Lacrosse Ball Feeding Device
Design Report 5
Team 18

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December 14, 2015

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EXECUTIVE SUMMARY

The goal of this project is to further develop a ball feeding device to be installed in a new practice facility for our sponsor the University of Michigan's Varsity Men's and Women's Lacrosse teams. An interview with men's varsity Coach John Paul, yielded several main requirements. First, the machine should be able to simulate realistic play, including throws and bounce shots, by being able to launch lacrosse balls at changeable speeds (between 40 and 100 mph), directions (covering a 30x30 yard room), angles (horizontal range of ±60° from the center and vertical range of ±30° from the horizontal), and frequencies. Moreover, to enable useful single player practice, the device should be easy to set-up, automated via a user-friendly interface, and contain up to 80 lacrosse balls in a hopper. Lastly, safety for the players and the device must be considered by incorporating warning lights, emergency stops and sensors, and a durable shield for the machine.

Our approach in creating design concepts utilized functional decomposition to divide the overall function of our project into subsystems (protecting the device, protecting the players, launching lacrosse balls, and setting up the machine) based on these user requirements and specifications. To assess our concepts, we used Pugh charts for each sub-function. Our chosen design concepts focus on four main sub-functions: safety, hopper, feed rate, and control systems. Safety of the prebuilt prototype is addressed by installing sheets of half-inch thick acrylic glass on the front and back with aluminum support bars connecting them and netting on the sides. Furthermore, we chose a netted hopper supported by upper and lower brackets mounted on the rear of the shield with a tube leading to the ball launcher. Ball feed rate will be controlled by a dual shaft motor with press-fit wheels on each side that have notches cut to allow lacrosse balls to roll one at a time through the feed tube to the launching wheels. Sensors will be incorporated into this system to activate LED lights installed on the front of the shield to indicate system power and ball launch. The system will be controlled by an Arduino board loaded with GRBL firmware connected via a USB cable to Windows tablet with the GRBL app installed.

Since DR4 we have manufactured some of the parts needed for our prototype. Our biggest concern is the arrival of the shield and netting from the manufacturer. We contacted each vendor in hopes of expediting the order. However, if the materials do not arrive in time for the design expo, we are in the process of creating back-up plans to supplement the shield and netting. Moreover, without these essential pieces we have not yet begun testing and validation.

Our validation plan addresses the subsystems mentioned previously. We will test machine performance by empirically testing the speed a ball can be launched through video recording and the area a ball can be launched through distance measurements. Single player controllability will be confirmed by running a drill sequence we developed in Gcode that will take in lacrosse balls from the hopper and launch at programmed angles and frequencies. Durability will be evaluated by shooting lacrosse balls at the shield looking for cracking, chipping, or deformation. Lastly safety features will be verified by the functioning front mounted LED lights. We have made one minor change to the feed-rate system in that the wheels are being enlarged because we did not account for the thickness of the tubing in its design. Furthermore, based on the input we received from Coach Paul our design incorporates the latest information.

PROBLEM DESCRIPTION

This is a continuation of a previous project: Men's Lacrosse team at the University of Michigan is planning to include a programmable feeding mechanism for lacrosse balls in the new lacrosse facility.

This device should be able to feed balls in game-like situations, with which players can conduct small group or individual training. The requested product should be capable of pitching lacrosse balls at a range of azimuth and elevation angles, achieving a top speed of approximately 70 to upwards of 100 mph [1].

The initial prototype (after 1 semester) only addresses the design challenges of aiming and launching lacrosse balls. The validated user requirements are the range of azimuth and elevation angles, and vertical travel, while the top speed for the prototype wasn't verified in empirical test yet. This phase of this project addresses other functions of the final design, specifically collecting, storing, launching balls, and implementing a user interface that would allow a single player to effectively practice within the facility. When all of these parts come together, the end result will be a state-of-the-art lacrosse practice facility that will give the University of Michigan's team an edge over their competition.

Literature Review

Lacrosse was originally a Native American tribal game used to strengthen young warriors and accustom them to close combat, as shown in Fig. 1 below [3]. The first documented game of lacrosse was played on June 4, 1763 between the Ojibwa and Sauk tribes outside of Fort Michilimackinac. British troops stationed at the fort were captivated by this exciting and rough sport. Unfortunately for the soldiers, the two teams suddenly dropped their playing sticks, grabbed their weapons, and slaughtered the on looking soldiers [4]. Despite this rocky start, lacrosse is the fastest growing sport in the United States with participation increasing by 300% in the last decade [5, 6, 24].

Figure 1: Native Americans playing an early version of lacrosse [4].

At The University of Michigan, Oosterbaan Field House serves as playing field for lacrosse as well as a variety of sports. Constructed in 1970, Oosterbaan Field House features two end-line filming stations, a climate-controlled playing/spectator environment and sideline for 800 people. Through additional research, we discovered that while lacrosse injuries are less common than similar injuries in football and hockey, they can still be very serious and occasionally fatal [1, 6]. Thus, we need to keep player safety in mind as we continue to develop our design. [24]

Benchmarks

Following the prototype from the last semester, some products have been identified that meet some of the specified user requirements. These products are: a baseball pitching machine that's been converted into a lacrosse ball machine, a four wheeled baseball pitching machine, a baseball pitching machine with adjustable height, a pneumatic baseball pitcher, and finally, a tennis ball launcher. Some features of these products have been modified and applied in our prototype from the previous semester. The prototype was inspired from the common baseball pitching machine, and can pitch at a range of azimuth and elevation angles, achieving a top speed. However, it is still a portable design rather than a build-in system with architectural design, and doesn't provide user-friendly programmable interface [24].

Conversion of baseball machine for lacrosse balls. One patent of a lacrosse ball machine is a conversion from a single drive wheel baseball pitching machine [8]. There are two major modifications involved. The first major modification is based on the physical difference between baseball and lacrosse ball. From our research, a standard NCAA baseball is between 9 and 9.5 inches in circumference [9] and a standard NCAA lacrosse ball in both men's and women's competition is between 7.75 and 8 inches in circumference [10, 11], which indicates that the pitching machine should be modified to decrease the ball compression space. The second major modification is based on the height of the pitching point. A baseball pitching machine shoots a ball from a height between 40 to 50 inches, while a lacrosse ball release height can reach to 70-90 inches, due to the length of lacrosse ball stick. The strength of this conversion is its simplicity and low cost. However, it is not a sufficient solution. For example, it doesn't provide different azimuthal angles for pitching point, nor a range of launch height, and has limited capability for elevation angle adjustment [24].

Pitching machine with variable types of spin. A recent design for a baseball pitching machine utilizes four spinning wheels to propel the ball, so as to allow variable types of spin on the ball [12]. It is because the spin on a baseball can drastically affect the way it moves, which is likely to arise as we try to design a machine to launch ball similar to baseball [7]. However, since the ball spin of a shot does not noticeably alter the trajectory of lacrosse ball, we don't need to involve this additional complexity in our design [24].

Pitching machine with adjustable height. There is a design for baseball pitching machine which allows the ball to be pitched at variable heights by means of a rack and pinion system. [13]. However, this patent doesn't provide the flexibility in launch angles [24].

Pneumatic pitching machine. Pneumatic pressure is another way to pitch baseballs [14]. The main advantage of pneumatic launchers is the use of a pre-charged, high-pressure accumulator, eliminating the need for an additional power source during operation. However, since the final product for this continued project will not be portable, it will pose a potential risk; a leak within or damage to the device's accumulator could cause catastrophic failure, resulting in injury or death to users. Thus, these are clearly not appropriate for our design as safety is a high priority [24]

Programmable ball pitching machine. Furthermore, from the record of the previous team, we know that the University of Michigan women's lacrosse team uses a tennis ball machine to practice goalie skills. Though this solution lacks the realism required to train more experienced goalies, such commercial tennis ball machines utilize portable, programmable memory units and remote control, which will be useful for our design, especially considering the user-friendly feature [17, 18, 24]. There is also a baseball pitching machine throwing machine with programmable control for profiling pitches [22]. A programmable controller is included to control the rotational speed of each individual wheel to change the pitch type of baseball, the horizontal and vertical position. A smart card reader can be employed for programming of the controller, and this machine can be connected to a video display to simulate the actual pitching of a baseball by a pitcher. However, it isn't adjustable in angle, and for lacrosse ball, the multi-wheel speed control to vary pitch type of baseball is unnecessary and will induce additional cost.

Ball Return System for pitching machine. Additionally, there exists a patent for a conveyor belt system that returns baseballs to the pitching machine when used in a batting cage [15]. The return system will help fulfill a similar need in our system is to return the lacrosse balls to the launcher which can will facilitate the small group or individual training [24]. There is also a patent which can collect and return balls with a vacuum tube terminating designed [23].

Baseball pitching Machine with Batter Signaling Notification. From the research of previous team, a common feature in baseball pitching machines is an indicator to notify the batter when a ball is about to be pitched [16]. This design can emulate the windup of pitcher as a visual cue to the batter. Thus for a more realistic, coordinated practice scenario, some sort of audible or visible indicator that alerts the player before each ball launch might be important to add realism to our machine, while also serving as a safety feature [24].

Among the existing products, there is not an individual product that can meet with all requirements. However, most of them have some features that can meet with some of the user requirements with some modification. We gain inspirations from these features, synthesize them with a more profound mechanism consideration to push this continued project forward to its end result as a state-of-the art lacrosse practice facility.

Following the project from last semester, we are now in the stage to make as much progress in the direction of architectural build-in design, programmable interface, ball collective hopper mechanism, as well as pitching notification indicator. The architectural build-in design will be the end result of the whole project, while since we are to build a portable product this semester, we will leave it to the future improvement. We will further study the existing tennis ball machines for the programmable interface, ball return conveyor system of baseball pitching machine for the collective hopper design, and baseball pitching machine with batter signaling notification for our pitching notification indicator.

USER REQUIREMENT

As specified during an interview with the University of Michigan's men's varsity lacrosse Coach John Paul, we have obtained a list of user requirements that we have translated into engineering specifications. Although most specifications for what features that the final product must be capable of were set by Coach Paul we have added in a few more that we believe to be necessary for a successful lacrosse ball launching mechanism. Future specifications may be added once we have been able to interact with other coaches for the lacrosse team as well as the players themselves.

Table 1: User Requirements and Specifications

System	User Requirements	Engineering Specifications	Priority	Source
Machine Capabilities	Launch lacrosse balls	Compression space 2.5 in. (size of lacrosse ball)	1	External
	Two launch sources	Two machines	3	Coach
	Adjustable horizontal angles	±30° from vertical with respect to neutral configuration	1	External
	Ability to pitch bounce shots	Must be able to be fired at -30° from the horizontal at a target 9 ft away	1	Coach
	Adjustable vertical angles	±30° from horizontal	1	External
	Adjustable feed rate	User controllable, 3 second minimum between launches	2	Coach/External
	Simulates realistic speeds	Launch speeds of 30-100 MPH	1	Coach
	Able to cover entire facility	30 yds x 30 yds	2	Coach

Ease of Use	Easy to set up	<10 steps, <5 min setup time	3	External
	Easy to load	Loaded within 10 min	3	External
	High ball capacity	Minimum capacity of 80 balls with hopper system	2	Coach
	Programmable	Ball speed, direction, and frequency	1	Coach
	Single player use	Automated control system, must be accessible	2	Coach
Safety	Durable	Able to withstand ball impacts of up to 100 MPH	2	Coach
	Safety	Emergency stop, notification sounds and lights on ball launch	1	Coach

For many of the engineering specifications, specific values were given from the coach for exactly what was needed. As for the external sources, we determined that in order to cover the 30 by 30 yard facility with two machines, we would need to set horizontal ranges at about ±60° from center. For the vertical ranges, as speed will also be a determining factor in the height of the ball when it reaches the player, we determined it should only need a range of ±30° from the horizontal. This will cover both air and ground bounce shots. The ease of use requirements can be somewhat vague when translating from user to engineering specifications. We determined that since the goal of the project is for one person to be able to practice by themselves that setup and loading times were not our biggest concern. Therefore, a loose specification of less than 10 steps and 5 minutes for setup and 10 minutes for loading would be reasonable amount of time.

CONCEPT GENERATION

In order to generate concepts for our lacrosse ball launching machine, we first created a functional decomposition. This consisted of our team translating user requirements into engineering specifications that we could measure quantifiably to be able to test whether we successfully addressed the requirement. From these engineering specifications, we were able to come up with functions that our machine needed to be capable of in order for it to meet these requirements. Because we knew exactly what functions we needed to handle, it was then a matter of brainstorming concepts that would be able to complete the functions.

The categories that we decided to generate concepts for consisted of safety, shield, hopper, feed rate, and control systems. Each of these systems had a few different concepts provided by our team members as there was no one, perfect way to go about completing the needed function. For safety purposes, a light and noise source are to be added to the machine when launching balls. The way this alert can be triggered can either be via a pressure paddle along the ball feeding tube that is activated by the ball passing over it, or, have it integrated into the ball release mechanism so that once the ball is released, the signal is triggered. Our shield concepts were all fairly similar but boiled down to either a full shield completely encasing the machine with a large door for easy access, or a half shield covering just the front so as to allow full access without needing to open a door. As a hopper needed to essentially be a large container with a way to feed balls into the launcher, the actual design did not vary much but instead, the placement being either on the side or the top of the shield was what needed to be decided upon. Next on the list was the feed rate mechanism. Methods to give a steady feed rate, one ball at a time were to have a linear actuator control a small trap door ramp to allow one ball to pass at a time or two have two linear actuators, spaced one ball apart, that alternated in their up or down position so that at any given time, only one ball would be in between them at most resulting in only one ball being released into the feed tube at a time. Finally, concepts for the controls included creating a control panel on the outside of the shield, or installing manual controls near each of the actual motors they controlled on the machine itself. Sketches of each of the concepts developed are documented in Appendix B.

CONCEPT SELECTION

In order to score the concepts in a slightly more objective way rather than purely opinionated, we formed nine different criterion to judge them on, each with a given weight determined by importance. Concept designs were then given scores for the criteria based on how well we thought they addressed the concern. The concept design with the highest total score at the end would be the one we choose for our current working concept. Each criterion was given a weight of 1, 2, or 3, with 3 being the most important to our design. The concept designs were then given a similar score of 1, 2, or 3 on how well they achieved the criterion they were being scored on. These two numbers were then multiplied together and each section was added together for a total score for each concept design.

The criteria we set forth to judge whether the concepts were the most useful were the following: safety, controllable launching, user friendliness, architectural concern, manufacturability, cost, size, feasibility, and reliability. As safety for both the machine and the players is always a major concern, we gave this a rating of 3. If the machine is easily damaged by high speed lacrosse balls, then it will always be in need of repair. Also, if the machine is prone to injuring players, it becomes too dangerous to use. Controllable launching was also of major importance to our concept designs. We need the machine to have a wide range of launching, adjustable launching direction, and an adjustable launching frequency. The first two were given a rank of 3 because they are direct user requirements. The third was given a rank of 2 since the machine must be able to vary launching frequency, but it does not have to be very precise in its frequency measurement. Aspects inherent to the user friendliness were hopper fed ball-loading and a simple control system. Hopper fed ball-loading was given a 3 since we want one player to be able to practice by themselves instead of having someone else feed the machine balls. The simple control system only warranted a 1 however, because as long as the controls had a manual option, they should be relatively easy to understand with just a bit of training or explanation of how it works. As for architectural concerns, we considered the machine being safe to be revised as built-in as a 1 and reduced complexity of the structure to be a 2. Because the facility will not actually be built for another two years, our final design will not be the final product that will be put into the facility. We chose to give manufacturability a rank of 3 as we are short on both time and money to create the machine which will reduce difficulties for us in fabrication of the pieces. Cost was given a rank 1 since we may be able to receive extra funds from the facility money pool, but if we could work within the $400 default limit given to us, it would make things faster and easier. Size was a mild concern because in the facility, there will be plenty of room for the machine and any additions resulting in a rank of 1. Feasibility was probably our biggest concern since a concept that is impossible to implement given our time, money, and abilities has no place in our design warranting a rank of 3. Finally, we judged our concepts on reliability. Our final deliverable for the end of the semester is essentially a proof of concept. Because it will probably not be the final product that is installed into the facility, our machine does not need to be reliable for years to come. Instead, it must last at least through the semester for testing and potential practice use because it may be revised the very next semester anyways. Therefore, reliability was given a rank 1.

The concept designs we put through this process differed in a couple ways each so that we would be able to discern clearly which one scored the highest. The highest scoring design consisted of the pre-built machine with a full shield and large door, fixed launcher height, a tube ball feed from the hopper, a safety indicator integrated into the ball release mechanism, and a manual control panel installed on the outside of the shield. Other designs differed in an elevator transmission for the ball feed, a pressure paddle for the safety indicator, controls installed directly on the component they controlled, and a half shield. After discovering our best design concept based on point values, we all agreed that it was the best option that we were able to come up with so far.

Key Design Drivers and Challenges

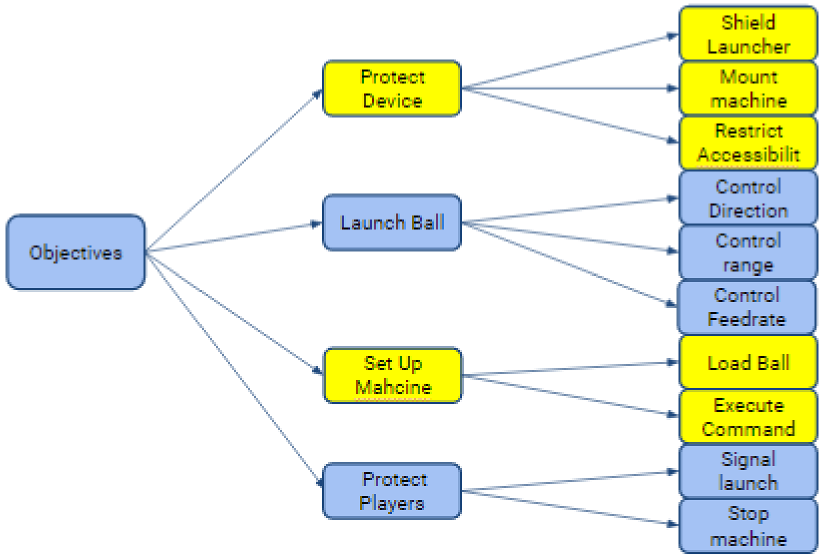

Figure 2: Primary design drivers and the derived engineering functions

According to the benchmark and feedback requirement, we set up the four primary design drives of the launching machine for this semester: protecting device, launching lacrosse ball, setting up machine (or ease of use), and protecting players. To achieve these goals, we derived sub functions for each single one from the aspect of engineering requirement. We will need to derive more exact engineering specification after engineering analysis for each of these sub functions by design review 3.

