

Final Written Report

Team 00LAX: Lacrosse Ball Feeding Device

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ABSTRACT

The varsity men's lacrosse team at the University of Michigan is designing a new training facility, and would like to implement a programmable lacrosse ball launcher to simulate practice conditions for individual/small group training. The device should be able to launch balls at various speeds and angles input by the user from set locations within the facility. This report details the design process, selected concept, analysis, testing, validation and verification that went into designing and building a prototype lacrosse ball feeding device.

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PROBLEM DESCRIPTION AND BACKGROUND

We were approached by the University of Michigan's Varsity Men's Lacrosse Head Coach, John Paul, about designing a customized programmable lacrosse ball pitching system that would be integrated into a purpose-built room in the varsity lacrosse building, part of the upcoming athletic campus. The requested system, as described by Coach Paul, would consist of two wall-mounted pitching machines, capable of pitching lacrosse balls at a range of azimuth and elevation angles, achieving a top speed of approximately 70 mph [1]. The overall goal of this project is to provide the lacrosse team with a state-of-the-art automated system where players can conduct small group or individual training. Individual practice is essential for athletes and teams to succeed. For example, Larry Bird regularly stayed after practice to shoot an extra 150 jump shots. This dedication and individual focus is how he became such a tremendous shooter, and the same principles are true for lacrosse [2]. Our goal is to create a machine specifically designed to facilitate individual training for Michigan lacrosse players.

Literature Review

The game of lacrosse was originally a Native American 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].



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

Through additional research, we examined other aspects of sport that could be relevant to our problem. We learned that 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 balls similar to baseballs [7]. We also

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.

Benchmarks

Through our background research and patent searching, we have identified five existing products that meet some of our specified user requirements. These products are: a baseball pitching machine that has 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.

Conversion of baseball machine for lacrosse balls. Though several preliminary patent searches, we have identified many products that are relevant to the problem presented to us. One such patent details a method to convert a baseball pitching machine, with a single drive wheel, into a machine that is capable of shooting smaller lacrosse balls [8]. The first major modification that needs to be made to the pitching machine is to decrease the ball compression space*. Since 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], the compression space of the machine must be reduced by 68%. The second major modification is increasing the height from which the ball is ejected from the machine. A baseball pitching machine shoots a ball from a height of between 40 to 50 inches. A lacrosse ball is often thrown from a stick, so the release height must be much higher, approximately 70-90 inches from the ground [8]. By modifying a baseball pitching machine in these two ways, the machine is now capable of shooting a lacrosse ball. A drawing of this process is shown in Fig. 2 below.

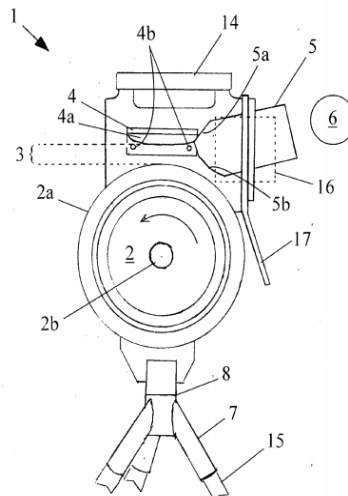


Fig. 2: Drawing of pitching machine conversion to pitch lacrosse balls [8].

The main advantages of this specific conversion are its simplicity and its low cost. The method is a quick and easy way to convert a \$200 machine designed to pitch baseballs into one that can shoot lacrosse balls. However, this simple conversion alone is not a sufficient solution. Because the sport of lacrosse is fundamentally different from baseball, a machine designed specifically to replicate the conditions of lacrosse is needed. The most obvious example of this is that a simple baseball pitching machine does not have the flexibility to shoot a ball at different azimuthal angles and has very limited capability for elevation angle adjustment. Also, while high-level (70-90 in.) passes are common in lacrosse, shots on goal are often thrown from a variety of release heights, including waist-level, as we observed when we attended a Michigan varsity lacrosse practice. Because of this, we determined that adjustable launch height is important for an effective lacrosse pitching system. Furthermore, Coach Paul requested customizable programming capabilities for replicating specific training scenarios while being entirely integrated into a purpose-built room. This application requires a stationary system, rather than a typical portable pitching machine. Finally, Coach Paul expressed that he was not interested in a cheap conversion, but rather a state-of-the-art, purpose-built machine. Such conversions could be useful, but alone are not sufficient.

Pitching machine with four wheels. There are many other styles and features that have been implemented in pitching machines for baseballs and tennis balls that could prove useful in our design. A recent design for a baseball pitching machine (shown in Fig. 3a, below left) utilizes four spinning wheels to propel the ball, where varying the speed of each wheel allows for variable types of spin on the ball [12]. These different spins mimic the different types of pitches that batters see and are essential in training a batter. In baseball, these types of spins can drastically affect the flightpath of the ball, hence the reason why pitchers intentionally will throw different types of pitches [7]. Through interviews with the goalies on the team, however, we have learned that ball spin of a shot does not noticeably alter the trajectory of a lacrosse ball. Because of this, the additional complexity of trying to impart different spins onto a lacrosse ball is avoided, since it is unnecessary to accurately replicate a lacrosse shot.

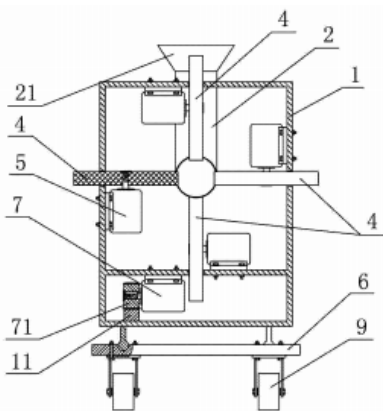


Fig. 3a: Pitching machine with four wheels [12].

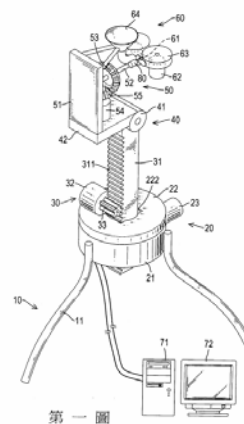


Fig. 3b: Pitching machine with variable launch height [13].

Pitching machine with adjustable height. Through our patent search we also discovered a design for a baseball pitching machine that allows for the ball to be pitched at variable heights, shown in Fig 3b on p. 5, bottom right [13]. The launcher height is varied by means of a rack and pinion system. Since lacrosse shots are thrown from a variety of heights, a machine that has the ability to be height adjustable is ideal. However, this design still has the drawbacks associated with being designed for the game of baseball, mainly lack of flexibility in launch angles and the inability to launch lacrosse balls.

Pneumatic pitching machine. Pneumatic pressure is another way to pitch baseballs [14]. An example of a pneumatic pitching machine is shown in Fig. 4a, below left. The main advantage of pneumatic launchers is their use of a precharged, high-pressure accumulator, eliminating the need for an additional power source during operation. However, since our design will not be portable, this is an unnecessary 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, and portability is unnecessary.

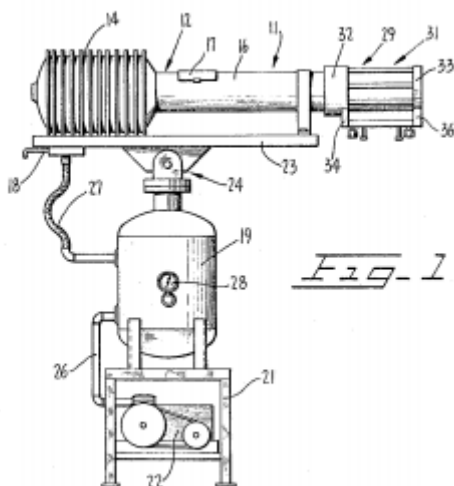


Fig. 4a: Pneumatic pitching device [14].

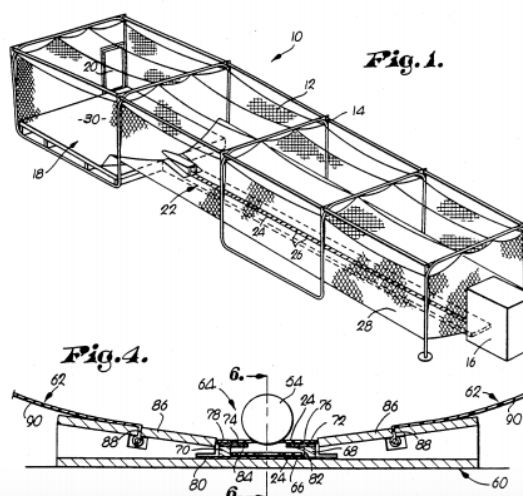


Fig. 4b: Conveyor belt ball return for a batting cage [15].

Additional pitching machine features. Additionally, there exists a patent for a conveyor belt system that returns baseballs to the pitching machine when used in a batting cage [15]. A similar need would be present in our system to return the lacrosse balls to the launcher. Examination of this patent could aid our design of a return system.

One final feature that is common in baseball pitching machines is an indicator to notify a batter when a ball is about to be pitched [16]. This feature is designed to emulate the windup of the pitcher as a visual cue to the batter, allowing for a more realistic, coordinated practice scenario. A lacrosse shot or pass also has a distinct wind up, which provides a similar visual cue to the

player. 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.

There clearly exist a lot of individual solutions to the problem presented to us by Coach Paul. The main reason that these solutions are insufficient for our needs is that there doesn't exist a single system that encompasses all of our user requirements. There isn't currently a system that can fire at a variety of angles, change the height of the launch, offer lacrosse-oriented programming features, while being easy to load and operate by a single user. Thus, while individual features of these designs may be useful for lacrosse, relying on a single machine is still insufficient.

Tennis ball machines. During our interview with Coach Paul, he discussed the current solution that the University of Michigan women's lacrosse team uses to facilitate goalie practice. They use a tennis ball machine to practice goalie skills. The main advantage of using tennis balls is their similar size, high visibility, and light weight compared to a lacrosse ball. These factors significantly reduce risk of injury. However, this solution lacks the realism that is required to fully train more experienced goalies. Many commercial tennis ball machines utilize portable, programmable memory units and remote control, which could also be useful for our design [17, 18], but once again, these machines alone are not sufficient for our needs.

In summary, we have identified five products that meet some of our 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. The key user requirements that each of these products meets are shown in Table 1 below.

Table 1: Benchmarking existing solutions for athletic ball launching/pitching machines.

Requirement	Converted baseball machine	Four wheel baseball machine	Baseball machine w/ height adjustment	Pneumatic baseball machine	Tennis ball launcher
Launch lacrosse balls	yes	no	no	no	no
Adjustable angles	yes	yes	yes	yes	yes
Adjustable height	no	no	yes	no	no
Realistic launch speed	yes	yes	yes	yes	no
Programmable	no	no	no	no	yes

USER REQUIREMENTS & ENGINEERING SPECIFICATIONS

All of the user requirements were generated from an interview with the main sponsor, Coach Paul. He outlined the functions that are essential for our design to meet. For each user requirement, we produced a corresponding engineering specification. The user requirements and engineering specifications are summarized in Table 2 below.

Table 2: User requirements and corresponding engineering specifications.

User Requirements	Engineering Specifications
Launch lacrosse balls	Compression space 2.5 in. or less [10]
Launch height simulates player	Maximum launcher height of 6ft. [19]
Adjustable horizontal angles	$\pm 60^\circ$ from vertical with respect to neutral configuration [20]
Ability to pitch bounce shots	Must be able to be fire at -30° from the horizontal at a target 9 feet away [21]
Adjustable vertical angles	$\pm 30^\circ$ from horizontal [21]
Simulates realistic speeds	Top speed at least 70 MPH [1]
Machine must be stable	Zero net moment when machine is still
Programmable	Must have accessible control system

Rationale for specifications

To achieve the user requirement of launching lacrosse balls we determined that we will need a compression space of 2.5 in or less. This measurement is based on the patent for the conversion of a baseball pitching machine to a lacrosse ball pitching machine [8], and the diameter of regulation NCAA lacrosse balls [10]. A compression space of at most 2.5 in. will ensure that whatever method we utilize will effectively impart momentum to the lacrosse balls.

In order to design our launcher to simulate the mechanics of a lacrosse shot, like release height and bounce, we attended a varsity men's lacrosse practice. Practice observation helped us to determine the vertical launcher height. It was clear from practice that lacrosse players commonly release the ball at head height. The average height of a player on the team is six feet according to the team roster [19].

Additionally, we looked at the blueprints for the practice facility to determine the dimensions of the room we'll be implementing the device in. Based on the 22 -yard by 22-yard square room, we determined that being able to launch balls across a horizontal range of 60° to either side (with two launchers equally spaced within the wall) will result in over 98% coverage of the room, as shown in Fig. 5a (p. 10, left). At practice, we also observed that a bounce shot is a common way to shoot on goal. We determined that a maximum negative angle of 30° was needed to replicate these bounce shots based on the geometry of the launcher height and the requirement that all

shots must be taken at least nine feet away from the goal [21]. A similar 30° requirement above the horizontal will allow the machine to simulate passes as well as shots. This geometry is shown in Fig. 5b below, right.

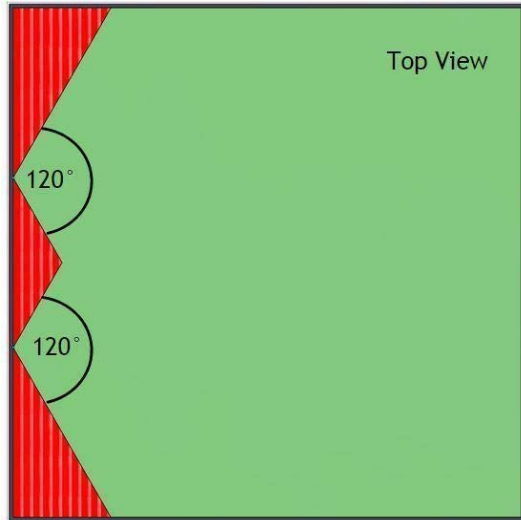


Fig. 5a: Horizontal angle range.

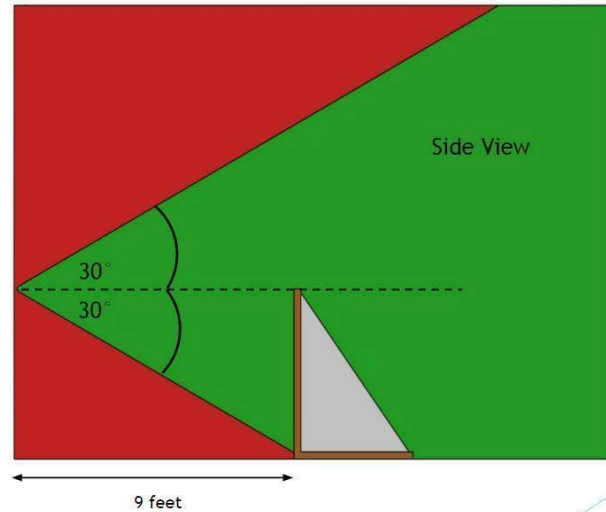


Fig. 5b: Vertical angle range.

Coach Paul requires that our lacrosse ball launching machine be able to simulate realistic game speeds. From research, we determined that the maximum speed of a lacrosse ball shot is approximately 100 MPH [1]. Most lacrosse shots, however, are not that fast, so a top speed of 70 MPH is sufficient to simulate game play.

Identifying the stability requirement and associated engineering specification came from our detailed engineering analysis, which will be discussed later in the report. Due to the mechanics of both moving a potentially heavy launcher vertically, and the recoil from actually launching a ball, keeping the machine stable is a vital aspect for it to function properly. Thus, we determined that if there is no net moment within the machine as it moves and fires, then it would be stable enough for repeated use, and won't fall over or suffer from other similar problems.

One of the key user requirements is that our lacrosse ball launcher needs to be capable of being programed. The user needs to be able to adjust the vertical and horizontal angle of the launcher as well as the speed of the shot. These adjustments will be incorporated into an overall control system for the launcher.

While not explicitly defined by Coach Paul, the described pitching system will also have an inherent reliability requirement. Because it will be part of a facility that will be used by the lacrosse team for many years, a comparable machine lifetime is expected. Additionally, exposed parts of the launching mechanism will need to be durable enough to withstand being hit by a

lacrosse ball thrown at full speed by a player. We initially also considered a requirement that the device have a minimum cycle time of three seconds, but because this feature will be part of the final construction implemented into the building (along with the ball collection and storage features), we decided that it was outside the scope of our project for this semester. Finally, there is the vital aspect of player safety we must consider in our design. While helmets are required during practice and play, our review of relevant literature revealed being hit by a lacrosse ball at speed, even when wearing proper equipment, can cause injury or even death [1, 6]. This necessitates a player-controlled remote kill switch in case of emergency. To ensure safety during use and maintenance, we'll need to ensure that the device is stable and unmoving when the power is disconnected, and that all users know not to insert body parts, pieces of clothing, or other detritus into the exposed slot from which lacrosse balls are launched.

CONCEPT GENERATION

In order to generate a large number of unique and innovative concepts, we utilized four main concept generation methods. These methods were individual brainstorming, design heuristics, functional decomposition, and Method 6-3-5, which we adapted to our needs as Method 4-3-3.

Brainstorming & Design Heuristics

Individual brainstorming was the first method used in the concept generation process. Each team member individually generated three general solutions. The designs generated by this first wave of brainstorming are documented in the Appendix. Many of the ideas that were produced from the individual brainstorming were very similar and therefore design heuristics cards were used in order to force more creative ideas. Each team member was given three cards that contained various design suggestions. Each card was somehow incorporated into each of the three previously brainstormed solutions. Some examples included: twisting, lifting, folding, and spinning. By using these design cards, more novel and innovative ideas were discovered. There are many other functions that our machine must be able to perform, so a more directed concept generation method was used next in order to focus on each part of the machine.

Functional Decomposition

A lacrosse ball launcher can be broken down into the following main functions: feeding lacrosse balls into storage, storing said lacrosse balls, feeding balls into the launcher, aiming the launcher, and launching the balls. We limited the scope of our project to just aiming the launcher and launching the balls, in addition to controlling how we aim the prototype. Controlling the system will be addressed later on in the semester once we have a prototype to control. Launching the balls can't be broken down further, but aiming the launcher has sub functions. A functional diagram for our problem can be seen in Fig. 6 on p. 12.

