game to be successful, a certain level of strategy must be involved. In FWI the players often remained stationary and tried to shoot the ball into the opponent's goal while helpers chased the balls and reloaded the players' ammo supply. The game has the potential to be faster paced and entertain the players on a higher level. It also must remain simple enough to be taught in the short amount of time available to Friday Club members (a weekly event at the Cal Poly Rec Center for people with disabilities to gather and play games such as soccer and basketball) and similar environments such as a physical education class period. Even with this constraint, adding more aspects to the game, such as obstacles or higher point values for shooting the ball through the back of your opponent's goal, would enhance the game and bring more satisfaction and enjoyment to everyone involved.

**Table 1:** Project specifications listed with respective design considerations.

| Spec # | Parameter Description | Requirement or Target (Units) | Tolerance | Risk | Compliance |
|---|---|---|---|---|---|
| 1 | 100% uninjured participants | 100% | 0 | L | I |
| 2 | All game components fit in 2 trucks/vans when collapsed | 140 $ft^3$ | max | H | T |
| 3 | Weight of each position's components | <50 lbs | max | L | T, S |
| 4 | Propels balls | 35 mph | ±5 | M | A, T, S |
| 5 | Launch angle range | 0 to 30° | +5 | M | A, T, I, S |
| 6 | Projectile Distance | >30 ft | min | M | A, T, I, S |
| 7 | Game learning time | <10 minutes | +2 | L | T |
| 8 | 1 person can keep score | 1 person | 0 | L | I |
| 9 | Switch user | <1 minute | max | L | T, S |
| 10 | Retrieval carts collection rate | 5 balls/10 min. | ±2 | L | T |
| 11 | Structural component less than $25 to fix | <$25 | +10 | L | I |
| 12 | 80% of people surveyed say the game is fun | 80% | min | L | I |
| 13 | Participants per team | 5 | max | L | I |

Table 1 shows the main specifications that our team will strive to meet in this project. Next to the parameter description, in the 3rd column, is the value that we will attempt to reach or remain under, depending on the specification. The 4th column indicates the tolerance, or the range we will accept about that value, and the 5th column indicates how difficult we anticipate it will be to meet that requirement (L=Low difficulty, M=Medium difficulty, H=High difficulty). The final column indicates the method by which we will assess whether or not the requirement was met (I=Inspection, T=Testing, A=Analysis, S=Similarity).

From the first specification, safety as always is our number one priority. Through careful safety consideration during the design process, we will not allow any participants to be injured due to equipment failure. However it must be understood Foam Wars is a physical activity, and like any other physical activity, minor bumps and bruises may occur during game play. Specifications 2 and 3 detail the size and weight requirements. Portability is also one of the top considerations since the goal is to make Foam Wars available to athletes all over the country. Similarly, the weight is of importance because the carts will need to be lifted in and out of vehicles with relative ease. Specifications 4-6 detail the requirements of the launcher system. Based on the results from FWI and the space requirements of a basketball court, the values for speed, launch angle, and distance would be ideal to produce a game that

is exciting, yet safe. Kinematic analyses of these values can be found in Appendix A. Specifications 7-9 detail game play requirements: the game needs to be simple enough so that a new participant can learn the game in a short period of time and the scoring system needs to be straightforward so that only one person is needed to keep score. The FWI attachment system that features bungee cords worked very well and will continue to be used to quickly switch users. Specification 10 will absolve the need for extra helpers to retrieve balls that miss their target. Making ball retrieval a duty of one or more of the participants adds strategy and independence to the game. Next, specification 11 ensures that all structural components used will be replaceable at a reasonable cost. Lastly, specifications 12-13 deal with creating a game that everyone can become excited about. By involving five members on a team, the game will have an element of interdependence that will make all participants feel needed by their teammates.

Out of these specifications, we have two high risk considerations. These are the specifications that we will have to work particularly hard to meet. The volume of the collapsed carts is going to be a challenge. Portability is a top priority and being able to transport the cart components for each team in a van would be ideal. The other high risk specification is keeping the replacement cost of any structural part under $25. We will have to be clever with our designs and keep this cost consideration in mind throughout the design process.

A detailed analysis of our objectives can be found in our Quality Function Deployment (QFD) Matrix, located in Appendix B. A QFD matrix ranks specifications based on the importance of the customer requirements. The "% Importance" row is a relative ranking system that shows which specifications are most important.

# Chapter 2: Background Information

We began this assignment by doing background research on the first version of the project (Figure 1) to learn as much as possible from our predecessors. FWI consists of a frame made of aluminum and PVC covered in netting that forms a

**Figure 1: The completed Foam Wars I carts.**

protective cage which is then bungeed to a wheelchair. A box-shaped goal is mounted on top of this frame and a foam ball launcher is affixed to the side of the frame. The user then launches balls at opponents who have an identical setup on their cart. They also have the ability to alter the launch angle by raising and lowering the launching mechanism, and the objective is to score points by shooting the ball into the opponent's goal. The person with the most points at the end of the allotted time wins.

In addition to studying FWI equipment, we also spoke with Michael Lara, the sports coordinator for Special Olympics in San Luis Obispo County. Having witnessed Foam Wars in action, he was able to provide some input about the functionality of the game. Some of the main issues he mentioned included the difficulty of transporting the structures, inadequate scoring system, and the lack of a ball recovery. In the future, we plan to remain in close contact with him. We will also make frequent trips to Friday Club to get feedback from athletes for whom Foam Wars is intended.

We also took time to understand the American Disabilities Act (ADA) as it applies to our project. It will be important to incorporate the relevant dimensions for wheelchair accessibility that are outlined in the ADA into Foam Wars. For example, we must make sure that the users will have comfortable clearance for their arms and legs as well as easy access to launcher controls while their wheelchair is attached to the cart. For a more detailed description of the ADA, please refer to Appendix C.

Once we reached the brainstorming and concept development portion of the project, we turned to various sources in order to stimulate our creativity. Being that a main requirement is collapsibility, we turned to a book by Per Mollerup titled "Collapsible: The Genius of Space-Saving Design." This book features the "12 Principles of Collapsibility" and shows many examples of each. Our final design for the universal cart base came from a picture of an expanding easel. In addition to this source, we browsed sites such as youtube.com to investigate how existing products could be applied to our project. This included watching video of a tennis ball hopper in action for ball retrieval ideas and a recap of the 2009 First Robotics Competition (a program for high school students sponsored by NASA) for game design ideas. In order to gain a greater understanding of aspects that we were not as familiar with as we needed to be, we turned to Wikipedia.com. Such aspects included rivets for the universal cart base attachment method, and stepper motors for the trigger mechanism.

# Chapter 3: Design Development

## Method of Approach

The challenging problem that was presented to us requires a highly organized and purposeful approach in finding a solution. In addition to patiently progressing through a very deliberate series of steps, we must also remain open to iterate at every level. This will ensure that we stay on track by keeping the project close to the interests of our client. These iterations will generally occur as we discover issues with our design that conflict with feasibility or the customers' needs, and although it is a crucial part of the design process, we will attempt to keep the need to iterate at a minimum.

The first step of our approach was to fully understand the problem as defined by our client and identify the project requirements. Communication was the key to success at this stage. After the problem was fully understood, the needs outlined by the client were translated into project requirements with measurable specifications. This provides a tool for the future that can be used to test whether our design meets the original needs.

The next step in our approach was to conduct research in the area of the project. It is natural at this point to immediately begin thinking about solutions and want to begin building prototypes. However, restraint must be exercised in order to produce a quality product. Having background knowledge in unfamiliar areas such as disability awareness and the history of sports for athletes with disabilities proved vital in later stages of idea generation. Also, because this is the second version of Foam Wars, we had an advantage during this stage. The first group provided us a plethora of information in the form of research, design and testing that we are learning from and improving upon.

Once we had an adequate understanding of the fields related to the assignment, our next task was to brainstorm possible solutions. At this point we realized the importance of entertaining all ideas without putting much emphasis on considerations like cost and practicality of construction. The goal was to begin developing creative ideas without limiting ourselves based on preconceived notions. Some concepts that may be initially disregarded due to such mental barriers may eventually develop into plausible and unique solutions.

After considering various solutions generated during the brainstorming process, the next step was to narrow the list and select the best option. This was a difficult choice as it is not always obvious if a particular idea will work in practice or only in theory. However, by analyzing the strengths and weaknesses of different designs based on how well they fulfilled the project requirements, we were able

to identify our top choices. One of the main factors at this time was to make sure that the equipment we designed was based on an exciting game, instead of the opposite where a game was created around equipment that would be easy to engineer. By prioritizing the game aspect over the equipment, we feel the end product will best meet the customer's needs.

Following the idea generation stage, we began drawing concepts, being very thorough in thinking about all of the components and how they relate to the project requirements. It will save a lot of time and money to realize problems at this point while everything is still on paper. After developing concepts, we narrowed our ideas and selected a final design, analyzing the parts in detail and determining exactly what we will need to begin building the equipment.

Now that the equipment design details have been finalized, we will order parts from available manufacturers and build the system. The parts will be standardized and easy to replace in case they fail and need replacing or iterations are necessary. After building is complete, the design will be physically tested against the project requirements. Shortcomings will be identified and we will make modifications to improve the quality and functionality. In addition, once the carts are usable, we will bring them to Friday Club where athletes can provide us with feedback.

In the end, the underlying goal governing this project is to create an exhilarating game that is universally accessible. We plan to keep this final result in mind throughout the process and have modeled our approach to encourage the creation of a great game.

### Idea Generation and Design Process

Once the requirements were clearly understood, we began thinking of solutions to meet the customer's needs. We began this process by meeting Friday Club members and had them play with the FWI equipment. We then asked for their opinions on what they liked and disliked about FWI, and what they would like to see incorporated in the new design. It was interesting to see the project through the eyes of our target audience, and although we were only able to talk to a few people, we gained some valuable insight. Their main concerns were creating a fun game and designing robust equipment that would withstand the test of time. In addition to these somewhat casual conversations, we also held two brainstorming sessions in which we thought of solutions for our various subsystems (see results in Appendix D). During the first session, which consisted of only the engineering division of our team, we brainstormed retrieval systems, launching mechanisms, goal systems, and frame designs. During the second session, the kinesiology students joined the engineers and we brainstormed ideas for game rules

in addition to the previously mentioned topics discussed during the first session. Some of the ideas brought up during these sessions were questionable at best, but by delaying judgment until later, we opened ourselves up to come up with creative solutions. Next we began the slow and deliberate process of carefully analyzing and discussing each idea in order to determine which ones would end up in our final design. With the long list of ideas that we had compiled for each subsystem, we narrowed our list by discarding concepts that would surely not meet the given requirements.

To organize our approach, the requirements of the equipment needed for Foam Wars were broken down into 3 different sub systems: the ball launcher, the ball retrieval system, and the frame, and final concepts were selected using decision matrices**.** A decision matrix rates each requirement of the system against a datum point (possibly an existing design) as better, worse, or same. From the ball launcher's decision matrix (Table2), we determined that using the tennis ball pitching machine from FWI would be the best solution, with slight modifications to increase the robustness of the system. One of the main issues we anticipate with the other options is inconsistency. The pitching machine would constantly be running so a ball would be launched simply by entering the chamber, whereas the other ideas would require complex reloading, cocking and triggering mechanisms.

**Table 2: Decision matrix for ball launcher**

| Criteria | Weight | Nerf Gun | Pneumatic Gun | Potato Canon | Crossbow | Mod. Pitching Machine | FWI Pitching Machine |
|---|---|---|---|---|---|---|---|
| Consistency | 5 | 1 | -1 | -1 | -1 | 1 | D |
| Loading Speed | 5 | 1 | -1 | -1 | 0 | 1 | |
| Minimal Outside Intervention | 3 | -1 | 0 | 1 | -1 | 1 | A |
| High Initial Velocity | 4 | -1 | 1 | 1 | 1 | 0 | |
| Safety | 2 | 0 | -1 | -1 | -1 | 1 | T |
| Weight | 2 | 1 | 1 | -1 | -1 | 0 | |
| Size | 2 | 1 | 1 | -1 | -1 | 0 | U |
| Easy to Aim | 4 | 1 | 1 | 1 | 1 | 1 | |
| | **Sum** | **14** | **0** | **-5** | **-6** | **19** | M |

From the ball retrieval system's decision matrix (Table 3), a completely autonomous system for collecting and reloading balls was abandoned in favor of a human helper to reload the balls into the cart. This decision increases reliability of the system at the cost of adding *some* element of outside assistance required to run the game. We received confirmation from the customer that this sacrifice would produce a better overall product.

**Table 3: Decision matrix for ball retrieval system**





| Criteria | Weight | Tennis ball Collector | Snow plow | Conveyor belt (Velcro) | Driving range golf ball collector | Other people |
|---|---|---|---|---|---|---|
| Feasible | 5 | 1 | 1 | 1 | 1 | |
| Low cost | 2 | 1 | 1 | 1 | -1 | D |
| Transport ball from game arena to re-load station | 5 | -1 | 1 | 1 | -1 | A |
| Manufacturability | 3 | -1 | 1 | -1 | -1 | T |
| Minimal noise produced | 3 | 1 | 1 | 1 | 1 | U |
| Minimal Volume when stored | 4 | -1 | -1 | -1 | -1 | M |
| Weight | 3 | 1 | 1 | -1 | -1 | |
| **SUM** | **-** | **1** | **17** | **5** | **-9** | |

From the decision matrix for the frame (Table 4), the modular design was the clear winner. Instead of forcing all components into one system, the frame was separated into the subsystems, making the equipment as a whole much more portable than the other ideas. It also increases the practicality of the design because if one subsystem fails, Foam Wars could still be played using the rest of the equipment.

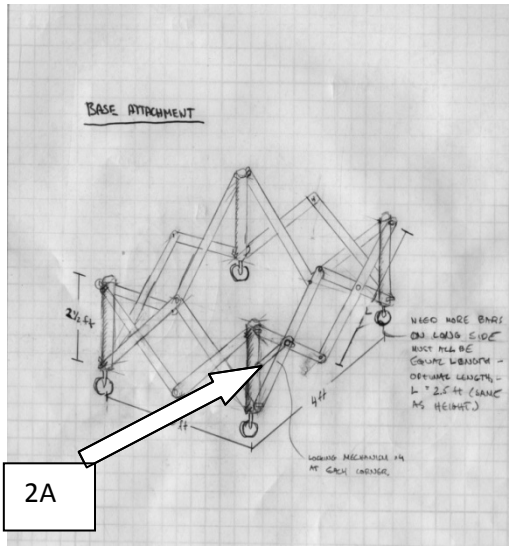
**Table 4: Decision matrix for base cart frame**

**Table 4:** Decision matrix for base cart frame.




| Criteria | Weight | Tent-Pole | Telescoping | Accordion | Modular | Foam Wars I |
|---|---|---|---|---|---|---|
| Portability | 5 | + | + | + | ++ | D |
| Lightweight | 3 | + | + | + | + | A |
| ADA compliance | 2 | S | S | S | S | T |
| Manufacturability | 4 | + | + | - | + | U |
| Quick user attachment | 2 | S | S | S | S | M |
| Durability | 3 | S | S | - | ++ | |
| **Total** | | 12 | 12 | 1 | 23 | - |

Several complete concepts were generated incorporating the selected subsystem designs (Appendix E). The winning designs from the decision matrices were combined with primary considerations for portability and weight to aid the ease of transportation, considering up to 10 carts must be moved at a time. Now that solutions for the customer's requirements were beginning to take shape, sketches of initial concepts were made. Figure 2 shows the initial base attachment. The four walls expand and collapse similar to a hat rack and are locked into place by an arm hinged about the corner posts (2A). The Cage attachment shown in Figure 3 has four posts with netting wrapping around them that slide into the base attachment during assembly and are locked in place during game play (3A).




**ent Initial Design**

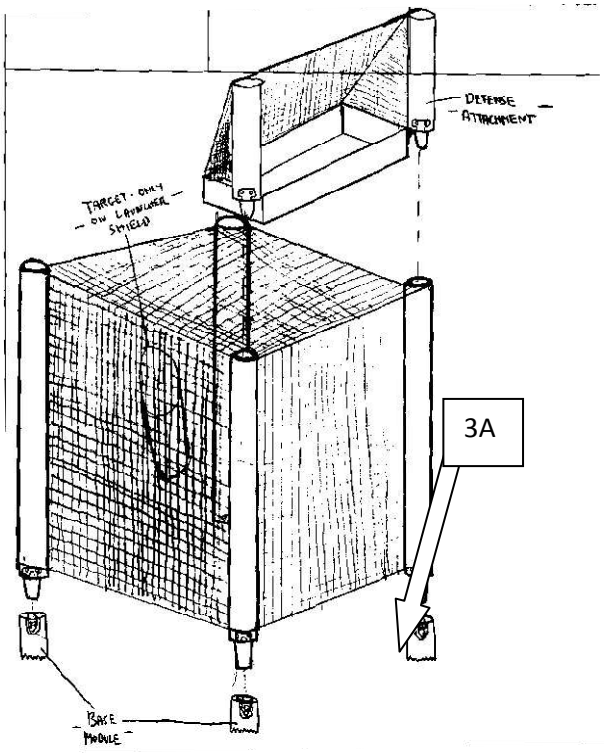



**Figure 3: Cage Attachment Initial Design**

The retrieval attachment (Figure 4) initial design has the shape of a snowplow and attaches to the front posts of the base cart. Finally, the launcher attachment (Figure 5) is the subsystem that has demanded the most consideration up to this point in the design process. There are many components to the launcher assembly and special issues to keep in mind such as the fact that we cannot collapse the odd-shaped pitching machine. The attachment shown has a similar collapsibility feature as the base cart, and has a plate on which the pitching machine and ball reservoir will be mounted.

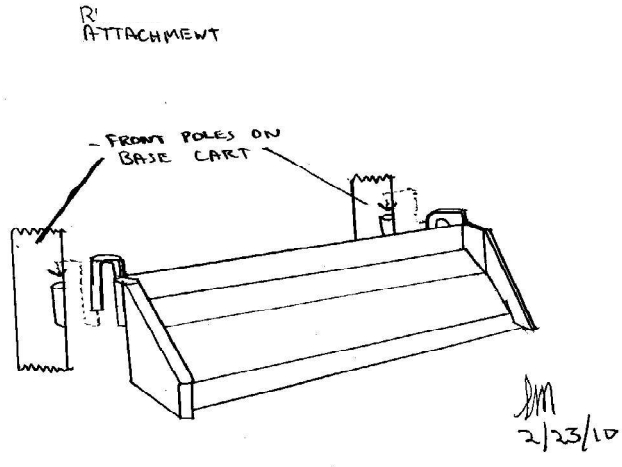



**Figure 4: Retrieval Attachment Initial Design**

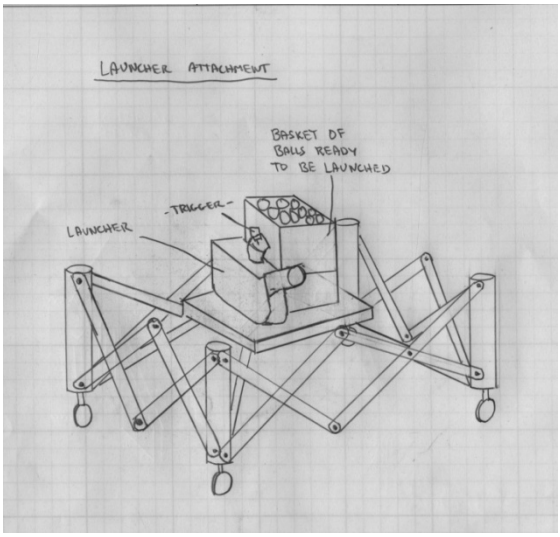



**Figure 5: Ball Launcher Attachment Initial Design**

# Chapter 4: Description of Final Design

## Overall Description

They key breakthrough in our design process was separating the subsystems. By giving different components and duties to multiple players, rather than having an all-encompassing “super cart”, teamwork and strategy become integral to the game. This leads to a more fun and exciting game as players must rely on each other and have the opportunity to master certain positions, similar to the way a quarterback and running back in football have unique yet mutually dependent roles. The five main pieces of equipment include a universal cart base, a protective cage for the launcher and defense players, a ball retrieval attachment, a goalie attachment, and a launcher attachment. These pieces are assembled to create three different positions played by five players on a team. Two players will be ball launchers (Figure 8), two will serve as ball retrievers (Figure 6) and the final player will play goalie(Figure 7).

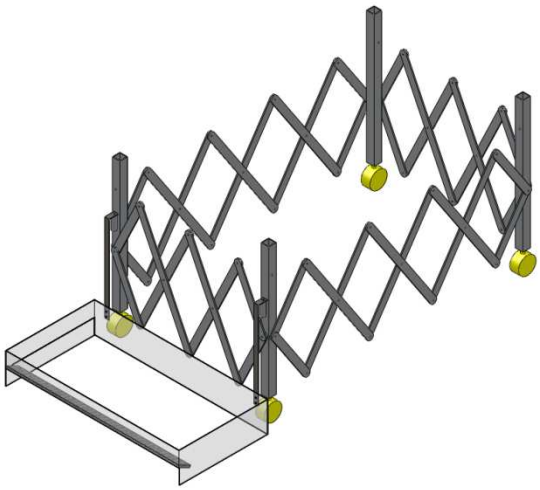


**Figure 6: Retrieval Attachment Final Design**

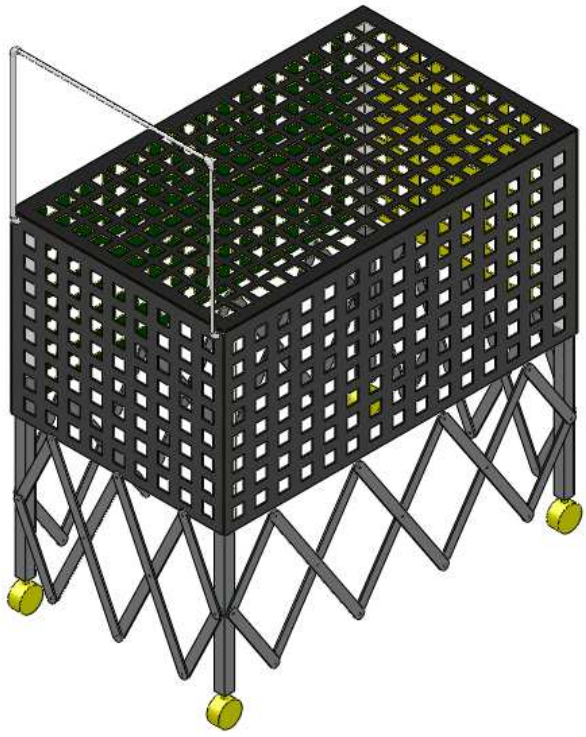


**Figure 7: Goalie Attachment Final Design**

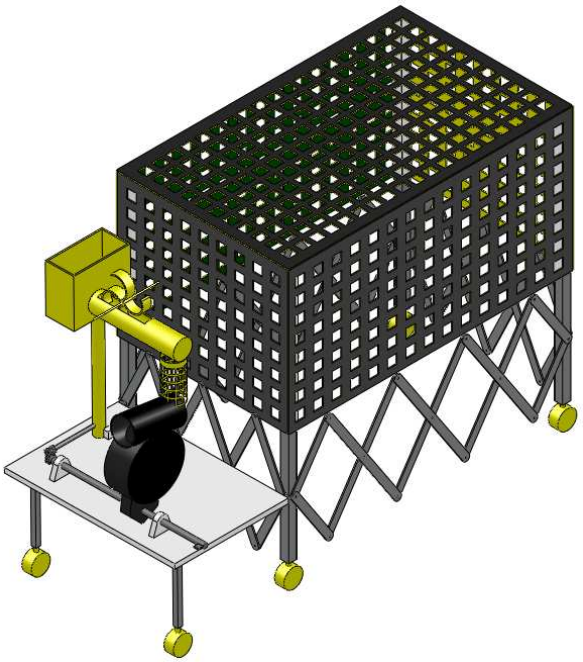


**Figure 8: Launcher Attachment Final Design**

## Detailed Design Description

The universal cart base is composed of four expanding/collapsing sections. When expanded (Figure 9), a sturdy rectangular base on wheels is formed. To keep the base expanded during game play, a bar will be locked into place. When collapsed, (Figure 10) the unit takes up a minimal amount of space, approximately 0.75' x 1' x 2.5' (note that wheels are not shown in this figure). Since there will be more of these bases than any other subsystem, the collapsibility of this part is especially important. An additional benefit to this design is that if a full set of ten is being stored or transported, they can nest within each other to minimize space. To do this collapse one base cart, place it in the middle of the next base cart, and collapse the second base cart around the first. This may be helpful depending on the geometry of the vehicle used for transporting the equipment. The cage attachment (Figure 11) is a simple design consisting of four poles with netting in between that fit into the universal cart base and are latched into place. On the back side of the cage attachment for the launcher cart is small net target about the diameter of a basketball. However on the goalie cart, an additional catching attachment is affixed on top of the cage attachment (Figure 12). If the goalie is able to intercept the opponent's ball, extra point(s) are awarded.