The project goal of projecting device aims to prevent the machine from breaking easily even with high velocity balls thrown at it. This is important since our machine will be installed in the new practice facility and may be impacted by lacrosse balls with speeds up to 100 mph. To achieve this goal, there are three design specifications as shielding launcher, mounting machine, and restricting the accessibility of the launcher inside the shield. The engineering fundamentals will be set with force analysis of the outer shell followed by experimentation.

Launching lacrosse ball is also our main focus, which requires the design able to adjust and control the direction of launching ball, the speed of the launched ball (which will achieve a broad range), and the frequency of launching ball. As desired by our sponsor, Mr. Paul, the machine should provide an effective practice session, and balls must be shot in game like situations. The hardware structure for launching ball has been construct in the last semester, and we are to improve them to be more controllable in this semester. Consider that, we are to perform tests to shoot balls at different speeds and frequencies to set engineering specifications.

The ease of setting up machine is another concern, which requires an automatic loading ball system and a user friendly interface or control panel for players to input expected launching performance. This concern is what mentioned by the sponsor as to allow players to quickly and easily use the machine to practice alone. More engineering specification for the ball loading system will be set with force analysis examined on the structure.

The last one as protecting players is always the most primary concern for any machine design. We must keep users safe as a high priority as injuries are not an option. To achieve goal, two subsystems are required, the launching indicator and emergency stop. Our team are to test certain “worst case scenarios” in the future to see whether it is acceptable or not.

On one hand, the prototype construct in the last semester has reduced a lot work on hardware for our team, on the other hand, however, the complexity of the current design, especially regarding to the complicate control referring to three software interaction has put a lot of extra work for this project. To develop automatic control without technical support in the field of Electrical Engineering and Computer Science will be challenge. Based on this consideration, we are to set aside the current controller and develop a new manual control system, and leave the software control for the future project team in relevant field.

Another challenge is the fabrication and mounting of the safety shield. The material selection is the first issue. The shield should be robust enough to both support the weight of the hopper and protect the inner launcher structure. This requirement would often come with a trade-off regarding to the ease of manufacturing.

Chosen Design and Mockup

To construct our mockup, we evaluated all concept designs for each critical subsystem through the use of five separate Pugh charts (Appendix A) to determine the designs that we deemed best. Based on these designs, we constructed a mockup lacrosse launcher machine, incorporating elements from the current design as well as our new concepts. We used foam board, cardboard, wooden dowel rods, construction paper, and fasteners to complete our mockup. We designed our mockup to be approximately ⅓ scale. Pictured in figure 3 below is our finished mockup.

Figure 3: Mockup concept design

During construction, we learned that the full shield design is going to be difficult to manufacture, and that its feasibility is related to what material we choose. Also, its sheer size will be an issue when it comes to total weight of the machine and the torque required by the base plate mounted motor to rotate the device. Another insight gained through the mockup construction was the overall packaging of the machine. By creating a small scale version, we are able to understand where our parts and subsystems are going to get a clear visualization of our final full scale prototype.

CONCEPT DESCRIPTION

The following is a rendering of our complete concept design, with specific subsystem designs to follow.

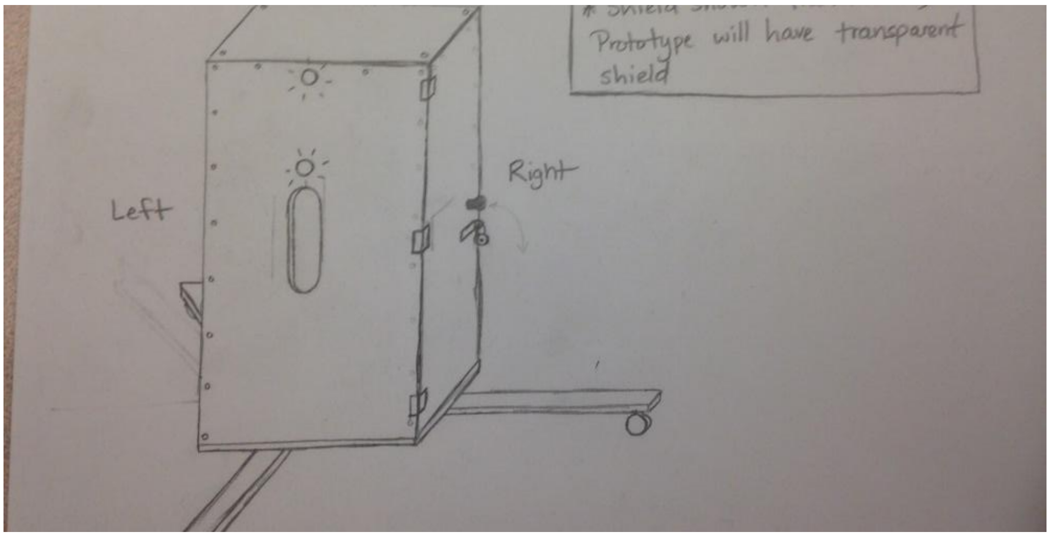

Figure 4: Complete Design Sketch of lacrosse ball machine

Hopper and Feed Tube

Based on the initial design for a rear mounted hopper from Design Report 2, we came up with a more finished design that will be easy to manufacture, be low in total weight, and be cheap to implement. This design features an upper and lower hopper support bracket, with netting strung in the middle to act as the body of the hopper. The netting will be tensioned using a dual lower bracket that captures the net, as explained later. Netting allows us to have a visual on the lacrosse balls in the hopper and allows us to see if bridging resulting in a jam and failure to feed is occurring. If such jamming occurs, the netting gives us the ability to see the problem and hopefully fix it. If all balls need to be purged from the hopper to fix the problem, the netting can be quickly dismantled.

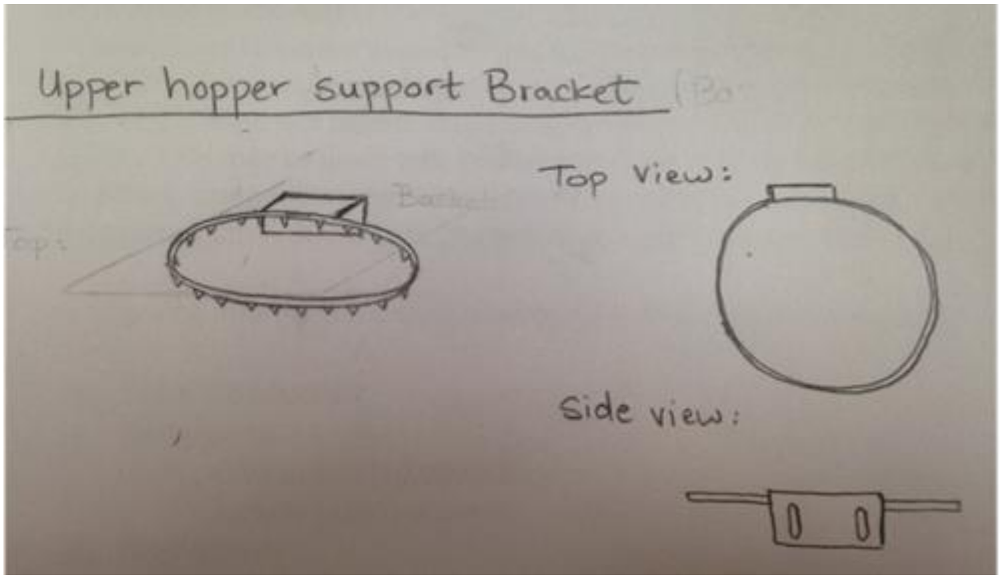

Figure 5: Upper Hopper Support Bracket Design Sketch

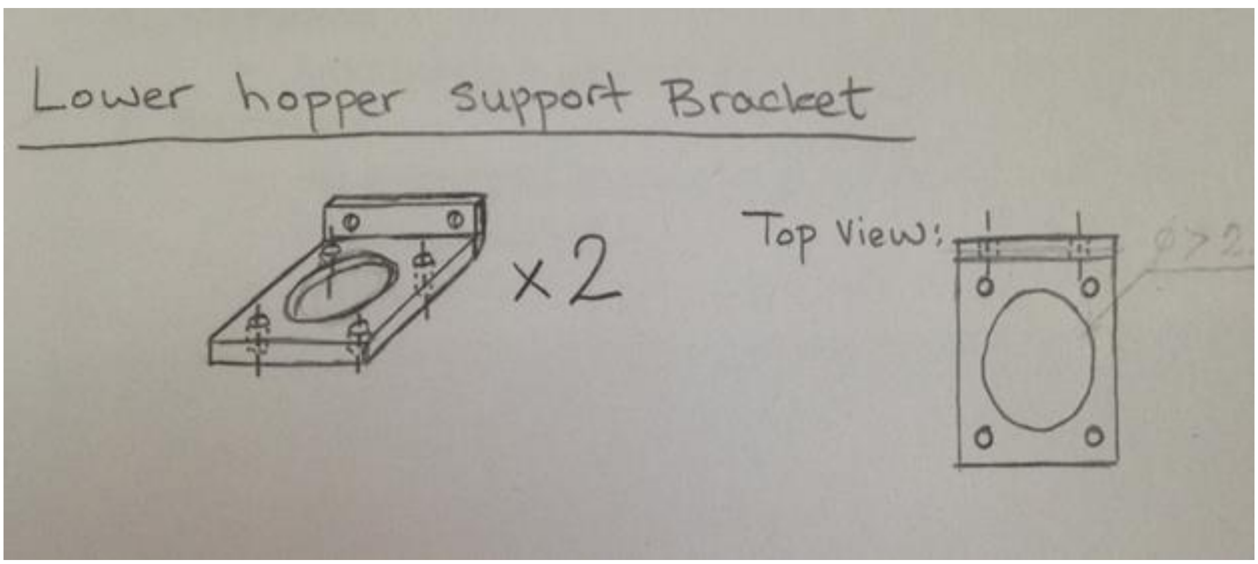

Figure 6: Lower Hopper Support Bracket Sketch

The lower support brackets will be made from ¼” 6061 Aluminum and the upper bracket will be fashioned from a steel basketball rim. The basketball room is extremely strong and has the correct size and shape for the upper bracket. It also has pre-installed prongs for netting attachment that we can use to secure our hopper netting. The netting we chose is Woven treated hockey netting, and has a break strength of 335 pounds [28]. This will be more than adequate for the forces exerted by the balls in the hopper as seen in the engineering analysis section.

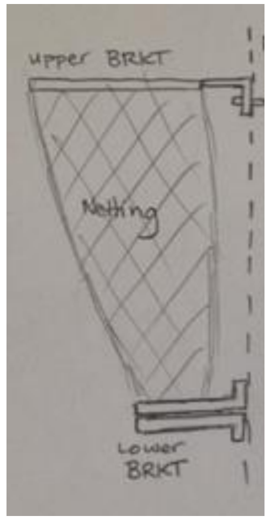

Figure 7: Complete Netted Hopper Design

The Feed tube presented somewhat of a challenge because we needed something flexible while still being strong and durable. Also, how it would be attached to the hopper presented another problem. We found flexible PVC pipe that has an inner diameter of 3 inches, large enough for lacrosse balls, and strong enough to not tear over time. All flexible piping is ribbed to some extent to allow for bending, but these ribs would possibly interrupt the travel of lacrosse balls and cause them to bounce through the tubing and lose momentum. The flexible PVC we found had minimal ribbing to allow for smooth ball travel. However, further testing will have to be done to confirm that the ball runs into little resistance while traveling through this tubing. To attach the feed tube to the hopper, we determined that the best way would be to cut out the center hole in the lower support bracket to be the size of the outer diameter of the PVC feed tube. Then we would fit the tube to the hole in the bracket, and using high strength glue, permanently bond the two together. This will ensure that there is a smooth transition and uninterrupted flow from the hopper down through the lower support brackets and into the feed tube.

Control Panel

For the final design, we are going to use Arduino with GRBL firmware and software Universal Gcode Sender in a Window system. A Windows tablet will be mounted on the shield of the launching machine. The player can send command to control the direction of the machine via the software Universal Gcode Sender.

Figure 8: Arduino, USB adapter and android device [25],[26],[27]

As a result of our engineering analysis, the control panel should include three function components: a controller, a communicator, and a control interface. For the controller, we will use the Arduino chip left from the previous prototype, which has been flashed with GRBL firmware. This transformed Arduino chip can compile g-code and works similarly to a CNC controller, although it loses the capability to compile in Arduino coding language. The communicator we selected is a USB cable. We determined to use the USB port to transmit a message between the controller and control interface. Though blue tooth and Wi-Fi can also transmit a message between these devices, compared to USB cable, the cost for a Bluetooth or Wi-Fi module for an Arduino chip is more expensive. Also, our customer did not mention remote control is essential. The controller interface can be any tablet device with Window capabilities, since the app runs on an Android operating system. Compared to manual panel control, this method can greatly reduce our time and cost. This control method makes the maximum use of the existing works.

Dual Wheel Ball Release

The dual wheel ball release subsystem was created to make sure that only one ball would be able to be released from the hopper to the shooting subsystem at a time at a rate that could be specified by the user. As compared to the initial dual pin system, the dual wheel system we formulated is a safer and a more reliable concept. Instead of using a pins linked to motor shafts in a way that would create a vertical motion, we have decided to use press-fitted wheels with a concave piece cut out of each one for our ball feeding mechanism (Figure 9). The wheels will be spaced one lacrosse ball length away from each other so that while one ball is ready to be released, the rest will still be held behind the back wheel. Each wheel will protrude into the tubing through its own slot so as to be able to block the balls from flowing until it turns to allow one ball through (Figure 9). The driver for this subsystem will be a Tamiya double gearbox kit. It is two motors combined into one piece so that they both get the same input and do not function independently. This assures that each shaft will spin at the same speed at the same time so that we can offset the position of the concavity of the wheels so only one wheel will allow a ball through at one time. The design ensures that we will have no failure mode in which the balls would flow freely to the shooting subsystem resulting in possible rapid firing. The subsystem will be attached to the tubing that the balls flow through on the inside of the shield so that it will remain protected (Figure 10).

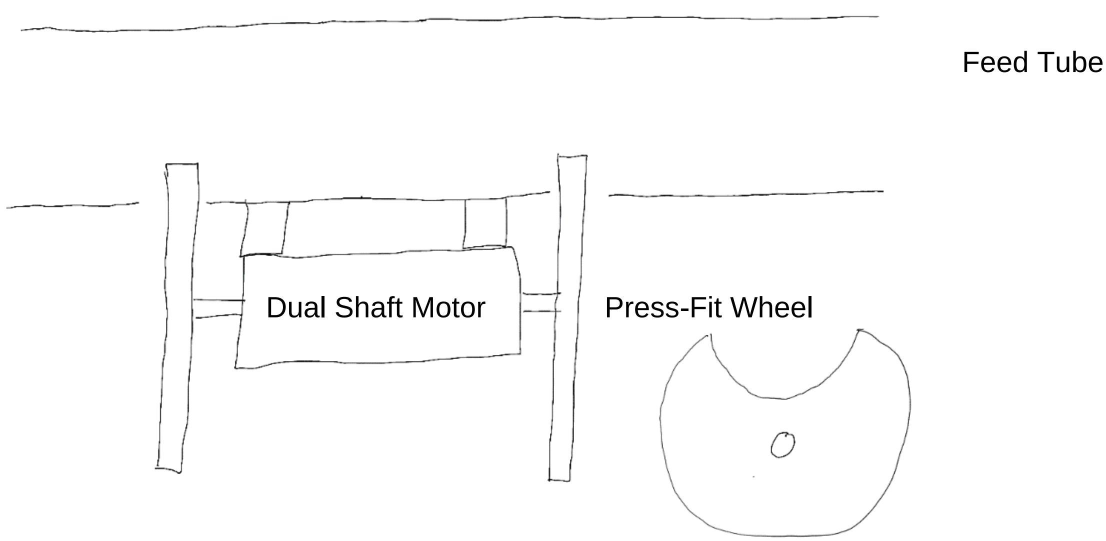

Figure 9: Dual wheel ball feeding mechanism

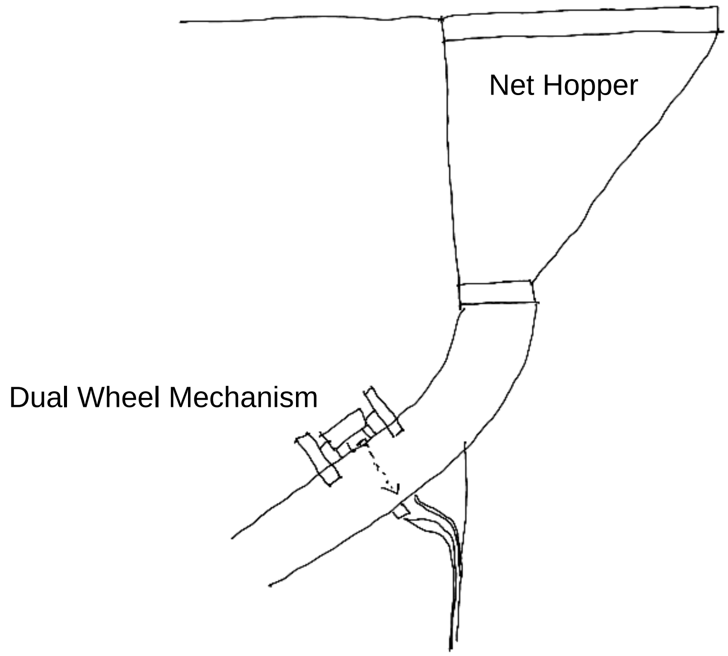

Figure 10: Dual wheel mechanism incorporated onto feed tube

Safety Sensors and Indicators

In order to keep the users safe, we decided to install safety indicators in the form of two lights visible when using the machine. The first is to indicate that a ball is between the two wheels and ready to be launched (Figure 11) while the second is to indicate that a ball has traveled through the tube and is at the portion just before hitting the spinning wheels and is therefore either about to be launched or is stuck in the tubing. The lights will turn off once the ball they are sensing is no longer blocking the sensor resulting in a flash if the ball rolls past or a solid light if the ball is resting in front of the sensor.

The sensor-indicator system will be a simple circuit consisting of a photocell, a power source, and multi-colored LEDs. One sensor LED will be placed in a hole on one side of the tube while a photocell will be placed on the other side of the tube directly across from it. While the photocell can see the light from the sensor LED, the other indicator LEDs that indicate to the player if there is a ball present will be off. Once the light from the sensor LED is blocked, we will know a ball is present in that area as the indicator LEDs will then be lit up. The indicator LEDs will be two different colors so that the user can easily identify where the ball is located in the machine.