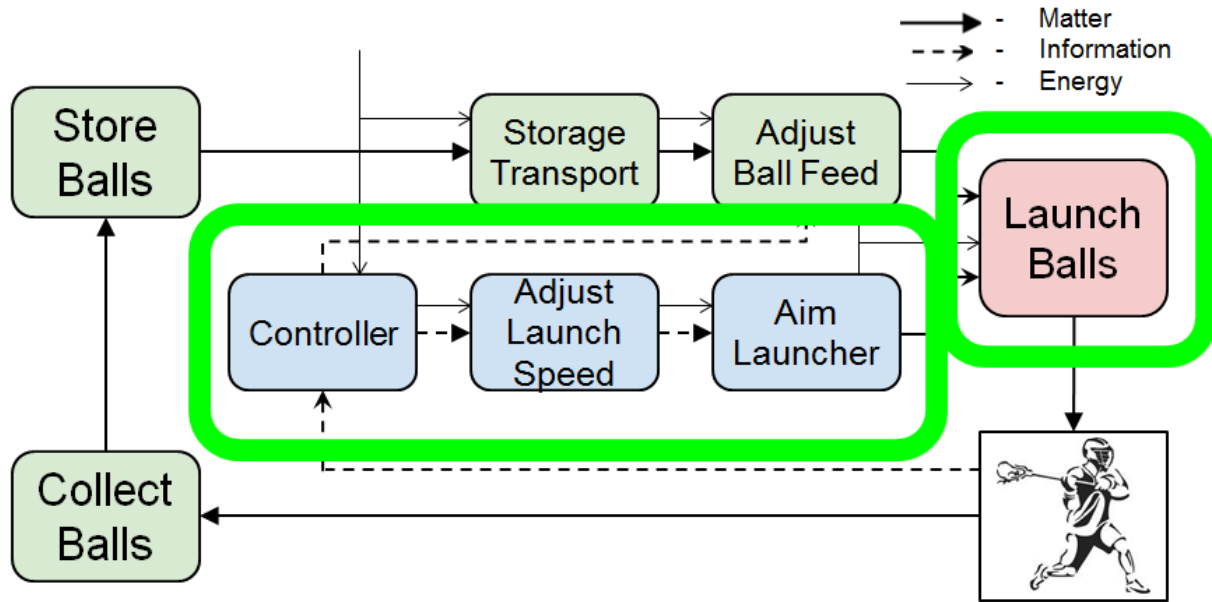


Fig. 6: Functional diagram for our problem. The scope of our project is limited to aiming and launching lacrosse balls, with controlling the system for our prototype.

Aiming the launcher can be further broken down into three additional sub functions: vertical axis rotation, horizontal axis rotation, and vertical translation. Once these sub functions were identified, concepts were generated in a group setting as solutions to each individual function. By breaking down the overall machine into its individual functions, ideas can be directly compared, and the overall design will be a combination of the best ideas. This works well for our design because we focused on the interchangeability of ideas. Once ideas were generated for these four main sub functions, it was clear that many designs were very similar and utilized the same method to achieve the desired function. Similar designs were combined so that only significantly different concepts remained. All of the concepts generated can be found in the Appendix, but concepts for the specific sub functions we chose to focus on are detailed below.

Launcher. There were many different ideas for how to launch a lacrosse ball, but all the ideas boiled down to three main methods. The first included using spinning wheels to propel the ball, similar to a typical baseball pitching machine. The second concept involved using compressed air to shoot the lacrosse balls, like a canon. Finally, the third concept utilizes a spring and lever arm to throw the lacrosse balls. All three of these sketches can be seen in Fig. 7a (p. 13, left). The actual comparison of these concepts is detailed later in the report.

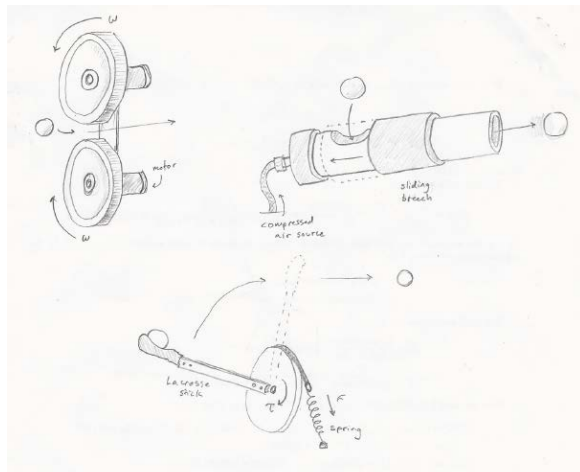


Fig. 7a: Concepts for launching the lacrosse ball.

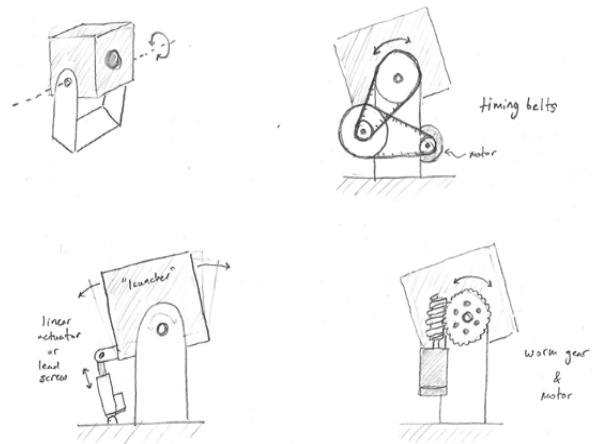


Fig. 7b: Concepts for adjusting elevation angle.

Aiming: vertical angle. Most of the concepts for adjusting the vertical angle of the launcher involved using devices to add mechanical advantage to a motor that would drive the rotation. Most of the devices we considered are already designed to transfer rotational motion, though some seemed more suited to the task than others, as discussed later in the report. The concepts are shown in Fig. 7b, above right, and include using a series of timing belts and pulleys to turn the launcher, and a worm-spur gear assembly. A slightly different design was to use a lead screw or linear actuator, and to position it such that the linear motion of the actuator would alter the launch angle of the launcher.

Aiming: horizontal angle. Once again, the concepts we developed for changing the horizontal angle of the device involved devices that added mechanical advantage to a motor that would drive the rotation. A timing belt and pulley was considered, in a concept that was similar to the one that utilized a timing belt to alter vertical angle. Additionally, we considered using a spur and a ring gear to drive rotational motion, or using a harmonic drive to do the same. All of these concepts are shown in Fig. 8a, below left.

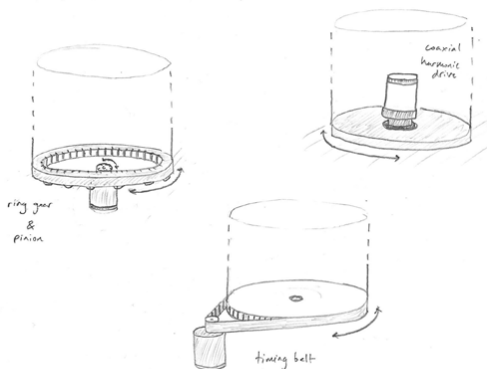


Fig. 8a: Concepts for changing azimuthal angle.

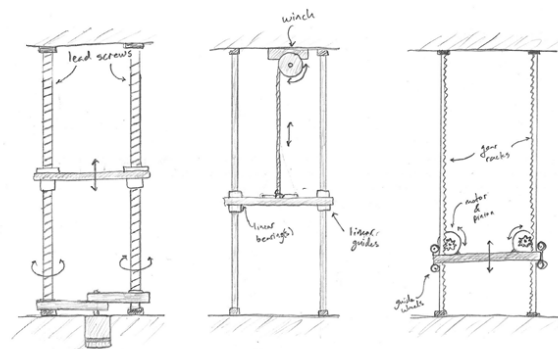


Fig. 8b: Concepts for changing vertical elevation.

Vertical translation. Concepts for allowing vertical translation of our device are different in that they involve translating the rotational movement of a motor to linear movement of our device. As such, we considered using lead screws driven by a motor, a winch/pulley system with linear bearings, and a rack and pinion system. All of these concepts translate the rotational motion of a motor to linear displacement. These concepts are shown in Fig. 8b, above right.

Method 4-3-3

The final method of concept generation was the 4-3-3 method, an adaption of the 6-3-5 method, where each of six team members generated three new concepts with five minutes per concept. For our purposes, we only had four team members and spent three minutes per concept, hence the change in the name of the method. Each of the three concepts was then passed to each team member for them to add on to or change. The specific function that we focused on during this exercise was the ball feeding mechanism. Examples of the originally generated ideas and the additions that team members made are shown in the Appendix. The purpose of this method is to combine the ingenuity of individual brainstorming with the process of building off team member's ideas to generate the most well rounded solutions. Unfortunately, due to time constraints, we ultimately decided to exclude the ball feeding sub functions from our scope for this project.

CONCEPT SELECTION

In order to logically and objectively assess the individual designs, we used a Pugh chart for each sub function. Each sub function is related to the four design drivers under adjustability: launching and aiming under vertical rotation, horizontal rotation, and vertical translation. By utilizing four different Pugh charts, we were able to avoid the forced constraints of integration. One full design, for example, may have a great launching mechanism but a poor translation mechanism. For our particular design, the sub functions are completely interchangeable.

Feasibility

Under the constraints of ME 450, our proposed concept is not feasible. Excluding the \$1600 launcher, the harmonic drives themselves eat up the entirety of the \$400 budget. Fortunately, our sponsor has allowed us to go over budget in order to effectively demonstrate a proof of concept. Because of the temporal constraint, we had to reduce the functionality of our concept to just aiming and launching. There was simply not enough time to incorporate reloading, storing and feeding. We don't believe there are many technical constraints, as we have very minimal manufacturing to be done. The reason we can achieve this is because we plan to integrate the various sub functions into one coherent machine, and that will be done through incorporations of L-brackets and linear rails--essentially a robust frame for the subcomponents.

Selection Criteria

By using our four Pugh charts, we were able to rationalize certain sub concepts for specific sub functions. We weighted each criterion on a scale of 1 to 5 based on its importance. We judged each concept's performance per criteria on a scale of 1 to 5 based on how well it applies itself to said category. With the exception of two criteria, the Pugh charts for launching, vertical rotation, horizontal rotation, and vertical translation are the same, though there are minor differences in weight for some criteria.

Reliability. This product will undergo the same process nearly 100,000 times over an estimated course of three years and we want to make sure that when a lacrosse ball is launched at a specific angle, it is launched from the same position each time. We ranked reliability a 5 for all four sub functions, because it is extremely important that our device has a long enough lifetime.

Speed. Speed is one of two categories only found in our Pugh chart for the launching mechanism. One of our engineering specifications is to launch a lacrosse ball at a top speed of 70 miles per hour. Because of this engineering specification, speed is ranked at 5 for weight. Because the speed at which it takes to aim isn't as important, it was not used as a criteria for the aiming sub functions.

Manufacturability. This criterion is related to the time we expect to spend machining or assembling. We believe the bulk of ensuring this prototype's success will come from the controls, so we want to minimize the time we spend in the shop. Therefore, manufacturability in terms machining and assembling is ranked at 5 for weight for all sub functions.

Ease of control. Programmability is another user requirement. As with the other user requirements, we ranked it at 5 for weight. For the launching sub function, ease of control relates to controlling the speed at which lacrosse balls are fired at. For the aiming sub functions, ease of control relates to evaluating actuator movement (i.e. pure rotational motion vs converting rotational motion to linear motion).

Complexity. Complexity is important because of time constraints and is related to manufacturability in terms of designing and debugging. We can also define complexity as the number of moving parts and components to deal with. We gave it a 4 for both launching and aiming sub functions. Note that a higher score for complexity actually meant it is more advantageous and appealing while a low score meant it was too complex to work with (i.e. a simple concept gets a 5, while a complex concept gets a 1).

Price. Price is ranked at a 3 because it is not a major concern to us for this particular project. Typical upscale launchers are priced at \$20,000 to \$40,000, so our sponsors are expecting we will need to blow past the initial \$400 for the prototype. At the same time, we would like to be

sensible enough where we can consider our options when comparing the effectiveness of certain options. In other words, we shouldn't use an option just because it's expensive.

Weight. Because the final machine will be built into a wall, we did not consider weight to be a very significant criterion. The weight of the components we expect to use will be just as comparable to the frame used to hold everything in place. We recognize that more powerful actuators will have to be used, but because price isn't too high a priority, we can get away with ranking weight at 2.

Volume. Volume follows the same justification as weight in that the final product will be tucked away behind a wall of the new facility. Volume may play a role in transporting from place to place for when we test but ideally the machine should remain stationary. Volume is ranked at 2 for both launching and aiming sub functions.

Safety. Finally, we have a ranking of 2 for safety for both launching and aiming sub functions. While this appears alarming, we again emphasize that the final product of this design will be behind a wall in its own machine room. This means we do not have to worry about clothing getting stuck to spinning equipment or pinch points, as long as we have signage telling users not to insert anything into the slot from whence balls are launched. We may have a safety concern from flying balls, but this is similar to current normal practice conditions, where risk is assumed by the players and dealt with by wearing protective equipment during play.

Concept Comparison

As discussed above, the four Pugh charts we used to evaluate our concepts are shown in the tables below.

Table 3: Pugh Chart for comparing concepts for ball launching function.

LAUNCHER		Buy	Buy	Buy	Build	Build	Buy
CRITERIA	WEIGHT	Three Wheel	Two Wheel	One Wheel	Spring Arm	Pneumatic	Tennis Launcher
Reliability	5	5	5	3	3	4	5
Speed	5	5	5	4	3	5	3
Manufacturability	5	4	5	5	2	1	4
Ease of control	5	5	5	5	3	2	5
Complexity	4	3	4	5	2	1	3
Price	3	1	2	3	4	4	1
Weight	3	1	2	3	3	5	2
Volume	2	1	2	3	1	5	3
Safety	2	1	2	3	2	4	5
Lifetime	1	5	5	5	3	2	5
TOTAL	--	122	141	140	93	111	127

Launcher. Our top concept for the launching function was the two-wheeled launcher. The main advantage to using a two wheel launcher is that it is relatively compact and easier to control. For

example, only two motors would need to sync up, as opposed to three. We went further with this two wheel concept and searched for several commercial baseball pitchers. A comparison chart is posted in Table 4 below.

Table 4: Comparison chart for commercial two-wheeled baseball pitching machines.

				
Brand	First Pitch	JUGS	Rawlings	Rawlings
Launcher	TW Fastball	TW	Spinball Wizard	Pro Line 2
Speed (BB)	105 mph	105 mph	105 mph	105 mph
Mass	129 lbs	150 lbs	59 lbs	59 lbs
Adjustability	None (comp.)	None (comp.)	Yes	Yes
Wheel Type	Pneumatic	Pneumatic	Solid	Solid
Safety	None	None	Rear guard	Rear guard
Price	\$1,729	\$2,200	\$1,600	\$2,100

We chose the Spinball Wizard from Rawlings because of its low cost and, most importantly, its adjustability. The back plate to which the motors are attached already has milled slots for adjusting the spinners for different ball sizes. This saves us enormous amounts of time in designing and assembling. An issue that may arise is that because we are using a commercial product, when we run into any problems it may take longer to debug and fix. It would be difficult to back trace the error. We also lose a bit of the interchangeability with feeding into the launcher because it comes at a predetermined size. Fortunately, feeding into the launcher is no longer user requirement we plan to meet and for the purpose of the design expo, we are fine.

Aiming: vertical angle. The next function is aiming. The aiming function further breaks down into three more sub functions: vertical angle, horizontal angle, and vertical translation. The Pugh chart for the first of three aiming sub functions is shown in Table 5 below.

Table 5: Pugh Chart for comparing concepts for adjusting elevation angle.

VERTICAL ANGLE						
		<i>Buy</i>	<i>Build</i>	<i>Buy</i>	<i>Buy</i>	<i>Buy</i>
CRITERIA	WEIGHT	Spur gears	Belts	Worm Gears	Lead screw	Harmonic Reducer
Reliability	5	4	4	5	5	5
Manufacturability	5	5	4	5	4	5
Ease of Control	5	5	5	5	4	5
Complexity	4	3	2	5	4	4
Price	3	3	5	2	1	1
Weight	2	1	4	3	4	5
Volume	2	3	3	4	2	5
Safety	2	4	2	4	4	5
TOTAL	--	107	106	123	104	124

For vertical angle, our top two concepts were worm gears and harmonic drives. Harmonic drives are very compact and lightweight. Because they are coaxial, we can confine all the transmission to a very small space. Their main advantage comes from the ability to severely limit backlash, thus preventing them from being back-driven. This is especially important for repeatability. Unlike a gearbox or belt system, however, harmonic drives are not easily accessible, and they are expensive. If we run into any issues, we would likely have to replace the harmonic drive entirely. Should that be an issue, we can fall back on worm gears, which will take up more space, but offer similar advantages in limiting the ability to be back-driven.

Aiming: horizontal angle. Our vertical angle and horizontal angle Pugh charts are very similar; however, this is a noticeable difference in the advantage of spur gears instead of worm gears. The Pugh chart for this sub function is shown below in Table 6.

Table 6: Pugh chart for concepts that adjust azimuthal angle.

HORIZONTAL ANGLE		Buy	Build	Buy	Buy	Buy
	Weight	Spur gears	Belts	Worm Gears	Lead screw	Harmonic Reducer
Reliability	5	4	4	3	5	5
Manufacturability	5	3	2	1	2	5
Ease of Control	5	5	5	5	1	5
Complexity	4	5	4	5	1	4
Price	3	5	5	1	3	1
Weight	2	4	4	4	4	5
Volume	2	4	4	3	1	5
Safety	2	5	4	4	4	5
TOTAL	--	121	110	90	71	124

For the horizontal angle adjustment, our top two concepts are now the harmonic drive (as before for vertical angle adjustment) and spur gears. The reason for this second place change is due to the effects of gravity being negligible. Before, the spur gears were more prone to error because the inertia and weight of the launcher could influence its repeatability, and even back drive the motor. With this sub function being in the horizontal plane, we only have to worry about spacing. Again, the harmonic drive's advantages and disadvantages carry over. We would save a lot of space and eliminate possible hysteresis effects compared to traditional gear setups. But cost could be an issue, along with availability if the parts were to fail.

Vertical translation. Our final sub function for this stage of the project is the vertical translation. The Pugh chart for this sub function can be found in Table 7, p. 19. Our top two concepts for the vertical translation were the lead screw and differential pulley. The lead screw's advantages are its reliability and precision. It is easy to repeat an elevation due to the linear nature of how the device converts rotational movement into linear movement.