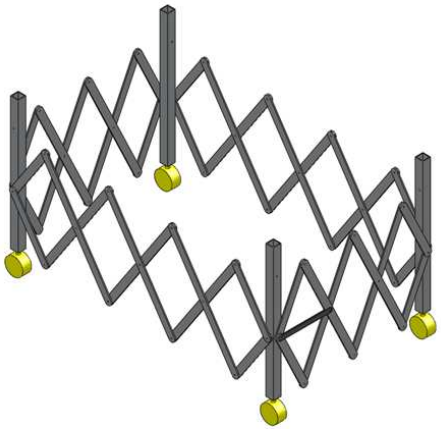


**Figure 9: Expanded Base Cart**

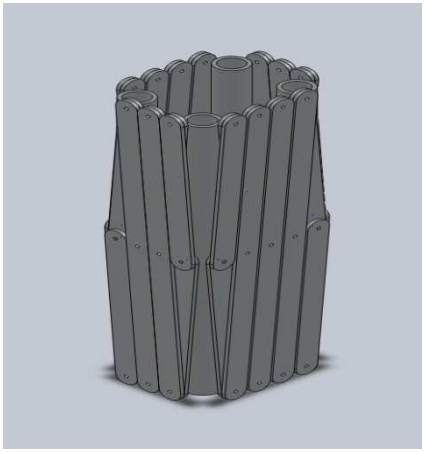


**Figure 10: Collapsed Base Cart**

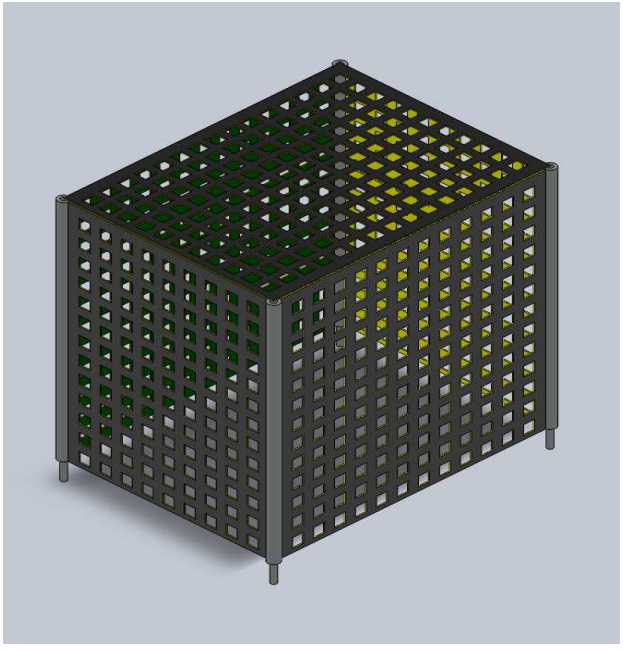


**Figure 11: Cage Attachment**

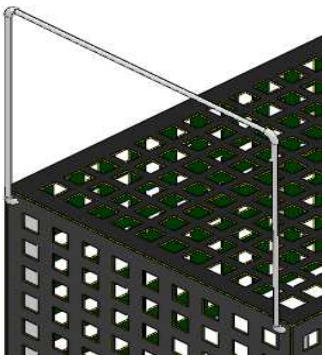
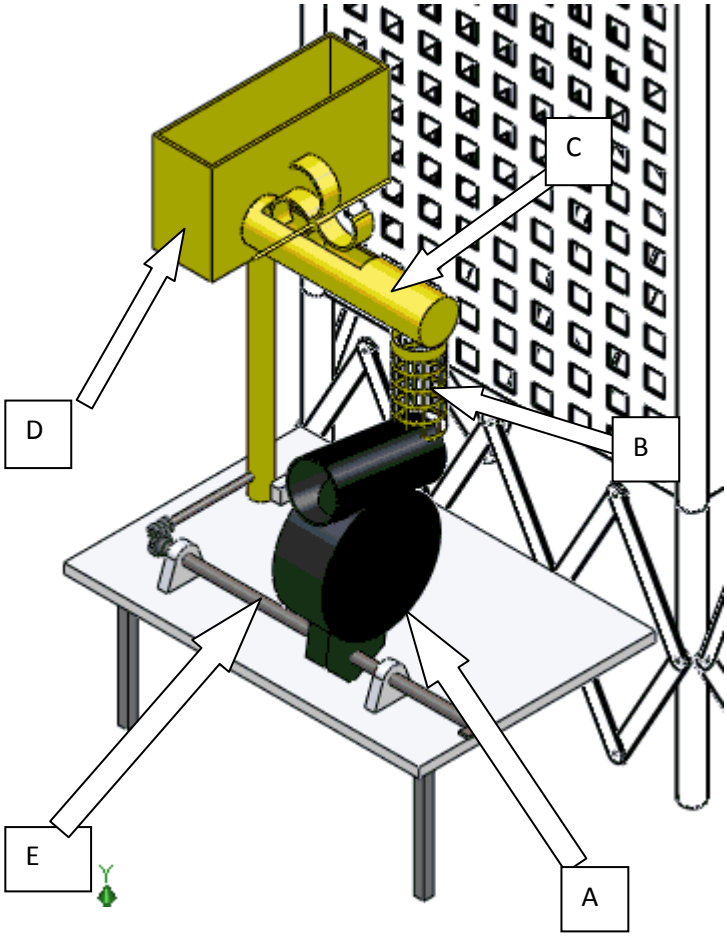


**Figure 12: Defender Attachment on top of Cage Attachment**




The launcher attachment (Figure 13) consists of a pitching machine (A) and loading assembly, and is mounted on a base that is easily attached to the universal cart base. This funneling net (B) feeding tube (C) and ball reservoir (D) will be clear so that the player can clearly see how much ammo they have remaining before needing to visit the reloading station. A trigger mechanism is used to consistently release one ball per button depression, and finally, a steel rod is fixed to the base of the pitching machine (E) which rotates, allowing the user to change the launch angle.

**Figure 13: Launcher Attachment**

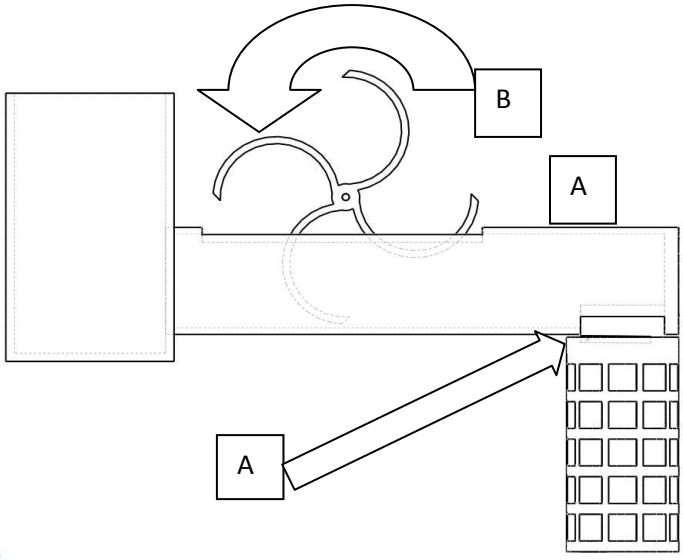



**Figure 14: Detail of Loading Assembly**

For a clearer understanding of the loading assembly, please refer to Figure 14. When the player presses the fire button on their remote, a horizontal flap located at (A) rotates down out of the way, releasing a ball to fall down through the pitching machine and launch. After a short delay of about 1.5 seconds, the turnstile (B) rotates one quarter turn, loading the next ball into the chamber. This design allows a ball to fire instantaneously, and prevents players from firing all their balls at the same time.

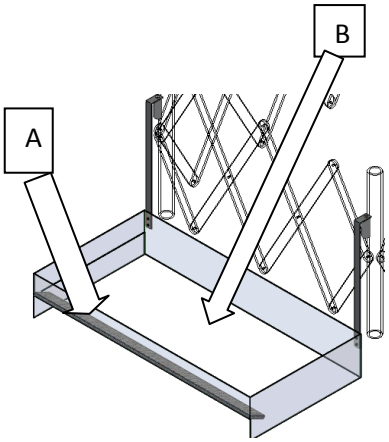



**Figure 15: Retrieval Attachment Final Design**

The retrieval device (Figure 15) attaches directly to the universal cart base. At the front end (A) there are paint brush bristles angled backwards towards the base cart so that balls can enter the collection area (B), but not exit if the cart moves backwards. The player must collect the balls with the attachment and push them over to the reload station where a neutral assistant will move the balls from the retriever to the launcher cart. This requires a certain amount of skill by the player to quickly maneuver around other players and provide ammunition to their teammates.

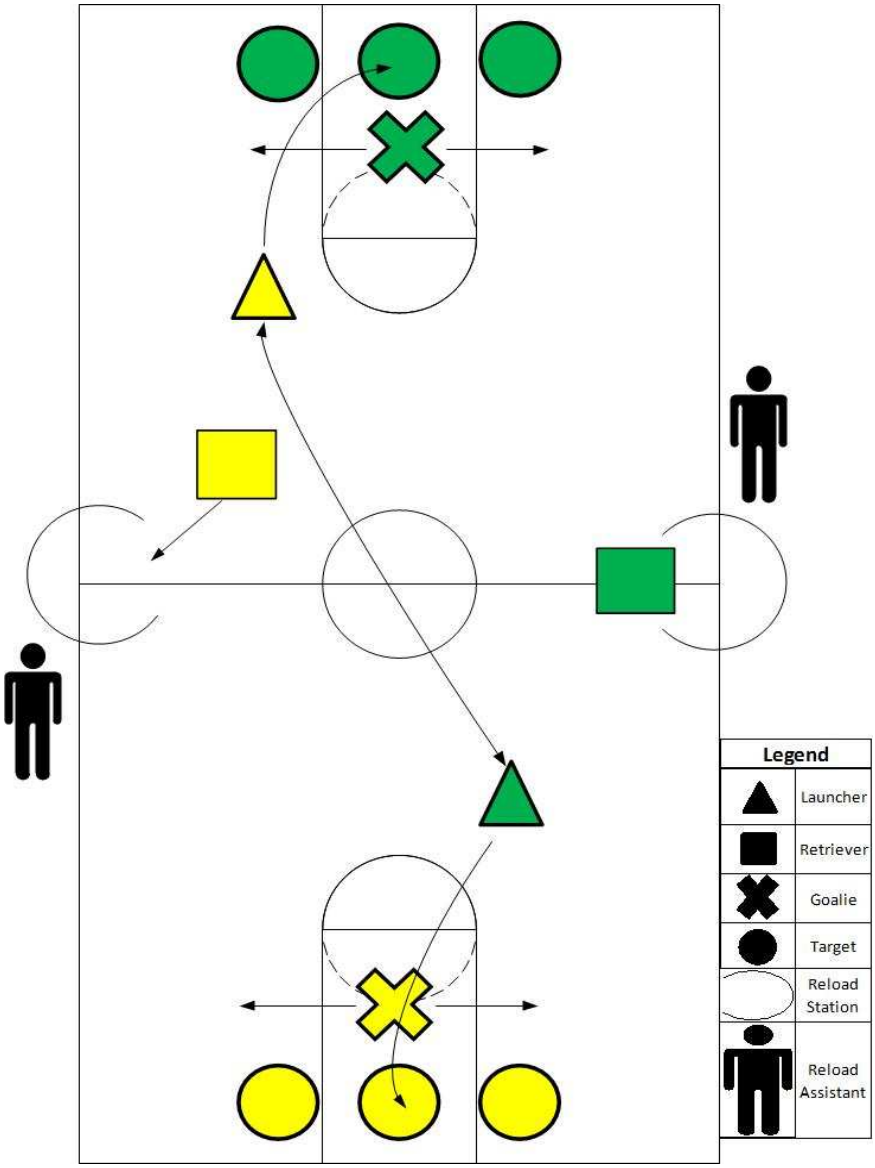



**Figure 16: Overhead View of Game Layout**

As for the game rules (Figure 16), three players will be on each team and it will be played in a gym. Three hoop goals will be at each end of the gym and will be defended by the defensive goalie cart. A reload station will be on each sideline at half court, consisting of a circle on the ground, a bucket, and a neutral assistant. This helper will put the balls collected by the retrievers into a bucket and when a launcher needs balls, they will be reloaded. The players must be within the circle to receive assistance. When the launcher cart shoots a ball through either of the three hoop goals of the opposing team, one point will be awarded to the launcher's team. When the ball is captured by the goalie in his/her attachment, one

point is awarded to the goalie's team. Finally, when the ball is shot into the goal of an opposing team's launcher cart, five points will be awarded. During the game, an official scorekeeper will stand at each end of the court and count the balls that pass through the hoops. After the game is over, they will then count the number of balls in the launcher cage attachments to determine the final team score.

## Analysis Results

This design of the game and equipment fully meets the requirements as defined by the customer. The game play requires teamwork and is exciting while the equipment is robust and collapsible, making Foam Wars practical for many different organizations and institutions. Now that the game and equipment have been designed, testing must ensue to confirm that we have met our objectives.

## Analysis to be Conducted (as of 4/23/10):

Substantial analysis and testing will be required for the base cart. Because every cart is built upon an identical base cart, any repeated failures with significant downtime would be catastrophic to proper game play. To ensure strength and reliability for this component, a combination of formal engineering analysis and prototype testing will be employed. Standard structural analysis will be applied to each part in the base cart to eliminate the possibility of bending or fracture in the members and joints upon impact. Extensive impact testing will be applied to a prototype base to confirm engineering analysis.

Due to the simplicity and low cost of the ball retrieval design, a prototype will be made to test on a basketball court surface to ensure the attachment can successfully collect and retain foam balls.

Designing a consistent and robust trigger mechanism for the launcher has proved to be a complicated and design intensive process. It was a major weak point of the first Foam Wars iteration which we intend to correct. With the help of Dr. Ridgley and Dr. Murray, Mechanical Engineering professors at Cal Poly with mechatronics expertise, we will select an appropriate motor and microcontroller to ensure a reliable single-button-press firing system.

Dr. Taylor put us in contact with a consultant that provided us with some alternate solutions for some of the components. Mark Theobald, a highly talented engineer with experience developing adaptive equipment, sent us some part drawings for a ball loader

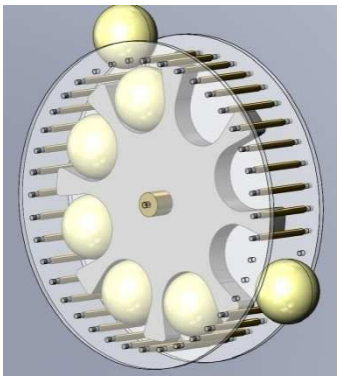


**Figure 17: Mark Theobald's ball loader concept**

system (Figure 17)and a ball retrieval system (Figure 18). A benefit to his version of the ball loader is that instead of requiring two motors (one for the turnstile and one for the release flap) one motor would suffice. The ball reservoir and pitching machine would not have to be modified from the current design to incorporate his version. As we continue to research the electronic components necessary we will keep this alternate solution in mind. The ball retrieval that Mr. Theobald suggested is much more complex than our design and would require a motor and various moving parts. Therefore we will keep this alternate solution in mind as well, but are far more inclined to stay with the current design in this case. Dr. Taylor has also put us in contact with John Lee, a rehabilitation technologist at the Central Coast Assistive Technology Center who suggested a specific sip-puff mechanism from a company called Origin Instruments. Adding the sip-puff mechanism to control the launcher would further expand the user base of the game and allow more people to participate. Collaboration with Mr. Lee will be required to select and calibrate an appropriate remote for controlling the launcher.

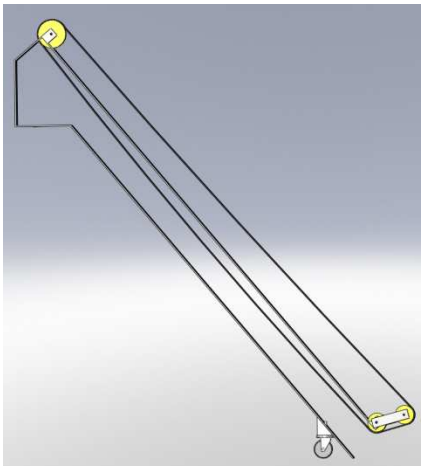


**Figure 18: Mark Theobald's retriever concept**

Once we have prototypes of all the components, we will verify that the equipment collapses and expands properly and all subsystems interact seamlessly to form one cohesive system. We will test the launcher and trigger extensively to test durability and confirm that one ball is consistently released at a time and that the speed is approximately the same for each launch. Once all the equipment is built, we will test the game itself to make certain that there are no glitches or unnecessary inconveniences in how the game is played. To accomplish this we will survey the players and make sure that they feel the game is fun.

## Cost Breakdown (as of 4/23/10)

In order to make Foam Wars feasible for as many people as possible, it must be designed to be available relatively cheap. This includes prices for both parts and prices for manufacturing considerations such as cutting and machining. Although we are working with a fairly lenient budget in terms of what is available from our sponsor, our aim is to be as cost-efficient as possible. Therefore, Table 5summarizes our anticipated costs. A more thorough cost analysis for each component can be found in Appendix F. The two tables below show the current prototype cost as well as the estimated project cost. We are currently ready to spend $296.12 to build one prototype each of the Cage, Goalie and Retriever Attachments, and Base Cart. Building these prototypes will validate our designs and

highlight any design flaws that exist at a relatively cheap cost to our sponsor. Once further research has been conducted on the launcher attachment, we will compile a new cost analysis and prototype the launcher attachment as well.

| Current Prototype Cost | | |
|---|---|---|
| Component | Qty. | Total Cost |
| Base Cart | 1 | $116.91 |
| Cage Attachment | 1 | $134.00 |
| Goalie Attachment | 1 | $16.58 |
| Retreiver Attachment | 1 | $28.63 |
| **Total Prototype Cost:** | | **$296.12** |

**Table 5: Cost Breakdown for Prototyping**

| Total Estimated Project Cost | | | |
|---|---|---|---|
| Component | Qty. | Cost/Unit | Total Cost |
| Base Cart | 10 | $116.91 | $1,169.10 |
| Cage Attachment | 10 | $134.00 | $1,340.00 |
| Goalie Attachment | 2 | $16.58 | $33.16 |
| Retreiver Attachment | 4 | $28.63 | $114.52 |
| Launcher Attachment (Structural) | 4 | $236.04 | $944.16 |
| Launcher Attachment (Electronics) | 4 | ~$200.00 | $800.00 |
| Labor | 10 | $17.00 | $170.00 |
| **Total Component Cost:** | | | **$4,570.94** |

**Table 6: Cost Breakdown for Entire Project**

### Material, Geometry, Component Selection and Basic Manufacturing Plan

Specifying the correct materials for each component of the carts is crucial to avoiding failure and costly repairs. Considerations for material selection include reliability, reasonably easy maintenance and repair, as well as keeping weight and cost to a minimum.

The base cart is the most important consideration, because it must be able to withstand impact loads in case of collisions, as well as support the weight and mounting of each of the various attachments. For added durability, the base cart will be constructed using aluminum square tubing for each corner post and flat aluminum plates for each side. This will increase reliability, stability and impact strength over standard PVC pipe. To ensure smooth and repeatable collapsibility with minimal effort, rivets and will be used to secure the joints. The materials needed are all readily available from three sources: McMaster Carr (online), McCarthy Steel (San Luis Obispo), and Home Depot. After acquiring materials, assembly will require cutting the stock aluminum to necessary lengths, drilling holes in the plates and posts, and fastening everything together using rivets and bolts.

The cage attachment will use similar square tubing, however, the lesser strength requirements of the assembly will allow for standard PVC parts to complete the frame. Strong netting will be used to maintain the shape of the cage and protect the participant from incoming fire. The goalie interceptor attachment will be constructed in a similar fashion using PVC tubing and netting. These attachments will

be the simplest to assemble. The PVC tubes will be cut to the necessary. PVC elbows will be attached to the cage attachment with J-B Weld. The netting will be attached with zip ties on all sides of the cage and goalie attachments except the rear of the cage, where a plastic utility hook will allow this flap to be temporarily fixed during game play. This makes it so the entire cage attachment does not need to be removed to switch users.

The retrieval attachment can be constructed from a readily available under-the-bed plastic storage container. The front of the tub will be cut out and acrylic flaps will be hinged to allow a one-way gate to allow balls to enter, but not exit. The acrylic flaps are held at an angle by nylon strapping. The retriever attaches to the base cart with 6" hooks that fit into eyes located on the inside face of the base cart posts.

Finally, the complex launcher attachment consists of many parts to be acquired from a variety of manufacturers as detailed in the cost analysis in Appendix F. The pitching machine will have a hole drilled through the base and attached with JB Weld to a steel rod which is fixed to the base plate with bushings. The reservoir box will have a hole drilled in the bottom corner (for the feeding tube) and glued to the top of the telescoping post. The feeding tube will have a slot cut into the top for the turnstile and the net will be glued to the end of the feeding tube. A Velcro strap at the bottom of the net will allow temporary attachment to the pitching machine during game play. Unstrapping the Velcro will allow the telescoping tube to collapse, making transportation easier. The folding legs will be attached to the base plate with the provided screws. 

### Special Safety Considerations

As with any engineering design, safety is a very important consideration. FWI provided a great deal of security to the players due to the netted cage design. The players really enjoy this feeling so we will continue to use this design for the launcher and goalie carts where they either have targets on them or are defending targets. The retrieval position is not designed to be outfitted with the cage attachment but if a player wants that protection, it is easy to accommodate that request because the player already has the universal cart base. (Update: The retrievers will have cage attachments at all times.)

As for other safety considerations, foam balls will be used. When shot at 35-50 mph (max) they would be felt but would not leave any permanent damage. All pinch points and sharp edges will be either removed during assembly or be made obvious to helpers and players alike through warning

labels. All electrical equipment will be of the highest quality and risk of shock will be minimized by placing these components inside a plastic box. 

### Maintenance or Repair Considerations

Many projects on the NSF grant have featured complicated, custom components that are difficult to replace. Therefore, “standard, replaceable parts” is a primary customer requirement set forth in the early stages of the project. In order to satisfy this requirement, we are going to feature components that can be purchased locally or online, or that are easily manufacturable. Consequently, if a part breaks, it can be replaced quickly so that Foam Wars can continue to be played. Additionally, because the various aspects and responsibilities of the game are split into multiple components, an incomplete set of equipment can still be used. As for maintenance, we will know more once the building and testing phases have commenced. 

## Chapter 5: Design Verification Plan

### Test Description and Necessary Equipment

The testing procedure will be organized based on four categories: launching, defending, retrieving, and collapsing. For the launcher, various tests will be performed to confirm that the launch distance, speed, and angle meet our design specifications. We will also test the trigger mechanism rigorously to verify that exactly one ball is released per button press and that the time between button press and ball launch is minimal.