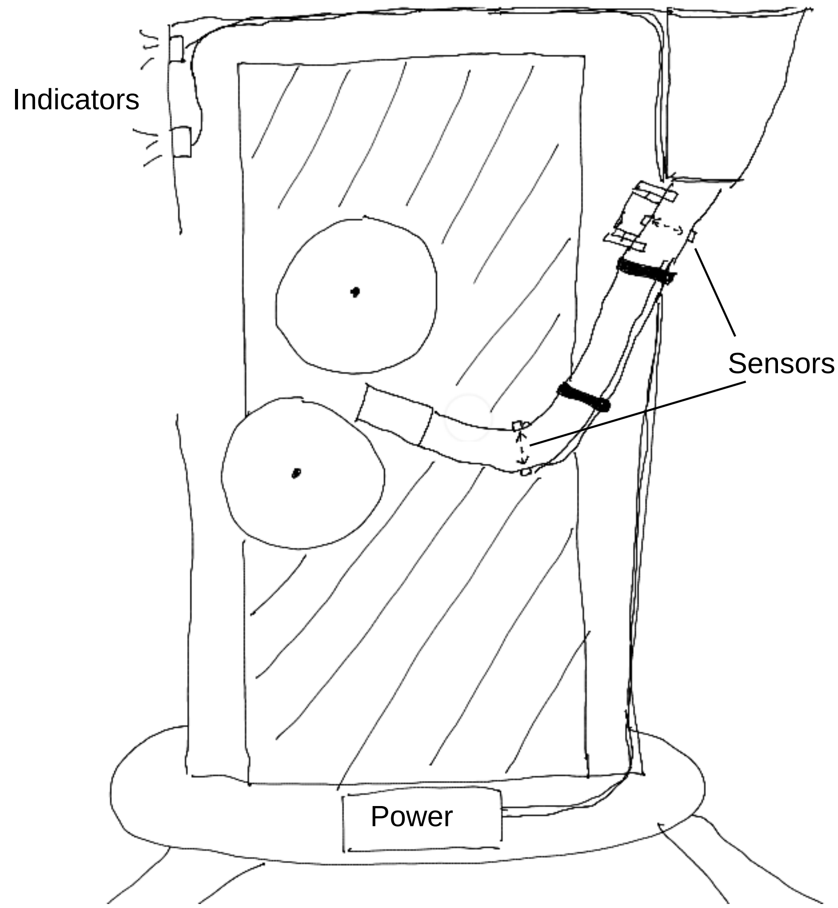

Figure 11: Sensor and indicator machine incorporation

Shield
As stated previously, players will be using our device as a practice aid and thus our machine will be susceptible to getting hit by a ball. We developed a shield that would protect our device in the event of impact. Additional benefits of the shield include protecting players from the moving parts of our mechanism. We included a large door in our design allowing access to the machine for potential maintenance. The shield is made up of two 72"x24"x0.472" Plexiglas sheets mounted on the front and rear and netting on the sides. The Plexiglas sheets are used in the front and back because we expect the most damaging ball impacts will occur at the front with a head-on impact and the rear shield supports the weight of the hopper system. Netting is used on the sides to reduce cost and weight while still providing adequate protection. Holes will be cut in the shield for the ball feeding tube and ball launching. We will fix the height of the launcher to approximately three feet to minimize the size of the cut hole. The Plexglas sheets will be mounted to the baseplate via aluminum L brackets and 0.25" bolts. To gain access to the internal mechanisms of the machine, the netting can be unbolted with two wrenches.

ENGINEERING ANALYSIS

To prove that our design could function under real world conditions and provide the means to achieve the goals we set forth to accomplish, we conducted engineering analysis on all components critical to the device function and in danger of possible failure.

Hopper and Feed Tube

To conduct analysis of the hopper system, we used static force analysis. The possible failure mechanisms we saw would most likely be failure of the fasteners securing the upper and lower brackets to the machine shield and failure (tearing) of the netting. Since our hopper must accommodate at least 80 balls, each weighing 5.5 ounces, we determined that an adequate maximum load in the hopper to be 12 kilograms. To analyze for a worst-case-scenario situation, we did moment analysis of the upper and lower brackets, where the total mass of all balls was positioned at the outermost point away from the anchoring of the brackets to the shield. This analysis gave us the static tensile force acting on the bolts holding supporting the brackets, which will help us to determine the correct hardware to purchase to prevent failure. Once bolts have been chosen, a fatigue analysis will be done to determine whether they will be able to withstand the force of lacrosse balls being dumped into the hopper and the impulse that experts over many cycles.

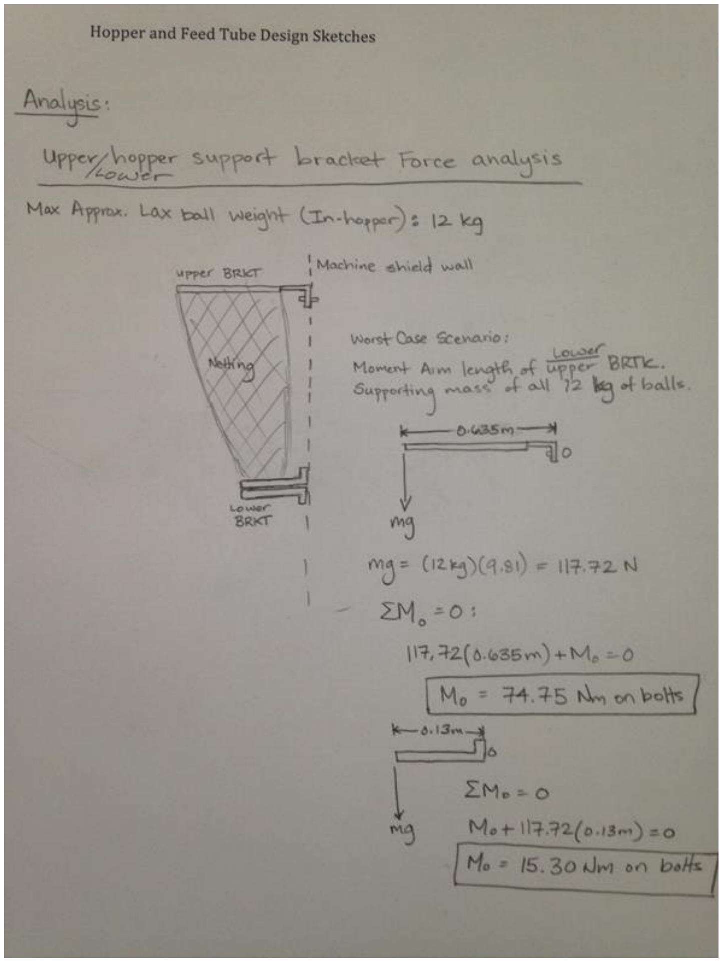

Figure 12: Static force analysis of the upper support bracket

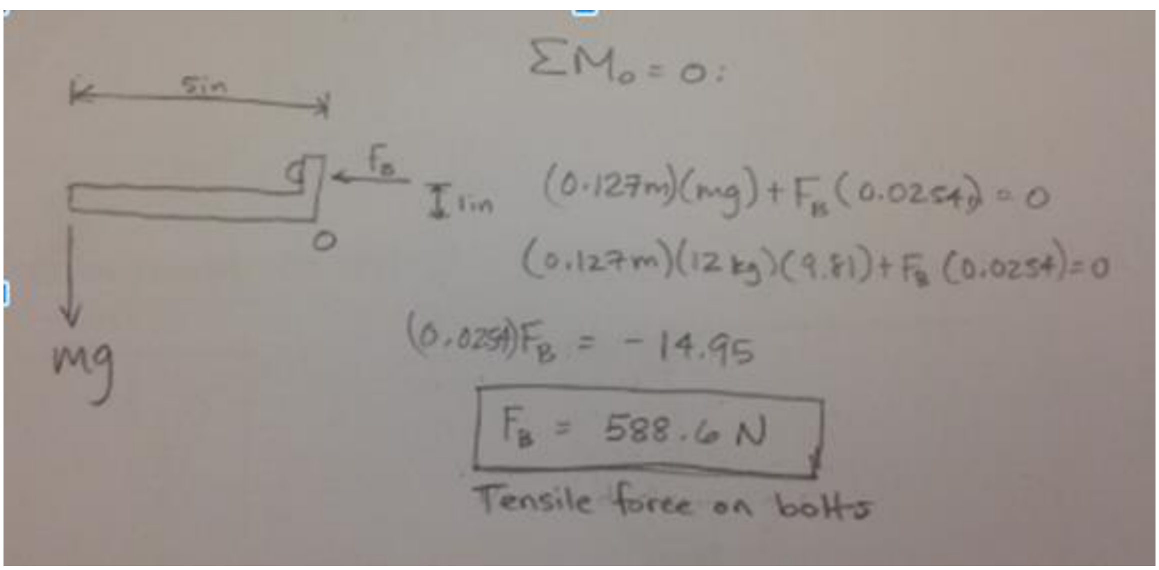

Figure 13: Static force analysis of the lower support bracket

Next, we analyzed forces acting on the net, more specifically the pressure exerted by all of the lacrosse balls on the net. To do this, we again assumed a worst-case-scenario where the weight of all 80 balls was resting on one single ball, which was exerting an equal and opposite force on the net. We determined that the area of net taking this load would be about the area of half of the surface area of a lacrosse ball. After our calculations, we found the pressure exerted on the net to be 2.7 PSI, which was well within the net's breaking strength. However, like with the support brackets, we need to conduct dynamic testing of the net, specifically when balls are dumped into the hopper and the force of their fall is absorbed completely by the net. Conducting a fatigue analysis is not critical for the hopper because our solution is a short term one that will not be implemented into the built in machine design.

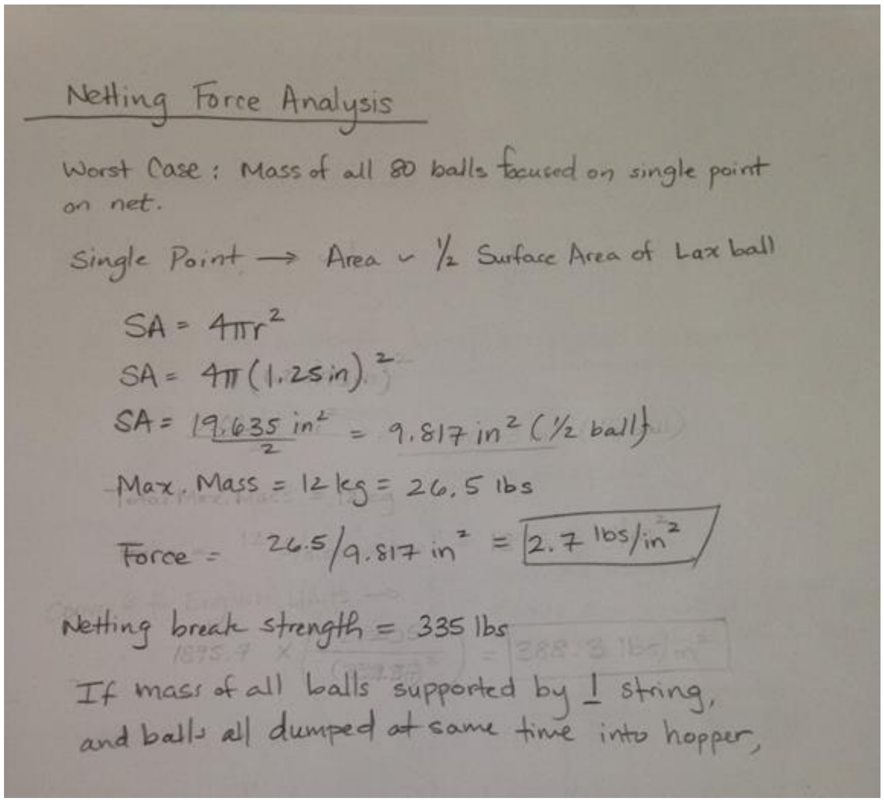

Figure 14: Hopper net force analysis

Control Panel

Since both the GRBL firmware on Arduino and the software Universal Gcode Sender on Windows tablet are integrated, the main issue for this design is the feasibility of the communication between the Arduino chip and the Windows tablet. Since the windows tablet has USB port integrated, this issue can be solved by a standard A-B USB cable.

Other concern is then focus on the calibration of the actual step of change in the direction and the input step value on the interface of the software. We have tested the input command with input step 1, and the direction changed in the target direction for 1 degree.

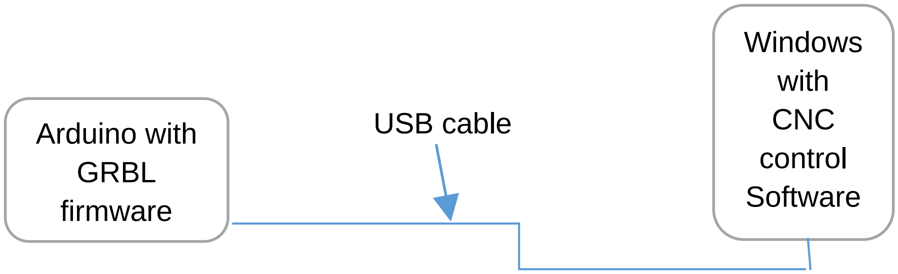

Figure 15: Schematic of circuit for app control

Dual Wheel Ball Release

In order to make sure they weight of the balls would not potentially break the shaft and wheels when they are blocking, a simple theoretical model of worst case force analysis was done. As shown in Figure 16, the hopper will have a maximum number of balls giving a maximum weight in the hopper. Since the tubing will be at an angle from the vertical, the wheels would only have to support just under that amount. Since the wheels have a given diameter, there would also be a moment exerted on the shaft. Using this knowledge and the worst case assumptions, the shaft would only need to be able to support a moment of 2.76 Nm which is more than manageable by the hexagonal steel shafts.

As for the speed at which the shaft needs to rotate, the Tamiya double gearbox kit offers switchable gear ratios. To meet our engineering specification of one ball every three seconds as the maximum feed rate, we were able to determine the fastest speed at which the wheels need to be able to rotate. Using the no load speed and gear ratios from the gearbox specifications, we then determined that a gear ratio of 344:1 would be necessary for the range at which we wanted our motor to operate (Figure 17).

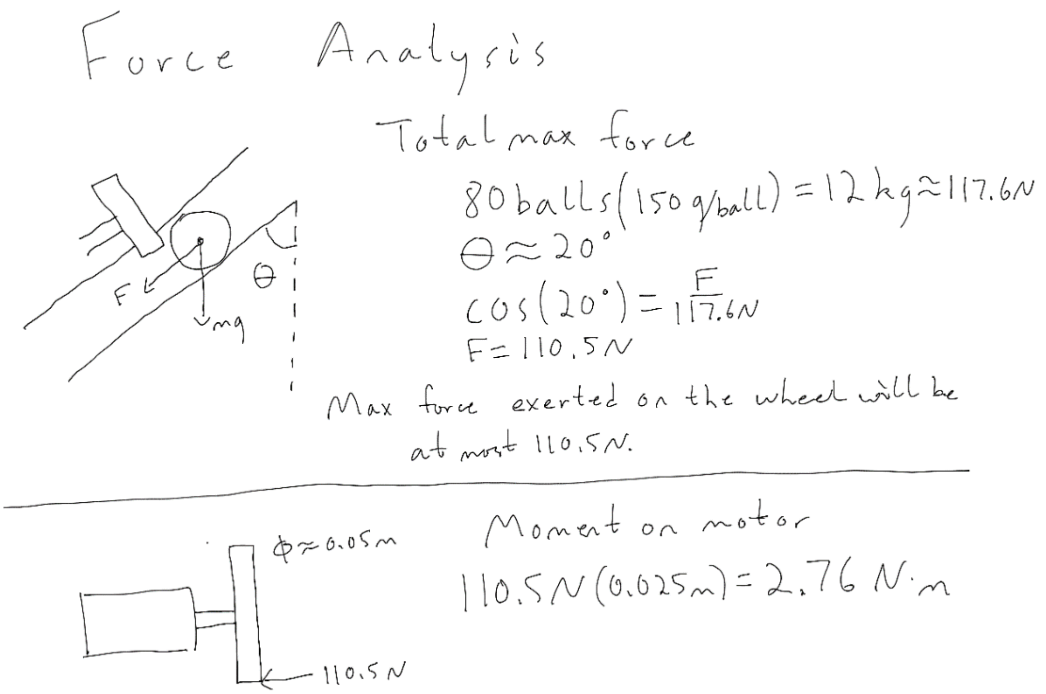

Figure 16: Force analysis of feed wheels

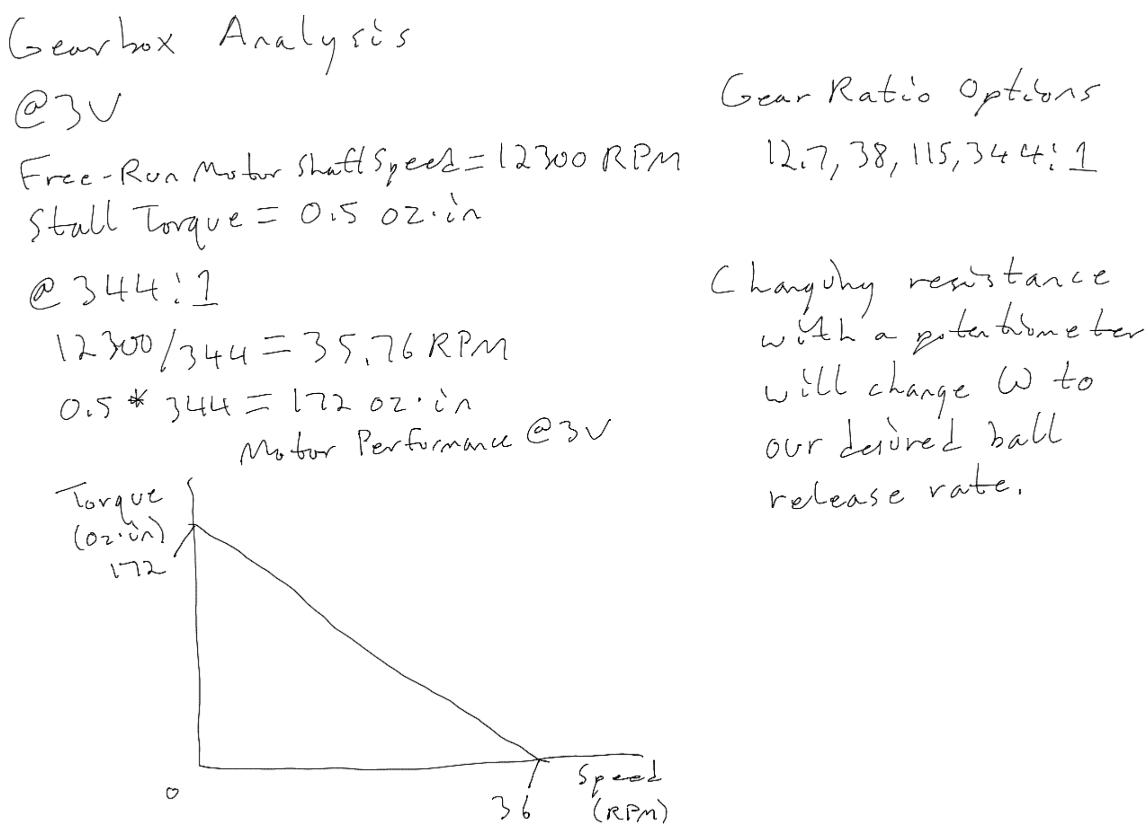

Figure 17: Gearbox Analysis

Safety Sensors and Indicators

The circuit mechanism for the sensor-indicator system is shown in Fig.18. It can be divided into 3 sections: input, controller, and output. The input section contains a resistor with resistance R1, a photo-resistor with resistance Rp, whose value varies with the intensity of light, and a power supply with voltage V1. The controller is an Arduino chip. The current I of the input section will be read by the Analogread pin A. The value of I will be compared with the threshold current I_{th} to determine the output signal of the Digitalwrite pin B. The output section contains LEDs in parallel, whose voltage supply is the output from pin B. There is another optional variable t_{delay} set in the controller, whose value can be adjusted to keep the LEDs lighting for an expected time period.