Table 7: Pugh chart for adjusting vertical elevation.

VERTICAL OFFSET	Weight	Buy	Buy	Build	Buy
		Lead Screw	Rack and Pinion	Differential Pulley	Twisted Strand Actuator (TSA)
Reliability	5	5	4	4	2
Manufacturability	5	5	4	4	5
Ease of Control	5	5	5	5	3
Complexity	4	3	2	5	4
Price	3	2	2	5	5
Weight	2	5	3	5	5
Volume	2	5	3	1	1
Safety	2	5	3	4	5
TOTAL	--	123	97	120	103

Lead screws are also very compact, so they save volume. Additionally, they can handle large loads, such as the system of our launcher and the harmonic drives along with it. Some drawbacks, however, include their low efficiency, higher cost, and possible need for maintenance.

FINAL CONCEPT

For our final concept, we combined the top four sub concepts, using one per category. Our final concept incorporates a commercially available two-wheeled pitching machine, two harmonic drives (one for the vertical and one for the horizontal rotation), and a ball screw (for the vertical translation). Because this system is the least complex, in terms of numbers of moving parts, we expect to spend minimal time debugging any errors. Should a specific component fail, or should we learn that for some reason it is no longer feasible, we could replace that component with the next best sub concept per sub function. For example, if we couldn't acquire a harmonic drive, we could go with spur gears and our design would not be affected too significantly, sans the change in size and complexity. The major disadvantage to our final concept is the cost. We expected to spend over ten times the budget allotted for ME 450 which was possible through the support of the athletic department. A sketch of the final concept and a picture of our sketch model for the concept are shown in Fig. 9 on p. 20

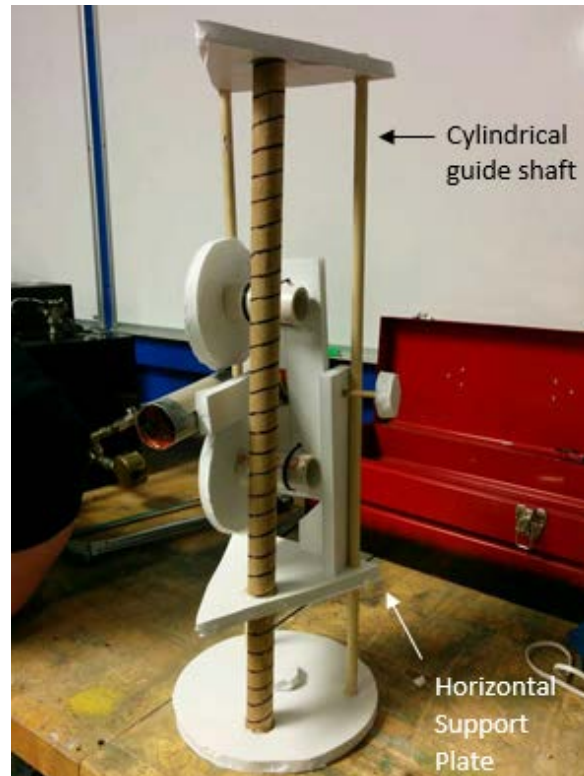


Fig. 9: Sketch model of final concept. Shown are the two-wheeled pitching machine, small cylinders that represent harmonic drive transmissions, and a lead screw

Following a meeting with Steve Donoghue, the construction project manager for the new facility, we were able to move forward with purchasing the commercially-available baseball pitching machine. The involvement of the commercial launcher means less flexibility with interchangeability, but we believe the time saved versus creating one from scratch is greater than the time that may be spent debugging issues that arise from using third-party hardware.

Concept Description

From our sketch model, we created a refined CAD model of our prototype, taking into account the information that we learned through the generation of our sketch model as well as through our engineering analysis. There were two major changes to our sketch model that are reflected in our refined design. The first design change is a result of our engineering analysis. We replaced the cylindrical linear guide shafts with T-slot extrusion linear slider shafts, as shown in Fig. 10 on p. 21

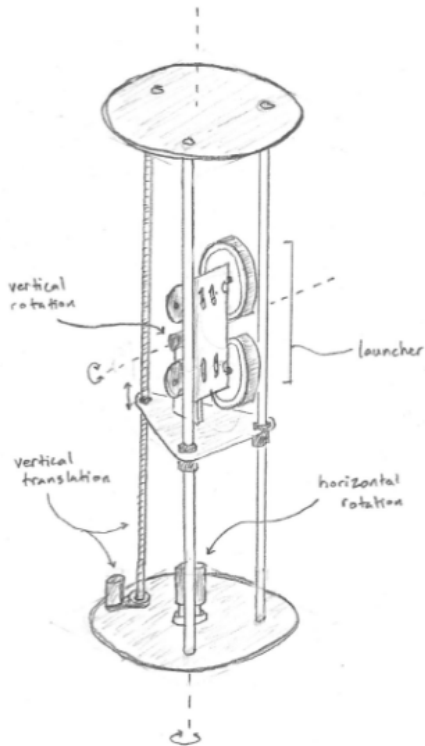


Fig 10a: Sketch of final concept.



Fig. 10b: CAD model of final concept.

Based on the engineering analysis performed to determine the stability of our design, we determined that the cylindrical linear guide shafts were not optimal to support the horizontal forces that would be seen when a ball is shot. Because of the offset between the launcher's center of mass and the lead screw which supports the mass, an unacceptably large moment is generated, which is not effectively resisted by the linear guides when mounted to a horizontal support plate. Linear motion guides are not intended to handle powerful torques, and the lead screw would experience greatly increased friction and wear. By placing a second linear bearing along each linear guide, the moment could be effectively countered by a lateral reaction force against each linear bearing, reducing friction and increasing stability. This is detailed in our engineering analysis section of this report. The T-slot extrusions, in combination with the vertical support plate, are much more suited to handle this torque load, and provide the additional benefit of being structural elements. In our first model, an additional frame would have been required to maintain alignment of the linear shafts and properly constrain their ends. The T-slot extrusions serve as the frame of the machine, as well as linear motion guides for vertical translation.

The other major design change that was made between our sketch model and our refined model was changing the translating support plate from a horizontal plate to a vertical plate as seen in Fig 10 on pg. 19. This change was made based on construction of our sketch. Once our model was dimensioned in CAD, it was clear that a horizontal support plate would interfere with the motors on the bottom plate. By reorienting this plate to be vertical, the launcher can translate

through its full range of motion. Besides that, the vertical support plate allows us to support the guide shafts closer to the launcher, which will reduce the moment force on the linear sliders, as well as facilitating the inclusion of a second linear bearing on each extrusion. This final concept has remained the same since DR 3; no significant changes have been made in the process of building our prototype. We achieved a perfect design “in the first shot” by making many small changes early on in the design process. Careful consideration was applied to each component and assembly while producing the CAD model, so that any potential issues were addressed before they occurred with the physical prototype. Thus, by the time the “design freeze” occurred during DR 4, any and all issues we might have faced had already been addressed. The final constructed prototype, as of DR 5, can be seen in Fig. 11 below.



Fig. 11: Final prototype of the launcher.

Motor selection for vertical rotation, vertical translation, and horizontal rotation were based primarily on the static loading characteristics of the launcher. Load dynamics were not considered because launch angle adjustment rates were not specified by our user requirements; to clarify, adjustment ranges (3-6 ft. vertical translation range) were specified, but adjustment speeds (e.g. 6 in/sec. vertical translation speed) were not specified. Because the ball screw offered the lowest mechanical advantage of all axes of motion (3.77 theoretical, versus 50 for the harmonic drives), the vertical translation was used to determine a baseline motor torque requirement. Another important consideration was low internal friction of the ball screw; while this imbues a high mechanical efficiency (~90%), it allows significantly large axial loads to back drive the ball screw. This necessitates a constant holding torque to maintain the pitching machine

at a constant height. Because of this, bipolar brushless DC motors (commonly referred to as stepper motors) were selected for all motion axes.

Stepper motors offer several advantages that make them extremely well-suited to this application. Due to their high pole count, stepper motors are typically operated in discrete rotational steps (hence their title) with an angular resolution equal to the number of poles, and because they are locked in-phase while powered, they exert a constant holding torque. The chosen NEMA 23 motors can move in discrete steps of 1.8° ($360^\circ/200$ poles), and exert a holding torque of 457 oz.-in. The stepping nature of their movement also allows for robust open-loop control of motion axes, eliminating the need for feedback sensors, such as encoders and tachometers. Although stepper motors require more complex driver circuitry, this additional cost was deemed acceptable due to their clear advantages. The selected NEMA 23 stepper motors and its bipolar stepper driver are shown in Fig. 12a and 12b, respectively.

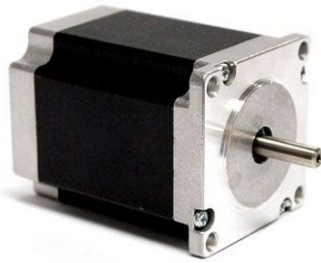


Fig. 12a: NEMA 23 stepper motor.



Fig. 12b: Bipolar stepper drive.

Once we had obtained the pitching machine for our final design, we were able to directly measure its relevant dimensions to create an accurate representation for our CAD model. The overall launcher assembly is composed of several sub-assemblies: the frame, the carriage, and the base. Because the pitching machine was an off-the-shelf component, exploded views have not been included; however, we have included exploded views showing the various components within each sub-assembly. The frame consists of the support plates and brackets, T-slot extrusions, and the drivetrain assemblies for vertical translation and horizontal rotation (including the ball screw and harmonic drive, discussed above). The carriage consists of large plate with attached T-slot rollers for vertical translation, as well as a harmonic drive and motor for vertical rotation of the pitching machine. The base fairly simple; it consists of swiveling casters (to allow for easy prototype mobility), tubular legs, and a turntable bearing system that allows the frame support plate to rotate relative to the base. Fig. 13a-13h (p. 24-25) show the finalized CAD model, along with exploded views for each sub-assembly discussed above. Note that fasteners have been omitted from exploded views for clarity.



Fig. 13a: Launcher CAD assembly.



Fig. 13b: Clockwise: carriage, frame, and base sub-assemblies.



Fig 13c: Carriage assembly.

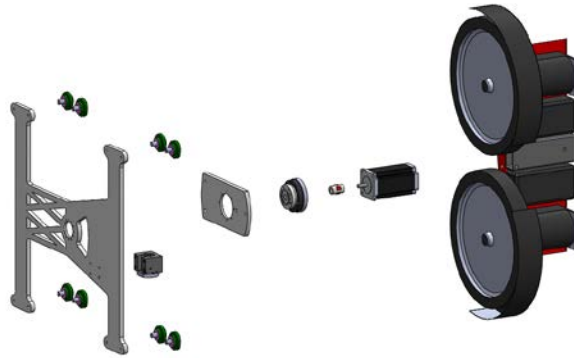


Fig 13d. Exploded carriage assembly.



Fig. 13e: Frame assembly.



Fig. 13e: Exploded frame assembly.



Fig. 13g: Base assembly.



Fig. 13h: Exploded base assembly.

Additionally, detailed engineering drawings for all manually-manufactured (i.e. non-CNC) components can be found in Appendix C.

Controls - Hardware

We actually use several different programs running at the same time to control our machine. We also use several components. The first component is the Arduino UNO microcontroller. We flashed GRBL firmware on to the Arduino to enable it to run with g-code compatible software. As a result, we lose the ability to code in Arduino's native language. However, our machine is now able to run as if it were a CNC machine. A flow diagram of the controls hardware can be seen in Fig. 14, below.

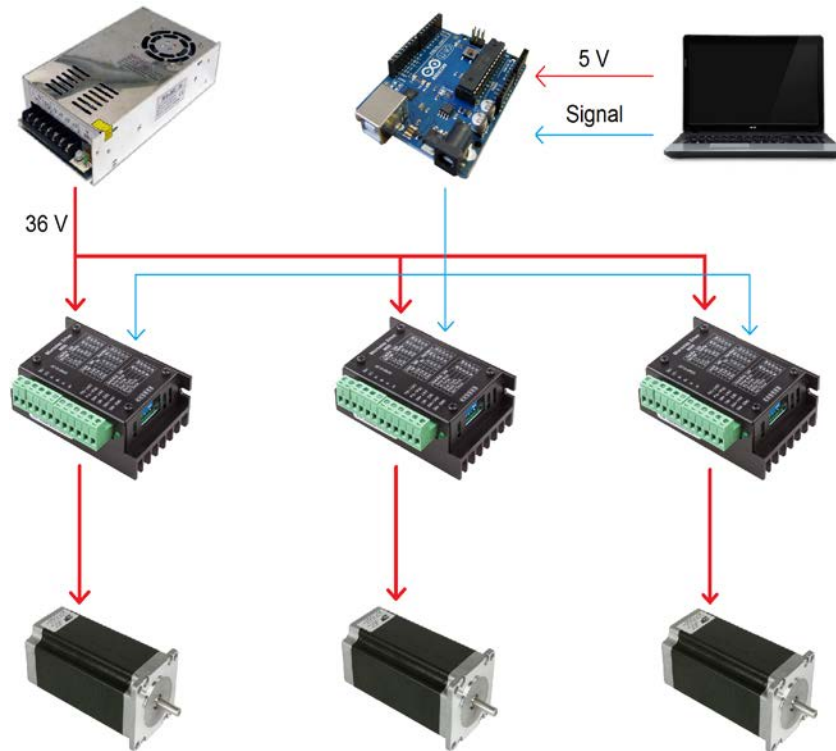


Fig. 14: Schematic of motor control

From the Arduino, we jump into the second component, the DM542A motor drivers. From the drivers, we connect to the NEMA 23 Stepper motors. We also have a 36 V power supply running to the three drivers as well. On the other end of the Arduino is the connection via USB to a laptop running the appropriate software. Fig. 15, below, contains the pinout diagrams of the Arduino and motor driver:

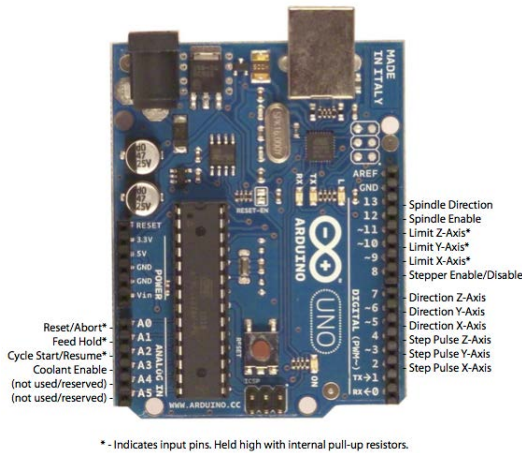


Fig. 15a: Pinouts of Arduino chip.

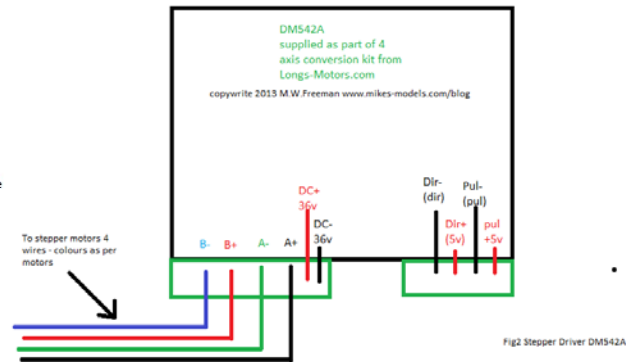


Fig. 15b: Pinouts of motor driver.

Each motor driver gets designated to an axis of motion. For example, Arduino Pin 7 (Direction Z-Axis) would connect to the Dir+ pin on the driver. We had wires for the 3 axis' direction and step pulses, ground, and two limit switches.

Controls - Software

On the software side of things, we ran three programs concurrently: The g-code software UniversalG-codeSender, a script compiler HotKey, and a controller mapping software Joytokey. We chose to go with UGS, because this software allows you to cycle through the motors in any step size you choose with a keyboard stroke, i.e. the arrow keys. This made debugging and executing very easy. In the command tab, you can send specific g-code commands to the Arduino which will pass them accordingly to the drivers for operation. The code "G90 G0 X0 Y0 Z0" for example, instructs the machine to return to its established origin. Initially, we ran through the various parameters revealed by typing "\$\$" into the command bar and adjusted the velocities, accelerations and feed rates accordingly. Once those were finalized, we were able to cycle through a specific distance using keyboard strokes.

Manual Inputs

For the purpose of Expo, we thought it would be a good idea to run the machine with human input via a game controller. We used both a Playstation 3 controller and Xbox 360 controller, but both required specific setup instructions that can be found online in numerous tutorials. We'll continue our breakdown using the 360 controller as an example. Using the software Joytokey, we

were able to set certain inputs sent to the controller (i.e. pressing Up on the 360's digital pad) to a keystroke from the keyboard (translating to pressing up the Up Arrow key). This way we could design our game controller scheme around UGS preprogrammed controls. We also mapped other buttons to specific g-code commands. A diagram of the controller layout can be seen in Fig. 16, below.

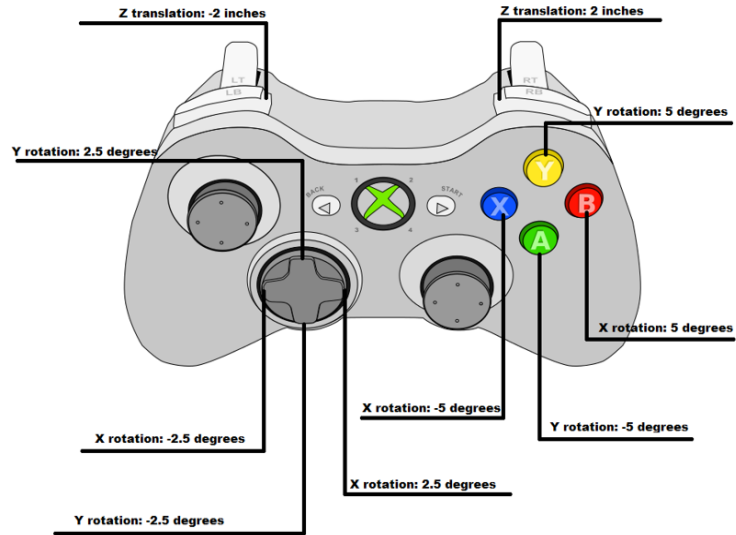


Figure 16: Manual control through Xbox360 controller

However, we needed a third program that translated single keystrokes from a keyboard into a full string, followed by an enter command. This is where HotKey came in. Eventually, we had things set up so that pressing A on the 360 controller mapped to an S keystroke from a keyboard. HotKey then reads that S from the keyboard and inputs `G91 G0 Y-5{Enter}` into the command bar of UGS which ultimately pitches down the launcher 5 degrees.