For the retrieval cart, a prototype will be constructed to test for adequate performance. The retriever attachment must mount up cleanly to the base frame, and also consistently recover balls it runs over without letting any escape. A separate test will determine if the amount of time to unload the collected balls into the retrieval zone is adequate not to unnecessarily stall game play.

For the goalie cart, a test will be run to make sure that the interceptor attachment will mount correctly to the cage attachment. Separate tests will also be run in order to determine if the interceptor will be able to catch and hold opponent’s shots without falling out, so that they may be counted towards the team’s points at the end of the round, and to determine if the maximum amount of balls the interceptor can hold will be adequate for proper game play.

Collapsing and transporting is a primary customer requirement for this project. Testing for this will consist of the following processes. First, each disassembled component will be weighed to make

sure that it is less than 50 pounds. Next, all components for one team will be collapsed to their minimal state and tested for volume. This will be done by fitting them into the back of a van (approximately 3' x 3' x 5'). Finally, a group of volunteers will be gathered to test set up time for the game from 100% collapsed components in van to 100% assembled components on the court.

**DVPR**

In order to properly test our equipment, we created a Design Verification Plan and Report for each of the main subsystems as well as one for collapsibility/transportation concerns. A DVPR outlines all the testing required to make sure all the specified requirements have been met. This outline includes a description of the test to be performed, defining what is required of the component to pass the test, who is responsible for conducting the test, how many and which parts will be tested, and when the testing will occur. In addition, once we have completed the test, the DVPR will also contain the results and whether or not the tests were passed. The details are provided in Appendix G.

# Chapter 6: Management Plan

The team working on the Foam Wars project includes three engineering students and three Kinesiology students. Our engineering team consists of three undergraduate mechanical engineering seniors - Sumant Advani, Sivadas Menon, and Casey Pieplow – who are responsible for designing and constructing the wheel chair attachment to be used in the game. Our Kinesiology counterparts are Lisa Martin, Theresa Field, and Eduardo Rivas (first two quarters) and Courtney Mahaffey and Lauren Granadino (last quarter). Their job is to design and implement the rules of the game for the participants. Since these two processes are dependent on one another, communication between the two groups is vital. The roles for each member of the engineering team are as follows:

Casey Pieplow is in charge of documenting team progress and identifying possible roadblocks that may arise. His duties include updating status reports and organizing team meetings. He is responsible for the cage, goalie, and retriever attachment construction, as well as helping out with the construction of the launcher attachment frame.

Sivadas Menon is our communication liaison, and is responsible for maintaining contact and coordinating with our Kinesiology department counterparts and our team and faculty advisers. Sivadas is the mechatronics master on the project and is responsible for the construction of the launcher attachment.

Sumant Advani is our resource investigator, in charge of finding new resources and contacts, and researching and complying with ADA standards. Sumant monitors team progress by coordinating and monitoring tasks among the team. He is in charge of the construction of the base carts.

Although each of us has our own specific tasks, our collaborative goal will be to produce certain deliverables by the following dates. A more comprehensive timeline can be found in Appendix H.

| | |
|---|---|
| Concept Design Report: | February 25, 2010 |
| Design Report Draft: | March 14, 2010 |
| Critical Design Review Presentation: | April 8, 2010 |
| Final Design Report: | April 22, 2010 |
| Project Update Report: | June 3, 2010 |
| Final Hardware Demo: | November 8, 2010 |
| Senior Project Design Expo: | December 2, 2010 |

# Chapter 7: Product Realization

Figure 19: Complete Retriever Position

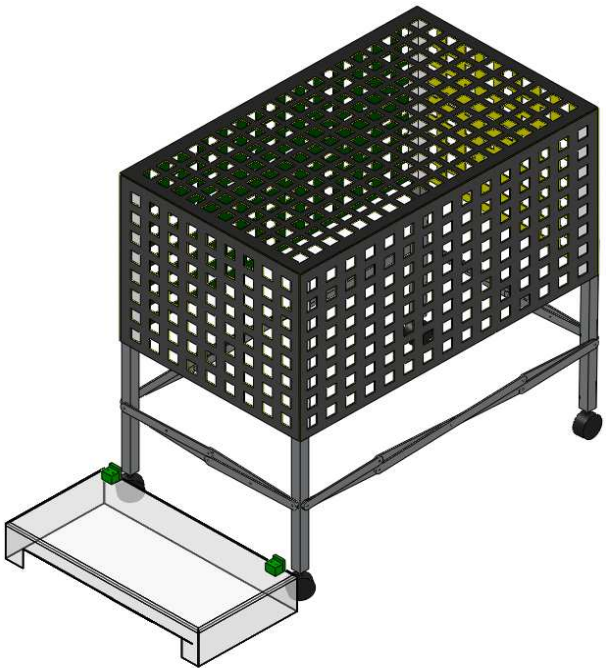


Figure 20: Final Design of Complete Retriever Position

Figure 21: Complete Goalie Position

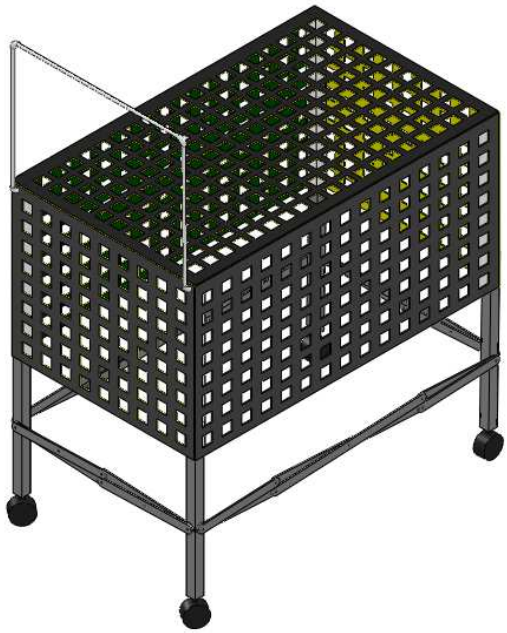
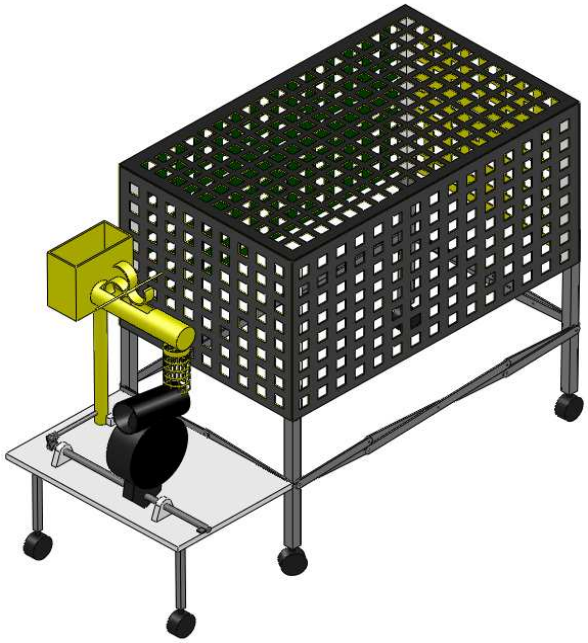


Figure 22: Final Design of Complete Goalie Position



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## Base Cart

### Detailed Manufacturing Breakdown

ir attached

1. For 1 ¼” x ¼” aluminum flat bar, cut:
   a. 4 x 30.5” Lengths (L)
   b. 8 x 18.5” Lengths (M)
   c. 8 x 16.0” Lengths (S)
2. Deburr and round all sharp edges and corners
3. Drill ¼” holes at ¾” from each end, as well as in the center of the 4 longer bars
4. For 1 ¾” square tubing, cut:
   d. 4 x 30” Lengths
5. For each square tube piece, drill a through hole at 15” from bottom edge and 16.5” from bottom edge on adjacent face
6. On the face with the hole at 15” from bottom edge, drill a 3/16” hole 6” from bottom edge.
7. Thread each hole with ¼” – 20 tap and handle
8. For the sides of the base cart, assemble 2 L bars and 4 S bars in accordion pattern

9. Cut 2 8” lengths of double sided Velcro and drill ¼” hole at one end. Position over the top two joints where the L bars meet the S bars
10. Rivet each joint using ¼” aluminum rivets, except each end where the S bars meet
11. For front/back of the base cart, assemble 4 M bars in diamond pattern
12. Cut 1 8” length of double sided Velcro and drill ¼” hole at one end. Position over top joint of diamond
13. Rivet top and bottom joint using ¼” aluminum rivets. Leave each end
14. Assemble base cart by fastening the ends of each accordion/diamond assembly to square tube corners posts with 2 ¾” bolts, ¼” washers and corresponding lock nuts. Do not tighten all the way. Long accordion assembly connects to 15” high holes and short diamond assembly connects to 16.5” high holes
15. Cut 4 9” length of 1 7/16” square wood and drill 15/32” holes 1” deep in the bottom of each piece
16. By hand, screw wheels into each length of wood. Holes will thread themselves. Slide each length into bottom of corners posts of base cart.
    e. Note: If the wood pieces do not easily slide in, take a file and thoroughly deburr the inside edges of each corner post
17. Fix each wheel assembly to base cart by drilling 1/8” wood screw through remaining holes in corners posts. Make sure wheels are flush with bottom of base cart before fastening
18. Expand base cart to fully open position (with flat bars completely straight) and fully tighten all 8 bolts until assembly is completely rigid. Wrap all 6 Velcro straps tightly around each joint
19. To collapse base card for transport, unwrap all 6 Velcro straps, loosen all 8 bolts 2 turns and push to collapsed position. Tighten each bolt 2 turns.

## Differences from Design

After constructing the prototype for the universal base cart, several areas showed potential for improvement.

ase Cart Collapsed

Rivets at the corner posts proved insufficiently stiff enough to support the cart in an upright position, so they were upgraded to ¼” x 2 ¾” bolts with matching nylon lock nuts. This design change eliminated the need for a locking arm to latch the cart in place, since the bolts could simply be torqued down with the cart in the desired position. While this improves robustness of the cart, it slightly increases the setup time required. Having two people expand each cart is ideal and reduces setup to an acceptable time.

After examining the prototype model, the riveted joints were found to be the weakest point of the design. The amount of riveted joints was reduced by lowering the number of flat bars and increasing their length. To retain the original dimensions of the square cart, the only way to

achieve this was to fully extend the diamonds to horizontal. This also had the effect of increasing the rigidity of each side while also reducing the overall weight of the cart by overlapping the bars, increasing its effective thickness. The rivets were also upgraded to ¼" diameter from 3/16" to prevent shearing of the joints under load. Wider Velcro straps around each joint to prevent any slipping when the cart was fully expanded, and provide easier to grab handles for transportation when the cart is collapsed.

### Recommendations for Future Manufacturing of Design

To further improve the base carts and make them easier to use, there are still several points that can be improved upon. Upgrading to bolts on the corner posts improved rigidity, however completely locking the cart in place involves torqueing the bolts down significantly, requiring a substantial amount of effort by the user. This also complicates setup by a single person because the carts have a tendency to not stay upright while the bolts are being tightened, so a second person is required to hold the posts in place. A larger heavy hex bolt with a wider head height would make it easier to lock in place and also ensure the cart remains locked because of the higher surface area of the bolt in contact with the corner post surface. Due to the size of the caster wheels, the carts should not be completely collapsed, but instead a distance of about 8" from each corner post should be left to prevent wheel-to-wheel interference. This may not be evident to the average assistant who will be collapsing the cart during clean up without specific instructions. This parameter would still allow the carts to fit in a 1' x 1' square area for easy portability. Collapsing the carts all the way makes them difficult transport as they will need to be carried instead of rolled away. A recommendation to eliminate these shortcomings would be the addition of a telescoping rod that connects the inside faces of each corner post at their base, to limit the amount that each side is able to collapse. Fixing this rod to each post would also keep each corner post parallel and upright at all times, making set up easier and not significantly increasing the complexity and weight of the cart.

## Launcher Attachment

### Detailed Manufacturing Breakdown

**Electronic Manufacturing**

1.) Upload code shown in Appendix H to Arduino UNO board.
2.) Attach the main switch, joystick, Linear Actuator, motor, L298N motor driver, and Arduino UNO microcontroller board, 12V battery, and terminal strip according to the schematic shown in Appendix I.

Note: Wires to/from the Arduino are simply inserted into the appropriate pins. Wires to/from the terminal strip are inserted into appropriate jacks, and screwed down to secure into place. Wires from the battery are inserted into battery terminals and screwed into place using screws provided with the battery. Wires to/from the main switch, motor, linear actuator, joystick, and L298N motor driver must be soldered into place.

**Hardware Manufacturing**

1.) Using 2x2 Doug Fir wood beams, cut four pieces of 24" length, four pieces of 36" length, and four pieces of 10 3/4" length
2.) Assemble frame for launcher with 2x2 pieces using 1" wood screws and 2 1/2" L brackets
3.) Using ¼" MDF, cut two pieces of 2' x 3' length(top and bottom of launcher), and one piece of 1' x 2' length (rotating platform)
4.) Remove 1½" squares from each corner on one piece of 2'x3' MDF for bottom of Launcher attachment
5.) Attach four 3" brackets onto bottom of launcher to anchor battery. Use the battery to ensure spacing of brackets relative to each other
6.) Drill one 5/16" hole for Linear Actuator bracket 1.5' from side and 9" from back of launcher bottom, and one 5/16" hole for Linear Actuator in rotating platform in the center of PVC Flange holes
7.) Drill ½ " hole into two small blocks of dimensions 2"x 1½"x1½" and attach blocks onto the two corners on shorter side of 1'x2' MDF using 1" wood screws
8.) Attach 2" PVC flange piece by drilling four ¾" holes onto rotating platform. Use PVC flange piece as reference to ensure holes line up properly
9.) Drill three 5/16 " holes through pitching machine base and through rotating platform. Be sure to reference these holes with location of flange piece to ensure that reloader will ultimately line up with entrance of pitching machine
10.) Attach two 4" L brackets with ½" holes in them onto 2'x3' MDF for top of launcher using ½" bolts with holes 2" from back and centered with 1' between them
11.) Use ½" threaded rod to fix rotating platform to top of launcher through L brackets and small blocks
12.) Cut 3" hole on bottom corner of 11½"x 7 3/8 "x6" reloader box
13.) Drill two ¼" holes on side of reloader box for motor clamp
14.) Build ramp using 3"x15" piece of mdf (for bottom of ramp) and two 2"x15" (for side rails of ramp). Glue these three pieces together and glue into reloader box using wood glue. Make sure the ramp is angled such that even when system is at its maximum incline, the ramp is still angled below horizontal to allow the next ball to roll into reloader.
15.) Attach motor to reloader box using 1" Omega shaped clamp and two M6 x 1inch bolts. Make sure to insert motor lead snugly into hole on the turnstile piece of the reloader

16.) Use JB weld to attach reloader box onto top of reloader, making sure to line up ball hole on box with ball hole on reloader
17.) Use JB weld to attach rapid prototyped reloader onto top of 2" x 2' PVC tube
18.) Use JB weld to fix PVC tube to 2" PVC flange
19.) Use ¼" spacers and leftover ¼" mdf to mount Arduino, L298N, and terminal strip. Attach all pieces to mdf, and screw mdf onto available space towards back of rotating platform
20.) Use four 3½"x4" (sides) and one 3½"x3½" (bottom) of mdf to build box to hold joystick. Drill ¼" hole on one side piece for wires to be led through before gluing all pieces together. Use #32 threaded rod and bolts to attach joystick through provided holes and through bottom piece. Attach 12" Velcro to bottom of box to be used by player to attach to wheelchair arm

**Figure 27: Launcher Attachment Final Product**

## Differences from Design

There were several differences made from the final design to the actual launcher attachment that was built. First, instead of rotating the pitching machine with a rod through its base, all of the components (pitching machine, reloader, and reservoir box) were all mounted on a platform that rotates independent of the rest of the launcher attachment using a linear actuator mounted underneath. Without this, the torque required to rotate the pitching machine would made it necessary to use a very heavy duty motor. Also, due to the complexity of the electronic components required to make the launcher work, we were forced to abandon the collapsibility aspect of the attachment. Therefore instead of having folding legs, the base of the launcher is solid and does not collapse. The reloader we used in the final product is also different from the final design. We used the rapid prototype machine to create a cylinder with a horizontal turnstile inside of it instead of the vertical turnstile originally designed. The reservoir box is

mounted on top of the reloader, and each button push causes the turnstile to rotate, dropping one ball into the pitching machine, and allowing a new ball to drop into the reloader from the reservoir box.

### Recommendations for Future Manufacturing of Design

There are many improvements that we feel could be made to make the launcher a better overall product. Unfortunately, due to the complexity of this attachment, it was not feasible for us to implement all of these recommendations in the time we had available. The first recommendation would be to rapid prototype everything above the pitching machine, meaning the reloader, reservoir box, motor mount, etc. We used JB weld to secure these components on top of a 2" PVC tube, and this resulted in a top heavy structure that would rock and sway during game play, giving a sense of fragility. Having a more solid custom made part would help make the attachment feel more robust in general. Also, it would be wise to enclose the microcontroller, terminal strip, and motor driver in some sort of plastic case. The current model has these components exposed to the environment, and could easily be damaged or cause wires to come loose if it were hit by a ball. Another recommendation would be to use one battery for the pitching machine, and a separate battery for the rest of the electronic components. We noticed that during use, there would be random rotations of the motor and linear actuator after the pitching machine had been on for a few minutes, and could be due to the large current draw. Next, it would be recommended that instead of having a solid base, some sort of collapsibility is explored for the launcher. This will be difficult because of the wiring, but it would serve to make transportation much easier. Finally, the reloader should be modified so that the arms of the turnstile are longer, which would make it possible to use foam balls instead of the hard plastic balls that must be used with the current launcher attachment. The problem here is that the foam balls get stuck between the turnstile and the walls of the reloader's cylinder, and could be fixed it the space between the two was reduced to a very small clearance.

## Cage Attachment

### Detailed Manufacturing Breakdown

1. Cut 5' lengths of 2" square PVC tubing in half
2. Prime the plastic with aerosol plastic primer
3. Paint half the tubes Sun Yellow and half the tubes Meadow Green
4. Install plastic plugs in the top of all tubes.
5. Drill clearance hole for #10 bolts 6" up from bottom in center of tube

**Figure 28: Cage Attachment Final Product (for Launcher Position)**

6. Install bolts in holes and screw on nuts
7. Expand base cart to use as template
8. Slide PVC tubes over aluminum base posts with end of screw facing inward
9. Stretch 2'-6" x 13' piece of netting around the 3 vertical sides (5' side, 3' side, 5' side)
    - Note: For goalie cart, netting needs to cut to allow for elbows to come through netting
10. Use 11" zip ties to fasten netting to posts
11. With 4" zip ties, fasten 3' x 7'-6" netting over top and remaining side
    - Notes:
        - For launcher cart, use netting with 12" pouch
        - Use 11" zip ties where necessary to ensure that top is taught (wrap top netting over top of posts)
        - Back flap to remain loose on right side, so fasten left side of back flap to post
12. Install self-adhesive hook to back right post (for closing purposes)
13. For goalie attachment netting, zip tie small goalie net in place on top of cage attachment.
14. For Goalie posts:
    - Drill 13/16" hole located 2" down from top of posts
    - Screw in a ½" MPT x ½" FPT 90 into hole cut in the cage attachment post. A ½" MPT x ¾" Slip coupler can then be screwed into this elbow.
15. Cut off excess ends of zip ties
16. Fasten small Velcro straps in place that will hold goalie netting onto goalie frame during gameplay
17. Cut 2'-3" length of 1.5" wide Velcro strap
18. Punch 3/16" hole in one end of strap
19. Fasten Velcro strap to right back post with 3/16" rivet and washer
20. For retriever only, weave appropriate colored yarn around 12" hole in order to make it stand out (see picture above)

### Differences from Design

The cage attachment final product was nearly identical to the cage attachment design. Only minor changes were made. The original design idea was for a piece of pipe to be fixed to the bottom of the entrance/exit flap, with the flap being temporarily attached to the rest of the cart with bungee cords during gameplay. Instead, we fixed the left side of the flap to the post and placed a hook on the right post that the netting attaches to during gameplay. The final design was easier to construct and simpler.

### Recommendations for Future Manufacturing of Design

For the netting itself, sewing together the sections of netting along the top of the cage attachment would look more professional and would eliminate the gaps between zip ties. For attachment to the posts, a method other than zip ties that could eliminate the rather sharp edges of sheared zip tie would improve the design.

## Goalie Attachment

### Detailed Manufacturing Breakdown

1. Cut ¾" PVC pipe (Four 24" lengths, two 32" length)
2. Paint two 24" pipes, one 32" pipe, and four ¾" PVC elbows Sun Yellow, and remaining 3 pipes and four ¾" PVC elbows Meadow Green
3. Sand down ends of pipe slightly to allow for easy fit into elbows
4. Drill 3/16" hole at 12" mark of 24" pipe
5. Cut 9" length of 1.5" Velcro
   Rivet Velcro onto one 24" pipe

**Figure 29: Goalie Attachment Final Product**

### Differences from Design

There are no changes that were made from the design of the goalie attachment.

### Recommendations for Future Manufacturing of Design

Except for sewing the goalie netting to the cage attachment netting, there are no other recommendations for future manufacturing of the goalie attachment.

## Retriever Attachment

### Detailed Manufacturing Breakdown

1. Cut 3.5" x 32" rectangular hole in long side of tubs as shown in picture
2. Cut 3" x 8" rectangles out of acrylic sheeting (four for 1 retriever)
3. Using 3/16" drill bit specially designed for plastic, drill holes for hinges in acrylic (I located the hinges at 1/3 and 2/3 along the length of the flaps)
4. Using same drill bit, drill hole in dead center of flap for nylon strap to connect to
5. Fasten hinges to acrylic flaps with 5/32" rivets
6. Cut 6.5" lengths of nylon strap (four for 1 retriever)
7. Punch holes ½ from each end that rivet will pass through

**Figure 30: Retriever Attachment Final Product**

8. Fasten nylon straps to acrylic flaps with a washer on back to ensure that strap does not fall off
9. Drill holes in tub right above large rectangular hole for hinges
10. Fasten hinges to tub with 5/32” rivets (the location of these holes has to be perfect to ensure that the hinges can move freely)
11. Drill holes in top of tub where nylon straps will connect (it’s a guessing game to get right angle of flaps for ball size and friction coefficient, but I went 5” from edge of tub)
12. Attach 1/4” strips of felt around bottom of tub (if not sticky enough, use hot glue)
13. Cut 2” lengths of 1.5” x 1.5” wood (two per retriever)
14. Drill two 1/4” holes in blocks
15. Cut 2” x 2” square out of ½” plywood
16. Screw plywood to block as shown in picture
17. Paint the assembly the appropriate color (yellow or green)
18. Fasten assembly to tub with 1/4” bolt and nut as shown in picture
19. Screw 6” hook into 1/2” plywood (1-3/8” up from bottom, so that location is 8” from ground)
20. Drill hole in base cart inside face (see picture) and attach the eye that hook mates to for gameplay

**Figure 31: Hook used to attach Retriever to base cart**

### Differences from Design

The retriever changed quite a bit from the original design. For one the only modification we made to the tub was cutting a 3.5” x 32” rectangle out of the front of the tub. We did not cut out the bottom of the tub do due the problems with rigidity this would cause. Instead, we just flipped the tub upside down. We also did not cut out a side slot for ball removal. This was due to the fact that the connection to the base cart was now simply a hook and eye instead of the metal bracket system. When the assistant needs to remove the balls from the retriever, he/she will simply lift the tub and collect the balls into a bucket. Another major change was the system with which the balls could enter through the front opening, but not exit. The original design called for an angled piece of foam. This was not feasible to manufacture. Instead, angled acrylic flaps were used that allow the balls to enter because they are hinged and can swing upward. But when a ball tries to get out the front, it hits this flap and cannot escape.