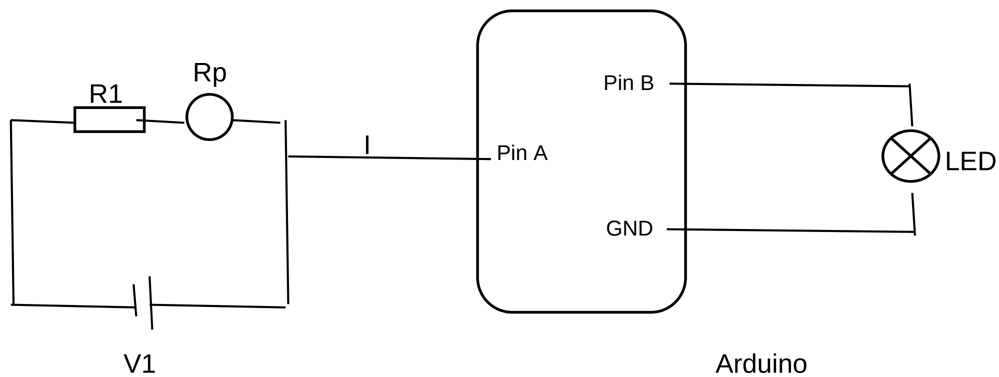

Figure 18: Safety sensor and indicator circuit

The resistance of photo-resister Rp ranges from 300 Ohm exposed to light to 5k Ohm in dark. The supply voltage V1 is 6 volts, and the maximum current for the analog input pin of Arduino is 40 mA [Ref.]. Thus, to secure the circuit and Arduino chip, the minimum value of R1 should be

$$R_1 = \frac{V_1}{I_{max}} - R_{pmin} = \frac{6V}{40mA} - 300ohm = -150\ ohm \qquad \text{Eqn. 1}$$

In this sense, R1 can be of any value. While we still determined to keep the resister R1 in the circuit so as to protect the circuit if the photo-resister doesn't work. Thus we the minimum value of R1 when Rp is short circuited:

$$R_1 = \frac{V}{I_{max}} = \frac{6V}{40mA} = 150\ ohm \qquad \text{Eqn. 2}$$

After the photo resister arrived, we are to test the values of the input current I from Arduino under the sensing condition, and then set the threshold current I_{th} to be the medium of the values of I in ball blocking light case and no ball blocking light case.

For the Digitalwrite pin B, it will output a DC current of 20mA [31], which is just the working current of LED. We didn't add extra resister for this output circuit since Arduino has its protect resisters of kilo-Ohms integrated.

We only use the value of I_{delay} for the indicator to notify the ball is about to shoot. It is because the ball travels fast across the tube, the LED will only light in a flash. In case the player doesn't see this flash, we will hole the LED on for 3 seconds. We didn't use this time delay when the ball comes across the hopper dual pin system, since the ball will be blocked in the due-pin system for a few seconds.

Shield

As stated previously, players will be using our device as a practice aid and thus our machine will be susceptible to getting hit by a ball. We developed a shield that would protect our device in the event of impact. Additional benefits of the shield include protecting players from the moving parts of our mechanism. The shield consists of two 6 feet x 2 feet x 0.472 inch sheets of acrylic glass, aluminum support bars, and netting. The acrylic sheets will be mounted on the front and rear of the machine. We chose these positions because impact is most likely to occur at the front of the machine and the hopper weight will be supported by the rear sheet. The sheets will be supported by aluminum L-brackets mounted at the bottom and aluminum bars connecting the sheets. Netting will be used on the sides of the machine to still allow protection but also allow players to see into the mechanism for potential problems such as a ball clog. Holes will be cut in the shield for the ball feeding tube, ball launching, and access to the controls.

Engineering Analysis

To determine the material we will use to construct the shield, we conducted theoretical modeling of a lacrosse ball hitting our shield. According to the National Operating Committee on Standards for Athletic Equipment (NOCSAE), lacrosse balls can weigh up to 5.25 oz. Based on our information from Coach Paul, lacrosse players can throw a ball at speeds up to 100 mph. With this information we solved for the momentum of a ball, *p*, using Equation 3:

$$p = mv \qquad \text{Eq. 3}$$

where *m* and *v* are the mass and velocity respectively. We estimated that at most the time of impact, *t*, would be 0.2 seconds and assumed that there would be no loss of ball speed after impact. We used Equation 4 to solve for the force, *F*, of one ball on the shield to be 15 lbf.

$$F = \frac{2p}{t} \qquad \text{Eq. 4}$$

Next we solved for the kinetic energy, *E*, of one ball to compare to manufacturer specifications using Equation 5:

$$E = \frac{1}{2}mv^2 \qquad \text{Eq. 5}$$

Our calculated kinetic energy is 110.5 ft-lb. Based on this and similar experimentation done by the manufacturer with a baseball, we concluded that 0.472 inch acrylic glass would be suitable for our use with a safety factor of around 2.

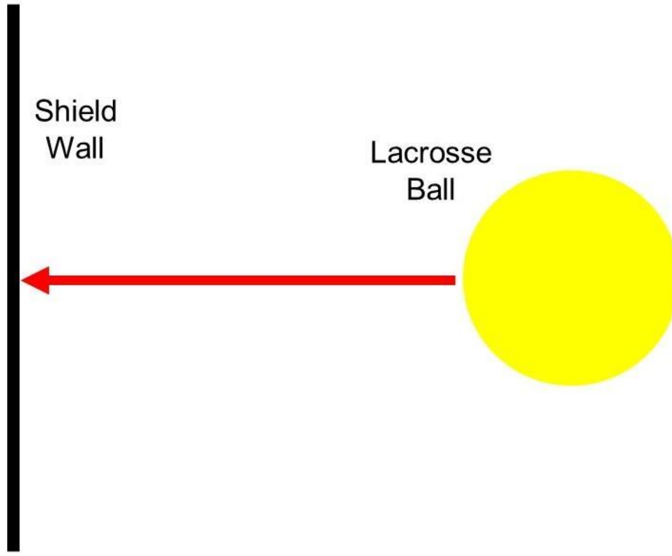

Figure 19: Lacrosse ball impact on shield wall

Failure Mode and Effects Analysis

As shown in Table 2, the aspect of our design with the highest risk was the ball release subsystem. This is the part responsible for releasing balls from the hopper to the ball shooting subsystem one at a time at a reasonable rate. Although the possible occurrence that this subsystem would fail was relatively low and it is easy to detect, the severity was very high. If the dual pin system failed, both pins could be down at the same time allowing free flow of the balls from the hopper to the shooting subsystem resulting in a rapid firing of balls. As this could then injure the user while impeding the primary function of the entire mechanism, it was categorized as a potentially catastrophic failure. Because of the slim likelihood and ease of detection however, the overall risk rating associated with this subsystem was still within the acceptable range. As this was our highest source of risk by far, we decided to change the dual pin system to a dual wheel system so that the balls would always be blocked by at least one wheel at a time in the case of failure of the subsystem.

Table 2: FMEA

Subsystem	Potential Failure Mode	Potential Causes of Failure	Potential Effects of Failure	Severity	Occurrence	Detection	RPN
Rotating Wheels (Shooting)	Stop moving, won't stop moving	Faulty wiring, stuck ball	Practice interrupted, extra balls shot	8	2	2	32
Translational/ Rotational Motors	Stop moving, won't stop moving	Faulty wiring, stuck ball	Incorrect aiming	6	2	2	24

Hopper	Not feeding balls	Rip in material, Stuck ball	Practice interrupted	6	6	1	36
Ball Release	Not feeding balls, feeding too many balls	Pins stuck, stuck ball	Practice interrupted, rapid ball shots	10	4	2	80
Shield	Broken	Ball impact	Practice interrupted, unprotected machine	5	1	1	5
Control Panel	Unresponsive machine adjustment	Faulty wiring, no power, broken components	Practice interrupted, machine uncontrollable	7	2	1	14
Safety Alerts	Fail to alert/ activate	Faulty wiring, broken sensor	Potential injury of user	10	2	2	40

CURRENT CHALLENGES

There is challenge in control panel. As discussed, we are using app to control the direction. Whether this android app can be successfully connected with the controller still remains to be test. Even there are some cases using tablet to control CNC machine, our transformed Arduino chip is not a standard CNC device, and the multi-version of software induce other problems in compatibility. Regarding to these issues, we have back-up design as Bluetooth communication for app control or return to our previous manual control.

Another challenge comes from the automated ball feeding system. Especially when the ball is shot from a positive angle in vertical axis. In our current design, the inertia of the ball as it falls from upper hopper should push it forward to overcome this angle. Though we have done the engineering analysis for moment in these design, unexpected collision and friction induced when the ball rolling through the tube may potentially failed our current design.

One challenge is the cost. As the progress of our project, more components are required to be purchased, thus we need to ask the sponsor’s approval, which is time consuming. Moreover, efforts in reducing cost will inevitably be a constraint when we select the material we used to construct the machine, which will post negative effect on the performance of the machine.

Another challenge will be time. Since all design should be finalized by DR 4, we only have two more weeks to check the feasibility of our current design. However, we are still waiting for some purchased components’ arrival to execute the test. These shipping time have put extreme pressure on our project.

INITIAL MANUFACTURING PLAN

Listed below is the initial manufacturing plan for each subsystem mentioned previously: the Hopper and Feed Tube, Dual wheel feed mechanism, safety sensors and indicators, controls, and the shield.

Hopper and Feed Tube

Install the upper hopper bracket using provided mounting hardware and machined holes in the upper shield wall. Cut netting to correct size. Once cut, attach to the prongs on upper hopper bracket. Machine 2 lower hopper brackets (6061 Aluminum ¼" plate). Install one bracket first, with provided hardware to the machined holes in shield wall. Extend netting down and through the center hole of the lower bracket. Tension the netting, and install the second lower bracket, pinching the netting in between both brackets. Once net is pinched, tighten both lower brackets together using provided hardware. Take flexPVC tubing and press into center hole of the lower bracket. Use glue or strong adhesive on flexPVC outer surface to secure to the inner wall of the bracket hole.

Dual Wheel Ball Release

The wheels will be milled from a 0.25" aluminum plate. Each wheel is 5 cm in diameter with a hole in the middle that will be just large enough to press fit the shafts of the motors into. The wheels will then be milled to create the concave indents large enough for a lacrosse ball to roll through. The tubing will then need to have slots cut into it at 1" wide and at least 0.26" long in order for the wheels to protrude into it without too much excess room. Once the tube is prepared and the wheels are press-fit, the subsystem can be mounted to the tube with the brackets supplied in the Tamiya double gearbox kit.

Safety Sensors and Indicators

The only manufacturing necessary for the safety sensors will be cutting holes in the tubing to match the size of the photocell and LEDs respectively. The photocells and LEDs will then be fastened on to the tube so that they are in flush with the inside of the tube so as not to disturb the flow of a ball through the tube. Indicator LEDs will similarly be fastened to the inside of the shield so they remain visible from outside of the shield to the user. The wiring will then be fastened along the tube and shield to the power source.

Shield

The Plexiglas walls of the shield will come precut to size and will require only the drilling of holes for the feed tube and for the ball release. To secure the walls together, we will use screws to drill the walls together. We will also drill holes for the attachment of the hinges and holes for the attachment of the lock and handle for the door.

Table 3: Preliminary Bill of Materials

Quantity	Material	Price
4	60" x 24" x 0.5" Acrylic Sheets (Shield Wall) Evonik Industries ACRYLITE extruded (FF), sheet, Colorless 0A000 GT	$665
1	24" x 24" x 0.5" Acrylic Sheet (Shield Lid) Evonik Industries ACRYLITE extruded (FF), sheet, Colorless 0A000 GT	$70
3	Gatehouse Brass Hinges (Door) Lowe's - Item # 311939, Model # 890293	$2
1	Gatehouse Locking Hasp (Door) Lowe's - Item # 220376, Model # 33035BBXLG	$4
1	Mastercraft Lock	-
1	Tamiya Double Gearbox Kit Pololu – Part # 114	$9.25
2	Aluminum Plate 6063 ¼"x6"x18"	$20.10
15	Red LED LED Supply – Part # L2-0-R5TH20-1	$7.70
15	Green LED LED Supply – Part # L1-0-G5TH15-1	$7.70
1	Mini Photocell Karlsson Robotics Part # SEN-09088	$1.50
1	Standard Rim Spalding – 7811SR	$31.01
1	60" x 60" Woven #42Treated Hockey Net 1 ½" West Coast Netting – W42HT-1 ½"	$23.00
1	60" x 3" ID white UltraFlex thinwall FlexPVC	$52.45
1	Male MicroUSB to Female USB Cable eBay – Item # 151792740303	$2.49
1	Android Device	~$50
1	5V Power Supply TRC Electronics – PLA15F-5	$15.76
2	Resistors 50 Ohm	-
3	Photo resistor 300 Ohm-5kOhm	$3.50

FINAL DESIGN

Our Final design that we choose is shown in figure 20 below. The primary subsystems, the hopper and feed tube assembly, the shield, and the ball feed control system are labeled on the figure. Also included is an exploded view of the ball feed system motor and gearbox to illustrate and further explain our design (Figure 21).

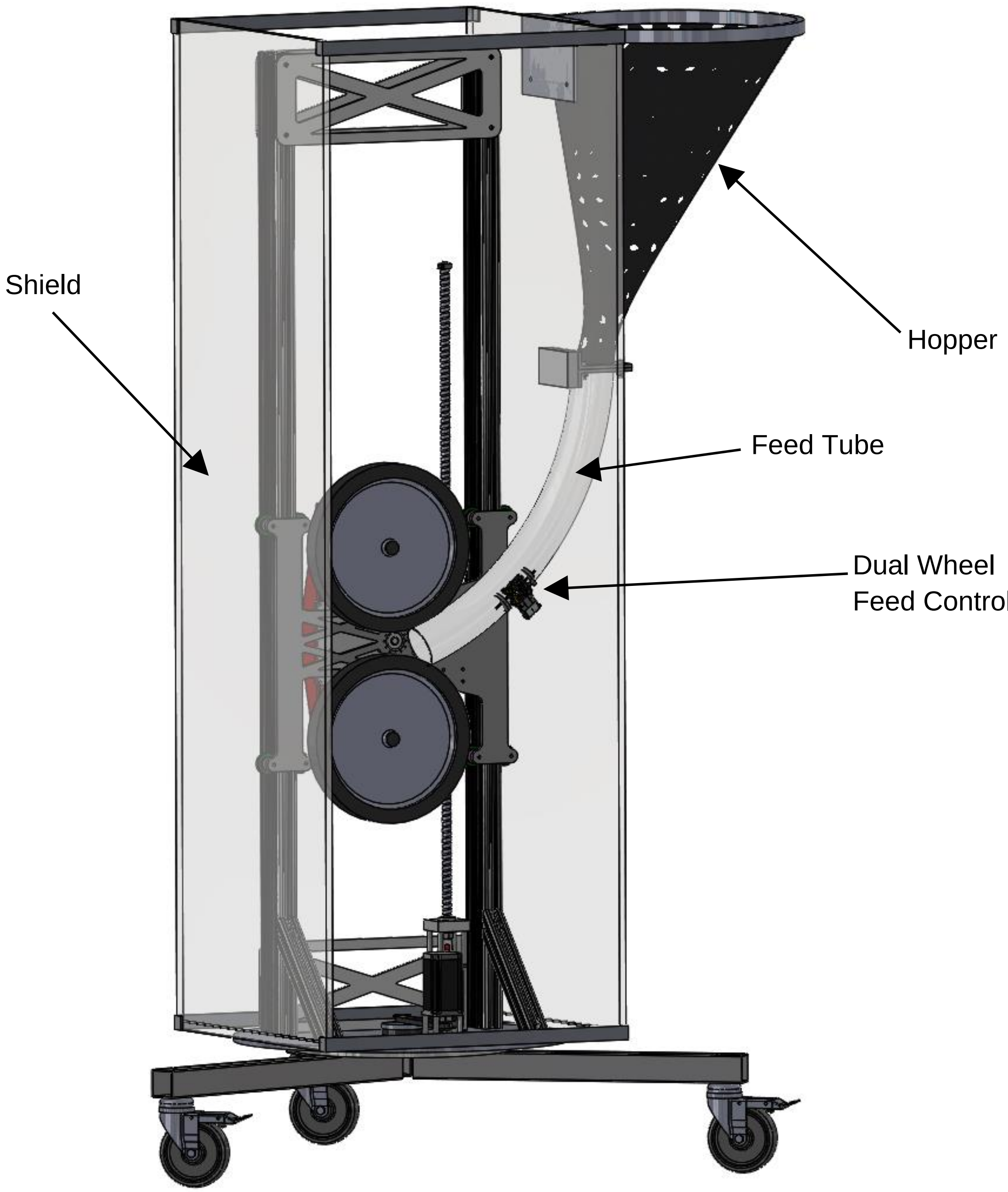

Figure 20: Our Final Design in SolidWorks, with labeled subsystems.