Autonomous Mode

In the last few days before Expo, we were finally able to figure out how to work with autonomous control. By entering the following three lines: `G91 G0 Y27.792{Enter} G0 Z18{Enter} G92 X0 Y0 Z0 G90{Enter}` into the command bar when the machine is initially in its powered down position (all the way on the ground, pitching downwards), the machine will first correct its y position, then its z position, and treat this neutral configuration as its origin. In our script we have this mapped to Alt+Home, as a hacked homing function. From then on, sending a command to UGS in the form of `G90 Xa Yb Zc` will send the launcher to coordinates (a,b,c) moving all axes simultaneously. Therefore, you can load a text file with a list of coordinates and use the File Mode tab in UGS to make it run said preplanned coordinates.

Adding $g4 p.x$, where x is in seconds, will pause the machine in between coordinates, allowing a ball to be fed in time before its next move. This could prove to be very useful for future teams working on integrating a feeding mechanism.

It is important to note that we did not program for jumping between the two methods of control to be implemented. Cycling through with the *Manual Input* keystrokes will reset the machine's default origin, rendering *Autonomous Mode* obsolete. You will have to power down the machine, let it fall to its stable, powered down position and rehome the machine.

ENGINEERING ANALYSIS

The engineering analysis we performed on our final concept addressed four primary design drivers: being able to aim the launcher over a variety of angles and heights that cover the entire practice facility, being able to launch a lacrosse ball at the required top speed, and being stable throughout the process of moving the launcher and launching the ball. For determining the angles we need to cover, we mostly relied on kinematics to calculate potential launch trajectories of the lacrosse balls. To determine the torque requirements necessary to launch a ball at the required speed, we used classical dynamics. And finally, we relied on static force analysis to determine the reaction forces that will occur within the machine during use, and thus to evaluate its stability. Once we had the commercial baseball pitching machine in our possession, we also employed empirical testing to determine how well it meets the speed requirement compared to our theoretical analysis, and how repeatable (with regards to accuracy) its launches are.

Launch Trajectories

Our engineering specifications state a specific range of angles for both the horizontal and vertical directions of the launcher: ± 30 degrees for the vertical plane and ± 60 degrees for the horizontal plane. There is also a three feet range required for the vertical translation. We wrote a script on MATLAB that utilizes kinematic analysis to draw the various trajectories fired at these positions. In Fig. 17 p. 29, we have a side view and top view of the plotted trajectories with the axis confined to the dimensions of the practice room.

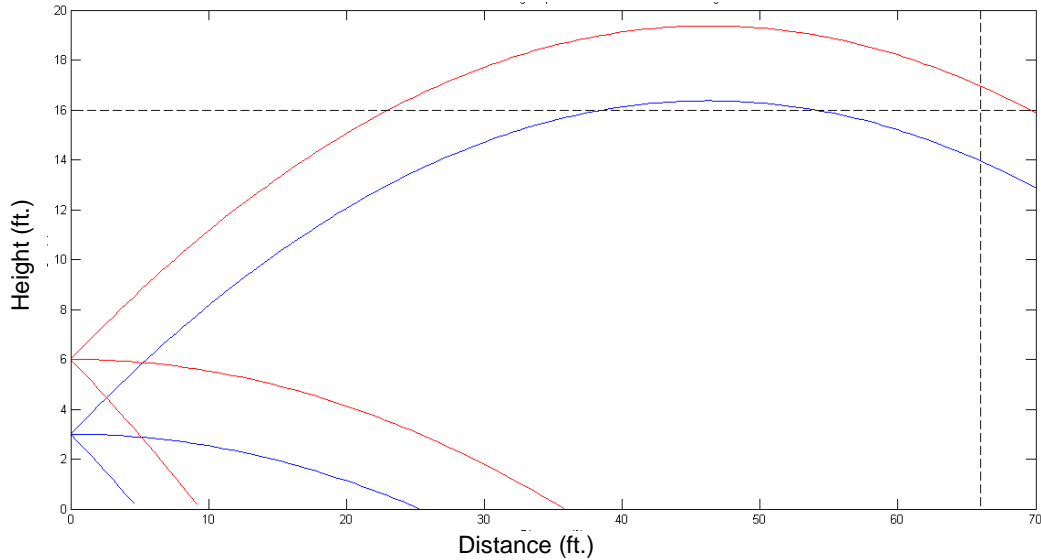


Fig. 17: Launch trajectories at 3ft. and 6ft. at 40 mph.

The curves branch out from a minimum height of 3 feet and maximum height of 6 feet. Each initial height spawns three additional curves for positive 30, 0 and negative 30 degrees at a speed of 40 mph. To calculate the trajectories we used the following kinematic equations:

$$d_y = v_{0y}t - 0.5at^2 + y_0 \quad d_x = v_{0x}t \quad v_{0x} = v_0 \cos\theta \quad v_{0y} = v_0 \sin\theta \quad (\text{Eq. 1, 2, 3, 4})$$

Reaction Force at Speed

For determining the force required to accelerate the ball to its achieved speed, we applied the principle of conservation of momentum (Eq. 6, below). Because we did not have the launcher physically available, we had to make several assumptions. First, we found a manual for the commercial launcher online, and estimated the diameter of the spinning wheels by scaling up the 3” tube listed in the instructions. We estimated the radius to be 5 in., or 0.127 m. Then we applied a simple motion tracking to commercial footage of the launcher posted on the company’s YouTube page. By counting the frames, we were able to find a Δt of about 0.0417 s. The footage we used had the launcher set at about 60 mph, or 27.3 m/s. We can plug this into Eq. 9 and the result is a force of 95 N. Using the radius we estimated earlier, we calculated a torque of about 12 Nm. Using this reaction force, we can continue evaluating the stability of our frame.

$$J = F \Delta t \quad \Delta p = m_f v_f - m_i v_i \quad (\text{Eq. 5, 6})$$

$$\Delta t = \frac{\text{frame}_{\text{end}} - \text{frame}_{\text{start}}}{24} \quad T = F \times r \quad F = \frac{\Delta p}{\Delta t} \quad (\text{Eq. 7, 8, 9})$$

Stability

In order to evaluate the stability of our design, we analyzed the main carrier frame using static techniques. Specifically, in order to consider the machine “stable”, we want to ensure that there isn’t any net bending moments occurring in the frame during its use. The first step in this analysis was to draw a free body diagram (FBD) of the frame plate, which is shown in Fig. 18 below. The FBD shows where the forces acting on the frame act, and give the relevant dimensions of the frame. The launching mechanism is not part of the free body, but it is shown transparently for reference.

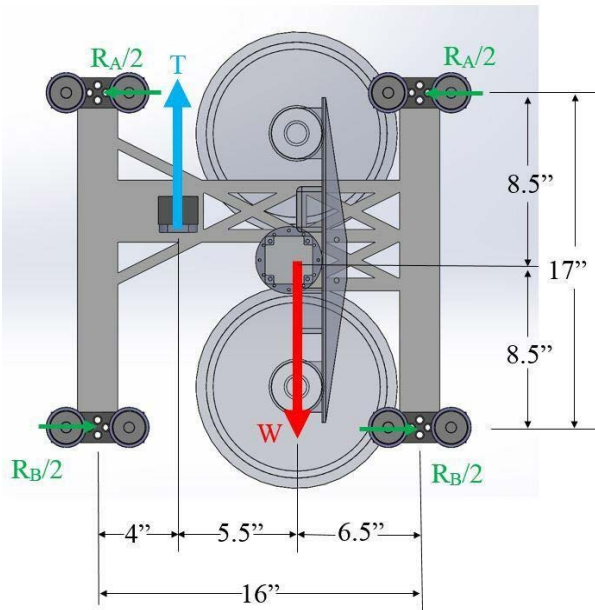


Fig. 18a: FBD for frame when not operational.

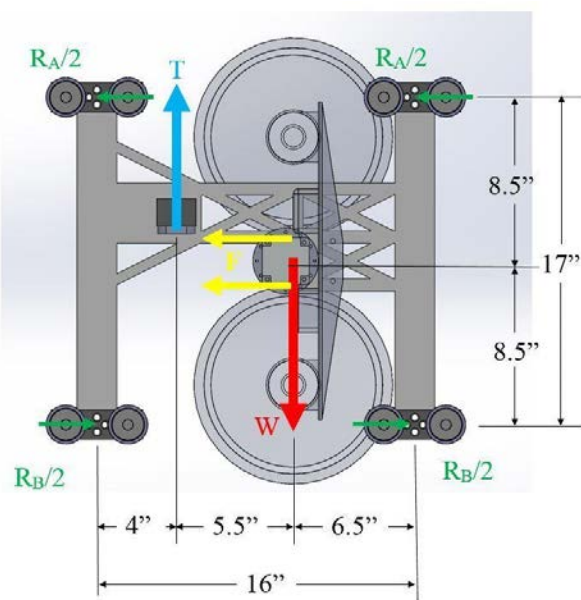


Fig. 18b: FBD for frame, mid-launch.

As shown above, there are two different scenarios possible: when the machine isn’t launching a ball, and when it is. When the machine launches a ball, there is a reaction force present as a result of imparting force to the ball, and this changes the resulting reaction forces in the supports.

The principles we’ll use here are that a moment is given by the cross product of a force and the lever arm over which it acts, and Newton’s second law of motion, for both forces in a single direction, and moments about a rigid body. These formulas are given by Eqs. 10, 11, and 12 below:

$$M = F \times l \quad \sum F = ma \quad \sum M = I\alpha \quad (\text{Eq. 10, 11, 12})$$

In these equations, M is the applied moment, F is the applied force, l is the lever arm of the applied force, m is the mass of a body, a is its acceleration in a given direction, I is the moment

of inertia of the body, and α is the body's angular acceleration. If we want zero net moment in the frame, then $\Sigma M = 0$, thus it follows that $\alpha = 0$ as well. We also want the linear acceleration in the horizontal direction to be zero. Knowing this, we can use these equations with the known weight of the launcher to determine what the reaction forces in the supports will be.

The launcher is listed as being approximately 60 pounds, including the legs, and from our SolidWorks model, we determined that the aluminum mounting plate will weigh about five pounds. Thus, we decided that an overestimate for the total weight (marked W on the FBD) is about 75 lbs., or about 333 N. The maximum possible thrust from our chosen stepper motor (marked T on the FBD) is about 1500 N, so we should easily be able to move the launcher up and down in the vertical direction. Using these numbers and the dimensions in the FBD shown in Fig. 14a, we calculated that the reaction forces on the top supports and bottom supports will both be 107.7 N, or approximately 25 lbs. Each load will be split between the two supports, so we decided to use supports that are rated for a load of 25 lbs. each so a safety factor of two is incorporated into our design.

The FBD of the frame is slightly different when a lacrosse ball is being launched, as shown by Fig. 18b. Based on the calculations of torque required to launch a lacrosse ball at a given speed (discussed above), we determined that the force imparted to the ball (and thus the same force experienced by the frame based on Newton's third law of motion) will be 94.9 N. Working this into the same calculation performed before, the new loads will be 60.3 N split between the top two supports, and 155.2 N split between the bottom two supports. The greater force occurs at the bottom supports, and works out to be about 35 lbs. between both supports. Each support therefore has a safety factor of 1.4. Because this calculation is based on an overestimate of the weight of our launcher, it won't be as close in practice as the calculation seems to show. Also, this is a dynamic load, and it will occur over very small time periods, so the frame won't be constantly loaded in this manner. Thus, we've decided that the support rollers we've chosen are more than sufficient for our needs.

Empirical Testing

Once had obtained the commercial baseball pitching machine, we were able to test the machine to determine how well it meets our requirements. We tested the machine in Oosterbaan Fieldhouse, an athletic facility at the University of Michigan. We made use of the net-enclosure batting cages used by the baseball team to contain our launches, and prevent any potential accidents involving the teams that were practicing in the Fieldhouse during our tests.

Setup procedure consisted of physically setting up the launcher, powering it via a standard 120-volt wall outlet, and positioning approximately 10 yards from a provided lacrosse goal. The machine was turned on, and the launcher wheels brought to a steady speed. To evaluate how precise the launcher's shots were, we made use of a video camera to record repeated shots from

different camera angles. Video recordings along the line-of-sight of the launcher helped us to evaluate the launcher's accuracy, and isometric angles that showed the entire test setup helped us gauge the launch speed. As we observed the testing, all of the shots hit repeatedly within a small area of the goal, consistent with where the machine was aimed. Thus, we judged that the precision of the launcher is sufficient for our needs. A picture of our testing setup can be seen in Fig. 19.



Fig. 19: Launcher test setup. Goal is approx. ten yards from launcher, both enclosed in batting cage net.

We performed initial tests with the launcher at its initial setup, using the original factory settings. Specifically, each launcher wheel was initially four notches out from the innermost notch, which was the default setting for use with baseballs. However, we found that this setting was ineffective for lacrosse balls, because the launch speed was much lower than we calculated; an approximate time/distance speed calculation using a stopwatch resulted in a speed of about 50 mph. To account for the lacrosse ball's smaller diameter, the launcher's compression space had to be reduced to increase traction between the ball and the wheel, increasing launch speed. The compression space was reduced by one notch (approximately 0.25 in.). The resulting speeds were too fast to be accurately measured with a stopwatch (due to the latency of human reaction times), which made us confident that the new setting greatly increased launch speed. The adjusting notches for the motors on the launcher are shown in Fig. 20, p. 33.



Fig. 20: Notches allow wheel spacing to be adjusted to accommodate balls of various sizes.

Since DR 4, we were able to obtain a radar gun that allowed us to more accurately measure the speeds of the launched lacrosse balls. We repeated the empirical testing, and determined that the speeds from the launcher were still not fast enough to meet our user requirements. Thus, we again adjusted the wheels, bringing the top wheel one notch closer to the center (again, reducing the compression space by approximately 0.25 in.). With this setup, we measured that the launcher consistently fired balls at about 75 mph when the motors were running at maximum speed, which is fast enough to meet our user requirement for speed.

Validation Protocol

Due to the nature of our user requirements, most of them can be validated simply through observation. Specifically, now that our motors have been programmed and implemented, we can validate our user requirements for vertical travel, elevation angle range, and azimuthal angle range by operating the prototype and observing how far it can move. The vertical travel requirement can be validated by measuring the range of vertical travel with a tape measure. Similarly, the elevation and azimuthal angle ranges can be measured with a protractor while operating the machine. For the elevation angle, we also have hard stops and limit switches implemented that will prevent the machine from over rotating and possibly damaging some of its components. For the azimuthal angle, we actually have exceeded our requirement because the requirement assumed that the device would be built into a wall. Since our prototype is free-standing, it actually is free to make complete 360° rotation, which is more than our requirements specified. These observational tests will also allow us to verify the programmability of our device. We want to evaluate its limits by utilizing the motors we've implemented and the programs we've worked with to control them, rather than moving the machine by hand. Thus, if

the requirements for travel can be met via the motors, then the programmability requirement will also inherently be met. Visuals detailing our travel validation for the final prototype can be seen in Fig. 21, below.

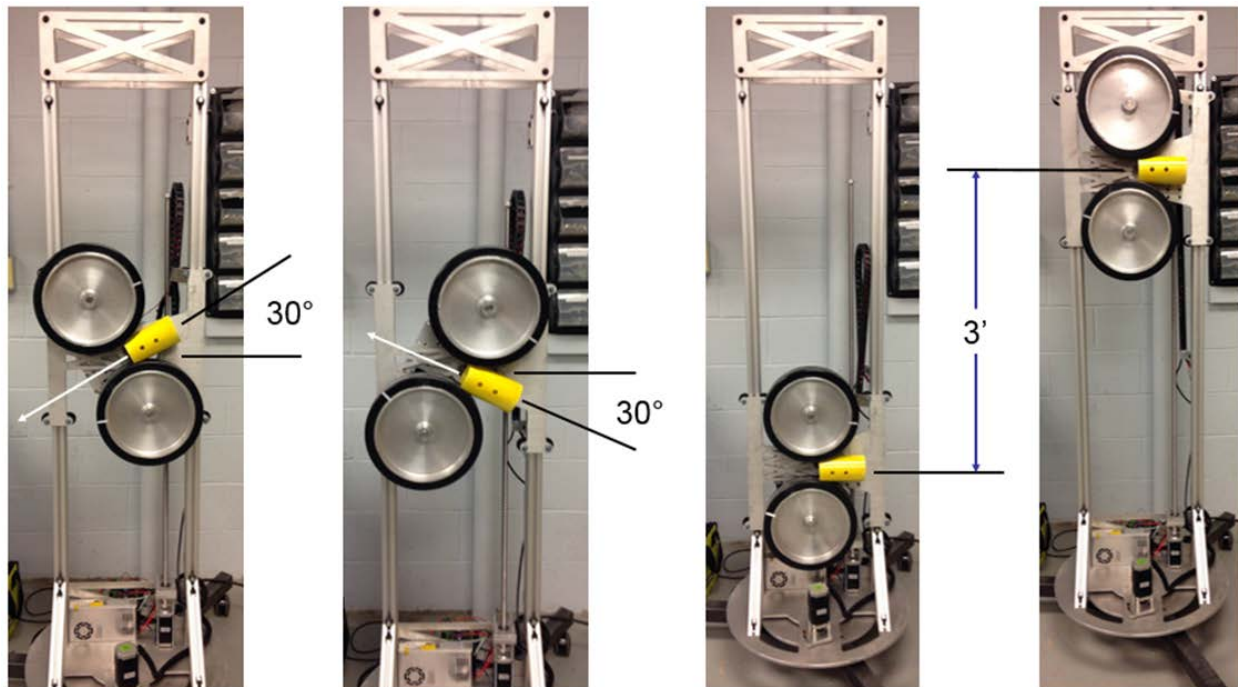


Fig. 21: Validation included measuring travel ranges for elevation angle and vertical travel, shown above. The ranges measured meet our engineering specifications.