### Recommendations for Future Manufacturing of Design

Due to the complexity of this project and the number of components, we were forced to include an assistant at the reload station to take the collected balls from the retriever and put them into the reloader box. Ideally, this assistant would not be necessary. A device that would be able to collect the balls scattered around the court and allow the retriever player to automatically deposit the balls into

his/her team's launcher reloader box would remove all outside help from the game except for score keepers. This would make the game autonomous and allow the players to feel even more in control.

## Chapter 8: Design Verification

The procedure we followed for testing was a concurrent build-test method. By this we mean that as we were building the subsystems, we were testing them for rigidity and robustness along the way. If we found that the product we built did not meet our standards, we would modify the hardware, connections, etc. to improve the product. After we declared that the subsystems themselves were of good quality, we focused on the interfaces between the subsystems to ensure that there was a solid connection and that movement during gameplay would be smooth and reliable. For the connection between the cage and goalie attachments, the J-B Weld connecting the elbow to the PVC post failed upon impact from a ball during Expo. We quickly enhanced the connection with more reliable materials before turning in the final product. In order to ensure that all equipment could fit in a van per our specifications, we transported the equipment we had manufactured up to that point (everything except for launchers) in an ADA compliant DRC van to Mott Gymnasium. There we demonstrated this equipment for the Kinesiology students. For further details, refer to Appendix G for our DVPR.

## Chapter 9: Conclusion

Overall, we feel as if FW2 was a very successful project. The collapsibility of the attachments made it possible for us to transport all of the equipment from our project room in the engineering building to the Technology Park by the Dairy Unit with relative ease using a van borrowed from the Disability Resource Center. Even the launcher attachment, which does not collapse, was small enough individually to transport without much difficulty. Also, even though the reloader system has areas for improvement as outlined earlier, it was able to fire balls consistently and effectively.

Although the final product was not perfect, the recommendations we provided should help the next group that works in this project to build on the knowledge base we have compiled. We would like to thank Dr. Taylor for giving us the opportunity to work on such a worthwhile project, and wish him the best of luck with this project and others in the future.

# Bibliography

Mollerup, Per. *Collapsible: the Genius of Space-saving Design*. San Francisco, Calif.: Chronicle, 2001. Print.

## Appendix A: Determining Launch Distance Specification

These calculations provide validation concerning the distance requirements of the ball launcher mechanism. Because we do not currently know the height at which the launcher will be mounted, we performed analysis at a launcher height of 2 feet and 5 feet, and both extremes in terms of angle of launch, 0° and 30° above the horizontal. The distances at these four situations encompass the range we might see once the equipment is built, and justify the specifications we selected.

### Height = 2 feet, Launch Angle = 0°:

$$\Delta y = V_{0,y}t + \frac{1}{2}gt^2$$

$$2ft = 0 + \frac{1}{2}\left(32.3\frac{ft}{s^2}\right)t^2$$

$$t = 0.35\ sec$$

$$\Delta x = V_{0,x}t + \frac{1}{2}at^2$$

$$\Delta x = (35mph)(0.35\ sec) + 0$$

**Horizontal Distance = $\Delta x = 18ft$**

### Height = 2 feet, Launch Angle = 30°:

$$\Delta y = V_{0,y}t + \frac{1}{2}gt^2$$

$$2ft = (-35sin30°mph)(t) + \frac{1}{2}\left(32.3\frac{ft}{s^2}\right)t^2$$

$$t = 1.67\ sec$$

$$\Delta x = V_{0,x}t + \frac{1}{2}at^2$$

$$\Delta x = (35cos30°mph)(1.67\ sec) + 0$$

**Horizontal Distance = $\Delta x = 74ft$**

**Height = 5 feet, Launch Angle = 0°:**

$$\Delta y = V_{0,y}t + \frac{1}{2}gt^2$$

$$5ft = 0 + \frac{1}{2}\left(32.3\frac{ft}{s^2}\right)t^2$$

$$t = 0.56\ sec$$

$$\Delta x = V_{0,x}t + \frac{1}{2}at^2$$

$$\Delta x = (35mph)(0.56sec) + 0$$

**Horizontal Distance = $\Delta x = 29ft$**

**Height = 5 feet, Launch Angle = 30°:**

$$\Delta y = V_{0,y}t + \frac{1}{2}gt^2$$

$$5ft = (-35sin30°mph)(t) + \frac{1}{2}\left(32.3\frac{ft}{s^2}\right)t^2$$

$$t = 1.77\ sec$$

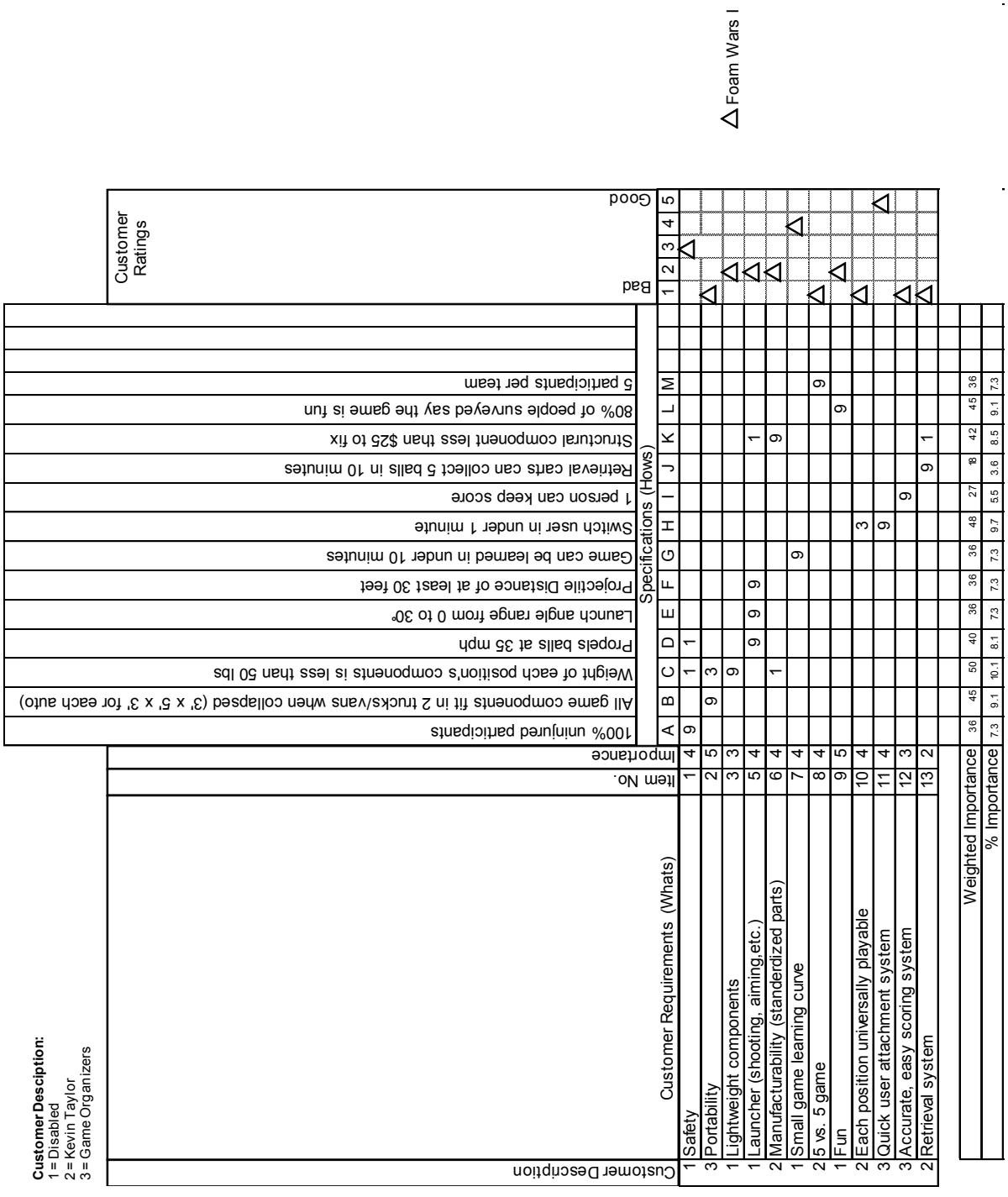
$$\Delta x = V_{0,x}t + \frac{1}{2}at^2$$

$$\Delta x = (35cos30°mph)(1.77\ sec) + 0$$

**Horizontal Distance $= \Delta x = 79ft$**

As you can see from the calculations, we expect a range of distances from 18 feet (2' launch height at 0°) to 79 feet (5' launch height at 30°). Although this range is fairly large, we expect a much smaller range in practice. This is because one of the assumptions used to make this a quick calculation was that there will be no effect due to air drag. If the force due to drag was added to our analysis, the distances would be smaller. Thus using these values and general engineering intuition, we settled on a specification of launch distance of at least 30'.

# Appendix B: Quality Function Deployment Matrix



# Appendix C: American Disabilities Act (ADA) Standards:

## 4.2 Space Allowance and Reach Ranges

- **4.2.1* Wheelchair Passage Width.** The minimum clear width for single wheelchair passage shall be 32 in (815 mm) at a point and 36 in (915 mm) continuously (see Fig. 1).
- **4.2.2 Width for Wheelchair Passing.** The minimum width for two wheelchairs to pass is 60 in (1525 mm) (see Fig. 2).
- **4.2.3* Wheelchair Turning Space.** The space required for a wheelchair to make a 180-degree turn is a clear space of 60 in (1525 mm) (see Fig. 3).

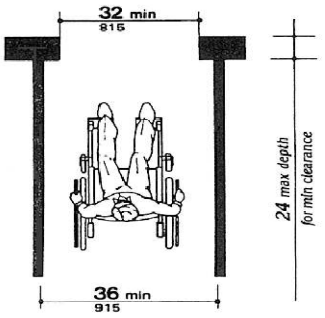



Fig. 1
Minimum Clear Width
for Single Wheelchair

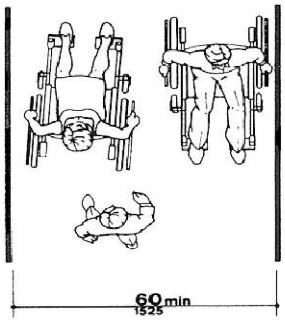
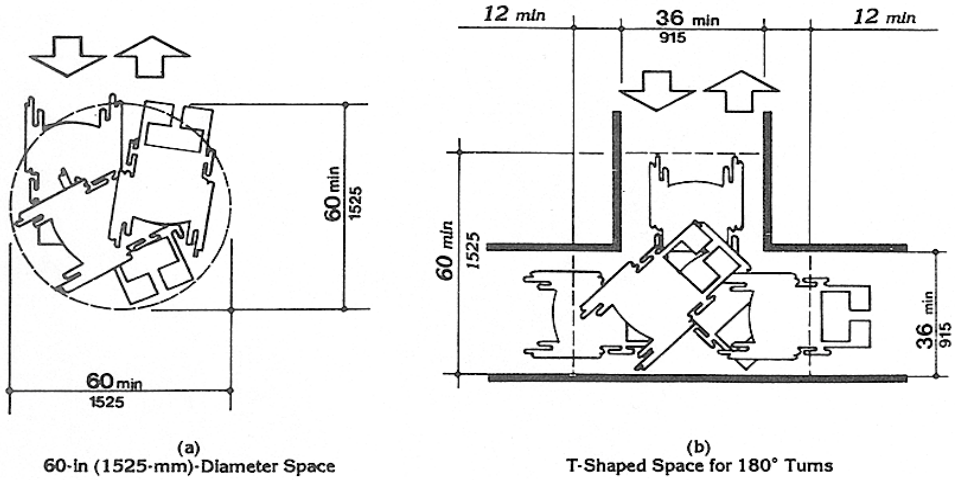



Fig. 2
Minimum Clear Width
for Two Wheelchairs

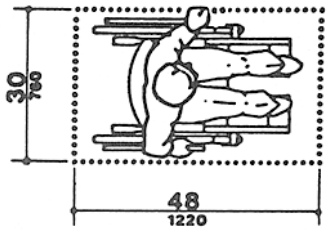



(a)
60-in (1525-mm)-Diameter Space

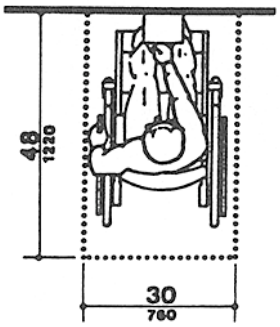
(b)
T-Shaped Space for 180° Turns

Fig. 3
Wheelchair Turning Space

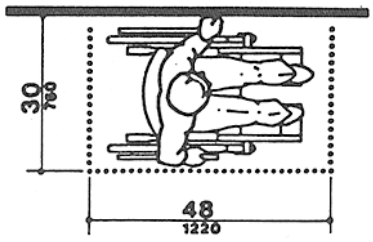
- **4.2.4* Clear Floor or Ground Space for Wheelchairs.**
    - **4.2.4.1 Size and Approach.** The minimum clear floor or ground space required to accommodate a single, stationary wheelchair and occupant is 30 in by 48 in (760 mm by 1220 mm) (see Fig. 4(a)). The minimum clear floor or ground space for wheelchairs may be positioned for forward or parallel approach to an object (see Fig. 4(b) and (c)). Clear floor or ground space for wheelchairs may be part of the knee space required under some objects.
    - **4.2.4.2 Relationship of Maneuvering Clearance to Wheelchair Spaces.** One full unobstructed side of the clear floor or ground space for a wheelchair shall adjoin or overlap an accessible route or adjoin another wheelchair clear floor space. If a clear floor space is located in an alcove or otherwise confined on all or part of three sides, additional maneuvering clearances shall be provided as shown in Fig. 4(d) and (e).



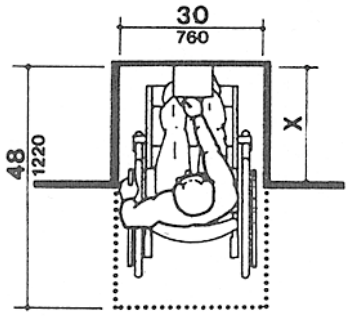

(a)
Clear Floor Space



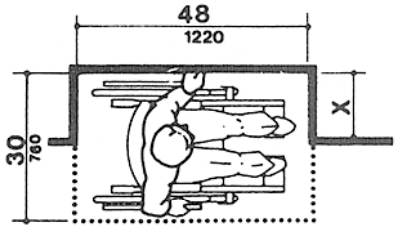

(b)
Forward Approach




(c)
Parallel Approach

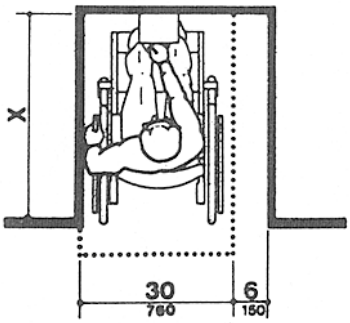



NOTE: x ⩽ 24 in (610 mm).

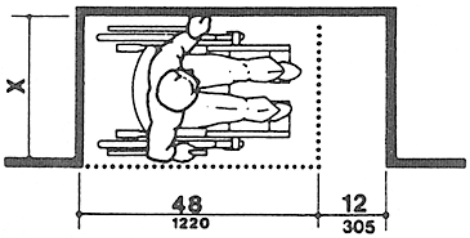



NOTE: x ⩽ 15 in (380 mm).

(d)
Clear Floor Space in Alcoves




NOTE: If x > 24 in (610 mm), then an additional maneuvering clearance of 6 in (150 mm) shall be provided as shown.

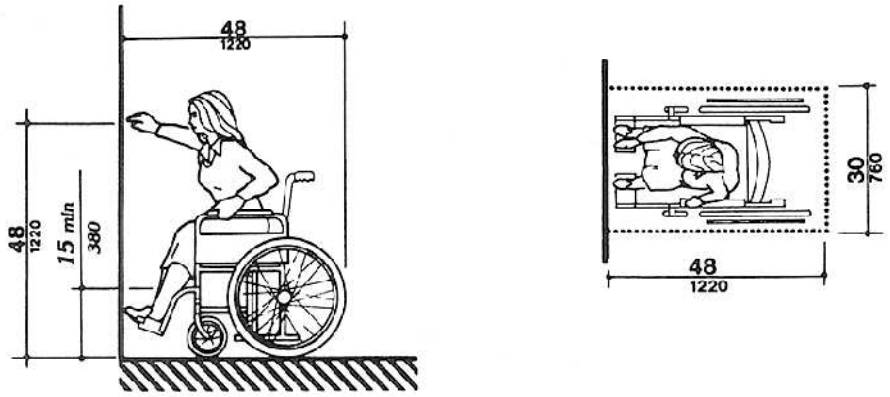



NOTE: If x > 15 in (380 mm), then an additional maneuvering clearance of 12 in (305 mm) shall be provided as shown.

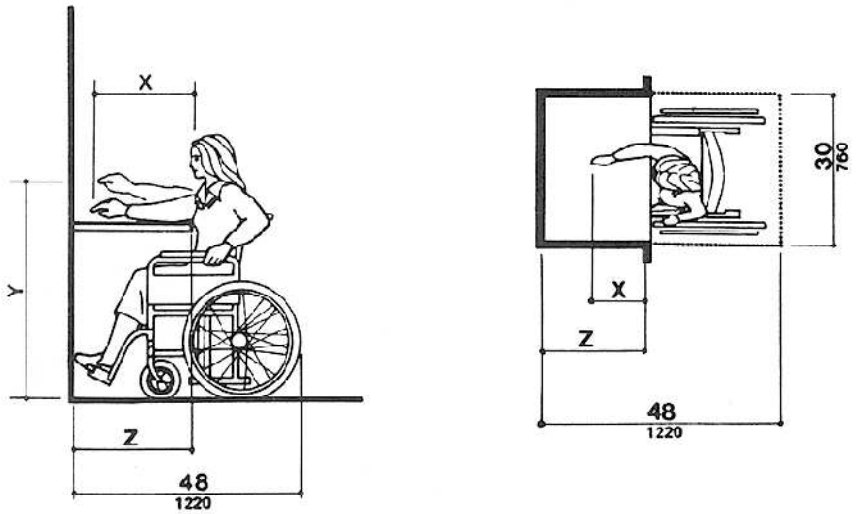
(e)
Additional Maneuvering Clearances for Alcoves

**Fig. 4**
**Minimum Clear Floor Space for Wheelchairs**

- **4.2.5* Forward Reach.** If the clear floor space only allows forward approach to an object, the maximum high forward reach allowed shall be 48 in (1220 mm) (see Fig. 5(a)). *The minimum low forward reach is 15 in (380 mm).* If the high forward reach is over an obstruction, reach and clearances shall be as shown in




(a)
High Forward Reach Limit



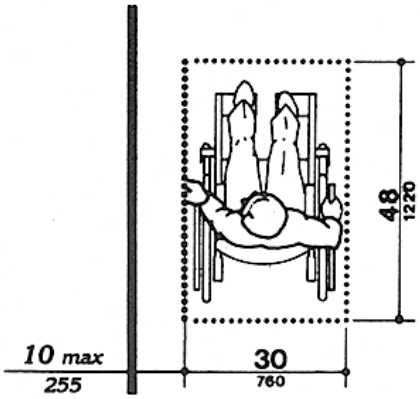

NOTE: x shall be ≤ 25 in (635 mm); z shall be ≥ x. When x < 20 in (510 mm), then y shall be 48 in (1220 mm) maximum. When x is 20 to 25 in (510 to 635 mm), then y shall be 44 in (1120 mm) maximum.

(b)
Maximum Forward Reach over an Obstruction

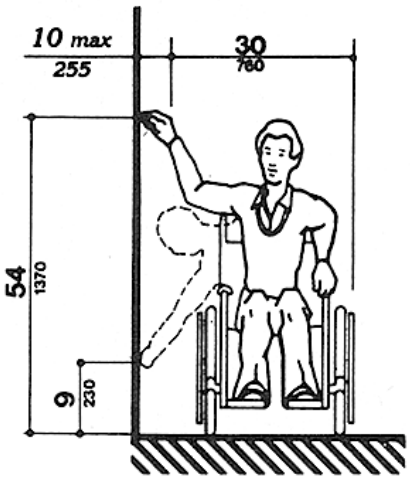
**Fig. 5**
**Forward Reach**

Fig. 5(b).

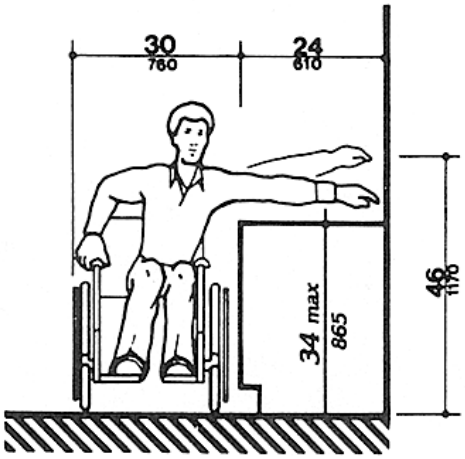
- **4.2.6* Side Reach.** If the clear floor space allows parallel approach by a person in a wheelchair, the maximum high side reach allowed shall be 54 in (1370 mm) and the low side reach shall be no less than 9 in (230 mm) above the floor (Fig. 6(a) and (b)). If the side reach is over an obstruction, the reach and clearances shall be as shown in Fig 6(c).