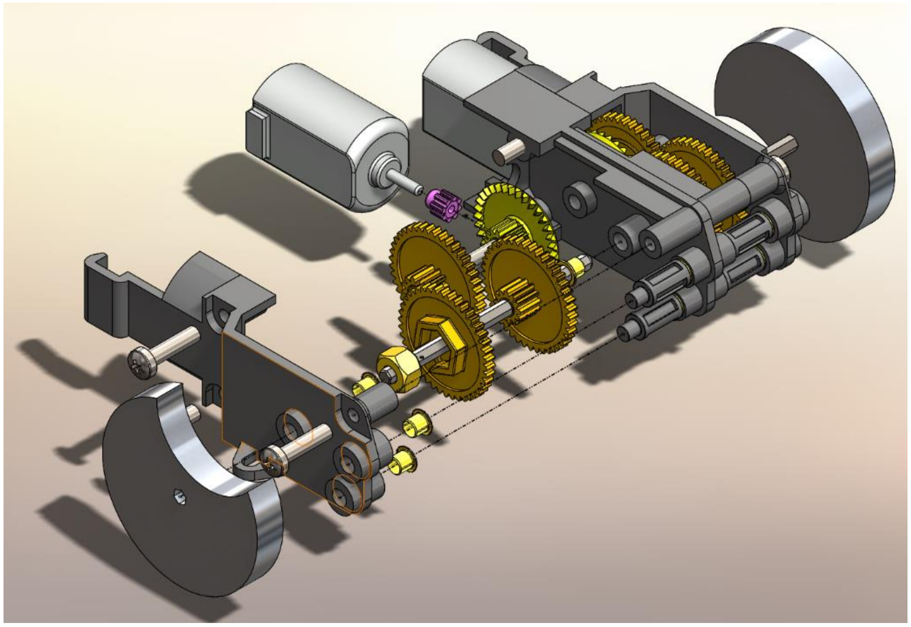

Figure 21: Exploded view of the dual wheel ball feeding device

VALIDATION PROTOCOL

We developed our validation plan according to the subsystems we designed. Specifically, the subsystems for the requirement as machine performance, single player controllable, machine durability, features for safety.

Machine performance: The machine performance is evaluated by the ball travelling speed, vertical and azimuthal angle adjustable range, and shooting range. Both the ball travelling speed and shooting range will be validated by empirical testing with the aid of video record. The launcher will be set up to shot target spots around 30 x 30 yd. room, with its wheels running at steady speed. The ball travelling speed can be evaluated from the video record after then, and the shooting range can be evaluated by the range the ball can cover. The vertical and azimuthal range will be measured with a protractor while operating the machine.

Single player controllable: This feature can be evaluated by the performance of automated ball feeding, and hopper capacity. The performance of automated ball feeding can be evaluated by the controllable ball feed rate. We will set measure the actual range of available feed rate selection with the aid of second meter. Turning on the machine, the knob for feed rate control will be set to different value labeled. We will compare the actual feed rate twice when the hopper is full or nearly empty of balls, and compare both these two values with the feed rate labeled. The capacity of hopper will be evaluated by loading a full box of hopper, and count the number of balls loaded.

Machine durability: The machine durability design aims to protect the machine from ball impact. Thus, to validate the machine durability, we will shoot the machine with real balls, and observe whether the machine shield can stand the impact.

Safety features: The safety feature is evaluated by the performance of the shooting ball indicator, which will also be validated by empirical test with the aid of video recording. We will measured the time gap between the indicator flashing and ball shooting, with different feed rate setting cover the range of feed rate setting.

Since some of the validation will require empirical test, which will need transporting the finished machine to Oosterbaan Fieldhouse. The transportation of the machine will be a big issue, or if we can get approval to test the machine on north campus. Moreover, we will need a well-equipped video recording device. We are now still at the stage of built up the machine, and we plan to have the validation don by Design Review 5, thus we need to send the application for approval before Design Review 4.

DISCUSSION AND DESIGN CRITIQUE

After having completed our design and been able to do some testing, we have developed a better working knowledge of our machine which provided us with ideas on how to better manage problems after the fact and ways the machine may be improved in the future. The biggest factor that would have helped us out during the semester would have been to order our parts earlier. Because we received our final parts three days before design expo, a lot of stress was put on our team as well as restriction of most of our testing. Had the finance problems been resolved earlier, we could have ordered rush shipping for the most important components and therefore had a much more polished final product that did not need to be thrown together quickly. However, we were restricted financially to the point where we were considering other options for the shielding subsystem even after reducing it to just two Plexiglas walls. Although there are other solutions that could work, we still believe the Plexiglas to be the best as it provides a firm support as well as the needed protection for the machine.

From testing of the ball feed subsystem, we learned that a different type of tubing to transfer the balls from the hopper to the firing subsystem would have much better results. The tubing currently used was both very stiff, forcing us to remove the bottom brackets and attach it to the hopper directly, and also very sticky which when combined with the tackiness of the lacrosse balls provided too much friction for the dual wheel ball release subsystem to function. Solutions may involve a flexible tubing with a much lower coefficient of friction on the inside, some sort of lubing system to allow the contact between lacrosse ball and dual wheel ball release to glide freely, or even just stronger motors to drive the dual wheel ball release. It could also be changed to a completely different concept altogether such as some of our earlier concepts that did not quite make the cut or something we did not think of.

As mechanical engineers, we did not receive quite as much training in programming and electrical wiring as would have been necessary to bring the machine to its full potential. With some EECS support, we believe the user interface and machine capabilities could have been much more in depth than we could make them ourselves. A suggestion would be to perhaps make the machine an EECS senior design project in a following semester to follow through on ideas such as an Xbox Kinect sensing system to allow user motion controls from afar rather than a tablet or laptop on the machine itself.

A photo of our final product is shown in Figure 22.

Figure 22: Final lacrosse ball launcher mechanism

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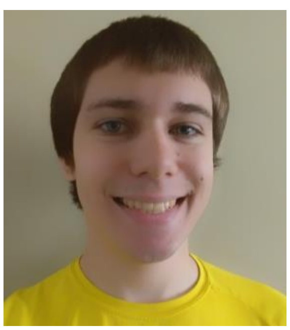
David Brink graduated from Wiley E. Groves High School in 2011 and is finishing his final semester of B.S.E in Mechanical Engineering at the University of Michigan. He has worked for the IOE Ergonomics Department as a research aid to Professor Charles Wholley and has interned for two summers at Roush Industries, collaborating in autonomous vehicle prototyping as well as class 8 heavy truck benchmark performance testing. After graduation, he intends to pursue his interest in emergency room physiatry and apply to Medical School. His interest and past lacrosse experience drew him to this project.

Matthew Maranzano is a senior at the University of Michigan pursuing a B.S.E. in Mechanical Engineering, minor in Mathematics, and specialization in sustainable engineering. While at Michigan, he has worked as a drafter, peer mentor, and student event organizer. After graduating in Winter 2016, he hopes to take his team-work, leadership, and CAD experience to the automotive industry as a designer. His love of Michigan athletics and desire to solve open-ended design challenges naturally drew him to the lacrosse ball feeding device project.



Dominic Piazza is studying Mechanical Engineering at the University of Michigan and will finish his BSE in December of 2015. Following his interest in computers and using programs for real world modeling applications, he created a robot in SolidWorks for his ME 250 team which later went on to win a class-wide competition. He is now studying finite element software in order to help him become a designer in the auto industry after graduation. His love to be able to create something and plan out every individual piece so that it may be later fabricated into a final, tangible masterpiece is what drove him to choose the lacrosse ball launcher project.

Mengyao Ruan is currently a senior at the University of Michigan, pursuing a BSE in mechanical engineering, with a BSE in Electrical and Computer Engineering in Shanghai Jiao Tong University. In her high school year, she was the member of province team to compete in the Chinese Math Olympics and won a bronze medal in the finals. In 2015 summer, she did research on 3D printing in Wu Manufacturing Center, helped to set model to optimize the printing parameters setup for soft material printing. She is interested in constructing control model for the real world.

APPENDIX

Appendix A: Pugh Chart

Pugh Chart - User Safety

		Weight	Indicator with signal from pressure paddle	Indicator signal integrated with feed control system
Safety	Protect Device	**3**	3	3
	Protect Players	**3**	3	3
Controllable Launching	Wide Range of Launching	**3**	3	3
	Adjustable Launching Frequency	**2**	3	3
	Adjustable Launching Direction	**3**	3	3
User Friendly	Automatic Ball-loading	**3**	3	3
	Straight forward Control	**1**	3	3
Architectural Concern	Safe to Be Revised as Built-in	**1**	3	3
	Reduced Complexity of Structure	**2**	3	3
Manufacturability		**3**	1	2
Cost		**1**	2	3
Reliability		**1**	1	3
Feasibility		**3**	2	2
Size		**1**	2	3
Totals			77	84

Pugh Chart - Shield

		Weight	Full Shield with door	Half Shield
Safety	Protect Device	**3**	3	1
	Protect Players	**3**	3	2
Controllable Launching	Wide Range of Launching	**3**	2	3
	Adjustable Launching Frequency	**2**	3	3
	Adjustable Launching Direction	**3**	2	2
User Friendly	Automatic Ball-loading	**3**	3	3
	Straight forward Control	**1**	3	3
Architectural Concern	Safe to Be Revised as Built-in	**1**	3	2
	Reduced Complexity of Structure	**2**	2	3
Manufacturability		**3**	2	3
Cost		**1**	2	3
Reliability		**1**	3	2
Feasibility		**3**	2	2
Size		**1**	1	2
Totals			73	72

Pugh Chart - Hopper

		Weight	Rear mounted with tube feed	Top mounted with elevator feed
Safety	Protect Device	**3**	3	3
	Protect Players	**3**	3	3
Controllable Launching	Wide Range of Launching	**3**	3	3
	Adjustable Launching Frequency	**2**	3	3
	Adjustable Launching Direction	**3**	3	3
User Friendly	Automatic Ball-loading	**3**	3	3
	Straight forward Control	**1**	3	3
Architectural Concern	Safe to Be Revised as Built-in	**1**	3	3
	Reduced Complexity of Structure	**2**	3	3
Manufacturability		**3**	3	1
Cost		**1**	3	2
Reliability		**1**	2	1
Feasibility		**3**	3	2
Size		**1**	1	2
Totals			87	77

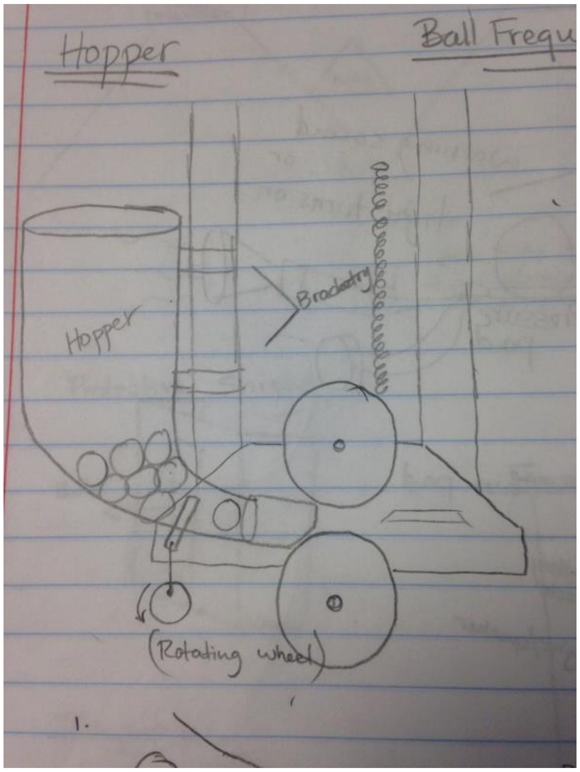
Pugh Chart - Feed Rate

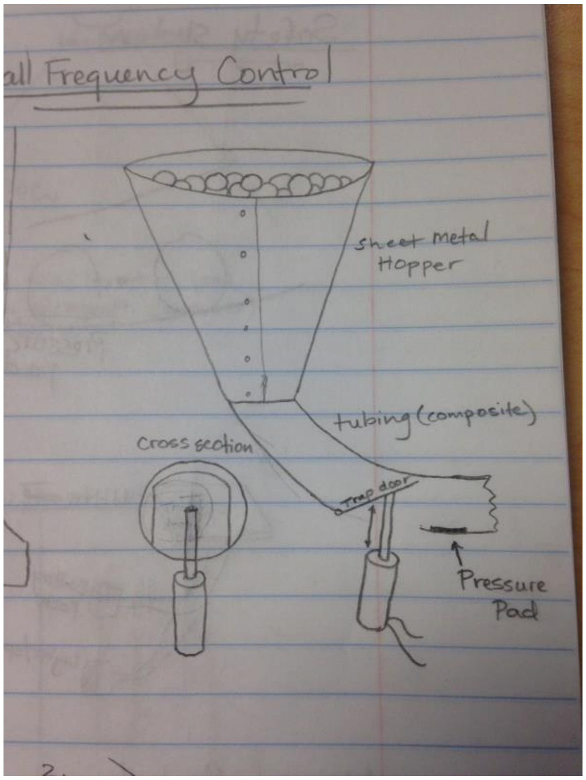
		Weight	Trap door feed controller	Dual Pin Feed Controller
Safety	Protect Device	**3**	3	3
	Protect Players	**3**	3	3
Controllable Launching	Wide Range of Launching	**3**	3	3
	Adjustable Launching Frequency	**2**	3	3
	Adjustable Launching Direction	**3**	3	3
User Friendly	Automatic Ball-loading	**3**	3	3
	Straight forward Control	**1**	2	3
Architectural Concern	Safe to Be Revised as Built-in	**1**	3	3
	Reduced Complexity of Structure	**2**	2	2
Manufacturability		**3**	2	2
Cost		**1**	3	3
Reliability		**1**	1	3
Feasibility		**3**	2	2
Size		**1**	2	3
Totals			78	82

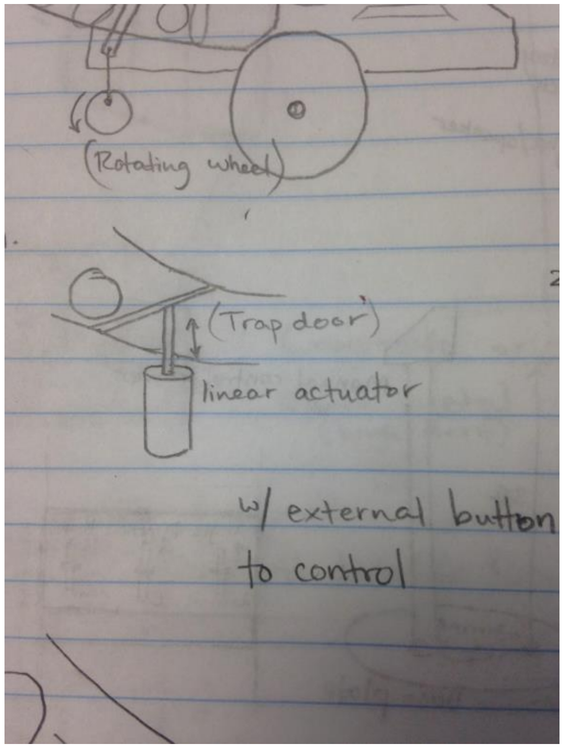
Pugh Chart - Controls

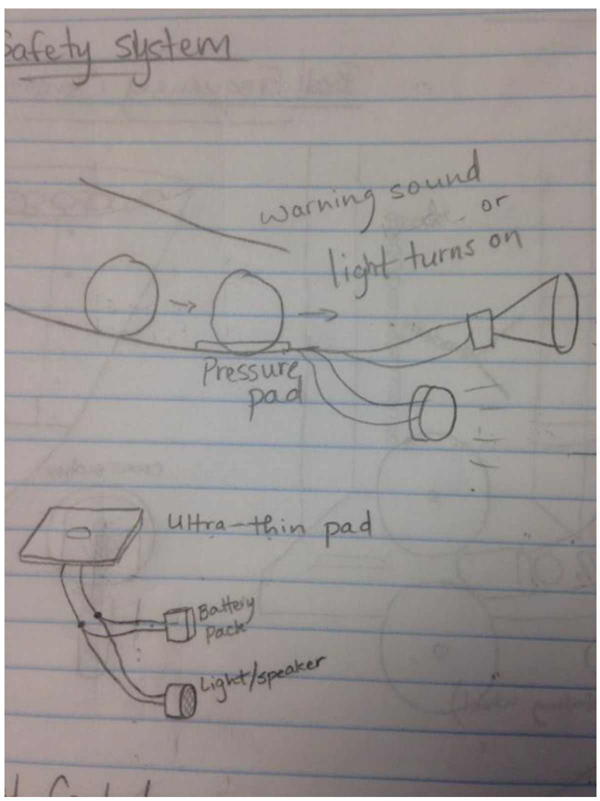
		Weight	External Control Panel	Remote Control
Safety	Protect Device	**3**	3	3
	Protect Players	**3**	2	3
Controllable Launching	Wide Range of Launching	**3**	3	3
	Adjustable Launching Frequency	**2**	3	3
	Adjustable Launching Direction	**3**	3	3
User Friendly	Automatic Ball-loading	**3**	3	3
	Straight forward Control	**1**	3	3
Architectural Concern	Safe to Be Revised as Built-in	**1**	2	3
	Reduced Complexity of Structure	**2**	3	2
Manufacturability		**3**	3	1
Cost		**1**	3	2
Reliability		**1**	3	2
Feasibility		**3**	3	1
Size		**1**	3	3
Totals			86	74