Our top speed requirement has already been validated by our empirical testing, described above. This top speed should be unchanged from building the prototype because no alterations were made to the launcher itself. Due to the infeasibility of transporting the finished machine to Oosterbaan Fieldhouse, it is unlikely that we'll be able to perform more empirical testing there. However, if we can get approval to test the machine on north campus, we will be able to verify that the top speeds have remained the same by again measuring launch speed with our radar gun. Because of the mismatch in ball types used for the machine, we will also compute the proper correlation for set speed on the launcher to actual, verified launch speed of the lacrosse ball.

FAILURE MODES AND EFFECT ANALYSIS

In order to ensure that we've addressed potential risks associated with the design concept we've chosen, we performed a Failure Modes and Effect Analysis (FMEA) on our chosen concept. This method ensures that we've examined potential ways the components in our design could fail, that we've considered the consequences should any of these failures occur, and that we've taken the necessary steps to reduce the possibility that any of these failure modes will occur. The results of this analysis are shown in Appendix D.

The component of our chosen design that has the highest risk is the launcher wheels, which has a Risk Priority Number (RPN, which takes into account the severity and probability of the failure, as well as how likely we would be to detect it) of 28. The failure of this component earned 7 out of 10 for the severity scale because if the wheel tread gets worn down, it won't be able to impart the top speed we need to the lacrosse balls. This constitutes a degradation of the primary function of the component. Additionally, this issue would be difficult for us to detect before it reaches the consumer because the wearing down of the tread on the wheels of the pitching machine will likely occur over an extended period of time. However, a difference of only one or two miles per hour in top speed is unlikely to be readily detectable by a lacrosse player, so we determined that the likelihood of detection for the problem would be 4 out of 10.

It was also reassuring that the failure mode is highly unlikely to actually occur. The pitching machine that we are implementing in our final concept includes a five-year manufacturer's warranty, so we can expect the wheels to work as desired for at least five years. This caused us to assign a score of 1 out of 10 to the occurrence score for this failure mode. Additionally, should failure occur, the safety of the players wouldn't be put in jeopardy; the machine would just require maintenance to replace the wheels. This would be more of an annoyance than a serious problem: replacement parts are readily available, and the machine would just have to be taken out of commission for a short time while the wheels are replaced. These facts, combined with an RPN of less than 30, have assured us that the risk associated with our chosen concept is at an acceptable level.

MANUFACTURING PLAN

In order to effectively manufacture our lacrosse ball launcher, we developed manufacturing plans for the parts of our design that needed to be fabricated. These manufacturing plans are detailed in Appendix E. Due to time constraints, we have attempted to limit the amount of manufacturing that that was necessary, and instead buy many of our components off the shelf. A full list of all of the components in our design, both fabricated and bought, is shown in our Bill of Materials in Appendix F. The majority of our fabricated parts were initially cut on the water jet. The water jet was used to cut each piece to the desired profile, and then the mill was used to drill holes in the fabricated parts. The combination of the water jet and mill was ideal for our design because the water jet is the fastest and most accurate tool to cut intricate shapes in metal, and the mill is the most accurate way to drill holes in our parts. We do not currently have a plan to mass manufacture our design. Our project is meant to be a state of the art design that is custom built for the men's lacrosse team. Because of this, it is not relevant to propose a plan to mass manufacture our design.

DISCUSSION

Overall, our prototype performed excellently, and not only met our design requirements (discussed above in the Empirical Testing and Validation Protocol sections, p. 31-34), but

exceeded our performance expectations. At the design expo, it was a hit with many groups that saw it: interested parents enjoyed hearing about it, while students on field trips for high schools and students here at the University enjoyed testing it themselves with protective equipment, a crosse, and a net. The design expo also allowed us to reflect on our chosen concept. We were able to evaluate its strengths and weakness, and how we addressed the weaknesses, in addition to what future work remains for the project in coming semesters.

Prototype Strengths

The biggest strength that our prototype exhibited was how it met all of our design requirements. It was fully functional at design expo: We were able to launch balls (we used whiffle balls instead of lacrosse balls as a safety precaution, but a quick modification allows it to fire lacrosse balls instead) at varying speeds, and aim through a wide range of elevation angles, azimuthal angles, and launch heights. The machine was incredibly stable and its aim was incredibly repeatable, and we were even able to program routines that it could run automatically, in addition to being manually controlled with a laptop and Xbox 360 controller. Team members and spectators at the expo thoroughly enjoyed experiencing it firsthand; lacrosse equipment, lent to us by the team, was used to simulate the practice conditions that the machine will eventually be used for, and it was a huge success. Joe Hennessy, a representative of the team, was present to observe, and he told us that he's extremely excited to see it work, and to see the first step taken toward making the team's vision of their new facility a reality.

Prototype Weaknesses

There were, however, some weaknesses to our chosen design that we addressed throughout the process as they occurred. One such weakness was that the G code that we used to program the controls for our machine was a language that was unfamiliar to our team. Thus, we had to learn how to use G code as we implemented it, which involved much more work than would've been necessary had we been able to use a familiar programming language. The additional work was well-worth the result, however. Once the controllers were successfully programmed, the G code made precise control of the machine extremely easy, and allowed easy programming of preset launch locations that could run automatically, without user input.

Another weakness with our design came from the fact that the stepper motors we used to drive the launch locations can only exert a holding torque when they are powered. The result of this, which we experienced firsthand, was that when the power to the machine was cut, it would tend to relax under its own weight, and its vertical position would sink to the bottom of the frame because of the extremely low friction at the ball screw. This could cause a safety hazard if someone were tinkering with the controllers or parts below the launcher, and were in the way of the machine as it moved down. However, the danger associated with this isn't as grievous as it may seem. The stepper motors exhibit a back EMF when they are back driven, as is the case when the launcher sinks down the ball screw. This back EMF briefly allows the motor to exhibit

its holding torque, which then ceases the back driving for a moment. This then repeats until the launcher has come to rest on the hard stops we implemented to prevent it from damaging the equipment at the base of the frame. As a result, it doesn't free-fall when power is cut, it actually falls slowly, and in discrete steps. So if power is cut while someone is working at the base of the machine, they might be startled by its sudden movement, but they would have ample time to move out of the way, and prevent injury. Additionally, this hazard wouldn't occur for the final version of our design, which will be implemented behind a wall. It only poses a problem for our prototype, where the frame is exposed.

To mitigate this danger during the design expo, we designed an emergency stop procedure that doesn't actually cut power to the device. Instead, the emergency stop consisted of removing the USB cable that supplies power to the Arduino board and stepper motor controllers. Cutting power to the controllers ensures that the aiming motors stop running, so that the launcher stops moving, but the stepper motors still provide holding torque to hold the launcher in place. This allows us to prevent the machine from moving if there's a problem, like someone being in the way of the machine, without imposing the additional danger of it being back driven as a result of the launcher's weight. Additional mitigation came in the form of signage making it clear to bystanders not to touch the machine, or to be anywhere close to it while the machine was in motion.

One final weakness in our design involved the spinning wheels on the pitching machine. Because of the inertia of the wheels as they spin, they don't immediately stop when power is disconnected from the device. Again, signage warning users against touching the machine should mitigate any danger, but having a physical brake system to slow the wheels down more quickly could help reduce risk associated with the moving parts. However, such brakes aren't available on any commercial pitching machines, and therefore would have to be designed later on in the project timeline as future work.

Recommendations and Future Work

As discussed above, for the purposes of this semester, we limited the scope of our project to aiming and launching lacrosse balls. This leaves the other functions of the project to future ME 450 groups, or to the engineers and architects who will be implementing the final machines into the lacrosse facility. These functions include collecting, storing and transporting balls to the launcher, and final programming with design of a user interface.

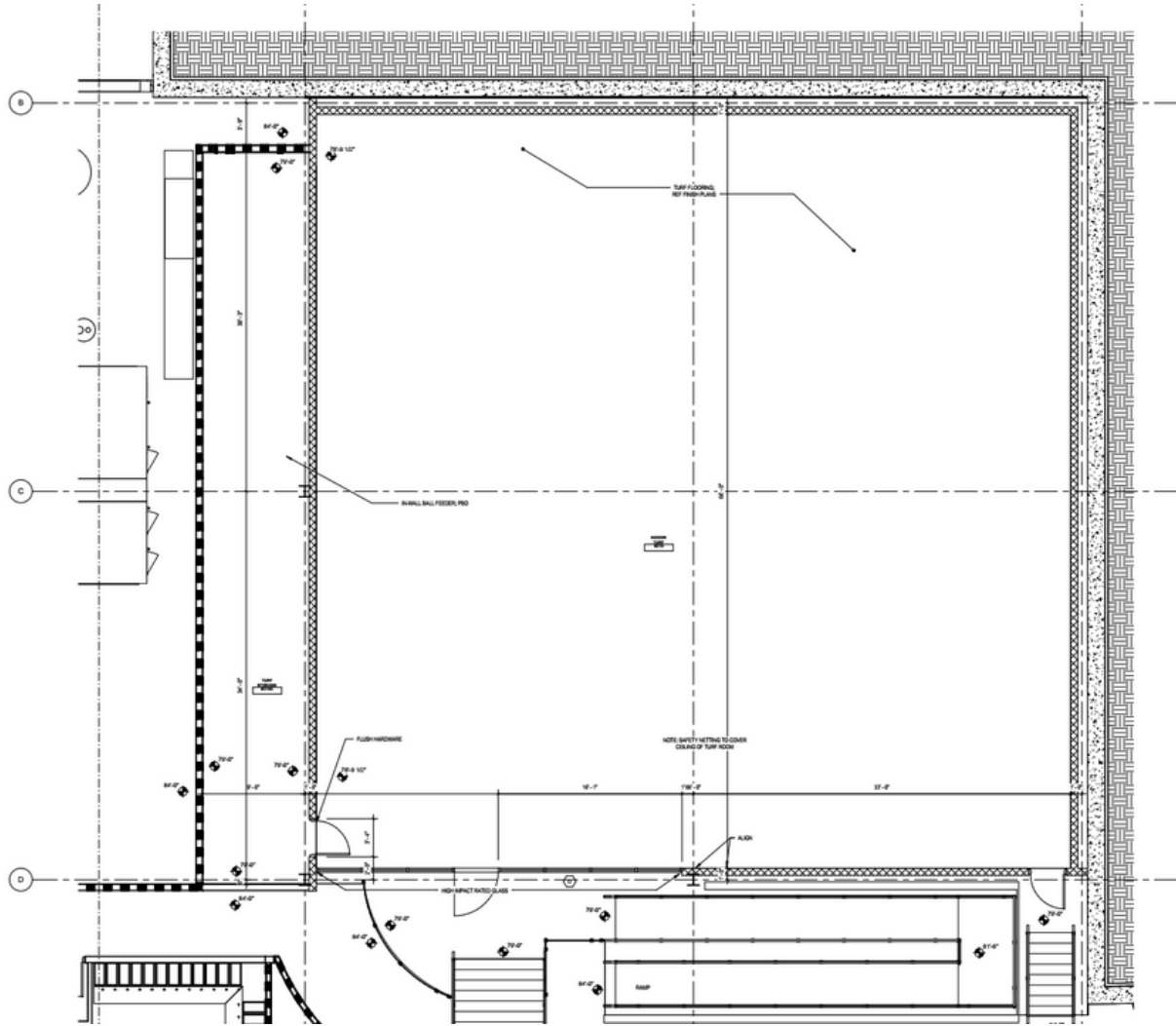
Both of these aspects would be useful for the design because they would remove the need for operators to be anywhere near the machine. For the purposes of our prototype, a team member had to stand next to the machine and feed balls in by hand, while another team member had to control the machine (unless a program was compiled and run, which we were able to do). Having an automated hopper system would prevent the need for a person to feed the machine by hand,

which would ensure that it could be used by a single person, and mitigate some of the danger associated with standing near heavy moving parts. This is likely a solution that can be explored by another ME 450 group that can then be extrapolated to a large enough size to be implemented into the practice facility. Similarly, a CE or EECS design team could design a workable user interface that would allow a single player to set up the machine automatically from remote location, which could then be implemented into the practice facility as well.

Regarding our current prototype, the main recommendations are that it shouldn't be used for individual practice without having some sort of protective screen or wall around the device, and at least one other person should be present to either control the device, or stop it in the event of an emergency (in addition to loading balls into the machine, addressed above). The prototype is a proof-of-concept for a machine that will eventually be built into the wall of a practice facility, but for the purposes of this course, our prototype had to be somewhat movable. Thus, it couldn't be built behind a wall that would prevent users from being subjected to potentially dangerous moving parts. We included warning signs to alert users to this possible danger, developed an emergency stop procedure, and never used the device alone to mitigate the risks associated with the machine. Thus, if the team plans to utilize the machine, they should follow the same safety procedures we did to prevent any accident or injury, at least until a protective barrier and remote stop can be implemented by future teams.

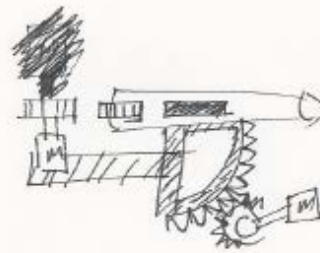
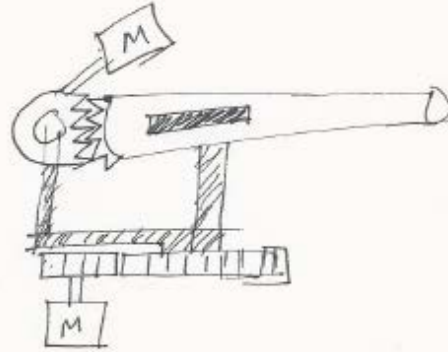
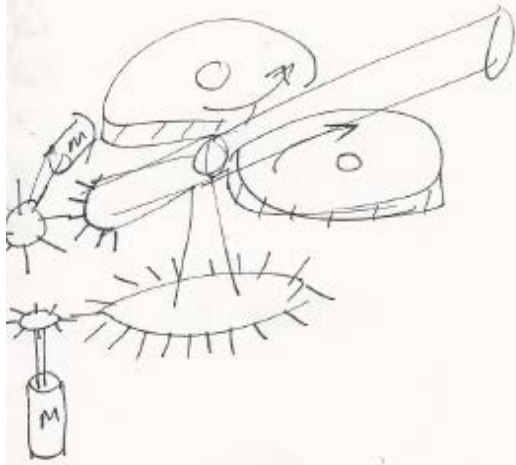
APPENDIX