(a)
Clear Floor Space Parallel Approach




(b)
High and Low Side Reach Limits

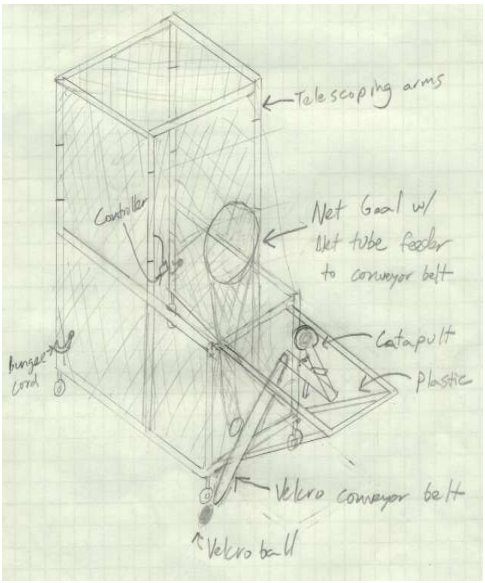



(c)
Maximum Side Reach over Obstruction

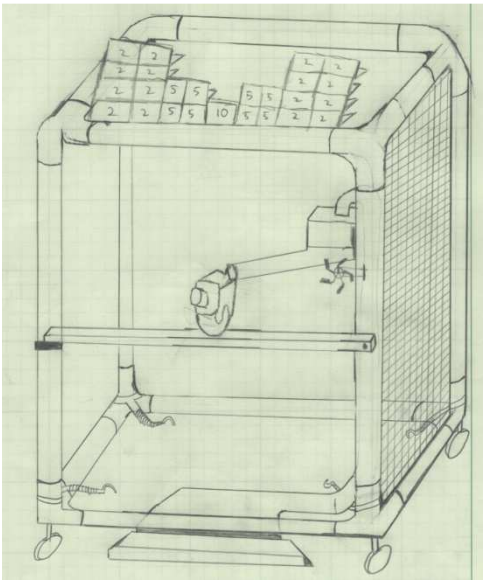
**Fig. 6**
**Side Reach**

| Loading Launcher | Frame Design | Launching Mechanism | Retrieval | Goal | Game Rules |
|---|---|---|---|---|---|
| ramp | telescoping | catapult | vacuum/non-power | inverted pyramid/cone | movement |
| PVC pipe | tent poles | slingshot | driving range carts | net | badminton racquet |
| funnel | coat rack | nerf gun | tennis baskets | bulls eye | defense |
| conveyor belt | accordion | air cannon | conveyor belts | Velcro/sweeper | tennis racquet |
| people/helpers | collapsible | pitching machine (baseball, softball, tennis) | other people | ski ball | safety |
| Remote control | swivel | rotating shaft | magnet | field goal posts | 1 person blindfolded |
| feed from goal | plastic siding | lever | Velcro | pressure sensor | 3 legged teams |
| catapult | PVC | pulley | catapult | light | inflatable shapes |
| vacuum-->leaf blower | aluminum | gears | net | bowling pins | obstacle course |
| feed straight to launcher from ground | pins | pulley | scooped by launcher | balloons | Halo, Mariokart objectives |
| PVC pipe funnel into launcher | hinges | gears | roller coaster | basket | include whole class |
| beer bong | sliding door | spring | escalator | ball feeder | Nerf gun for non-cart players |
| | bungee cords | potato cannon | re-fueling station | obstacle course | targets around course |
| | sphere | bottle rocket | cartridges | team targets | offense/defense (rotate) |
| | adjustable cart height | gun on front | sweeper | defenders | Different games w/ same equip. |
| | skateboard cart | launcher feed back | elevator | side targets | Capture the Flag (hide object, jail, etc.) |
| | netting/barrier | adjustable controls | pulley/ratchet | ball sensor | No puppy guarding, cherry picking |
| | simple/standardized parts | controls (multi-task) | spring (pinball) | dunk tank | court boundaries |
| | portable | shoot/move at same time w/ 1 hand | golf range ball collector | higher targets than launcher | cart stops working after so many hits |
| | multitask move/shoot | dog launcher | windmill | sound for moving/scoring | timeframe (quarters |
| | secure upper netting where felt was | distance/angle | Ferris wheel | targets on all sides | scoops/lacrosse sticks |
| | | pinball | paddle boat | | targets on side (dunk tanks) |
| | | paintball | tractor scoop | | shooting zones (max shots per zone or time) |
| | | crossbow | dump truck | | body suits |
| | | large "easy" button | garbage truck | | laser vests |
| | | rubber band | magnet | | 1 shot per press |
| | | spit wad | dog/animal | | scoring/point system |
| | | | water jet | | 1st team to # points |
| | | | | | relay race |
| | | | | | hit target to move on |
| | | | | | 1 person game |
| | | | | | carnival duck game |
| | | | | | position for player (use tools) |
| | | | | | more points for other teams balls |
| | | | | | only recover own balls |

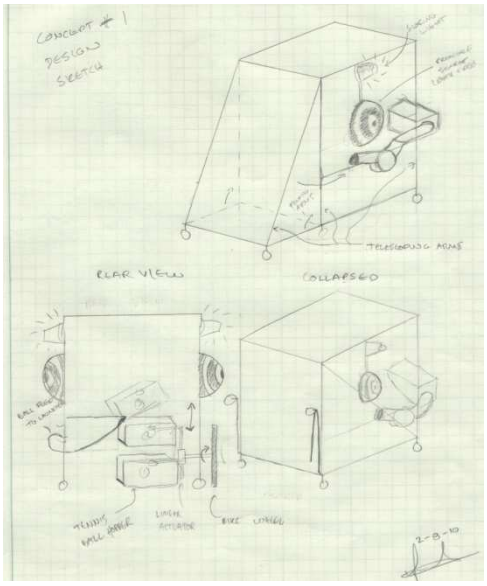
# Appendix E: Initial Concepts



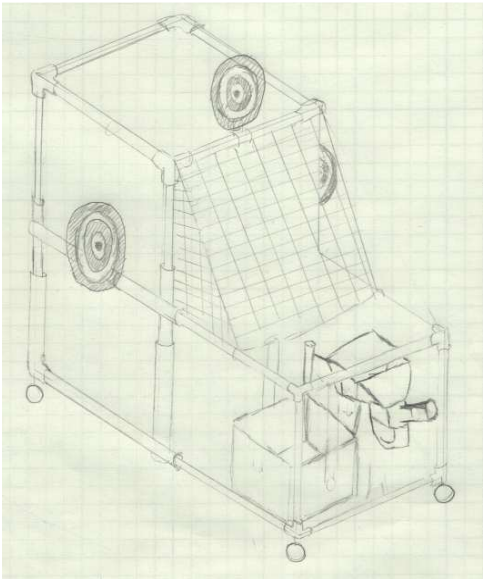

The above drawing represents our telescope design. The frame design would make this concept very portable and lightweight; however the catapult launching mechanism is unrealistic.



The above drawing represents our tent pole concept. This design incorporates a simple scoring system and an easily collapsible frame, but the vacuum required for the ball recovery might be noisy and difficult to integrate with the rest of the equipment.




We called this design the hopper, as it uses a clever ball retrieval method similar to a tennis ball hopper. However it has a frame that would not be very portable and the launcher mechanism attached to the side was not a desirable characteristic.



Combining best characteristics from the previous three concepts, this design theoretically meets all the customer requirements. However by combining all subsystems into one cart, we greatly increase the complexity of the project and make it difficult to design a game that has a team element. Therefore our next concepts increase the “fun-factor” of the game by separating the components into positions that can be played by several players on a team.

## Appendix F: Cost Breakdown

| Final Project Cost | | | |
|---|---|---|---|
| **Component** | **QTY** | **Cost/Unit** | **Total Cost** |
| Base Cart | 6 | $161.06 | $966.36 |
| Cage Attachment | 6 | $96.04 | $576.24 |
| Goalie Attachment | 2 | $27.93 | $55.86 |
| Retreiver Attachment | 2 | $66.50 | $133.00 |
| Launcher Attachment | 2 | $489.67 | $979.34 |
| | **Total Game Cost:** | | $2,710.80 |

| Base Frame | | | | | |
|---|---|---|---|---|---|
| **Part** | **Qty** | **Vendor** | **Product ID** | **Cost/Unit** | **Total Cost** |
| Aluminum Bars 1/4” x 1 1/4” x 12' | 3 | McCarthy Steel | 4490T28 | $22.51 | $67.53 |
| Square Aluminum Tubing 1 3/4”x 1/8” x 10' | 1 | McCarthy Steel | 6546K13 | $41.83 | $41.83 |
| Wheels | 4 | McMaster-Carr | 23005T41 | $10.37 | $41.48 |
| 1/4" Rivets (100 pack) | 0.50 | McMaster-Carr | 97447A653 | $13.77 | $6.89 |
| 1/4" - 20 x 2 3/4" Hex head Cap Screw (25 pack) | 0.33 | McMaster-Carr | 91309A553 | $4.51 | $1.49 |
| 1/4" - 20 Nylon Lock Nuts (25 pack) | 0.33 | McMaster-Carr | 95856A245 | $4.32 | $1.43 |
| Washers (50 pack) | 0.17 | Home Depot | 8034 | $2.25 | $0.38 |
| | | Total Component Cost | | | $161.01 |
| | | Complete Game Cost (x6 carts) | | | $966.09 |

## Cage Attachment

| Part | Qty | Vendor | Product ID (Model #, SKU, etc.) | Cost/Unit | Total Cost |
|---|---|---|---|---|---|
| 2" Square PVC Tubing | 10 ft | Professional Plastics | 85095K82 | $4.19 | $41.93 |
| 2" Square Finishing Plug (50) | 1 bag | McMaster-Carr | 9565K18 | $2.86 | $2.86 |
| Square Netting | 1 cage | Just For Nets | 1" Golf Netting | $36.27 | $36.27 |
| Green Spray Paint | 3 can | Home Depot | | $0.58 | $1.75 |
| Yellow Spray Paint | 4 can | Home Depot | | $0.58 | $2.33 |
| Plastic Primer | 1 can | Home Depot | | $0.55 | $0.55 |
| 30' Velcro strap | 1 ea | Home Depot | 075967913724 | $3.33 | $3.33 |
| 11" Zip Ties (500/bag) | 1 bag | Home Depot | | $4.51 | $4.51 |
| 4" Zip Ties (100/bag) | 1 bag | Home Depot | 32076070373 | $0.67 | $0.67 |
| Plastic Utility Hook (packs of 2) | 0.5 pack | Rite Aid | - | $3.69 | $1.85 |
| Misc. rivets, washers | - | - | - | - | - |
| **Note: PVC tubing and netting purchased for 10 cages, but this table only shows costs for 6 cages** | | | Total Component Cost | | $96 |
| | | | Total Cost for 6 cages | | $576.24 |

## Goalie Attachment

| Part | Qty | Vendor | Product ID (Model #, SKU, etc.) | Cost/Unit | Total Cost |
|---|---|---|---|---|---|
| 3/4" PVC (10 ft length) | 1 Pieces | Home Depot | 811000012753 | $0.98 | $0.98 |
| 3/4" PVC Elbow | 2 ea | Home Depot | 049081140649 | $0.29 | $0.58 |
| 1/2" PVC Elbow MPT x FPT | 2 ea | Home Depot | 049081141868 | $0.68 | $1.36 |
| 3/4" x 1/2" MADP | 2 ea | Home Depot | 049081131685 | $0.58 | $1.16 |
| Square Netting | 1 section | Just For Nets | 1" Golf Netting | $19.38 | $19.38 |
| Small Velcro Straps (package of 50) | 1 ea | Home Depot | 556511 | $4.47 | $4.47 |
| Zip Ties (cost applied to Cage Attachment) | - | - | - | - | - |
| Misc. J-B Weld and paint | - | - | - | - | - |
| | | | Total Component Cost | | $27.93 |
| | | | Total Cost for 2 Goalies | | $55.86 |

## Retriever Attachment

| Part | Qty | | Vendor | Product ID (Model #, SKU, etc.) | Cost/Unit | Total Cost |
|---|---|---|---|---|---|---|
| 39" x 20" x 6.5" storage tub | 1 | ea | Walmart | B000M39HQI | $18.74 | $18.74 |
| 0.093" 20' x 32" Acryllic Sheet | 1 | ea | Home Depot | 202089 | $6.15 | $6.15 |
| 1" Hinge (2/pack) | 4 | ea | Home Depot | 240974 | $1.89 | $7.56 |
| White Polypropelene Strapping | 4.5 | yards | Joanne Fabric | - | $1.00 | $4.50 |
| 5/32" Rivets (50/pack) | 1 | ea | Home Depot | 608113 | $4.96 | $4.96 |
| Rivet Gun | 1 | ea | Home Depot | 100097261 | $9.47 | $9.47 |
| Felt Pads | 1 | ea | Home Depot | 039003099506 | $1.90 | $1.90 |
| 6" Hook and Eye | 2 | ea | Home Depot | 030699153350 | $3.49 | $6.98 |
| 3/16" Drill Bits for Platic | 2 | ea | McMaster-Carr | 27465A83 | $3.12 | $6.25 |
| Misc. bolts and wood | - | - | - | - | - | - |
| | | | | Total Component Cost | | $66.50 |
| | | | | Total Cost for Full Game | | $132.99 |

**Launcher Attachment**

| Part | QTY | Vendor | Cost/Unit | Total Cost |
|---|---|---|---|---|
| Franklin Field Master Pitching Machine | 2 | Sports Authority | $129.99 | $259.98 |
| MDF for launcher base | 1 | Home Depot | $18.43 | $18.43 |
| 2x2 for launcher base | 8 | Home Depot | $1.98 | $15.84 |
| Caster Wheels | 6 | McMaster Carr | $10.73 | $64.38 |
| Threaded Rod | 2 | Home Depot | $4.47 | $8.94 |
| 2" PVC Flange | 2 | Farm Supply | $11.99 | $23.98 |
| 2" PVC Post | 2 | Home Depot | $3.49 | $6.98 |
| JB Weld | 1 | Home depot | $4.57 | $4.57 |
| Motor Clamp | 2 | Ace Hardware | $2.59 | $5.18 |
| Motor | 2 | Virtual Village | $10.99 | $21.98 |
| Arduino Uno | 2 | Sparkfun.com | $29.99 | $59.98 |
| L298N motor driver | 2 | Sparkfun.com | $2.99 | $5.98 |
| Terminal strip | 2 | Radio Shack | $5.99 | $11.98 |
| 12 Guage wire | 1 | Radio Shack | $16.00 | $16.00 |
| 22 Guage wire | 2 | Radio Shack | $4.99 | $9.98 |
| Reservoir Box | 6 | Walmart | - | $24.82 |
| Linear Actuator | 2 | Progressive Automatiosn | $140.50 | $281.00 |
| Battery | 2 | Battery Plus | $62.99 | $125.98 |
| Battery Charger | 1 | Battery Plus | $26.99 | $26.99 |
| Hardware Screws/Bolts/Lbrackets | - | Home Depot/Ace Hardware | - | $100.00 |
| | | **Total Component Cost:** | | **$489.67** |
| | | **Total Game Cost:** | | **$1,092.97** |

# Appendix G: Design Verification Plan

## DESIGN VERIFICATION PLAN AND REPORT

| **CUSTOMER:** Dr. Kevin Taylor | **PROJECT:** Foam Wars II | **ENGINEERS:** Sivadas Menon, Sumant Advani, Casey Pieplow | | | | | **Criteria:** Launching | |
|---|---|---|---|---|---|---|---|---|
| **TEST PLAN** | | | | | | | | |
| **Item No** | **Specification or Clause Reference** | **Test Description** | **Acceptance Criteria** | **Test Responsibility** | **Test Stage** | **SAMPLES TESTED** | | **TIMING** | |
| | | | | | | **Quantity** | **Type** | **Start date** | **Finish date** |
| 1 | Propels balls at 35 mph | Launch balls and record speed with radar | Average launch speed is at least 35 mph | Casey, Das | Final Production Part | Launcher | Final Production Part | 11/10/2010 | 11/23/2010 |
| 4 | Launches ball from 0° to 30° | Measure the angle that the launcher can rotate | Spec met | Das, Sumant | Final Production Part | Launcher | Final Production Part | 11/10/2010 | 11/23/2010 |
| 5 | Balls launches at least 30 feet | Launch balls and measure distance from launcher to landing spots | Average distance is at least 30 feet | Casey, Sumant | Final Production Part | Launcher | Final Production Part | 11/10/2010 | 11/23/2010 |
| 6 | Launches 1 ball per button press | Inspection | Spec met | Casey, Das | Final Production Part | Launcher | Final Production Part | 11/10/2010 | 11/23/2010 |

## DESIGN VERIFICATION PLAN AND REPORT

| **CUSTOMER:** Dr. Kevin Taylor | **PROJECT:** Foam Wars II | **ENGINEERS:** Sivadas Menon, Sumant Advani, Casey Pieplow | | | **Criteria:** Launching | | | |
|---|---|---|---|---|---|---|---|---|
| **TEST PLAN** | | | | | | | | |
| Item No | Specification or Clause Reference | Test Description | Acceptance Criteria | Test Responsibility | Test Stage | SAMPLES TESTED | | TIMING | |
| | | | | | | Quantity | Type | Start date | Finish date |
| 1 | All componants for 1 FW2 Team fit in 3'x3'x5' volume | Collapsibility Test: With only 2 people, load collapsed equipment into the "Mona" van from Cal Poly DRC | All equipment fits into van cargo area | Sumant, Das | Prototype | 5 Base Carts, 2 Launcher Carts, 2 Cage Attachments, 1 Retreival Attachment | Prototype | 5/27/2010 | 5/27/2010 |
| 2 | | | Equipment is not damaged | Casey, Das | Prototype | | Prototype | 5/27/2010 | 5/27/2010 |
| 3 | | | Equipment can be unloaded and used again | Sumant, Casey | Prototype | | Prototype | 5/27/2010 | 5/27/2010 |
| 4 | Weight of each position's componants less than 50 lbs, excluding user and wheelchair | Weigh each subsystem | Each assembled subsystem < 50 lbs | Das | Prototype | 1 Base Cart + 1 Launcher; 1 Base Car + 1 Retreival Attachmet; 1 Base Cart with 1 Cage Attachment and 1 Interceptor Attachment | Prototype | 5/28/2010 | 5/28/2010 |
| 5 | Full game can be set up in < 10 minutes | Time a random group of volunteers as they assemble all equipment | Game must be ready to play in < 10 minutes | Das | Final Production Part | 10 Base Carts, 4 Launcher Carts, 4 Cage Attachments, 2 Retreival Attachment | Final Production Part | 5/29/2010 | 5/29/2010 |

# DESIGN VERIFICATION PLAN AND REPORT

| **CUSTOMER:** Dr. Kevin Taylor | **PROJECT:** Foam Wars II | **ENGINEERS:** Sivadas Menon, Sumant Advani, Casey Pieplow | **Criteria:** Retriever |
|---|---|---|---|

## TEST PLAN

| Item No | Specification or Clause Reference | Test Description | Acceptance Criteria | Test Responsibility | Test Stage | SAMPLES TESTED | | TIMING | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Quantity | Type | Start date | Finish date |
| 1 | Recovers ball into collector | Run over balls with retriever | Accepts balls into collector zone | Sumant, Das | Prototype | 2 retrievers | Prototype | 5/20/2010 | 5/21/2010 |
| 2 | Balls do not escape | Push retriver cart 20' with balls inside | No balls escape | Das, Sumant | Prototype | 2 retrievers | Prototype | 5/20/2010 | 5/21/2010 |
| 3 | Quick unloading into retrieval zone | One person empties collector with broom | Entire collector evacuated in <20s | Casey, Sumant | Prototype | 2 retrievers | Prototype | 5/22/2010 | 5/23/2010 |
| 4 | Mounts easily to frame | Inspection | Mounting surfaces line up correctly | Casey, Das | Prototype | 2 retrievers | Prototype | 5/22/2010 | 5/23/2010 |

# DESIGN VERIFICATION PLAN AND REPORT

| **CUSTOMER:** Dr. Kevin Taylor | **PROJECT:** Foam Wars II | **ENGINEERS:** Sivadas Menon, Sumant Advani, Casey Pieplow | **Criteria:** Goalie |
|---|---|---|---|

## TEST PLAN

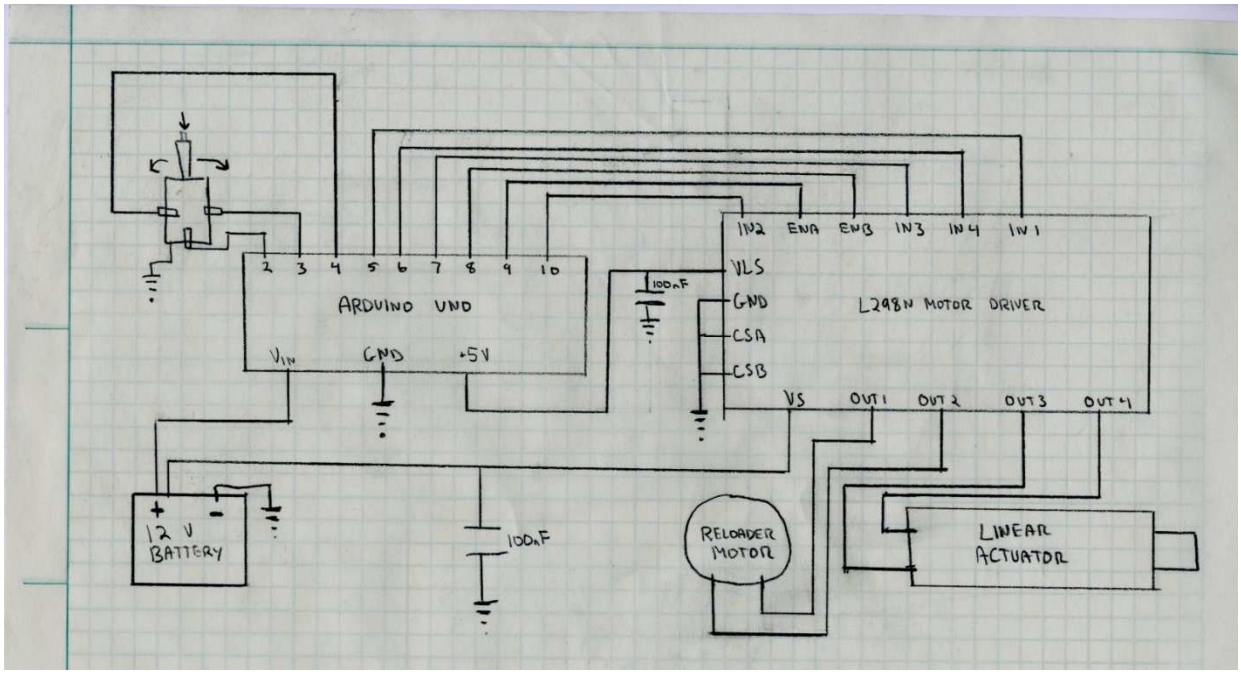
| Item No | Specification or Clause Reference | Test Description | Acceptance Criteria | Test Responsibility | Test Stage | SAMPLES TESTED | | TIMING | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Quantity | Type | Start date | Finish date |
| 1 | Catches balls in interceptor | Shoot balls toward interceptor | Accepts balls into interceptor bucket | Sumant, Das | Prototype | 2 Goalies | Prototype | 5/20/2010 | 5/21/2010 |
| 2 | Balls do not escape | Vigorous Maneuvers | No balls fall out | Casey, Das | Prototype | 2 Goalies | Prototype | 5/20/2010 | 5/21/2010 |
| | | Shoot balls toward interceptor | No balls fall out | Das, Sumant | Prototype | 2 Goalies | Prototype | 5/20/2010 | 5/21/2010 |
| 3 | Can hold enough balls | Load interceptor with balls | Can hold at least 20 balls without any falling out | Casey, Sumant | Prototype | 2 Goalies | Prototype | 5/22/2010 | 5/23/2010 |
| 4 | Mounts easily to cage attachment | Inspection | Mounting surfaces line up correctly | Casey, Das | Prototype | 2 Goalies | Prototype | 5/22/2010 | 5/23/2010 |