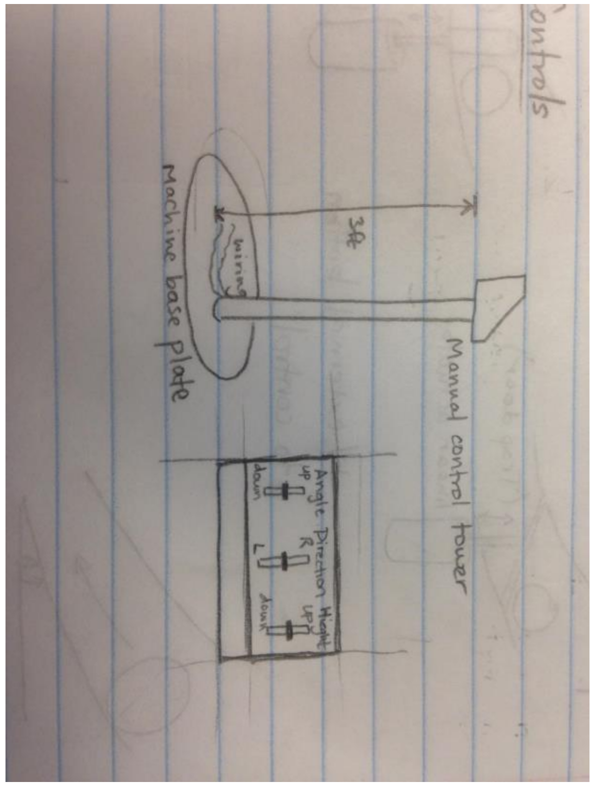
Appendix B: Concept Generation

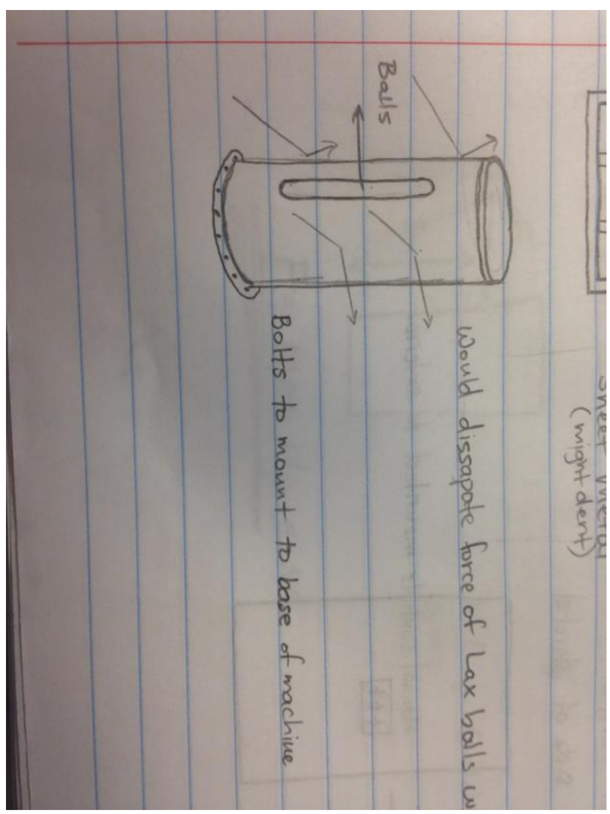


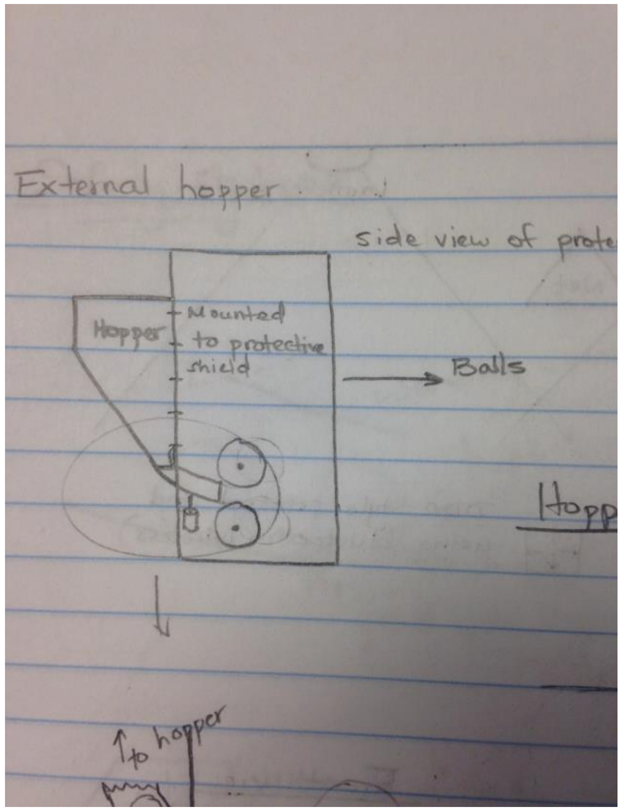


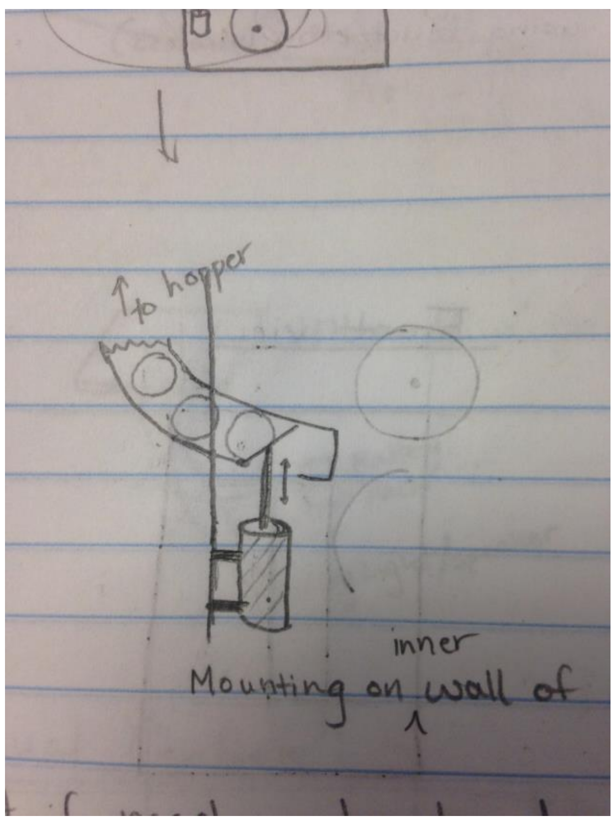

(Rotating wheel)
(Trap door)
linear actuator
w/ external button
to control

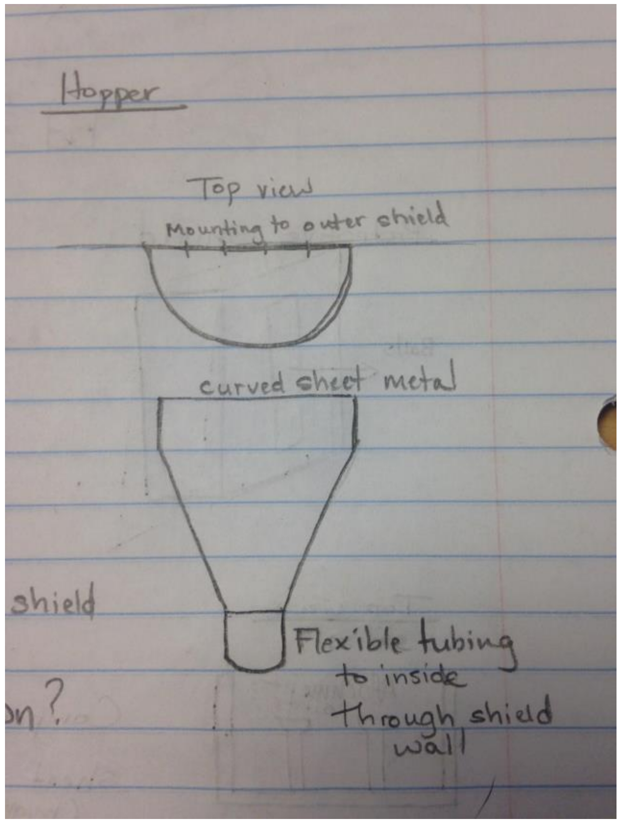

Safety system
warning sound or
light turns on
Pressure pad
Ultra-thin pad
Battery Pack
Light/speaker

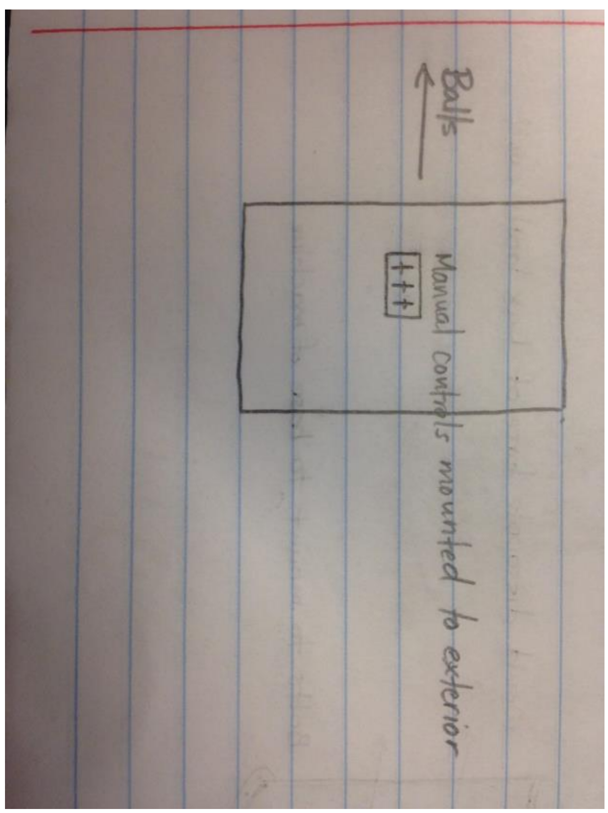

ontrols
Manual control tower
3ft
wiring
Machine base plate
Angle Direction Height
up
down
R
L
up
down

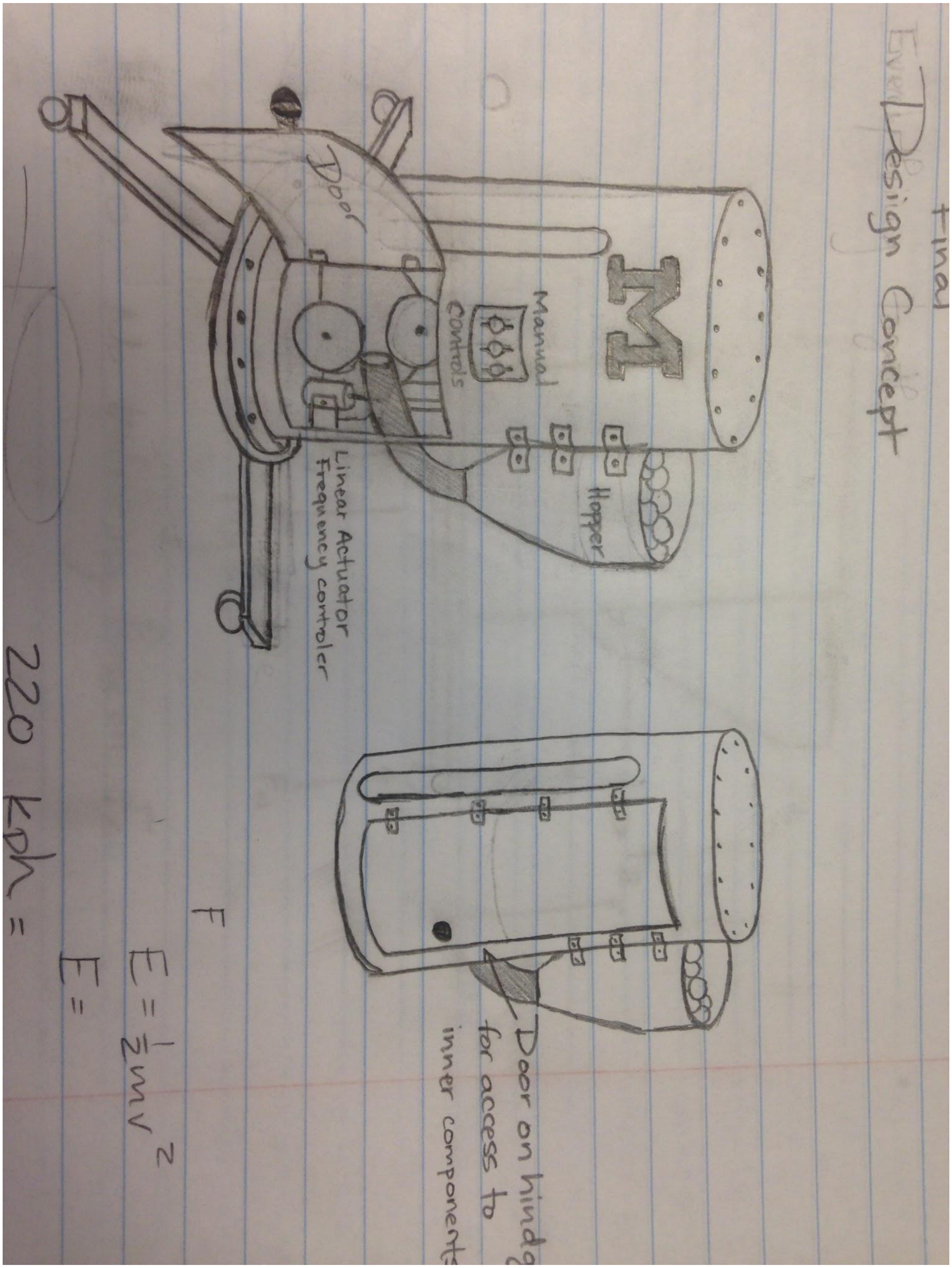

Balls
Would dissapate force of Lax balls w
(might dent)
Bolts to mount to base of machine

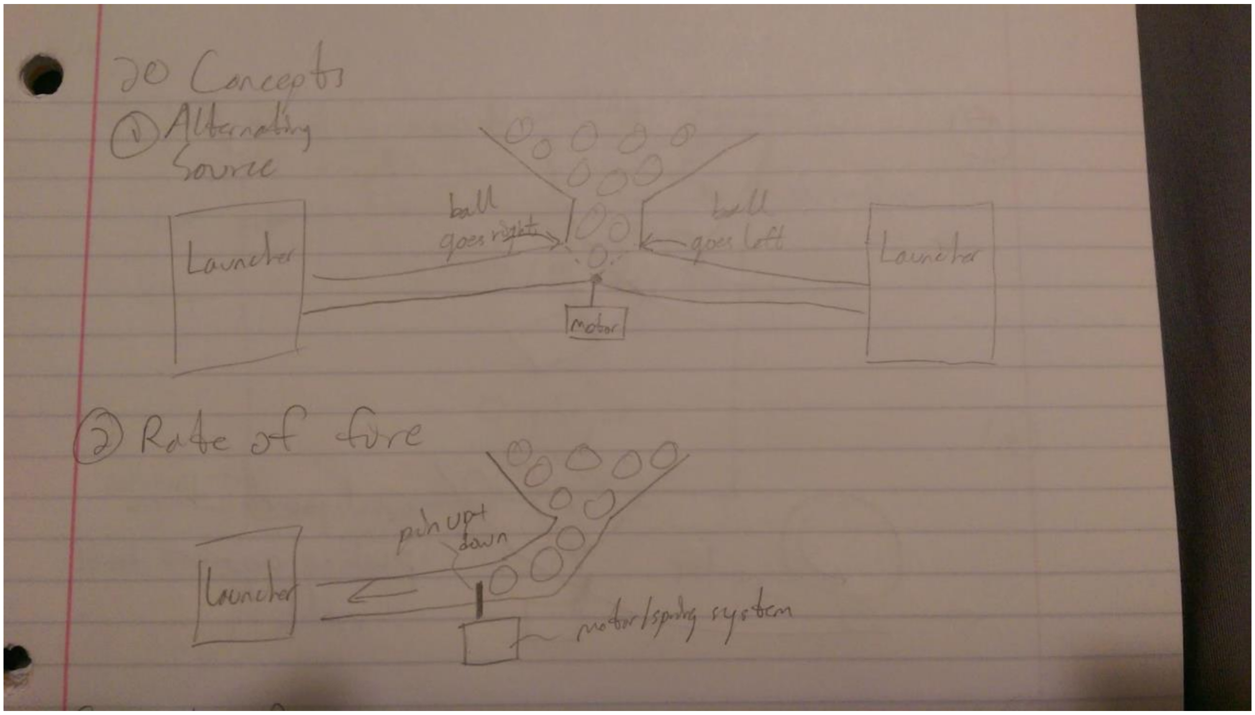

External hopper
side view of prote
Hopper
Mounted to protective shield
Balls
Hopp
to hopper