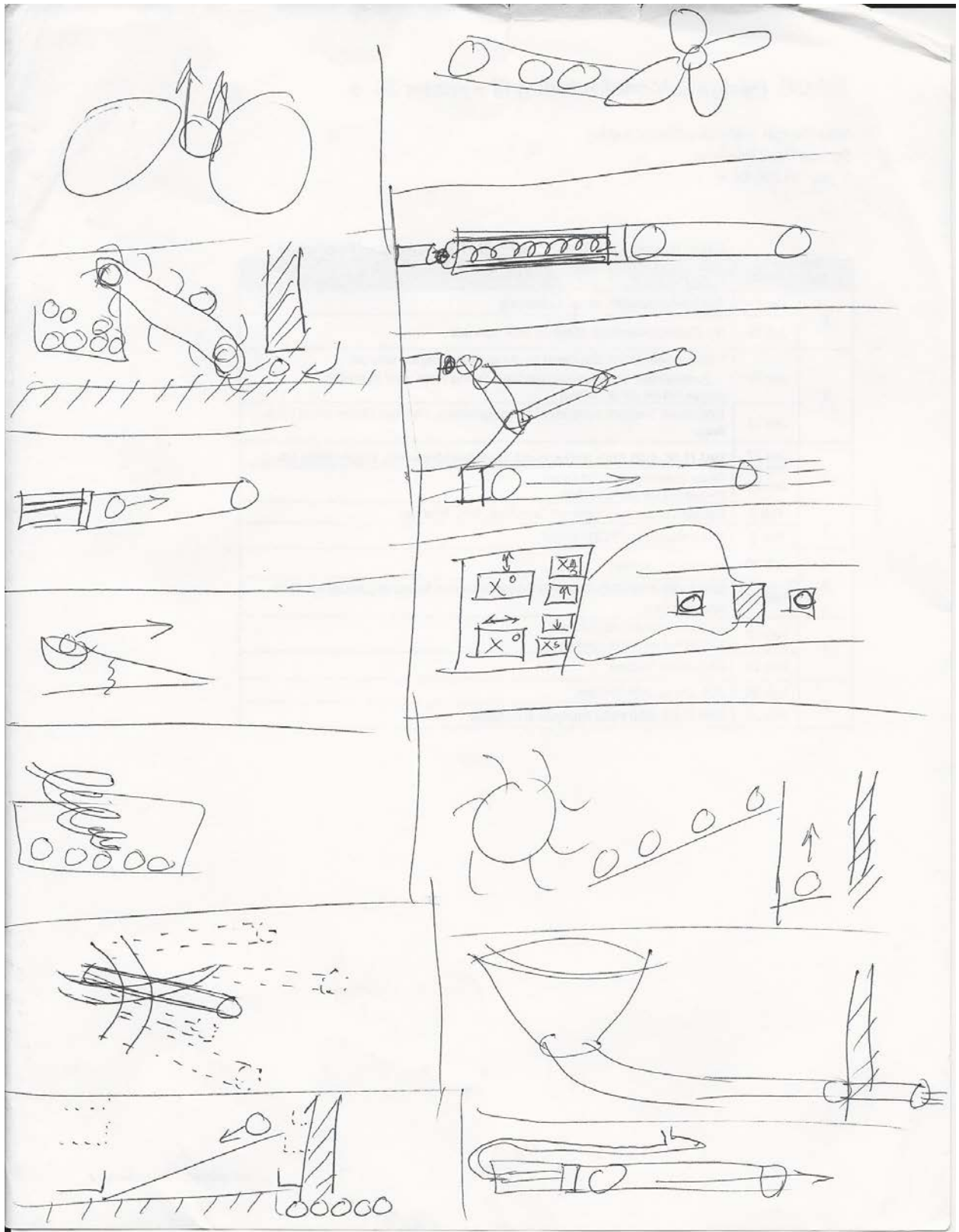
A. Architecture Plans



B. Generated Concepts

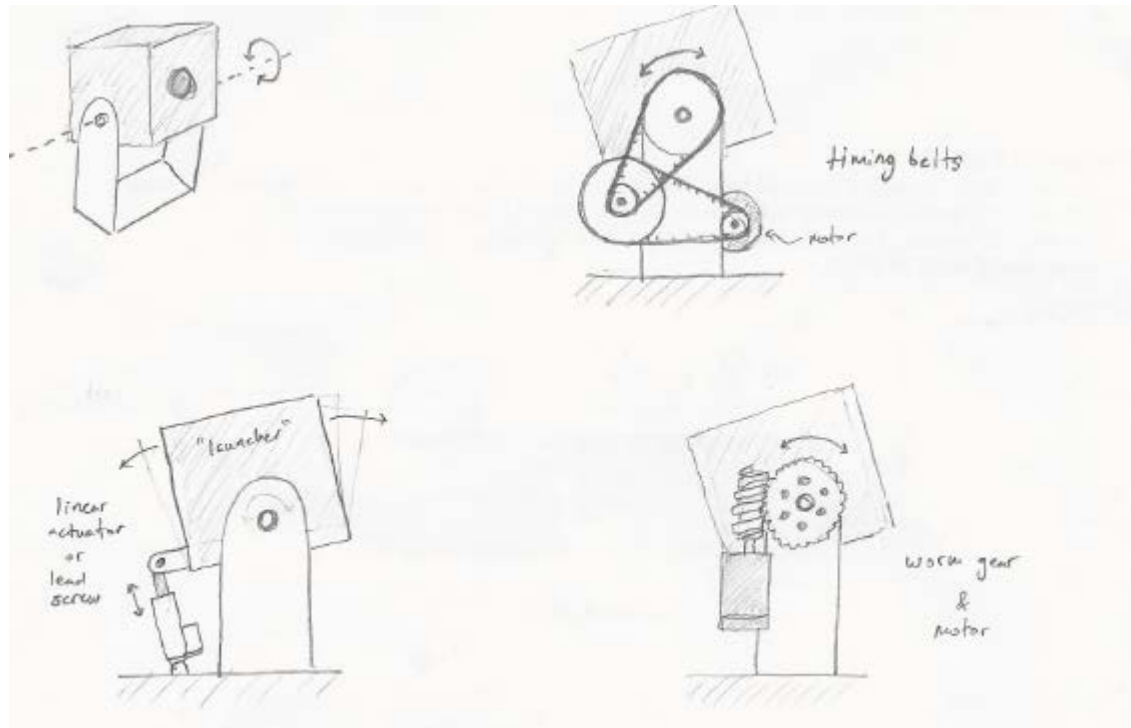
Brainstorming Concepts



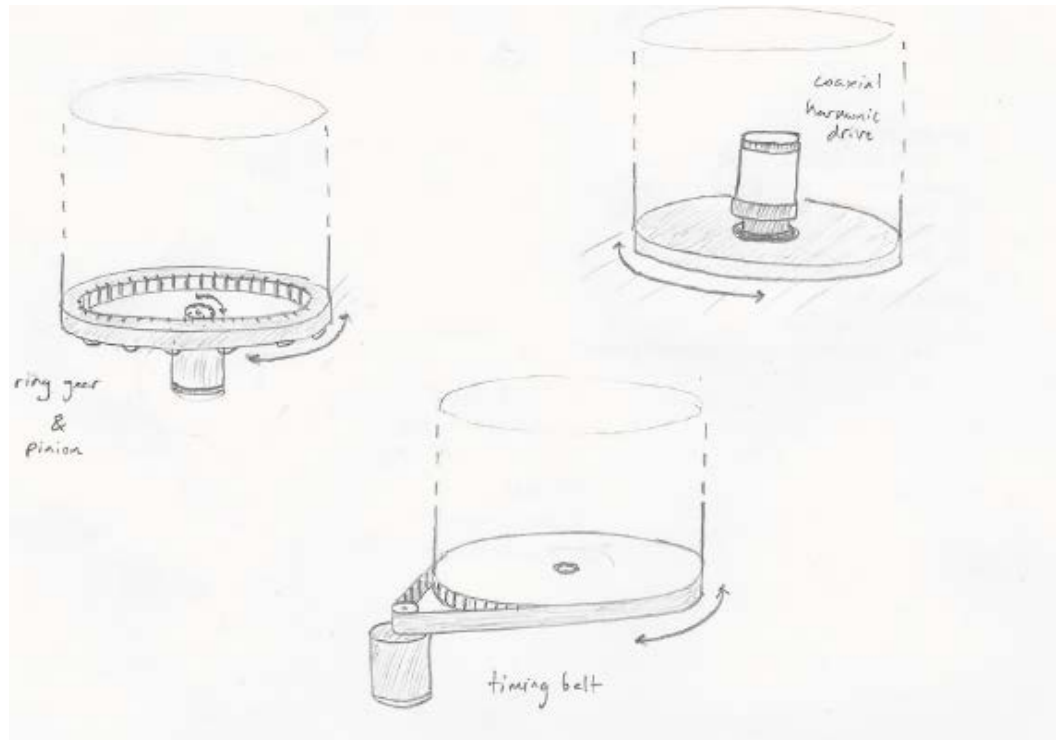


Functional Decomposition Concepts

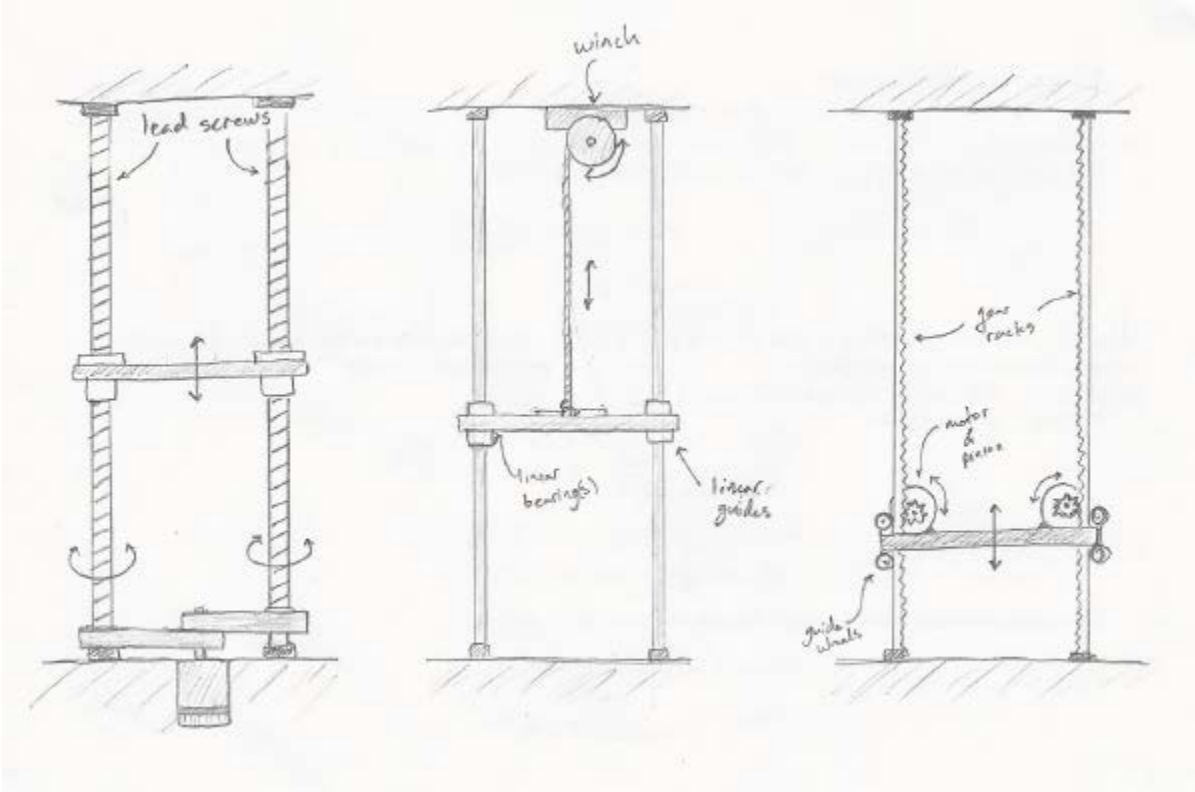
Vertical Rotation



Horizontal Rotation



Vertical Translation

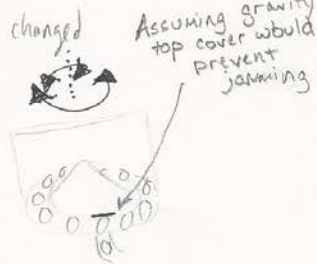


Method 4-3-3 Concepts

- rotating plate with one hole uncovered at a time
- Speed of rotation can be changed easily
- slope in center forces balls to the ring

- maybe rotate ccw and cw
↳ oscillate

If oscillating, only need 3 holes
→ slope bottom ring toward front



- sounds good.

- Looks good, maybe add sensors to detect whether each hole is occupied? cpu closes hole when filled?

Vertical rotating feeder

- picks up balls and delivers at variable speed

Retractable surfaces on wheel would allow clearance

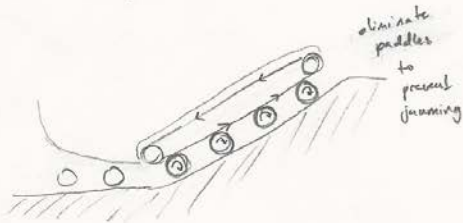
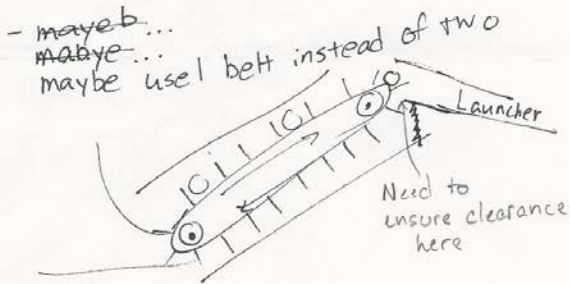
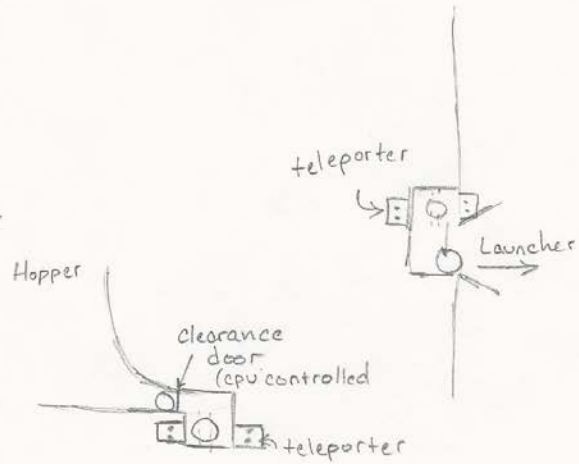
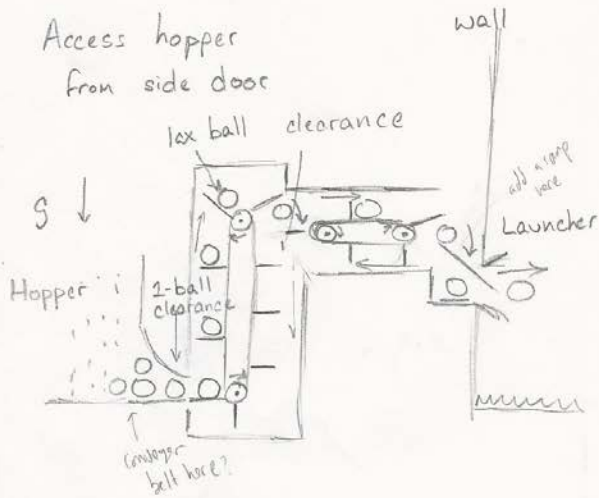


- had the same idea.

Subfunction: Ball Feeding / Control

1.) Conveyor

2.) Teleporter

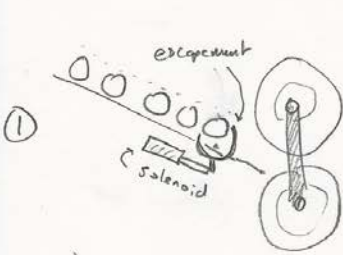


- negative mass/energy for wormhole stabilization (neglecting quantum scale casimir forces) have not been proven to exist (yet!)

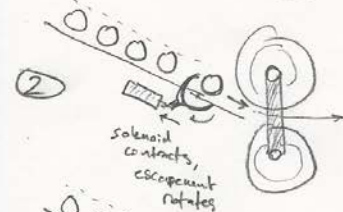
Auger-Screw conveyor

Cam + follower for geneva drive
 → like allowing air into cylinder for ICE

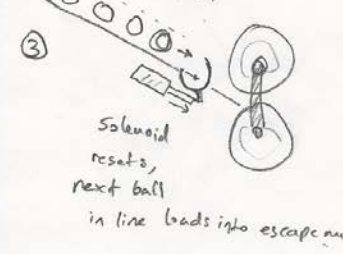
ball feed: escapement



Hopper above, build feed tube such that balls feed single-file

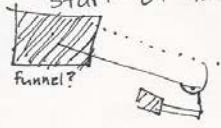


shape of escapement prevents other balls from being released.

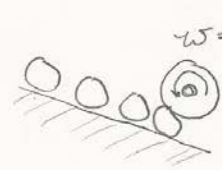


solenoid contracted by electric motor? AC motor could be ideal. Timing controlled/programmed by CPU

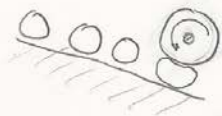
How fast would we be able to reset this? you'll need some mechanism for the start of the line before the solenoid



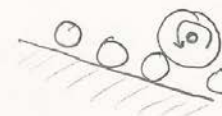
ball feed: roller



$\omega = 0$, slow



slightly compliant roller compresses balls, forcing them to grip bottom of feed chute.

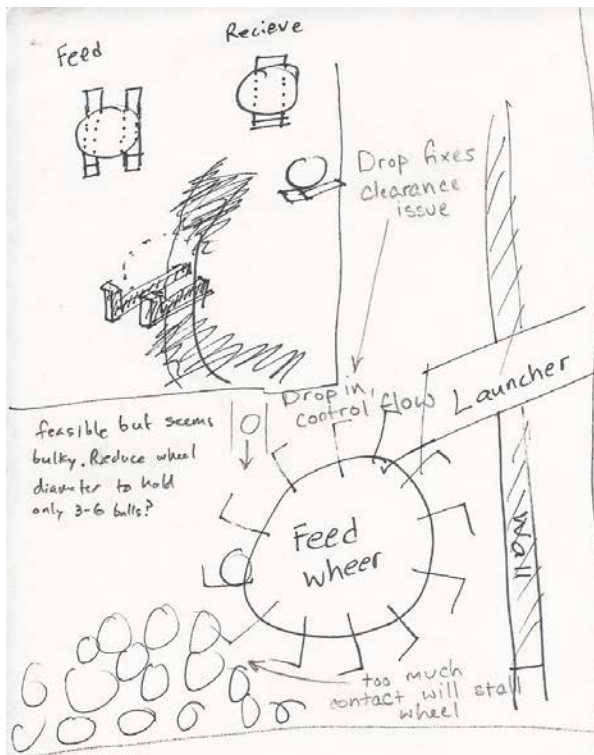


Looks like a single-wheel launcher

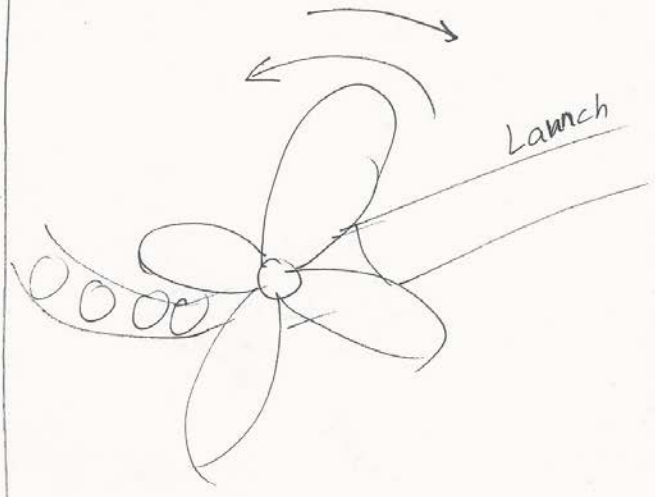
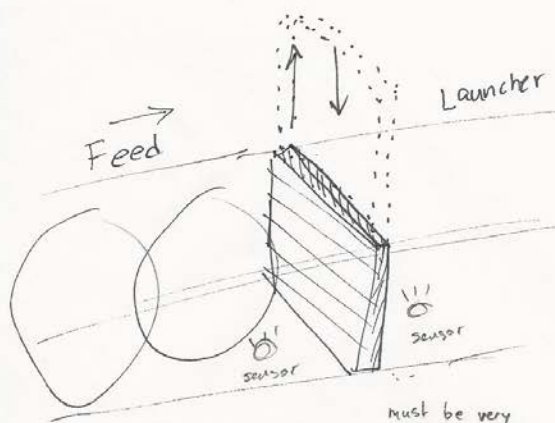
How do we ensure consistency? What if balls get stuck