# Appendix H: Arduino Code

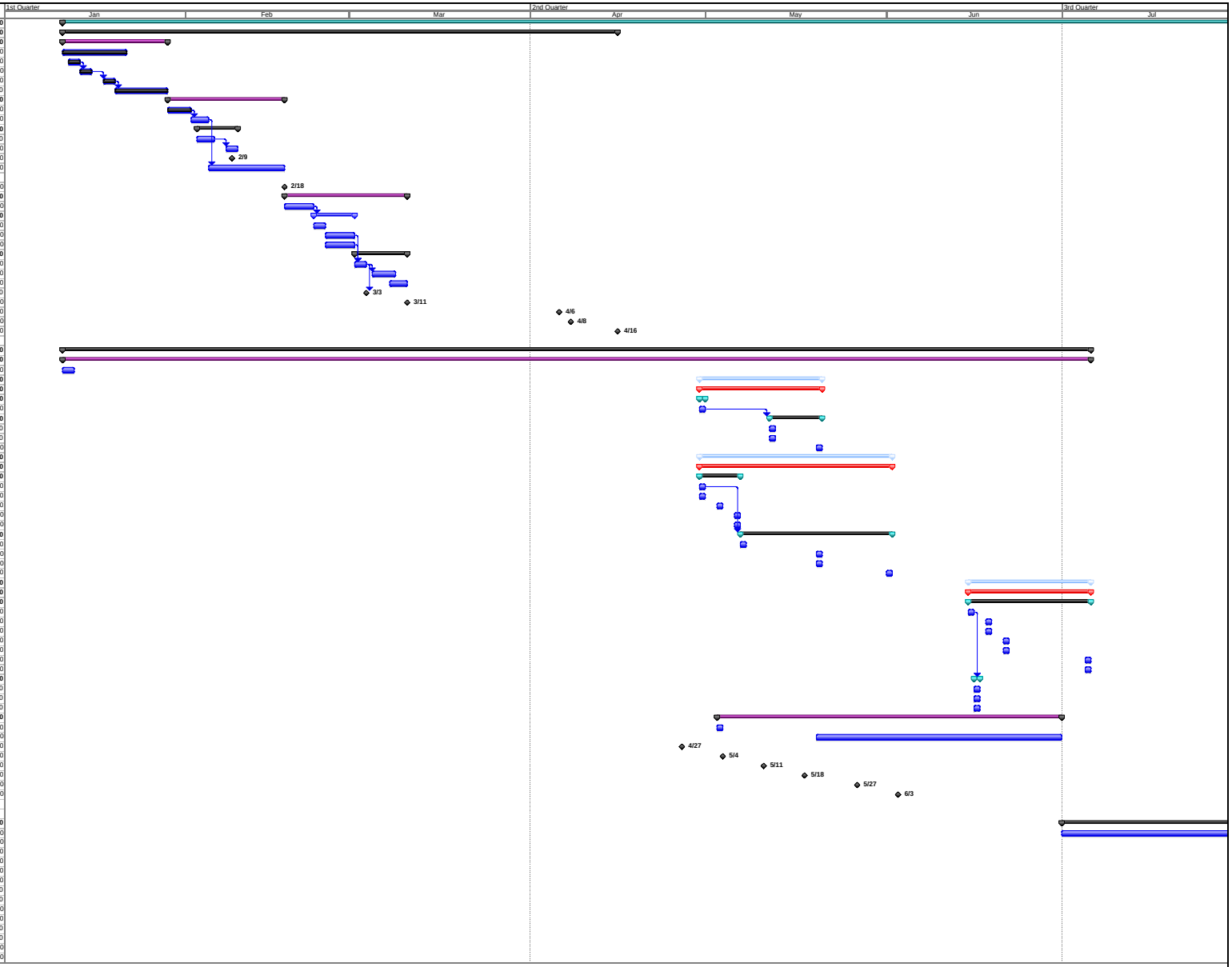
```
const int buttonPin = 2;     //RedButton switch pin
const int raisePin = 3;      //raise actuator switch pin
const int lowerPin = 4;      //lower actuator switch pin
const int motorPin =  5;     //motor output pinl
const int motorPin2 = 10;    //motor ourput pin2
const int LALowerPin = 6;    //LA lower output pin
const int LARaisePin = 7;    //LA raise output pin
const int EnableMotor = 8;   //Enables H-Bridge for Motor
const int EnableLAPin = 9;   //Enables H-Bridge for LA

void setup() {
            // initialize the input and output pins from switch and to L298:

  pinMode(buttonPin, INPUT);
  digitalWrite(buttonPin, HIGH);  //activates internal pull up resistor for motor switch
  pinMode(raisePin, INPUT);
  digitalWrite(raisePin, HIGH);   //activates internal pull up resistor for Linear Actuator lowering switch
  pinMode(lowerPin, INPUT);
  digitalWrite(lowerPin, HIGH);   //activates internal pull up resistor for Linear Actuator raising switch
  pinMode(motorPin, OUTPUT);      //sets motor, LA, and H-Bridge pins as output
  pinMode(motorPin2, OUTPUT);
  pinMode(EnableMotor, OUTPUT);
  pinMode(EnableLAPin, OUTPUT);
  pinMode(LARaisePin, OUTPUT);
  pinMode(LALowerPin, OUTPUT);

  digitalWrite(EnableMotor, HIGH);  //enable side A H-bridge on L298N
  digitalWrite(EnableLAPin, HIGH);  //enable side B H-bridge on L298N
}
```

```
void loop(){

  if ((digitalRead(buttonPin) == LOW)) {
    // turn motor on:
    digitalWrite(motorPin, HIGH);
    digitalWrite(motorPin2, LOW);
    delay(800);                 //rotate motor for 0.8 sec
    digitalWrite(motorPin, LOW);
    delay(2000);                //Pause for 2 sec to disallow rapidfire
  }
  else {
    // turn motor off:
    digitalWrite(motorPin, LOW);
  }
  if ((digitalRead(raisePin) == LOW)) {
    // raise LA:
    digitalWrite(LARaisePin, HIGH);
    digitalWrite(LALowerPin, LOW);
    delay(500);                 //raise LA for 0.5 seconds
    digitalWrite(LARaisePin, LOW);
    delay(100);                 //debouncing
    }
  else if ((digitalRead(lowerPin) == LOW))  {
    // lower LA:
    digitalWrite(LALowerPin, HIGH);
    digitalWrite(LARaisePin, LOW);
    delay(500);                 //lower LA for 0.5 seconds
    digitalWrite(LALowerPin, LOW);
    delay(100);                 //debouncing
  }

  else  {
    digitalWrite(LARaisePin, LOW);
    digitalWrite(LALowerPin, LOW);
  }
}
```

## Appendix I: Wiring Diagram



| ID | Task Name | Duration | Start |
|---|---|---|---|
| 1 | **Foam Wars II** | **238 days** | **Mon 1/11/10** |
| 2 | **Design Process** | **69 days** | **Mon 1/11/10** |
| 3 | **Problem Definition and Background Research** | **14 days** | **Mon 1/11/10** |
| 4 | Meet All Project Contacts | 9 days | Mon 1/11/10 |
| 5 | Quality Function Deployment | 2 days | Tue 1/12/10 |
| 6 | Compliance Matrix | 2 days | Thu 1/14/10 |
| 7 | Gantt Chart | 2 days | Mon 1/18/10 |
| 8 | Project Proposal | 7 days | Wed 1/20/10 |
| 9 | **Concept Design** | **14 days** | **Fri 1/29/10** |
| 10 | Detailed Schedule and Gantt Chart | 2 days | Fri 1/29/10 |
| 11 | Decision Matrix | 3 days | Tue 2/2/10 |
| 12 | **Idea Generation** | **5 days** | **Wed 2/3/10** |
| 13 | Feasibility and Analysis | 3 days | Wed 2/3/10 |
| 14 | Review Concepts | 2 days | Mon 2/8/10 |
| 15 | Presentation: Concept Design Review | 0 days | Tue 2/9/10 |
| 16 | Compile Concept Design Report | 9 days | Fri 2/5/10 |
| 17 | | | |
| 18 | Concept Design Report Due | 0 days | Thu 2/18/10 |
| 19 | **Final Design Report** | **15 days** | **Thu 2/18/10** |
| 20 | DFMEA and DVP&R | 3 days | Thu 2/18/10 |
| 21 | **1st Order Analysis** | **5 days** | **Tue 2/23/10** |
| 22 | Compile Part Specifications | 2 days | Tue 2/23/10 |
| 23 | Select Materials | 3 days | Thu 2/25/10 |
| 24 | Design for Manufacturability and Servicability | 3 days | Thu 2/25/10 |
| 25 | **2nd Order Analysis** | **7 days** | **Tue 3/2/10** |
| 26 | Create SolidWorks Models | 2 days | Tue 3/2/10 |
| 27 | Create 2D Drawings | 2 days | Fri 3/5/10 |
| 28 | Identify Vendors/Source Components | 3 days | Mon 3/8/10 |
| 29 | End of Quarter Meeting w/ Sponsor | 0 days | Wed 3/3/10 |
| 30 | Design Report Draft Due | 0 days | Thu 3/11/10 |
| 31 | Critical Design Review Presentation (Class) | 0 days | Tue 4/6/10 |
| 32 | Critical Design Review Presentation (Sponsor) | 0 days | Thu 4/8/10 |
| 33 | Final Design Report PDF Due 5pm | 0 days | Fri 4/16/10 |
| 34 | | | |
| 35 | **Prototyping and Testing** | **126 days** | **Mon 1/11/10** |
| 36 | **Procurement** | **126 days** | **Mon 1/11/10** |
| 37 | Get Approval for Funding | 2 days | Mon 1/11/10 |
| 38 | **Base Cart** | **15 days** | **Fri 4/30/10** |
| 39 | **Order Parts** | **15 days** | **Fri 4/30/10** |
| 40 | **Critical Parts** | **1 day** | **Fri 4/30/10** |
| 41 | Stock Aluminum | 1 day | Fri 4/30/10 |
| 42 | **Secondary parts** | **7 days** | **Wed 5/12/10** |
| 43 | Teflon Washers | 1 day | Wed 5/12/10 |
| 44 | Rivets | 1 day | Wed 5/12/10 |
| 45 | Wheels | 1 day | Thu 5/20/10 |
| 46 | **Attachments** | **23 days** | **Fri 4/30/10** |
| 47 | **Order Parts** | **23 days** | **Fri 4/30/10** |
| 48 | **Critical Parts** | **5 days** | **Fri 4/30/10** |
| 49 | Netting | 1 day | Fri 4/30/10 |
| 50 | PVC Tubing | 1 day | Fri 4/30/10 |
| 51 | Storage Container | 1 day | Mon 5/3/10 |
| 52 | Brackets | 1 day | Thu 5/6/10 |
| 53 | PVC Tubing | 1 day | Thu 5/6/10 |
| 54 | **Secondary parts** | **18 days** | **Fri 5/7/10** |
| 55 | PVC Tubing | 1 day | Fri 5/7/10 |
| 56 | Zip Ties | 1 day | Thu 5/20/10 |
| 57 | Velcro | 1 day | Thu 5/20/10 |
| 58 | Hula Hoops | 1 day | Tue 6/1/10 |
| 59 | **Launcher** | **15 days** | **Tue 6/15/10** |
| 60 | **Order Parts** | **15 days** | **Tue 6/15/10** |
| 61 | **Critical Parts** | **15 days** | **Tue 6/15/10** |
| 62 | Pitching Machine | 1 day | Tue 6/15/10 |
| 63 | Platform | 1 day | Fri 6/18/10 |
| 64 | Power Source | 1 day | Fri 6/18/10 |
| 65 | Motors | 1 day | Mon 6/21/10 |
| 66 | Microcontrollers | 1 day | Mon 6/21/10 |
| 67 | Gears | 1 day | Mon 7/5/10 |
| 68 | Loader | 1 day | Mon 7/5/10 |
| 69 | **Secondary parts** | **1 day** | **Wed 6/16/10** |
| 70 | Storage Container | 1 day | Wed 6/16/10 |
| 71 | Wheels | 1 day | Wed 6/16/10 |
| 72 | Legs | 1 day | Wed 6/16/10 |
| 73 | **Design** | **43 days** | **Mon 5/3/10** |
| 74 | Look at "extras" | 1 day | Mon 5/3/10 |
| 75 | Manufacturing | 30 days | Thu 5/20/10 |
| 76 | Draft Design Status Report Due | 0 days | Tue 4/27/10 |
| 77 | Ethics Memo Due | 0 days | Tue 5/4/10 |
| 78 | Team Presentation Ethics | 0 days | Tue 5/11/10 |
| 79 | Team Presentation Ethics | 0 days | Tue 5/18/10 |
| 80 | Prototype and Test Plan Review | 0 days | Thu 5/27/10 |
| 81 | Project Update Report to Sponsor | 0 days | Thu 6/3/10 |
| 82 | | | |
| 83 | | | |
| 84 | **Building and Senior Project Expo** | **115 days** | **Thu 7/1/10** |
| 85 | Finalize Component Designs and Select/Purchase all part | 50 days | Thu 7/1/10 |
| 86 | Senior Exit Exam | 0 days | Thu 10/21/10 |
| 87 | Complete First Base Cart | 20 days | Mon 9/20/10 |
| 88 | Complete First Cage/Retriever | 20 days | Mon 9/20/10 |
| 89 | Complete First Launcher | 27 days | Mon 9/20/10 |
| 90 | Check Base Cart/Cage/Retriever Compatibility | 7 days | Mon 10/18/10 |
| 91 | Assemble Complete Carts | 5 days | Wed 10/27/10 |
| 92 | Test/Tweak Completed Carts (1 of each so far) | 6 days | Wed 11/3/10 |
| 93 | Final Hardware Demo - Bonderson Courtyard | 0 days | Thu 11/11/10 |
| 94 | Construct Remaining Carts | 8 days | Fri 11/12/10 |
| 95 | Project Testing/Tweaking | 6 days | Wed 11/24/10 |
| 96 | Thanksgiving Break | 4 days | Wed 11/24/10 |
| 97 | Senior Project Design Expo | 0 days | Thu 12/2/10 |
| 98 | Final Project Reports Due | 0 days | Thu 12/9/10 |




Project: Gantt Chart Complete 1-27
Date: Mon 10/25/10

Task | Split | Progress | Milestone | Summary | Project Summary | External Tasks | External Milestone | Deadline

| ID | Task Name | Duration | Start |
|---|---|---|---|
| 1 | **Foam Wars II** | **238 days** | **Mon 1/11/10** |
| 2 | **Design Process** | **69 days** | **Mon 1/11/10** |
| 3 | **Problem Definition and Background Research** | **14 days** | **Mon 1/11/10** |
| 4 | Meet All Project Contacts | 9 days | Mon 1/11/10 |
| 5 | Quality Function Deployment | 2 days | Tue 1/12/10 |
| 6 | Compliance Matrix | 2 days | Thu 1/14/10 |
| 7 | Gantt Chart | 2 days | Mon 1/18/10 |
| 8 | Project Proposal | 7 days | Wed 1/20/10 |
| 9 | **Concept Design** | **14 days** | **Fri 1/29/10** |
| 10 | Detailed Schedule and Gantt Chart | 2 days | Fri 1/29/10 |
| 11 | Decision Matrix | 3 days | Tue 2/2/10 |
| 12 | **Idea Generation** | **5 days** | **Wed 2/3/10** |
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| 17 | | | |
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| 28 | Identify Vendors/Source Components | 3 days | Mon 3/8/10 |
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| 30 | Design Report Draft Due | 0 days | Thu 3/11/10 |
| 31 | Critical Design Review Presentation (Class) | 0 days | Tue 4/6/10 |
| 32 | Critcal Design Review Presentation (Sponsor) | 0 days | Thu 4/8/10 |
| 33 | Final Design Report PDF Due 5pm | 0 days | Fri 4/16/10 |
| 34 | | | |
| 35 | **Prototyping and Testing** | **126 days** | **Mon 1/11/10** |
| 36 | **Procurement** | **126 days** | **Mon 1/11/10** |
| 37 | Get Approval for Funding | 2 days | Mon 1/11/10 |
| 38 | **Base Cart** | **15 days** | **Fri 4/30/10** |
| 39 | **Order Parts** | **15 days** | **Fri 4/30/10** |
| 40 | **Critical Parts** | **1 day** | **Fri 4/30/10** |
| 41 | Stock Aluminum | 1 day | Fri 4/30/10 |
| 42 | **Secondary parts** | **7 days** | **Wed 5/12/10** |
| 43 | Teflon Washers | 1 day | Wed 5/12/10 |
| 44 | Rivets | 1 day | Wed 5/12/10 |
| 45 | Wheels | 1 day | Thu 5/20/10 |
| 46 | **Attachments** | **23 days** | **Fri 4/30/10** |
| 47 | **Order Parts** | **23 days** | **Fri 4/30/10** |
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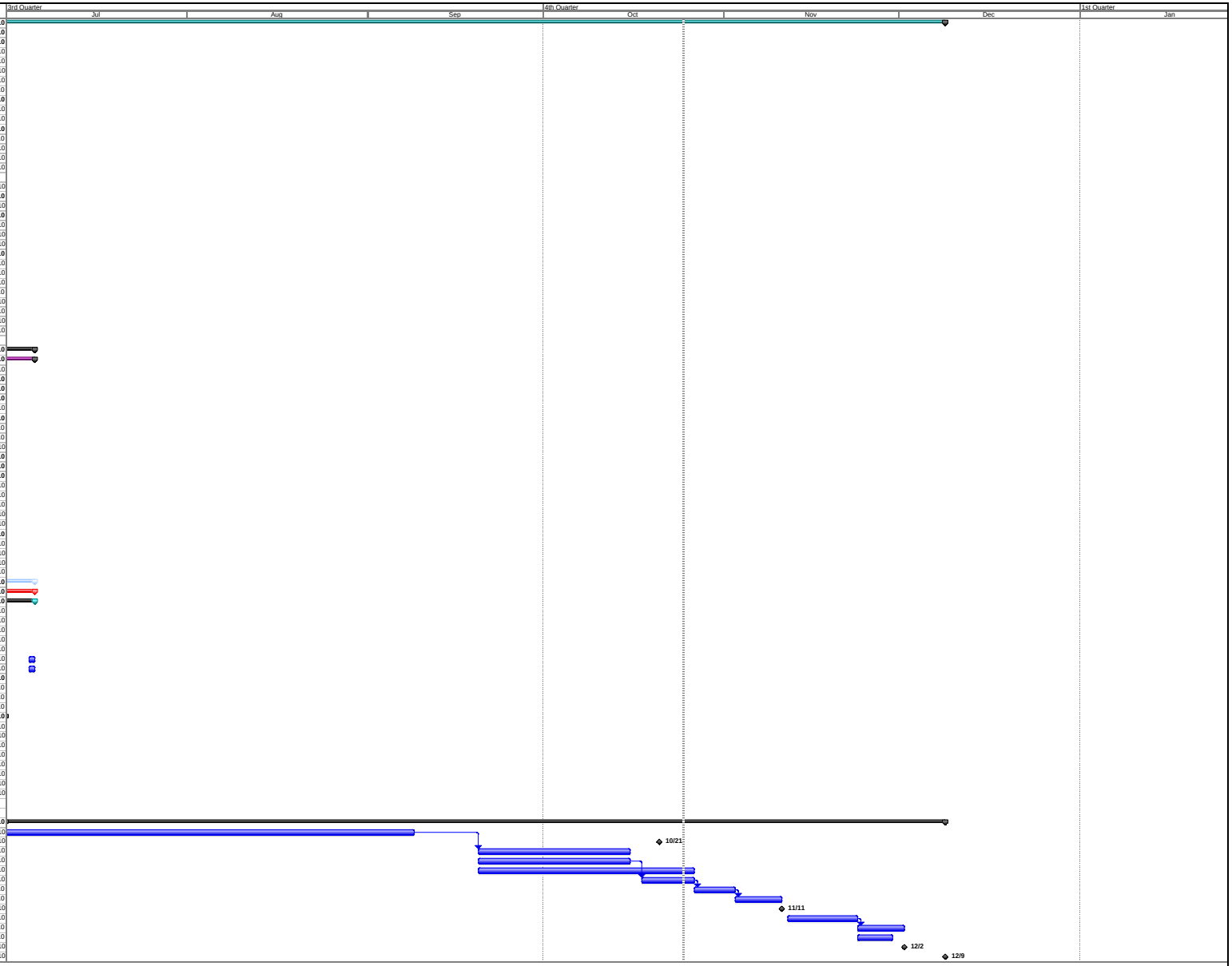
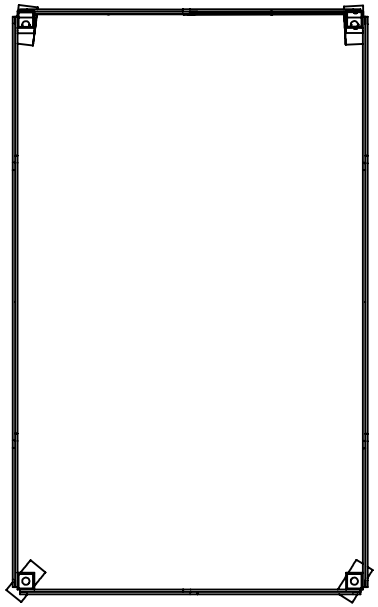
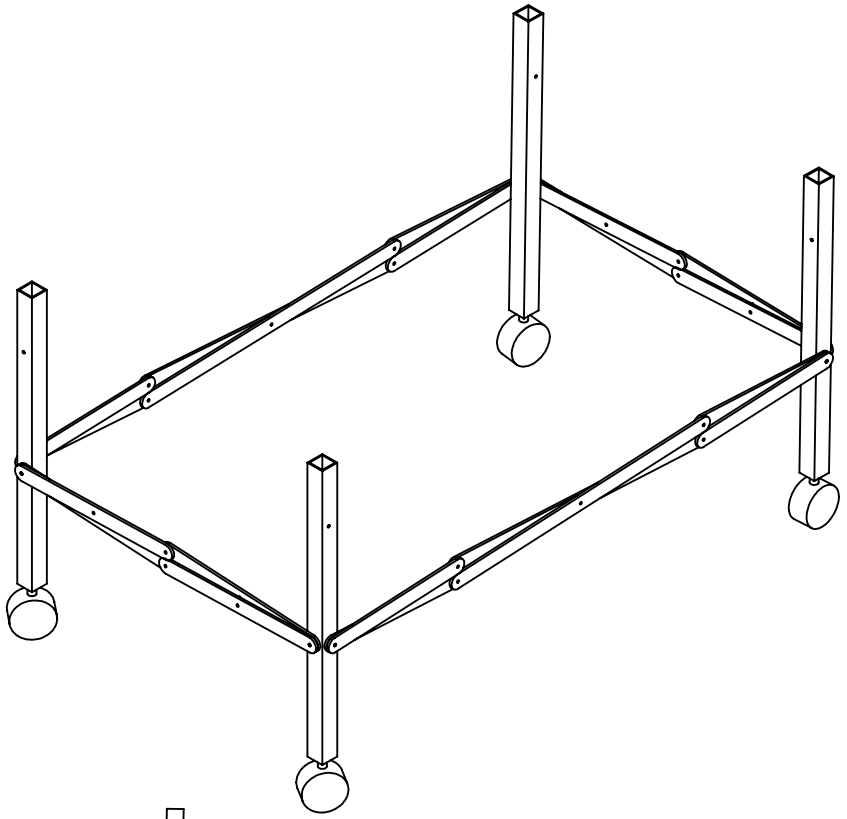
| 52 | Brackets | 1 day | Thu 5/6/10 |
| 53 | PVC Tubing | 1 day | Thu 5/6/10 |
| 54 | **Secondary parts** | **18 days** | **Fri 5/7/10** |
| 55 | PVC Tubing | 1 day | Fri 5/7/10 |
| 56 | Zip Ties | 1 day | Thu 5/20/10 |
| 57 | Velcro | 1 day | Thu 5/20/10 |
| 58 | Hula Hoops | 1 day | Tue 6/1/10 |
| 59 | **Launcher** | **15 days** | **Tue 6/15/10** |
| 60 | **Order Parts** | **15 days** | **Tue 6/15/10** |
| 61 | **Critical Parts** | **15 days** | **Tue 6/15/10** |
| 62 | Pitching Machine | 1 day | Tue 6/15/10 |
| 63 | Platform | 1 day | Fri 6/18/10 |
| 64 | Power Source | 1 day | Fri 6/18/10 |
| 65 | Motors | 1 day | Mon 6/21/10 |
| 66 | Microcontrollers | 1 day | Mon 6/21/10 |
| 67 | Gears | 1 day | Mon 7/5/10 |
| 68 | Loader | 1 day | Mon 7/5/10 |
| 69 | **Secondary parts** | **1 day** | **Wed 6/16/10** |
| 70 | Storage Container | 1 day | Wed 6/16/10 |
| 71 | Wheels | 1 day | Wed 6/16/10 |
| 72 | Legs | 1 day | Wed 6/16/10 |
| 73 | **Design** | **43 days** | **Mon 5/3/10** |
| 74 | Look at "extras" | 1 day | Mon 5/3/10 |
| 75 | Manufacturing | 30 days | Thu 5/20/10 |
| 76 | Draft Design Status Report Due | 0 days | Tue 4/27/10 |
| 77 | Ethics Memo Due | 0 days | Tue 5/4/10 |
| 78 | Team Presentation Ethics | 0 days | Tue 5/11/10 |
| 79 | Team Presentation Ethics | 0 days | Tue 5/18/10 |
| 80 | Prototype and Test Plan Review | 0 days | Thu 5/27/10 |
| 81 | Project Update Report to Sponsor | 0 days | Thu 6/3/10 |
| 82 | | | |
| 83 | | | |
| 84 | **Building and Senior Project Expo** | **115 days** | **Thu 7/1/10** |
| 85 | Finalize Component Designs and Select/Purchase all part | 50 days | Thu 7/1/10 |
| 86 | Senior Exit Exam | 0 days | Thu 10/21/10 |
| 87 | Complete First Base Cart | 20 days | Mon 9/20/10 |
| 88 | Complete First Cage/Retriever | 20 days | Mon 9/20/10 |
| 89 | Complete First Launcher | 27 days | Mon 9/20/10 |
| 90 | Check Base Cart/Cage/Retriever Compatibility | 7 days | Mon 10/18/10 |
| 91 | Assemble Complete Carts | 5 days | Wed 10/27/10 |
| 92 | Test/Tweak Completed Carts (1 of each so far) | 6 days | Wed 11/3/10 |
| 93 | Final Hardware Demo - Bonderson Courtyard | 0 days | Thu 11/11/10 |
| 94 | Construct Remaining Carts | 8 days | Fri 11/12/10 |
| 95 | Project Testing/Tweaking | 6 days | Wed 11/24/10 |
| 96 | Thanksgiving Break | 4 days | Wed 11/24/10 |
| 97 | Senior Project Design Expo | 0 days | Thu 12/2/10 |
| 98 | Final Project Reports Due | 0 days | Thu 12/9/10 |