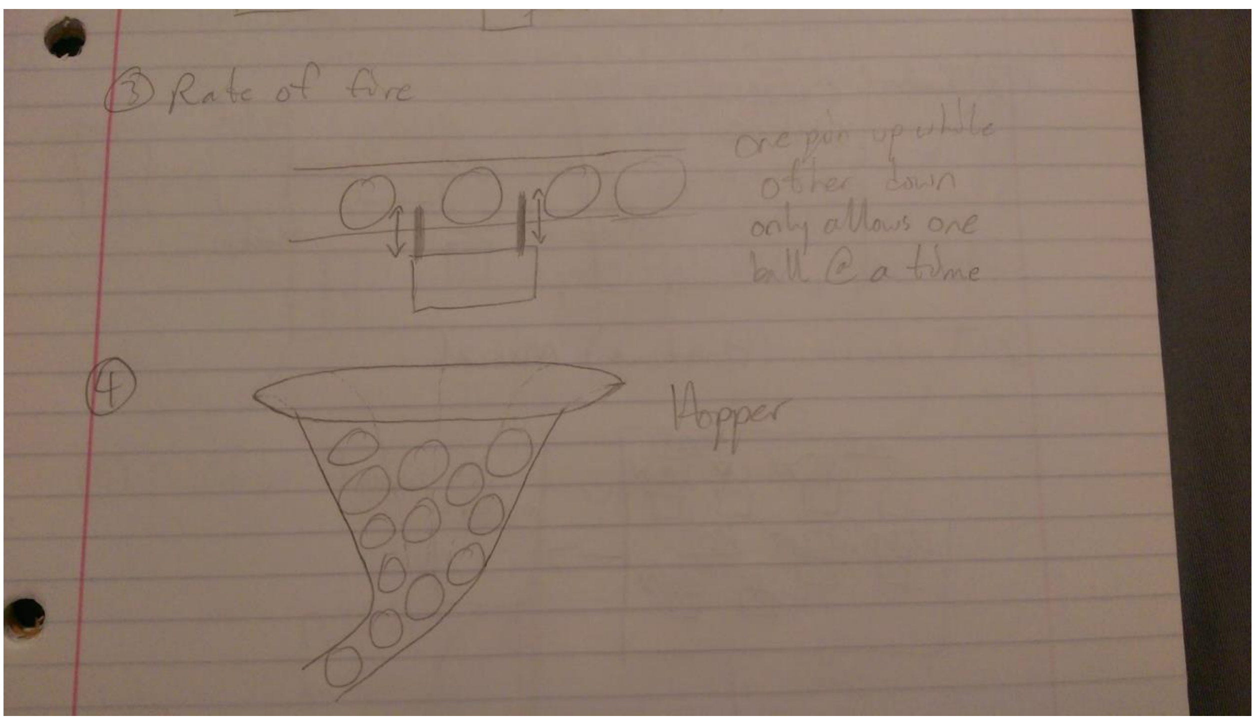

to hopper
Mounting on inner wall of

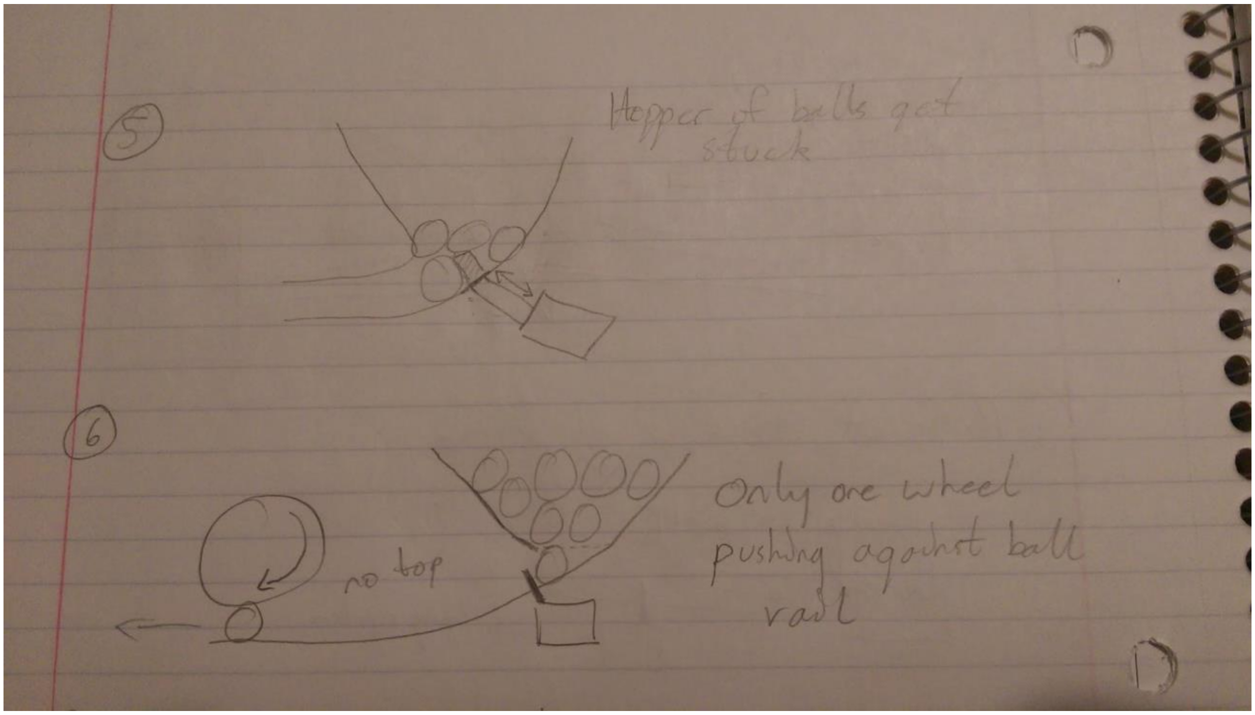

Hopper
Top view
Mounting to outer shield
curved sheet metal
shield
Flexible tubing
to inside
through shield
wall

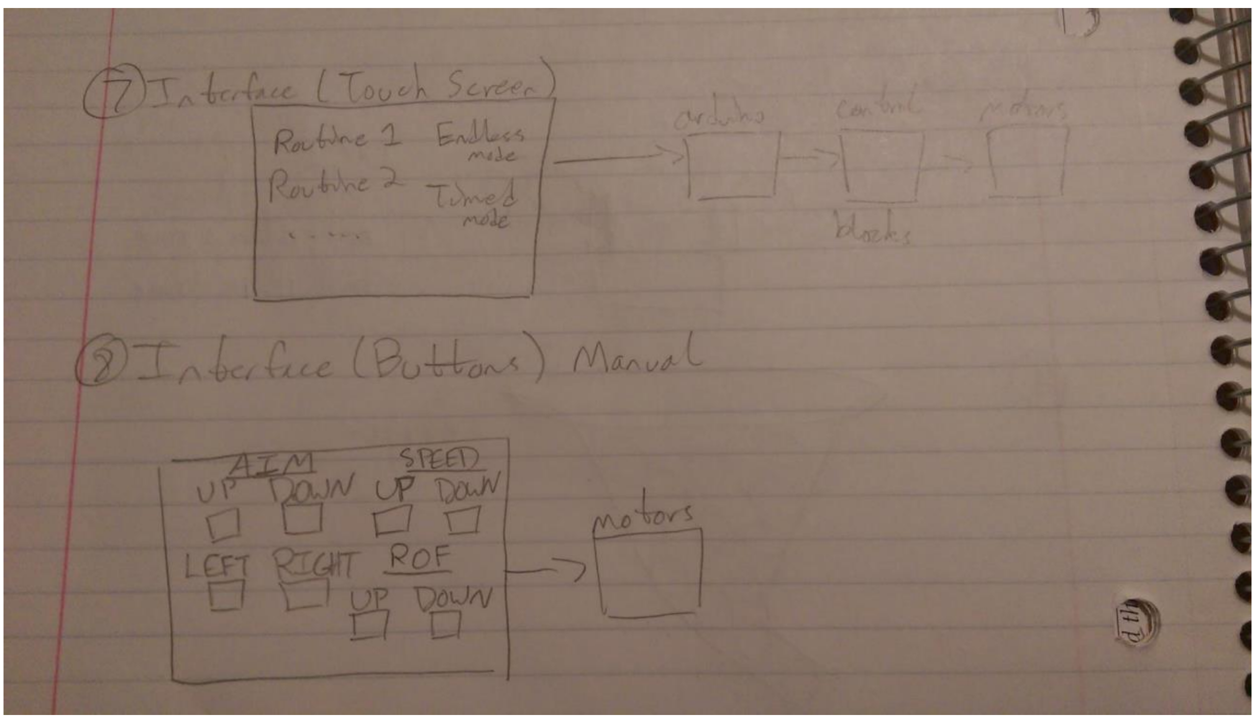

Balls
Manual controls mounted to exterior

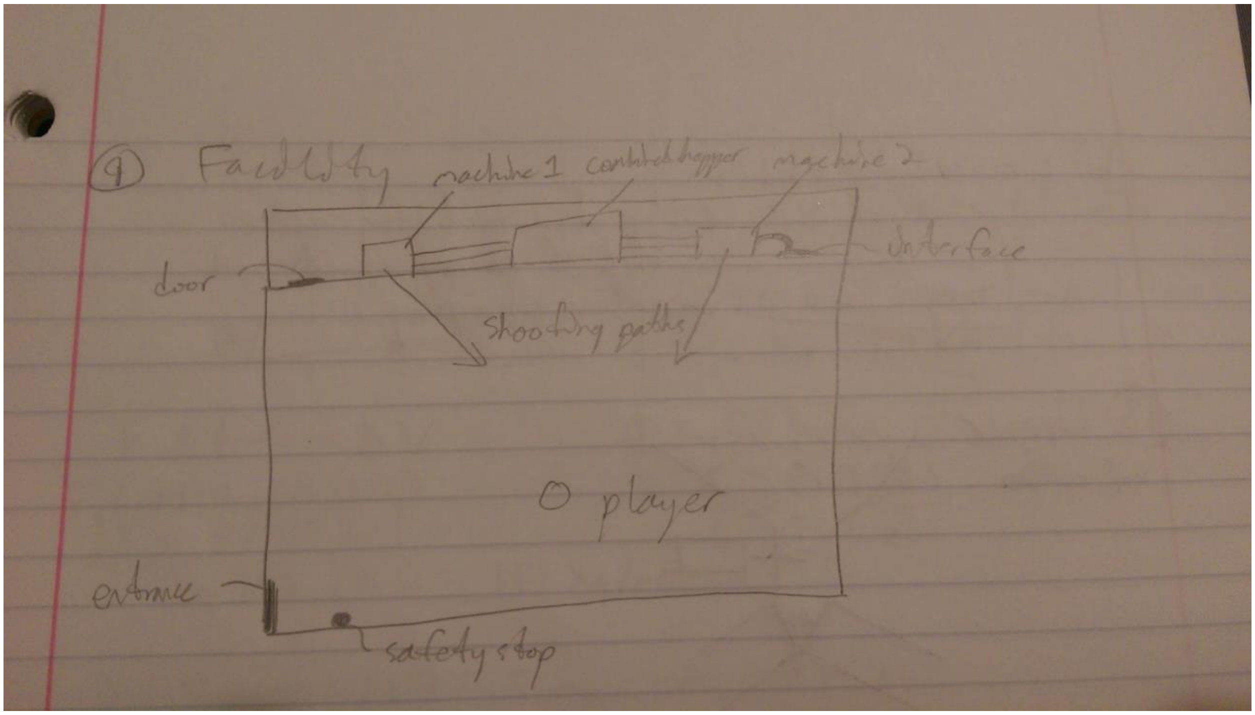

Final Design Concept
Door
Manual controls
Hopper
Linear Actuator Frequency controler
Door on hinge for access to inner components
F
E = 1/2 mv^2
E =
220 kph =

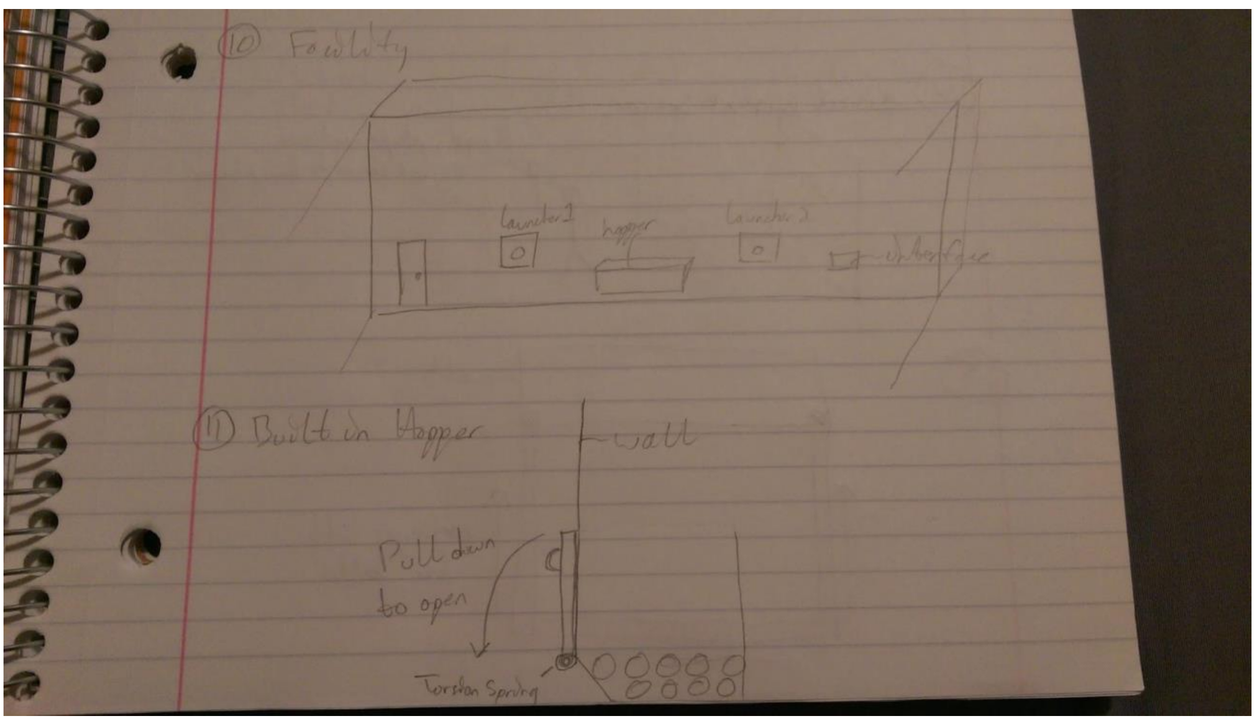

2D Concepts
① Alternating Source
ball goes right
ball goes left
Launcher
Launcher
motor
② Rate of fire
pin up + down
Launcher
motor/spring system

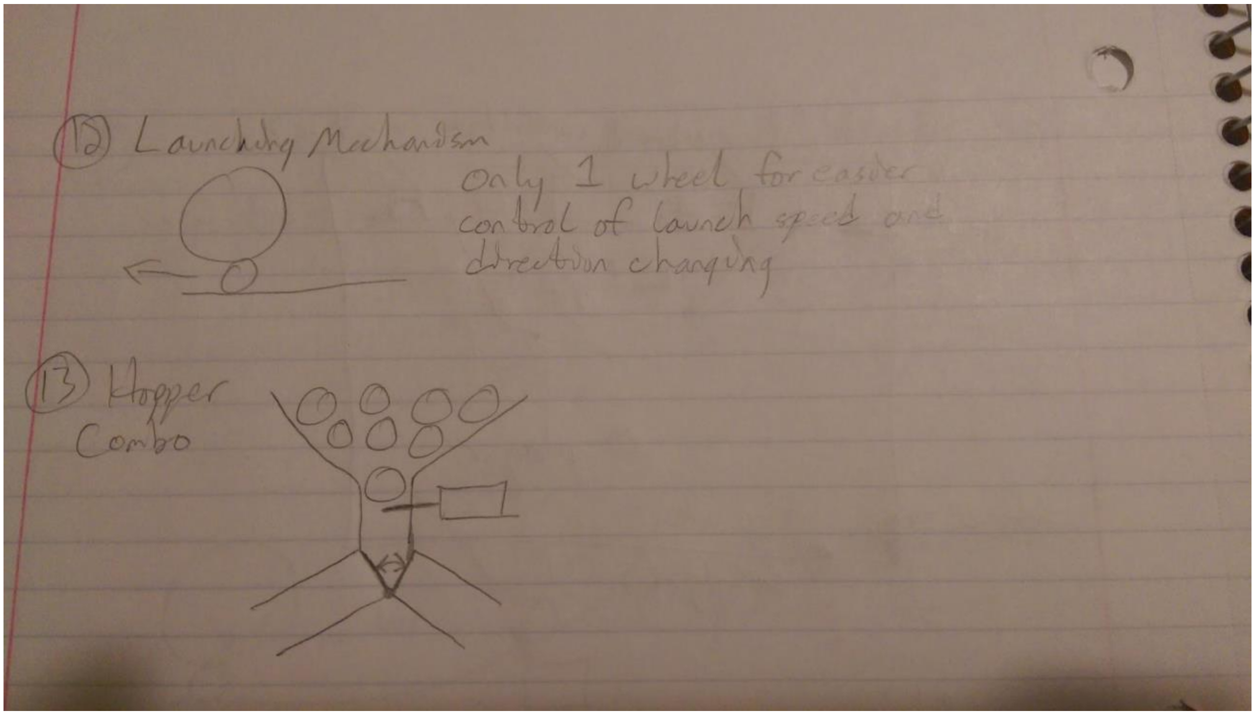

③ Rate of fire
one pin up while other down only allows one ball @ a time
④
Hopper

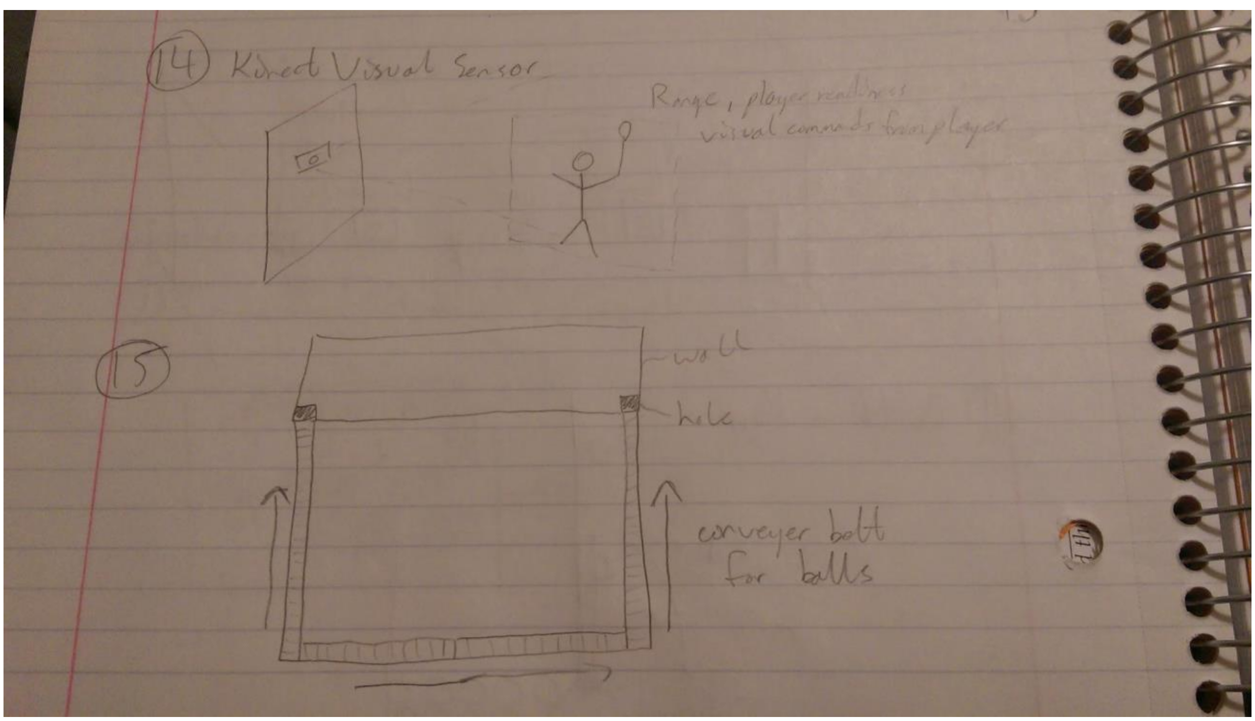

5
Hopper of balls get stuck
6
no top
Only one wheel pushing against ball rail


7 Interface (Touch Screen)
Routine 1
Endless mode
Routine 2
Timed mode
arduino
control
motors
blocks
8 Interface (Buttons) Manual
AIM
SPEED
UP DOWN UP DOWN
LEFT RIGHT ROF
UP DOWN
motors