Would need to ensure slope is great enough that balls can clear wheel

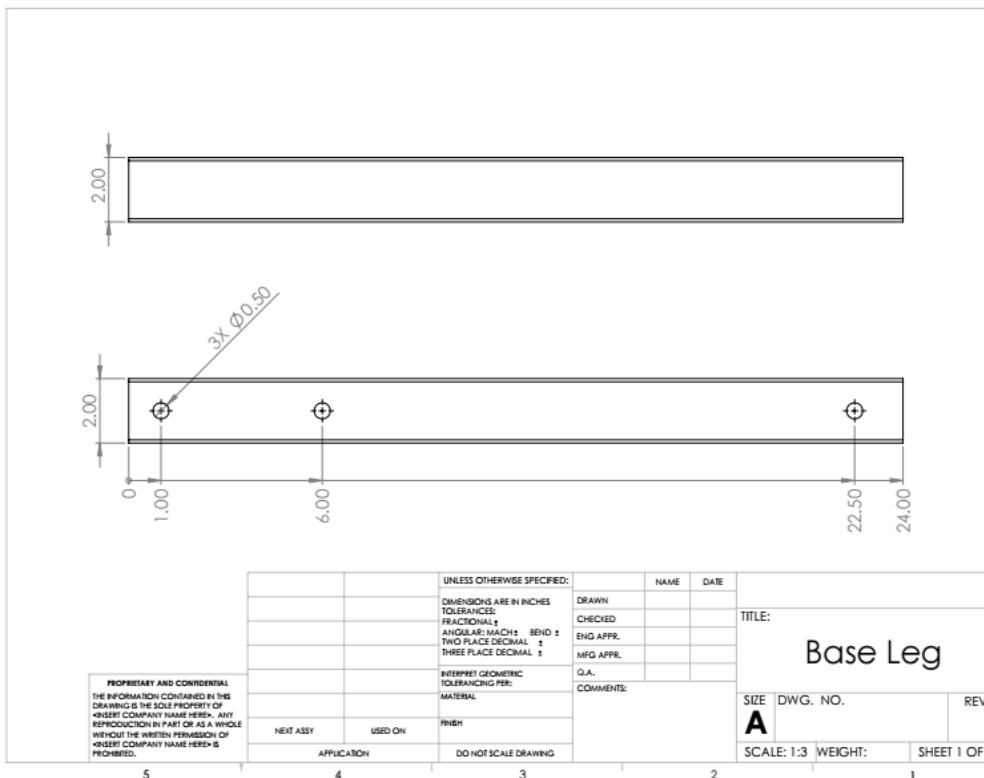
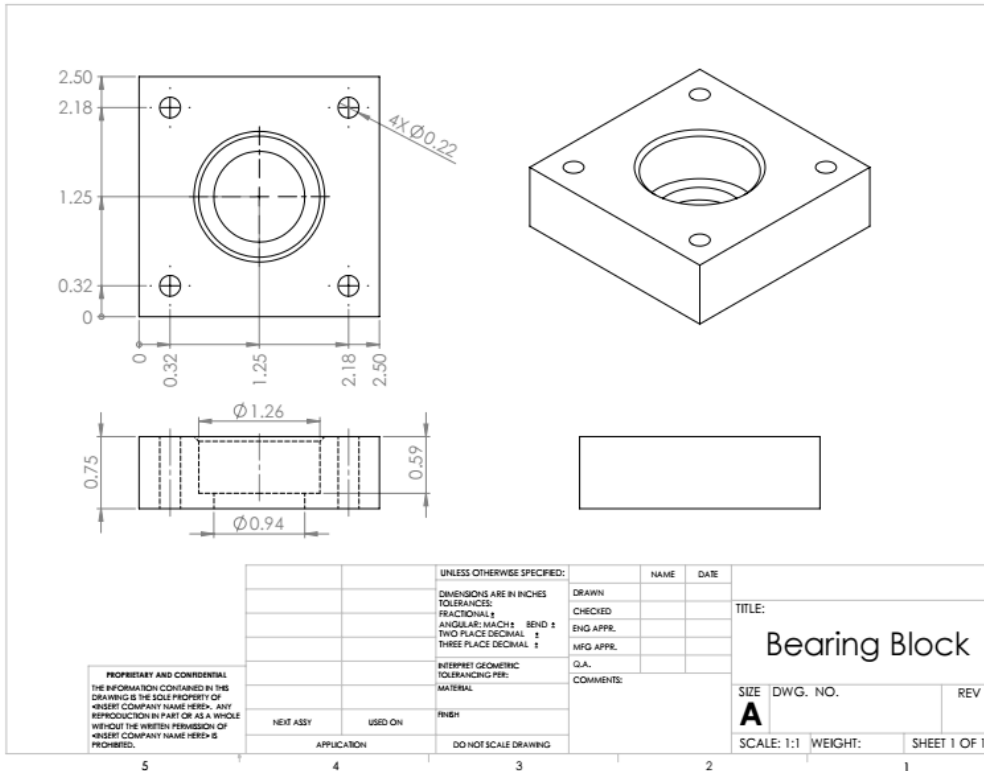


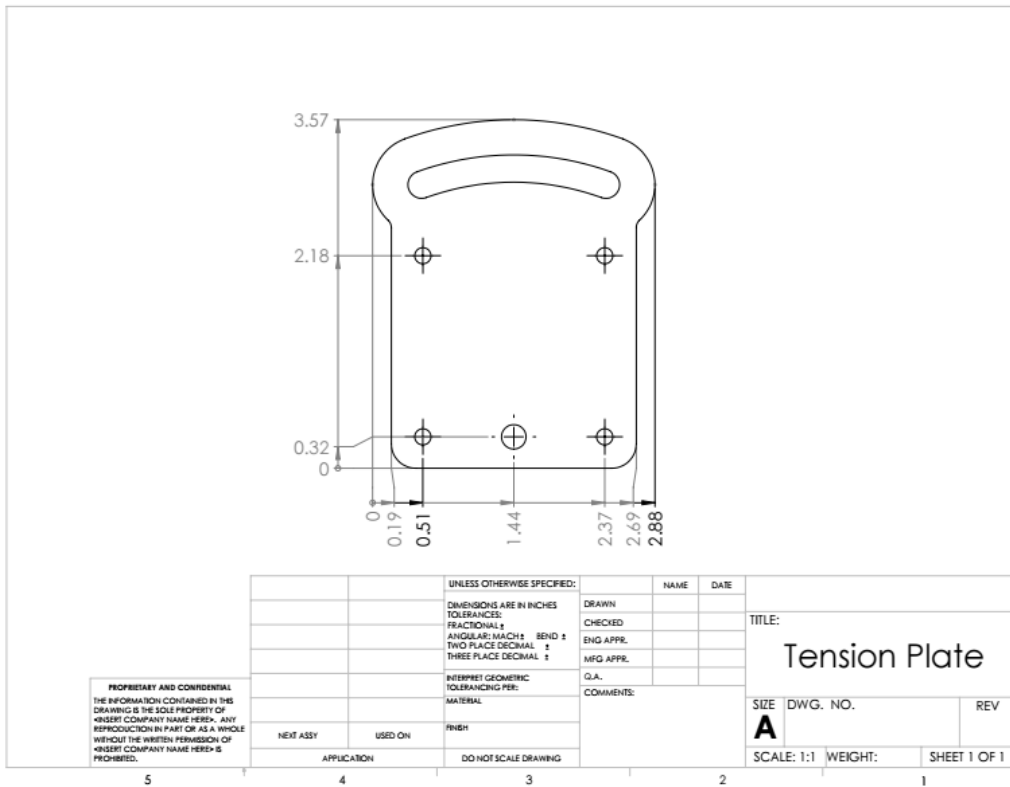
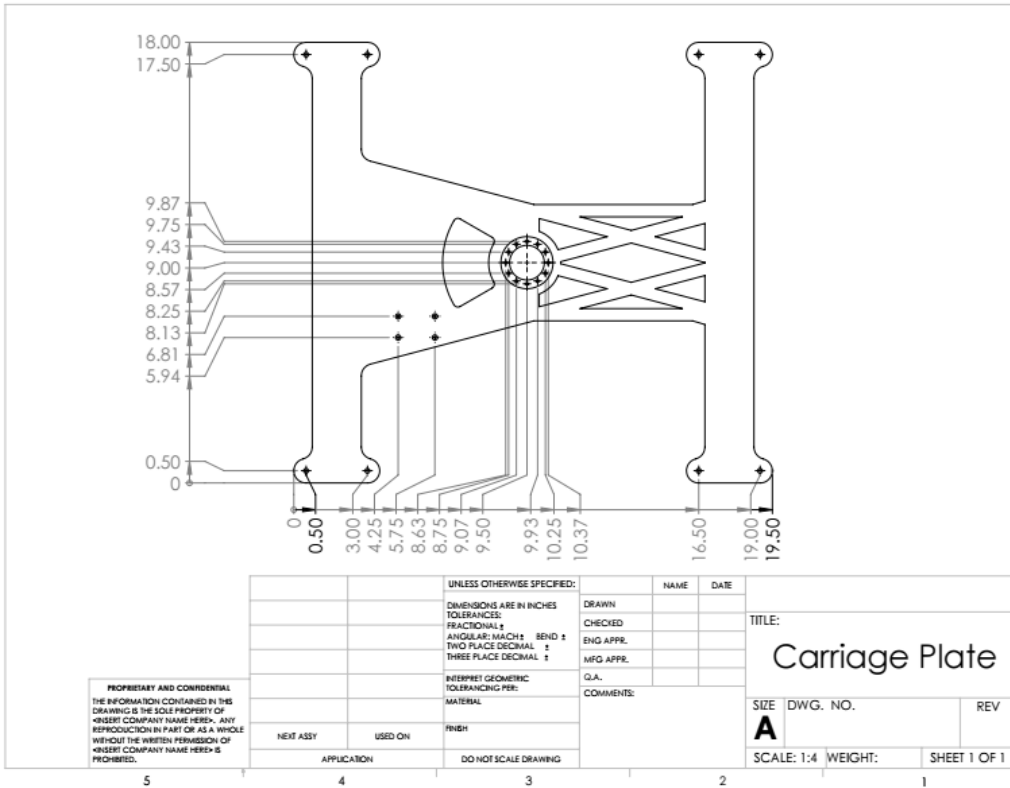


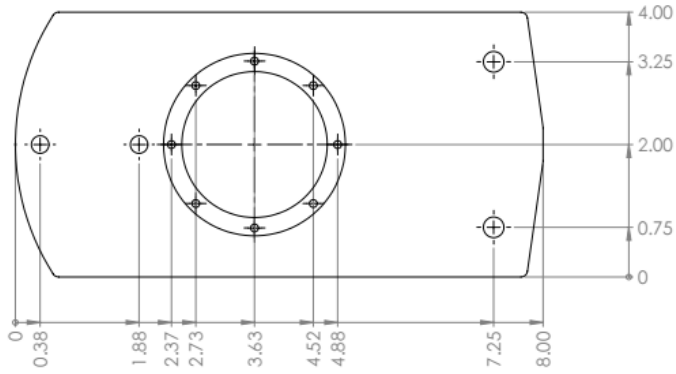
* Geneva Drive



C. Engineering Drawings







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		UNLESS OTHERWISE SPECIFIED:		NAME	DATE		
		DIMENSIONS ARE IN INCHES		DRAWN		TITLE:	
		TOLERANCES:		CHECKED		Harmonic Mount	
		FRACTIONALS		ENG APPR.		SIZE DWG. NO.	
		ANGULARS MATCH		MFG APPR.		REV	
		TWO PLACE DECIMAL ±		G.A.		SCALE 2:3 WEIGHT: SHEET 1 OF 1	
		THREE PLACE DECIMAL ±		COMMENTS:			
		INTERPRET GEOMETRIC TOLERANCING PER:					
		MATERIAL:					
NEXT ASSY		USED ON					
APPLICATION		DO NOT SCALE DRAWING					

5

4

3

2

1

D. Failure Modes and Effect Analysis

FMEA No.:	Component/Item	Function	Failure Mode	Failure Cause	Local Failure Effect	Global Failure Effect	Sev/ Severity Reasoning	Occ/ Occurrence Reasoning	Failure Detection	Det/ Detection Reasoning	Risk	Failure Handling
1	Ball Launcher Launcher Wheels	Impart kinetic energy to projectile balls across launch rails	Loss of surface friction on wheel	Repeated wear as a result of friction with ball surfaces	Wheels won't be able to impart required impulse to projectile balls	Machine won't be able to launch balls with required top speeds	7 Launch speed is an engineering requirement, thus losing top speed is a degradation of the component's primary function.	1 Machine has five-year manufacturer's warranty on wheels, and projectile balls are smaller than baseballs, thus should cause less wear with use.	Notice that launch speeds decline with repeated use.	4 Problem will tend to increase with repeated use, thus it will likely only be noticeable after it's been in use for some time. However, speed reduction of only a few mph won't be noticeable.	28	Machine must be taken out of Commission for wheels to be replaced. Replacement parts provided in the event of failure within warranty lifetime.
2	Launch Controls	Control speed of wheels, thus controlling speed of launched projectile balls.	Electrical failure	Poor connection causes open circuit	No control over motors that drive launcher wheels	Machine won't be able to launch balls at all or launch at single speed.	8 No control over motors prevents launcher from performing primary function.	3 Factory-built controls must be altered to work when our system but careful soldering will prevent poor connections from occurring.	Visual inspection of motors failing to spin launcher wheels	1 If motor's work spin witness, it will be obvious that we need to repair poor electrical connections.	24	Repair connection, solder more carefully to ensure good connection.
Frame/Infrastructure												
3	Holder Plate	Connect launching mechanism to lead screw and supporting linear bearings	Yield or fracture of plate material	Shear strength of plate insufficient to support weight of launcher	Launching device won't be able to hold in place within machine	Machine won't be able to adjust vertical height or vertical angle of launcher	8 Adjusting launch height and angle are primary functions of device.	1 Theoretical analysis of statics is being used to ensure that design is stable and plate can support launcher weight.	Visual inspection of launcher-holder plate assembly	1 Plate failure will be visibly obvious when constructing device.	8	Plate must be redesigned, likely constructed of stronger/more rigid material.
4	Alignment Rails/Linear Bearings	Allow smooth vertical linear motion and support weight of launcher	Bearing failure	Excessive wear from cyclic use exacerbated by any misalignment	Bearing will hinder linear translation or fail to support launcher weight	Machine won't be able to change launcher height as effectively	7 Failure would cause degradation of primary function.	1 Theoretical analysis will ensure that selected bearings can support necessary dust, careful alignment will prevent excessive wear, wear from repeated use will take a long time to occur.	Visual inspection of bearings as launcher translates vertically, careful tolerances on machining plans	3 Visual inspection will reveal misalignment but caution during machining will be more effective for detecting a problem early.	21	Retool to ensure bearings are built with proper alignment.
Actuators/Transmission												
5	Motors	Produce rotational movement in horizontal and vertical planes, also produce linear vertical translation	Unable to move launcher to required extremes in given directions	Unable to provide necessary torque to transmission	Transmission will fail to transmit torque to drive shafts	Machine won't be able to alter directions to aim launching mechanism	8 Failure would prevent device from performing primary function.	1 Motor and transmission will both be carefully chosen to ensure that necessary torque will be available.	Visual inspection of motor/driver shaft	1 It will be obvious if the motor stalls while attempting to drive the transmission.	8	Chosen motors or transmissions will have to be changed to better suit the weight of the design.
6	Harmonic Drives	Provide mechanical advantage to allow motors to output torque required to move launching device	Unable to move launcher to required extremes in given directions	Mechanical advantage isn't enough to step motor torque up to required torque	Torque output to drive shaft won't be sufficient to move launcher at desired speed	Machine won't be able to change aiming direction, or will change direction too slowly.	7 Failure would cause degradation of primary function.	1 Theoretical analysis will ensure that selected harmonic drive combined with selected motor can provide required torque output.	Visual inspection of launcher as it changes direction	1 It will be obvious if the transmission can't input enough torque to the drive and it struggles to aim the launcher.	7	Chosen transmission or motor will have to be changed to better suit the weight/benefit of the launcher.
7	Ball Screw	Allow motor to translate linearly when driven by a motor, support weight of launching mechanism	Unable to translate launcher vertically, unable to support weight of launching mechanism	Bending moment due to weight imbalance increases friction, weight is beyond capacity	Lead screw will have difficulty moving launcher up and down, or won't be able to move it at all	Machine won't be able to change release height of ball launcher	7 Failure would cause degradation of primary function.	1 Theoretical analysis ensures that selected lead screw can support launcher weight, additional support from rib-bearing reduces bending moment.	Visual inspection of launcher as it translates vertically	1 It will be obvious if the lead screw experiences a large bending moment or is unable to support the weight that the lead screw must support.	7	Chosen lead screw must change or a counterweight can be implemented to reduce the weight that the lead screw must support.

E. Preliminary Manufacturing Plans

Part Name: Bottom Plate

Raw Material: 6061 T6 Aluminum 24" x 24" x 0.375"

Step #	Process Description	Machine	Fixture	Tool(s)	Speed (RPM)
1	Load aluminum stock and pre-generated .ord file, cut outer profile and internal pockets	Water Jet	N/A	N/A	N/A
2	Clamp piece in mill for finish machining, center on vise slot	Mill	Vise	Center finder	1000
3	Drill & tap holes for M5 motor mounting screws	Mill	Vise	M5 tap drill / tap	1200
4	Drill & tap holes for M3 harmonic drive mounting screws	Mill	Vise	M3 tap drill / tap	1600
5	Drill & tap holes for T-slot frame attachment bolts (5/16-18)	Mill	Vise	5/16-18 tap / tap drill	800
6	Ream hole for dowel pin and press-fit	Mill	Vise	0.249 reamer	100
7	Drill & tap holes for turntable bearing	Mill	Vise	TBD	TBD

Part Name: Top Plate

Raw Material: 6061 T6 Aluminum 24" x 24" x 0.375"

Step #	Process Description	Machine	Fixture	Tool(s)	Speed (RPM)
1	Load aluminum stock and pre-generated .ord file, cut outer profile and internal pockets	Water Jet	N/A	N/A	N/A
2	Clamp piece in mill for finish machining, center on vise slot	Mill	Vise	Center finder	1000
3	Drill & tap holes for T-slot frame attachment bolts (5/16-18)	Mill	Vise	5/16-18 tap / tap drill	800

Part Name: Base Plate

Raw Material: 6061 T6 Aluminum 24" x 24" x 0.375"

Step #	Process Description	Machine	Fixture	Tool(s)	Speed (RPM)
1	Load aluminum stock and pre-generated .ord file, cut outer profile and internal pockets	Water Jet	N/A	N/A	N/A
2	Clamp piece in mill for finish machining, center on vise slot	Mill	Vise	Center finder	1000
3	Drill & tap holes for M3 harmonic drive mounting screws	Mill	Vise	M3 tap drill / tap	1600
4	Drill & tap holes for T-slot frame attachment bolts (5/16-18)	Mill	Vise	5/16-18 tap / tap drill	800
5	Drill & tap holes for turntable bearing	Mill	Vise	TBD	TBD

Part Name: Carriage Plate

Raw Material: 6061 T6 Aluminum 18" x 18" x 0.375"

Step #	Process Description	Machine	Fixture	Tool(s)	Speed (RPM)
1	Load aluminum stock and pre-generated .ord file, cut outer profile and internal pockets	Water Jet	N/A	N/A	N/A
2	Clamp piece in mill for finish machining, center on vise slot	Mill	Vise	Center finder	1000
3	Drill & tap holes for T-slot frame roller carriages (5/16-18)	Mill	Vise	5/16-18 tap / tap drill	800
4	Drill & tap holes for harmonic drive mounting screws (M3)	Mill	Vise	M3 tap drill / tap	1600
5	Drill & tap holes for ball nut mount (M5)	Mill	Vise	M5 tap drill / tap	1200