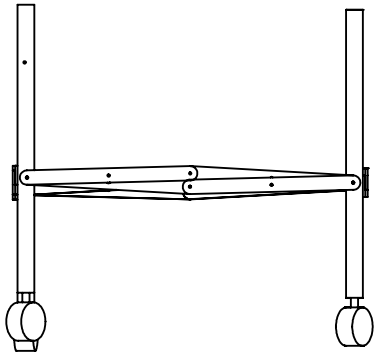


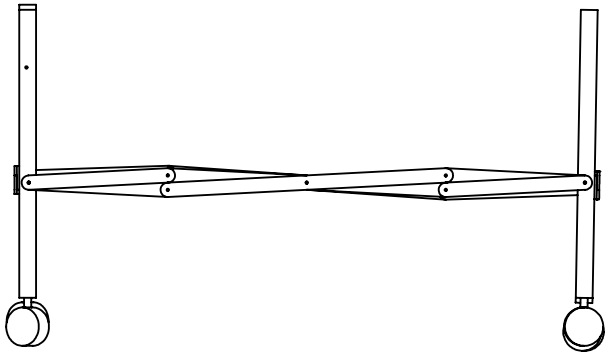

Project: Gantt Chart Complete 1-27
Date: Mon 10/25/10

Task | Split | Progress | Milestone | Summary | Project Summary | External Tasks | External Milestone | Deadline



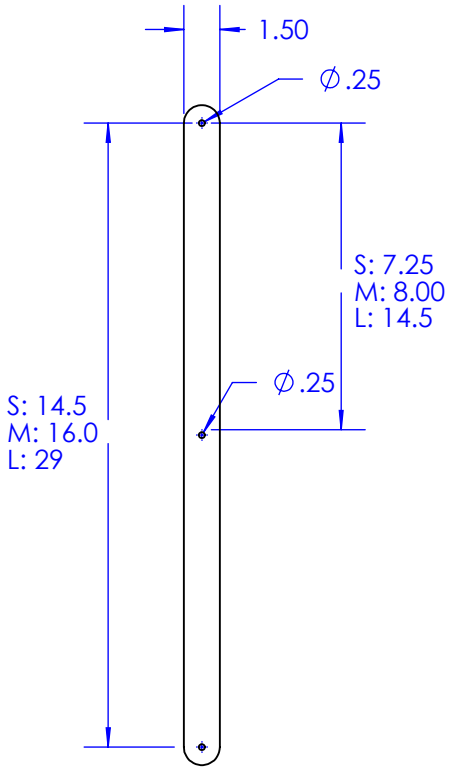


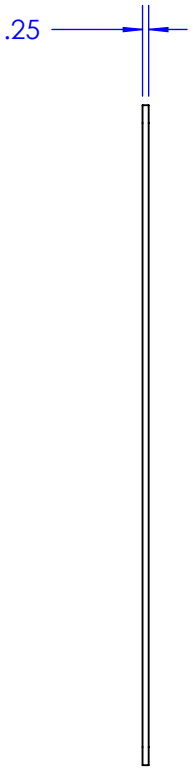




| | | | |
|---|---|---|---|
| *Foam Warriors II* | | NEXT ASSY: 2 | SIGNATURE: |
| Mechanical Engineering CAL POLY | | DRAWING #: 1.1 | MATERIAL: |
| | TOLERANCE: ±0.1 | UNITS: Inches | TITLE: Universal Base Cart |
| | SCALE: 1:20 | DATE: 12-2-2010 | NAME: Sumant Advani |

5 4 3 2 1

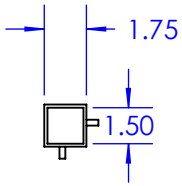


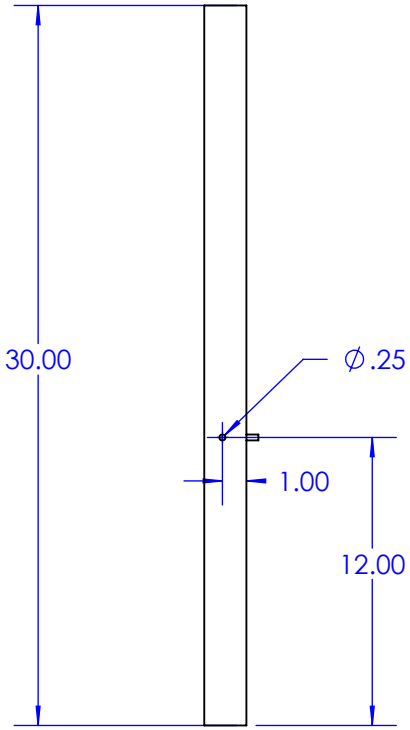



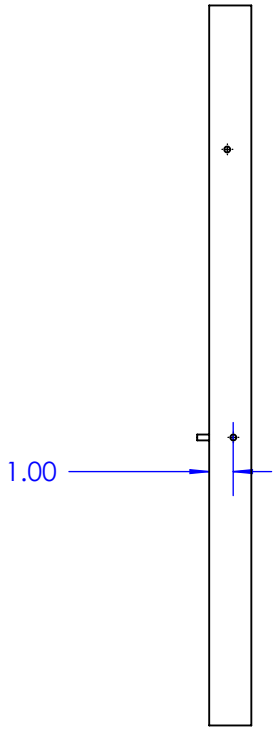

Note: "S', 'M', and 'L' Denote the respective lengths for the small, medium, and large flat plates. All other dimensions are identical

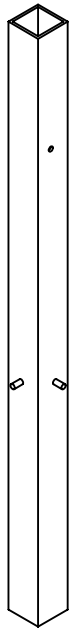
| | | | |
|---|---|---|---|
| *Foam Warriors II* Mechanical Engineering CAL POLY | | NEXT ASSY: 1 | SIGNATURE: |
| | | DRAWING #: 1.1 | MATERIAL: Aluminum |
| | TOLERANCE: ±0.1 | UNITS: Inches | TITLE: Aluminum Plate |
| | SCALE: 1:8 | DATE: 12-2-2010 | NAME: Sumant Advani |

5 4 3 2 1



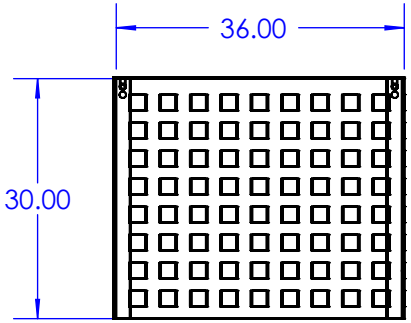



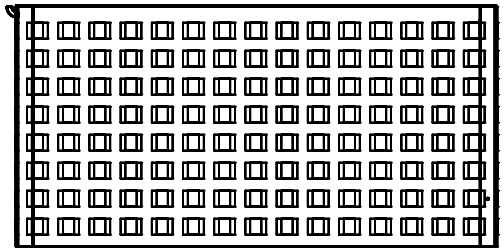



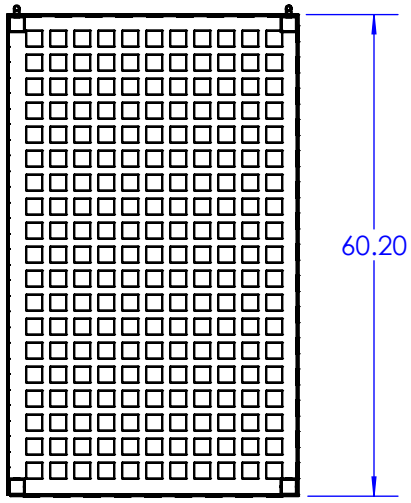
| | | |
|---|---|---|
| *Foam Warriors II* | NEXT ASSY: 1 | SIGNATURE: |
| Mechanical Engineering CAL POLY | DRAWING #: 1.1 | MATERIAL: Aluminum |
| TOLERANCE: ±0.1 | UNITS: Inches | TITLE: Aluminum Square Tube |
| SCALE: 1:8 | DATE: 12-2-2010 | NAME: Sumant Advani |

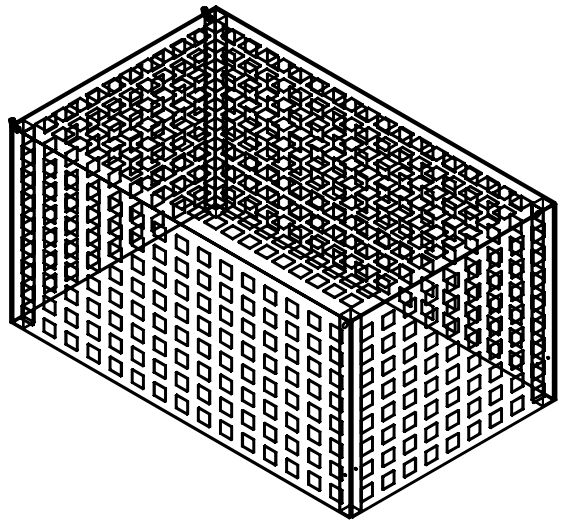
5 4 3 2 1

| ITEM NO. | DESCRIPTION | PART NUMBER | QTY. |
|---|---|---|---|
| 1 | PVC Post | 85095K82 | 2 |
| 2 | PVC Post with Hole | 85095K82 | 2 |
| 3 | Elbow | 406-005HC | 2 |





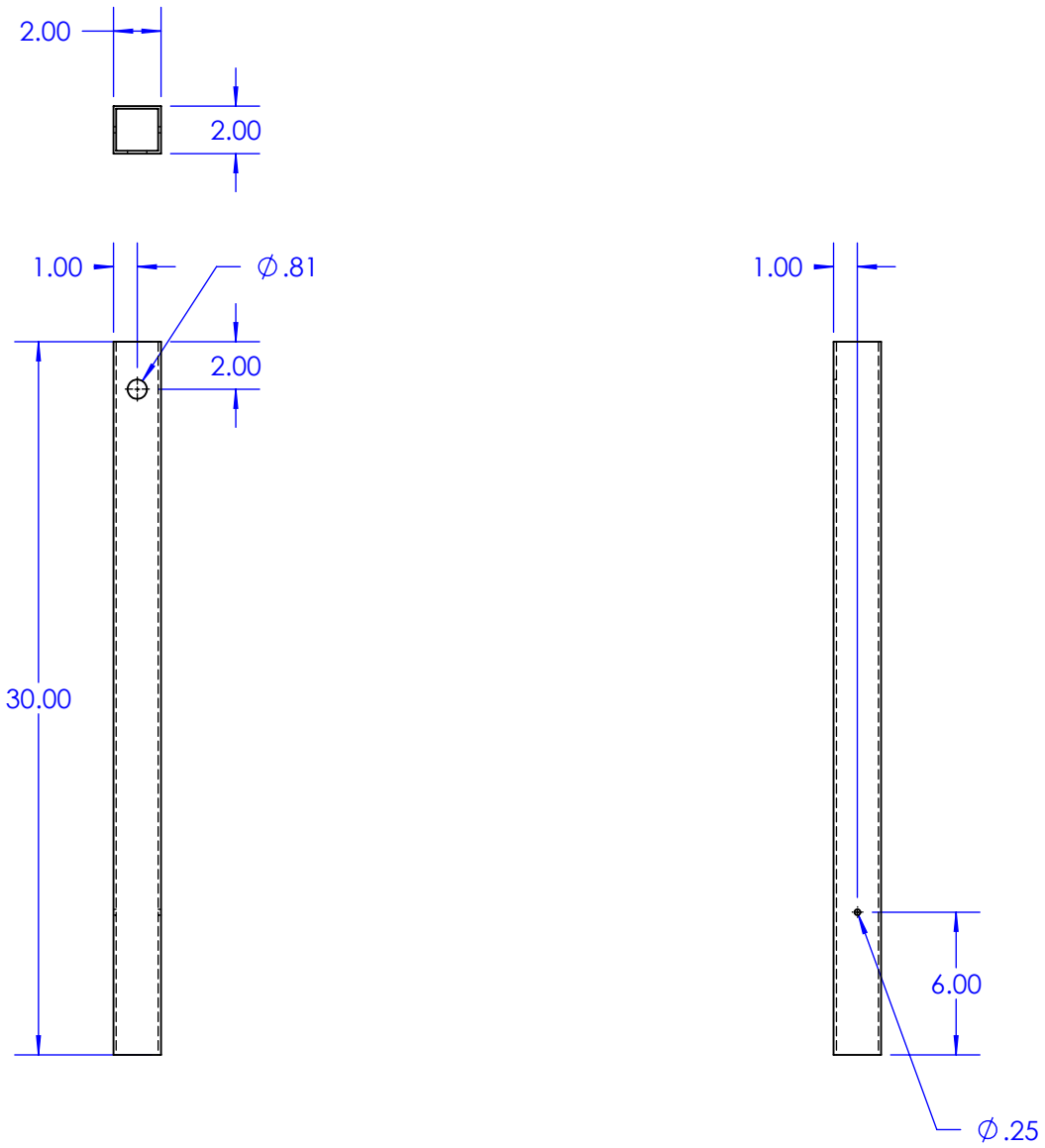



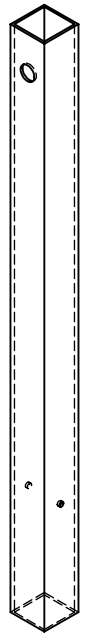
*Foam Wars II*

Mechanical Engineering CAL POLY

| | | |
|---|---|---|
| | NEXT ASSY: N/A | SIGNATURE: |
| | DRAWING #: 2 | MATERIAL: PVC + Netting |
| TOLERANCE: ±0.1 | UNITS: Inches | TITLE: Cage Attachment |
| SCALE: 1:24 | DATE: 4/20/2010 | NAME: Casey Pieplow |

5 4 3 2 1

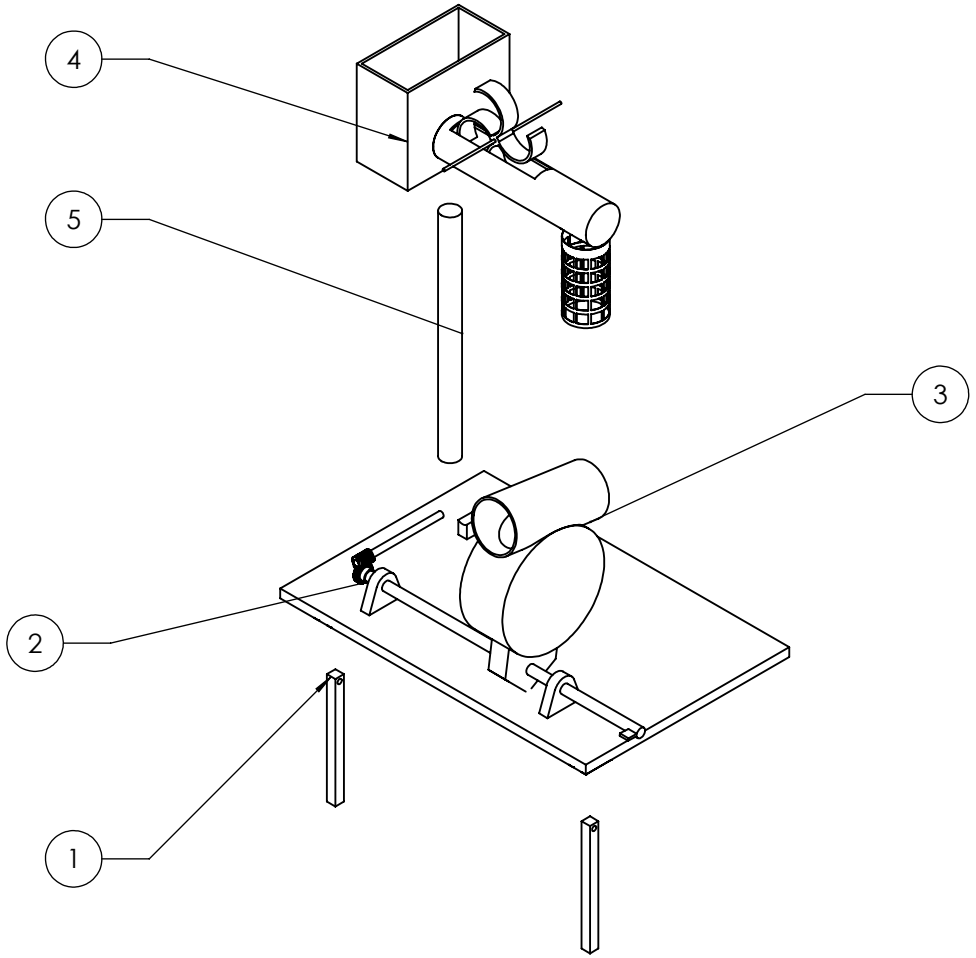


| | | | |
|---|---|---|---|
| *Foam Wars II* | | NEXT ASSY: 2 | SIGNATURE: |
| Mechanical Engineering CAL POLY | | DRAWING #: 2.1 | MATERIAL: PVC |
| | TOLERANCE: ±0.1 | UNITS: Inches | TITLE: PVC Post |
| | SCALE: 1:8 | DATE: 12/6/10 | NAME: Casey Pieplow |

5 4 3 2 1

| ITEM NO. | DESCRIPTION | PART NUMBER | QTY. |
|---|---|---|---|
| 1 | Launcher Base Leg | | 2 |
| 2 | Launcher Base Plate | 3.2 | 1 |
| 3 | Launcher | | 1 |
| 4 | Reloader | 3.1.3 | 1 |
| 5 | Support Post | | 1 |

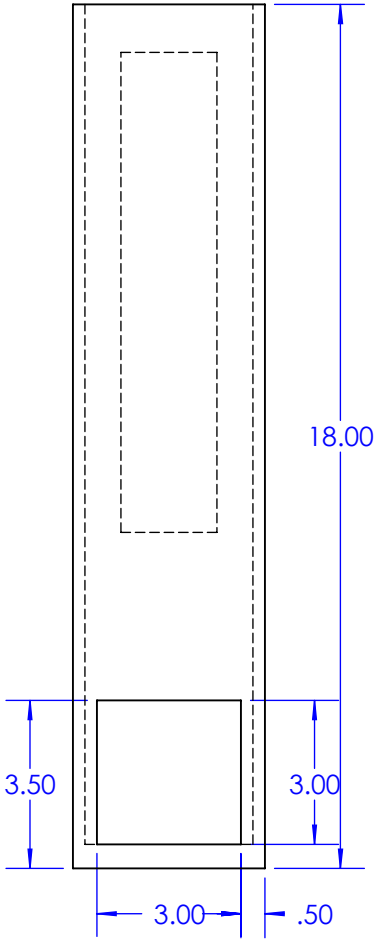


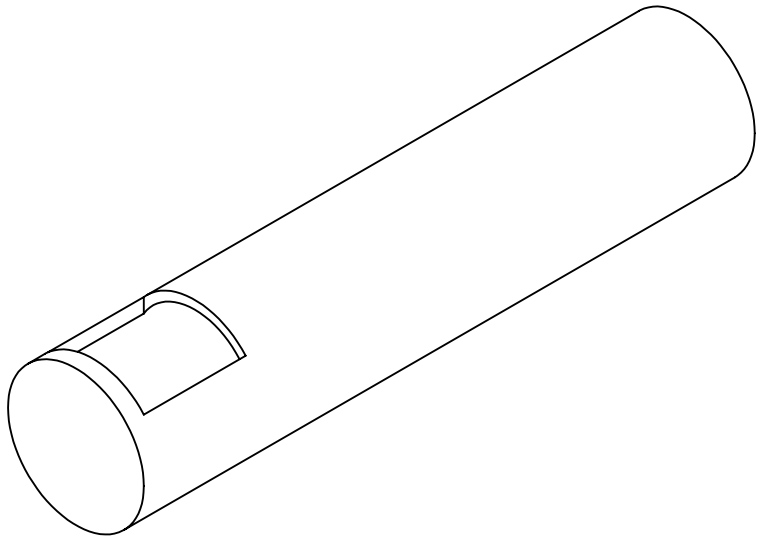

*Foam Wars II*

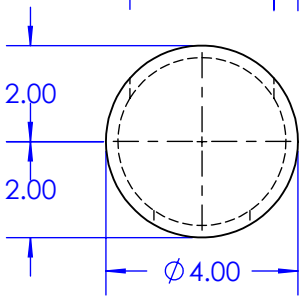
Mechanical Engineering CAL POLY

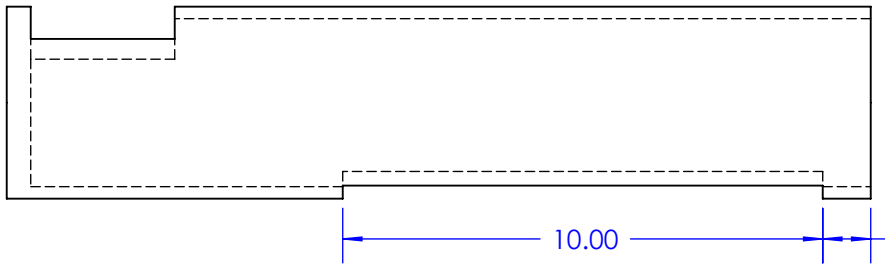
| | | |
|---|---|---|
| | NEXT ASSY: N/A | SIGNATURE: |
| | DRAWING #: 3 | MATERIAL: |
| TOLERANCE: ±0.1 | UNITS: Inches | TITLE: Launcher Attachment (Original) |
| SCALE: 1:16 | DATE: 4/22/10 | NAME: Das Menon |

5 4 3 2 1



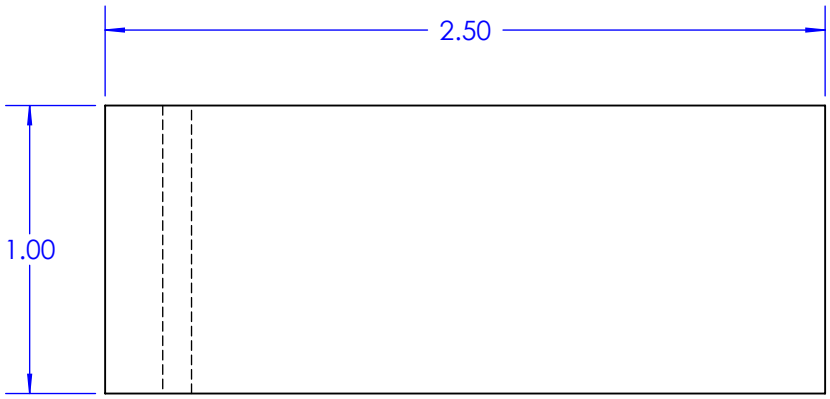



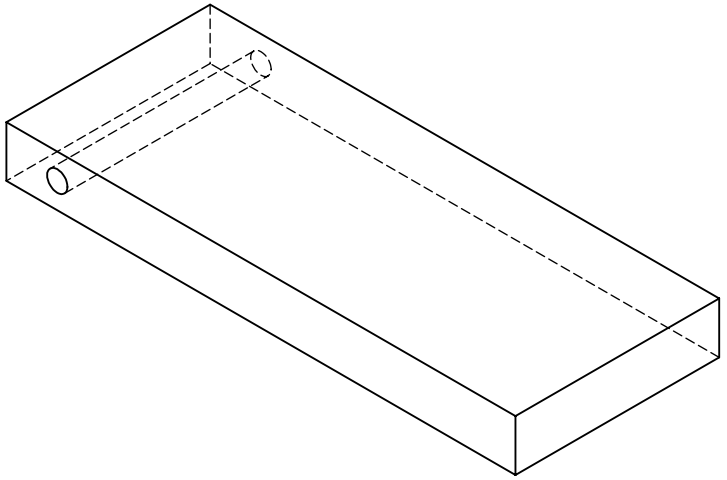


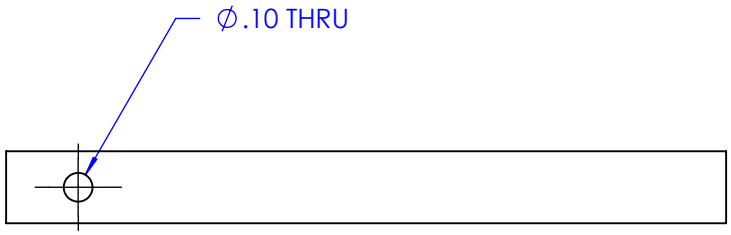



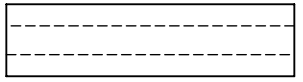

| | | |
|---|---|---|
| *Foam Wars II* | NEXT ASSY: 3.1 | SIGNATURE: |
| Mechanical Engineering CAL POLY | DRAWING #: 3.1.1 | MATERIAL: PVC |
| TOLERANCE: ±0.1 | UNITS: Inches | TITLE: Feeding Tube |
| SCALE: 1:4 | DATE: 4/22/10 | NAME: Das Menon |