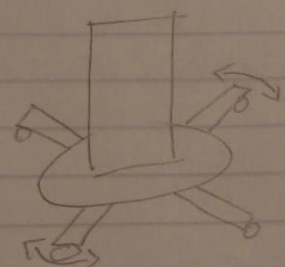

9 Facility
machine 1
controlled hopper
machine 2
interface
door
shooting paths
player
entrance
safety stop


10 Facility
Launcher 1
hopper
Launcher 2
interface
11 Built in Hopper
wall
Pull down to open
Torsion Spring


12 Launching Mechanism
Only 1 wheel for easier control of launch speed and direction changing
13 Hopper Combo


14 Kinect Visual Sensor
Range, player readiness
visual commands from player
15
wall
hole
conveyer belt for balls

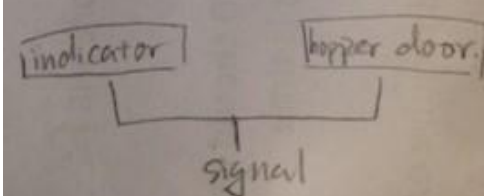
(16) Wheel stand



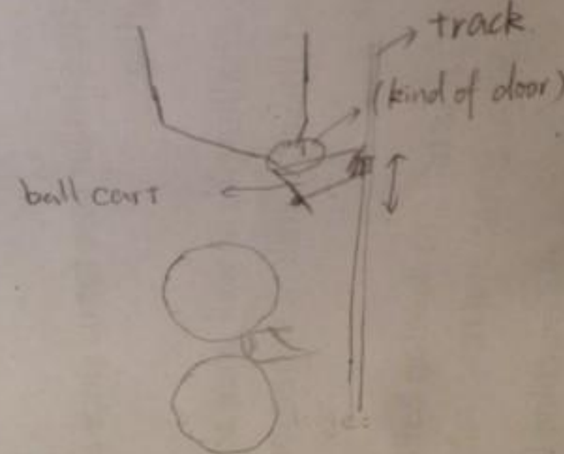
Make one able to swivel to get through doorways

indicator:

instead of using sensor to get the ball launching use the same signal to emit indicator as that used to control the hopper door.



hopper system: for ball conveying to launch wheels

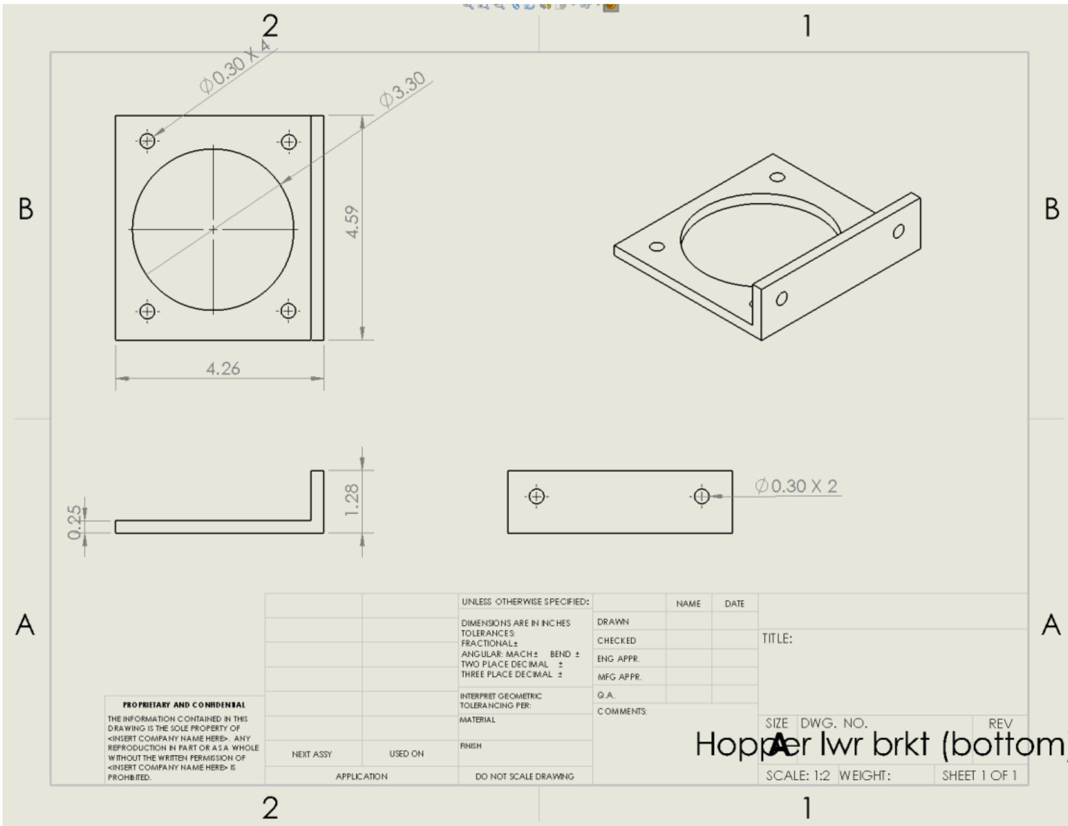


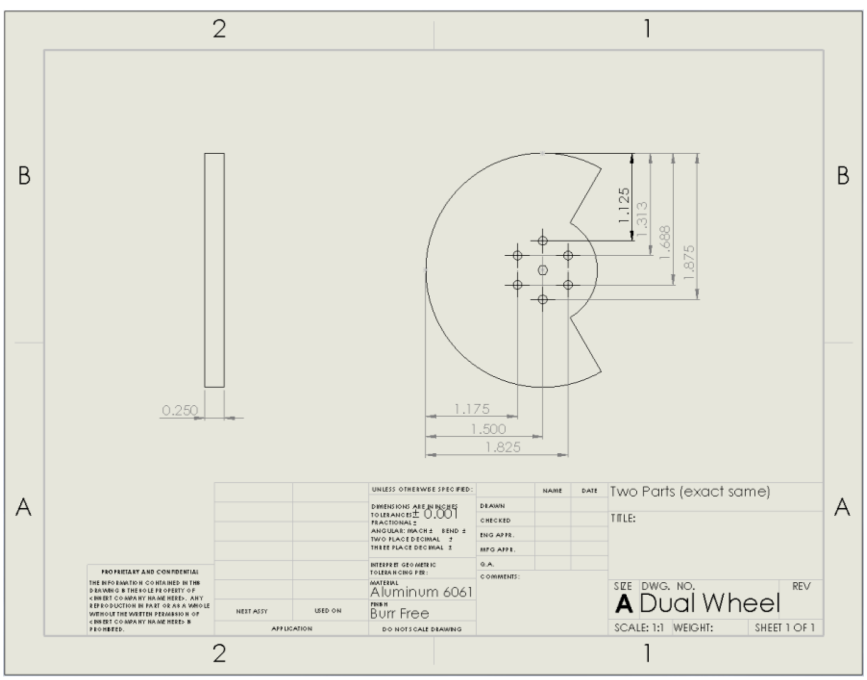
interlock on the door of the shield.

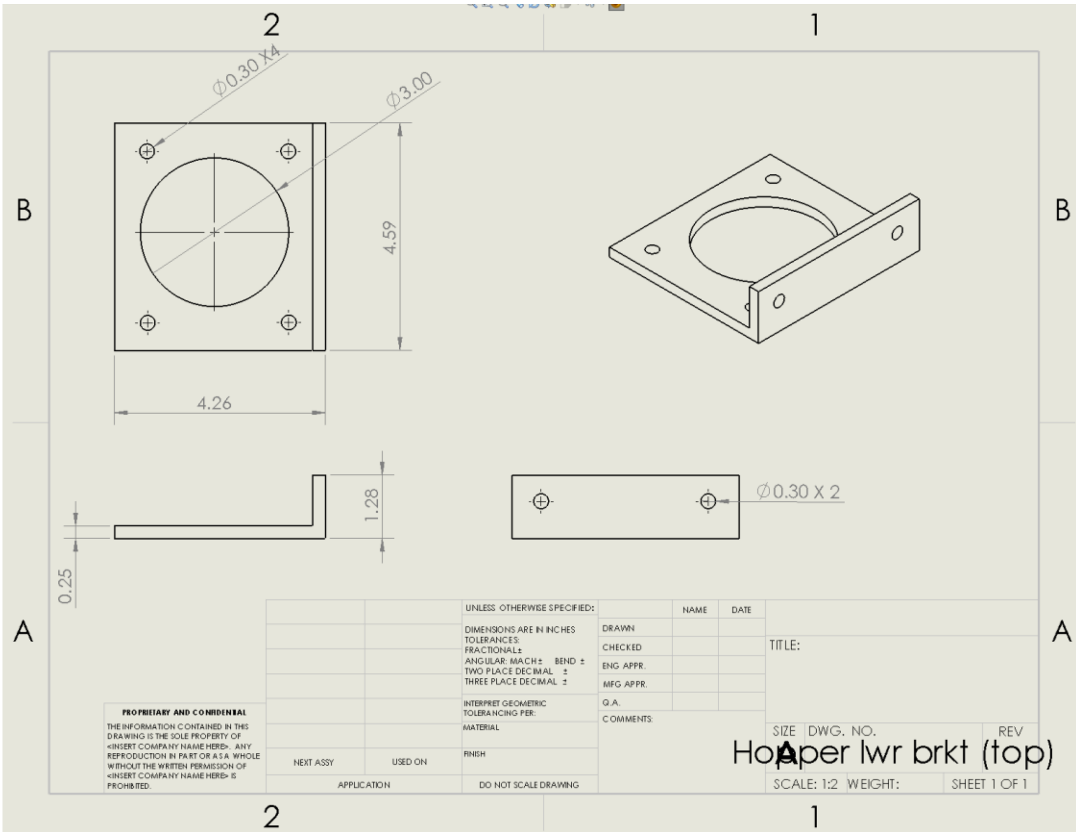
whenever the door of the shield changes its state (open or close), the whole system stop as if the on/off switch turns to "off", until repush the switch to "on".

achieved by adding line of code into controller, eg. Arduino.

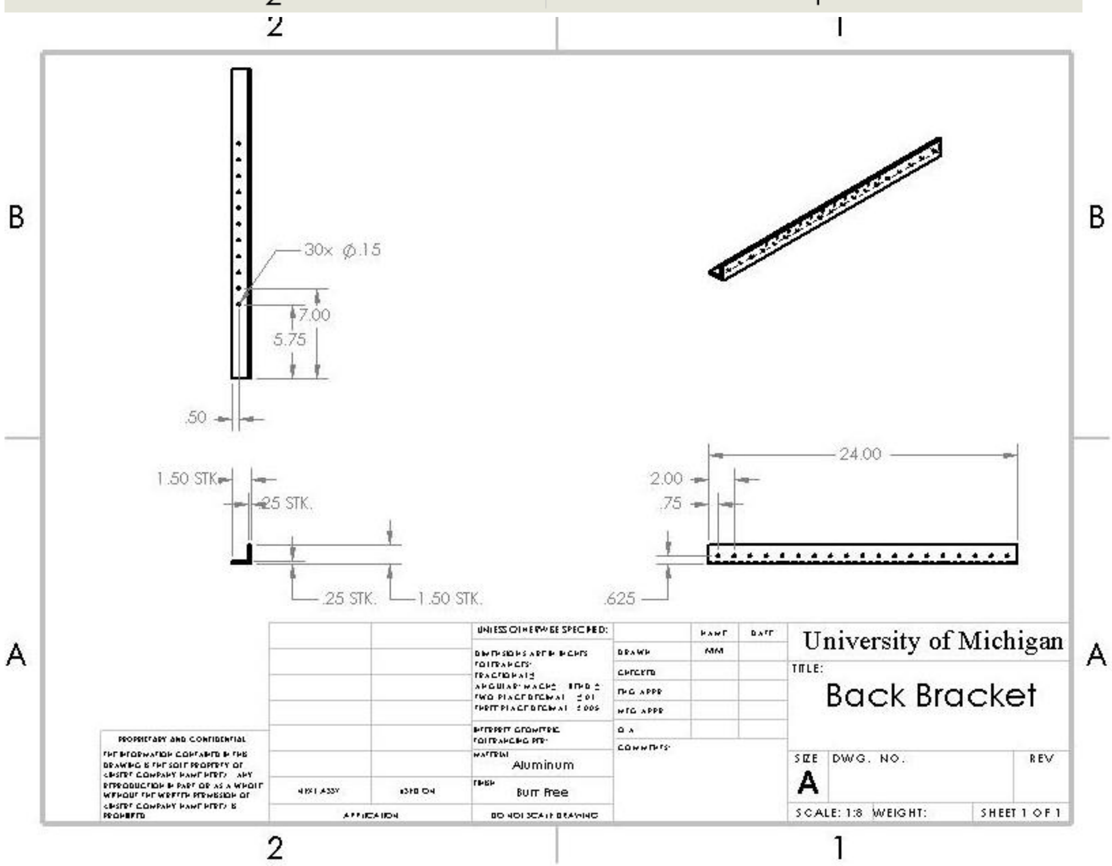
Appendix C: Manufacturing Drawing



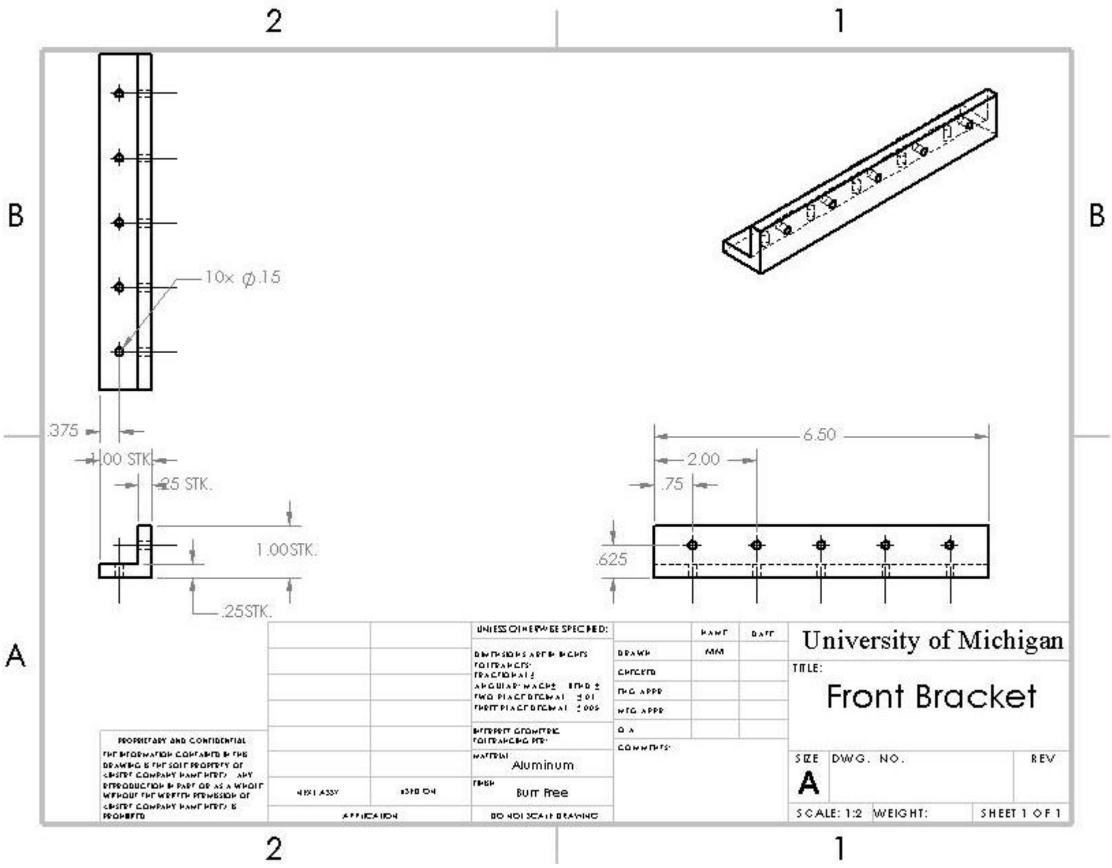




Ø0.30 X4
Ø3.00
4.59
4.26
1.28
0.25
Ø0.30 X 2
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
SIZE
DWG. NO.
REV
A
Hopper lwr brkt (top)
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING



30x Ø.15
7.00
5.75
.50
1.50 STK.
.25 STK.
.25 STK.
1.50 STK.
24.00
2.00
.75
.625
University of Michigan
TITLE:
Back Bracket
Aluminum
Burr Free
SIZE
DWG. NO.
REV
A
SCALE: 1:8
WEIGHT:
SHEET 1 OF 1



10× ⌀.15
.375
1.00 STK.
.25 STK.
1.00STK.
.25STK.
6.50
2.00
.75
.625
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
MM
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
Aluminum
FINISH
Burr Free
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
University of Michigan
TITLE:
Front Bracket
SIZE
A
DWG. NO.
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1

Appendix D: DR5 Project Plan

	Task Name	Duration	Start	Finish
1	**DR4 to DR5 Plan**	**15 days**	**Thu 11/12/15**	**Wed 12/2/15**
2	DR4 presentation (All)	1 day	Thu 11/12/15	Thu 11/12/15
3	DR4 Report Turn-in (All)	1 day	Fri 11/13/15	Fri 11/13/15
4	**Matt's Tasks**	**13 days**	**Mon 11/16/15**	**Wed 12/2/15**
5	Built-in Concept Design for machine	3 days	Mon 11/16/15	Wed 11/18/15
6	Shielding CAD, further analysis, and part sourcing	6 days	Thu 11/19/15	Thu 11/26/15
7	Contact Sponser and summarize progress	2 days	Fri 11/27/15	Mon 11/30/15
8	DR5 Preparation	2 days	Tue 12/1/15	Wed 12/2/15
9	**Dominic's Tasks**	**13 days**	**Mon 11/16/15**	**Wed 12/2/15**
10	Test and benchmark current prototype	4 days	Mon 11/16/15	Thu 11/19/15
11	Dual Wheel feed system CAD, further analysis	5 days	Fri 11/20/15	Thu 11/26/15
12	Feed system part sourcing	2 days	Fri 11/27/15	Mon 11/30/15
13	DR5 Preparation	2 days	Tue 12/1/15	Wed 12/2/15
14	**David's Tasks**	**13 days**	**Mon 11/16/15**	**Wed 12/2/15**
15	Test and benchmark current prototype	4 days	Mon 11/16/15	Thu 11/19/15
16	Hopper and feed tube CAD	3 days	Fri 11/20/15	Tue 11/24/15
17	Hopper and feed tube Dynamic Analysis	3 days	Wed 11/25/15	Fri 11/27/15
18	Hopper and feed tube parts sourcing	2 days	Mon 11/30/15	Tue 12/1/15
19	DR5 Preparation	1 day	Wed 12/2/15	Wed 12/2/15
20	**Mengyao's Tasks**	**13 days**	**Mon 11/16/15**	**Wed 12/2/15**
21	Layout of user interface system	5 days	Mon 11/16/15	Fri 11/20/15
22	grbl firmware and app acquisition	6 days	Mon 11/23/15	Mon 11/30/15
23	DR5 Preparation	2 days	Tue 12/1/15	Wed 12/2/15