Part Name: Vertical Harmonic Mount

Raw Material: 6061 T6 Aluminum 4" x 7.5" x 0.375"

Step #	Process Description	Machine	Fixture	Tool(s)	Speed (RPM)
1	Load aluminum stock and pre-generated .ord file, cut outer profile and internal pockets	Water Jet	N/A	N/A	N/A
2	Clamp piece in mill for finish machining, center on vise slot	Mill	Vise	Center finder	1000
3	Drill & tap holes for M3 harmonic drive mounting screws	Mill	Vise	M3 tap drill / tap	1600
4	Drill & tap holes for launcher mounting	Mill	Vise	TBD	TBD

Part Name: AC Bearing Support Block

Raw Material: 6061 T6 Aluminum 2.5" x 2.5" x 1"

Step #	Process Description	Machine	Fixture(s)	Tool(s)	Speed (RPM)
1	Clamp part in vise; face side(s) until 2.5" x 2.5"	Mill	Vise	3/8 end mill	800
2	Locate edges of part, zero mill spindle X-Y axes	Mill	Vise	Center finder	1000
3	Pocket / bore 32mm-dia. pocket for AC bearing (7/16" deep)	Mill	Vise	32mm end mill / boring bar	TBD
4	Drill 5mm thru-holes for ball screw drive attachment studs	Mill	Vise	5mm drill	1200
5	Flip part, locate edges	Mill	Vise	Center finder	1000
6	Pocket / bore 32mm-dia. pocket for AC bearing (7/16" deep)	Mill	Vise	32mm end mill / boring bar	TBD

Part Name: Tension Plate

Raw Material: 6061 T6 Aluminum 3.5" x 5" x 0.375"

Step #	Process Description	Machine	Fixture	Tool(s)	Speed (RPM)
1	Load aluminum stock and pre-generated .ord file, cut outer profile and internal pockets	Water Jet	N/A	N/A	N/A
2	Clamp piece in mill for finish machining, center on vise slot	Mill	Vise	Center finder	1000
3	Drill & tap holes for M5 motor mounting screws	Mill	Vise	M5 tap drill / tap	1200
4	Drill / ream hole for dowel pin	Mill	Vise	0.255 reamer	100

Part Name: Support Plate

Raw Material: 6061 T6 Aluminum 17" x 5.5" x 0.25"

Step #	Process Description	Machine	Fixture	Tool(s)	Speed (RPM)
1	Load aluminum stock and pre-generated .ord file, cut outer profile and internal pockets	Water Jet	N/A	N/A	N/A
2	Clamp piece in mill for finish machining, center on vise slot	Mill	Vise	Center finder	1000
3	Drill 5/16 thru-holes for mounting to T-slot frame	Mill	Vise	5/16 drill	800

F. Bill of Materials

Status	Item	Manufacturer	Part #	Qty.	Price ea.	Total Cost
4/10/2015	Ball Screw and Nut			1	115.88	115.88
Arrived	Harmonic Reducer			2	179.9	359.8
Arrived	Ball Nut Mount	Bancroft Electronics	1604 1605 1610	1	28.5	28.5
Arrived	6mm x 8mm Flexible Shaft Coupler			1	11.99	11.99
Arrived	8mm x 10mm Flexible Shaft Coupler			1	11.99	11.99
3/24/2015	Flange Bearing	Boca Bearings	UFLO00-10MM	1	9.95	9.95
Arrived	Angular Contact Bearing	VXB Ball Bearings	5201-2RS	1	11.94	11.94
Arrived	Timing Belt Pulley	Amico	S14070200AM2727	2	7.87	15.74
Arrived	Timing Belt	Polybelt	170XL037	1	6.44	6.44
Arrived	Stepper Motor Kit	Nema	23HS9430	1	270.99	270.99
3/24/2015	Cable Drag Chain	Amico	S13061500AM1523	1	18.47	18.47
Not ordered	Paddle Switch	Woodstock	D4151	1	15.17	15.17
Arrived	Limit Switch	Uxcell	ME-8198	6	4.89	29.34
Not ordered	Relay Module	Vidianna	B00SGUP9CU	1	9.79	9.79
Arrived	6061 3/8 and 1/4 Aluminum Plate	Alro Metals		1	414.26	414.26
Arrived	T-Slot Brace	McMaster	47065T06	2	17.86	35.72
Arrived	Slotted Beam	McMaster	47065T108	2	67.3	134.6
23-Mar	Locking Wheels	McMaster		2	53.52	107.04
Arrived	Fixed Wheels	McMaster		1	31.04	31.04
Arrived	Turntable	McMaster	1544T12	1	13.73	13.73
Arrived	T-Slot Brace	McMaster	47065T12	2	17.86	35.72
26-Mar	Roller Wheels	Framing Tech	RLR3908	8	7	56
	Total Cost					1744.1

Machined Parts

Part	Material	Manufacturing Process	Qty
Bottom Plate	6061 3/8 Aluminum Plate	Waterjet	1
Top Plate	6061 3/8 Aluminum Plate	Waterjet	1
Base Plate	6061 3/8 Aluminum Plate	Waterjet	1
Carridge plate	6061 3/8 Aluminum Plate	Waterjet	1
Vertical Harmonic Mount *	6061 3/8 Aluminum Plate	Waterjet and Mill	1
Angular Bearing Support	6061 3/8 Aluminum Plate	Mill	1
Tension Plate	6061 3/8 Aluminum Plate	Waterjet and Mill	1
Support Plate	6061 3/8 Aluminum Plate	Mill	1

G. Ethical Design

Ethical Design - Lisa

The main ethical concerns that we have addressed in our design are centered on safety. There is inherent risk associated with any sort of athletic activity, however our prototype will have extra risk associated with it. Lacrosse balls shot at high speeds can be deadly and each year players are killed by getting hit with lacrosse balls. Our goal was to minimize this risk to the user. The main ways we decided to do this was through visual warnings, physical safety measures, and software safety precautions. There will be signs on the machine that indicate that it contains spinning parts and to keep hands and clothes away from these spinning parts. The two main parts that carry this risk are the pitching wheels and the ball screw. Both of these parts have the ability to become entangled in loose hair or clothing and cause a major safety risk.

The physical safety measures that will be in place in our design will be emergency stop buttons and guards. It is very important that our launcher be able to be shut down immediately in case of an emergency. Not including an emergency stop on the device could lead to many injuries occurring as a result of using our machine. In terms of machine guards, there are wheels guards to protect the user from the launching wheels. We have also designed our prototype in a way that will make it easy to completely encase. Putting a guard around the entire machine would protect the user from all of the moving parts and make them as safe as possible.

Finally, software safety precautions will be included as well. Our team is not in charge of the final software but we can make safety recommendations for that software. One of the recommendations is that there is a check to make sure that the player is wearing a helmet at all times while in the room. A check like this would make the machine much safer to use.

Ethical Design - Peter

Unfortunately, there is no way to eliminate the safety risks associated with operating a pitching machine, whether for baseballs, softballs, tennis balls, etc. Because of the inherent risk of injury associated with lacrosse (during practice or play), the end-user of this machine is assumed to be aware of these risks. Many concerns were brought up during previous design reviews. One especially memorable example occurred during DR3, when an audience member asked how we would prevent player injury if they were hit with a lacrosse ball. I responded that there was no way to truly guarantee player safety, and that deaths had occurred during lacrosse games in the past. Because it is assumed that players will be wearing proper protective equipment and maintain a high level of situational awareness (as during any practice session or game), the most important risk-mitigation features we can include are based on effectively controlling the machine. This includes use of emergency stops and travel limits implemented in the software. Beyond traditional safety equipment, one feature that I strongly recommend (in future iterations) is a remote emergency-stop switch, similar to a key fob, or perhaps attached to a wrist band,

which would allow the player to immediately disable the machine in the event of an injury. In addition to active safety features, passive features such as positive stops on all axes, guards around the launcher wheels, and electrical isolation of all motor and controller systems. Another easy solution to help guarantee safe operation is the inclusion of various warning labels around pinch points, moving parts, or high voltage components. We intend to include basic signage for the design expo.

Ethical Design - Tyler

As with any mechanical engineering projects, engineering ethics has been at the forefront of our minds throughout the design process. Due to the nature of our project, we didn't encounter any issues involving conflicts of interest or business practices, except in terms of using a pitching machine provided from another company. During our benchmarking, we made sure that our plans did not infringe on any existing patents, and that our use of a pitching machine in our design was not in a way that infringed on its existing patent either.

Concerns about public safety were the most important ethical issues we faced during the process. Lacrosse, like any other full-contact sport, can be dangerous, and has inherent risks involved in playing it. Similarly, our machine carries some risk with it due to the fact that it fires projectiles at over 70 mph. Throughout the course of our project, we've done everything possible to mitigate those risks, and prevent potential injury. At the times we've spun up the launcher and actually launched balls, we made sure to do so in a closed environment (i.e. batting cage), and made sure that everybody who was working with the machine was aware of the potential risks, alert enough to not be caught off-guard, and out of harm's way. This method proved to be very successful; we've had no incidents of any kind throughout the semester. We'll be sure to make it clear to Coach Paul that similar precautions should be taken in its potential use with the team, to prevent any possible injury.

Beyond the actual launching of lacrosse balls, our machine can also be dangerous in that it has many moving parts, and some of the parts being moved are quite heavy. As such, we have designed it such that it can be controlled from a safe distance. No part of the controls are within harm's way on the machine, and we'll make it clear to Coach Paul that any observers or bystanders should be a good distance clear of the machine to prevent any possible injury. Additionally, we've planned to produce signage that warns any users about the danger involved with the spinning or moving parts of the machine, and to stay clear of them at all times. This should ensure that the machine operates as intended, and can be used to help improve the skills of the University of Michigan varsity men's lacrosse team, without being used dangerously and causing injury to players or bystanders.

Ethical Design - Gulam

Our machine was designed for a very small niche of people. It is intended to be used as supplemental aid for lacrosse practice. During the start of the term, at Design Review 1, we were fielded a question about whether we were concerned about having all these lacrosse balls laying around on the floor while a player was prepping for the next shot. The question was to bring awareness regarding a tripping hazard, i.e. the already caught and dropped lacrosse balls. I replied with a very confident and casual “No, of course not.” The reason for my rather brash response is that this “tripping hazard” is an accepted risk. When players are practicing now, without the machine, they are still catching and dropping lacrosse balls all over the field. The same hazard is present regardless. In this situation, our machine is not adding risk.

During the Ethics lecture, the speaker raised a hypothetical question to help us tackle the issue of identifying ethics. That question was to imagine a loved one using the machine. But because our machine is intended for qualified people, in other words, dedicated lacrosse players, it’s not a question that fits all cases. Similar to the situation above, the fact that our machine is designated for very specific use, it’s difficult finding many ethical issues or concerns in our control. Even the launch speed is currently designed to be physically changed and that is an associated risk in regular lacrosse practice. We even have our work cut out for us as the machine can physically only output a max speed of 75 mph, which falls in our sponsor’s 70-80 mph range, when the launcher was originally rated for 110 mph maximum.

Where our machine does present concerns, however, is the electrical side of things. We have 36 volts powering three motors at 3 amps. In fact, currently, it is possible to rotate the platform 360 degrees, having the ball screw run out of track, and slamming the launcher into the rails. By Expo, we will have a considerable number of soft stops and hard stops that tell the program to halt and cut power, respectively. The wheels have the highest potential of injury and they will be equipped with rear guards. We also expect to include appropriate warning messages on the machine such as taking caution while the motors are running, not sticking fingers into the wheels, etc.

H. Environmental Impact

Environmental Impact - Lisa

The main environmental impacts of our design are in terms of materials. Our prototype utilizes a lot of aluminum and that material is very energy intensive to produce. Besides that, our machine will consume energy during its use phase. However this impact might be negated by the nature of the project. The goal of the machine is to be used in a small room for individual practice. If this small room can be utilized rather than the entire field then the machine might cut down on electricity use by the team overall. Finally the end of life of our machine. Since the machine is not enclosed it should be pretty easy to maintain and repair. This will ensure that it has a long lifetime and reduce the overall environmental impact. At the end of life most of the components will be able to be recycled. The aluminum will all be able to be recycled and will have a very low impact overall. Also the electronics will be able to be recycled. Overall, our prototype will not have too much of a negative impact on the environment.

Environmental Impact - Peter

Because our machine is not intended to be mass-produced, environmental impact was not given special consideration. However, since our machine uses traditional construction materials, its environmental impact will be negligible compared to the construction of the athletic facility where it will be placed. The frame of the machine is almost entirely aluminum. While aluminum is energy intensive to produce, it also has a comprehensive recycling infrastructure, making it a recoverable resource. Many of the off-the-shelf components (such as the motion axes or fasteners) are not consumable, and could be reused in later ME 450 projects. If this is not an option, various electronics recycling facilities exist, although recovering constituent materials is a very energy-intensive process. However, there are many possible energy-saving features that could be included in our machine to help offset its environmental impact. For example, the horizontal rotation motor could be deactivated when not in motion; unlike the motors for vertical rotation and translation, its static holding torque is not needed when the machine is not needed. If a counterweight or spring system was added to the other axes, they could also be deactivated when not in use, further decreasing energy usage. The use of off-the-shelf components also extends the overall life of the machine. If a particular component wears out or breaks, it can simply be swapped out, instead of scrapping the entire machine. Along those same lines, bearings were included on all loaded faces, to decrease wear and extend the life of the machine as much as possible.

Environmental Impact - Tyler

Another important facet of the ASME Code of Ethics is that mechanical engineers must consider the environmental impact of their work. With regards to our design, the biggest environmental impact likely comes from the production of the aluminum that our machine is made out of. Aluminum production can take a toll on the environment in terms of energy and water use, and

our design uses a lot of aluminum. However, more environmentally-friendly materials wouldn't have suited our needs in terms of strength, durability, and lightweightness. Thus, it is critical that once our machine has reached the end of its lifetime that it is scrapped and all of the aluminum is recycled properly. This will help reduce the overall environmental impact from our project. Similarly, recycling the electrical components of the machine once it's reached the end of its life will also help to stem the project's environmental impact. This impact is also lessened by the fact that our device is one-of-a-kind, and won't be mass produced.

Another large environmental impact from our project is the electricity that is needed to run the machine. Assuming it will be used by the team for a number of years, it could potentially draw a large amount of power. Batteries wouldn't be able to provide the required power, and they can have drastic environmental effects also if disposed of improperly. As such, the best way to stem this environmental impact is to source cleaner sources of electrical energy. Since it'll be used at UM, it'll draw power from the UM power plant, which utilizes natural gas, a resource that is already much better for the environment than coal or oil. However, continuing to research better, cleaner energy alternatives will continue to help stem the environmental impact of our project, although this is outside the scope of the project itself.

Environmental Impact - Gulam

Admittedly, we did not pay much attention to the environmental consequences for our project. Our machine is not intended to be a mass manufactured product but a specially customized prototype. The final build will be installed into the wall of a machine and that already implies it will have a large carbon impact. For our prototype, we tried to use recycled parts from leftover scrap metal in the assembly room. We also reused a lot of the electrical components from the mechatronics room as opposed to purchasing new ones.

For improvements, I believe most of the environmental impact is influenced by the energy consumption in running the machine. In other words, the programming and controls will take up the most significant contributions. Future programmers can run it a little more efficiently with proper shut off times. This can also include a certain cool down period between uses so as to wear out the machine less over time. I think an interesting idea would be to recycle worn down lacrosse balls (referred to as greasers for being too slick for any useful practice) into a type of rubber for the wheels of the launcher.

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AUTHORS



Lisa Cooper grew up in Libertyville, IL and graduated from Libertyville High School in 2011. She then attended the University of Michigan and enrolled in the College of Engineering. From 2012-2013 Lisa worked as an Instructional Aide for two Engineering 100 classes. In 2014 she worked at NSK as a testing and analysis intern. She is currently in her senior year pursuing a degree in Mechanical Engineering. After graduation she has accepted a job at the Puget Sound Naval Shipyard in Seattle, Washington.



Peter Gerow is a senior at the University of Michigan, and is currently working toward a BSE in mechanical engineering. He worked as a design engineer at Mectron Engineering Co. in summer of 2014, and currently operates a sole proprietorship based on engineering consulting and rapid fabrication services for the University of Michigan hospital. He plans to pursue an MSE in biomechanics after graduation.



Tyler Huntress received his high school diploma from Herbert Henry Dow High School (Midland, MI) in 2011. He enrolled at the University of Michigan later that year, pursuing a BSE in mechanical engineering. He has been distinguished with the Branstrom Freshman Prize, seven-time Dean's List award recipient, and a James B. Angell Scholar for five consecutive semesters. He worked as a research assistant in the combustion lab at UM, characterizing fuel-spray properties of farnesene and other hydrocarbons, in 2013. In 2014, he worked for Chrysler Group, LLC, in NVH Limit analysis in Kokomo, Indiana. After graduation, in 2015, he plans to return to UM to pursue his MSE, also in mechanical engineering. He has played the piccolo with the Michigan Marching and Basketball Bands since 2011, and is an active member of Kappa Kappa Psi, the National Honorary Band Fraternity. His performance in the Marching Band was honored with the Wanda W. Lincoln Scholarship. As a three-sport varsity athlete in high school, his natural affinity for athletics drew him to choose this project.



Gulam Islam graduated from the High School for Math, Science and Engineering at City College New York in 2011. As the name implies, he had some early exposure to the engineering track with courses like digital electronics, design, drafting and production, architecture, and principles of engineering. While in high school, he was the captain of his robotics team, where he and his team earned the school's first-ever engineering award. Hoping to continue his interest in mechatronics, Gulam attended the University of Michigan pursuing a bachelors' degree in mechanical engineering. During his sophomore year, he worked at the APRIL Robotics Laboratory where he worked on improving a zeroth prototype for the APRIL Lab's Magic 2010 Competition winners as well as designing and building a new

customizable prototype with varying axle-track and wheelbase geometry. In 2014, Gulam traveled to Nagoya University, Japan to participate in an intensive automobile summer program where he toured various Japanese automobile companies and attended lectures from a myriad of industry professionals. The mechatronics aspect of this project is what drew Gulam to it. He looks forward to seeing the results of his and his teammates' efforts.