5 4 3 2 1



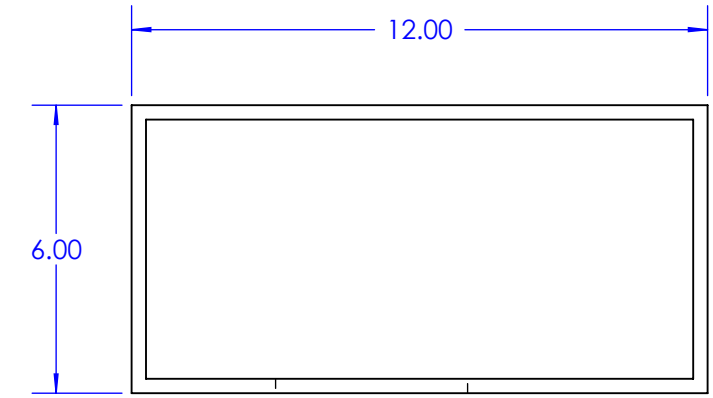



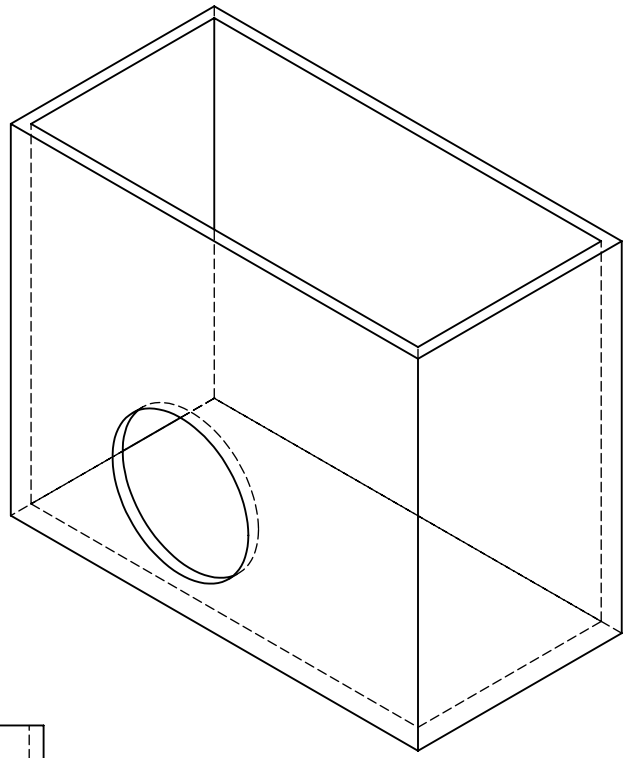


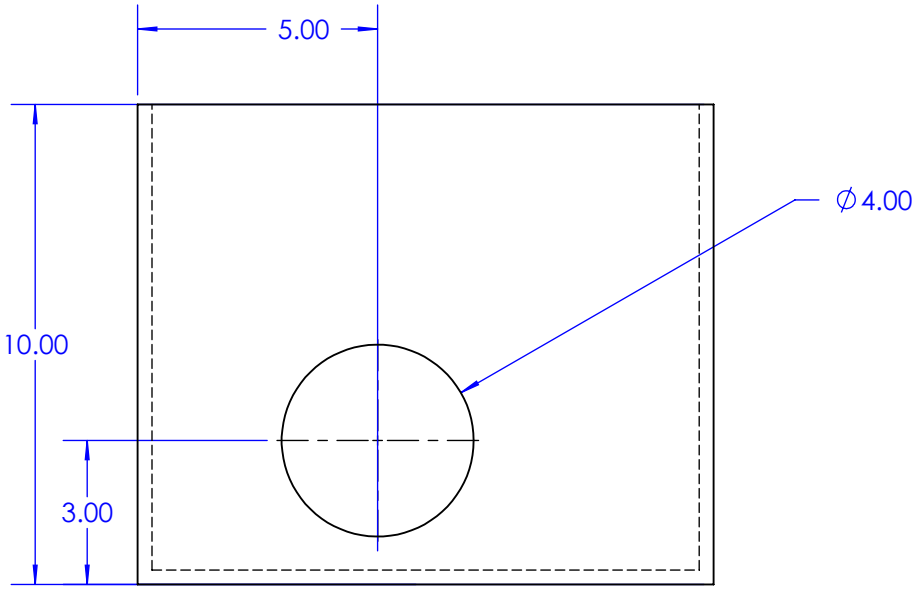



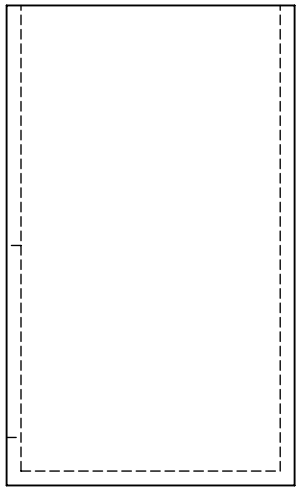
| | | | |
|---|---|---|---|
| *Foam Wars II* Mechanical Engineering CAL POLY | | NEXT ASSY: 3.1 | SIGNATURE: |
| | | DRAWING #: 3.1.2 | MATERIAL: Aluminum |
| | TOLERANCE: ±0.1 | UNITS: Inches | TITLE: Ball Release Flap |
| | SCALE: 3:2 | DATE: 4/22/10 | NAME: Casey Pieplow |

5 4 3 2 1





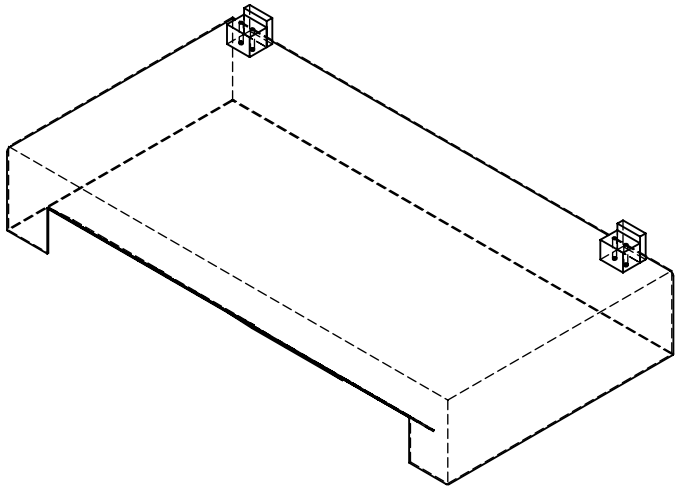
# Foam Wars II

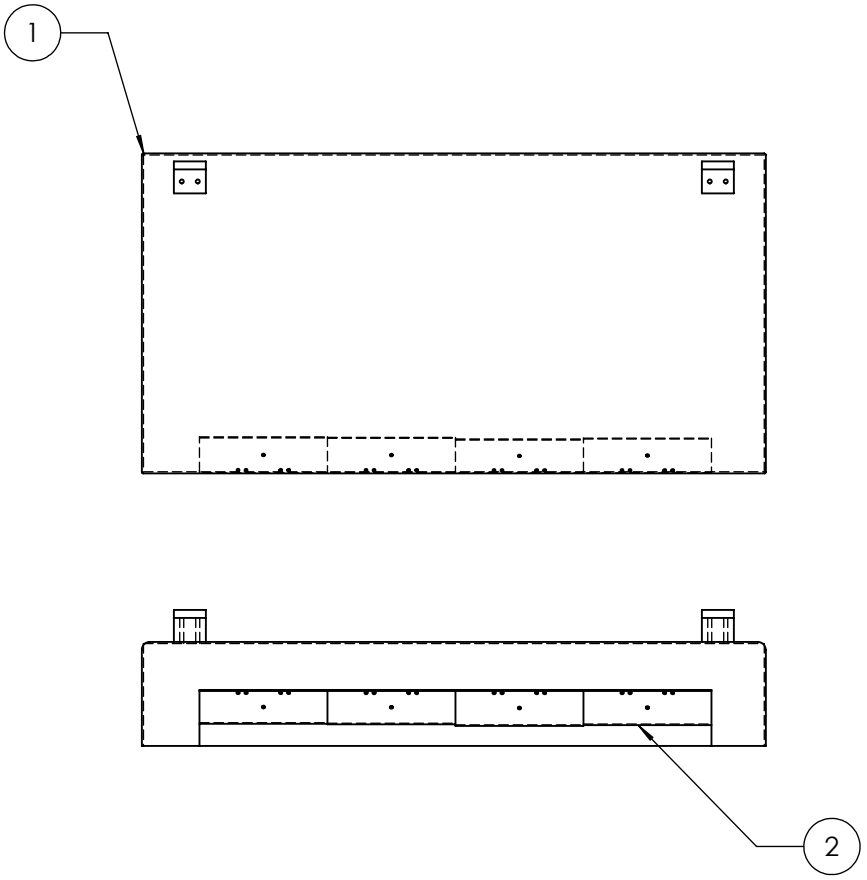
Mechanical Engineering CAL POLY

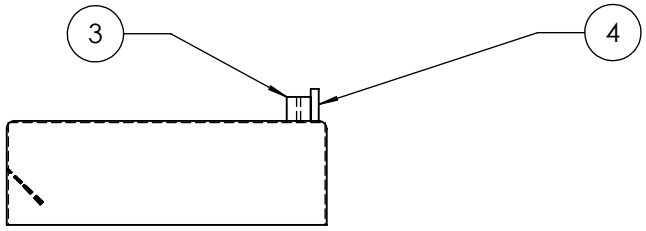
| | | |
|---|---|---|
| | NEXT ASSY: 3.1 | SIGNATURE: |
| | DRAWING #: 3.1.3 | MATERIAL: Plastic |
| TOLERANCE: ±0.1 | UNITS: Inches | TITLE: Ball Reservoir |
| SCALE: 1:4 | DATE: 4/22/10 | NAME: Casey Pieplow |

5 4 3 2 1

| ITEM NO. | DESCRIPTION | PART NUMBER | QTY. |
|---|---|---|---|
| 1 | Tub | 4.1 | 1 |
| 2 | Flap | 4.2 | 4 |
| 3 | Small Block | N/A | 2 |
| 4 | Front Wood | N/A | 2 |





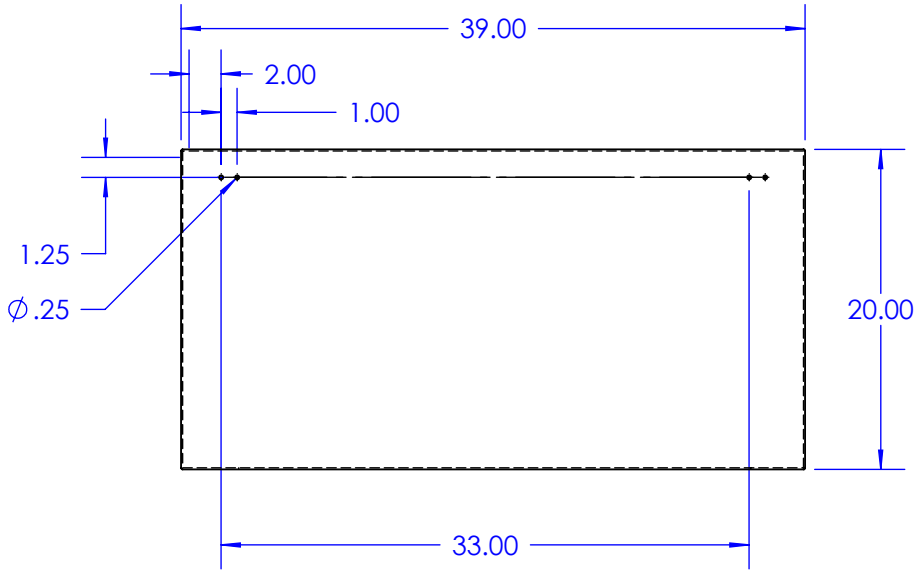



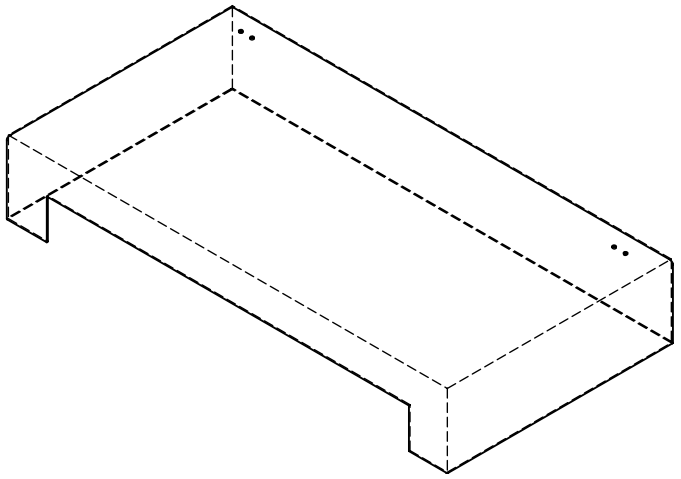

*Foam Wars II*

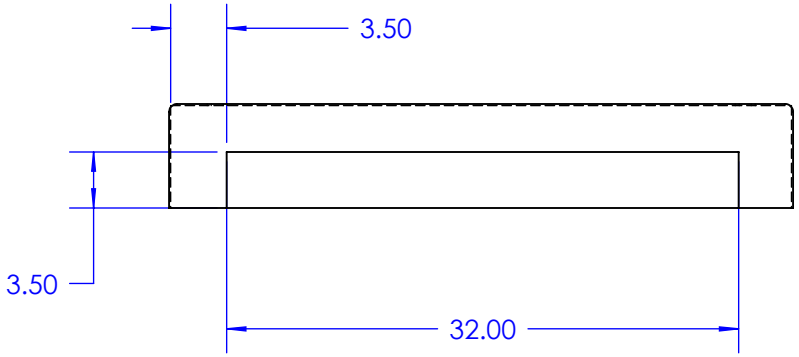
Mechanical Engineering CAL POLY

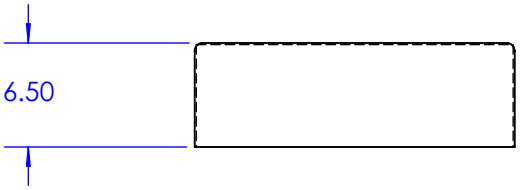
| | | |
|---|---|---|
| | NEXT ASSY: N/A | SIGNATURE: |
| | DRAWING #: 4 | MATERIAL: |
| TOLERANCE: ±0.1 | UNITS: Inches | TITLE: Retriever Attachment |
| SCALE: 1:12 | DATE: 12/6/10 | NAME: Casey Pieplow |

5 4 3 2 1





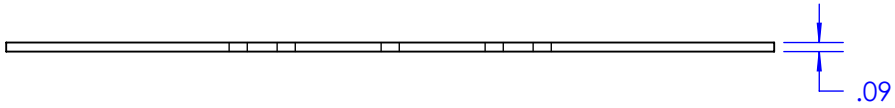



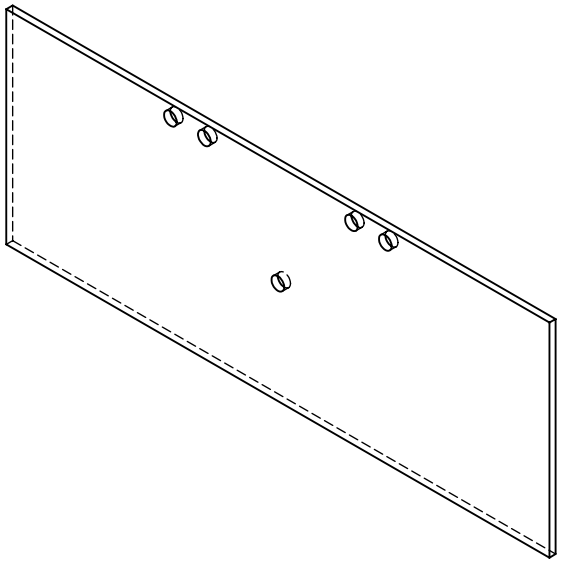

*Foam Wars II*

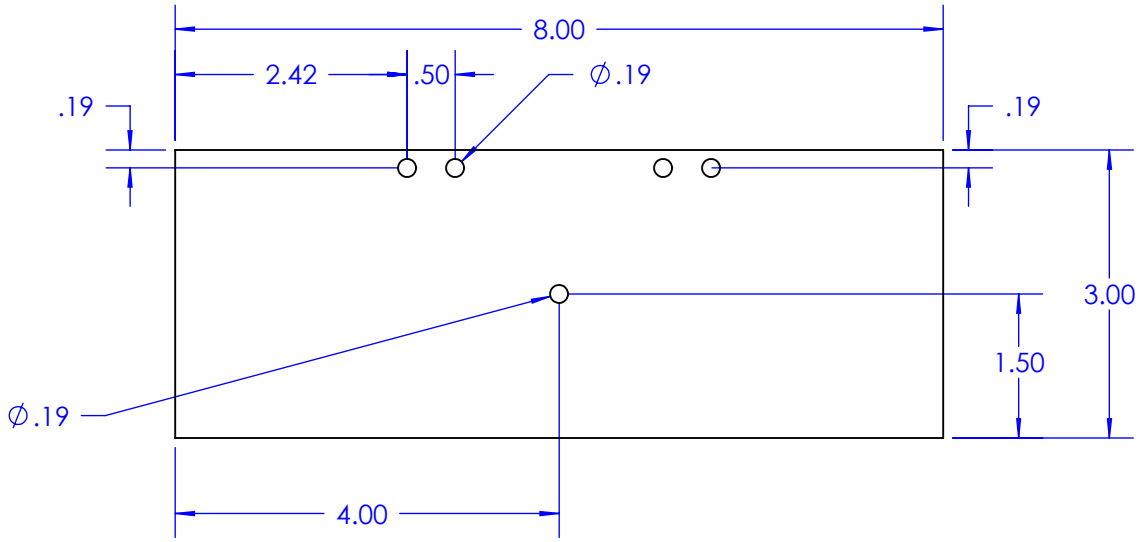
Mechanical Engineering CAL POLY

| | | |
|---|---|---|
| | NEXT ASSY: 4 | SIGNATURE: |
| | DRAWING #: 4.1 | MATERIAL: Plastic |
| TOLERANCE: ±0.1 | UNITS: Inches | TITLE: Tub |
| SCALE: 1:12 | DATE: 12/6/10 | NAME: Casey Pieplow |

5 4 3 2 1



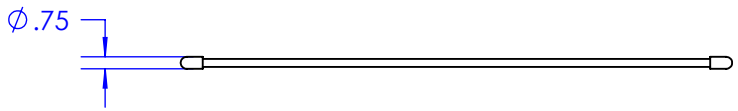


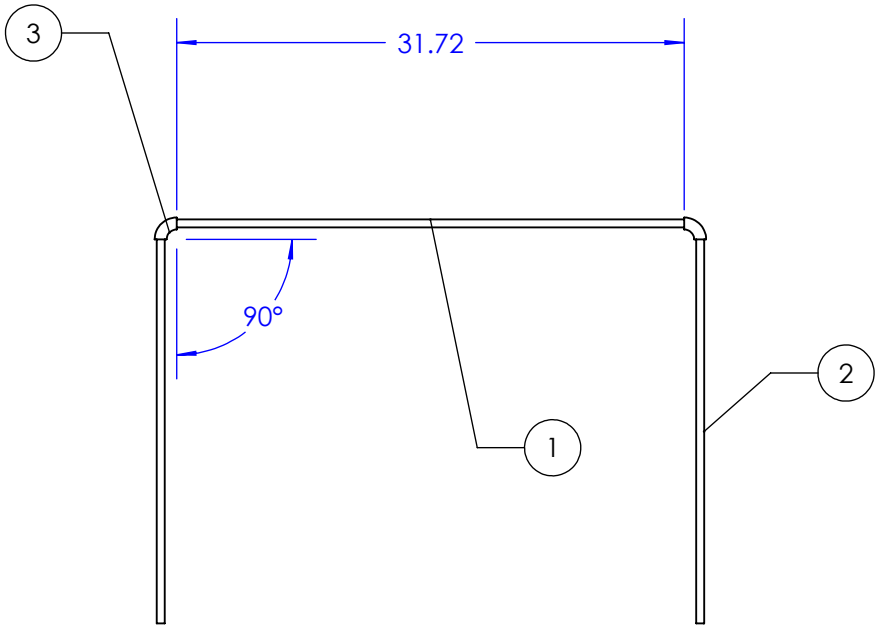


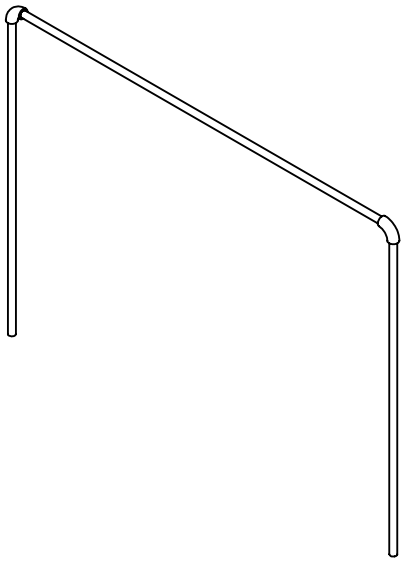

| | | | |
|---|---|---|---|
| Foam Wars II | | NEXT ASSY: 4 | SIGNATURE: |
| Mechanical Engineering CAL POLY | | DRAWING #: 4.2 | MATERIAL: Acrylic |
| | TOLERANCE: ±0.1 | UNITS: Inches | TITLE: Flap |
| | SCALE: 1:1 | DATE: 12/6/10 | NAME: Casey Pieplow |

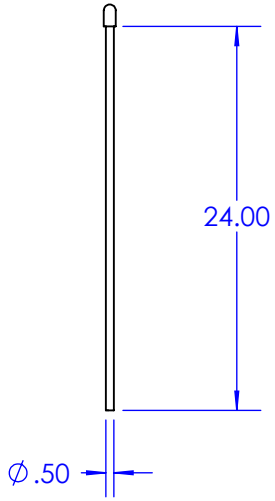
5 4 3 2 1

| ITEM NO. | DESCRIPTION | PART NUMBER | QTY. |
|---|---|---|---|
| 1 | Horiz. Goalie Pipe | PVC 04005 0600 | 1 |
| 2 | Vertical Goalie Pipe | PVC 04005 0600 | 2 |
| 3 | Elbow | 406-005HC | 2 |






| | | | |
|---|---|---|---|
| *Foam Wars II* Mechanical Engineering CAL POLY | | NEXT ASSY: N/A | SIGNATURE: |
| | | DRAWING #: 5 | MATERIAL: PVC |
| | TOLERANCE: ±0.1 | UNITS: Inches | TITLE: Goalie Attachment |
| | SCALE: 1:12 | DATE: 4/20/2010 | NAME: Casey Pieplow |

5 4 3 2 1